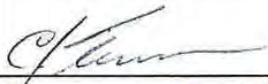


	<b>AREVA Federal Services LLC</b>		
	<b>Engineering Information Record</b>		
<b>Document No.:</b> EIR-3016795	<b>Rev. No.</b> 001	<b>Page 1 of 373</b>	
<b>Project No.:</b> 00225.03.0050	<b>Project Name:</b>	DOE Atlas Railcar	
<b>Title:</b> Atlas Railcar Phase 1 Final Report			
<b>Summary:</b> This document contains the final report for Phase 1 of the DOE Atlas Railcar project.			
<b>Contains Unverified Input / Assumptions:</b> - Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>			
	<b>Printed Name</b>	<b>Signature</b>	<b>Date</b>
<b>Preparer:</b>	Slade Klein		10/28/16
<b>Checker:</b>	Chuck Temus		10/28/16
<b>Approver:</b>	Don Hillstrom		10/28/16
<b>Other:</b>	Todd Heavner Engineering Manager		10/31/16
<b>Other:</b>	Dorothy Davidson Corporate Sponsor	DAVIDSON Dorothy	<small>Digitally signed by DAVIDSON Dorothy          DN: ou=AREVA GROUP, 2.5.4.1.5=44F787104936389197FB,          cn=DAVIDSON Dorothy          Date: 2016.10.31 13:47:51 -0400</small>

AFS-EN-FRM-012 Rev. 02 (Effective April 27, 2015)  
 Refer to AFS-EN-PRC-019

# Design and Prototype Fabrication of Railcars for Transport of High-Level Radioactive Material

## Phase 1: Mobilization and Conceptual Design

DE-NE0008390

Prepared by: AREVA Federal Services LLC



### REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	Sep 30, 2016	All	Initial issue
1	Oct 28, 2016	Various	Revised to incorporate DOE review comments; see related resolution matrix for details.

## DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency, contractor, or subcontractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency, contractor, or subcontractor thereof.

## TABLE OF CONTENTS

<b>EXECUTIVE SUMMARY .....</b>	<b>ES-1</b>
<b>1.0 PHASE 1 INTRODUCTION .....</b>	<b>1-1</b>
1.1 <i>Report Content and Layout.....</i>	<i>1-1</i>
1.2 <i>Introduction of Project Team Members and their Roles .....</i>	<i>1-2</i>
1.3 <i>Deliverable Status .....</i>	<i>1-3</i>
1.4 <i>Phase 1 Chronological Outline .....</i>	<i>1-4</i>
<b>2.0 GENERAL INFORMATION .....</b>	<b>2-1</b>
2.1 <i>Supporting Information and Regulatory Requirements.....</i>	<i>2-1</i>
2.2 <i>Cask Information and Data .....</i>	<i>2-3</i>
2.3 <i>Use of SAR Designs in Conceptual Cradle Designs.....</i>	<i>2-5</i>
<b>3.0 CONCEPTUAL CRADLE DESIGNS .....</b>	<b>3-1</b>
3.1 <i>Conceptual Cradle Functional Requirements .....</i>	<i>3-2</i>
3.2 <i>Conceptual Cradle Operational Requirements .....</i>	<i>3-2</i>
3.3 <i>Conceptual Cradle Maintenance Requirements.....</i>	<i>3-2</i>
3.4 <i>Additional Conceptual Cradle Design Considerations .....</i>	<i>3-2</i>
3.5 <i>Atlas Railcar Cradle Family 1.....</i>	<i>3-2</i>
3.6 <i>Atlas Railcar Cradle Family 2.....</i>	<i>3-4</i>
3.7 <i>Atlas Railcar Cradle Family 3.....</i>	<i>3-5</i>
3.8 <i>Atlas Railcar Cradle Family 4.....</i>	<i>3-7</i>
3.9 <i>Railcar-to-Cradle Interface.....</i>	<i>3-8</i>
<b>4.0 CONCEPTUAL RAILCAR DESIGNS .....</b>	<b>4-1</b>
4.1 <i>Conceptual Prototype Railcar Designs .....</i>	<i>4-1</i>
4.2 <i>Atlas Railcar.....</i>	<i>4-1</i>
4.3 <i>Buffer Railcar .....</i>	<i>4-3</i>
4.4 <i>Change in Atlas Railcar Configuration from 8 to 12 Axles.....</i>	<i>4-3</i>
<b>5.0 LOADING PROCEDURES.....</b>	<b>5-1</b>
<b>6.0 FUNCTIONAL AND OPERATIONAL REQUIREMENTS DOCUMENT.....</b>	<b>6-1</b>
<b>7.0 REFERENCES.....</b>	<b>7-1</b>
<b>APPENDIX A – CONCEPTUAL CRADLE DESIGNS.....</b>	<b>A-1</b>
<b>APPENDIX B – CASK RAILCAR CONCEPT .....</b>	<b>B-1</b>
<b>APPENDIX C – BUFFER RAILCAR CONCEPT .....</b>	<b>C-1</b>
<b>APPENDIX D – GENERAL LOADING PROCEDURES.....</b>	<b>D-1</b>
<b>APPENDIX E – CASK &amp; BUFFER RAILCAR FUNCTIONAL &amp; OPERATIONAL     REQUIREMENTS DOCUMENT .....</b>	<b>E-1</b>

## LIST OF FIGURES

FIGURE 3-1: FAMILY 1 HI-STAR 100 CASK, CONCEPTUAL CRADLE, AND END STOPS .....	3-3
FIGURE 3-2: FAMILY 2 NAC MAGNATRAN CONCEPTUAL CRADLE DESIGN .....	3-5
FIGURE 3-3: FAMILY 3 ENERGYSOLUTIONS TS125 CONCEPTUAL CRADLE DESIGN.....	3-6
FIGURE 3-4: FAMILY 4 AREVA TN MP187 CASK AND CONCEPTUAL CRADLE DESIGN .....	3-8
FIGURE 3-5: ATLAS RAILCAR STANDARDIZED ATTACHMENT COMPONENTS .....	3-9

## LIST OF TABLES

TABLE 1-1: PRIMARY PROJECT PARTICIPANTS AND ROLES .....	1-2
TABLE 1-2: PHASE 1 DELIVERABLES AND STATUS .....	1-6
TABLE 2-1: NOMINAL CHARACTERISTICS OF SPENT NUCLEAR FUEL TRANSPORTATION CASKS .....	2-4
TABLE 3-1: CASK ROTATION LOADING .....	3-10
TABLE 3-2: MAXIMUM CRADLE TO RAILCAR CLEARANCES .....	3-10

## LIST OF ACRONYMS

AAR	Association of American Railroads
AFS	AREVA Federal Services
APDE	AFS Principal Design Engineer
CG	Center of Gravity
CLIN	Contract Line Item Number
CO	DOE Contracting Officer
CoC	Certificate of Compliance
COR	DOE Contracting Officer's Representative
DBRD	Design Basis Requirements Document
DOE	Department of Energy
EEC	Equipment Engineering Committee
EIR	Engineering Information Record
FFP	Firm-Fixed Price
FORD	Functional and Operational Requirements Document
GTCC	Greater-Than-Class-C
HLRM	High-Level Radioactive Material
HLW	High-Level Radioactive Waste
MHF	MHF Logistics
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PM	Project Manager
PQAP	Project Quality Assurance Plan
QAPD	Quality Assurance Program Description
REV	Rail Escort Vehicle

RFI	Request for Information
SAR	Safety Analysis Report
SN3	Stoller Newport News Nuclear
SNF	Spent Nuclear Fuel
SOW	Statement of Work
TTCI	Transportation Technology Center, Inc.

## EXECUTIVE SUMMARY

In preparation of an integrated nuclear waste management program, the United States Department of Energy (DOE) is preparing for future large-scale transport of spent nuclear fuel (SNF), high-level radioactive waste (HLW), and Greater-Than-Class-C (GTCC) waste. A part of this preparation includes developing a fleet of railcars to be used for the transport of High-Level Radioactive Material (HLRM) and GTCC waste.

The DOE Contract DE-NE0008390 titled “Design and Prototype Fabrication of Railcars for Transport of High-Level Radioactive Material” was awarded to AREVA Federal Services, LLC (AFS) in August 2015. Prototype railcars are to include both a cask railcar to haul HLRM casks (hereafter, the cask railcar is specifically referred to as "Atlas") and two buffer railcars used for spacing between the train engine and Atlas railcar(s), the Atlas railcar(s) and escort railcar, and for weight distribution between Atlas railcars, as deemed necessary.

In addition to the development of design and fabrication requirements, the key contract requirement is for the railcars to be approved by the Association of American Railroads (AAR) as compliant with AAR Standard S-2043 (*Performance Specification for Trains Used to Carry High-Level Radioactive Material*). This standard prescribes the performance guidelines that must be met by trains carrying HLRM. These guidelines optimize vehicle performance and incorporate the best available technology to minimize the chances of derailment.

This project, governed by DOE Contract Number DE-NE0008390, has been divided into three phases as summarized below:

- 1) Phase 1 includes:
  - 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; and
  - d) The railcar’s functional, design, operational, and maintenance requirements.
- 2) Phase 2 includes:
  - a) The submission of the preliminary design packages of the Atlas and buffer railcars designed to meet the AAR Standard S-2043 requirements;
  - b) The subsequent receipt from the AAR of a “notice to proceed with the test phase” which allows the prototype railcars to be built in accordance with Section 3.2.1 of S-2043; and
  - c) The delivery of the design data package to the DOE.
- 3) Phase 3 includes:
  - a) The fabrication and delivery of the prototype Atlas and buffer railcars; and
  - b) The delivery of an as-built package for upcoming railcar AAR S-2043 approval testing and future production fabrication of both the Atlas and buffer railcars.

This report titled “Design and Prototype Fabrication of Railcars for Transport of High-Level

Radioactive Materials, Phase 1: Mobilization and Conceptual Design” compiles the work that was completed during Phase 1. This report includes a summary of the approach and results in meeting Phase 1 contract objectives, including the challenge in meeting S-2043 requirements and a resulting change in the prototype railcar’s configurations, and provides copies of Phase 1 deliverables in the appendices for reference.

The version of the Atlas railcar discussed in this report is a 12-axle configuration that is capable of carrying 15 spent nuclear fuel transportation cask models. As this report was being completed in late September 2016, a contract modification added the HI-STAR 190 SL and XL transportation casks to the list of cask models. The next phase of the design process, Phase 2, Preliminary Design, will include all the changes to the Atlas Railcar design necessary to transport these two casks.

## 1.0 PHASE 1 INTRODUCTION

This section provides background information regarding this report's content and layout, an introduction to the project's team members and their roles, and a status summary of Phase 1 deliverables.

### 1.1 Report Content and Layout

This report specifically summarizes the efforts and accomplishments of Phase 1. Sections 2.0 through 6.0 provide a summary of the contractual requirements, approach, challenges, and results in meeting Phase 1 contract objectives, as well as general loading procedures of the cask-to-cradle-to-railcar process. Specifically, each section includes:

- Section 2.0 provides general information regarding contractual and regulatory requirements and an overall description of the included casks to be carried by the Atlas railcar.
- Section 3.0 provides descriptions of the conceptual design of the cask cradles to be used to transport standard industry HLRM casks (as identified by the DOE) on the Atlas railcar; the conceptual cradle's functional, operational, and maintenance requirements; and each cask cradle family's conceptual design. Also included is a description of the standardized cradle-to-Atlas railcar interface mechanisms—a design, which although conceptual in Phase 1, will be detailed, designed, and maintained in Phase 2's preliminary railcar design.
- Section 4.0 provides conceptual Atlas and buffer railcar designs used in Phase 1 to support the development of the conceptual cradle designs and to provide a basis for the project's Phase 2 preliminary design of the Atlas railcar and buffer railcar.
- Section 5.0 provides the purpose and scope of the General Loading Procedures, the methodology used to generate the procedures, and a description of the procedures' format.
- Section 6.0 provides the cradles' and railcars design basis requirements in the Design Basis Requirements Document (DBRD)/Functional and Operational Requirements Document (FORD) as well as the Atlas and buffer railcars operational and maintenance requirements.
- Section 7.0 provides a listing of references used in this report.
- Appendices for this report include the actual deliverables/conceptual design supporting documents, which were submitted to and approved by the DOE. These will be utilized in the future preliminary and detailed design of the Atlas railcar's cask cradles and production railcars. Enclosed appendices include:
  - Appendix A – Conceptual Cradle Designs
    - Appendix A.1 – Family 1 Cradle Conceptual Design
    - Appendix A.2 – Family 2 Cradle Conceptual Design
    - Appendix A.3 – Family 3 Cradle Conceptual Design
    - Appendix A.4 – Family 4 Cradle Conceptual Design
    - Appendix A.5 – Cradle-to-Railcar Interface
    - Appendix A.6 – Bounding Conditions

- Appendix B – Atlas Cask Railcar Drawing and Description
- Appendix C – Buffer Railcar Drawing and Description
- Appendix D – General Loading Procedures
- Appendix E – Functional and Operational Requirements

The drawings and calculations included in Appendix A.1 through A.5 are provided as images as they are now formally issued to the DOE.

## 1.2 Introduction of Project Team Members and Their Roles

The Atlas project team has managed the Atlas project from the proposal process, through the Phase 1 conceptual design of the cask cradles and railcars, and will continue to do so through Phase 2 preliminary railcar design and the upcoming Phase 3 prototype railcar fabrication process. AFS has primary responsibility for the project and integration of team members. AFS SNF transport cask subject matter experts (SMEs) provide project engineering oversight, conceptual design of the cask cradles, and design of the cradle-to-railcar interface system. Stoller Newport News Nuclear (SN3) performs peer reviews of the cradle-to-railcar interface system. Kasgro Rail is the designer and fabricator for the Atlas and buffer railcars. Kasgro Rail is supported by Transportation Technology Center, Inc. (TTCI) which provides dynamic modeling and a preparation of the S-2043 request package seeking AAR approval to build and test the prototype railcars. AREVA TN generated the cask-to-cradle-to-Atlas railcar General Loading Procedures with peer review performed by MHF Logistics (MHF).

Table 1-1 provides a listing of primary project participants performing independent managed tasks along with their defined roles.

**TABLE 1-1: PRIMARY PROJECT PARTICIPANTS AND ROLES**

Participant	Role
AREVA Federal Services (AFS)	Project integrator and overall responsibility for contract execution Cask design and Safety Analysis Report (SAR) data collection and review Cask cradle conceptual designs Cradle-to-railcar interface system design
Stoller Newport News Nuclear (SN3)	Peer review of Atlas railcar cradle attachment interface design and cask/cradle/railcar loading procedures based on work performed as design verifier of cradle for U.S. Navy M-290 cask railcar
Kasgro Rail	Atlas railcar attachment peer review Atlas and buffer railcars conceptual designs Atlas and buffer railcars designs including finite element analysis and modeling Submission of AAR Equipment Engineering Committee (EEC) S-2043 data package Fabrication of Atlas and buffer prototype railcars
Transportation Technology Center, Inc (TTCI)	Dynamic modeling of Atlas and buffer railcars designs Preparation of AAR S-2043 approval request package Interface with the AAR EEC
AREVA TN	Cask-to-cradle-to-Atlas railcar general loading procedures

Participant	Role
MHF Logistics (MHF)	Peer review of general loading procedures as a transportation logistics company specializing in rail services

Throughout this report, specific reference to a company name will refer specifically to that company. The use of “TEAM” refers to all or a portion of the above listed companies based on assignments or as defined in current discussions.

### 1.3 Deliverable Status

All Phase 1 contract deliverables have been submitted to and approved by the DOE. However, due to the recent configuration change to a 12-axle railcar, the Cradle Attachment Conceptual Design (CLIN 1, Event 2) and the Payload/Size Bounding Conditions (CLIN 1, Event 3) have been revised since the original approved submittal.

#### *Change in Atlas Railcar Configuration*

The Atlas Railcar design is based on the utilization of the U.S. Navy's M-290 cask railcar basic design and components as it is the only railcar to successfully be approved for use under the AAR S-2043 requirements. The TEAM also selected the M-290's components as they are the only existing components used to establish S-2043 compliant dynamic models (built by TTCI). The first conceptual design used the M-290 trucks with a standard 8-axle configuration.

In late May 2016, the selected M-290 trucks for the 8-axle Atlas railcar and buffer railcar failed initial Phase 2 dynamic modeling simulations. Simulation results indicate that railcar trucks fail the "hunting" criteria during high-speed stability and dynamic curving simulations. Hunting refers to the self-oscillation of the railcar trucks between the railroad tracks, decreasing railcar stability and railway adhesion.

As a result of the above and extensive evaluation of options, the TEAM switched to a 12-axle configuration of the Atlas railcar in early August 2016. The TEAM determined that the 12-axle configuration presents the highest probability of meeting AAR S-2043 requirements while minimizing risk and schedule impacts. Additional information regarding this configuration change is provided in Section 4.4.

## 1.4 Phase 1 Chronological Outline

The following provides a summary of tasks performed on the project.

- 1) The project was received and accepted and the project plans were generated, submitted, and approved by the DOE (including the DBRD).
- 2) Information regarding the 15 casks, listed in Attachment A of the Statement of Work (SOW) [3] (reference Table 2-1), was gathered from public information sources. Proprietary SAR, cask data, and information secured from the casks suppliers.
- 3) Cask data was reviewed and the TEAM determined that all casks could be placed into four distinct cradle support methods based on cask similarities (refer to Section 3.0). This led to four cradle families that all 15 individual conceptual cradle designs would fit into.
- 4) In parallel, the TEAM determined that a common cask cradle-to-Atlas attachment interface system was feasible for all conceptual cradle designs, allowing a single set of attachment points to be utilized on the Atlas railcar deck.
- 5) Atlas railcar payload information was gathered from the cask and initial cradle concepts, and bounding loads were determined, checked, and approved.
- 6) To support the cradle attachment interface and the generation of the future general loading procedures, Kasgro was given the bounding payload conditions and generated Atlas and buffer railcar conceptual designs. These were provided to the DOE for information only, as they are not Phase 1 deliverables.
- 7) After the determination of bounding payload conditions, the conceptual cradle calculations and conceptual cradle drawings were developed. These were checked individually and against each other, and AFS peers performed an independent design review. The conceptual cradle designs were then submitted to and approved by the DOE.
- 8) After the conceptual Atlas railcar was completed, the conceptual cradle attachment interface design started, which included the placement of the attachment system on the conceptual Atlas railcar deck. The attachment interface calculation and drawings were completed and checked and AFS peers performed an independent design review. SN3 engineering staff peer checked the attachment interface system and their comments were incorporated. The conceptual cradle attachment interface was submitted to and approved by the DOE.
- 9) With a conceptual cradle design, cradle attachment interface, and Atlas railcar determined, AREVA TN developed the cask-to-cradle-to-Atlas railcar general loading procedures. MHF SMEs reviewed the procedures, with comments incorporated. The procedures were then submitted to the DOE and approved.
- 10) The DBRD was revised according to S-2043 operational and maintenance requirements, thus meeting the deliverable requirements of the FORD. The DBRD/FORD were submitted to and approved by the DOE.
- 11) Phase 2 preliminary railcar designs were started immediately after the completion of the conceptual railcar designs by Kasgro, including the preliminary design of the railcar structure and its finite element analysis and modeling. Once this was completed, Kasgro provided TTCI pertinent data to initiate the building of dynamic models of the Atlas and buffer railcars.

- 12) Once TTCI completed the initial dynamic Atlas and buffer railcar models, the dynamic models were tested by running simulations. Before further preliminary design tasks were completed, the simulations for high speed stability and tracking were purposely run to determine if the railcars had issues meeting S-2043 requirements. At this point, it was learned that the railcars failed the simulations as the railcars' trucks restricted their ability to meet S-2043 requirements (refer to Section 4.4).
- 13) The TEAM immediately evaluated possible solutions for alternate railcar trucks, found no suitable alternatives, and then studied the probable outcomes of the continuance of the 8-axle Atlas railcar's preliminary design configuration. As a feasible alternative, the 12-axle M-290 railcar was evaluated and determined to have significantly less risk in meeting S-2043 requirements within project schedule constraints. The TEAM also determined that the buffer car would need to emulate the U.S. Navy's escort railcar's framework and structure, undercarriage and truck design in order to meet S-2043 requirements.
- 14) AFS provided a contract notification of the configuration change and requested to change the Phase 1 and Phase 2 final delivery dates as a result of the work to be repeated in the preliminary design of the Atlas and buffer railcars. The AFS Project Manager (PM) and AFS Corporate Sponsor met with the DOE Contracting Officer's Representative (COR) and presented the failed modeling results and the evaluation of the alternatives.
- 15) As a result of discussions with the DOE COR, the TEAM has incorporated the 12-axle Atlas railcar configuration into Phase 1. This includes the following reviews and changes:
  - a. Bounding conditions revised
  - b. Cradle attachment interface revised
  - c. Conceptual cradle design revisions not needed
  - d. General loading procedures revision not needed
  - e. DBRB/FORD revision not needed
  - f. Final calculations and drawings released for Phase 1 report submission
16. AFS generated and submitted the Phase 1 Final Report.

A listing of Phase 1 deliverables and their status is included in Table 1-2.

**TABLE 1-2: PHASE 1 DELIVERABLES AND STATUS**

<b>Event</b>	<b>Description</b>	<b>Accomplishment Expected</b>	<b>Approval Status</b>
1	Delivery of AFS Project Plans and DOE Kick-off Meeting	Plans submitted: <ul style="list-style-type: none"> <li>• Project Management Plan</li> <li>• Engineering Work Plan</li> <li>• Draft Design Basis Document</li> <li>• AAR S-2043 Design Submittal Package</li> <li>• Project QA Plan</li> <li>• Engineering Oversight Plan</li> <li>• DOE Kickoff Meeting Package</li> </ul>	Approved
2	Cradle Attachment Conceptual Design	Submittal of Conceptual Design for cradle attachment (Note: drawing and calculation revised for 12-axle configuration change; included in Appendix A.5)	Approved
3	Payload/Size Bounding Conditions	Documentation showing final payload size bounding conditions (Note: bounding conditions submittal revised for 12-axle configuration change; included in Appendix A.6)	Approved
4	Cradle Conceptual Design	Submittal of conceptual design for cradles	Approved
5	General Loading Procedures	Submittal of General Loading Procedures	Approved
6	Functional and Operational Requirements Document & Phase 1 Report	Submittal of FORD & Phase 1 Report	FORD Approved, Phase 1 Report (this report) under review as of October 1, 2016

## 2.0 GENERAL INFORMATION

### 2.1 Supporting Information and Regulatory Requirements

#### *Railroad Transportation Requirements*

The Atlas and buffer railcars must comply with AAR's "Manual of Standards and Recommended Practices," including Standard S-2043 titled "Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043" [4].

The cask and buffer railcar design and fabricator must be approved to AAR Manual Standards and Recommended Practices, Section J – Quality Assurance M-1003 (2014) [5].

#### *Other DOE Requirements*

The contract states that the cask and buffer railcars are to comply with other applicable standards as specified in the Oak Ridge National Laboratory (ORNL) report, *Cask Railcar System Requirements Document* [20]. If there is any contradiction between the System Requirements Document and the contract's SOW, the SOW takes precedence. Note that in AFS' Request for Information (RFI) AFS-RFI-00225-0001-00 [6], Table 3-3 of the ORNL requirements document [20] was questioned regarding the establishment of bounding design requirements specifically for the conceptual cradle designs. The DOE responded to the RFI that the table "simply lists the largest and heaviest cradle characteristics that exist at this time," hence, the word "bounding" is used to describe these characteristics. As a result, AFS has not limited its conceptual cradle designs specifically to the values in this table and has determined bounding conditions necessary to meet AAR S-2043 and AAR Plate C requirements.

As specified by the DOE, a total of 15 separate transportation cask designs were considered for the development of the conceptual cradle designs, and for bounding the Atlas railcar's dynamic modeling requirements to AAR S-2043. The cradles are to be tall enough and open-ended so that the impact limiters can be attached to a cask after the cask is secured to the cradle while on the Atlas railcar. Each cask design will need a cradle designed to position the Center-of-Gravity (CG) low for stability during transport (see Appendix A.6 on bounding conditions). However, the cradle design will position the impact limiter with a clearance of at least one inch above the cask car deck. In order to understand cask and impact limiter dimension and handling requirements, AFS interfaced with transportation cask vendors identified in SOW Attachment A [3]. AFS obtained and/or verified specific cask information for conceptual cradle designs to meet S-2043 design, operational performance, monitoring, maintenance, and testing requirements (e.g., the height of the cask's CG above the railcar deck, the weight on each axle, etc.). The cask cradle must also be specifically designed to meet the requirements of AAR Rule 88 (which specifies the minimum mechanical requirements for railcars used in interchange commerce service), as included in the AAR 2015 Field Manual of the AAR Interchange Rules [2].

The Atlas railcar, including a cradle and a cask, and buffer car clearances must fit within AAR Plate C, except when loaded with casks that are more than 128 inches wide. Transporting casks that are more than 128 inches wide will require special route analysis that is not a part of this contracted scope of work. The requirements for Plate C are contained within AAR Standards S-2028 [7], S-2029 [8], and S-2030 [9]. These standards are referenced in AAR Standard S-2043, Section 4.7.9.1 [10]. Note that there is a pending change from Plate C to Plate E based on the

change in configuration from an 8-axle Atlas railcar to a 12-axle Atlas railcar.

### ***Nuclear Regulatory Commission (NRC) Requirements***

NRC regulations require HLRM to be shipped in transport casks certified in accordance with 10CFR71 [11]. The cask cradle and its attachments are to meet commercial grade requirements.

### ***Code Requirements***

The following design codes were used in the development of the conceptual cradle design. ANSI N14.6 was used to provide a lifting criteria for the cradles, since they are required to lift the loaded cask. ASME Boiler and Pressure Vessel Code and ASTM codes were used to provide material properties, primarily material yield and ultimate strengths.

### ***Project Quality Requirements***

In the completion of the Atlas project, AFS is utilizing the AFS Quality Assurance (QA) Program, AFS-QA-PMD-001 [13], which establishes the corporate QA requirements used to implement work activities. The program and its implementing procedures are based on ASME NQA-1-2008/2009a [12] and are organized in the 18 requirements of ASME NQA-1.

The AFS QA program includes the development of a tailored project quality assurance plan (PQAP). AFS developed PQAP QA-3014737 [14], which identifies the project-specific requirements such as safety class, project codes, and procedures to tailor the program to meet the project requirements.

Kasgro Rail activities for the Atlas and buffer railcars will be performed in accordance with Kasgro Rail's AAR M-1003-approved QA program [15]. AFS' project management and engineering will provide oversight to ensure contract requirements are met.

Also, incorporated into DOE contract DE-NE0008390, Part III, Attachment J-C, is the "AFS Quality Assurance Surveillance Plan" – generated during the proposal phase of this project – which is incorporated into the PQAP. This surveillance plan is the basis of the AFS Engineering Oversight Plan and compliance matrices, included in the various subsections of Appendix A.1 through A.5.

These requirements apply not only to Phase 1 of the project, but also to Phases 2 and 3.

### ***Specific Project Quality Requirements***

A summary of specific project quality requirements includes:

- AAR S-2043 titled Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043 [4]
- AAR-M1003 titled AAR Manual Standards and Recommended Practices, Section J – Quality Assurance M-1003 (2014) [5]
- AFS Quality Assurance Program Description (QAPD), AFS-QA-PMD-001 [13]
- AFS Project Specific QA Plan, QA-3014737, Design and Prototype Fabrication of Atlas Railcars for HLRM [14]
- AFS "Quality Assurance Surveillance Plan" as incorporated into DOE contract DE-NE0008390, Part III, Attachment J-C [16]

These requirements are incorporated into the single PQAP for the execution of conceptual design, procedural development, report generation, preliminary design, AAR S-2043 modeling, and data submission, detail design, fabrication and delivery of the Atlas and buffer railcars.

### *Project Communications*

An internal TEAM project meeting is held weekly with TEAM members in order to assess project status, issues and resolutions, schedule progress, and resource needs. This meeting is supplemented by various project status conference calls and a routinely published action item list (internal to the TEAM).

A monthly project status report is due to the DOE CO and COR by the tenth day of each month, as detailed in contract DE-NE0008390, Part III, Attachment J-A, and as described in contract section 2.5.3. The report includes the following:

- PM's narrative highlights and status assessment regarding technical progress for each active project phase;
- Deliverable status;
- Schedule and cost performance indexes;
- Issues/concerns (cost, schedule, technical) including forecasted or expected variances, recommended resolution or mitigation, and progress toward resolution or mitigation;
- A summary of upcoming activities over the next 90 days; and
- A listing of project milestone dates and forecast variances.

The monthly status report is considered the official record of the project. The monthly project status report is followed by a project review meeting occurring mid-month following the reporting month. The setup of this meeting is coordinated by the AFS Project Manager (PM) and the COR.

## **2.2 Cask Information and Data**

Conceptual cask cradle designs must accommodate the 15 cask designs listed in Attachment A of the SOW [3], as subsequently modified by a contract modification and by AFS Request for Information Number AFS-RFI-00225-0013-00. Table 2-1 is a modified table incorporating all accepted changes. As this report was being completed in late September 2016, a contract modification added the HI-STAR 190 SL and XL transportation casks to the list of cask models. These two casks will be added to this table during Phase 2 of the design process.

**TABLE 2-1: NOMINAL CHARACTERISTICS OF SPENT NUCLEAR FUEL TRANSPORTATION CASKS**

Manufacturer and Model	Length without Impact Limiters (in.)	Length with Impact Limiters (in.)	Diameter without Impact Limiters (in.)	Diameter with Impact Limiters (in.)	Empty Weight with Impact Limiters (lb.)	Loaded Weight with Impact Limiters (lb.)
<b>NAC International</b>						
NAC-STC	193.0	273.7	99.0	128.0	188,767-194,560	241,664-254,589
NAC-UMS UTC	209.3	273.3	92.0	124.0	178,798	248,373-255,022
MAGNATRAN	214.0	322.0	110.0	128.0	208,000	312,000
<b>Holtec International</b>						
HI-STAR 100	203.25	307.5	96.0	128.0	179,710	272,622-279,893
HI-STAR HB	128.0	230.8 <sup>a</sup>	96.0	128.0 <sup>a</sup>	-- <sup>b</sup>	187,200
HI-STAR 180	174.37	285.04	106.30	128.0	< 308,647	308,647
HI-STAR 60	158.94	274.37	75.75	128.0 <sup>a</sup>	< 164,000	164,000
<b>AREVA Transnuclear</b>						
MP187	201.5	308.0	92.5	126.75	190,200	265,100-271,300
MP197	208.0	281.25	91.5	122.0	176,710	265,100
MP197HB	210.25	271.25	97.75	126.00	179,000	303,600
TN-32B <sup>c</sup>	184.0	261.0 <sup>a</sup>	97.75	144.0 <sup>a</sup>	-- <sup>d</sup>	263,000 <sup>a</sup>
TN-40	183.75	261.0	99.52	144.00	-- <sup>d</sup>	271,500
TN40HT	183.75	260.9	101.0	144.0	-- <sup>d</sup>	242,343
TN-68	197.25	271.0	98.0	144.0	< 272,000	272,000
<b>Energy Solutions</b>						
TS125	210.4	342.4	94.2	143.5	196,118	285,000

Source: Contract DE-NE0008390, Modification #3, Part I, Section C, Attachment A - Transport Cask Characteristics, and AFS Request for Information AFS-RFI-00225-0013-00 regarding contract DE-NE0008390, Attachment A [3] - Transport Cask Characteristics, dated March 7, 2016.

a. Estimated

b. HI-STAR HB transportation casks are already loaded so they would not be shipped empty.

c. This is the TN-32B that DOE plans to use in the High Burnup Dry Storage Cask Research and Development Project, and ship from North Anna Nuclear Power Plant. The TN-32B does not currently have a transport certificate of compliance. The dimensions and weight with impact limiters for the TN-32B are estimated.

d. TN-40 transportation casks are authorized for single use shipments and would not be shipped empty. TN-32B and TN40HT transportation casks are authorized for single use shipments and would not be shipped empty on an S-2043 cask car.

## 2.3 Use of SAR Designs in Conceptual Cradle Designs

Some licensed cask designs utilize the cask cradle design listed in its NRC 10CFR71-licensed SAR general arrangement drawings. In many instances, the general arrangement drawing detailing the cask cradle (including detailed dimensions and CG locations) is part of the NRC Certificate of Compliance (CoC); however, some cask suppliers have made the drawings proprietary, leaving cradle and support requirements unknown or undefined to the public.

As a result of the inconsistent availability of information regarding SAR provided cradle designs and the potential cradle's use (i.e., cradle defined as lifting skid only, nuclear station transport use only, highway transport, use not defined, etc.), AFS chose, with DOE agreement, to neglect constraints (e.g., basic design, detail dimensions, and CG locations) for the cask cradles contained in the SAR General Arrangement Drawings for each of the 15 casks involved in this project [1]. This approach enabled AFS to avoid the lack of information mentioned above, while not hindering the development of the Atlas railcar or its capability to handle the various transport loads.

Using reasonable engineering judgement, information available that conceptually complies with the requirements of 10CFR71 for the cask, and requirements from the AAR Field Book Rule 88 [2], AFS designed the conceptual cradles using the same cask-to-skid/cradle interface locations outlined in publicly available SARs. This provides the DOE with a single Atlas railcar that has the capability to transport all of the casks listed in the contract's SOW, Attachment A – Transport Cask Characteristics [3].

All conceptual cradle designs are to interface with the railcar in the same locations and hence, be interchangeable. Therefore, it is possible that conceptual cradle designs vary from the SAR cradle design to accommodate the required railcar and payload's combined CG. The cask supplier should review and possibly revise their SARs to allow their supplied casks to be transported by the Atlas railcar.

Specific public documents used for information in the conceptual cradle design package include:

- Docket Number 71-9235, *NAC-STC Storage and Transport Cask Safety Analysis Report*, Non-Proprietary Version, Rev. 15, March 2004.
- Docket Number 71-9356, *MAGNATRAN® Submittal*, Non-Proprietary Version, Revision 12A, October 2012.
- Docket Number 71-9356, *MAGNATRAN® RAI Response Package Submittal*, Non-Proprietary Version, Revision 14A, October 2014.
- Docket Number 71-9270, *NAC-UMS Universal MPC System, Safety Analysis Report*, Non-Proprietary Version, Revision UMST-00A, May 2000.
- Docket Number 71-9270, *List of SAR Changes for NAC UMS® Transport SAR Revision 2*, Non Proprietary Version, November 2005.
- Certificate Number 9270, Certificate of Compliance, Rev. 4, U.S. Nuclear Regulatory Commission.
- Docket Number 71-9255, *Safety Analysis Report for the NUHOMS®-MP187 Multi-Purpose Cask*, Non-Proprietary Version, Revision 17, July 2003.

- Docket Number 71-9302, *NUHOMS®-MP197 Transportation Package Safety Analysis Report*, Non-Proprietary Version, Revision 7, AREVA TN.
- Certificate Number 9302, “Certificate of Compliance for Radioactive Material Packages, Package Identification Number USA/9302/B(U)F-96,” Revision 7, U.S. Nuclear Regulatory Commission.
- Docket Number 71-9313, *TN-40 Transportation Packaging, Safety Analysis Report*, Non-Proprietary Version, Revision 16, June 2011.
- Docket Number 71-9293, *TN 68 Packaging Safety Analysis Report*, Non-Proprietary Version, Revision 4, January 2001.
- Certificate Number 9293, Rev 4, U.S. Nuclear Regulatory Commission.
- Docket Number 71-9276, *Fuel Solutions™ TS125 Transportation Cask Safety Analysis Report*, Non-Proprietary Version, Revision 6, BNL Fuel Solutions Corporation.
- Certificate Number 9276, “Certificate of Compliance for Radioactive Material Packages, Package Identification Number USA/9276/B(U)F-96,” Revision 4, U.S. Nuclear Regulatory Commission.
- Certificate Number 9336, “Certificate of Compliance for Radioactive Material Packages, Package Identification Number USA/9336/B(U)F-96,” Revision 0, U.S. Nuclear Regulatory Commission.
- Docket Number 71-9336, Safety Analysis Report on the HI-STAR 60 Transport Package, Non-Proprietary Version, Revision 2, May 2009.
- Docket Number 71-9336, Safety Evaluation Report, Rev 0
- Docket Number 71-9261, Safety Analysis Report on the HI-START 100 Cask System, Non-Proprietary Version, Revision 15, October 2010.
- Certificate Number 9325, “Certificate of Compliance for Radioactive Material Packages, Package Identification Number USA/9325/B(U)F-96,” Revision 2, U.S. Nuclear Regulatory Commission.
- Docket Number 71-9325, Safety Analysis Report on the HI-STAR 180 Package, Non-proprietary Version, Revision 6, April 2014.
- Docket Number 71-9325, Safety Evaluation Report, Revision 2.

The TN-32B and TN-40HT were completed using the TN-40 SAR information, as discussed in Section 3.0 of the calculation enclosed as Appendix A.3.2 [17]. Additional design inputs from proprietary vendor information was used for the HI-STAR 60, HI-STAR 100, HI-STAR 180 and HI-STAR HB.

### ***Additional Data Sources***

In addition to the cask SARs, sources for related cask data included the NRC’s ADAMS public searchable database and information requested directly from and provided by the cask suppliers themselves. If used, data acquired from sources other than the SARs is referenced in the applicable cradle or cradle interface calculations.

### 3.0 CONCEPTUAL CRADLE DESIGNS

As part of this project, DOE has contracted with AFS to design transport package cradle concepts for the 15 SNF transport casks listed in Attachment A of the SOW [3] as well as a single standardized railcar tie-down interface.

AFS was responsible for conceptual designs of cradles that accommodate each of the casks listed in Attachment A of the SOW [3]. The conceptual cradle designs were necessary to determine the height of the cask CG above the railcar deck, the weight on each axle, etc., as required to perform analysis and provide supporting information needed for designing the Atlas railcar. The conceptual cradle designs will not be carried through to preliminary or final design under this contract. The design requirements for the conceptual cradle designs were published in the DBRD, discussed in Section 6.0, and enclosed in Appendix E. These requirements were taken from the SOW with some additional requirements added by the design TEAM.

AFS has chosen to divide the 15 casks into 4 groups based on the cask tie-down methods. This allowed a minimized number of required cradle designs with each cradle grouping containing configurations for each cask. These four groups are referred to as “families” herein, and are described below with full description in Sections 3.5 through 3.8:

- Family 1 Casks that need end stops to restrain axial (longitudinal) movement. The casks rest on a single or multiple saddles with straps restraining lateral and vertical movement. Casks included in this family are the TN-32, TN-40, TN-40HT, HI-STAR 60, HI-STAR 100, HI-STAR-100HB, and the HI-STAR 180.
- Family 2 Casks that are restrained axially and vertically by their lower trunnions (or pocket trunnions in some cases). Casks included in this family are the MAGNATRAN®, NAC-STC™, NAC-UMS™, and the TN-68.
- Family 3 Casks with an integral shear key. Casks included in this family are the MP197, MP197HB, and the TS-125.
- Family 4 Casks with an integral shear key where the cask rests on multiple saddles with a frame restraining vertical movement. The only cask in this family is the MP-187.

The cradle-to-Atlas railcar connection was designed using common (standardized) attachment points that accommodate all cradle designs. All conceptual cradle designs were designed to attach to the railcar using the standardized attachment points. The standardized attachments are described in Section 3.9 and shown in Figure 3-5 in Section 3.9.

The conceptual cradle designs were developed using scoping hand calculations. Cradle weight and CG calculations were performed using hand calculations or spreadsheets. The stress criteria for sizing the conceptual cradle components was based on the 7.5g longitudinal/2g vertical/2g lateral loading, with the resulting loads compared to material yield stress. Each cradle family is supported by a structural calculation and drawing. The individual cradle family structural calculations use first principle manual calculations to evaluate/size the primary structural members on the cradle concepts. Bounding or conservative component evaluations are used, where appropriate, to reduce the number of required evaluations. The lifting criteria applied to the conceptual cradles were conservative in accordance with ANSI N14.6 [18].

The conceptual design of each cradle was evaluated to provide good assurance that a design can be made to support the applied loads. Each cradle is required to support the 7.5g/2g/2g

transportation loads taken individually. In addition, it was demonstrated that lifting load path components in the cradle can support the combined load of the cradle and package to support transfer between modes of transportation. The AAR Field Book Rule 88 [2] was used to define the load cases for evaluation.

### 3.1 Conceptual Cradle Functional Requirements

Conceptual cradle functional requirements are documented in Section 2.2.2 of the AFS document, Engineering Information Record (EIR)-3014611, DBRD (as enclosed as Appendix E) for the Atlas railcar. Conceptual cradle functional requirements are derived from the SOW and from ORNL/TM-2014/596. Functional requirements include conceptual cradle payload, conceptual cradle design scope and required outputs, and operational considerations that impact design and conceptual cradle loading requirements.

### 3.2 Conceptual Cradle Operational Requirements

Conceptual cradle operational requirements are documented in Section 2.3.2 of AFS document, EIR-3014611, DBRD (as enclosed as Appendix E) for the Atlas railcar. Cradle operational requirements include accommodation of the 15 cask designs listed in Table 2-1 above, and the requirement to facilitate loading and unloading operations of the Atlas railcar when the conceptual cradle is in a loaded or unloaded condition.

### 3.3 Conceptual Cradle Maintenance Requirements

Conceptual cradle maintenance requirements were not included in the Phase 1 scope. However, some cradle maintenance requirements, which impacted the conceptual cradle design, were considered by AFS and were added to Section 2.5 of the DBRD as discussed in Section 3.4 below.

### 3.4 Additional Conceptual Cradle Design Considerations

Additional conceptual cradle design considerations were determined by AFS and were documented in Section 2.5 of the DBRD (as enclosed as Appendix E) for the Atlas railcar. These design requirements supplement the SOW requirements and are included due to their relevance to the conceptual cradle design. Additional design considerations include conceptual cradle lifting, conceptual cradle accommodation of cask handling, clarification of conceptual cradle loading requirements, intermodal transfer design requirements, and temperature range for the conceptual cradle material properties.

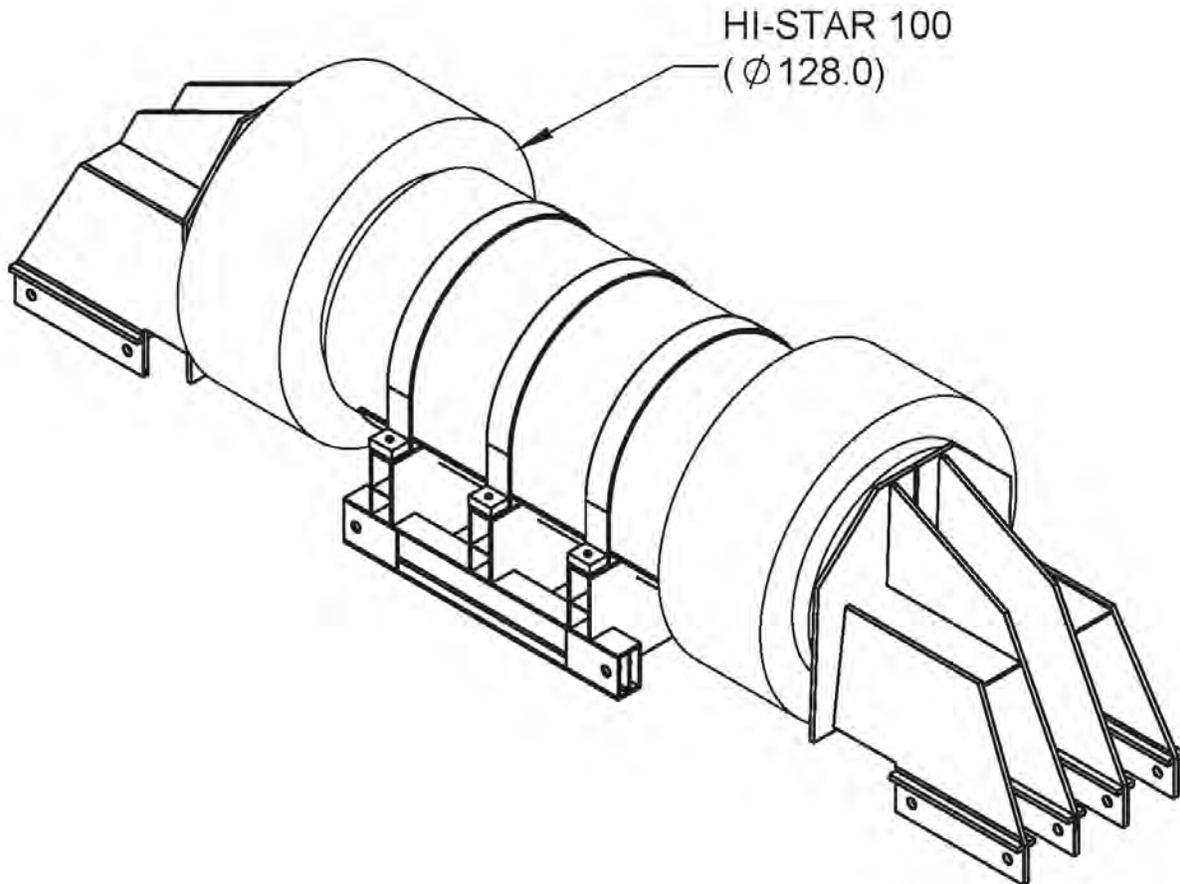
### 3.5 Atlas Railcar Cradle Family 1

Conceptual cradle designs in Family 1 support the Holtec HI-STAR 100, HI-STAR-100HB, and the HI-STAR 180 casks (Figure 3-1), as well as the Transnuclear TN-32B, TN-40, TN-40HT casks. Casks in Family 1 do not have shear keys and are restrained axially (longitudinally) by means of end stops touching the ends of the cask impact limiters. The cask rests on multiple saddles, which along with tie-down straps, provide lateral and vertical restraint. Supporting documents generated for the Family 1 cradle are listed below and enclosed in Appendix A.1:

- DWG-3015137, Atlas Railcar Cradle Family 1 Conceptual Drawing
- CALC-3015133, Atlas Railcar Family 1 Conceptual Cradle Structural Calculation

The Family 1 cradles use the same basic design configuration for each cask. The cask impact limiters interface with cradle end stops, which provide longitudinal restraint at each end of the cask. Casks rest on the central cradle frame, which includes multiple saddles with tie-down straps that provide vertical and lateral restraint.

**FIGURE 3-1: FAMILY 1 HI-STAR 100 CASK, CONCEPTUAL CRADLE, AND END STOPS**



The cradle frame is constructed from two main I-beams, which sandwich the saddle cross members. There is no cask trunnion interface or cask shear key. The central frame is a welded construction with the saddles and cross member weldments welded to the main I-beams. There are four pin locations in the central frame attachment of the cradle to the railcar. These pin locations provide vertical restraint for the cradle. The central frame is not restrained longitudinally, as the end stop assemblies provide this restraint. Lateral restraint for the central frame is provided by the main frame I-beams, both of which interface with the railcar. Longitudinal, restraint, and lateral connections for end stop assemblies are provided by pinned and blocked connections to the railcar.

The end stop assemblies can be lifted using lifting hardware (shackles or hoist rings) installed above the CG locations specified on the drawing. The cradle and loaded cask can be lifted using a lifting strap located beneath the protruding saddle plates, interior to the end saddles, and

combined with a lift beam to provide a vertical lift. A concept of a personnel barrier is included in the conceptual cradle design to meet package SAR requirements and to provide a reasonable cradle weight. This is a temporary barrier to be used when the cask is placed on the cradle to protect personnel from surface or proximity of cask surface due the potential for a high temperature or radiological exposure. The materials specified for this conceptual cradle is primarily carbon steel.

The TN-40, TN-40HT and TN-32 central cradles have three cut outs in the cradle weldment that allow clearance for cask tie-rod installation. Package tie-rods are used to attach the impact limiters to the package.

All Family 1 cradle concepts are approximately 505 inches long (to the outside end of the end stop assemblies which includes the cask length). The end stop assemblies vary from 94 to 132 inches long and 100 to 142 inches tall. The central cradle is approximately 137 inches long and varies from 94 to 132 inches tall. The nominal central cradle weight varies between 9,000 lb. and 20,000 lb., the end stop weight (per railcar end) varies between and 22,600 lb. and 28,600 lb. the total cradle weight varies between 54,200 lb. and 70,200 lb.

The cradle designs in this family have small variations in their designs when compared to the designs depicted in the SARs. These differences are due to variations in the Atlas railcar cradle requirements and omission of information in the publicly available SARs. Some cask centerline heights depicted in SAR cradle drawings may not match SAR (figure or cradle drawing) locations. If dimensions were included in the SAR text, they were met. For example, the SAR cradle drawing for TN-40 shows the cask centerline (radial CG) much higher than the final design. Additionally, the HI-STAR 60 has an option to be axially supported at the trunnions in lieu of the end stops. However, as documented in AFS -RFI-00225-010-00, AFS chose to support the HI-STAR 60 with end stops. Even with these differences, the conceptual cradle designs provide loads that should bound the final design railcar loads for each of these casks.

### 3.6 Atlas Railcar Cradle Family 2

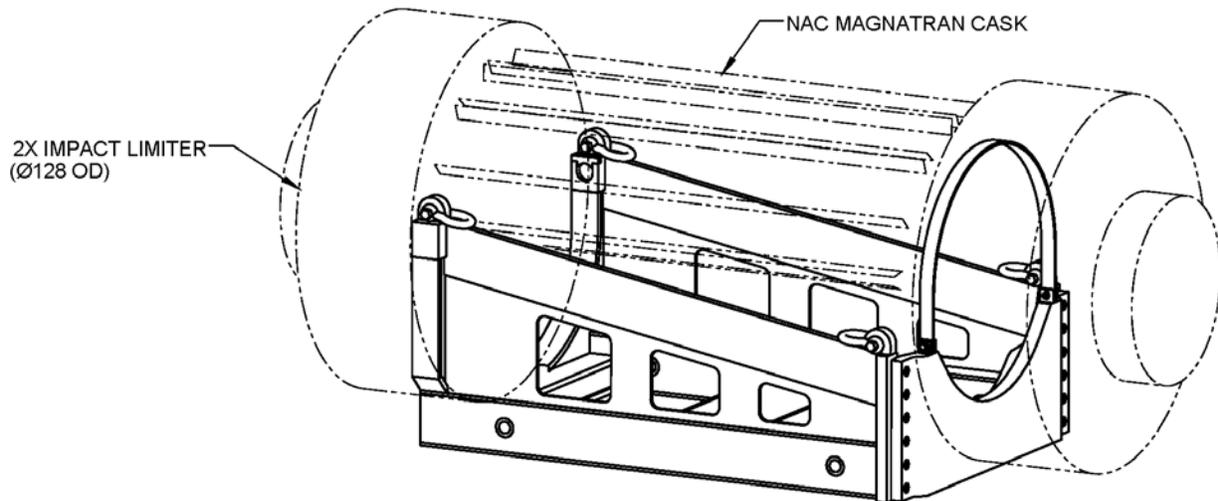
Conceptual cradle designs in Family 2 support the NAC International NAC MAGNATRAN®, NAC-STC™, and NAC-UMS™ casks as well as the Transnuclear TN-68 cask (Figure 3-2). Casks in Family 2 are restrained axially and vertically by their lower trunnions (or pocket trunnions in some cases). Supporting documents generated for the Family 2 cradle are listed below and enclosed as Appendix A.2:

- DWG-3015138, Atlas Railcar Cradle Family 2 (NAC) Conceptual Drawing
- DWG-3015277, Atlas Railcar Cradle Family 2 (TN-68) Conceptual Drawing
- CALC-3015134, Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

The NAC cradles use the same basic design configuration for each cask. The cask trunnions or trunnion pockets interface with the cradle trunnion interface, which provides axial and vertical restraint for the cask. The opposite end of the cask rests on a front saddle and is constrained vertically with a front strap tie-down. Axial cask support is also provided by the fastened front saddle, which interfaces with the cask upper forging. The cradle frame is constructed from two main I-beams, which sandwich the center cradle shear block and other cross members. The trunnion interface is tied into the bottom and front saddle with plates running down the length of the cradle side. The front saddle is fastened to the cradle frame using bolts. There are four pin

locations for attachment of the cradle to the railcar. These pin locations provide vertical cradle restraint. Longitudinal cradle restraint is provided by the cradle shear block and lateral restraint by the main frame I-beams, both of which interface with the railcar.

**FIGURE 3-2: FAMILY 2 NAC MAGNATRAN CONCEPTUAL CRADLE DESIGN**



The TN-68 has a similar design to the NAC cradles, but with a different trunnion tower and front saddle design. These were changed to accommodate the slightly different tie-down methodology. The front saddle and front strap provide vertical restraint and the saddle includes cutouts that provide clearance for package tie-rods (used to attach the impact limiters to the package). The trunnion interface is a trunnion tower and cap for axial and vertical cask restraint.

The NAC conceptual cradles and loaded package can be lifted using hoist rings installed in the four lifting lugs on the corners of the cradle frame and combined with a lift beam. The TN-68 conceptual cradle and loaded package can be lifted using four bolted or welded lift lugs attached to the side main cradle frame inboard of the railcar pin attachment points. A lift beam should be used to provide a vertical lift. A concept of a personnel barrier is included in the conceptual cradle design to meet package SAR requirements and to provide a reasonable cradle weight. The materials specified for the Family 2 conceptual cradle is primarily carbon steel with bronze specified for the cask trunnion interface and aluminum specified for the personnel barrier.

All the Family 2 cradle concepts are approximately 150 to 190 inches long and 80 to 90 inches tall. The nominal cradle weight varies between 27,000 lb. and 42,000 lb.

The cradle designs in this family have small variations in their designs when compared to the designs depicted in the SARs. These differences are due to variations in the Atlas railcar cradle requirements and omission of information in the publicly available SARs. Specifically, the NAC cradle drawings are listed in the NRC CoC, but are not available to the public. Even with these differences, the conceptual cradle designs provide loads that should bound the final design railcar loads for each of these casks.

### **3.7 Atlas Railcar Cradle Family 3**

Conceptual cradle designs in Family 3 support the AREVA TN MP197, MP197HB casks as well

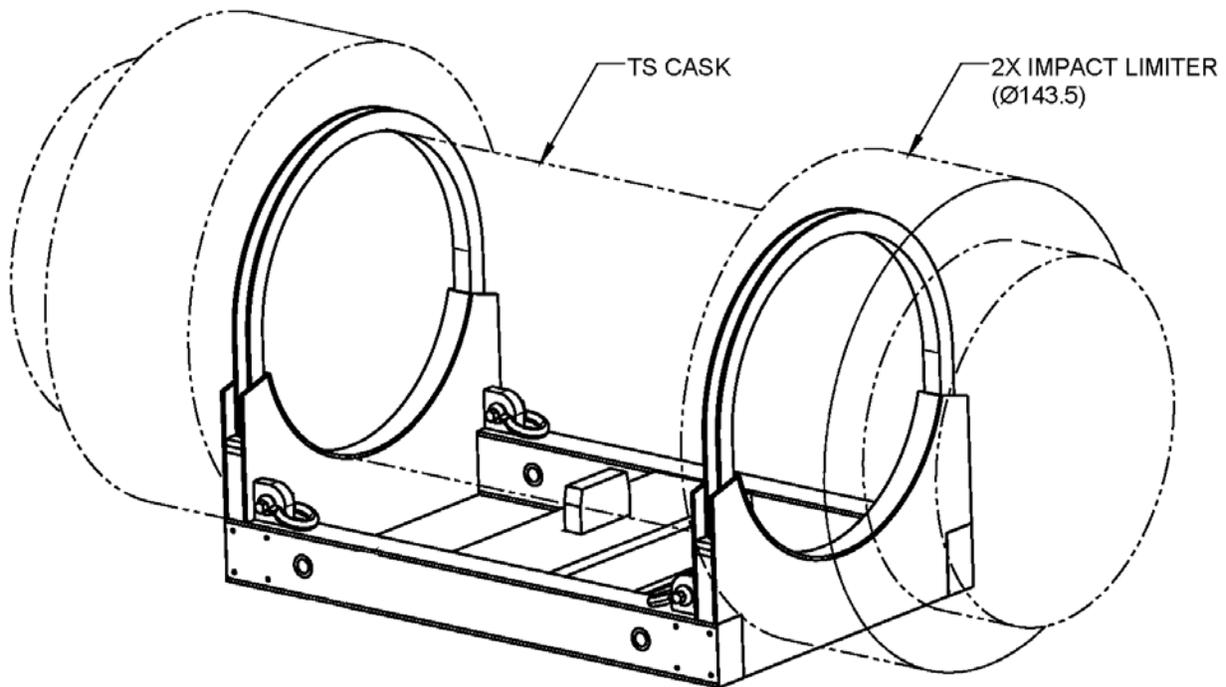
as the Energy Solutions TS125 cask (Figure 3-3). Casks in Family 3 are restrained axially by an integral shear key and vertically by saddles and tie-down straps.

Supporting documents generated for the Family 3 cradle are enclosed as Appendix A.3 and include:

- DWG-3015139, Atlas Railcar Cradle Family 3 Conceptual Drawing
- CALC-3015135, Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

The Family 3 cradles use the same basic design configuration for each cask. The cask rests on front and rear saddles which, along with the tie-down straps, provide vertical cask restraint. Axial cask support is provided by a shear key that protrudes into the cask. The cradle frame is constructed from two main I-beams which sandwich the center cradle shear block and saddle cross members. There are four pin locations for attachment to the cradle railcar. These pin locations provide vertical cradle restraint. Longitudinal cradle restraint is provided by the cradle shear block and lateral restraint by the main frame I-beams both of which interface with the railcar.

**FIGURE 3-3: FAMILY 3 ENERGYSOLUTIONS TS125 CONCEPTUAL CRADLE DESIGN**



The Family 3 conceptual cradles and loaded package can be lifted using shackles installed in the four lifting lugs on the top of the cradle frame I-Beams combined with a lift beam to provide a vertical lift. Detailed cradle designers should note that the four lifting lugs may not be accessible when the personnel barrier is in place and considerations should be given during the cradle's detailed design. Optionally, bolt-on lift lugs may be used as attachment points instead of the gusset attachment points, however the bolt-on lift lugs must be removed for transport. A concept of a personnel barrier is included for each cask in the conceptual cradle design to meet package SAR requirements and to provide a reasonable cradle weight for supporting cask railcar

bounding load calculations. The Family 3 conceptual cradle is primarily carbon steel with stainless steel specified for the personnel barrier.

All of the Family 3 cradle concepts are approximately 180 inches long and 114 to 126 inches tall. The nominal cradle weight varies between 26,000 lb. and 30,000 lb.

The cradle designs in this family have small variations in the conceptual cradle designs when compared to the designs depicted in the SARs. These differences are due to variations in the Atlas railcar cradle requirements and omission of information in the publicly available SARs. Lifting provisions were not included in the original AREVA TN MP197 and 197HB public SARs, which drove adjustments in the saddle gusset design to allow for a lifting lug provision. A similar provision was provided in the TS125 cradle, while maintaining bolt-on lifting lugs.

Details of the cradle side rail size and design for each cradle were developed to support Atlas railcar loads based on a shared connection point design. Sizing of the personnel barriers was based on the nominal 1-inch impact limiter to deck height requirement and the height of the side rails. Even with these differences, the cradle designs provide loads that should bound the final design rail car loads for each of these casks.

### 3.8 Atlas Railcar Cradle Family 4

The conceptual cradle design in Family 4 supports the AREVA TN MP-187 package. The cask has an integral shear key, rests on multiple saddles, and has a structural frame resisting vertical movement. Supporting documents generated for the Family 4 cradle are listed below and enclosed in Appendix A.4:

- DWG-3015140, Atlas Railcar Cradle Family 4 Conceptual Drawing
- CALC-3015136, Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

For the Family 4 cradle (Figure 3-4), the cask rests on front and rear saddles which, along with the installed structural frame, provides vertical and lateral cask restraint. Axial cask restraint is provided by a shear key that protrudes into the cask. The cradle frame is constructed from two main I-beams which sandwich the center cradle shear interface and saddle cross members. There are four pin locations for attachment of the cradle to the railcar. These pin locations provide vertical cradle restraint. Longitudinal cradle restraint is provided by the cradle shear interface and lateral restraint is provided by the main frame I-beams both of which interface with the railcar.

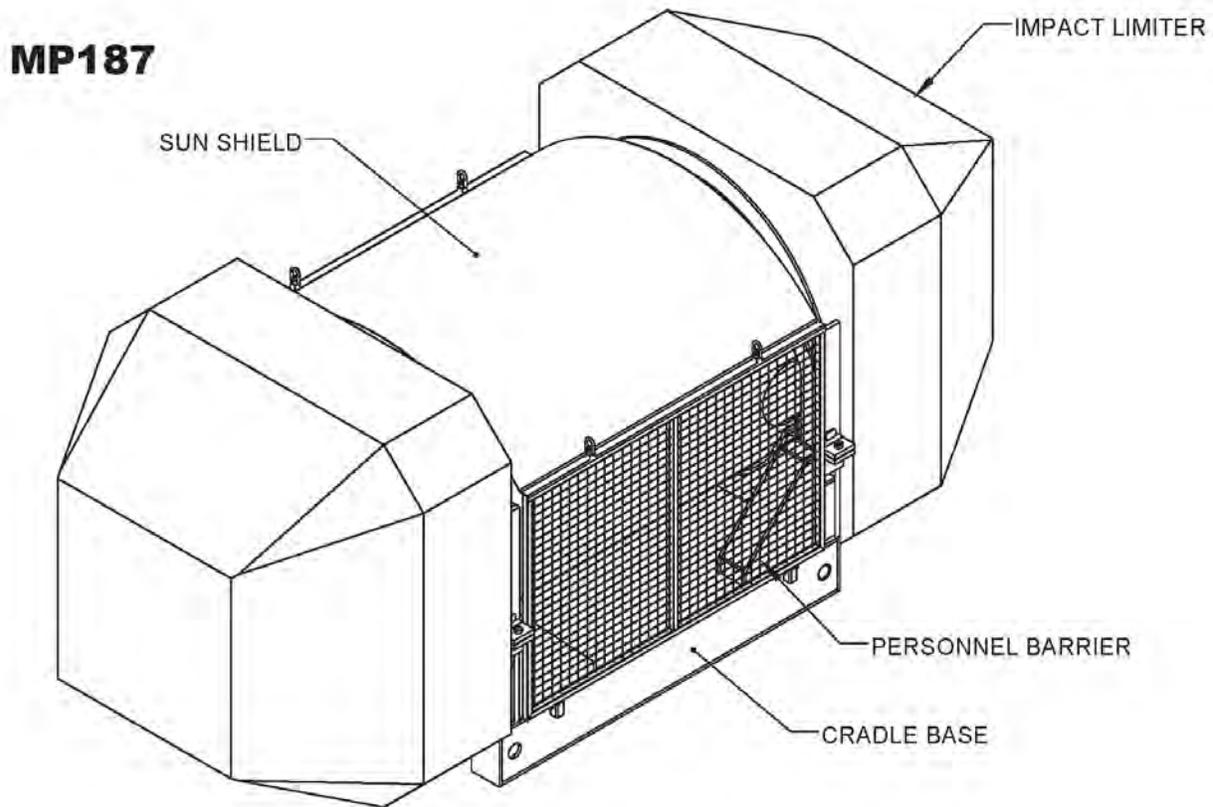
The Family 4 conceptual cradle and loaded package can be lifted using hoist rings installed in the four threaded lift point holes located on the top of the cradle structural frame and combined with a lift beam to provide a vertical lift. A concept of a personnel barrier is included in the conceptual cradle design to meet package SAR requirements and to provide a reasonable cradle weight. The materials specified for the Family 4 conceptual cradle is primarily carbon steel with stainless steel specified for the personnel barrier.

The Family 4 cradle concept is approximately 138 inches long and 124 inches tall. The nominal cradle weight is 36,800 lb.

The cradle design in this family has small variations when compared to the design depicted in the SARs. These differences are due to the Atlas railcar cradle requirements and the cradle depicted in the SAR. Even with these differences, the conceptual cradle designs provide loads that should

bound the final design railcar loads for this cask.

**FIGURE 3-4: FAMILY 4 AREVA TN MP187 CASK AND CONCEPTUAL CRADLE**



### 3.9 Railcar-to-Cradle Interface

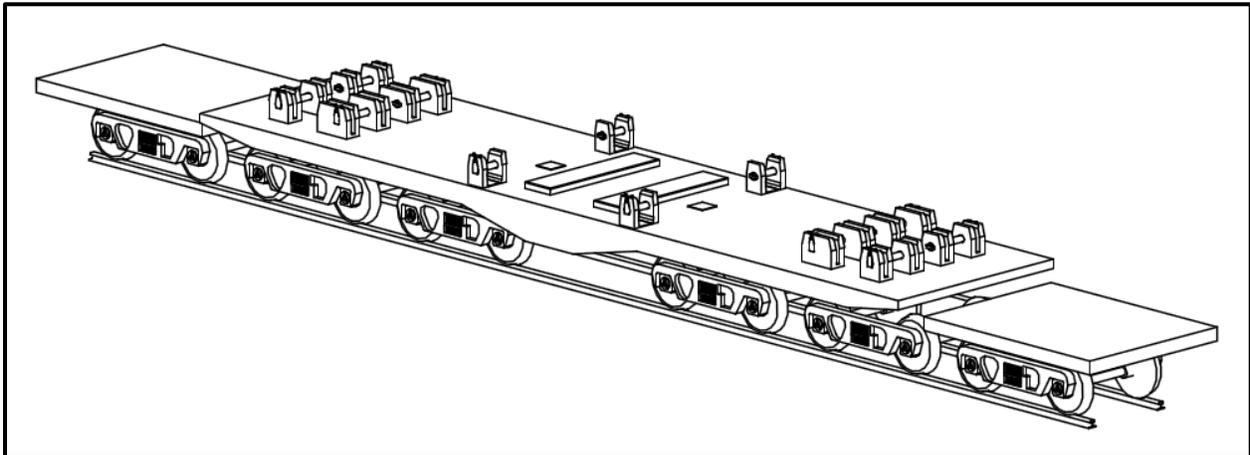
The Atlas railcar is designed with standardized attachment points welded to the car deck. The blocks and pinned connections provide a uniform connection between the railcar and the conceptual cradle designs and accommodate all of the 15 cask designs listed in the SOW. Supporting documents generated for the standardized attachment design are listed below and enclosed as Appendix A.5:

- DWG-3015278, Atlas Railcar Cradle Attachment Components
- CALC-3015276, Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

The Atlas Railcar Standardized Attachment Components are depicted in AFS Drawing DWG-3015278 and are shown in Figure 3-5 and Appendix B. There are four center pin attachment blocks welded to the railcar that are used for cradle designs in Families 1 through 4. The cradles are secured laterally and vertically using four attachment pins inserted through the center pin attachment blocks. Longitudinal support for cradle Families 2 through 4 is provided by two shears welded to the railcar. Family 1 cradle end stop assemblies are supported using the outer 16 attachment blocks welded to the railcar. The end stop assemblies are pinned in place.

The conceptual design of each cradle was evaluated to determine the tie-down loads applied to the railcar via the standardized attachment components. Each cradle is required to support the 7.5g/2g/2g tie-down loads taken individually per Section 2.2.2.13 of the DBRD. The bounding loads from the 15 package designs and associated conceptual cradle designs were applied to the standardized attachment components. The bounding cradle loads were considered in the structural evaluation of the Atlas railcar standardized attachment components and the design was shown to be adequate.

**FIGURE 3-5: ATLAS RAILCAR STANDARDIZED ATTACHMENT COMPONENTS**



The standardized attachment components will be fabricated and attached to the Atlas railcar. These attachment points must accommodate both the conceptual and the final cradle designs for all 15 casks listed in the SOW. The conceptual cradle designs are not final and some small changes are anticipated in the final cradle design (to be performed at a later date). Therefore, an additional factor of 1.1 was added to the bounding loading inputs to provide increased conservatism in the standardized attachment component design.

The standardized attachments were evaluated using manual calculations to evaluate the standardized attachment components including the pin attachment blocks, the shear blocks, and the attachment pins shown in AFS drawing DWG-3015278 (enclosed as Appendix A.5). Material properties were taken at 100°F per the DBRD.

The cradle conceptual design inputs were also used to calculate the combined CG and weight for the railcar, cradles, and casks. The combined CG and weight of the railcar and load were determined using the package weights and vertical CG locations, calculated weights and vertical CG locations of the conceptual cradle designs, and the railcar deck height and railcar vertical CG location provided by Kasgro Rail.

Some of the casks may have their impact limiters installed on or removed while the package is on the railcar deck. The distance between the attachment components is 376 inches. The minimum required clearance for impact limiter removal is 372 inches for the MP197 from Table 5-7 of Calculation 3015276-001, enclosed in Appendix A.5.2. In this bounding case, there is 4 inches of clearance. However, the clearance was calculated assuming the impact limiter has a flat bottom end. In reality, all of the cask impact limiters have some taper, which adds additional clearance.

To accommodate current SAR requirements and allow for operational flexibility, the Atlas railcar design must be able to accommodate up/down-ending of the casks which have bottom trunnions, while on the railcar. Table 3-1 shows the maximum vertical loads for the listed cask design and the location from the Atlas railcar centerline. These loads were used as an input to the railcar design.

The conceptual cradle designs for Families 2-4 are supported longitudinally by the two shear blocks welded to the Atlas railcar. The Family 1 conceptual cradles are supported longitudinally by the end stop assemblies.

**TABLE 3-1: CASK ROTATION LOADING**

<b>Cask rotated on cradle</b>	<b>Load on Railcar (lb.)</b>	<b>Horizontal distance from load to center of railcar (in.)</b>
TN-68	299,500	63.5
HI-STAR 60	234,400	67.56
NAC-STC	298,600	78.6
HI-STAR 180	371,347	81.75
NAC MAGNATRAN	356,000	89.3
NAC-UMS	299,000	89.3
TS-125	315,910	98.0

As required by the Family 1 cask SARs and discussed in the General Loading Procedures (enclosed as Appendix D), after installation of the end stop assemblies, shim material is installed in the gaps between the end stop assemblies and the impact limiters. Therefore, there is no clearance in the longitudinal direction for the Family 1 conceptual cradles.

All of the conceptual cradle designs are supported laterally by the center pin attachment blocks. The structural evaluation of the attachment components is documented in AFS calculation CALC-3015726 (enclosed as Appendix A.5). The maximum lateral clearance is shown in Table 3-2.

All of the conceptual cradle designs are supported vertically by the center pin attachment blocks. The maximum clearance can be calculated using the slot and hole maximum conditions and the smallest pin diameter. This assumes the hole/slot size is not reduced from misalignment which would reduce the clearance. Using dimensions from all conceptual cradle drawings and the attachment component drawing, the maximum vertical clearance is shown in Table 3-2 below.

**TABLE 3-2: MAXIMUM CRADLE TO RAILCAR CLEARANCES**

<b>Longitudinal</b>	<b>Lateral</b>	<b>Vertical</b>
0.86 inches	0.78 inches	0.312 inches

## 4.0 CONCEPTUAL RAILCAR DESIGNS

The Phase 1 conceptual designs of the Atlas and buffer railcars are primarily focused towards having a feasible prototype railcar design for use in the conceptual cradle designs and the conceptual design of the cradle-to-railcar attachment interface system. The conceptual railcar designs also support the generation of the general loading procedures. The conceptual designs of the Atlas and buffer railcars are not a specific Phase 1 deliverable, but are being provided for information only.

### 4.1 Conceptual Prototype Railcar Designs

The Atlas and buffer railcars were conceptually designed by Kasgro Rail. As originally offered in the proposal, the Atlas railcar's design is based on the utilization of the U.S. Navy's M-290 cask railcar for the following reasons:

- The accepted proposal from the TEAM was based on the utilization of the Navy's M-290 cask railcar basic design and components due to it being the only railcar to successfully be approved for use under the AAR's S-2043 requirements;
- The M-290s components were also selected, as they are the only existing components with established S-2043 component dynamic models built by TTCI;
- Both of these attributes allowed the project to greatly reduce the risk model for the Atlas project, in the TEAM's original proposal and the resulting awarded project, by providing AAR S-2043 approved railcars within the desired DOE railcar program schedule.

Based on the selection by the DOE of the TEAM's alternate proposal, the project team developed a conceptual 8-axle HLRM Atlas railcar with uniform attachment blocks for all 15 conceptual cradles and conceptual cradle end blocks.

A final attribute of using the M-290 railcar and components as a basis for the Atlas and buffer railcars is that the Phase 2 preliminary railcar design phase could start immediately after completion of the Phase 1 conceptual cradle designs, but before completion of other Phase 1 activities.

The use of a Kasgro Rail standard 4-axle flat deck railcar design with the utilization of the M-290's trucks was also considered as the basis of the buffer railcar for the same reasons of known design, components, fabrication process, and reduced risk while meeting schedule objectives.

During the initial Phase 2 preliminary design of the 8-axle Atlas railcar, it was discovered that the Atlas and buffer railcar designs did not meet S-2043 requirements related to high-speed stability and dynamic curving (see Section 4.4 for a detailed explanation). This change was incorporated into the Phase 1 deliverables with the configuration of the Atlas railcar now shown as a 12-axle railcar.

As this report was being completed in late September 2016, a contract modification added the HI-STAR 190 SL and XL transportation casks to the list of cask models. The same contract modification changed the design clearance requirement from the AAR's Plate C to Plate E. The next phase of the design process, Phase 2, Preliminary Design, will include these changes.

## 4.2 Atlas Railcar

Key design and functional criteria of the Atlas railcar include the following:

- Compliance with AAR S-2043 design and functional requirements [4];
- Compliance with applicable standards specified in Oak Ridge National Laboratory (ORNL) report titled AAR S-2043 Cask Railcar System Requirements Document [20];
- Carry HLRM casks as listed in Attachment A of the SOW [3];
- Standard off-the-shelf components used to the maximum extent practical;
- The Atlas railcar design shall include both an electronically controlled pneumatic brake system and a standard freight railcar pneumatic brake system;
- The Atlas railcar design shall include a remote monitoring system installed;
- Use of a flat deck railcar to allow placement and removal of cask impact limiters while the cask is loaded on the railcar;
- Use of standardized attachment points to accommodate uniform conceptual cradle designs attachment interfaces (see Section 3.9);
- Incorporation of jacking and tie down points on the railcar so that, if feasible, casks can be loaded vertically and down-ended into the cradle, whilst located on the railcar. The jacking and tie down points would be used to stabilize the railcar and ensure the off-center loads do not transfer through the railcar suspension;
- The railcar shall be symmetrical in its use; and
- The Atlas railcar including the cradle and cask payload shall fit within AAR Plate C railcar envelope limits, except for when carrying casks that are more than 128 inches wide. Note that there is a pending configuration change to AAR Plate E.

Specific Atlas railcar design and functional requirements can be reviewed in Section 2.2.1 of the DBRD/FORD as enclosed in Appendix E.

Key operational requirements of the Atlas railcar include the following:

- The Atlas railcar shall meet the operational requirements of AAR S-2043, Appendix B requirements [19];
- An “empty cask railcar” shall be a Atlas railcar with no payload;
- The Atlas railcar shall have both electronically controlled pneumatic brake system and the standard freight railcar pneumatic brake systems operationally ready; and
- A railcar inspection must occur before each use of the Atlas railcar in a HLRM consist.

Specific Atlas railcar operational requirements can be reviewed in Section 2.2.2 of the FORD as enclosed in Appendix E.

A drawing of the conceptual Atlas railcar can be found in Appendix B.1. A detailed conceptual Atlas railcar description is also provided in Appendix B.2. These documents and their data are provided for information only; the information is subject to change and is currently not under design control. Note that the Atlas railcar drawing and description reflect the configuration

change to a 12-axle cask railcar.

### 4.3 Buffer Railcar

Key design and functional criteria of the buffer railcar include the following:

- Compliance with AAR S-2043 requirements [4];
- Compliance with applicable standards specified in ORNL report titled AAR S-2043 Cask Railcar System Requirements Document [20];
- The buffer railcar will not carry HLRM;
- Standard off-the-shelf components used to the maximum extent practical;
- The buffer railcar design shall include both an electronically controlled pneumatic brake system and a standard freight railcar pneumatic brake system;
- The buffer railcar design shall include a remote monitoring system installed;
- The buffer railcar may be used to carry lightweight items necessary to support loading/unloading and transportation activities;
- Nothing on the buffer railcar shall obstruct the line-of-sight between the escort railcar and the Atlas railcars;
- The railcar shall be symmetrical in its use; and
- The buffer railcar including any payload shall fit within AAR Plate C railcar envelope limits. (Note that there is a pending configuration change to AAR Plate E.)

Specific Atlas railcar requirements can be reviewed in Section 2.2.1 of the FORD as enclosed in Appendix E.

Key operational requirements of the buffer railcar include the following:

- The buffer railcar shall meet the operational requirements of AAR S-2043, Appendix B requirements [19];
- The buffer railcar shall have both electronically controlled pneumatic brake system and the standard freight railcar pneumatic brake systems operationally ready; and
- A railcar inspection must occur before each use of the buffer railcar in a HLRM consist.

Specific Atlas railcar operational requirements can be reviewed in Section 2.2.2 of the FORD as enclosed in Appendix E.

A drawing of the conceptual buffer railcar can be found in Appendix C.1. A detailed conceptual buffer railcar description is also provided in Appendix C.2. These documents and their data are provided for information only; the information is subject to change and is currently not under design control.

### 4.4 Change in Atlas Railcar Configuration from 8 to 12 Axles

In late May 2016, the selected M-290 trucks for the 8-axle Atlas and buffer railcars failed initial dynamic modeling simulations. Simulation results indicated that railcar trucks failed the "hunting" criteria during high-speed stability and dynamic curving simulations. Specifically,

both the 8-axle Atlas cask and buffer railcars failed S-2043 requirements in empty and loaded railcar conditions, at moderate to high speeds, in standard elevation conditions, super-elevation conditions, and in some tangent sections.

The following activities occurred in an attempt to find a suitable railcar truck after the modeling simulations failed.

- 1) The TEAM re-checked the Atlas and buffer railcar dynamic models, simulation programs, the truck model's representation, and the truck component model's representation for correctness with no errors found.
- 2) Exchangeable truck components (springs, side bearings, wedges, end bearings) were replaced in the dynamic models to attempt to improve the truck's performance. In all resulting simulations, the cask and buffer railcars still failed high-speed stability and dynamic curving simulations.
- 3) ASF/Amsted, the designer and fabricator of the current swing-motion M-290 trucks, was contacted regarding the failed simulation results of the M-290 truck in an 8-axle Atlas railcar configuration, and failed simulations using modified M-290 truck components representations. ASF/Amsted said the swing-motion M-290 truck had been "maximized" to reduce hunting characteristics specifically for the M-290 12-axle cask railcar for the U.S. Navy. It was also believed that the three-truck arrangement combined with the damping effect of the longer "tri-span bolster" (structural bridge connecting three trucks and the railcar on each end of the railcar) of the U.S. Navy 12-axle M-290 railcar assisted in reducing hunting characteristics allowing the railcar to meet S-2043 requirements.
- 4) ASF/Amsted conceptually designed a new limited-motion control truck for the Atlas railcar. If chosen, this truck would have required ASF/Amsted to provide internal design and finite element analysis/modeling, non-recurring engineering, tooling, castings, gauging and pilot fabrication resulting in major cost and schedule impacts to the Atlas project. Additionally, this would also result in TTCI completing additional dynamic modeling development and S-2043 simulation development/modification. More importantly, the TEAM agreed that successfully meeting S-2043 requirements with the new truck was a significantly higher risk.
- 5) The TEAM also reviewed possible AAR M-976 approved trucks for potential detailed evaluation, modeling, and utilization on the 8-axle Atlas railcar in order to meet S-2043 high-speed stability and dynamic curving simulations. (Note: An AAR M-976 approved truck is an AAR evaluated and approved truck for heavy duty railcar use). Trucks on this list were selected for evaluation due to their known performance parameters and immediate availability. There are only two truck manufacturers on the AAR M-976 listing - ASF/Amsted and Standard Car Truck. However, the TEAM's SMEs' assessment concluded that the likelihood of successfully meeting S-2043 requirements with these trucks was very low. Also, data necessary to provide the physical properties, dimensions, suitable components, and anticipated responses of replaceable components for these available trucks was not available.
- 6) Of the three primary North American railcar truck manufacturers, only two have AAR M-976 approved trucks. Only ASF/Amsted accepts orders for customized, small-quantity railcar trucks supported by the engineering services needed to provide a feasible truck design throughout the modeling, simulation, final design, truck fabrication, and railcar assembly

process. This service would come with significant schedule and cost impact to the project. Other primary AAR truck manufacturers offer related truck design support services, but only in the design of a new railcar or in trucks to be fabricated in large quantities (typically more than 1,000 railcars and/or equivalent trucks).

- 7) Discussions occurred to determine if it was feasible to design damping effects into the 8-axle Atlas railcar's "bi-span bolster". This would require lengthening the bolster while also structurally reducing its strength and placing the supporting trucks further from the bolster's pivot/connection point to the railcar deck. In summary, lengthening and/or weakening the "bi-span bolsters" for proper damping effect was determined to create a fundamental weakness in the bi-span's structure given the weight load requirements of the 8-axle Atlas railcar.
- 8) A detailed decision tree was constructed to support the evaluation of the 8-axle truck alternatives, and a 12-axle Atlas railcar configuration as an alternative following failure of the 8-axle truck configurations. The decision tree portrays that continuing to pursue an 8-axle version of the Atlas railcar will increase project risk, specifically in meeting S-2043 requirements, and cause additional project duration. However, changing to a 12-axle Atlas railcar configuration significantly reduces current project risk and presents minimal additional schedule impacts. Therefore, the TEAM determined to change from an 8-axle Atlas railcar configuration to a 12-axle Atlas railcar configuration; and, duplicating Kasgro's M-290 cask railcar from the railcar deck down with the incorporation of the current Atlas cradle-to-railcar attachment interface on the 12-axle Atlas railcar's deck.
- 9) With limited information available on the U.S. Navy's Rail Escort Vehicle (REV), the TEAM has also reviewed the use of the ASF/Amsted escort railcar truck (as developed for Vigor Industries' REV for the U.S. Navy) on the buffer railcar. This truck has been demonstrated to meet AAR S-2043 dynamic modeling requirements and can be utilized on the buffer railcar by tailoring the railcar's truck placement and spacing, the railcar's undercarriage structure, and the railcar's weight. This work will occur simultaneously during the Atlas railcar re-design during Phase 2 preliminary design. The use of the escort railcar trucks was considered to be the least risky alternative when compared to other suitable truck alternatives which are AAR M-976 approved trucks or a standard duty truck that meets an even lower level of requirements. Permission to use the Vigor Industries'/U.S. Navy's escort railcar truck and structural design has been provided to the Atlas project.

## 5.0 GENERAL LOADING PROCEDURES

The Atlas Railcar General Loading Procedures fulfills the Phase 1 deliverable of DOE Contract DE-NE-0008390, Part I, Section C related to General Loading Procedures. These procedures include how to load each of the casks in Attachment A of the contract (shown in Table 2-1) [3] onto the Atlas railcar, including whether the impact limiters would be attached to the cask before or after the cask is placed on the railcar. The purpose of these general procedures is not to replace any detailed site-specific or cask-specific loading procedures. Its purpose is to inform the railcar and cask/cradle designers and users of equipment design features and operational requirements needed to accommodate the casks listed in Attachment A of the contract [3].

This contract deliverable provides a collection of general procedures that provide guidance for the loading of casks onto the transportation cradles and also the loading of the transportation cradles onto the railcar. Whenever possible, the procedures are provided in a general sense and apply to all of the contract Attachment A [3] casks (Table 2-1) and associated cradles. When relevant differences exist, specific subsections are included that may apply to a particular family of cradles or casks. There are a total of 15 unique casks and 4 conceptual cradle design families covered by these procedures, with each of the casks being assigned to a particular cradle design.

It was originally envisioned that this contract deliverable would include 15 separate collections of loading procedures, one for each of the casks under consideration. To capture the necessary activities for inclusion into the procedures, the following sources of information were gathered and reviewed to develop the loading procedures:

- Design drawings for the cradle and railcar designs developed under the above contract;
- Operating requirements for the casks, as found in the SARs and CoCs associated with each cask; and
- Operational experience of similar casks used for the transportation of spent nuclear fuel and radioactive waste products.

Once all of the above information was reviewed and compared for each of the casks, it was realized that 15 separate sets of loading procedures would be very similar between the various casks due to the general and high-level nature intended for these procedures. At this point, it was determined that, to the extent practical, a single set of loading procedures would be created that applied to all of the casks and only unique differences would be separately identified. To achieve this, all of the steps necessary to load the casks onto the transportation cradles and then the transportation cradles onto the railcar were organized into the following high-level activities:

- 1) Receive Railcar for Loading, including:
  - a) Placement, securement, and stabilization of the railcar that arrived with an empty transportation cradle; and
  - b) Removal of the transportation cradle end stops (not applicable to all casks).
- 2) Remove Transportation Cradle from Railcar, if necessary, including:
  - a) Disconnection of the transportation cradle from the railcar; and
  - b) Rigging and lifting of the empty transportation cradle.

- 3) Prepare Transportation Cradle for Loading, including:
  - a) Removal of the personnel barrier and cask tie-down straps;
  - b) Removal of the cask trunnions (not applicable to all casks);
  - c) Initial positioning of the cask impact limiter tie-rods (not applicable to all casks); and
  - d) Attachment of a separate down-ending device to the transportation cradle (not applicable to all casks).
- 4) Load Cask onto Transportation Cradle, including:
  - a) Rigging and lifting of the cask;
  - b) Removal of the cask shear key plugs (not applicable to all casks);
  - c) Placement of the cask onto the transportation cradle; and
  - d) Down-ending of the cask onto the transportation cradle (not applicable to all casks).
- 5) Prepare Cask for Transport, including:
  - a) Removal of the cask trunnions and installation of cask trunnion plugs (not applicable to all casks); and
  - b) Installation of cask-specific items, such as impact limiter spacers and thermal fins (not applicable to all casks).
- 6) Secure Cask to Transportation Cradle, including:
  - a) Installation of the cask tie-down straps.
- 7) Install Impact Limiters onto Cask, including:
  - a) Rigging and lifting of the cask impact limiters; and
  - b) Installation and securement of the cask impact limiters.
- 8) Install Personnel Barrier onto Transportation Cradle, including:
  - a) Rigging and lifting of the personnel barrier; and
  - b) Installation and securement of the personnel barrier. (Note: these activities could be performed with the cradle either on the ground or on top of the railcar.)
- 9) Install Transportation Cradle onto Railcar, if necessary, including:
  - a) Rigging and lifting of a loaded transportation cradle; and
  - b) Placement and securement of the transportation cradle onto the railcar.
- 10) Final Loading Activities, including:
  - a) Placement and securement of the transportation cradle end stops (not applicable to all casks); and
  - b) Removal of the railcar securement and stabilization devices.

The Atlas Railcar General Loading Procedures include three appendices that essentially make up the output information to be used by railcar/transportation cradle designers and end users. Appendix A contains the procedures that organize the high-level steps necessary for loading a

cask onto the railcar, with differences for certain casks and cradles specifically called out. Appendix B of the procedures presents an applicability matrix that identifies which specific sections of Appendix A apply to which cask. If an end user is only interested in one cask, they can use Appendix B to easily extract the applicable procedures from Appendix A. Appendix C contains figures of the railcar, cradles, and casks to allow the end user to visualize the specific components referred to in the procedures.

Considering that the contract only required procedures to load the cask onto the railcar, sequences and associated steps were not included for other activities, such as the unloading of a cask from the railcar. The Atlas Railcar General Loading Procedures, however, do identify when a collection of steps could be used for other activities, such as unloading and trans-loading of the cask, whether empty or loaded. Many times, these activities would simply require the user to reverse the order of the provided steps.

The main body of the Atlas Railcar General Loading Procedures contain the methodology used to create the procedures, any limitations of use and applicable assumptions, and also references to the source information. It is important to note that the provided procedures are based on the current conceptual designs of the cradles and Atlas railcar, with specific instructions, diagrams, figures and tables subject to change during final design and fabrication. Also, these procedures are intended for use only as a guide to support the development of site-specific procedures; therefore, they do not include specific site requirements, inspection requirements, license review requirements, or necessary transport notifications. These items will need to be developed by the end users having responsibility for each subject area at each location where the railcar, cradles, and casks will be used.

It should be noted that the change in the Atlas railcar from an 8-axle configuration to a 12-axle configuration caused a review of the General Loading Procedures with no impact or change to the procedures required.

## 6.0 FUNCTIONAL AND OPERATIONAL REQUIREMENTS DOCUMENT

AFS uses a DBRD to ensure compliance to SOW requirements, regulatory requirements, and industry standards by identifying specific design, functional, operational, and maintenance requirements for the prototype railcars. Its use is procedurally required by AFS engineering procedures.

The TEAM prepared a project specific DBRD listing contractual SOW, regulatory, and industry design requirements in a single document for the conceptual cradle, prototype Atlas railcar, and prototype buffer railcar. As the Phase 1 FORD deliverable includes the same design and functional requirements as the DBRD, plus specific operational and maintenance requirements for the cask and buffer railcars, the DBRD was revised to include those functional, operational and maintenance requirements. As a result, the DBRD and the FORD are now the same document.

The DBRD/FORD is a living document updated and revised throughout the project to include new requirements as they become known. The DBRD/FORD is also specifically scheduled to be reviewed at designated times throughout the project's period of performance, such as the start of each project phase. Also, the DBRD/FORD is to be periodically reviewed by the AFS PM and AFS Principal Design Engineer (APDE) to ensure requirements are being met. The APDE will prepare and update an appropriate compliance matrix to demonstrate that the DBRD requirements have been met by the project deliverables. Compliance matrices for the conceptual cradle designs and the cradle-to-railcar attachment interface are included in this report as the third subsection in the report's Appendix A.1 through Appendix A.5. Similar compliance matrices will be generated and reviewed for the cask and buffer railcar preliminary designs.

It should be noted that the change in the Atlas railcar from an 8-axle configuration to a 12-axle configuration caused a review of the DBRD/FORD with no impact to the DBRD/FORD required.

The DBRD/FORD, titled "Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar", AFS document/revision EIR-3014611-004, was submitted to the DOE COR and has received approval. It includes the following:

- Introduction
- Design Requirements
  - Regulatory Requirements
  - Functional Requirements
    - Cask/Buffer Railcar Functional Requirements
    - Conceptual Cradle Design and Functional Requirements
  - Operational Requirements
    - Cask/Buffer Railcar Operational Requirements
    - Conceptual Cradle Operational Requirements
  - Maintenance Requirements
  - Additional Design Considerations
    - References

The DOE approved FORD is included as Appendix E of this report.

## 7.0 REFERENCES

- [1] AFS Request for Information AFS-RFI-00225-0004-00 regarding inconsistent public cask information, November 24, 2015.
- [2] Association of American Railroads, 2015 Field Manual of the AAR Interchange Rules, Section C Requirements for Acceptance, Rule 88, 2015.
- [3] Department of Energy Contract DE-NE0008390, latest revision, Part I, Section C, Statement of Work, Attachment A, Transport Cask Characteristics.
- [4] Association of American Railroads, Manual of Standards and Recommended Practices, Section C, Car Construction Fundamentals and Details, Standard 2043, Performance Specification for Trains Used to Carry High-Level Radioactive Material, 2009.
- [5] Association of American Railroads, Manual of Standards and Recommended Practices, Section J, Quality Assurance M-1003, 2014.
- [6] AFS Request for Information AFS-RFI-00225-0001-00 regarding bounding conditions and data, November 20, 2015.
- [7] Association of American Railroads, Manual of Standards and Recommended Practices, Section C, Car Construction Fundamentals and Details, Standard 2028, Plate C – Equipment Diagram for Limited Interchange Service, 2013.
- [8] Association of American Railroads, Manual of Standards and Recommended Practices, Section C, Car Construction Fundamentals and Details, Standard 2029, Plate C-1 – Maximum Width of Cars with Curious Truck Centers, 2007.
- [9] Association of American Railroads, Manual of Standards and Recommended Practices, Section C, Car Construction Fundamentals and Details, Standard 2030, Plate D – Obtaining Maximum Allowable Width of Car, Other Than at Centerline of Car, For Unrestricted (Plate B-1) and Limited (Plates C-1, H-1, J-1, and K-1) Interchange Service, 2009.
- [10] Association of American Railroads, Manual of Standards and Recommended Practices, Section C, Car Construction Fundamentals and Details, Standard 2043, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Section 4.7.9.1, Railcar Clearance Section, 2009.
- [11] National Archives and Records Administration, Office of Federal Register, Code of Federal Regulations 60FR 50264, Title 10 – Energy, Chapter I – Nuclear Regulatory Commission, 10 CFR Part 71, Packaging and Transport of Radioactive Material, 2010.
- [12] American Society of Mechanical Engineers, Nuclear Quality Assurance-1, Standard NQA-1-2008 and addendum NQA-1A-2009.
- [13] AREVA Federal Services, Quality Assurance Program Description, AFS-QA-PMD-001 Rev 3, November 15, 2013.
- [14] AREVA Federal Services, Project QA Plan, Design and Prototype Fabrication of Atlas Railcars for HLRM, QA-3014737-002, January 14, 2016.
- [15] Kasgro Rail Corporation, Quality Assurance Manual for AAR Specification M-1003, Revision 29, December 14, 2015.

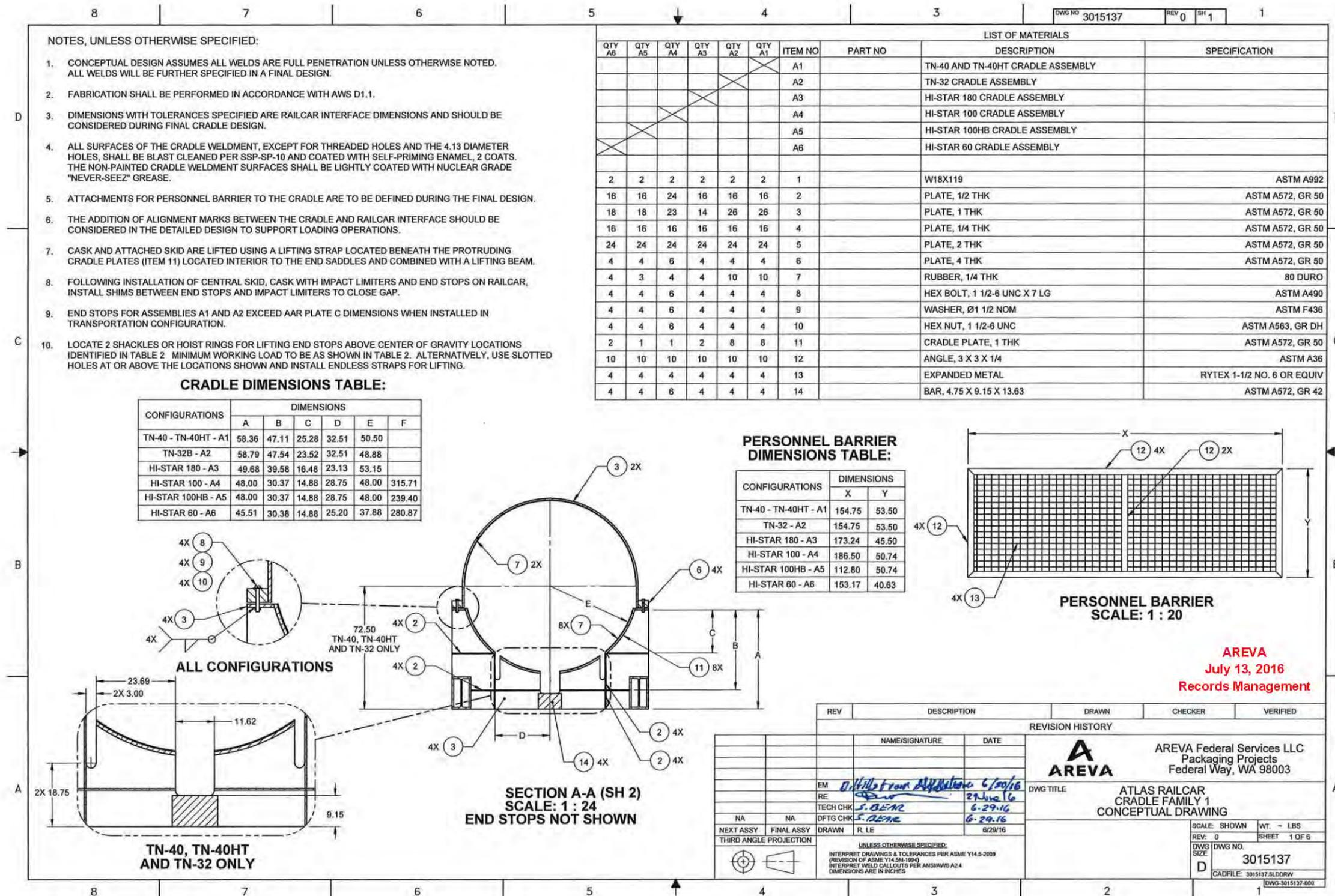
- [16] Department of Energy Contract DE-NE0008390, latest revision, Part III, Section J-C, Quality Assurance Surveillance Plan,
- [17] AREVA Federal Services, Atlas Railcar Family 3 Conceptual Cradle Structural Calculation, Calc-3015135 Rev 0, Section 3.0, Assumptions, June 29, 2016, enclosed as Appendix A.3.2 of this document.
- [18] American National Standards Institute, Standard N14.6, Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10,000 Pounds (4500 KG) or More, 1993.
- [19] Association of American Railroads, Manual of Standards and Recommended Practices, Section C, Car Construction Fundamentals and Details, Standard 2043, Performance Specification for Trains Used to Carry High-Level Radioactive Material, Appendix B, Operating Standard for Trains Used to Carry High-Level Radioactive Material, 2009.
- [20] Oak Ridge National Laboratories, AAR S-2043 Cask Railcar System Requirements Document, FCRD-NFST-2014-000093 Rev.1, ORNL/TM-2014/596, December 1, 2014.
- [21] AFS Request for Information AFS-RFI-00225-0013-00 regarding contract DE-NE0008390, Attachment A - Transport Cask Characteristics, dated March 7, 2016.

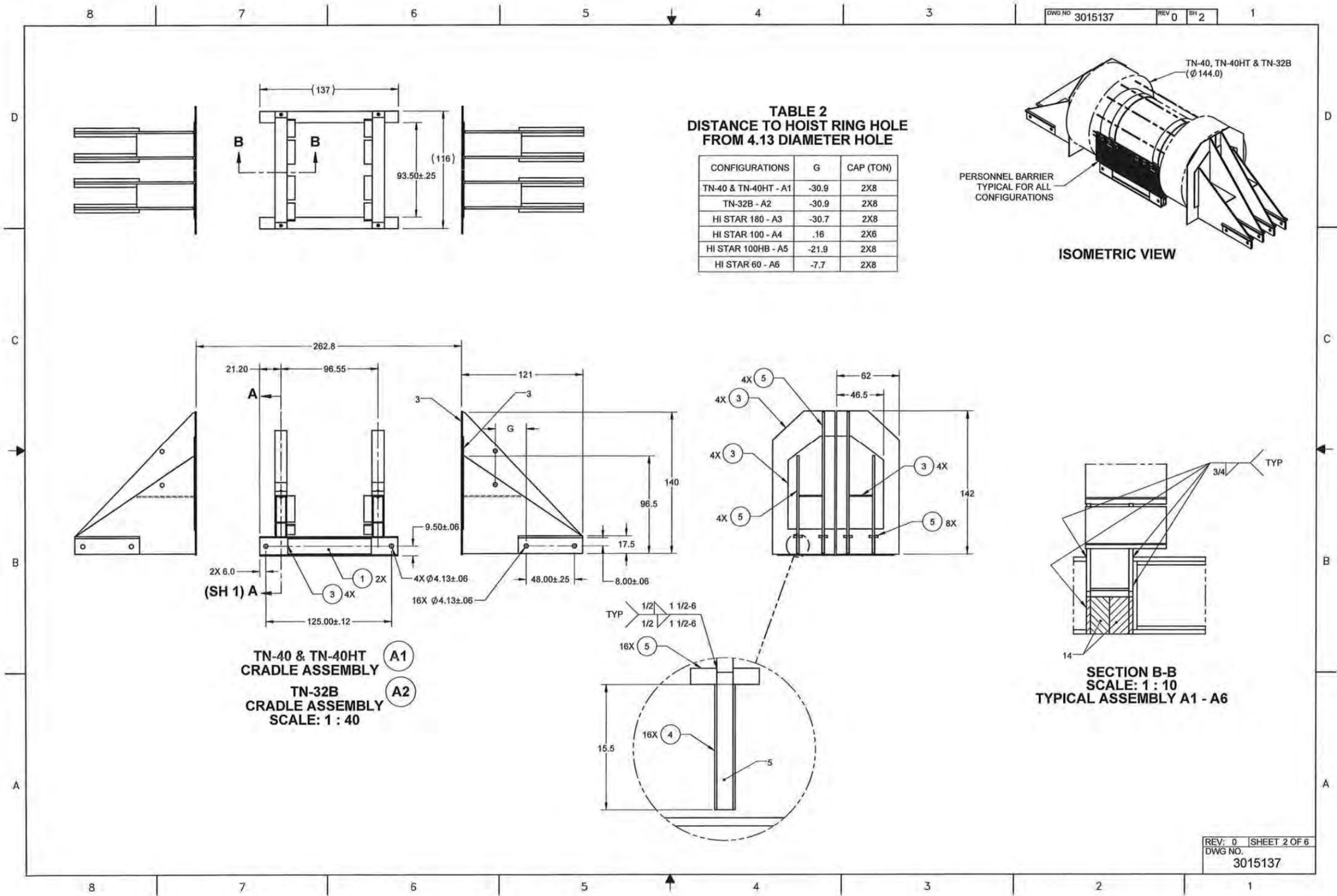
## Appendix A – Conceptual Cradle Designs

## APPENDIX A.1 – FAMILY 1 CRADLE

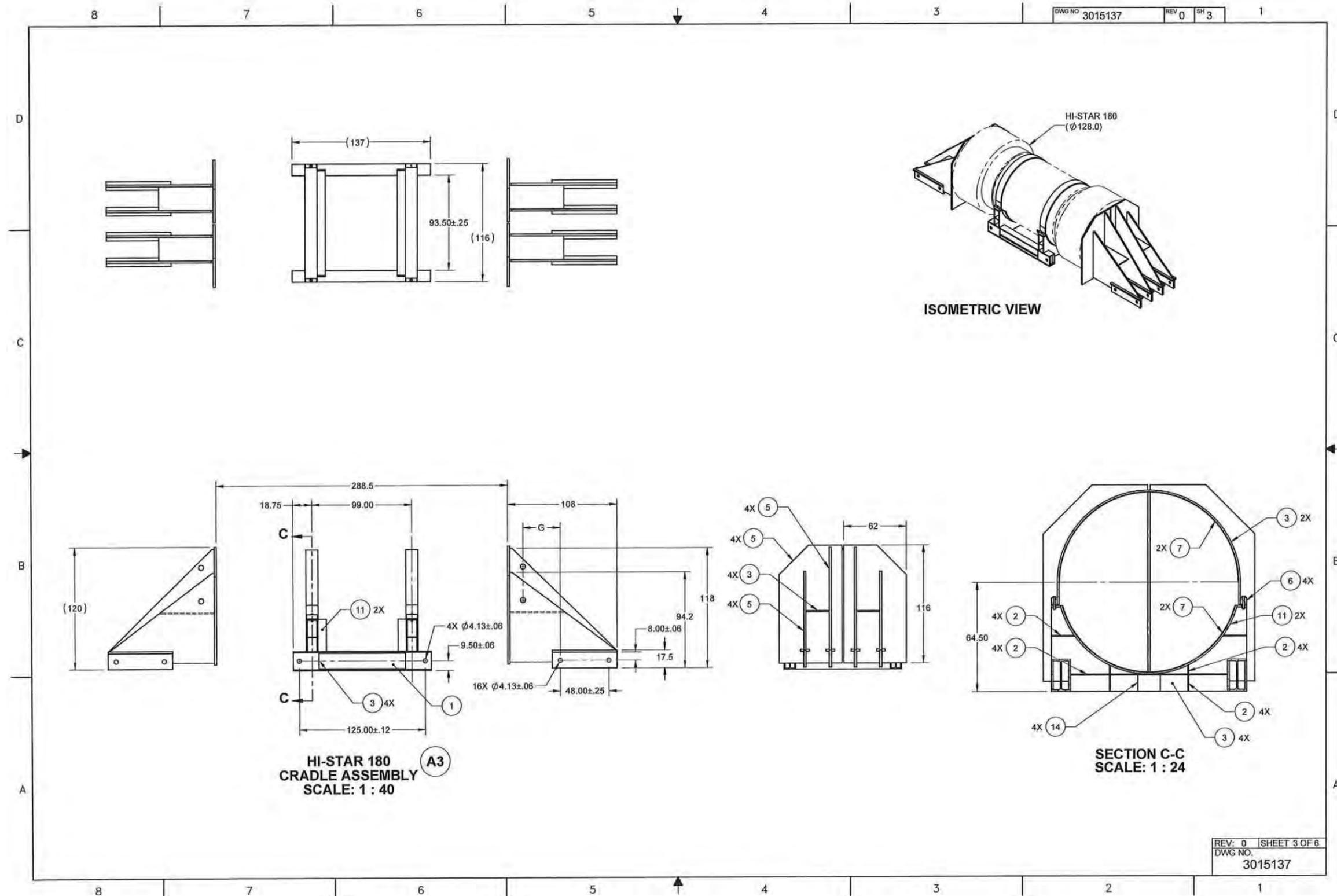
Appendix A.1.1 – Conceptual Drawings

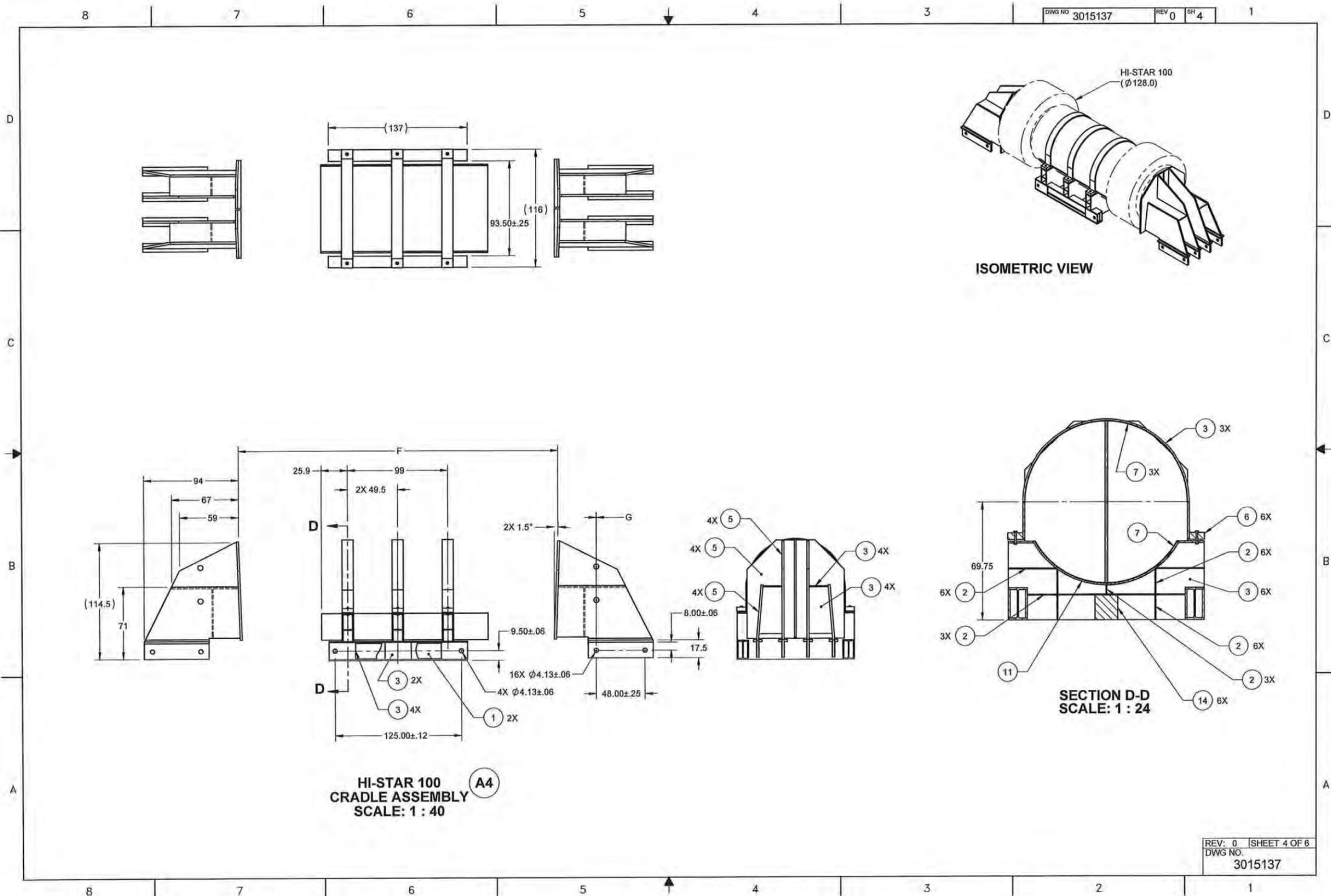
DWG-3015137-000  
Page 1 of 6

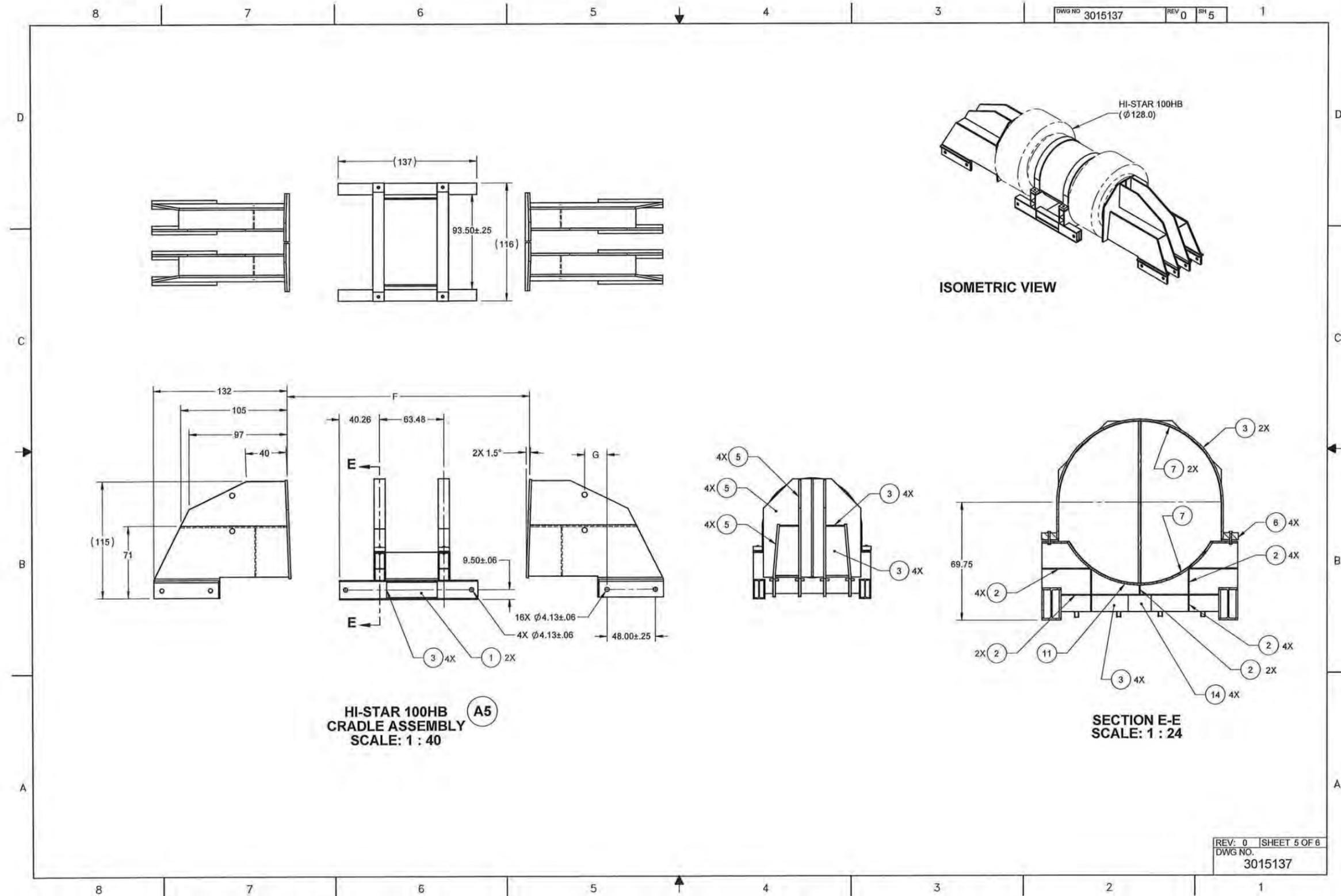


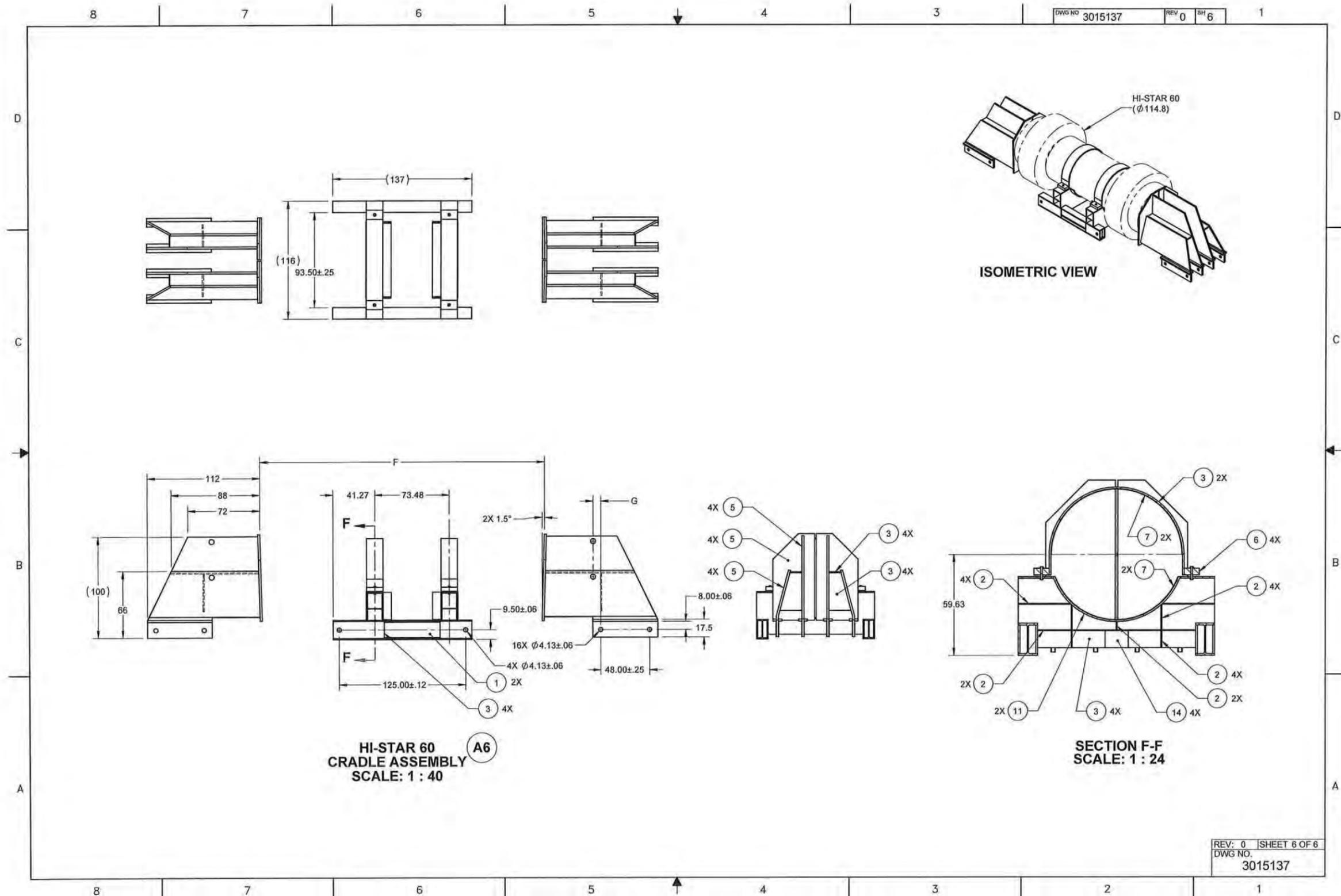


G-3015137-000  
 ie 3 of 6









REV: 0 SHEET 6 OF 6  
 DWG NO.  
 3015137

## Appendix A.1.2 – Structural Calculation

CALC-3015133-000  
 Page 1 of 30

	AREVA Federal Services LLC		
	CALCULATION		
Document No.:	CALC-3015133	Rev. No.	000
		Page 1 of 30	
Project No.:	00225.03.0050	Project Name:	DOE Atlas Railcar
Title: Atlas Railcar Family 1 Conceptual Cradle Structural Calculation			
<b>Summary:</b> This calculation documents the suitability of the conceptual design of the Family 1 Atlas Railcar cradles. Family 1 includes: AREVA-TN: TN40, TN-40HT, TN-32B and Holtec: Hi-Star 60, Hi-Star 100, Hi-Star 100HB and Hi-Star 180 casks.			
Contains Unverified Input / Assumptions: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>			
Software Utilized: Microsoft Excel 2010 Software Active in AFS EASI: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/> Error Reports & Associated Corrective Actions Reviewed: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>		Version: 14.0.7166.5000 (32 bit)	Storage Media: Yes: <input checked="" type="checkbox"/> No: <input type="checkbox"/>  Location: COLDStor
	Printed Name	Signature	Date
Preparer:	A. Ross	ROSS Alec 2016.06.29 08:26:30 -07'00'	29 June 16
Checker:	S. Bear	Scott Bear <small>Digitally signed by Scott Bear DN: cn=Scott Bear, o=AFS LLC, ou=Packaging, email=scott.bear@areva.com, c=US Date: 2016.06.29 13:18:28 -07'00'</small>	29 June 16
Approver:	<i>D. Hillstrom</i>	<i>Donald Hillstrom</i>	<i>6/30/16</i>
Other:	S. Klein	<i>S. Klein</i>	<i>6/30/16</i>

AFS-EN-FRM-002 Rev. 07 (Effective April 21, 2015)  
 Reference: AFS-EN-PRC-002

**AREVA**  
**July 13, 2016**  
**Records Management**

CALC-3015133-000  
Page 2 of 30



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 2 of 30

**Revision History**

<b>Rev.</b>	<b>Description</b>	<b>Affected Pages</b>	<b>Affected Files</b>
0	Initial Issue	All	All



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 3 of 30

**TABLE OF CONTENTS**

	Page
1.0 PURPOSE .....	4
2.0 METHODOLOGY .....	6
2.1 Geometry .....	6
2.2 Loads .....	7
2.3 Allowable Stresses .....	9
2.4 Material Properties .....	9
2.5 Beam Properties .....	9
3.0 ASSUMPTIONS .....	10
3.1 Justified Assumptions .....	10
3.2 Unverified Inputs/Assumptions .....	10
4.0 DESIGN INPUTS .....	10
5.0 CALCULATIONS .....	11
5.1 Check Bending of Longitudinal Beams .....	11
5.2 Evaluate the Saddles for the Design Loads .....	17
5.3 Evaluate the End Stops .....	23
5.4 Evaluate Strap Attachment Fasteners .....	26
5.5 Example Calculation of Attachment Lug Loads - Central Cradle .....	27
6.0 RESULTS AND CONCLUSIONS .....	29
6.1 Results of applicable literature searches .....	29
7.0 REFERENCES .....	30

**LIST OF TABLES**

Table 2.1: Applied Accelerations (Tie Downs) .....	7
Table 2.2: Summary of Loads .....	8
Table 2.3: Material Properties for ASTM A-992 and A572 .....	9
Table 4.1: Design Inputs .....	10
Table 5.1: Summary of Loads on Central Cradle .....	16
Table 5.2: Summary of Moments on Central Cradle .....	16
Table 5.3: Moments on End Stops .....	25
Table 6.1: Summary of Cradle and End Stop Weights and C.G.' .....	29



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

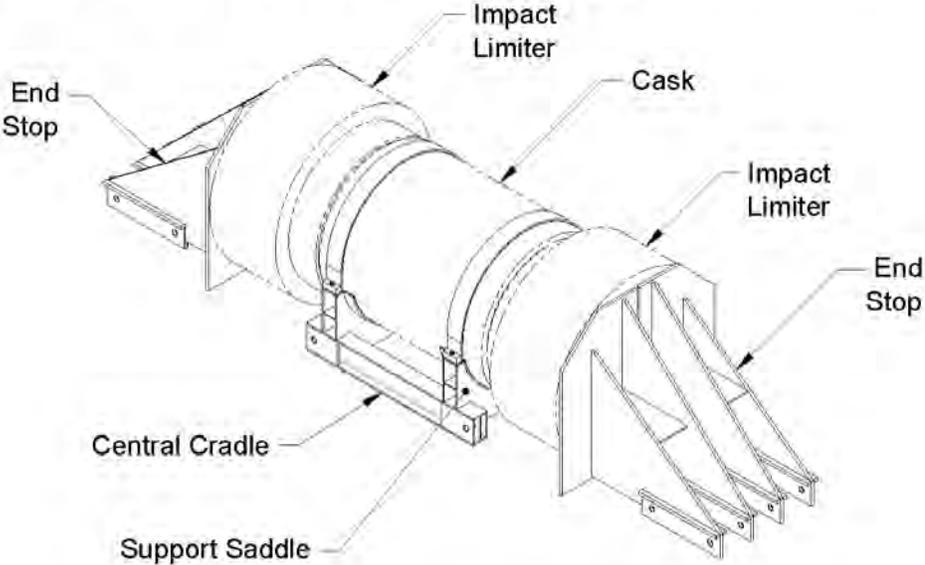
Project: 00225.03.0050

DOE Atlas Railcar

Page 4 of 30

**1.0 PURPOSE**

This calculation evaluates and documents the structural capabilities of the Atlas Railcar Cradle design concepts for the Family 1 casks. Family 1 includes the following casks: AREVA TN: TN-40, TN-40HT and TN-32B, Holtec International: Hi-Star 60, Hi-Star 100, Hi-Star 100HB (also referred to as the Hi-Star HB) and Hi-Star 180. This cask family (Family 1) is defined by the restraints defined/assumed for the cask. These casks all include end stops to restrain axial cask movement on the railcar during transport as shown in Figure 1.



**Figure 1 - Typical Family 1 Cask and Cradle**

The various designs, within Family 1, share the end stop requirement, however due to variations in the cask's geometries and licensing requirements, there are variations in the details.

The purpose of this design effort is the design of a railcar. In support of this, conceptual cradle designs are generated to define the height of each cask center-of-gravity above the bottom of the cradle and the weight on each rail car axle along with other information required to perform the analysis and provide simulated cask weights and supporting information needed for testing of the railcar.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 5 of 30

This calculation also documents the loads to the railcar attachments due to the defined tie-down loads of  $\pm 7.5$  g Axial (Longitudinal),  $\pm 2$ g Vertical and  $\pm 2$ g Lateral applied independently per § 2.2.2.13 of [7.4].

As such, the cradle and end stop designs are only concepts and the design of the cradle and end stops will not be completed (these cask supports will be designed by each cask vendor). This evaluation serves only to validate this design concept.

The casks included here are grouped by the means of support for the transport cask on the rail car. All of the above casks are supported by a central support frame (used to react the vertical and lateral loads) and end stops (used to react the axial loads). All of the casks, with the exception of the Hi-Star 60 and Hi-Star 180 are rotated to the horizontal orientation for rail transport prior to placement on the rail car. The Hi-Star 60 and Hi-Star 180 are expected to have the option of this rotation on the rail car. In the case this is required (the facility has rail access to the cask loading location), a removable rotation fixture, such as is currently used by Holtec International is expected to be used. The loads on the rail car will be bounded by the loads from the heavier Magnatran cask (312 kip), a Family 2 cask vs. the Hi-Star 60 (164 kip) or Hi-Star 180 (309 kip) per Attachment A of [7.1].

The Family 1 support saddles are of similar design and the central cradle varies largely based on the cask length and height above the deck of the rail car. All of the Family 1 designs are shown in drawing Atlas Railcar Cradle Family 1 Conceptual Drawing [7.2]. The cradles for the AREVA-TN casks include slots in the cradle support to provide clearance for the tie-rods used to support impact limiter attachment.

Similarly, the end stops are all similar. For both the end stops and the central cradle, the attachment points to the rail car are the same.

Using these similarities, only the bounding loads for each component evaluated will be included and will thus bound all designs for Family 1.

Evaluation of the proposed attachment points and associated pins are included in the Attachment calculation [7.3].

The attachment lugs are located on the rail car deck [7.5]. The central cradle and end stops are pinned to the attachment lugs using 4 inch diameter pins. The holes in the four lugs used to attach the central cradle are slotted such that the lugs react only vertical and lateral loads. The holes in the lugs used to attach the end stops have round holes in the eight pair (four pair at each end) of lugs located nearer the center of the railcar and slotted holes for the remaining eight pair of attachment lugs, thus only the pin locations nearest the cask react the cask axial loads.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 6 of 30

The lugs located nearer the ends of the rail car react only vertical and lateral (from the end stop) loads. As is the case for the central cradle, the end stops are attached with 4 inch diameter pins.

Lifting of the Family 1 central cradle and cask is accomplished by placing straps beneath the cradle plate of each central cradle (identified as Item 11 on the Cradle Conceptual drawing [7.2] and lifting with a spreader beam. Synthetic straps such as the Sparkeater® offered by Slingmax have sufficient strength and a continuous temperature rating of 300°F. These or another sling meeting the load and thermal requirements are acceptable to lift the Family 1 casks.

## **2.0 METHODOLOGY**

### **2.1 Geometry**

The Family 1 casks vary in outside diameter (at the cask support locations) from approximately 75-3/4 inches for the Hi-Star 60 cask to approximately 106-1/4 inches for the Hi-Star 180 cask. The largest diameter impact limiters are used on the TN-40 cask (144 inches) and the smallest are on the Hi-Star 60 (approximately 114-3/4 inches). The impact limiter diameter, with a 1 inch clearance, is the closest any cask may be located to the rail car deck. Some casks, due to their geometry, are located higher above the rail car deck, but in any case, the height above the deck is minimized in order to reduce the loads to the rail car as well as minimize the height of the Center-of-Gravity (C.G.) for the system (cask, cask supports and rail car).

The component weights and C.G.'s for both the casks and cradle/end stop designs are documented in eight (8) spreadsheets [7.10 through 7.17]. The spreadsheets are also used to determine the loads on the rail car attachment points.

Materials of Fabrication:

The main support beams for the central cradle are W18 X 119 per ASTM A992. The remaining components (plate) are fabricated from ASTM A572, Grade 50. Material properties are shown in Table 2.3.

The loads specified in § 2.2 are design loads and use the material yield point for the allowable stress per § 2.2.2.13 of the DBRD [7.4]. The acceptability of each component evaluated to the loads of § 2.2 will be determined by comparison with the yield strength and a Margin-of-Safety calculated as follows:

$$MS = \frac{\text{Allowable Load}}{\text{Applied Load}} - 1 \text{ or } \frac{\text{Allowable Stress}}{\text{Applied Stress}} - 1 \geq 0$$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050 -

DOE Atlas Railcar

Page 7 of 30

**2.2 - Loads**

Loads result from the accelerations specified in § 2.2.2.13 of [7.4]. The specified accelerations, listed in Table 2.1 are applied to each component/assembly. Each acceleration is applied separately. The resultant loads on the attachment points are developed in [7.10] through [7.17] and are summarized in Table 2.2.

**Table 2.1 – Applied Accelerations  
(Tie Downs)**

<b>Direction</b>	<b>Acceleration (g)</b>
Longitudinal (Axial)	7.5
Vertical	2
Lateral	2

Notes: 1. Above values from § 2.2.2.13 of [7.4]. The values shown are the net accelerations.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 8 of 30

**Table 2.2 – Summary of Loads**

	HI-STAR 100 (kip)	HI-STAR 100HB (kip)	HI-STAR 180 (kip)	HI-STAR 60 (kip)	TN-32B (kip)	TN-40 (kip)	TN40HT (kip)
<b>Pin Block 1 / Pin Block 4</b>							
vertical (+z)	164.6	114.8	209.7	104.2	254.1	267.9	236.0
vertical (-z)	-164.1	-105.6	-117.6	-74.7	-250.9	-222.4	-195.9
lateral (y)	300.4	210.0	406.6	208.5	278.9	285.5	256.2
<b>Pin Block 5</b>							
Axial (+x)	--	--	--	--	--	--	--
Axial (-x)	--	--	--	--	--	--	--
vertical (+z)	753.0	535.1	725.9	396.0	725.4	743.7	671.9
vertical (-z)	-753.0	-535.1	-725.9	-396.0	-706.8	-724.1	-652.2
lateral (y)	11.8	13.7	11.3	11.5	14.3	14.3	14.3
<b>Pin Block 9</b>							
Axial (+x)	607.6	448.6	634.5	393.3	534.1	547.1	496.0
Axial (-x)	-607.6	-448.6	-634.5	-393.3	-583.9	-596.9	-545.8
vertical (+z)	753.0	535.1	725.9	396.0	706.8	724.1	652.2
vertical (-z)	-753.0	-535.1	-725.9	-396.0	-725.4	-743.7	-671.9
lateral (y)	11.8	13.7	11.3	11.5	14.3	14.3	14.3
<b>Pin Block 13</b>							
Axial (+x)	607.6	448.6	634.5	393.3	534.1	547.1	496.0
Axial (-x)	-607.6	-448.6	-634.5	-393.3	-583.9	-596.9	-545.8
vertical (+z)	753.0	535.1	725.9	396.0	706.8	724.1	652.2
vertical (-z)	-753.0	-535.1	-725.9	-396.0	-725.4	-743.7	-671.9
lateral (y)	11.8	13.7	11.3	11.5	14.3	14.3	14.3
<b>Pin Block 17</b>							
Axial (+x)	--	--	--	--	--	--	--
Axial (-x)	--	--	--	--	--	--	--
vertical (+z)	753.0	535.1	725.9	396.0	725.4	743.7	671.9
vertical (-z)	-753.0	-535.1	-725.9	-396.0	-706.8	-724.1	-652.2
lateral (y)	11.8	13.7	11.3	11.5	14.3	14.3	14.3

Notes: 1. The loads are from [7.10] through [7.17]. Due to symmetry, the load magnitudes for pin locations 5 - 8, 9 - 12, 13 - 16 and 17 - 20, the loads are the same, therefore, Table 2.2 lists the loads at the first pin location in each group for each cask. Locations are defined in the attachment drawing [7.5].

2. An example calculation for P1 - P4 is shown in § 5.5 and for the axial loading for P5 - P20 in § 5.3.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050 -

DOE Atlas Railcar

Page 9 of 30

**2.3 Allowable Stress**

The acceptance criteria for the loads resulting from the accelerations shown in Table 2.1 is the material yield strength per § 2.2.2.13 of the DBRD [7.4]. The acceptance criteria for fillet welds and partial penetration groove welds is 0.6 times the yield strength. Conservatively, the base material yield strength will be used.

**2.4 Material Properties**

Material Properties are shown in Table 2.3 below.

**Table 2.3 – Material Properties for ASTM A992 and A572**

ASTM Material	Yield Point (ksi)	Ultimate Strength (ksi)
A992	50	65
A572, Grade 50	50	65
A572, Grade 42	42	60

Notes: 1. Properties from American Society for Testing and Materials [7.6] and [7.7]  
2. ASTM A572, Grade 42 is for materials greater than 4 inches in thickness.

**2.5 Beam Properties**

The longitudinal beam is a W18 x 119 with the following section properties (from AISC [7.8]):

$$A_b := 35.1 \text{ in}^2 \quad d := 19 \text{ in} \quad b_f := 11.3 \text{ in} \quad t_f := 1.06 \text{ in} \quad I_x := 2190 \text{ in}^4 \text{ and } I_y := 253 \text{ in}^4$$

The beam is boxed at the ends (from the end of the beam to the first saddle) with 1 inch thick A572 plate. The composite beam has the following section properties:

$$S_{maj} := \left[ 2190 \text{ in}^4 + 2 \frac{1 \text{ in} (19 \text{ in} - 2 \times 1.06 \text{ in})^3}{12} \right] \frac{2}{19 \text{ in}} = 315 \text{ in}^3$$

$$S_{min} := \left[ 253 \text{ in}^4 + 2 \left[ \frac{(1 \text{ in})^3 (19 \text{ in} - 2 \times 1.06 \text{ in})}{12} \dots + 1 \text{ in} \times (19 \text{ in} - 2 \times 1.06 \text{ in}) \left[ \frac{(11.3 \text{ in} - 1 \text{ in})^2}{2} \right] \right] \right] \frac{2}{11.3 \text{ in}} = 204 \text{ in}^3$$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 10 of 30

**3.0 ASSUMPTIONS**

**3.1 Justified Assumptions**

- 3.1.1 Nominal dimensions are used throughout this calculation. This is standard practice.
- 3.1.2 The TN-40HT cask is not yet licensed for transportation. This cask is a version of the TN-40 used for high burnup fuel. The same impact limiter geometry and attachment method used on the licensed TN-40 cask is assumed. This is reasonable due to the relationship between the TN-40 and TN-40HT casks.
- 3.1.3 The TN-32B cask is not yet licensed for transportation. The same impact limiter geometry and attachment method used for the TN-40 cask is assumed. This assumption is reasonable due to the likeness of the TN-32 cask to both the licensed TN-40 and TN-68 casks. Both casks have similar impact limiters and impact limiter attachments. Additionally, this same assumption (as to the similarity of impact limiter geometry and impact limiter attachment) has been made on the TN-32B High Burnup (TN-32B HBU) test project.

**3.2 Unverified Inputs/Assumptions**

None

**4.0 DESIGN INPUTS**

**Table 4.1 – Design Inputs**

<b>Cask</b>	<b>Cask Weight<sup>1</sup> Maximum (lb) (W<sub>c</sub>)</b>	<b>Cask Vert CG<sup>2</sup> from bottom of cradle (in) (d<sub>c, vcg</sub>)</b>
HI-STAR 100 ( <sub>hs100</sub> )	279,893	69.75
HI-STAR 100HB ( <sub>hshb</sub> )	187,200	69.75
HI-STAR 180 ( <sub>hs180</sub> )	308,647	64.5
HI-STAR 60 ( <sub>hs60</sub> )	164,000	59.63
TN-32B ( <sub>TN32</sub> )	263,000	72.5
TN-40 ( <sub>TN40</sub> )	271,500	72.5
TN40HT ( <sub>TN40HT</sub> )	242,343	72.5

Notes: 1. Values from Attachment A of the Statement of Work [7.1]  
 2. Values from Cradle Family 1 Conceptual Drawing.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

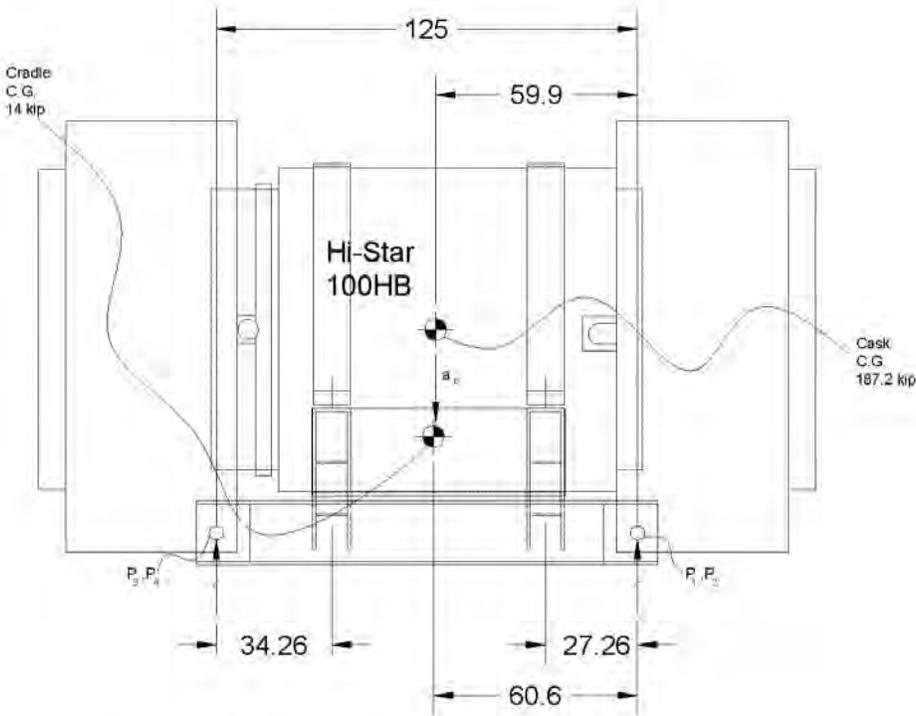
DOE Atlas Railcar

Page 11 of 30

**5.0 CALCULATIONS**

**5.1 Check Bending of Longitudinal Beams (W18 X 119)**

The longitudinal beams are attached to the railcar at the attachment lug locations (P1 - P4 on the attachment drawing [7.5]). The vertical loads are reacted by either the 1/2 inch thick shim plates (Item 2 on [7.5]) (downward) or the 4 inch diameter pins (upward). The loads on the beam are from the lateral and vertical loads only, the cask axial loads are reacted by the end stops. The center of the attachment lugs (and pins) are located 125 inches apart (see Figure 2).



**Figure 2 - Hi-Star 100HB Free Body Diagram (FBD), Vertical**



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 12 of 30

The vertical load is shared equally between the two beams and the lateral load is conservatively assumed to be reacted by only a single beam. The lateral load also causes a vertical load on the beam opposite the beam reacting the horizontal load. An example calculation of the moments is shown immediately below. The moments are calculated, using the same method as shown below for the remaining cradles and reported in Table 5.1.

The moment on the beam is simply the load at the attachment location (conservatively assume the center of the pin in lieu of the edge of the lug or shim plate) multiplied by the distance from the pin to the edge of the saddle. Conservatively, the dimension to the center of the saddle is used.

The force at the attachment is calculated by summing moments at pin location P1 as follows (the example is for the maximum moment case, the Hi-Star 100HB at the end near pin P3, see Figure 2 for FBD):

$$\text{Load}_{P3} := a_d \frac{W_{c\_hshb} \times d_{c\_hcg\_hshb} + W_{cr\_hshb} \times d_{cr\_hcg\_hshb}}{2 \times 125 \text{ in}} = -96.6 \text{ kip}$$

where:  $a_d = -2 \text{ g}$ ,  $W_{c\_hshb} = 187.2 \text{ kip}$ ,  $W_{cr\_hshb} = 14.4 \text{ kip}$ ,  $d_{c\_hcg\_hshb} = 59.9 \text{ in}$  and  $d_{cr\_hcg\_hshb} = 60.2 \text{ in}$  are from [7.13]. The load at P1 is:

$$\text{Load}_{P1} := \frac{a_d (W_{c\_hshb} + W_{cr\_hshb}) - 2 \times \text{Load}_{P3}}{2} = -105 \text{ kip}$$

The moment from the vertical load on the beam is:  $M := \text{Load}_{P3} \times 34.26 \text{ in} = -3310 \text{ in} \cdot \text{kip}$  where 34.26 inch is the distance from the pin location to the center of the saddle. The horizontal load for the lateral load is double the vertical load (the load is reacted by a single beam). Additionally, the opposite beam reacts a vertical load for the righting moment from the lateral load. The vertical reactions at each end are proportional to the distance from the C.G. to the attachments.

Determine the vertical reactions resulting from the lateral acceleration by summing moments, counter clockwise positive. The restoring moment from the cask weight is conservatively neglected.



AREVA Federal Services LLC

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 13 of 30

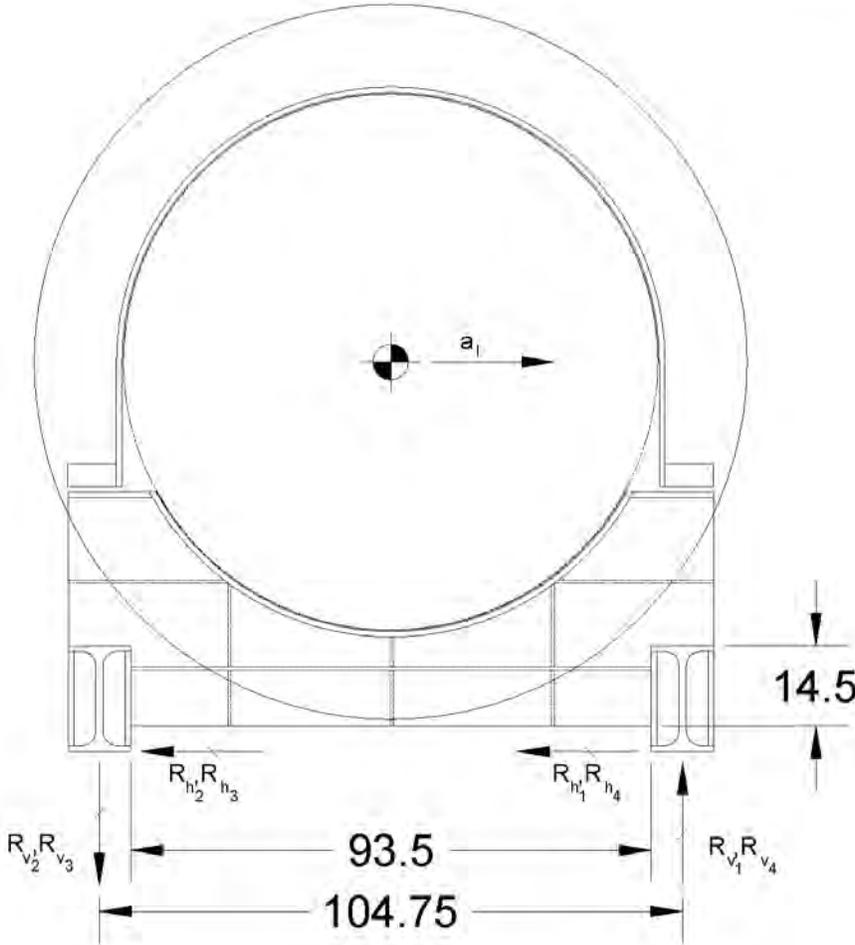


Figure 3 - Hi-Star 100HB Free Body Diagram (FBD), Lateral



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 14 of 30

$$\Sigma M_{P1\_P4} = 0 = \left[ -a_l (W_{c\_hshb} d_{c\_vcg\_hshb} + W_{cr\_hshb} d_{cr\_vcg\_hshb}) \right] \dots$$

$$+ \left[ -104.75 \text{ in} (R_{V2} + R_{V3}) \right]$$

where:  $a_l = 2 \text{ g}$  (Table 2.1),  $d_{c\_vcg\_hshb} = 69.75 \text{ in}$ ,  $d_{cr\_vcg\_hshb} = 28.4 \text{ in}$  (Table 4.1).

Sum forces in the vertical direction:

$$\Sigma F_y = 0 = R_{V1} + R_{V4} - R_{V2} - R_{V3}, \text{ therefore, } R_{V1} + R_{V4} = R_{V2} + R_{V3}.$$

As noted above, the reactions on each beam are inversely proportional to the distance from the centroid. The combined longitudinal centroid for the Hi-Star 100HB cask and cradle is:

$$\frac{W_{c\_hshb} \times d_{c\_hcg\_hshb} + W_{cr\_hshb} \times d_{cr\_hcg\_hshb}}{W_{c\_hshb} + W_{cr\_hshb}} = 59.9 \text{ in}$$

where the values are defined on the previous page.

Using the CG and the distance between the pins of 125 inches, the following relationship is found for the vertical reactions:  $R_{V1} \cdot 59.9 \text{ in} = R_{V4} (125 \text{ in} - 59.9 \text{ in})$  and the same relationship holds for  $R_{V2}$  and  $R_{V3}$  respectively.

Substituting and solving for  $R_2$ :

$$R_{V2} := \frac{a_l \left[ W_{c\_hshb} \times (d_{c\_vcg\_hshb} - 9.5 \text{ in}) + W_{cr\_hshb} \times (d_{cr\_vcg\_hshb} - 9.5 \text{ in}) \right]}{104.75 \text{ in} \left( 1 + \frac{59.9}{125 - 59.9} \right)} = 114.9 \text{ kip}$$

$$R_{V3} := \frac{59.9}{125 - 59.9} R_{V2} = 105.7 \text{ kip}$$

The corresponding moments are  $M_{V2} := R_{V2} \cdot 27.06 \text{ in} = 3108.1 \text{ in kip}$  and  $M_{V3} := R_{V3} \cdot 34.26 \text{ in} = 3620.7 \text{ in kip}$ . These moments resulting from the lateral acceleration are greater than the moments resulting from the vertical



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 15 of 30

acceleration, however, these moments act on the strong axis of the longitudinal beams. The horizontal component of the lateral acceleration is also reacted by a single beam. Referring to Figure 2 and summing the forces in the horizontal direction (positive right),

$$\Sigma F_h = a_l (W_{c\_hshb} + W_{cr\_hshb}) - R_{h1} - R_{h4}, R_{h1} 59.9 \text{ in} = R_{h4} (125 \text{ in} - 59.9 \text{ in}). \text{ Solving}$$

for  $R_{h1}$ :  $R_{h1} := a_l \frac{(W_{c\_hshb} + W_{cr\_hshb})}{1 + \frac{59.9}{125 - 59.9}} = 210 \text{ kip}$  and the resulting moment is:

$$M_{h1} := R_{h1} 27.06 \text{ in} = 5682 \text{ in}\cdot\text{kip}$$
 and the moment on the opposite end of the beam is:

$$M_{h4} := R_{h1} \frac{59.9}{125 - 59.9} 34.26 \text{ in} = 6619 \text{ in}\cdot\text{kip}.$$
 The moments resulting from the horizontal

components are higher and the section modulus of the beam resisting this moment is lower,

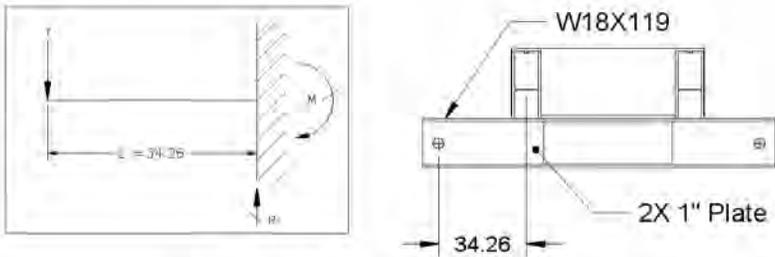
therefore, evaluation of the horizontal component is bounding for the beam.

The resulting stress for the composite W18X119 beam is:  $\sigma_{\text{minor}} := \frac{M_{h1}}{S_{\text{min}}} = 27.9 \text{ ksi}$  where

$$S_{\text{min}} = 204 \text{ in}^3 \text{ is from } \S 2.5.$$

The resulting margin is:  $MS := \frac{F_{y992}}{\sigma_{\text{minor}}} - 1 = 0.795 \rightarrow \text{Okay}$

The loads and moments on the central cradles are summarized in Tables 5.1 and 5.2 and demonstrate that the moment on the Hi-Star 100HB bound the remaining cradles. Note that the values shown in the tables are for the vertical acceleration and are for comparison only (used to demonstrate the bounding cradle).



**Figure 4 - Beam & Moment Diagram**



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 16 of 30

**Table 5.1 – Summary of Loads on Central Cradle**

Cask	Cask Weight Maximum (lb) ( $W_c$ )	Cask CG from pin (P1) (in) ( $d_{c\_hcg}$ )	Central Cradle weight (kip) ( $W_{cr}$ )	Central Cradle CG from P1 (in) ( $d_{cr\_cg}$ )	Load at P3 (kip) ( $Load_{P3}$ )	Load at P1 (kip) ( $Load_{P1}$ )
HI-STAR 100( <sub>hs100</sub> )	279,893	62.9	20.0	59.0	150.3	149.6
HI-STAR 100HB( <sub>hshb</sub> )	187,200	59.9	14.4	60.2	96.6	105.0
HI-STAR 180( <sub>hs180</sub> )	308,647	44.4	8.6	62.6	113.9	203.3
HI-STAR 60( <sub>hs60</sub> )	164,000	50.9	14.8	65.7	74.6	104.2
TN-32B( <sub>TN32</sub> )	263,000	63.0	13.0	62.9	139.1	136.9
TN-40( <sub>TN40</sub> )	271,500	62.5	12.6	56.7	141.5	142.6
TN40HT( <sub>TN40HT</sub> )	242,343	62.5	12.6	56.7	126.9	128.0

Notes: 1. The loads in Table 5.1 and the moments in Table 5.2 result from the vertical acceleration on the cask/cradle. As such, the reactions are opposite the applied acceleration in all cases and since the applied accelerations are bi-lateral ( $\pm 7.5$  g axial,  $\pm 2$  g vertical and lateral) only the magnitude is of importance.  
 2. In the table above, the column defines the main variable (such as  $W_c$  for cask weight) and the row defines the specific (such as <sub>hs100</sub>). The variable name is, for this example,  $W_{c\_hs100}$  and is the weight of the HI-Star 100 cask.

**Table 5.2 – Summary of Moments on Central Cradle Beam**

Cask	Distance from P1 to center of saddle (in) ( $d_{P1s}$ )	Distance from P3 to center of saddle (in) ( $d_{P3s}$ )	Moment	
			P3 End (in-kip) ( $M_{P3}$ )	P1 End (in-kip) ( $M_{P1}$ )
HI-STAR 100	13.375	12.625	1898	2,001
HI-STAR 100HB	27.06	34.26	3310	2,841
HI-STAR 180	13.25	12.75	1452	2,694
HI-STAR 60	16.25	35.27	2631	1,693
TN-32B	13.25	15.15	2107	1,814
TN-40	13.25	15.15	2144	1,889
TN40HT	13.25	15.15	1923	1,696



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

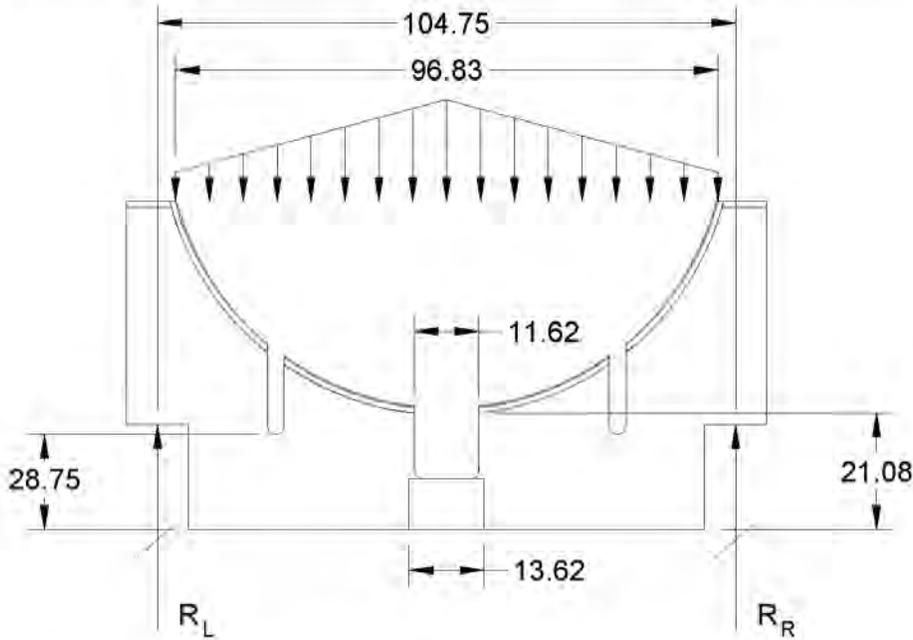
Page 17 of 30

**5.2 Evaluate the Saddles for the Design Loads**

The saddles support the vertical and lateral loads from the casks (the axial loads are reacted by the end stops).

The analysis below assumes a distributed load increasing toward the center of the cradle plates on the saddles. The saddles for the TN-40/TN-40HT and the TN-32 include cutouts for the tie-rods connecting the impact limiters. These cutouts reduce the depth of the saddles on these two cradles.

The weight of the TN-40 cask exceeds that of the TN-32 cask and the central cross-section of the TN-32 is less than that of the TN-40 [TN-40HT] cradle, therefore, the cross section of the TN-32 cradle will be used with the loads of the TN-40 cask, thus bounding both cradles.



**Figure 5 - TN-40 cradle Saddle with Major Points Identified - Vertical Loading**



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 18 of 30

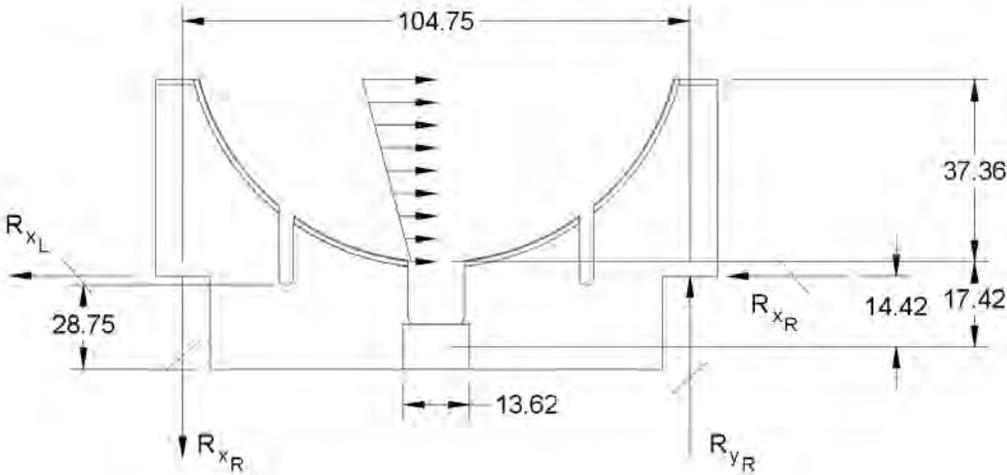
The saddle is modeled as a simply supported beam with a distributed load increasing toward the center. The moment is the highest at the center of the beam. The moment will be calculated using superposition, combining the moment calculated using case 8 (page VI-85) from Aluminum Design Manual [9] with the moment from the support offset to the edge of the cradle plate.

The moment at the center is:

$$M_{V\_saddle} := a_d \frac{(W_{c\_TN40}) 96.83 \text{ in}}{2 \times 6} + a_d \frac{104.75 \text{ in} - 96.83 \text{ in}}{2} \frac{(W_{c\_TN40})}{2}$$

$$M_{V\_saddle} = 5457 \text{ in kip}$$

Where  $W_{c\_TN40} = 271.5 \text{ kip}$  is from Table 5.1, 96.83 inches is the horizontal distance of the saddle plate ( $2 (48.875 + .25 + 1) \cos(15^\circ) = 96.83$ ), 48.875 is the radius of the TN-32 Cask, .25 and 1 are the thickness of the rubber and cradle plate) and  $a_d = 2 \text{ g}$  is the vertical acceleration.



**Figure 6 - TN-40 cradle Saddle with Major Points Identified - Lateral Loading**



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 19 of 30

In addition to the vertical loading, the lateral acceleration would also cause a moment on the central area of the saddle. Figure 6 above shows the loading where a triangular load distribution is assumed. In the lateral load case shown above, the load from cask weight is modeled as a triangle with the area equal to the weight of the cask. Each saddle supports one half of the cask weight and the saddles are supported by the W18 X 119 longitudinal beams. The first step is to determine the loads.

The triangular distribution is equivalent to the entire weight of the cask applied at the centroid of the area or 1/3 of the length from the top of the saddle.

Summing the moments (positive clockwise):

$$\Sigma M_R = 0 = \left( 17.42 + \frac{2 \times 37.36}{3} \right) \frac{W_{C\_TN40}}{2} - 104.75 R_{yL} - 14.42 R_{xL} - 14.42 R_{xR}$$

$$R_{yL} := 2 \frac{17.42 + \frac{2 \times 37.36}{3}}{104.75} \frac{W_{C\_TN40}}{2} = 110 \text{ kip}$$

where the moment resulting from the horizontal

reactions is conservatively neglected, the multiplier of 2 accounts for the applied lateral acceleration and the divisor of 2 account for the load sharing between the two saddles.

The resulting moment is simply the force multiplied by the distance:

$$M_{L\_saddle} := R_{yL} \frac{104.75 \text{ in}}{2} = 5761 \text{ in kip}$$

The TN-40 saddle, at the center section, is 9.15 inches tall (see Drawing 3015137, Sheet 1, Zone A7 [7.2]) and in addition to the 1 inch thick saddle plate, includes two 4-3/4 inch thick doublers.

The corresponding section modulus of the plates at the center is:

$$S_{saddle} := 2 \left[ \frac{1 \text{ in} (9.15 \text{ in})^2}{6} + \frac{4.75 \text{ in} (9.15 \text{ in})^2}{6} \right] = 160.5 \text{ in}^3$$

The moment due to the

lateral load is bounding and the resulting stress is:  $\sigma_{b\_TN40} := \frac{M_{L\_saddle}}{S_{saddle}} = 35.9 \text{ ksi}$

The corresponding Margin of Safety is:  $MS := \frac{F_{y572\_42}}{\sigma_{b\_TN40}} - 1 = 0.17$  where

$F_{y572\_42} = 42 \text{ ksi}$  is the material of the doubler.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 1 Cradle Structural Calculation

**Doc./Rev.:** CALC-3015133-000

**Project:** 00225.03.0050

DOE Atlas Railcar

Page 20 of 30

The doubler is only 2 inches longer than the 11.62 inch wide cutout. Assuming the same moment is present at the point where the doubler ends, the stress is:

$$\sigma_{b2\_TN40} := \frac{M_{L\_saddle}}{S_{2\_saddle}} = 38.9 \text{ ksi where}$$

$S_{2\_saddle} := 2 \frac{1 \text{ in} (21.08 \text{ in})^2}{6} = 148.1 \text{ in}^3$  This is the shortest unreinforced section of the saddle plates and because the maximum moment was used, bounds all other sections.

The corresponding margin of safety is:  $MS := \frac{F_{y572\_50}}{\sigma_{b2\_TN40}} - 1 = 0.285$  where

$F_{y572\_50} = 50 \text{ ksi}$  is from Table 2.3.

**Evaluate the Weld attaching the Saddle to the Longitudinal Beams**

The attachment weld is a 3/4 inch fillet weld on each outer side of the saddle plates (See Drawing 3015137, Sheet 2, Zone B2, Section B-B [2]). The two legs are horizontal across the beam flange and vertical along the 1 inch thick beam closure plate. Referring to Figure 3 and summing the moment about the weld on the right hand ( $R_{V1}$ ,  $R_{V4}$ ) beam (CCW positive).

$$\sum M_{RV1} = 0 = -a_l W_{c\_hs180} [d_{c\_vcg\_hs180} - 19 \text{ in} + (14.5 \text{ in} - 10.43 \text{ in})] \dots + 2 F_{RV23} (93.5 \text{ in} + 2 \times 2.5 \text{ in})$$

Solving for  $F_{RV23}$  (the load reacted by the weld):

$$R_{V23} := \frac{a_l W_{c\_hs180} [d_{c\_vcg\_hs180} - 19 \text{ in} + (14.5 \text{ in} - 10.43 \text{ in})]}{2 (93.5 \text{ in} + 2 \times 2.5 \text{ in})} = 155 \text{ kip}$$

where  $a_l = 2$  is for the 2g lateral load, the 2 in the denominator is for the number of saddles sharing the load,  $d_{c\_vcg\_hs180} = 64.5 \text{ in}$  is the height of the Hi-Star 180 cask above the bottom of the cradle from Table 4.1, 93.5 inches is the distance between the Item 1 beams from Figure 3 and 2.5 inches (rounded from 2.47 inches) and 10.43 inches is the location of the weld centroid (calculated below). This load is bounding because the cask weight is greatest and the distance between the I-Beams is the same for all cradles and the vertical weld leg is the smallest.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

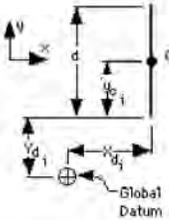
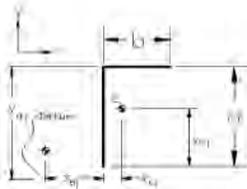
DOE Atlas Railcar

Page 21 of 30

Calculate fillet weld properties

Each of the two welds are comprised of two legs, the vertical and the horizontal. The horizontal leg is the width of the W18 X 119 flange. On all cradles except the Hi-Star 60 and the Hi-Star 100HB, the vertical leg of the weld is the height of the W18 X 119 beam. On the two exceptions, the saddle plates are shorter to provide clearance to the shear key on the Railcar. These two welds have a vertical leg 14.5 inches long as shown in Figure 3. The distance between the welds is the same for all cradles. The Hi-Star 100HB cask is heavier than the Hi-Star 60

The completed weld is shown below:



Weld Geometry

Weld Throat:  $h := \frac{.75 \text{ in}}{\sqrt{2}} = 0.53 \text{ in}$

Dimensions:  $d := 14.5 \text{ in}$  where d is the length of the vertical leg of the weld as shown in Figure 3

Weld Properties (Weld Number:  $i := i + 1, i = 1$ )

Weld Area:  $A_i := d \cdot h$   $A_i = 7.7 \text{ in}^2$

Weld Centroid:  $x_{d_i} := 0 \text{ in}$   $x_{d_i} = 0 \text{ in}$

$y_{c_i} := \frac{d}{2}$   $y_{c_i} = 7.25 \text{ in}$

Weld Offset

$X_{d_i} := 0 \text{ in}$

$Y_{d_i} := 0 \text{ in}$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

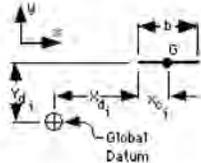
Page 22 of 30

Weld Properties (Weld Number  $i := 1 + 1, i = 2$ )

Weld Geometry

Weld Throat:  $h = 0.53 \text{ in}$

Dimensions:  $b := b_f = 11.3 \text{ in}$  where  $b_f$  is the flange width of the W18 X 119 beam



Weld Offset

$x_{d_i} := 0 \text{ in}$   
 $y_{d_i} := d$

Weld Area:  $A_i := b \cdot h$

$A_i = 6 \text{ in}^2$

Weld Centroid:  
 $x_{c_i} := \frac{b}{2}$   
 $y_{c_i} := 0 \text{ in}$

$x_{d_i} = 5.65 \text{ in}$   
 $y_{c_i} = 0 \text{ in}$

Composite Section Properties: (Welds:  $j := 1 .. i, i = 2$  welds)

Area:  $A_c := \sum_j A_j \quad A_c = 13.7 \text{ in}^2$

Centroid:  
 $x_c := \frac{\sum_j [(x_{d_j} + x_{c_j}) A_j]}{A_c}$   
 $x_c = 2.47 \text{ in}$

$y_c := \frac{\sum_j [(y_{c_j} + y_{d_j}) A_j]}{A_c}$   
 $y_c = 10.43 \text{ in}$

The weld shear stress is:  $\tau_{\text{weld}} := \frac{R_{V23}}{A_c} = 11.3 \text{ ksi}$  and the corresponding margin of safety

is:  $MS := \frac{.6 \times F_{y572\_50}}{\tau_{\text{weld}}} - 1 = 1.65 \quad \rightarrow \text{Okay}$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

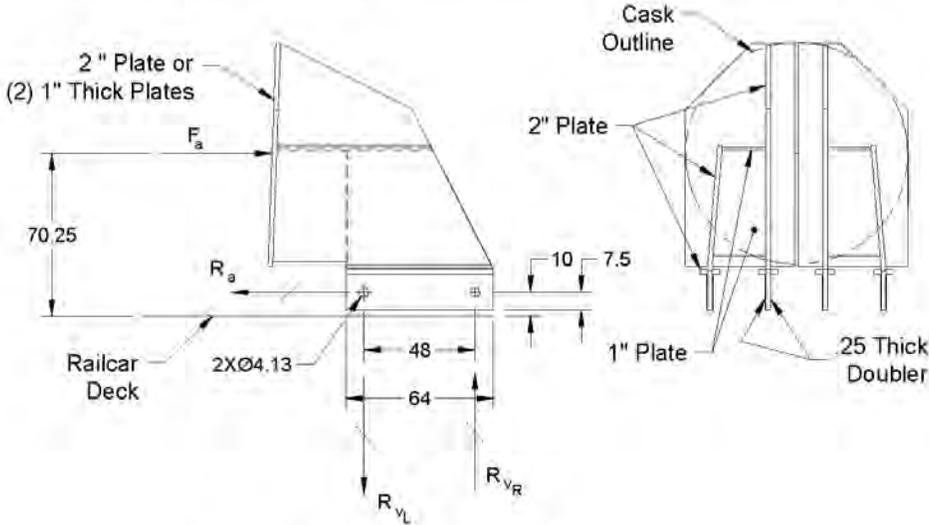
Page 23 of 30

**5.3 Evaluate the End Stops**

All of the end stops are constructed of the same materials and the construction is similar. The end stops are constructed largely from ASTM A572, Grade 50 plate, 2 inches thick except at the attachment locations where a 1/4 inch thick doubler is attached on each side of the plate and the stiffener plates are 1 inch thick.

The plates are pinned to the rail car attachment lugs using  $\varnothing$  4 inch pins in  $\varnothing$  4.13 inch holes or slots (the slots are in the attachment lugs at the pin locations closest to the end of the rail car and allow axial motion while the round holes serve to react the axial load from the cask).

A pair of end stops is located at each end of the rail car. Each end stop is comprised of 2, 2 inch thick vertical plates and a face plate (adjacent to the cask's impact limiters) of 2 inch thick plate or 2, 1 inch thick plates (total thickness 2 inches). There are additional 1 inch thick plates placed between the vertical plates to act as stiffeners (as shown in Figure 7).



**Figure 7 - End Stop - Hi-Star 100**



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 24 of 30

**Evaluate Bending on the Vertical Plates**

The maximum moment on any plate is at the pin attachment locations and all end stops are configured identically in this area, therefore, the cask/end stop with the largest applied moment bounds all others.

The combination of cask height, weight and central cradle weight for the Hi-Star 100 produces the highest moment load (see Table 5.3 below). The combined moment is:

$$M_{ES} := a_{ax} \left[ (W_{c\_hs100} + W_{cr\_hs100}) (d_{c\_vcg\_hs100} + .5 \text{ in} - 10 \text{ in}) \dots + 2 \times W_{es\_hs100} \times (d_{es\_vcg\_hs100} - 10 \text{ in}) \right] = 145 \cdot 10^3 \text{ in} \cdot \text{kip}$$

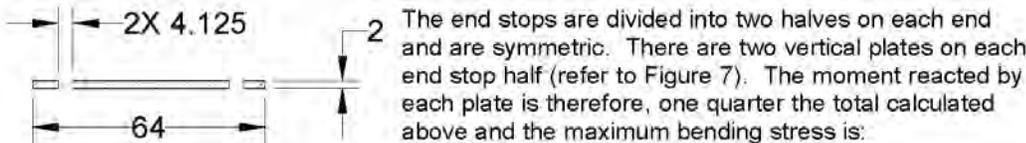
where:  $a_{ax} = 7.5 \text{ g}$  is the axial acceleration,  $W_{c\_hs100} = 279893 \text{ lbf}$  is the cask weight and  $W_{cr\_hs100} = 20 \text{ kip}$  is the central cradle weight both from Table 5.1 and

$d_{c\_vcg\_hs100} + .5 \text{ in} = 70.25 \text{ in}$  and 10 inches are from Figure 7 and 0.5 inches is the offset from the rail car deck provided by the shim plate located between the lugs.

The vertical reaction at the pin location is found by dividing the moment above by the distance between the holes.  $R_{vL} := M_{ES} \frac{1}{4 \times 48 \text{ in}} = 753 \text{ kip}$  where the 4 accounts for the number of lugs sharing the load and 48 inches is the distance between the holes from Figure 7.

The moment is reacted by the four vertical end stop plates, conservatively neglecting the doublers. The length of the plates through the pins is 64 inches and the corresponding section modulus, through the holes, (for one plate) is:

$$S_{ES} := \frac{\frac{2 \text{ in} (64 \text{ in})^3}{12} - 2 \left[ \frac{2 \text{ in} (4.125 \text{ in})^3}{12} + (4.125 \text{ in} \times 2 \text{ in}) \left( \frac{64 \text{ in}}{2} - 8 \text{ in} \right)^2 \right]}{32 \text{ in}} = 1068 \text{ in}^3$$



$$\sigma_{b\_ES} := \frac{M_{ES}}{4 S_{ES}} = 33.9 \text{ ksi} \text{ and the corresponding}$$

$$\text{margin of safety is: } MS := \frac{F_{y572\_50}}{\sigma_{b\_ES}} - 1 = 0.477 \quad \rightarrow \quad \text{Okay.}$$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 25 of 30

Stiffeners were added between the vertical plates on this design concept. If buckling or crippling is identified as a concern in the detailed design, additional stiffeners may be added.

**Table 5.3 – Moments on End Stops**

Cask	Cask Weight Maximum (W <sub>c</sub> ) (lb)	Cask Vert cg from bottom of cradle (d <sub>c_vcg</sub> ) (in)	Central Cradle weight (W <sub>cr</sub> ) (kip)	Moment at Base of End Stop (M <sub>ES</sub> ) (10 <sup>3</sup> in-kip)
HI-STAR 100 ( hs100)	279,893	69.75	23.3	145
HI-STAR 100HB ( hshb)	187,200	69.75	15.7	103
HI-STAR 180 ( hs180)	308,647	64.5	11.8	139
HI-STAR 60 ( hs60)	164,000	59.63	17.0	76
TN-32B ( TN32)	263,000	72.5	16.1	139
TN-40 ( TN40)	271,500	72.5	15.7	143
TN40HT ( TN40HT)	242,343	72.5	15.7	129

**Evaluate Shear Tear-out**

The same moment is reacted by the plate in shear at the pin locations, however, the attachment loads for each attachment location include both the vertical and axial loads acting at a single pin location. The highest combined load occurs for the Hi-Star 180 cask. Evaluation of this load bounds all other designs. The loads conservatively include the self weight of the end stops. The shear force, at one of the pin locations is:

$f_s := \sqrt{(594.8 \text{ kip})^2 + (718.8 \text{ kip})^2} = 933 \text{ kip}$  where 594.8 kip and 718.8 kip are the maximum attachment lug loads from Table 2.2 for pin block 9 on the Hi-Star 180 cask. Note: The lug located further from the cask (e.g. P8) has a slotted hole and reacts only a vertical load. The distance to the edge of a plate, parallel to the applied load, is:

$$d_{\min} := \frac{7 \text{ in}}{\cos\left(\text{atan}\left(\frac{594.8}{718.8}\right)\right)} - \frac{4.125 \text{ in}}{2} = 7.023 \text{ in}$$

where 7 inches is the distance from the

center of the hole to the bottom edge of the plate. The shear area is:

$$A_{s\_ES} := 2 \times 2.5 \text{ in} \times d_{\min} = 35.117 \text{ in}^2$$

where 2.5 inches includes the two .25 inch thick

doublers and the resulting shear stress is:  $\tau_{ES} := \frac{f_s}{A_{s\_ES}} = 26.568 \text{ ksi}$  and the corresponding

$$\text{margin of safety is: } MS := \frac{.6 F_{y572\_50}}{\tau_{ES}} - 1 = 0.129 \quad \text{--> Okay}$$

where  $F_{y572\_50} = 50 \text{ ksi}$  is from Table 2.3 and the 0.6 multiplier is defined in § 2.3



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 26 of 30

#### 5.4 Evaluate Strap Attachment Fasteners

The straps are attached using 2, 1 1/2-6 UNC ASTM A490 bolts threaded into nuts welded to the underside of the saddle plate.

##### Determine the required strength for the attachment bolts

The bolts react the load from the vertical load case or 2 g up. All cradle designs include 2 or more saddles and straps, therefore, sharing the load between two tie down straps bounds all load cases.

The maximum cask weight, from Table 5.3 is  $W_{c\_hs180} = 308.647 \text{ kip}$ . The load on a single bolt is:  $f_{\text{bolt}} := 2 \frac{W_{c\_hs180}}{2 \times 2} = 154.3 \text{ kip}$  where the multiplier of 2 is for the 2g up load case and the two's in the denominator are for the number of saddle straps and number of bolts on each strap.

The bolts have a tensile area of:  $A_{\text{bolt}} = 1.405 \text{ in}^2$  from ASTM A490 [7.18]. The stress on each bolt is:  $\sigma_{\text{bolt}} := \frac{f_{\text{bolt}}}{A_{\text{bolt}}} = 110 \text{ ksi}$  The yield strength of the bolt will be used as the

allowable strength. The margin of safety is:  $MS := \frac{F_{y\_bolt}}{\sigma_{\text{bolt}}} - 1 = 0.184 \rightarrow \text{Okay}$

where  $F_{y\_bolt} = 130 \text{ ksi}$  is from ASTM A490 for a 1 1/2-6 UNC bolt.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 27 of 30

**5.5 Example Calculation of Attachment Lug Loads - Central Cradle**

The Railcar attachment lug loads are shown in Table 2.2. An example calculation for the lug loads is shown below. The examples are for the Hi-Star 100 Cask and do not necessarily constitute the bounding lug load.

The lug loads result from the applied tiedown accelerations shown in Table 2.1. Lugs P1 - P4 are used to attach the central cradle. These lugs are slotted and will not react the axial loads resulting from the  $\pm 7.5$  g axial acceleration. These lugs react only the vertical and lateral loads. The load on lug P1 due to the vertical acceleration is determined by summing moments (CCW +) about the P3-P4 end of the central cradle:

$$\Sigma M_{P34} = 0 = a_u \left[ -W_{c\_hs100} (125 \text{ in} - d_{c\_hcg\_hs100}) \dots \right] + F_{P1V} 125 \text{ in} + F_{P2V} 125 \text{ in}$$

$$\left[ + -W_{cr\_hs100} (125 \text{ in} - d_{cr\_hcg\_hs100}) \right]$$

The reactions at P1 and P2 are the same (the cradle is laterally symmetric). Rearranging and solving for  $F_{P1V}$ :

$$F_{P1V} := a_u \frac{W_{c\_hs100} (125 \text{ in} - d_{c\_hcg\_hs100}) + W_{cr\_hs100} (125 \text{ in} - d_{cr\_hcg\_hs100})}{2 \times 125 \text{ in}}$$

$$F_{P1V} = 149.7 \text{ kip}$$

where:  $a_u = 2$  g is the upward vertical acceleration (Table 2.1),  $W_{c\_hs100} = 279893$  lbf is the weight of the Cask (Table 4.1),  $W_{cr\_hs100} = 20$  kip is the weight of the central cradle (Table 5.1),  $d_{c\_hcg\_hs100} = 62.88$  in and  $d_{cr\_hcg\_hs100} = 59$  in are the distances of the centroids from lug P1 for the cask and central cradle respectively (Table 5.1) and 125 inches is the longitudinal distance between the pins of the central cradle (Figure 2).

The vertical reactions at lugs P1/P2 and P3/P4 are inversely proportional to the distance from the combined centroid of the cask and central cradle. The combined centroid is:

$$d_{hcg\_hs100} := \frac{W_{c\_hs100} d_{c\_hcg\_hs100} + W_{cr\_hs100} d_{cr\_hcg\_hs100}}{W_{c\_hs100} + W_{cr\_hs100}} = 62.6 \text{ in} \quad \text{The load}$$

on the lugs at the opposite end of the central cradle are found by summing moments about the combined centroid:  $\Sigma M_{comb} = 0 = 2 F_{P1V} d_{hcg\_hs100} - 2 F_{P3V} (125 \text{ in} - d_{hcg\_hs100})$

where  $F_{P3V} = F_{P4V}$  due to lateral symmetry. Solving for  $F_{P3V}$ ,

$$F_{P3V} := F_{P1V} \frac{d_{hcg\_hs100}}{125 \text{ in} - d_{hcg\_hs100}} = 150.2 \text{ kip}$$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 28 of 30

There is a vertical load on lugs P1 - P4 in reaction to the lateral acceleration. The vertical load on lug P1 is found by summing moments about the line formed by lugs P2-P3 (CCW +):

$$\Sigma M_{P23} = 0 = -a_l [W_{c\_hs100} (d_{c\_vcg\_hs100} - 10 \text{ in}) + W_{cr\_hs100} (d_{cr\_vcg\_hs100} - 10 \text{ in})] \dots + F_{P1v} 104.75 \text{ in} + F_{P4v} 104.75 \text{ in}$$

The vertical loads on the ends are again inversely proportional to the distance from the combined centroid. Substituting and solving for  $F_{P1v}$  finds:

$$F_{P1v} := -a_l \frac{W_{c\_hs100} (d_{c\_vcg\_hs100} + .5 \text{ in} - 10 \text{ in}) + W_{cr\_hs100} (d_{cr\_vcg\_hs100} + .5 \text{ in} - 10 \text{ in})}{104.75 \text{ in} \left( 1 + \frac{d_{hcg\_hs100}}{125 \text{ in} - d_{hcg\_hs100}} \right)}$$

where:  $a_l = 2 \text{ g}$ ,  $W_{c\_hs100} = 279.893 \text{ kip}$ ,  $W_{cr\_hs100} = 20 \text{ kip}$ ,  $d_{c\_hcg\_hs100} = 62.88 \text{ in}$  and  $d_{cr\_hcg\_hs100} = 59 \text{ in}$  are repeated from above and 10 inches is the offset from the railcar deck to the hole in the lug as shown in Figure 2 and .5 inches is the offset from the deck to the bottom of the cradle.

$$F_{P1v} = -164.1 \text{ kip}, F_{P4v} := F_{P1v} \frac{d_{hcg\_hs100}}{125 \text{ in} - d_{hcg\_hs100}} = -164.6 \text{ kip} \quad F_{P1v} \text{ has the greater magnitude and is reported in Table 2.2.}$$

The lateral load on the central cradle attachment lugs is simply a sum of the forces calculation with the proportional load sharing as above. As discussed in § 5.1, the only one of the central cradle beams reacts the lateral load.

$$\Sigma F_{lat} = 0 = a_l (W_{c\_hs100} + W_{cr\_hs100}) - F_{P1l} - F_{P4l} \text{ and } F_{P4l} = F_{P1l} \frac{d_{hcg\_hs100}}{125 \text{ in} - d_{hcg\_hs100}}$$

$$\text{Solving for } F_{P1l} \text{ yields: } F_{P1l} := a_l \frac{W_{c\_hs100} + W_{cr\_hs100}}{1 + \frac{d_{hcg\_hs100}}{125 \text{ in} - d_{hcg\_hs100}}} = 299.4 \text{ kip} \text{ and}$$

$$F_{P4l} := F_{P1l} \frac{d_{hcg\_hs100}}{125 \text{ in} - d_{hcg\_hs100}} = 300.4 \text{ kip}$$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 29 of 30

**Table 6.1 – Summary of Cradle and End Stop Weights and C.G.'s**

Cask	Central Cradle weight (kip)	Central Cradle cg from Bottom of Cradle (in)	End Stop weight (Each) (kip)	End Stop CG from Deck	Total Cradle CG from Bottom of Cradle (in)
HI-STAR 100	20	27.3	11.8	61.1	51.5
HI-STAR 100HB	14	28.4	13.7	66.7	58.3
HI-STAR 180	9	28.7	11.3	60.0	54.6
HI-STAR 60	15	28.0	11.5	61.1	53.5
TN-32B	13	35.7	14.3	50.0	47.0
TN-40	13	32.5	14.3	50.0	46.5
TN4OHT	13	32.5	14.3	50.0	46.5

Notes: 1. There are four (4) end stops for each configuration, two (2) on each end. As discussed in § 5.3, two (2) end stops are located at each end. Total end stop weight is four (4) times the value shown in Table 6.1

**6.0 Results and Conclusions**

All stresses are below the maximum allowable stress as shown above. The cradles are acceptable for their intended use.

**6.1 Results of applicable literature searches or other applicable background data**

A literature search was not required for this calculation.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 1 Cradle Structural Calculation

Doc./Rev.: CALC-3015133-000

Project: 00225.03.0050

DOE Atlas Railcar

Page 30 of 30

## 7.0 REFERENCES

1. Department of Energy Contract DE-NE0008390, Part 1, Section C, Statement of Work.
2. AREVA Federal Services Drawing, DWG-3015137, Atlas Railcar Cradle Family 1 Conceptual Drawing, Rev. 0.
3. AREVA Federal Services Calculation, CALC-3015276, Atlas Railcar Cradle Attachment Calculation, Rev. 0.
4. AREVA Federal Services Engineering Information Record, EIR-3014611, Design Basis Requirements Document (DBRD) for the Atlas Railcar, Rev. 3.
5. AREVA Federal Services Drawing, DWG-3015278, Atlas Railcar Attachment, Rev. 0.
6. American Society for Testing and Materials, ASTM A992/A992M, Standard Specification for Structural Steel Shapes, 2011.
7. American Society for Testing and Materials, ASTM A572/A572M, Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel, 2007.
8. Steel Construction Manual, American Institute of Steel Construction, 13th Edition, Second Printing, July 2006.
9. *Aluminum Design Manual*, The Aluminum Association, 2010.
10. CALC 3015133\_Atlas - Loads Fam 1\_4.21.16.xlsx
11. CALC 3015133\_Hi-Star 60\_Railcar Loads.3.10.16.xlsx
12. CALC 3015133\_Hi-Star 100\_Railcar Loads.3.10.16.xlsx
13. CALC 3015133\_Hi-Star 100HB\_Railcar Loads.3.10.16.xlsx
14. CALC 3015133\_Hi-Star 180\_Railcar Loads.3.10.16.xlsx
15. CALC 3015133\_AREVA TN TN-32B\_Railcar Loads.3.10.16.xlsx
16. CALC 3015133\_AREVA TN TN-40\_Railcar Loads.3.10.16.xlsx
17. CALC 3015133\_AREVA TN TN-40HT\_Railcar Loads.3.10.16.xlsx
18. American Society for Testing and Materials, ASTM A490, Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength, 2010.

## Appendix A.1.3 – Compliance Matrix

### REQUIREMENTS FOR CRADLE DESIGN FROM EIR-3014611, "DESIGN BASIS REQUIREMENTS DOCUMENT (DBRD) FOR THE DOE ATLAS RAILCAR," REV 4<sup>1</sup>

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
Family No. 1: Casks covered: TN-40, TN-40H, TN-32B, Hi-Star 60, Hi-Star 100, Hi-Star 100HB, Hi-Star 180			
2.1	<b>Regulatory Requirements</b> Comply with AAR 2043	For the cradles the AAR requirements are called out below	Y
2.2	<b>Functional Requirements</b>		
2.2.2	<i>Cradle Functional Requirements</i>		
2.2.2.1	During transport, a transportation cask must rest on a cradle on top of the cask railcar deck.	All cradles interface with the railcar attachments that comply with this requirement.	Y
2.2.2.2	Conceptual cask cradle designs must accommodate the cask designs listed above and interface with cradle as indicated in the cask SARs.	All casks with their respective cradles for the family are evaluated.	Y
2.2.2.3	The conceptual cradle designs shall not be final designs or prototypes.	The conceptual design has sufficient margin to allow for specific design requirements.	Y
2.2.2.3.a	Conceptual design shall have a plus or minus 10% weight envelope evaluated.	The weight envelope evaluated allows for refinement of the design in the final design	Y
2.2.2.3.b	Center of gravity for the cradle shall be calculated and used to demonstrate the combined CG is met for the cask railcar and cradle of 98 inches or less. CG and loading distributions shall be detailed sufficiently to support railcar design and testing.	The CG for each cask cradle is calculated for the family. As shown in the Attachment Calculations all combined CGs are less than 98 inches.	Y
2.2.2.3.c	Cradle shall be capable of handling the loads specified in Section 2.2.2.13 ( Rule 88 loads)	The cradles are demonstrated to meet rule 88 loadings for all casks within the family.	Y
2.2.2.3.d	Cradle shall be capable in the final design to handle a fatigue evaluation per AAR rules.	The weight margin allowed for the cradle and the design loading for compliance with Rule 88 ensures that here is sufficient margin for the detailed design to comply with the fatigue evaluation require by AAR-2043 which references AAR M-1001.	Y
2.2.2.3.e	Cradle designs shall have hard dimensions for interface to railcar to ensure ability to be attached to railcar.	The railcar interface dimensions are tolerance to ensure fit up.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
2.2.2.4	The conceptual cradle design shall determine the height of the cask center of gravity above the railcar deck, the weight on each axle, etc. as necessary to perform the analysis and provide simulate cradle test weights and supporting information needed for testing the railcar.	Required parameters for testing the railcar are provided in the families individual calculations and in the attachment design calculations.	Y
2.2.2.5	When rotation is necessary, the cradle will include the required hardware, such as trunnion supports.	There are provision for the addition of a separate cask rotation fixture to be placed adjacent to the concept cradle in the case where cask rotation on the railcar is needed.	Y
2.2.2.6	The cradles will be tall enough and open-ended so that the impact limiters can be attached to a cask after the cask is secured to the cradle.	The cradle design allows installation of impact limiters after the cask is secured to the cradle.	Y
2.2.2.7	Each cask design will need a cradle designed to position the center of gravity low for stability during transport, but the cradle design will position the impact limiter with a clearance of at least one inch above the cask car deck.	Adequate clearance is allowed for installation of the impact limiters.	Y
2.2.2.8	The cask car (including a cradle and a cask) and buffer car clearances shall fit within AAR Plate C [3], except when loaded with the casks that are more than 128 inches wide.	The four Holtec casks which have impact limiter diameters of 128 inches cradle designs permit compliance with Plate C.	Y
2.2.2.9	Demonstrate that bonding weights both min and max meet a combined CG of 98 inches for the railcar, skid and fully loaded and empty cask.(personnel shield, impact limiters etc.) An alternative to adding ballast weight to the railcar may include requiring that the transport cradle for the lighter cask be designed to provide the ballast.	Cradles as designed meet the combined CG.	Y
2.2.2.10	The various cradles will be designed to fit a standard attachment mechanism. Tolerance to ensure.	Fits the common attachment receivers on the railcar.	Y
2.2.2.11	During loading operations, the cradle may be attached to the railcar first, followed by putting the cask on the cradle, but sometimes the cask will be on the cradle first. In that case, both the cradle and cask together will be hoisted onto the railcar deck. Lifting points permit this handling of the cask	Designs permit loading separately or with the cask on the cradle.	Y
2.2.2.12	The cask railcar shall incorporate a standardized attachment capability for coupling the cask cradle to the railcar. This	Attachments meet Rule 88 requirements.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	attachment must be capable of securely attaching loads of up to the maximum cask weight and the weight cradle. in accordance with the requirements of AAR Rule 88 A16c(3) [7].		
2.2.2.13	AAR Rule 88 A16c(3) does not specify if the securement system loading requirements are to be applied separately or simultaneously. Per direction from KASGRO (via the AAR EEC) transportation loading is not simultaneous and is applied separately. Also gravity is not applied in the vertical up or down accelerations, so +/- 2 g vertical only. Rule 88 A.16.C requires the following tie down loads (g force to yield):	Analyzed according to the direction of the AAR.	
2.2.2.13.a	7.5g Longitudinal	Met for all cradles and casks.	Y
2.2.2.13.b	2g Vertical	Met for all cradles and casks.	Y
2.2.2.13.c	2g lateral	Met for all cradles and casks.	Y
	<b>Operational Requirements</b>		
	The cradle must accommodate the camber in the railcar.	Interfaces allows for the camber.	Y
	Have clearances to install and remove impact limiters on the railcar.	Clearance provided.	Y
	Features and clearances to load the cask into the cradle on and off the railcar and to be able to load the cradle with the impact limiters and personnel shield if required in place, on railcar.	Features and clearances permits loading with or without the personnel barrier in place to allow for intermodal transfers	Y
	Operational Steps. Can it be used and how? The loading and unloading steps requested should address that.	Complies with loading procedures	Y
	<b>Maintenance Requirements</b>		
	Since none of the designs use corrosion resistance material, the life expectancy would be dependent on corrosion control by the use of "high quality weather resistant coatings". Strip and repaint as required. Use wear pads to minimize loss of coatings.	Wear pads and coatings adequately applied	Y
	<b>Additional Design Considerations</b>		
	The cask cradles should be designed to support the cask for lifting on and off the railcar (with or without the cask impact limiters installed) as specified in Section 2.2.2.11 above. Lifting attachments shall be designed in accordance with ANSI N14.6 (i.e. the	Lifting meets ANSI N14.6.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	combined maximum tensile stress or the maximum shear stress of all members in the load path shall not exceed smaller of $S_y/3$ or $S_u/5$ . A vertical lift is assumed (requiring the use of a spreader beam/frame). All lift points are assumed to support the load equally for the conceptual design. The lift points should be designed such that the personnel barrier is not removed to lift the cradle when loaded with a package. A dynamic load factor of 1.15 shall be included per the recommendations of CMAA Specification No. 70 [12].		
	For cradle attachment points, the attachment mechanism (pin/bolt) should be removable and shall be sized for manual handling (less than 50 lbs.) or provisions should be designed for mechanically assisted insertion.	Attachments pins have mechanisms for handling	Y
	The bottom of the cradle shall be flat to facilitate placement on a flat surface or intermodal transfer.	Cradle can sit on flat surface.	Y

<sup>1</sup>Approved calculation performed to DBRD Revision 3; all pertinent calculation references are carried forward in Revision 4.

## APPENDIX A.2 – FAMILY 2 CRADLE

Appendix A.2.1

DWG-3015138-000  
Page 1 of 8

NOTES, UNLESS OTHERWISE SPECIFIED:		LIST OF MATERIALS						
<p>1. CONCEPTUAL DESIGN ASSUMES ALL WELDS ARE FULL PENETRATION WELDS UNLESS OTHERWISE NOTED. ALL WELDS WILL BE FURTHER SPECIFIED IN A FINAL DESIGN.</p> <p>2. FABRICATION SHALL BE PERFORMED IN ACCORDANCE WITH AWS D1.1.</p> <p>3. DIMENSIONS WITH TOLERANCES SPECIFIED ARE RAILCAR INTERFACE DIMENSIONS AND SHOULD BE CONSIDERED DURING FINAL CRADLE DESIGN.</p> <p>4. ALL SURFACES OF THE CRADLE WELDMENT, EXCEPT FOR SHACKLE HOLES, PIN HOLES, AND ALL FASTENER SURFACES, SHALL BE BLAST CLEANED PER SSP-SP-10 AND COATED WITH SELF-PRIMING ENAMEL, 2 COATS. THE NON-PAINTED CRADLE SURFACES SHALL BE LIGHTLY COATED WITH NUCLEAR GRADE NICKEL 'NEVER-SEEZ' GREASE.</p> <p>5. ATTACHMENTS FOR PERSONNEL BARRIER TO THE CRADLE, AND PERSONNEL BARRIER LIFT POINTS, ARE NOT INCLUDED IN THE CONCEPTUAL DESIGN. ADDITIONAL COMPONENTS MAY BE ADDED AS NECESSARY.</p> <p>6. THE ADDITION OF ALIGNMENT MARKS BETWEEN THE CRADLE AND RAILCAR INTERFACE SHOULD BE CONSIDERED IN THE DETAILED DESIGN TO SUPPORT LOADING OPERATIONS.</p> <p>7 COVER INDICATED SURFACES WITH 1/8" FIBER REINFORCED ELASTOMER BEARING PAD MATERIAL OR EQUIVALENT.</p> <p>8 ITEMS 11 AND 13 ON ASSEMBLY A2, AND ITEMS 11 AND 14 ON ASSEMBLY A3, MAY BE DESIGNED AS A SINGLE HIGH STRENGTH FORGING WITH A MINIMUM YIELD STRENGTH OF 135 KSI.</p> <p>9 HEAT TREAT MATERIAL FOR MINIMUM YIELD OF 135 KSI.</p> <p>10 LIFT LUGS MAY BE ADDED AS REQUIRED FOR HANDLING.</p> <p>11 GUSSET HOLES SHOWN ARE REPRESENTATIVE ONLY. FINAL SIZING OF THE GUSSET HOLES IS NOT INCLUDED IN THE CONCEPTUAL DESIGN.</p> <p>12 PERSONNEL BARRIER PANELS REMOVED PRIOR TO LIFTING LOADED CRADLE, AND RE-INSTALLED PRIOR TO TRANSPORT.</p>								
	QTY A3	QTY A2	QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION	
				A1		NAC-MAGNATRAN CRADLE ASSEMBLY		
				A2		NAC-STC CRADLE ASSEMBLY		
				A3		NAC-UMS CRADLE ASSEMBLY		
	2	2	2	1		W18 X 119	ASTM A992 OR A572, GR 50	
	2	2	2	2		PLATE, .19 THK	ASTM A572, GR 50	
	2	2	2	3		PLATE, .75 THK	BRONZE	
	1	1	1	4		PLATE, .75 THK	ASTM A572, GR 50	
	7	7	7	5		PLATE, 1.0 THK	ASTM A572, GR 50	
	8	8	8	6		PLATE, 1.5 THK	ASTM A572, GR 50	
	2	2	2	7		PLATE, 1.75 THK	ASTM A572, GR 50	
	11	14	16	8		PLATE, 2.0 THK	ASTM A527, GR50	
	3	3	3	9		PLATE, 3.0 THK	ASTM A572, GR 50	
	6	6	6	10		PLATE 4.0 THK	ASTM A572, GR 50	
	2	2	2	11		FORGING, 12.0 THK	ASTM A350, GRADE LF 6	
	1	1	1	12		CASTING, 16 THK	ASTM A732 GR 10Q	
	-	2	-	13		BAR, Ø6.0	ASTM A434, CLASS BD	
	2	-	-	14		BAR, Ø8.0	ASTM A434, CLASS BD	
	-	-	4	15		SHCS, 1-8 UNC	ASTM A574	
	2	2	2	16		HEX BOLT, 1-1/2-6 UNC	ASTM A490	
	2	2	2	17		HEX NUT, 1-1/2-6 UNC	ASTM A563	
	12	12	12	18		SHCS, 2-1/4- 4.5 UNC	ASTM A574	
	4	4	4	19	G-2130	SHACKLE, 2.5-IN, 55 TONNE WLL	CROSBY OR EQUIVALENT	
	4	4	4	20		BAR, Ø6.5	ASTM A276, TYPE 304	
	AR	AR	AR	21		SHEET, EXPANDED/PERFORATED, .12 THK, 65% OPENING	ALUMINUM	
	AR	AR	AR	22		PLATE, .19 THK	ALUMINUM	

AREVA  
July 6, 2016  
Records Management

REV	DESCRIPTION	DRAWN	CHECKER	VERIFIED

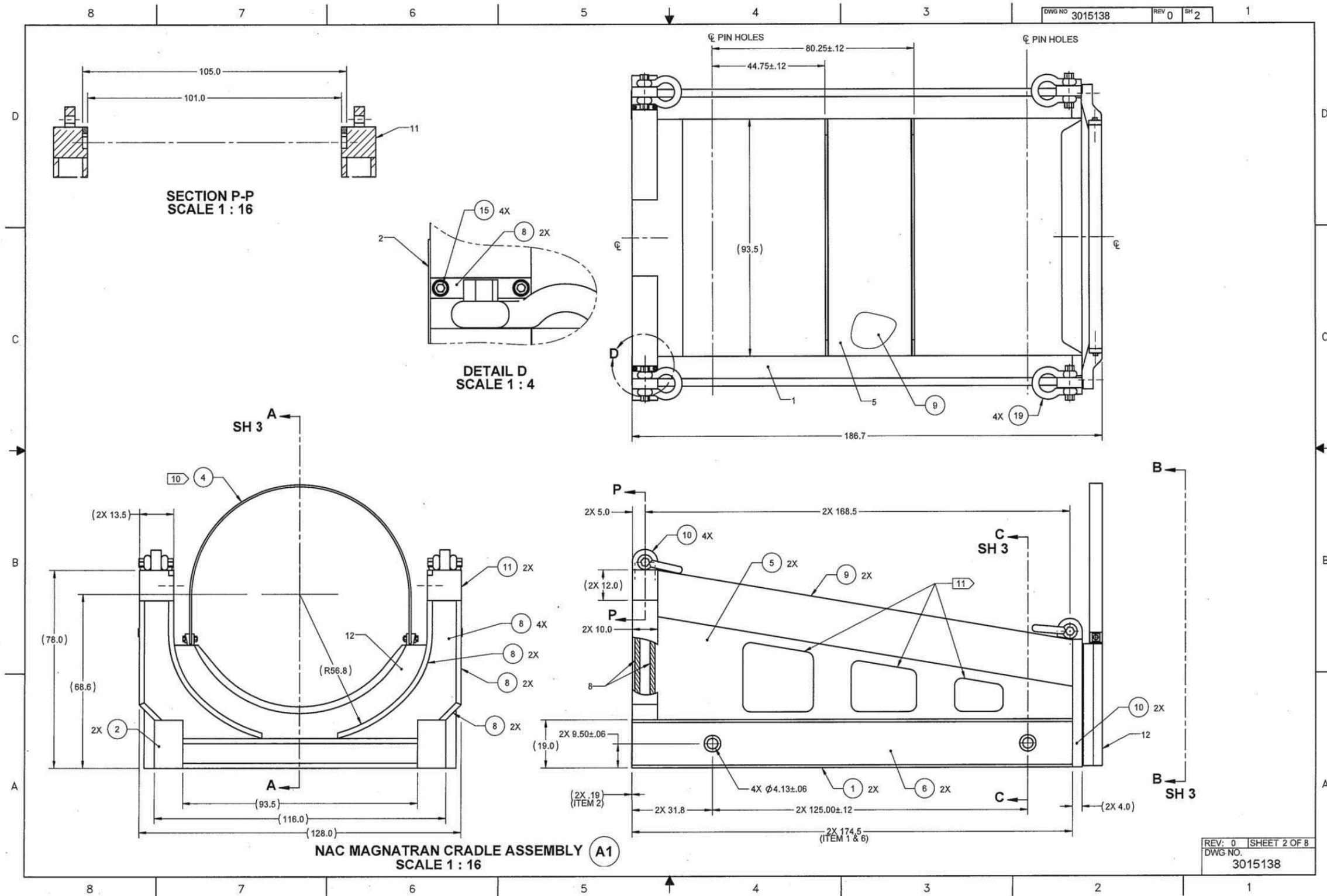
  

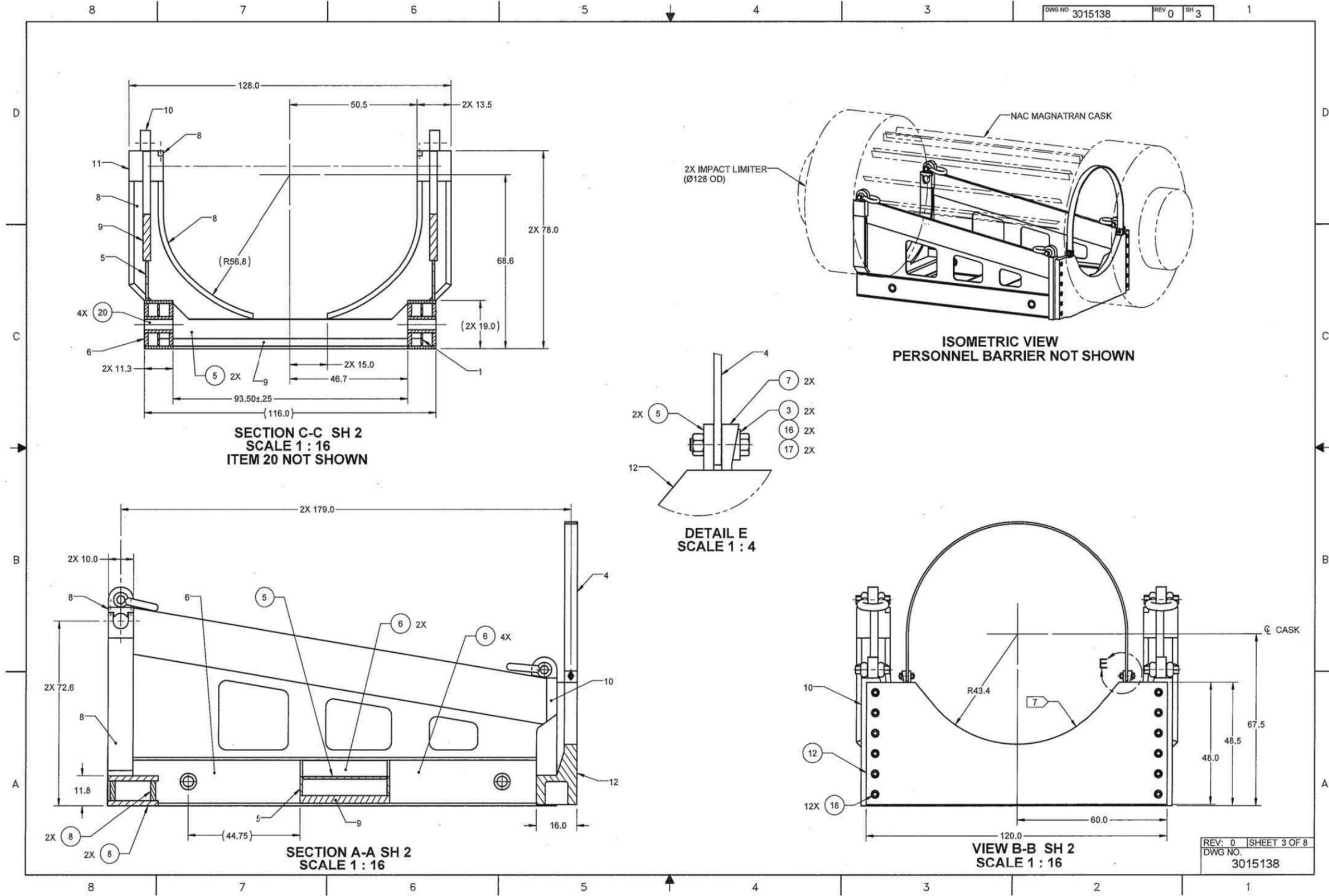
NAME/SIGNATURE		DATE
EM	<i>A. Hillstrom</i>	6/21/16
RE	<i>B. Johnson</i>	6/16/2016
TECH CHK	<i>S. Sen</i>	6-16-16
DFTG CHK	<i>S. Sen</i>	6-16-16
NA	NA	
DRAWN	P. PIKULIN	6-16-16

UNLESS OTHERWISE SPECIFIED:  
INTERPRET DRAWINGS & TOLERANCES PER ASME Y14.5-2009  
(REVISION OF ASME Y14.5M-1994)  
INTERPRET WELD CALLOUTS PER ANSI/AWS A2.4  
DIMENSIONS ARE IN INCHES

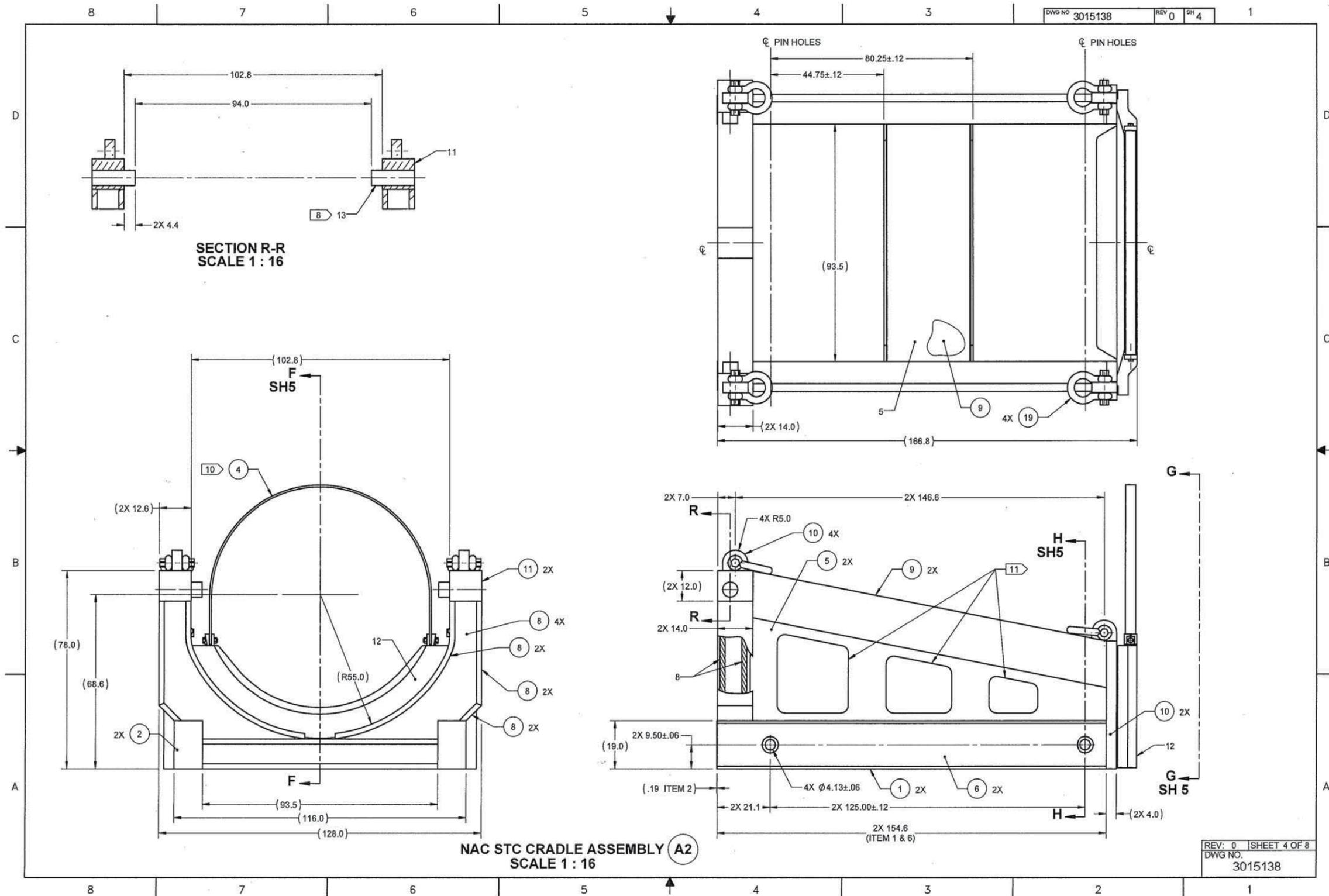
<b>AREVA</b>		AREVA Federal Services LLC Packaging Projects Federal Way, WA 98003	
DWG TITLE <b>ATLAS RAILCAR CRADLE FAMILY 2 (NAC) CONCEPTUAL DRAWING</b>			
SCALE: SHOWN	WT. ~	REV: 0	SHEET 1 OF 8
DWG NO. <b>3015138</b>	SIZE <b>D</b>	CADFILE: 3015138.SLDDRW	

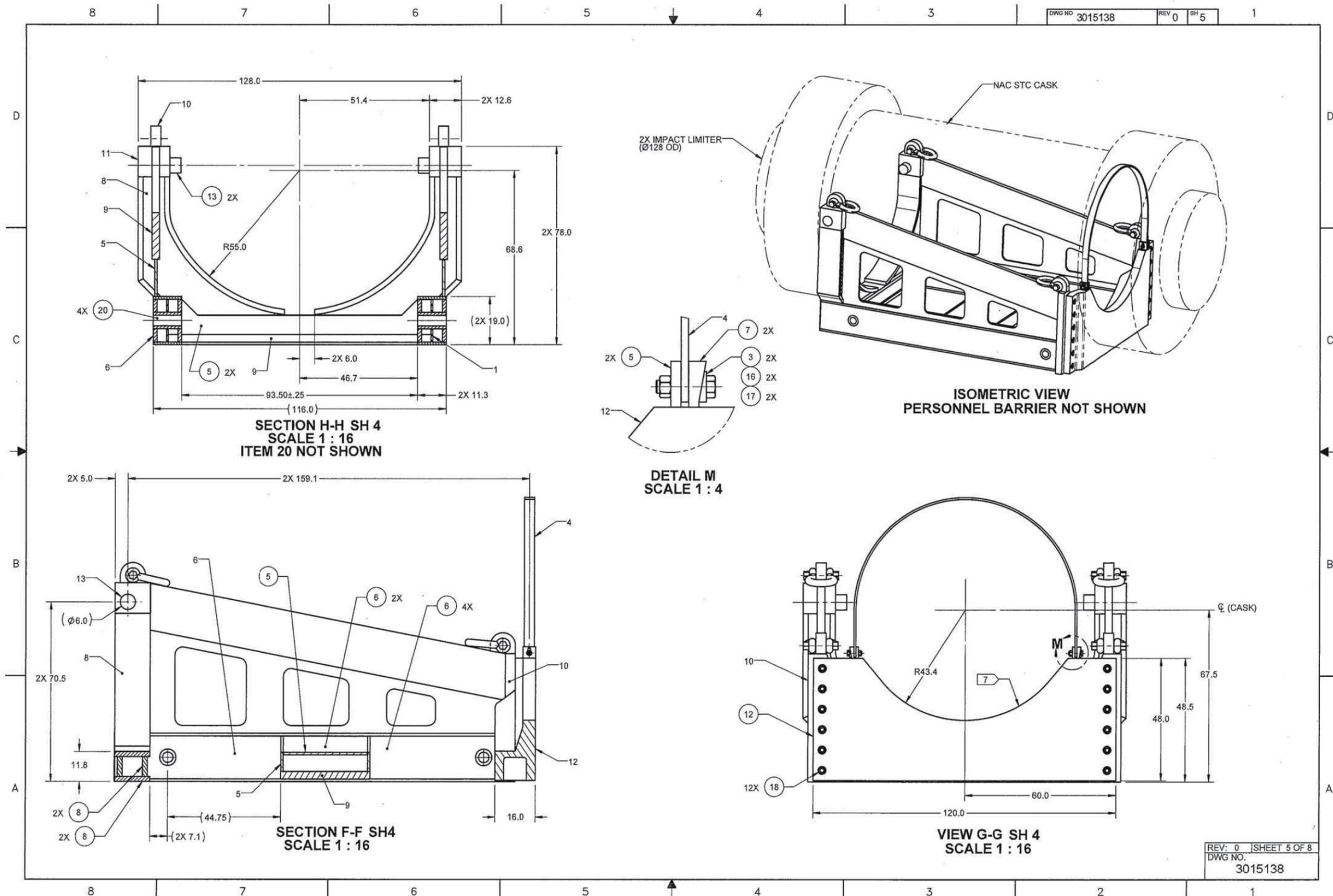
DWG-3015138-000  
 Page 2 of 8



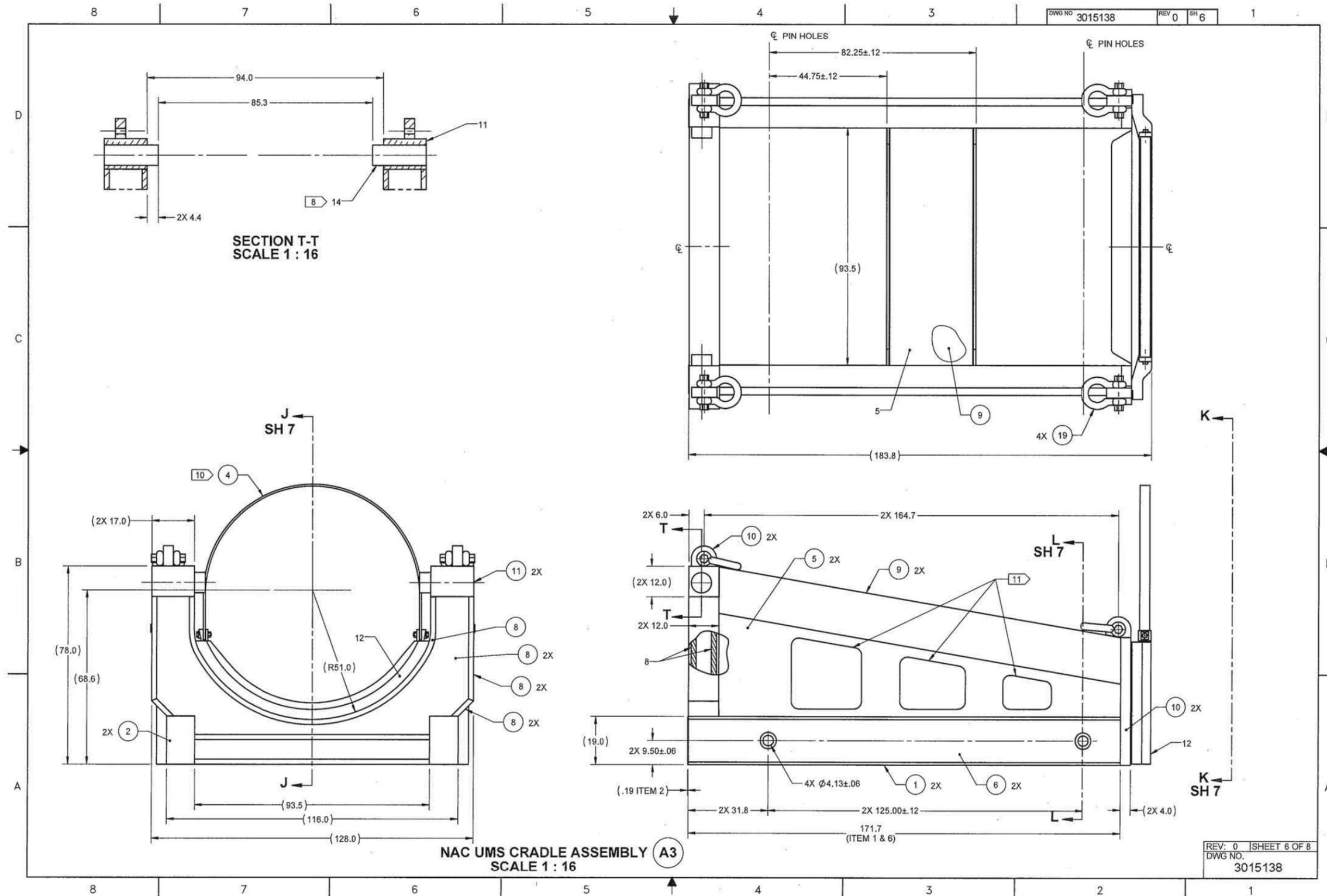


DWG-3015138-000  
 Page 4 of 8

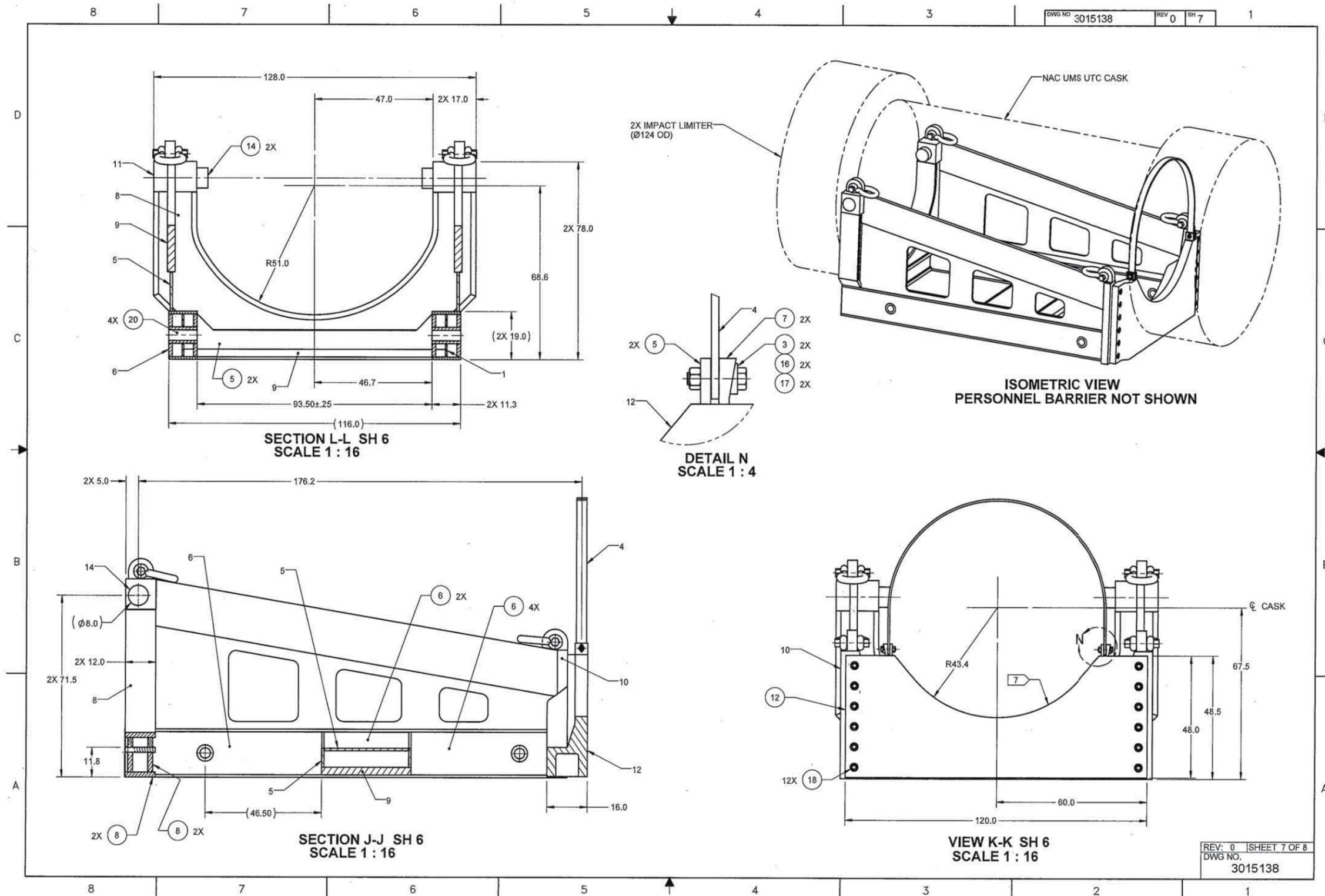


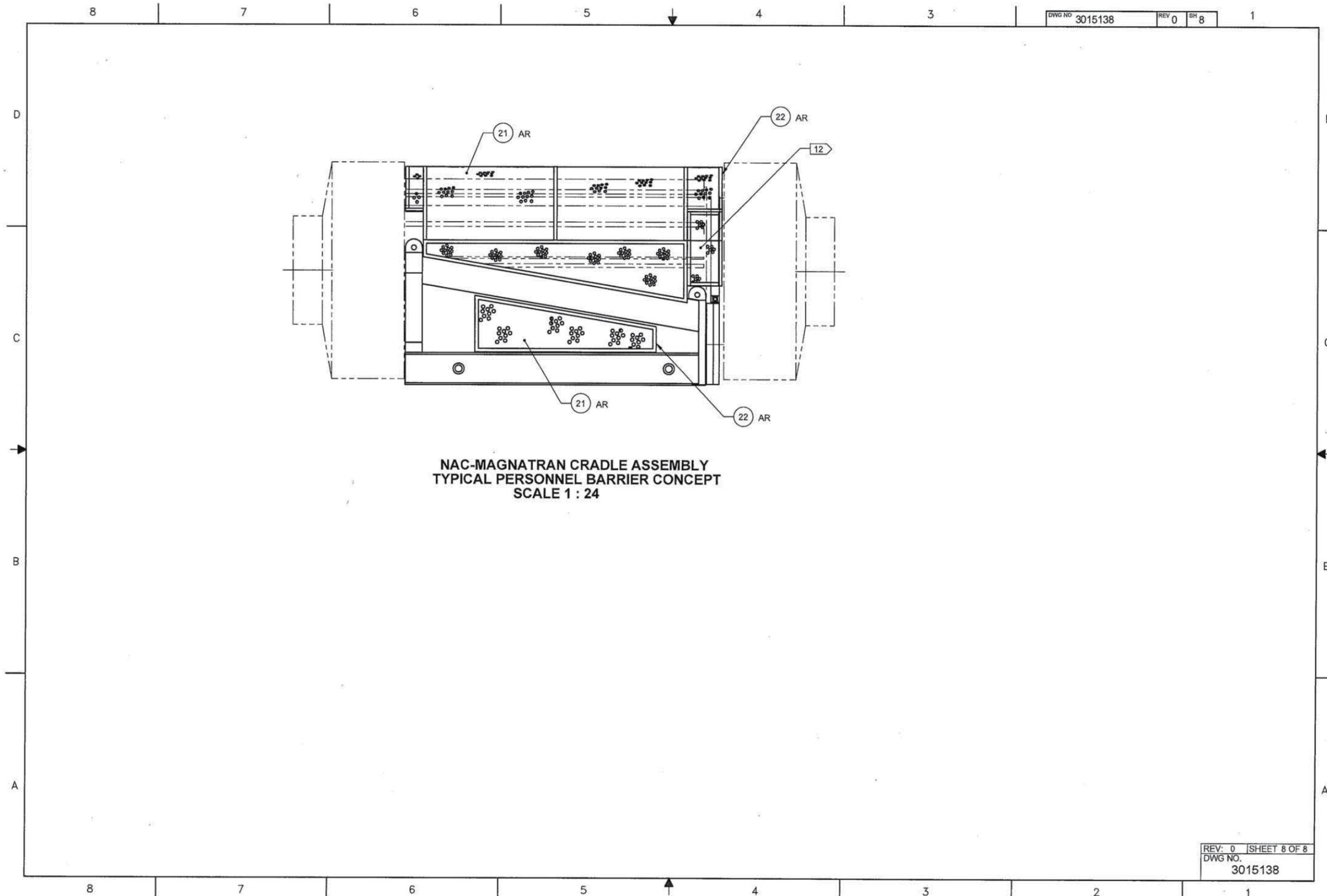


DWG-3015138-000  
 Page 6 of 8



DWG-3015138-000  
 Page 7 of 8





**NAC-MAGNATRAN CRADLE ASSEMBLY  
TYPICAL PERSONNEL BARRIER CONCEPT  
SCALE 1 : 24**

NOTES, UNLESS OTHERWISE SPECIFIED:		LIST OF MATERIALS																																																																																																													
<p>1. CONCEPTUAL DESIGN ASSUMES ALL WELDS ARE FULL PENETRATION WELDS UNLESS OTHERWISE NOTED. ALL WELDS WILL BE FURTHER SPECIFIED IN A FINAL DESIGN.</p> <p>2. FABRICATION SHALL BE PERFORMED IN ACCORDANCE WITH AWS D1.1.</p> <p>3. DIMENSIONS WITH TOLERANCES SPECIFIED ARE RAILCAR INTERFACE DIMENSIONS AND SHOULD BE CONSIDERED DURING FINAL CRADLE DESIGN.</p> <p>4. ALL SURFACES OF THE CRADLE, EXCEPT FOR SHACKLE HOLES, PIN HOLES, AND ALL FASTENER SURFACES, SHALL BE BLAST CLEANED PER SSP-SP-10 AND COATED WITH SELF-PRIMING ENAMEL, 2 COATS. THE NON-PAINTED CRADLE SURFACES SHALL BE LIGHTLY COATED WITH NUCLEAR GRADE NICKEL 'NEVER-SEEZ' GREASE.</p> <p>5. ATTACHMENTS FOR PERSONNEL BARRIER TO THE CRADLE, AND PERSONNEL BARRIER LIFT POINTS, ARE NOT INCLUDED IN THE CONCEPT DESIGN. ADDITIONAL COMPONENTS MAY BE ADDED AS NECESSARY.</p> <p>6. THE ADDITION OF ALIGNMENT MARKS BETWEEN THE CRADLE AND RAILCAR INTERFACE SHOULD BE CONSIDERED IN THE DETAILED DESIGN TO SUPPORT LOADING OPERATIONS.</p> <p>7 COVER INDICATED SURFACES WITH 1/8" FIBER REINFORCED ELASTOMER BEARING PAD MATERIAL OR EQUIVALENT.</p> <p>8 FRONT SADDLE NOTCHED TO CLEAR TN-68 IMPACT LIMITER TIE RODS.</p> <p>9 LIFT FEATURE MAY BE DESIGNED TO BE ATTACHED USING FASTENERS TO ENABLE REMOVAL FOR EMPTY CRADLE TRANSPORT UNDER AAR-S2028 PLATE C.</p> <p>10 GUSSETS CENTERED BEHIND LIFT POINTS.</p> <p>11 LIFT LUGS MAY BE ADDED AS REQUIRED FOR HANDLING.</p> <p>12 GUSSET HOLES SHOWN ARE REPRESENTATIVE ONLY. FINAL SIZING OF THE GUSSET HOLES IS NOT INCLUDED IN THE CONCEPTUAL DESIGN.</p>	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>QTY A1</th> <th>ITEM NO</th> <th>PART NO</th> <th>DESCRIPTION</th> <th>SPECIFICATION</th> </tr> </thead> <tbody> <tr> <td></td> <td>A1</td> <td></td> <td>TN-68 CRADLE ASSEMBLY</td> <td></td> </tr> <tr> <td>1</td> <td>1</td> <td></td> <td>W14 X 233</td> <td>ASTM A992 OR A572, GR 50</td> </tr> <tr> <td>2</td> <td>2</td> <td></td> <td>W18 X 119</td> <td>ASTM A992 OR A572, GR 50</td> </tr> <tr> <td>4</td> <td>3</td> <td></td> <td>PLATE, .19 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>3</td> <td>4</td> <td></td> <td>PLATE, .75 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>2</td> <td>5</td> <td></td> <td>PLATE, .75 THK</td> <td>BRONZE</td> </tr> <tr> <td>21</td> <td>6</td> <td></td> <td>PLATE, 1.0 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>8</td> <td>7</td> <td></td> <td>PLATE, 1.5 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>2</td> <td>8</td> <td></td> <td>PLATE, 1.63 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>2</td> <td>9</td> <td></td> <td>PLATE, 1.75 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>10</td> <td>10</td> <td></td> <td>PLATE, 2.0 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>1</td> <td>11</td> <td></td> <td>PLATE, 3.0 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>4</td> <td>12</td> <td></td> <td>PLATE, 4.0 THK</td> <td>ASTM A572, GR 50</td> </tr> <tr> <td>4</td> <td>13</td> <td></td> <td>FORGING, 6.5 THK</td> <td>ASTM A350, LFB</td> </tr> <tr> <td>2</td> <td>14</td> <td></td> <td>HEX BOLT, 1-1/2-6 UNC</td> <td>ASTM A490, TYPE 1</td> </tr> <tr> <td>2</td> <td>15</td> <td></td> <td>HEX NUT, 1-1/2-6 UNC</td> <td>ASTM A563</td> </tr> <tr> <td>4</td> <td>16</td> <td></td> <td>SHCS, 1-8 UNC X 4.0</td> <td>ASTM A490, TYPE 1</td> </tr> <tr> <td>4</td> <td>17</td> <td></td> <td>BAR, Ø6.5</td> <td>ASTM A276, TYPE 304</td> </tr> <tr> <td>4</td> <td>18</td> <td>G-2130</td> <td>SHACKLE, 2.5-IN, 55 TONNE WLL</td> <td>CROSBY OR EQUIVALENT</td> </tr> <tr> <td>AR</td> <td>19</td> <td></td> <td>SHEET, EXPANDED/PERFORATED, .12 THK, 65% OPENING</td> <td>ALUMINUM</td> </tr> <tr> <td>AR</td> <td>20</td> <td></td> <td>PLATE .19 THK</td> <td>ALUMINUM</td> </tr> </tbody> </table>	QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION		A1		TN-68 CRADLE ASSEMBLY		1	1		W14 X 233	ASTM A992 OR A572, GR 50	2	2		W18 X 119	ASTM A992 OR A572, GR 50	4	3		PLATE, .19 THK	ASTM A572, GR 50	3	4		PLATE, .75 THK	ASTM A572, GR 50	2	5		PLATE, .75 THK	BRONZE	21	6		PLATE, 1.0 THK	ASTM A572, GR 50	8	7		PLATE, 1.5 THK	ASTM A572, GR 50	2	8		PLATE, 1.63 THK	ASTM A572, GR 50	2	9		PLATE, 1.75 THK	ASTM A572, GR 50	10	10		PLATE, 2.0 THK	ASTM A572, GR 50	1	11		PLATE, 3.0 THK	ASTM A572, GR 50	4	12		PLATE, 4.0 THK	ASTM A572, GR 50	4	13		FORGING, 6.5 THK	ASTM A350, LFB	2	14		HEX BOLT, 1-1/2-6 UNC	ASTM A490, TYPE 1	2	15		HEX NUT, 1-1/2-6 UNC	ASTM A563	4	16		SHCS, 1-8 UNC X 4.0	ASTM A490, TYPE 1	4	17		BAR, Ø6.5	ASTM A276, TYPE 304	4	18	G-2130	SHACKLE, 2.5-IN, 55 TONNE WLL	CROSBY OR EQUIVALENT	AR	19		SHEET, EXPANDED/PERFORATED, .12 THK, 65% OPENING	ALUMINUM	AR	20		PLATE .19 THK	ALUMINUM
QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION																																																																																																											
	A1		TN-68 CRADLE ASSEMBLY																																																																																																												
1	1		W14 X 233	ASTM A992 OR A572, GR 50																																																																																																											
2	2		W18 X 119	ASTM A992 OR A572, GR 50																																																																																																											
4	3		PLATE, .19 THK	ASTM A572, GR 50																																																																																																											
3	4		PLATE, .75 THK	ASTM A572, GR 50																																																																																																											
2	5		PLATE, .75 THK	BRONZE																																																																																																											
21	6		PLATE, 1.0 THK	ASTM A572, GR 50																																																																																																											
8	7		PLATE, 1.5 THK	ASTM A572, GR 50																																																																																																											
2	8		PLATE, 1.63 THK	ASTM A572, GR 50																																																																																																											
2	9		PLATE, 1.75 THK	ASTM A572, GR 50																																																																																																											
10	10		PLATE, 2.0 THK	ASTM A572, GR 50																																																																																																											
1	11		PLATE, 3.0 THK	ASTM A572, GR 50																																																																																																											
4	12		PLATE, 4.0 THK	ASTM A572, GR 50																																																																																																											
4	13		FORGING, 6.5 THK	ASTM A350, LFB																																																																																																											
2	14		HEX BOLT, 1-1/2-6 UNC	ASTM A490, TYPE 1																																																																																																											
2	15		HEX NUT, 1-1/2-6 UNC	ASTM A563																																																																																																											
4	16		SHCS, 1-8 UNC X 4.0	ASTM A490, TYPE 1																																																																																																											
4	17		BAR, Ø6.5	ASTM A276, TYPE 304																																																																																																											
4	18	G-2130	SHACKLE, 2.5-IN, 55 TONNE WLL	CROSBY OR EQUIVALENT																																																																																																											
AR	19		SHEET, EXPANDED/PERFORATED, .12 THK, 65% OPENING	ALUMINUM																																																																																																											
AR	20		PLATE .19 THK	ALUMINUM																																																																																																											

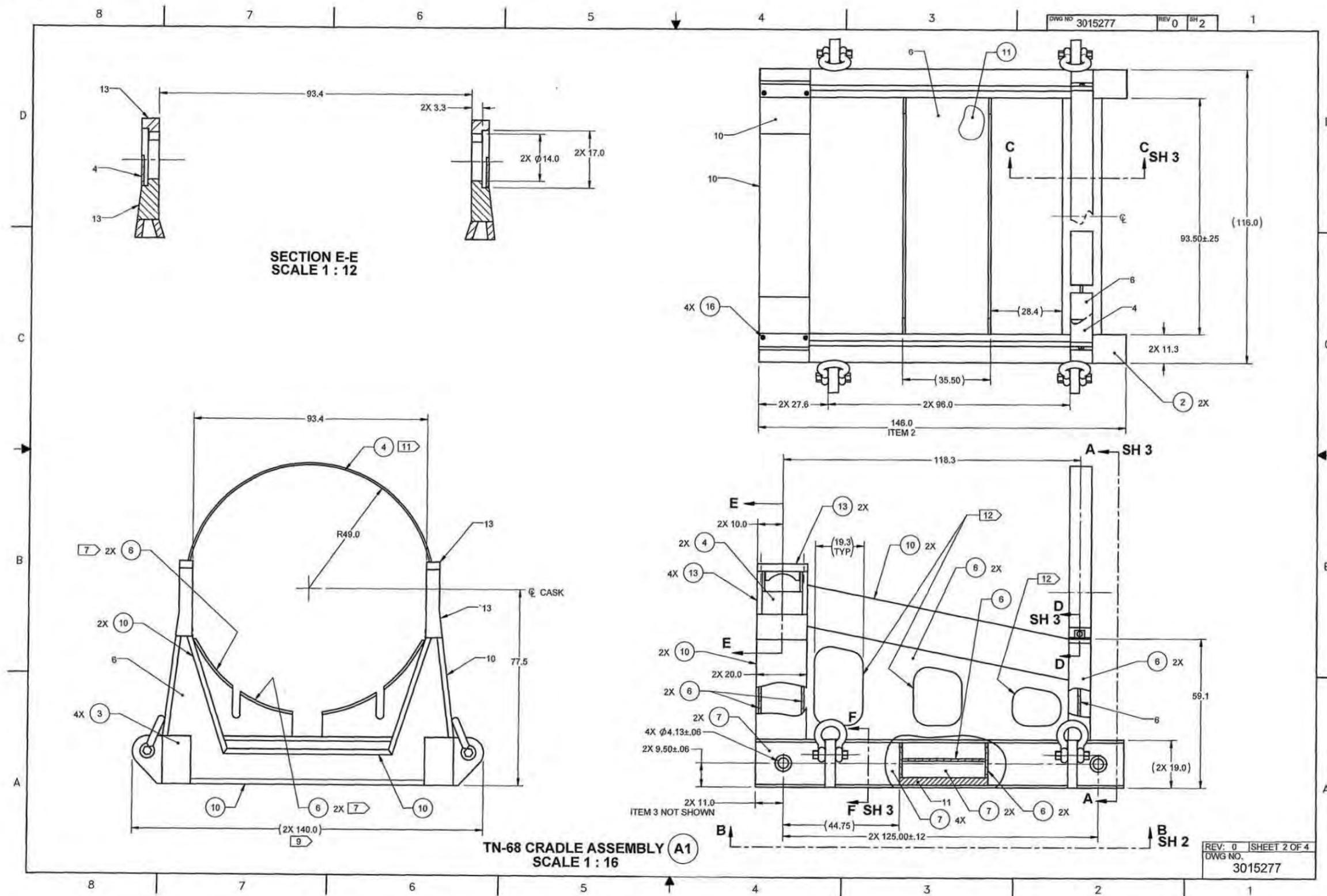
**AREVA**  
July 6, 2016  
Records Management

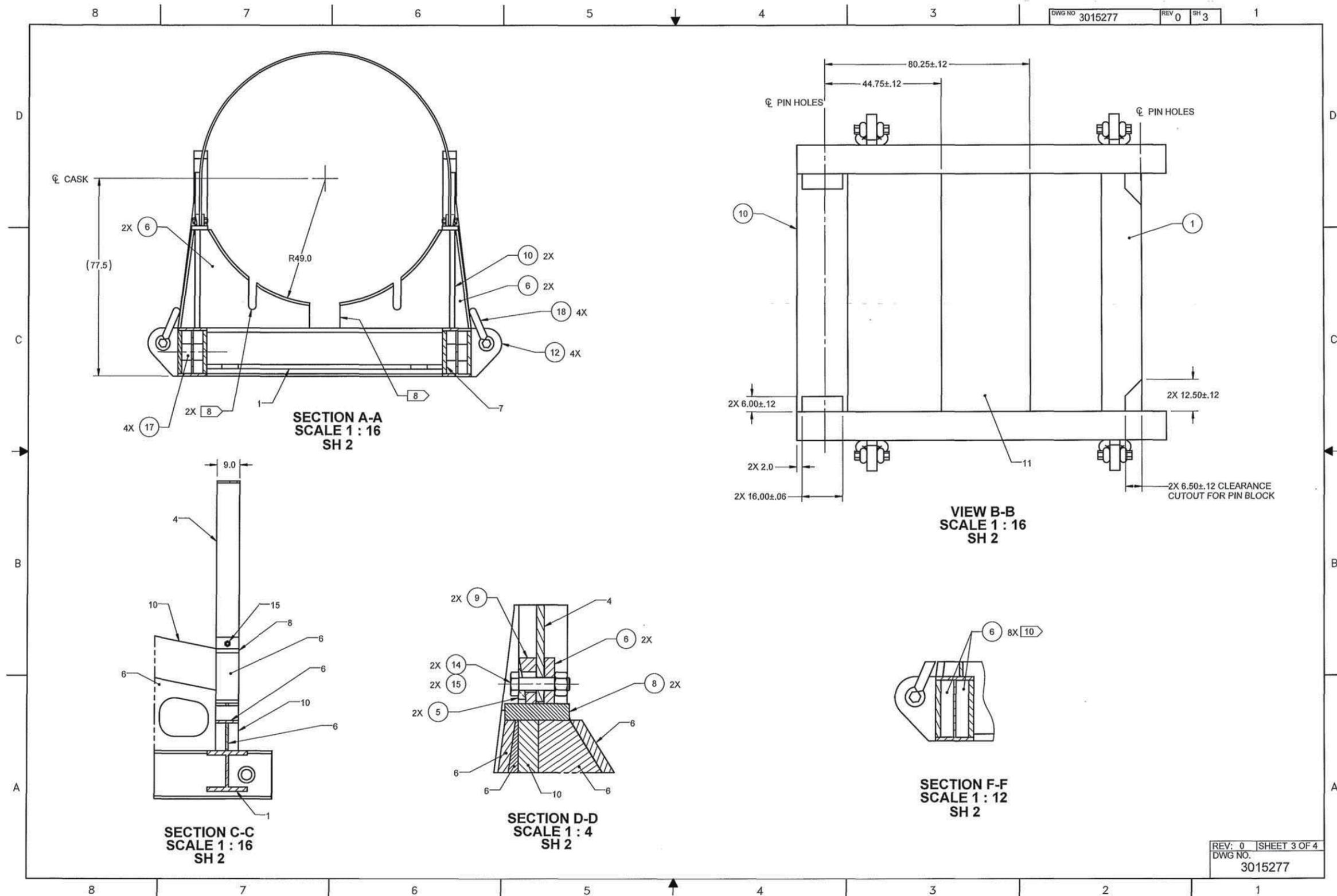
REV	NAME/SIGNATURE	DATE	DRAWN	CHECKER	VERIFIED
EM	<i>[Signature]</i>	6/21/16			
RE	<i>[Signature]</i>	6/16/2016			
TECH CHK	<i>[Signature]</i>	6.16.16			
DFTG CHK	<i>[Signature]</i>	6.16.16			
DRAWN	P. PIKULIN	6-16-16			

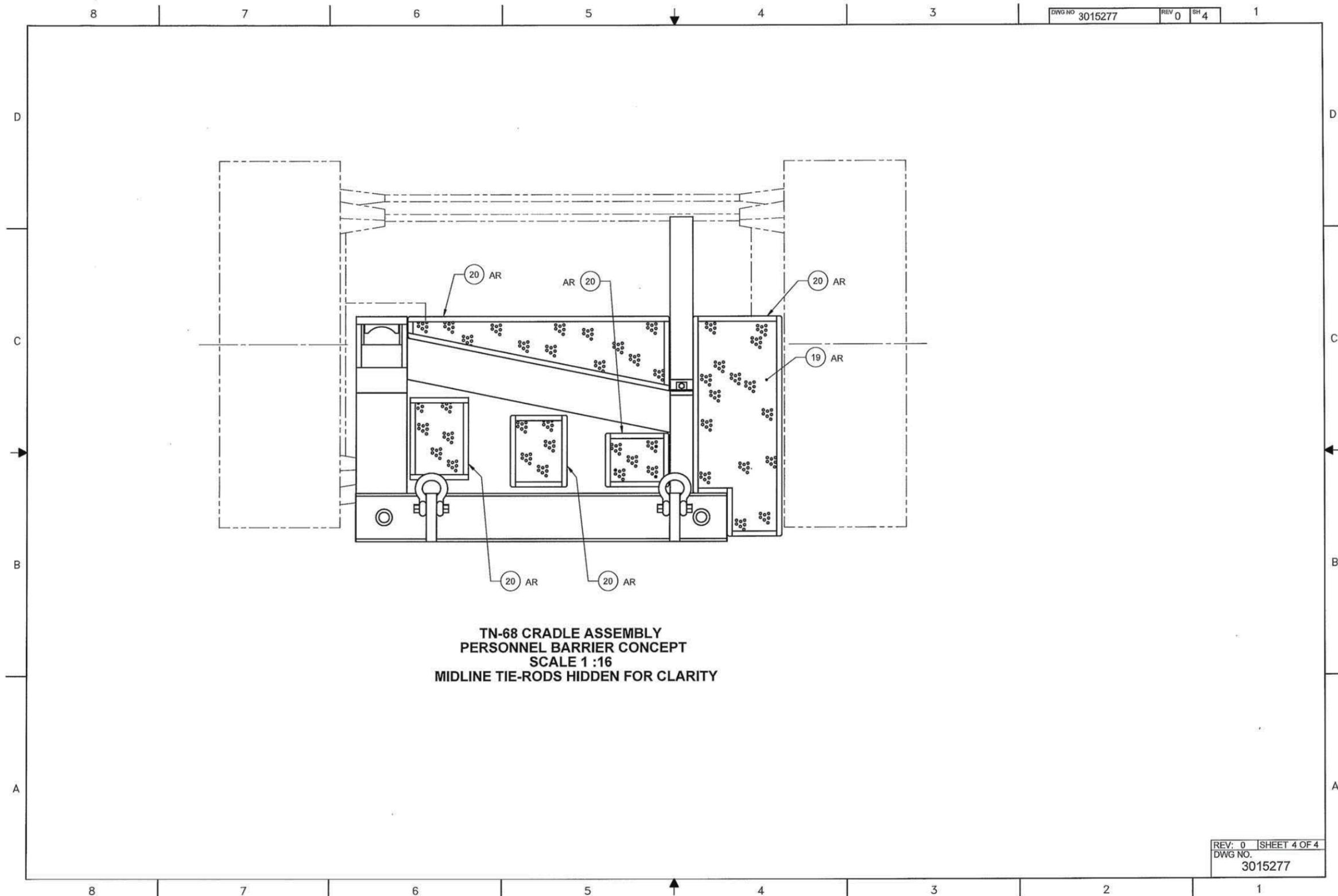
		<small>UNLESS OTHERWISE SPECIFIED: INTERPRET DRAWINGS &amp; TOLERANCES PER ASME Y14.5-2009 (REVISION OF ASME Y14.5M-1994) INTERPRET WELD CALLOUTS PER ANSI/AWS A2.4 DIMENSIONS ARE IN INCHES</small>	
<small>SCALE: SHOWN WT. -</small> <small>REV: 0 SHEET 1 OF 4</small> <small>DWG DWG NO. 3015277</small> <small>SIZE D CADFILE: 3015277.BLDORW</small>		<small>AREVA Federal Services LLC Packaging Projects Federal Way, WA 98003</small> <b>DWG TITLE</b> ATLAS RAILCAR CRADLE FAMILY 2 (TN-68) CONCEPTUAL DRAWING	



DWG-3015277-000  
 Page 3 of 4

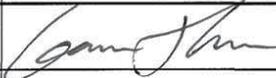


DWG-3015277-000  
Page 4 of 4



## Appendix A.2.2 – Structural Calculation

CALC-3015134-000  
Page 1 of 56

	AREVA Federal Services LLC		
	CALCULATION		
Document No.:	CALC-3015134	Rev. No.	000 Page 1 of 56
Project No.:	00225.03.0050	Project Name:	DOE Atlas Railcar
Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation			
<p><b>Summary:</b></p> <p>This document contains the structural sizing of the cask cradle concept designed for rail transport of the NAC International (NAC) MAGNATRAN<sup>®</sup>, NAC-STC<sup>™</sup>, and NAC-UMS<sup>™</sup> packages, as well as the AREVA TN-68 cask. Additional design details are asserted in this calculation since this is structural <u>sizing</u> calculation.</p> <p>This document is not safety related.</p>			
<p><b>Contains Unverified Input / Assumptions:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/></p>			
<p>Software Utilized: None</p> <p>Software Active in AFS EASI: Yes: <input type="checkbox"/> No: <input type="checkbox"/></p> <p>Error Reports &amp; Associated Corrective Actions Reviewed: Yes: <input type="checkbox"/> No: <input type="checkbox"/></p>		<p>Version: NA</p>	<p>Storage Media: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/></p> <p>Location: NA</p>
	Printed Name	Signature	Date
Preparer:	Gannon Johnson		6/29/16
Checker:	Scott Bear		6/29/16
Approver:	Donald Hillstrom		6/29/16
Other:	Slade Klein		6/29/16

AFS-EN-FRM-002 Rev. 07 (Effective April 21, 2015)  
Reference: AFS-EN-PRC-002

**AREVA**  
**June 30, 2016**  
**Records Management**

CALC-3015134-000  
Page 2 of 56



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 2 of 56**

**Revision History**

Rev.	Changes
0	Initial Release



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

**Table of Contents**

	<b>Page</b>
REVISION HISTORY .....	2
LIST OF TABLES .....	4
LIST OF FIGURES .....	4
1.0 PURPOSE .....	5
1.1 Project Background .....	5
1.2 Calculation Introduction .....	5
1.3 Cradle Concept Introduction .....	6
2.0 GENERAL METHODOLOGY .....	7
3.0 ASSUMPTIONS .....	7
3.1 Unverified Inputs and Assumptions .....	7
3.2 Justified Assumptions .....	7
4.0 DESIGN INPUTS .....	8
4.1 Conceptual Design Geometry .....	8
4.2 Design Loads .....	8
4.3 Material Properties .....	8
4.4 Package Data .....	9
5.0 CALCULATIONS .....	10
5.1 Loads Applied to the Atlas Railcar Interface .....	10
5.2 Loads Applied to the Cradle Interface Points .....	14
5.3 Structural Member and Weld Stress .....	15
6.0 RESULTS AND CONCLUSIONS .....	29
6.1 Railcar Interface Loading Summary .....	29
6.2 Concept Design Summary .....	29
6.3 Literature Search and other Background Data .....	29
7.0 REFERENCES .....	29
APPENDIX A : CRADLE CROSS SECTION DATA .....	32
APPENDIX B : CRADLE WEIGHT AND CENTER OF GRAVITY ESTIMATE .....	38



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

**List of Tables**

	<b>Page</b>
Table 4-1: Material Properties.....	8
Table 4-2: NAC Magnatran® Package Data.....	9
Table 4-3: NAC-STC™ Package Data.....	9
Table 4-4: NAC-UMS™ Package Data.....	10
Table 4-5: TN-68 Package Data.....	10
Table 5-1: Longitudinal Loading Input Values.....	12
Table 5-2: Railcar Interface Loading from +7.5g Longitudinal Load.....	12
Table 5-3: Railcar Interface Loading from ±2g Vertical Load.....	12
Table 5-4: Railcar Interface Loading from +2g Lateral Load.....	14
Table 6-1: Railcar Tie-down Loads.....	29
Table B-1: NAC Cradle Component Weight Summary.....	45
Table B-2: NAC Package and Cradle Combined Weight and CG Values.....	46
Table B-3: TN-68 Cradle Component Weight Summary.....	55
Table B-4: TN-68 Package and Cradle Combined Weight and CG Values.....	56

**List of Figures**

	<b>Page</b>
Figure 1-1: Magnatran® Cradle Concept Major Features.....	6
Figure 1-2: NAC-STC™ & NAC-UMS™ Cradle Concept Major Features.....	6
Figure 1-3: TN-68 Cradle Concept.....	7
Figure 5-1: Longitudinal Loading (Side View).....	11
Figure 5-2: Lateral Load Free Body Diagram (Top View).....	13
Figure 5-3: Lateral Load (Front View).....	13
Figure 5-4: Cradle Frames Side View (TN-68 Left & Magnatran® Right).....	15
Figure 5-5: TN-68 Trunnion Tower Section of Interest.....	19
Figure 5-6: NAC Cradle Front Saddle (Magnatran®) Cross-Section.....	20
Figure 5-7: Front Saddle Fastener Free Body Diagram for Longitudinal Load.....	22
Figure 5-8: Magnatran® Cradle Front Strap Tension Mechanism Concept (Front View).....	23
Figure 5-9: Shear Key Mid-Plane Cross Section.....	24
Figure 5-10: I-Beam to 3 inch Plate Weld Connection.....	24
Figure 5-11: NAC Cradle Lift Lug.....	25
Figure 5-12: TN-68 Cradle Lift Lug.....	26
Figure 5-13: TN-68 Cradle Front Saddle Beam Approximation for Lifting.....	28



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 5 of 56

**1.0 PURPOSE**

**1.1 Project Background**

The United States Department of Energy (DOE) is laying the groundwork for implementing an integrated nuclear waste management system. This includes preparing for future large-scale transport of spent nuclear fuel (SNF), high-level radioactive waste (HLW), and Greater-Than-Class-C (GTCC) waste; since transport will be a necessary component of any integrated nuclear waste management system. With this project the DOE will provide for the transportation of SNF (GTCC is transported similarly to SNF) and HLW by means of a specific railcar to carry SNF and HLW packages.

As part of this project, DOE has contracted with AREVA Federal Services (AFS) to design a single standardized railcar tie-down interface, and transport package cradle concepts for the 15 HLW transport packages (herein referred to as “packages”) listed in Attachment A of the Statement of Work [1].

AFS has chosen to divide the 15 packages into 4 groups based on the cask tie-down methods. These four groups are called as “families” herein, and are described in the following:

- Family 1 Packages with no shear keys and that are supported axially on the ends of the impact limiters. The packages may rest on a single or multiple saddles with straps restraining vertical movement. Packages included in this family are the TN-32, TN-40, TN-40HT, HI-STAR 60, HI-STAR 100, HI-STAR-100HB, and the HI-STAR 180.
- Family 2 Packages that are restrained axially and vertically by their lower trunnions (or pocket trunnions in some cases). Packages included in this family are the MAGNATRAN<sup>®</sup>, NAC-STC<sup>™</sup>, NAC-UMS<sup>™</sup>, and the TN-68.
- Family 3 Packages with an integral shear key. Packages included in this family are the MP-197, MP-197HB, and the TS-125.
- Family 4 Packages with an integral shear key. The cask rests on multiple saddles with a frame restraining vertical movement. The only package in this family is the MP-187.

**1.2 Calculation Introduction**

This calculation provides the preliminary structural evaluation for the Atlas Family 2 cradles as a proof-of-concept. These preliminary structural evaluations include the following:

- Railcar interface structural loads from the AAR Rule 88 accelerations (see Section 5.1)
- Stresses in the primary structural members and welds of the conceptual cradles from the AAR Rule 88 accelerations (see Section 5.3)
- Weight and center-of-gravity (cg) estimations (see Appendix B)

The railcar tie-down interface (including attachment pins) is detailed in drawing [2] and is analyzed in calculation [3] for the maximum interface structural loads calculated for each family.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 6 of 56

**1.3 Cradle Concept Introduction**

The NAC International (herein referred to as NAC) cradles use the same basic design configuration for each cask as described in Figure 1-1 and Figure 1-2. Personnel barrier components are not shown.

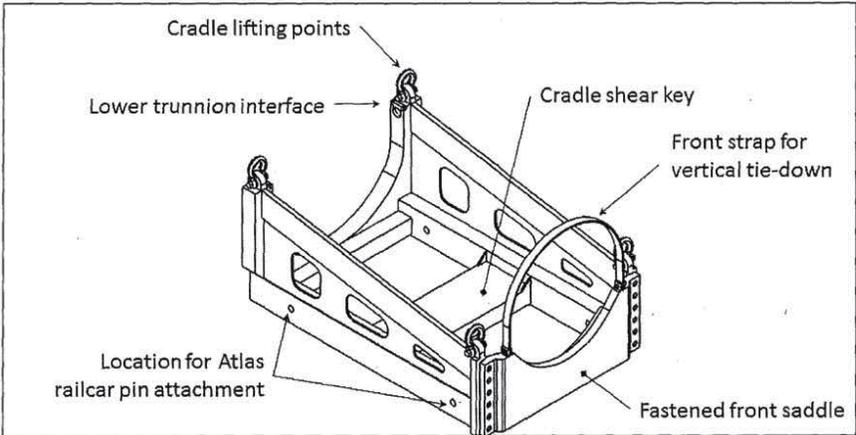


Figure 1-1: Magnatran® Cradle Concept Major Features

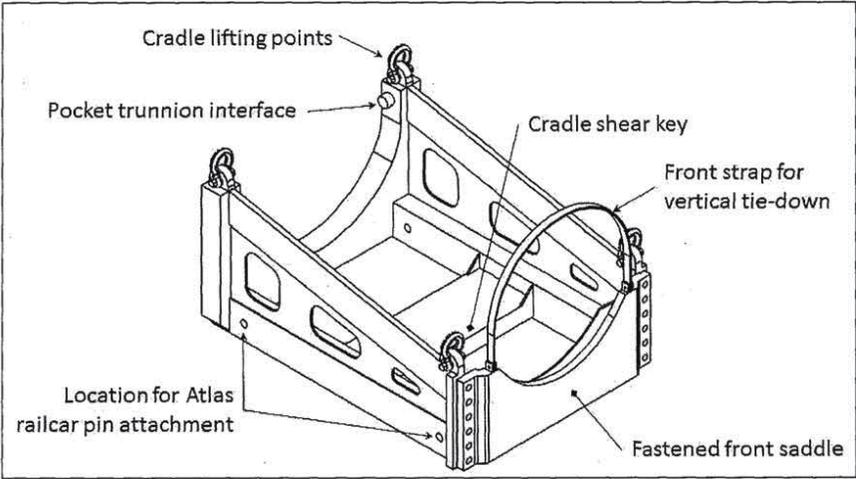


Figure 1-2: NAC-STC™ & NAC-UMS™ Cradle Concept Major Features



**AREVA Federal Services LLC**

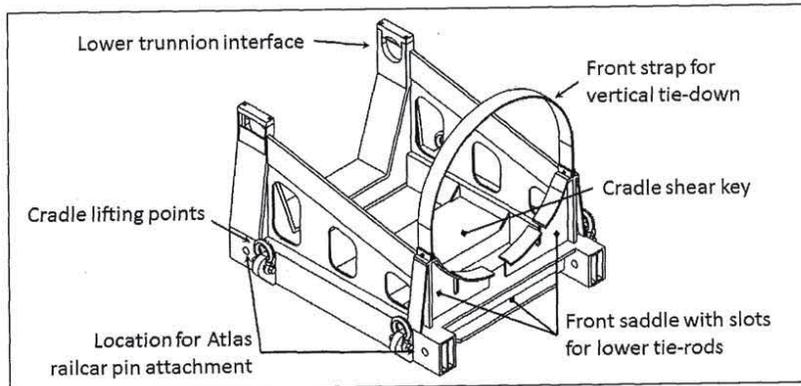
Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 7 of 56

The TN-68 has a similar design to the NAC cradles, but with a different trunnion tower and front saddle design. These were changed to accommodate the slightly different tie-down methodology. This design is presented in Figure 1-3 without personnel barrier components.



**Figure 1-3: TN-68 Cradle Concept**

All the cradle concepts are approximately 150 to 190 inches long and 80 to 90 inches tall. The nominal cradle weight varies between 27,000 lb. and 42,000 lb (see Appendix B).

**2.0 GENERAL METHODOLOGY**

This calculation uses first principle manual calculations to evaluate/size the *primary* structural members on the package cradle concepts. Cradle structural components and welds are sized such that the minimum margin of safety is +.20 to the material yield strength for the AAR loadings (see Section 4.2).

This calculation evaluates the conceptual design described in drawings [4] and [5]. Additional design detail is asserted in this calculation using figures since this is a structural *sizing* calculation for a conceptual design. Certain design details are also omitted until a detailed design of the cradles is required.

The lifting criteria applied to the cradle will conservatively be in accordance with ANSI N14.6 [6].

Stress allowables are defined where they are used, and the definition of “margin of safety” used herein is:

$$MS = \frac{\text{stress allowable}}{\text{calculated stress}} - 1$$

**3.0 ASSUMPTIONS**

**3.1 Unverified Inputs and Assumptions**

There are no unverified inputs or assumptions in this conceptual sizing calculation.

**3.2 Justified Assumptions**

1. Weld metal is conservatively assumed to have at least the strength of the adjoining base metal.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 8 of 56**

2. All weld joints, unless specified otherwise are equivalent to complete joint penetration welds.
3. Assumptions/Simplifications made for hand-calculations are asserted at various locations in Section 5.0 as required.
4. This calculation only considers nominal dimensions since this is only conceptual sizing.

**4.0 DESIGN INPUTS**

**4.1 Conceptual Design Geometry**

The conceptual cradle design geometry is presented in figures in Section 5.0 with the dimensions as required by the individual structural evaluation.

**4.2 Design Loads**

According to AAR Rule 88 the tie-down system for any payload carrying HLW on a railroad must not exceed the material yield strength when undergoing the following accelerations individually (see Section 2.2.2 and Section 2.5 of the Design Basis Requirements Document [7]):

- $a_x = \pm 7.5g$  longitudinal
- $a_z = \pm 2g$  vertical
- $a_y = \pm 2g$  lateral

All analyses herein shall only apply the inertial loads above and neglect the effects of gravity [7].

**4.3 Material Properties**

The following materials are conceptually used on the Atlas Family 2 Cradle. The density of steel and aluminum used for all weight estimates herein is 0.28 and 0.1 lb/in<sup>3</sup>, respectively. Weld metal is conservatively assumed to have at least the strength of the adjoining base metal. The material strength properties for the materials specified in drawings [4] and [5] are shown in Table 4-1.

**Table 4-1: Material Properties**

Material	Yield Strength (ksi)	Tensile Strength (ksi)
ASTM A992 [8], A572 Grade 50 [9]	50	65
ASTM A350, Grade LF6, Class 1 or Class 2 [30]	52	66
ASTM A732, Grade 10Q [10]	145	180
ASTM A434, Class BD [11], Oil quench 815°C (1500°F), Temper 540°C (1000°F)	135 <sup>(1)</sup>	150 <sup>(1)</sup>
ASTM A574 <sup>(2)</sup> [13]	135	170
ASTM A490, Type 1 [14]	130	150

Note(s): (1) These minimum strength values are readily achievable for 6 and 8 inch round bars with the specified heat treatment based on Tables 8 & 9 of [12].  
 (2) These material values are for a 2.25 inch diameter SHCS



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 9 of 56

Room temperature properties are used for the proof-of-concept calculations herein. Other materials could be used that have similar properties in the final design as desired.

**4.4 Package Data**

The following tables contain the package data that supports this calculation. It should be noted that the values are referenced in the horizontal transport configuration.

**Table 4-2: NAC Magnatran® Package Data**

Parameter	Value	Reference
Max. gross weight	312 kips	Table 2.12.2-1 of [15]
Center of gravity measured from cask bottom	102 to 108 in.	Figure 2.5.2-1 of [15]
Distance from lower trunnions to bottom of cask	17.7 in.	Figure 2.5.2-1 of [15]
Lower trunnion vertical offset from centerline	5.14 in.	Figure 2.5.2-1 of [15]
Vertical distance to centroid of front shear key reaction	39.39 in.	Section 2.5.2.1.3 of [15]
Distance between lower trunnions and front saddle	177.5 in.	$93.2 + 84.3 = 177.5$ from Figure 2.5.2-1 of [15]
Lower trunnion diameter	6 inches	Section 2.5.2.2.4 of [15]
Lower trunnion height	2.5 inches	Scaled from SAR drawing 71160-502, Rev 3NP in [16]

**Table 4-3: NAC-STC™ Package Data**

Parameter	Value	Reference
Max. gross weight	254.6 kips	Table 2.2-5 of [17]
Center of gravity measured from cask bottom	96 to 99 in.	Section 2.2 of [17]
Distance from lower trunnions to bottom of cask	18.15 in.	Section 2.5.2.2 of [17]
Lower trunnion vertical offset from centerline	3 in.	Figure 2.5.2-2 of [17]
Vertical distance to centroid of front shear key reaction	34.31 in.	Figure 2.5.2-1 of [17]
Distance between lower trunnions and front saddle	159.6 in.	$80.90 + 78.65 = 159.6$ from SAR Figure 2.5.2-1 of [17]
Lower trunnion diameter	6 in.	Section 2.5.2 of [17]
Lower trunnion pocket engagement	3.88 in.	Section 2.5.2.2.3 of [17]



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 10 of 56

**Table 4-4: NAC-UMS™ Package Data**

Parameter	Value	Reference
Max. gross weight	256 kips	Section 5.(a)(2) of [18]
Center of gravity measured from cask bottom	106 to 108.5 in.	Section 2.2 of [19]
Distance from lower trunnions to bottom of cask	17.6 in.	SAR Drawing 790-502 Rev 7 in [20]
Lower trunnion vertical offset from centerline	3 in.	SAR Drawing 790-502 Rev 7 in [20]
Vertical distance to centroid of front shear key reaction	33.98	Figure 2.5.2.1-2 of [19]
Distance between lower trunnions and front saddle	176.4 in.	Figure 2.5.2.1-1 of [19]
Lower trunnion diameter	8 in.	Section 2.5.2.2.1 of [19]
Lower trunnion pocket engagement	3.61 in.	Section 2.5.2.2.1 of [19]

**Table 4-5: TN-68 Package Data**

Parameter	Value	Reference
Max. gross weight	272 kips	Section 5.(a)(2) of [21]
Center of gravity measured from cask bottom	97 in.	Section 2.2 of [22]
Distance from lower trunnions to bottom of cask	27.4 in.	$13.25 + 160 - 145.84 = 27.41$ from SAR Drawing 972-71-2, Rev 2 in [22]
Lower trunnion vertical offset from centerline	0 in.	Drawing 972-71-1, Rev 1 [22]
Distance between lower trunnions and centerline of front saddle	118.25 in.	Figure 2.10.1-13 of [22]
Lower trunnion diameter	14.0 in.	Drawing 972-71-3, Rev 4 in [22]
Lower trunnion height	4 in.	Drawing 972-71-3, Rev 4 in [22]

**5.0 CALCULATIONS**

**5.1 Loads Applied to the Atlas Railcar Interface**

This section calculates the loads on the Atlas railcar and railcar-cradle interface from the inertial loads described in Section 4.2. The longitudinal loading is reacted by a shear key on the deck of the rail car at the center of the cradle; it is precluded from being reacted against the four pins by using horizontal slotted holes in the pin attachment blocks. The tipping moment created by the vertical offset of the cg from the reaction point is resisted by the four pins as shown in Figure 5-1 in the vertical direction.



AREVA Federal Services LLC

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 11 of 56

It should be noted that the reaction load vectors are assumed to be in the positive direction in the free-body-diagrams and equations of this subsection. This allows the coordinate system for the reaction loads applied to the railcar to be independent of the individual pin locations. Therefore, if the reaction value has a negative value, then it is oriented in the opposite direction shown in the following free body diagrams. It also should be noted that the reaction loads are relative to the cradle (i.e. the loads applied to the railcar will have an equal and opposite orientation to those calculated).

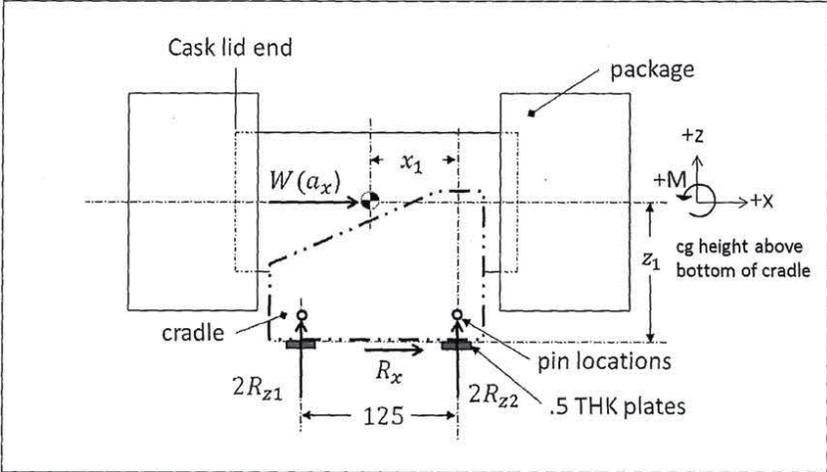


Figure 5-1: Longitudinal Loading (Side View)

The following equations are developed using basic principles. The moments from the loads and reactions are summed where the cradle contacts on the .5 inch thick plate located directly below Rz2 (see drawing [2]).

$$\sum F_x = W(a_x) + R_x = 0 \tag{Eqn. 5-1}$$

$$\sum M_{R2} = -W(a_x)(z_1) - 2(R_{z1})(125) = 0 \tag{Eqn. 5-2}$$

$$\sum F_y = 2R_{z1} + 2R_{z2} = 0 \tag{Eqn. 5-3}$$

where W is the combined weight of the package and the cradle, Rz1 & Rz2 are the reaction loads at each pin, and Rx is the reaction load on the shear key, and y1 is the vertical distance from the bottom of the cradle to the combined cg height from Table 5-1.

The weight and center of gravity (cg) inputs for each of the four packages are summarized in Table 5-1.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

**Table 5-1: Longitudinal Loading Input Values**

Packages	minimum cg distance to rear pins <sup>(1)</sup> , $x_1$ (in)	maximum cg distance to rear pins <sup>(1)</sup> , $x_1$ (in)	cg height from bottom of cradle <sup>(1)</sup> , $z_1$ (in)	package and cradle weight, $W^{(1)}$ (kips)
Magnatran <sup>®</sup>	57	65	62.5	354
NAC-STC <sup>™</sup>	60	66	61.5	297
NAG-UMS <sup>™</sup>	60	65	62.0	298
TN-68	67	69	73.0	299

Notes: (1) Combined package and cradle weights and centers of gravity values are from Appendix B.

Using the values in Table 5-1 in Equations 5-1 to 5-3, the results are as follows:

**Table 5-2: Railcar Interface Loading from +7.5g Longitudinal Load**

Packages	$R_{z1}$ (kips)	$R_{z2}$ (kips)	$R_x$ (kips)
Magnatran <sup>®</sup>	-664	664	-2,655
NAC-STC <sup>™</sup>	-548	548	-2,228
NAG-UMS <sup>™</sup>	-554	554	-2,235
TN-68	-655	655	-2,243

The -7.5g loading gives a symmetrical response with the load directions reversing from Table 5-2.

The vertical loads are assumed to be uniformly distributed over all four pins (per Section 2.5 of [7]). This simplification is appropriate because the combined cg is only offset from the center of the railcar attachment pins (spaced 125 inches part per [2]) by maximum of ±5 inches (see Table 5-1). The vertical reaction load at each pin ( $R_{z3}$ ) under this case is:

$$R_{z3} = \pm 2W / 4 \tag{Eqn. 5-4}$$

The vertical reaction loads using the weight values from Table 5-1 are presented in Table 5-3.

**Table 5-3: Railcar Interface Loading from ±2g Vertical Load**

Packages	$R_{z3}$ (kips)
Magnatran <sup>®</sup>	±177
NAC-STC <sup>™</sup>	±149
NAG-UMS <sup>™</sup>	±149
TN-68	±150



AREVA Federal Services LLC

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 13 of 56

The lateral loads are reacted by the pin retainer blocks as shown in Figure 5-2. The tipping moment created by the vertical offset of the cg to the lateral reactions,  $R_{y1}$  &  $R_{y2}$ , is reacted by the two pins furthest away from the pivot edge as shown in Figure 5-3. For conservatism the lateral reaction loads are placed at the bottom of the cradle.

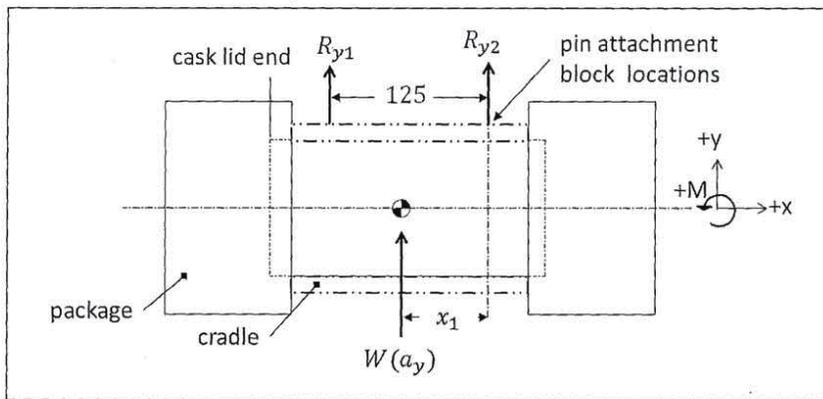


Figure 5-2: Lateral Load Free Body Diagram (Top View)

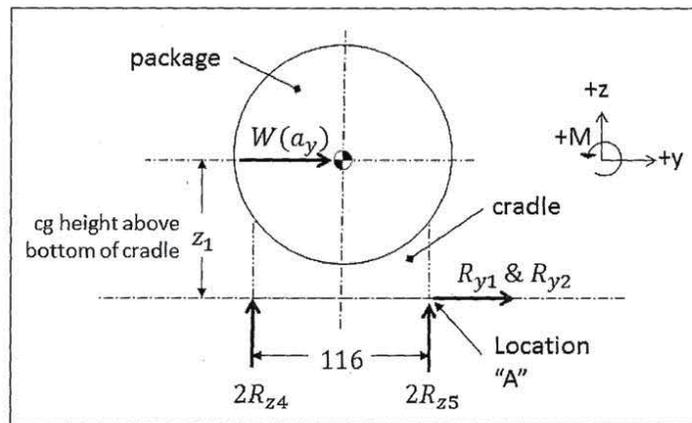


Figure 5-3: Lateral Load (Front View)



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 14 of 56**

The equations to solve for the lateral reaction loads, Ry1 and Ry2, are as follows:

$$\sum F_y = W(a_y) + R_{y1} + R_{y2} = 0 \quad \text{Eqn. 5-5}$$

$$\sum M_{Ry2} = -W(a_y)(x_1) - 125R_{y1} = 0 \quad \text{Eqn. 5-6}$$

The vertical pin reactions due to the lateral load, Rz4 & Rz5, are calculated using the following two equations:

$$\sum F_z = 2R_{z4} + 2R_{z5} = 0 \quad \text{Eqn. 5-7}$$

$$\sum M_A = -W(a_y)(z_1) - 2R_{z4}(116) = 0 \quad \text{Eqn. 5-8}$$

Using the values in Table 5-1 in Equations 5-5 to 5-8, the results are as follows:

**Table 5-4: Railcar Interface Loading from +2g Lateral Load**

Packages	R <sub>y1</sub> (kips)		R <sub>y2</sub> (kips)		R <sub>z4</sub> (kips)	R <sub>z5</sub> (kips)
	min x <sub>1</sub>	max x <sub>1</sub>	min x <sub>1</sub>	max x <sub>1</sub>		
Magnatran®	-323	-368	-385	-340	191	-191
NAC-STC™	-285	-314	-309	-280	157	-157
NAG-UMST™	-286	-310	-310	-286	159	-159
TN-68	-321	-330	-277	-268	188	-188

The maximum loads applied to the railcar interface are summarized in Section 6.1.

**5.2 Loads Applied to the Cradle Interface Points**

The cradles restrain the packages in the vertical and lateral directions by a combination of the lower trunnions, front saddle, and a strap over the top of the cask at the front saddle location (as shown in Section 1.3).

Instead of calculating the reaction loads under each load case, a simplified approach is taken since this is a proof-of-concept calculation. The center of gravity is assumed centered on the package tie-downs. Thus, the vertical and lateral loads are shared equally between the front saddle and rear trunnion(s). This approximation is valid since the tie-down points are close to being centered around the cask cg.

The TN-68 longitudinal loads are reacted entirely by the two trunnion towers. The NAC +7.5g longitudinal load is reacted by the front saddle, which the -7.5g longitudinal load is reacted by the trunnion towers.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 15 of 56

Also, the saddle/strap loads on NAC packages due to the small vertical offset of the lower trunnions (see Tables 4-2 through 4-4) from the package centerline during the  $\pm 7.5g$  longitudinal loading are neglected. These loads are minor compared to the vertical  $\pm 2g$  load on those components.

**5.3 Structural Member and Weld Stress**

The following structural members are analyzed for the highest applied load:

- Cradle Frame (see Section 5.3.1)
- NAC Trunnion Towers (see Section 5.3.2)
- TN-68 Trunnion Towers (see Section 5.3.3)
- NAC Front Saddle (see Section 5.3.4)
- Front Strap (See Section 5.3.5)
- Shear Key Weld (See Section 5.3.6)
- NAC Lifting Evaluation (5.3.7)
- TN-68 Lifting Evaluation (5.3.8)

Other members/loadings are not considered to be relevant to the current proof-of-concept phase of the project.

**5.3.1 Frame Analysis**

The frame on the cradles is sized to resist the longitudinal load by using gussets to support the trunnion towers and front saddles. The frame also resists the bending induced by the vertical loads being offset from the railcar connection pins. See Figure 5-4:

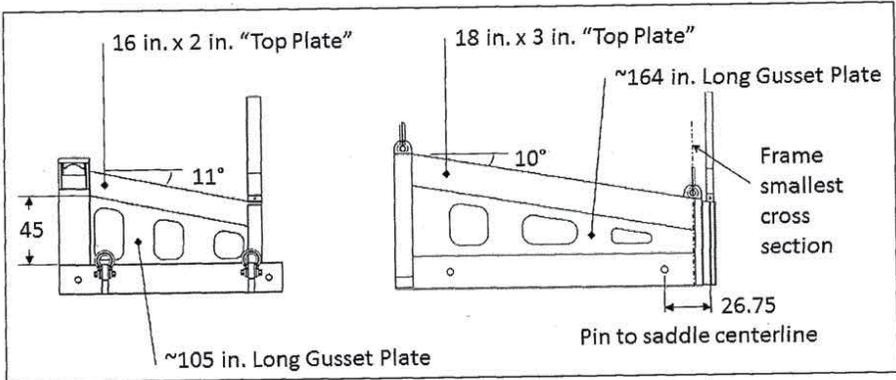


Figure 5-4: Cradle Frames Side View (TN-68 Left & Magnatran® Right)



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 16 of 56**

Longitudinal Load

The longitudinal load, when oriented towards the cask bottom, is reacted at the trunnion towers. The frame is anticipated to respond more like a truss system than a beam under this loading. Thus, the top plate and gussets are analyzed herein for their ability to transfer the load to the robust lower I-beams.

The bounding geometry in Family 2 is for the TN-68 cradle. This cradle has a 16 in. x 2 in. top plate that supports the trunnion tower (the NAC cradles have an 18 in. x 3 in. top plate). The average stress on the cross section in Figure 5-4 is:

$$\sigma = \frac{7.5(272)/\cos(11^\circ)}{2(16 \times 2)} = 32.5 \text{ ksi}$$

where the 7.5 load is per Section 4.2, the 272 kip TN-68 weight is per Table 4-5, and the top beam orientation is 11 degrees downward from the horizontal per Figure 5-4.

This part is made from ASTM A572, Grade 50 material. The margin of safety using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{50}{32.5} - 1 = +.54$$

The load is transferred from the top plate through a 1 inch gusset to the I-beam structure underneath. The limiting weld is the one connecting the gusset to the I-beam. Since the TN-68 cradle is the shortest for the Family 2 cradles, it has the highest load per linear inch of gusset. The effective weld length neglects welds beneath the access/lightening holes (holes are limited to 50% of the 105 inch length in Figure 5-4). The average shear stress, assuming a full penetration weld to the thinner 1 inch thick gusset see drawing [4]), is:

$$\tau = \frac{7.5(272)}{(2)(.5 \times 105)(1)} = 19.4 \text{ ksi}$$

where the 7.5 load is per Section 4.2, the 272 kip TN-68 weight is per Table 4-5.

This part is made from ASTM A572 or A992, Grade 50 material. The margin of safety using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{.6(50)}{19.4} - 1 = +.55$$

The gusset plate itself is placed in pure shear. This plate is evaluated for buckling under a pure shear load using Table 3 in Section 2.12(3) of Blodgett [27]. The plate length above and below the cutouts is neglected. The cutouts shall not exceed 50 percent of the overall length (b) as stated above. The two constants for the Blodgett case are:

$$\alpha = \frac{a}{b} = \frac{.5 \times 105}{45} = 1.16$$

$$k = \sqrt{3} \left( 5.34 + \frac{4}{\alpha^2} \right) = 14.4$$

where the plate height is conservatively the 45 inch height per Figure 5-4.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 17 of 56**

The critical buckling stress is:

$$\sigma_{cr} = \frac{\sqrt{3}k\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2 = 245 \text{ ksi}$$

where the elastic modulus of steel ( $E$ ) is 30,000 ksi, the Poisson's ratio of steel ( $\nu$ ) is .3, and the thickness of the plate is 1 inch. The critical buckling shear stress is:

$$\tau_{cr} = \frac{\sigma_{cr}}{\sqrt{3}} = 141 \text{ ksi}$$

The margin of safety using the stress in the welds (since they are full penetration) is:

$$MS = \frac{141}{19.6} - 1 = +6.1$$

Vertical Load

The worst case bending in the frame due to the vertical load is in the Magnatran<sup>®</sup> cradle. The saddle of that cradle takes half of the 2g vertical load and is cantilevered out 26.75 inches. Conservatively, the smallest cross section of the Magnatran<sup>®</sup> cradle is evaluated (see Figure 5-4). This cross section has a moment of inertia of 76,449 in<sup>4</sup> in the bending axis of interest (See Appendix A.1). The bending stress in that cross section is:

$$\sigma = \frac{(.5)(2)(312) \times 26.75 \times (50.2 - 21.8)}{76,449} = 3 \text{ ksi}$$

where the 2g vertical load is per Section 4.2, the 312 kip Magnatran<sup>®</sup> weight is per Table 4-2, the section height is 50.2 inches, and the section centroid is 21.8 inches above the bottom of the section (per Appendix A.1).

The margin of safety using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{50}{3} - 1 = +15.7$$

The vertical load will also place the connecting welds holding the 4 inch thick bolt plate to the frame in shear. Since the conservative evaluation above has a high margin of safety, a suitable weld pattern can easily be designed to carry the load in a final design.

**5.3.2 NAC Trunnion Towers**

The NAC trunnion towers are sized to resist the longitudinal load toward the bottom of the cask, the lateral and vertical loads.

Longitudinal Load

The trunnion tower is supported for the longitudinal load by the frame as stated in Section 5.3.1. However, it also creates torsion in the tower due the lower trunnion load being cantilevered out several inches (see Figure I-2). The worst case for this is the NAC-STC<sup>™</sup>. This tower is 12.6 inches deep, 14 inches wide, and has a 6 inch round bar cantilevered out 4.38 inches to engage the NAC-STC<sup>™</sup> trunnion pockets.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 18 of 56**

The 7.5g load is shared equally on the two round bars. The maximum shear at the center of the 6 inch round bar is:

$$\tau = \frac{4V}{3A} = \frac{(4)(0.5)(7.5)(254.6)}{(3)(\pi/4(6^2))} = 45.1 \text{ ksi}$$

where the 254.6 kip NAC-STC™ weight is per Table 4-3. The round bar is a heat treated A434, Class BD material with a minimum yield strength of 135 ksi (see Table 4-1). The margin of safety is:

$$MS = \frac{.6(135)}{45.1} - 1 = +.80$$

Each round bar engages 3.88 inches into the trunnion pocket (see Table 4-3). The bending stress at the outer surface of the bar is:

$$\sigma = \frac{(.5)(7.5)(254.6)(4.38 - 3.88/2) \times (6/2)}{\pi(6)^4/64} = 109.9 \text{ ksi}$$

where the 254.6 kip NAC-STC™ weight is per Table 4-3. The round bar is a heat treated A434, Class BD material with a minimum yield strength of 135 ksi (see Table 4-1). The margin of safety is:

$$MS = \frac{135}{109.9} - 1 = +.23$$

The tower structure is made from 2 inch plate. The cross section has the following torsional stress:

$$\tau = \frac{(.5)(7.5)(254.6) \left( \frac{12.6}{2} + 4.38 - \frac{3.88}{2} \right) \times \sqrt{\left( \frac{12.6}{2} \right)^2 + \left( \frac{14}{2} \right)^2}}{3,602} = 23.9 \text{ ksi}$$

where the 254.6 kip NAC-STC™ weight is per Table 4-3, the trunnion tower is 12.6 inches deep, 14 inches wide, and the polar moment of inertia is 3,602 inches<sup>4</sup> per Appendix A.2.

The margin of safety using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{.6(50)}{23.9} - 1 = +.26$$

Lateral Load

The worst case for the lateral load is the Magnatran®. This package has the highest weight and a similarly sized tower to the NAC-STC™ cask at 13.5 inches deep and 10 inches wide. The ±2g lateral load will be shared equally by one trunnion tower and the front saddle. The worst cross section for bending in the vertical part of the tower is 21 inches below the trunnion towers (see Appendix A.3). This is the distance at which the trunnion tower cross-section rapidly begins to increase.

The bending in the cross section is:

$$\sigma = \frac{(312)(21)(13.5/2)}{1,622} = 27.3 \text{ ksi}$$

where 312 kips is half the +2g load on the 312 kip Magnatran® weight in Table 5-1, and the moment of inertia is 1,622 in<sup>4</sup> per Appendix A.3.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 19 of 56

The margin of safety using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{50}{27.3} - 1 = +.83$$

Vertical Loads

The vertical load will cause bending and compression in the tower. This will be bounding in the NAC-STC™ tower due to the extent of the eccentric loading and smaller cross section.

The compression in the tower is:

$$\sigma = \frac{254.6}{90.5} = 2.8 \text{ ksi}$$

where 254.6 is half of the +2g load on the NAC-STC™ weight in Table 4-3, and the 90.5 area is from Appendix A.2.

The bending stress is:

$$\sigma_b = \frac{(254.6) \left( \frac{12.6}{2} + 4.38 - \frac{3.88}{2} \right) \left( \frac{12.6}{2} \right)}{1,813} = 7.7 \text{ ksi}$$

where 254.6 is half of the +2g load on the NAC-STC™ weight in Table 4-3, and the 1,813 inch<sup>4</sup> moment of inertia is from Appendix A.2.

The margin of safety on the combined stress using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{50}{2.8 + 7.7} - 1 = +4.8$$

**5.3.3 TN-68 Trunnion Towers**

The TN-68 tower has a much different design due to the presence of the tie-rods which are at the same elevation as the cask trunnions. This requires a thinner, more inline trunnion tower (see Figure 5-5). Unlike the NAC cradle designs, this trunnion tower does not have any eccentric loading placed on it due to the package geometry. Therefore, the only loading of concern is the lateral 2g loading.

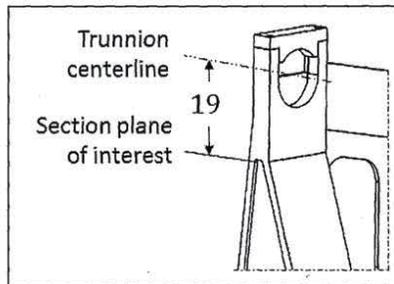


Figure 5-5: TN-68 Trunnion Tower Section of Interest



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 20 of 56

The smallest cross section of concern in the tower is at the base of the welded block 19 inches below the centerline of the trunnion as shown in Figure 5-5. The properties of this cross section are calculated in Appendix A.4. The bending stress in the cross section is:

$$\sigma = \frac{(272)(19)(6.5/2)}{434} = 38.7 \text{ ksi}$$

where 272 is half of the +2g load on the 272 kip TN-68 weight in Table 4-5, the 6.5 inch cross section height is per Appendix A.4, and the moment of inertia is 434 inch<sup>4</sup> per Appendix A.4.

This cross section is at the joint between the ASTM A350, grade LF6 forging and the ASTM A572 grade 50 plate. Using the lower 50 ksi yield strength from Table 4-1 for these two materials, the margin of safety is:

$$MS = \frac{50}{38.7} - 1 = +.29$$

**5.3.4 NAC Front Saddle**

Saddle Component

The Magnatran<sup>®</sup> front saddle is the bounding case for the inertial loads in Section 4.2. The concept for the NAC cradle saddles is a single cast part designed to clear the package neutron shield, impact limiter, and fins while engaging the package shear key (see Figure 5-6). The TN-68 front saddle is a different design, which has a structural response bounded by the lifting evaluation in Section 5.3.8.

The saddles that support the upper end of NAC packages are designed to act like a simply supported beam. The design accomplishes this by placing a groove on the two bolted faying surfaces along the center of the bolt pattern (pictured in Figure 5-6). This design also prevents prying loads on the screws.

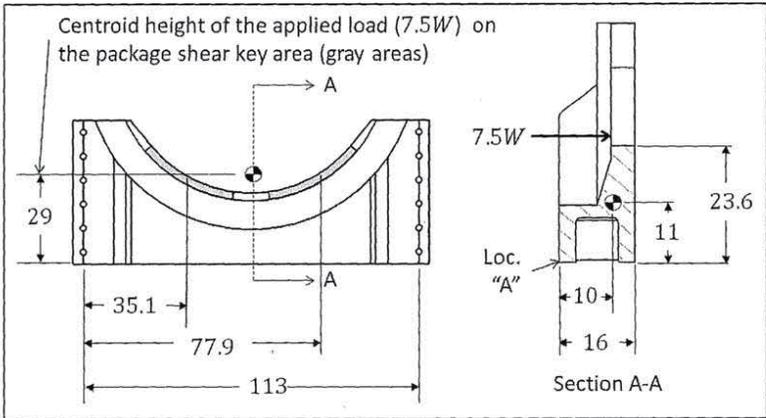


Figure 5-6: NAC Cradle Front Saddle (Magnatran<sup>®</sup>) Cross-Section



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 21 of 56**

The maximum shear in this “beam” is conservatively estimated using a 2.0 shape factor which is typically used for a thin walled beam section. The maximum shear near the center of the section is:

$$\tau = \frac{2V}{A} = \frac{(2)(0.5)(7.5)(312)}{177} = 13.2 \text{ ksi}$$

where the +7.5g load is per Section 4.2, the 312 kip weight is per Table 4-2, and the 177 inch cross section is per Appendix A.5.

The margin of safety, calculated using the 145 ksi yield strength of ASTM A732 Grade 10Q per Table 4-1, is:

$$MS = \frac{.6(145)}{13.2} - 1 = +5.6$$

The beam is loaded with two concentrated loads located 35.1 and 77.9 inches from the left side of the saddle as shown in Figure 5-6. Each of the two concentrated loads equals half of the 7.5g load. Using Beam Formula Case 2 in the Aluminum Design Manual [23], the maximum moment in the beam is:

$$M_{max} = 35.1(.5)(7.5)(312) = 41,067 \text{ kip} \cdot \text{in}$$

The maximum bending stress at the outer surface from this load is:

$$\sigma_b = \frac{41,067(16 - 6)}{4,664} = 88.1 \text{ ksi}$$

where the maximum distance to an outer surface from the centroid is 10 inches, and the moment of inertia is 4,664 in<sup>4</sup> per Appendix A.5.

The section will also be placed in torsion from the vertical offset of the section centroid from the applied load. The maximum torsional stress is the same location as the maximum bending stress at location ‘A’ on Figure 5-6. The distance from the cg to the point of interest is:

$$r = \sqrt{10^2 + 11^2} = 14.9 \text{ in.}$$

where the cg height is 11 inches and the maximum horizontal distance from the cg to a surface is 10 inches per Appendix A.5.

The torsional shear stress due to the applied load is:

$$\tau = \frac{(.5)(7.5)(312)(29 - 11)(14.9)}{11,354} = 27.6 \text{ ksi}$$

where the section centroid height is 11 inches, and polar moment of inertia is 11,354 in<sup>4</sup>. These values are calculated in Appendix A.5.

The maximum effective stress at the outer surface of the front saddle is:

$$\sigma_{eff} = \sqrt{(\sigma_b)^2 + 3\tau^2} = 100 \text{ ksi}$$

The margin of safety, calculated using the 145 ksi yield strength of ASTM A732 Grade 10Q per Table 4-1, is:

$$MS = \frac{145}{100} - 1 = +.45$$

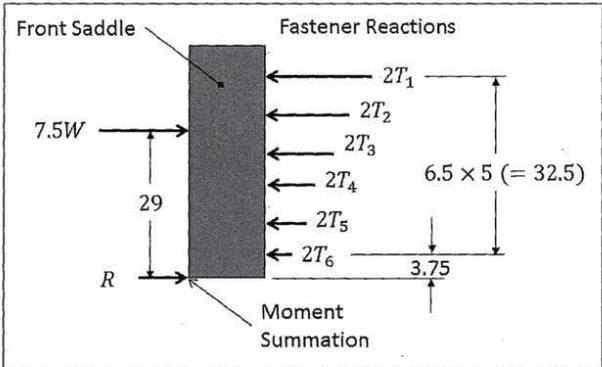


**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
 Doc./Rev.: CALC-3015134-000  
 Project: 00225.03.0050 - DOE Atlas Railcar

**Front Saddle Fasteners**

The saddle is bolted onto the cradle frame using twelve (12) 2.25-4.5UNC socket head cap screws (SHCS). Under the +7.5g longitudinal load, the saddle is assumed to pry around the bottom of the saddle as shown in Figure 5-7.



**Figure 5-7: Front Saddle Fastener Free Body Diagram for Longitudinal Load**

The bolt loads are calculated using the following equation for eccentric loads on a bolt pattern from Example 16-4 of [24]:

$$T_n = \frac{M d_n}{\sum d_k^2}$$

where  $M$  is the applied moment on the bolt pattern,  $d_n$  is the distance from the pivot to the bolt of interest, and  $d_k$  is the distance from the pivot point for each bolt in the pattern.

The bolt pattern starts 3.75 inches above the bottom of the saddle and has 6.5 inch spacing. Utilizing the equation above, the maximum tension load in the uppermost SHCS,  $T_1$ , is:

$$T_1 = \frac{(7.5)(312)(29) \times 36.25}{2(3.75^2 + 10.25^2 + 16.75^2 + 23.25^2 + 29.75^2 + 36.25^2)} = 391.8 \text{ kips}$$

The 2.25-4.5UNC SHCS have a tensile area 3.5 square inches per Table 2 of [13]. The average tensile stress in the fastener is:

$$\sigma = \frac{391.8}{3.5} = 111.9 \text{ ksi}$$

The margin of safety on the ASTM A574 SHCS is:

$$MS = \frac{135}{111.9} - 1 = +.21$$

where the 135 ksi yield strength is per Table 4-1.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

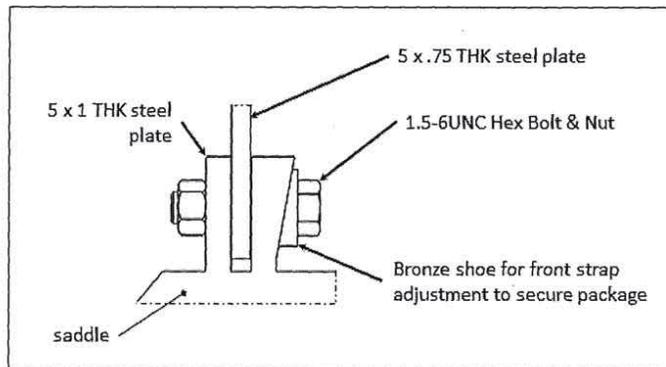
Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 23 of 56

**5.3.5 Front Strap**

The most limiting of the front strap designs in the Family 2 cradles is the Magnatran<sup>®</sup> design. The maximum load applied to the front strap is from the +2g vertical inertial load from Section 4.2. The front strap will react approximately half this load, while the two trunnion towers support the rest. The front strap on the Magnatran<sup>®</sup> is a .75 THK steel band that is 5 inches wide that is bolted onto the cradle. Two (2) 1.25-6UNC hex cap screws will tension the strap down onto the cradle to secure the package using an angled bronze shoe as shown in Figure 5-8.



**Figure 5-8: Magnatran<sup>®</sup> Cradle Front Strap Tension Mechanism Concept (Front View)**

The strap will act like a tension member over the top of the package. The tensile stress is:

$$\sigma = \frac{0.5(2)(312)}{(2)(.75)(5)} = 41.6 \text{ ksi}$$

The margin of safety using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{50}{41.6} - 1 = +.20$$

The 1.5-6UNC bolt has a tensile area of 1.405 inches (per Table 4 of [14]). The average shear stress in the two bolts, for a double shear configuration, is:

$$\tau = \frac{0.5(2)(312)}{2(2)(1.405)} = 55.5 \text{ ksi}$$

The margin of safety using the 130 ksi yield strength for ASTM A490 in Table 4-1 is:

$$MS = \frac{.6(130)}{55.5} - 1 = +.41$$

Additional design details of the front strap connection will be considered during the detail design.

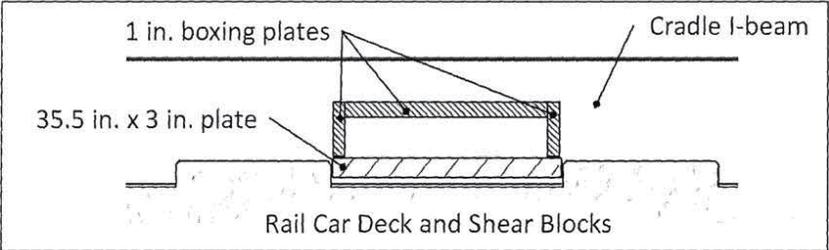


**AREVA Federal Services LLC**

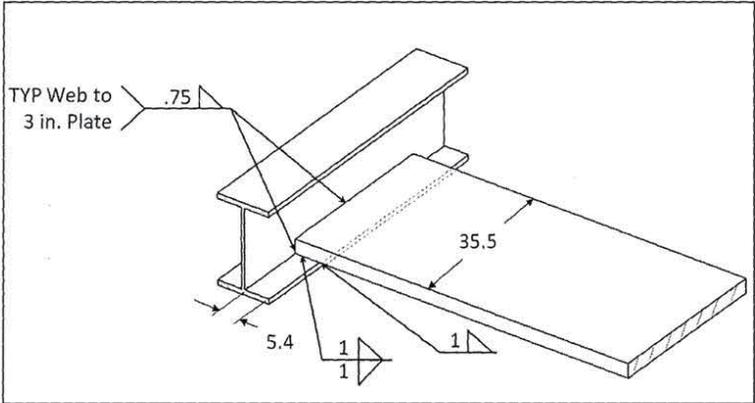
**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

**5.3.6 Shear Key Connection**

There is a 35.5 inch wide plate 3 inches thick at the bottom center of the cradle between the two I-beams. This plate rests between the two shear keys on the railcar (see cross Section in Figure 5-9). Since it is supported nearly full length by the two shear keys and is reinforced by a boxed section made from 1 inch plate, the only stress of interest is the average shear in the adjoining welds. Conservatively, only the welds connecting the 3 inch plate to the W19 I-beam are evaluated as shown in Figure 5-10.



**Figure 5-9: Shear Key Mid-Plane Cross Section**



**Figure 5-10: I-Beam to 3 inch Plate Weld Connection**

The maximum load will be from the Magnatran<sup>®</sup> package and cradle under the 7.5g inertial load specified in Section 4.2. The average shear stress in the weld group is:

$$\tau = \frac{(.5)7.5(356)}{(.707)(1)(35.5 + 2 \times 5.4) + (.707)(.75)(35.5 + 2 \times 3)} = 24.4 \text{ ksi}$$

where the combined package and cradle weight for the Magnatran<sup>®</sup> is 356 kips from Table 5-1, and the 35.5 inches is the plate width per Figures 5-9 and 5-10.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 25 of 56**

The margin of safety using the 50 ksi yield strength from Table 4-1 is:

$$MS = \frac{.6(50)}{24.4} - 1 = +.23$$

**5.3.7 NAC Lifting Evaluation**

Shackles and Lift Lugs

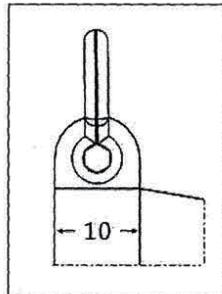
All the NAC package cradles use the same 4 point vertical lift design. The Magnatran<sup>®</sup> will be the bounding case due to the package's maximum gross weight. The rigging design shall be designed to distribute the package and cradle over all 4 lift points. The load per lift point in metric tons is:

$$F_{lift} = (1.15) \frac{356}{4} = 102.35 \text{ kips} = 46.4 \text{ t}$$

where the combined package and cradle weight for the Magnatran<sup>®</sup> is 356 kips from Table 5-1, and a dynamic load factor of 1.15 is applied per the specification for overhead traveling cranes published by the Crane Manufacturers Association of America [29].

A shackle with a work load of 55 metric tons will be adequate. For the conceptual design, a G-2130 Crosby shackle in [4] is used to size the attachment lugs. These shackles have a minimum ultimate strength of 6 times the working load limit and follow the latest revision of ASME B30.26 per the Crosby Group Online Catalog [25]. Therefore, these shackles are adequate to handle the required load.

The lift lugs are designed to fit the shackle. Thus, the bearing in the plate is not of concern. Following a general structural practice, the hole for the shackle is 2 times the pin diameter away from any edge. Thus, tensile and shear tear-out in the 4 inch thick lug are not of concern (see Section 16-2 of [24]).



**Figure 5-11: NAC Cradle Lift Lug**

The weld attaching the lifting lug to the structure is a 1.13 inch double sided fillet weld at least 10 inches in length. The shear in the weld is:

$$\tau = \frac{102.35}{2(.707)(1.13)(10)} = 6.4 \text{ ksi}$$

where 102.35 kips is the lifting force,  $F_{lift}$ , applied to the lift lug calculated above.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 26 of 56**

The margin of safety is calculated using the lesser of 1/3 yield and 1/5 ultimate in accordance with [6]. The material of the lug is the 50 ksi yield strength material from Table 4-1.

$$MS = \frac{.6 \times \min\left(\frac{50}{3}, \frac{65}{5}\right)}{6.4} - 1 = +.22$$

Cradle Structure

The lifting loads will be reacted out to the nearby package trunnions on the rear of the cradle. On the front of the cradle, the package will be supported on the robust front saddle casting. The twelve 2.25-4.5UNC socket head cap screws (SHCS) connecting the front saddle to the cradle frame will be placed in shear. The fasteners are threaded on the shear plane, so the 3.25 inch tensile area is used from Table 2 of [13].

$$\tau = \frac{(2)102.35}{(12)3.25} = 5.2 \text{ ksi}$$

where 102.35 kips is the lifting force,  $F_{lift}$ , applied to the lift lug calculated above.

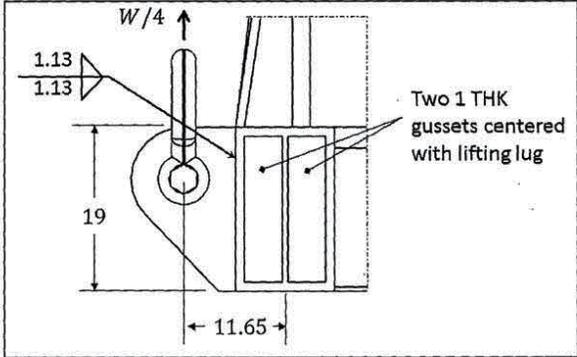
Using the same lifting criteria above for the ASTM A574 material in Table 4-1, the margin of safety is:

$$MS = \frac{.6 \times \min\left(\frac{135}{3}, \frac{170}{5}\right)}{5.2} - 1 = +2.9$$

**5.3.8 TN-68 Lifting Evaluation**

Lift Lugs

The TN-68 cradle is lifted using four of the same shackles used on the NAC packages. Four (4) 4 inch thick lugs are welded to the side of the I-beams and are attached with a 1.13 inch double sided fillet weld 19 inches long (see Figure 5-12). Centered behind the lift lugs are two 1 inch thick gussets to help transfer the load to the I-beam. The lugs could be bolted on as an option in the detailed design.



**Figure 5-12: TN-68 Cradle Lift Lug**



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 27 of 56**

The lift lugs are designed to fit the shackle and to have the hole for the shackle 2 times the pin diameter away from the edge. Thus tensile, shear tear-out, and also bearing stresses are not of concern. The connecting welds will be loaded in shear from the vertical load and bending.

The average shear over all four lugs is:

$$\tau' = \frac{(1.15)300(1/4)}{(2)(.707)(1.13)(19)} = 2.8 \text{ ksi}$$

where 300 kips is the maximum combined load of the TN-68 package and cradle from Table 5-1, the 19 inch long double fillet weld is per Figure 5-12, and a dynamic load factor of 1.15 is applied per the specification for overhead traveling cranes published by the Crane Manufacturers Association of America [29].

The shear from bending in the fillet welds being 6 inches from the side of the 11.3 inch wide I-beam is:

$$\tau = \frac{(1.15)(300/4)(6)(19/2)}{.707(1.13)(19^3/6)} = 5.4 \text{ ksi}$$

The margin of safety is calculated using the lesser of 1/3 yield and 1/5 ultimate in accordance with [6]. The material of the lug is the 50 ksi yield strength material from Table 4-1.

$$MS = \frac{.6 \times \min\left(\frac{50}{3}, \frac{65}{5}\right)}{\sqrt{2.8^2 + 5.4^2}} - 1 = +.28$$

Rear Cradle Structure

The lifting load path on the rear of the cradle is between the lugs and the trunnion towers. The most limiting section in this load path is the boxed I-beam section. This section will be placed in torsion by the lifting load. The I-beam polar moment of inertia is 4,871 in<sup>4</sup> per Appendix A.6. The torsional shear is:

$$\tau = \frac{(1.15) \frac{300}{4} (11.65) \left( \sqrt{\left(\frac{11.3}{2}\right)^2 + \left(\frac{19}{2}\right)^2} \right)}{4,871} = 2.3 \text{ ksi}$$

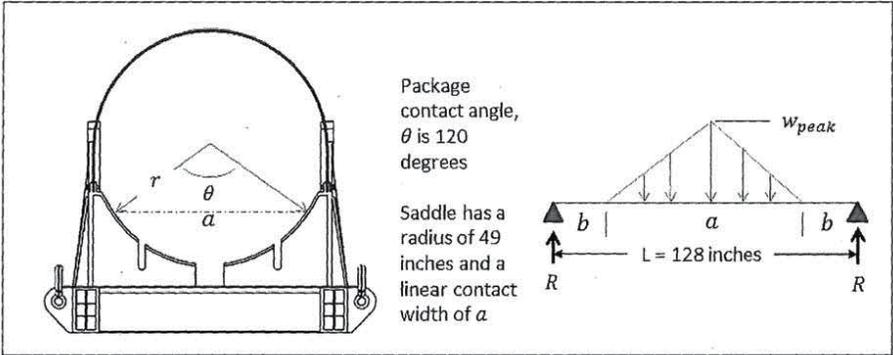
The bending in the I-beams due to the longitudinal distance between the lift point and the trunnion will be minor due to the strength of the frame structure in that orientation. The margin of safety is calculated using the lesser of 1/3 yield and 1/5 ultimate in accordance with [6]. The material of the lug is the 50 ksi yield strength material from Table 4-1.

$$MS = \frac{.6 \times \min\left(\frac{50}{3}, \frac{65}{5}\right)}{2.3} - 1 = +2.4$$

Front Saddle Structure

The lifting load path on the front of the cradle is between the lift lugs and the front saddle. The lifting load will place the front saddle W14x233 I-beam in bending. This will be conservatively analyzed as a simply supported beam neglecting any strength contribution from the rest of the frame. The package contact load distribution is conservatively assumed to be triangular and neglects the cutouts. This

simplification is justified since it will calculate a bounding moment at the center of the front saddle where the cross section is smallest. A beam diagram of the approximation is shown in Figure 5-13.



**Figure 5-13: TN-68 Cradle Front Saddle Beam Approximation for Lifting**

The width of the cradle contact is calculated using the law of cosines:

$$a = \sqrt{2(49)^2 - 2(49)^2 \cos(120^\circ)} = 84.9 \text{ inches}$$

The distance  $b$  is therefore:

$$b = \frac{128 - a}{2} = 21.6 \text{ inches}$$

The peak load at the center of the beam is therefore:

$$w_{peak} = \frac{300(.5)}{.5(84.9)} = 3.54 \text{ kip/inch}$$

where the front saddle supports half the 300 kip TN-68 package and cradle from Table 5-1, in a triangular distribution over the linear contact width as shown in Figure 5-13.

The reaction loads at both locations will be equal due to the symmetry of the beam. Thus, the reaction load,  $R$ , is:

$$R = .5(300)/2 = 75.0 \text{ kips}$$

This beam case is very similar to beam Case 8 in the Aluminum Design Manual [23]. The only difference is that the load is more centered. Since the shear in the beam is constant over the length “ $b$ ” the maximum moment at the center of the beam can be calculated as follows:

$$M = R(b) + \frac{wL^2}{12} = (75.0)(21.6) + \frac{(3.54)(84.9)^2}{12} = 3,746 \text{ kip} \cdot \text{in}$$

The W14x233 I-beam height is 16.04 inches tall and has a moment of inertia is 3,010 in<sup>4</sup> [26]. The bending stress is:



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 29 of 56**

$$\sigma_b = \frac{3,746 \left( \frac{16.04}{2} \right)}{3,010} = 10.0 \text{ ksi}$$

The margin of safety is calculated using the lesser of 1/3 yield and 1/5 ultimate in accordance with [6]. The material of the lug is the 50 ksi yield strength material from Table 4-1.

$$MS = \frac{\min\left(\frac{50}{3}, \frac{65}{5}\right)}{10.0} - 1 = +.30$$

**5.4 Fatigue**

The Atlas railcar Family 2 cradles will undergo cyclical loading. They are designed for a 50 year service life as described in Section 5.5 of [28]. It should be noted that the final design will require additional fatigue analysis for all welds and built-up sections.

**6.0 RESULTS AND CONCLUSIONS**

**6.1 Railcar Interface Loading Summary**

Table 6-1 is a summary of the bounding loads applied to the Atlas railcar interface in Section 5.1.

**Table 6-1: Railcar Tie-down Loads**

Railcar Attachment Load	Bounding Load, kips	Package and Reference
Vertical Pin Loads	±664	Magnatran <sup>®</sup> , Table 5-2
Lateral Pin Block Load	±385	Magnatran <sup>®</sup> , Table 5-4
Longitudinal Shear Key Load	±2,655	Magnatran <sup>®</sup> , Table 5-2

**6.2 Concept Design Summary**

The conceptual designs for the Family 2 packages were evaluated for the AAR tie-down loads and lifting. As can be seen in Section 5.3, all the margins of safety were at least +.20. This is deemed adequate to assure the cradle concepts are viable in support the Atlas railcar design.

**6.3 Literature Search and other Background Data**

A formal literature search was not applicable to this scope of work. All required background information is given under Section 1.1, *Project Background*.

**7.0 REFERENCES**

- Department of Energy Contract DE-NE0008390, Part 1, Section C, *Statement of Work*.
- AREVA Federal Services Drawing, DWG-3015278, *Atlas Railcar Cradle Attachment*, Rev. 0.
- AREVA Federal Services Calculation, CALC-3015276, *Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation*, Rev. 0.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 30 of 56**

4. AREVA Federal Services Drawing, DWG-3015138, *Atlas Railcar Cradle Family 2 (NAC) Conceptual Drawing*, Rev. 0.
5. AREVA Federal Services Drawing, DWG-3015277, *Atlas Railcar Cradle Family 2 (TN-68) Conceptual Drawing*, Rev. 0.
6. American National Standards Institute, ANSI N14.6, *for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 kg) or More*, 1993.
7. AREVA Federal Services Engineering Information Record, EIR-3014611, *Design Basis Requirements Document (DBRD) for the ATLAS Railcar*, Rev. 3.
8. American Society for Testing and Materials, ASTM A992/A992M, *Standard Specification for Structural Steel Shapes*, 2011.
9. American Society for Testing and Materials, ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*, 2007.
10. American Society for Testing and Materials, ASTM A732/A732M, *Standard Specification for Castings, Investment, Carbon and Low Alloy Steel for General Application, and Cobalt Alloy for High Strength at Elevated Temperatures*, 2002.
11. American Society for Testing and Materials, ASTM A434, *Standard Specification for Steel Bars, Alloy, Hot-Wrought or Cold-Finished, Quenched and Tempered*, 2006.
12. ASM International, ASM Handbook Volume 4, *Heat Treating*, 1991, pg 210.
13. American Society for Testing and Materials, ASTM A574, *Standard Specification for Alloy Steel Socket-Head Cap Screws*, 2011
14. American Society for Testing and Materials, ASTM A490, *Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength*, 2010a.
15. Docket Number 71-9356, *MAGNATRAN® Submittal*, Non-Proprietary Version, Revision 12A, October 2012.
16. Docket Number 71-9356, *MAGNATRAN® RAI Response Package Submittal*, Non-Proprietary Version, Revision 14A, October 2014.
17. Docket 71-9235, *NAC-STC Storage and Transport Cask Safety Analysis Report*, Non-Proprietary Version, Rev. 15, March 2004.
18. Docket 71-9270, *Certificate of Compliance*, Rev. 4.
19. Docket 71-9270, *NAC-UMS Universal MPC System, Safety Analysis Report*, Non-Proprietary Version, Rev. UMST-00A, May 2000.
20. Docket 71-9270, *List of SAR Changes for NAC UMS® Transport SAR Revision 2*, Non-Proprietary Version, November 2005.
21. Docket 71-9293, *Certificate of Compliance*, Rev. 4.
22. Docket 71-9293, *TN 68 Packaging Safety Analysis Report*, Non-Proprietary Version, Rev. 4, January 2001.
23. The Aluminum Association Inc., *Aluminum Design Manual*, 2010.



AREVA Federal Services LLC

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 31 of 56

24. Deutschman, A.D., Michels, W.J., Wilson, C.E., *Machine Design Theory and Practice*, Macmillan Publishing Co., New York, 1975.
25. The Crosby Group LLC, Online Catalog, *Crosby® Bolt Type Shackles*, Retrieved 1.28.2016.
26. American Institute of Steel Construction Inc., *Steel Construction Manual*, 13<sup>th</sup> Ed.
27. Blodgett, O., *Design of Welded Structures*, The James F. Lincoln Arc Welding Foundation, 1966.
28. AREVA Federal Services Calculation, CALC-3015135, *Atlas Railcar Family 3 Conceptual Cradle Structural Calculation*, Rev. 0.
29. CMAA Specification #70, *Specification for Top Running Bridge & Gantry Type Multiple Girder Electric Overhead Traveling Cranes*, Crane Manufacturers Association of America, Inc. 1994.
30. American Society for Testing and Materials, ASTM 350, *Carbon and Low-Alloy Steel Forgings, Requiring Notch Toughness Testing for Piping Components*, 2011.



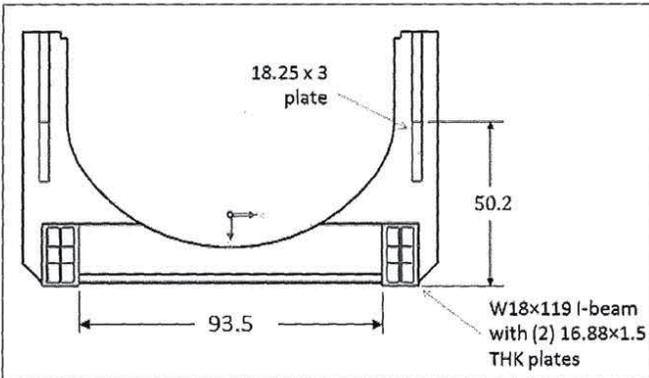
**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

**APPENDIX A: CRADLE CROSS SECTION DATA**

**A.1 Magnatran® Cradle Frame Cross Section**

The smallest cross-section (see Figure 5-4) on the NAC Magnatran® cradle is dimensioned below. The vertical gusset plate and lift lugs are neglected. Note that the 18x3 top plate is angled downwards at 10 degrees, so it is 18.25 inches tall the cross-section sketch below.



Individual area properties are calculated in the first table and the composite section properties are calculated in the lower table:

Part	QTY	Height (in)	Width (in)	Area, A (in <sup>2</sup> )	Y-Y Axis Inertia, I (in <sup>4</sup> )	Centroid Height, z (in)
W18x119 (per Table I-1 of [26])	2	19	NA	35.1	2190	9.5
I-beam Plate	4	16.88	1.5	25.32	601.2	9.5
Top Plate	2	18.25	3	54.75	1,519.6	41.1

Composite Section Properties

Area (QTY × Area)	281	in <sup>2</sup>
Centroid Height ( $\bar{z}$ )	21.8	in
Moment of Inertia	76,449	in <sup>4</sup>

The composite centroid is calculated using the following equation:

$$\frac{\sum Area \times z}{\sum A} = \bar{z}$$

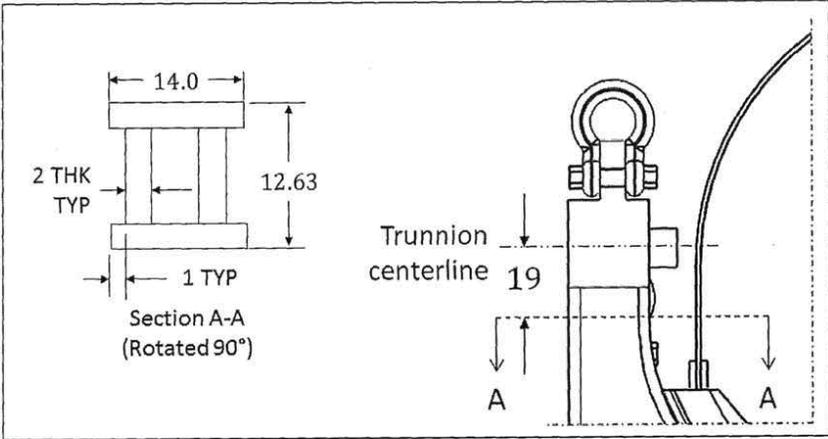
The composite moment of inertia is calculated using the parallel axis theorem.

$$I = \sum I_n + A_n(z_n - \bar{z})^2$$

**AREVA** AREVA Federal Services LLC  
 Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
 Doc./Rev.: CALC-3015134-000  
 Project: 00225.03.0050 - DOE Atlas Railcar

**A.2 NAC-STC™ Trunnion Tower**

The section properties of the limiting cross section evaluated in Section 5.3.2 on the NAC-STC™ cradle are calculated using the dimensions in the following sketch:



The centroid and moment of inertia values in the following table are calculated using the same equations described in Appendix A.1. Individual area properties are calculated in the first table and the composite section properties are calculated in the lower table.

Part	QTY	Height (in)	Width (in)	Area (in <sup>2</sup> )	X-X Axis Inertia, I <sub>x</sub> (in <sup>4</sup> )	Centroid Height, y (in)	Y-Y Axis Inertia, I <sub>y</sub> (in <sup>4</sup> )	Centroid Width, x (in)
2 THK Horizontal Plates	2	2	14	28	9.3	5.3125	457.3	0
2 THK Vertical Plates	2	8.63	2	17.26	107	0	5.8	5
<b>Composite Section Properties</b>								
Area (QTY × Area)		90.5		in <sup>2</sup>				
Centroid ( $\bar{y}$ )		0.0		in				
Moment of inertia X-X		1,813		in <sup>4</sup>				
Centroid ( $\bar{x}$ )		0		in				
Moment of inertia Y-Y		1,789		in <sup>4</sup>				
Polar Moment of Inertia		3,602		in <sup>4</sup>				



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

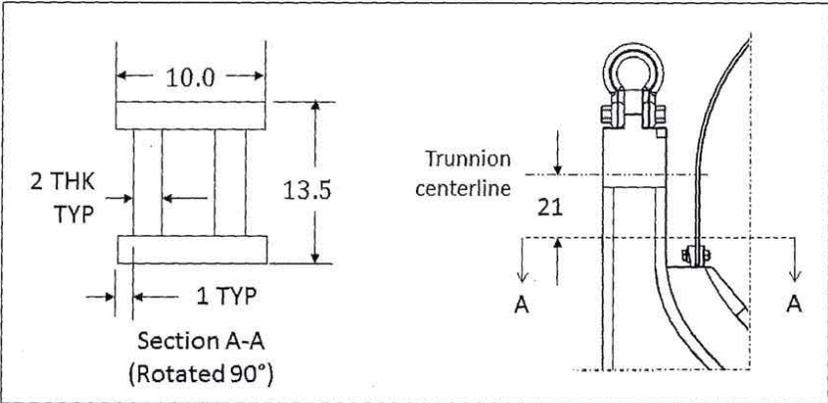
Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 34 of 56

**A.3 Magnatran® Trunnion Tower**

The section properties of the limiting cross section evaluated in Section 5.3.2 on the Magnatran cradle are calculated using the dimensions in the sketch below:



The centroid and moment of inertia values in the following table are calculated using the same equations described in Appendix A.1. Individual area properties are calculated in the first table and the composite section properties are calculated in the lower table.

Part	QTY	Height (in)	Width (in)	Area (in <sup>2</sup> )	X-X Axis Inertia (in <sup>4</sup> )	Centroid Height, y (in)
2 THK Horizontal Plates	2	2	10	20	6.67	5.75
2 THK Vertical Plates	2	9.5	2	19	143	0
Composite Section Properties						
Area (QTY × Area)		78.0	in <sup>2</sup>			
Centroid ( $\bar{y}$ )		0.0	in			
Moment of inertia X-X		1,622	in <sup>4</sup>			



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

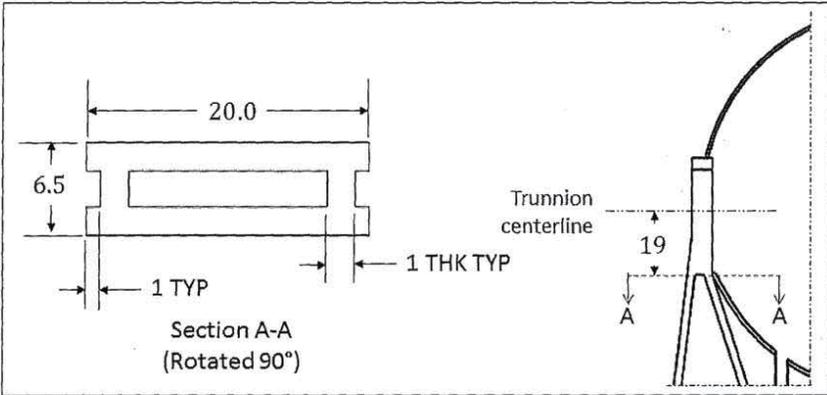
Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 35 of 56

**A.4 TN-68 Trunnion Tower Cross Section**

The section properties of the limiting cross section evaluated in Section 5.3.3 on the AREVA TN-68 cradle are calculated using the dimensions in the sketch below:



The centroid and moment of inertia values in the following table are calculated using the same equations described in Appendix A.1. Individual area properties are calculated in the first table and the composite section properties are calculated in the lower table.

Part	QTY	Height (in)	Width (in)	Area (in <sup>2</sup> )	X-X Axis Inertia (in <sup>4</sup> )	Centroid Height, y (in)
2 THK Horizontal Plates	2	2	20	40	13.33	2.25
2 THK Vertical Plates	2	2.5	1	2.5	1	0
Composite Section Properties						
Area (QTY × Area)	85.0	in <sup>2</sup>				
Centroid ( $\bar{y}$ )	0.0	in				
Moment of inertia X-X	434	in <sup>4</sup>				

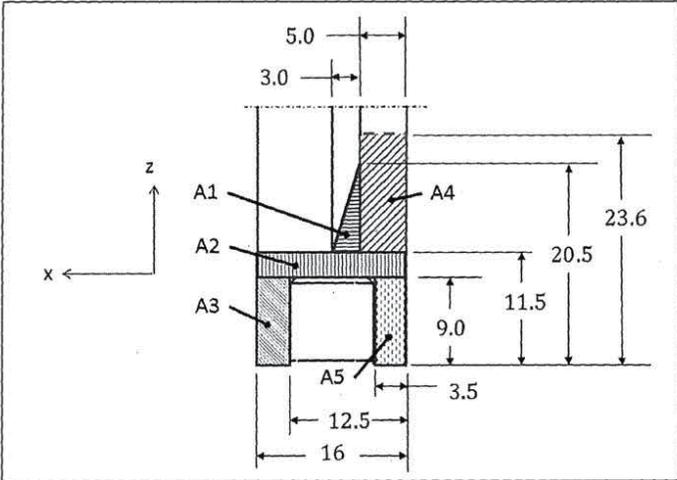


**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

**A.5 Magnatran® Front Saddle**

The cross section properties of the NAC front Saddle are calculated using a composite shape as described in the sketch below. The following sketch cross-section is based on the Section A-A from Figure 5-6.



The centroid and moment of inertia values in the following table are calculated using the same equations described in Appendix A.1. Individual area properties are calculated in the first table and the composite section properties are calculated in the lower table.

Area Number (see sketch)	QTY	Height (in)	Width (in)	Area (in <sup>2</sup> )	X-X Axis Inertia (in <sup>4</sup> )	Centroid Height, z (in)	Z-Z Axis Inertia (in <sup>4</sup> )	Centroid Width, x (in)
Triangle 1	1	9.0	3	14.25	71	14.7	7	6
Square 2	1	2.5	16	40	21	10.3	853	8
Square 3	1	9	3.5	31.5	213	4.5	32	14.3
Square 4	1	12.1	5	60.5	738	17.6	126	2.5
Square 5	1	9	3.5	31.5	213	4.5	32	1.75

Composite Section Properties	
Area (QTY × Area)	177 in <sup>2</sup>
Centroid ( $\bar{z}$ )	11.0 in
Moment of inertia X-X	6,690 in <sup>4</sup>
Centroid ( $\bar{x}$ )	6.0 in
Moment of inertia Z-Z	4,664 in <sup>4</sup>
Polar Moment of Inertia	11,354 in <sup>4</sup>



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**A.6 The Boxed I-beam Properties for all Group 2 Cradles**

The structural W18x119 I-beams have two (2) 1.5 inch thick plates welded between the two (2) 1.06 inch thick flanges. The section properties are calculated in the following table:

Part	QTY	Height (in)	Width (in)	Area (in <sup>2</sup> )	Y-Y Axis Inertia (in <sup>4</sup> )	Centroid Height, y (in)	Z-Z Axis Inertia (in <sup>4</sup> )	Centroid Width, y (in)
W18x119 (properties per Table 1-1 of [26])	1	19	11.3	35.1	2190	9.5	253	0
I-beam Plate	2	16.88	1.5	25.32	601.2	9.5	4.7	4.9

**Composite Section Properties**

Area (QTY x Area)	86	in <sup>2</sup>
Centroid Height ( $\bar{z}$ )	9.5	in
Moment of inertia Y-Y	3392	in <sup>4</sup>
Moment of inertia Z-Z ( $\bar{y} = 0$ in.)	1,478	in <sup>4</sup>
Polar Moment of Inertia	4,871	in <sup>4</sup>

The centroid and moment of inertia values in the table above are calculated using the same equations described in Appendix A.1.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

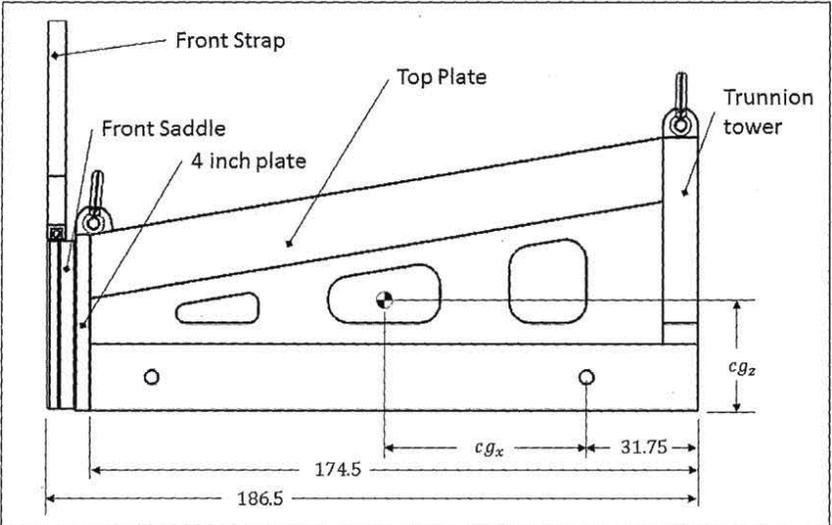
**APPENDIX B: CRADLE WEIGHT AND CENTER OF GRAVITY ESTIMATE**

**B.1 NAC Cradle Weight Estimate**

The following calculations estimate the bounding weight for the NAC cradled designs. Calculations are made for individual components and summarized in Tables B-1 and B-2.

The Magnatran<sup>®</sup> requires the longest cradle. Since the length is the primary weight factor, the Magnatran<sup>®</sup> will bound the NAC-UMS<sup>™</sup> and NAC-STC<sup>™</sup> cradle weights. The following general methodology was used in creating the weight estimation for the Magnatran cradle:

- Some features/components are neglected that have a negligible impact on the weight estimation
- Where sufficient detail is not provided by drawing [4], sketches are provided in this appendix
- Item weights and centroids are calculated individually then summed and evaluated in Tables B-1 and B-2
- The cradle center of gravity is measured from the pin location closet to trunnion towers (labeled the CGx coordinate shown in sketch below) and from the bottom of the cradle I-beam (labeled the CGz coordinate in sketch below)
- Steel density is taken as .28 lb/in<sup>3</sup> and the density of aluminum is taken as .1 lb/in<sup>3</sup>



**W18x119 Structural I-Beam** (NOTE: Holes and Tubing for the railcar pins are neglected.)  
 Weight per foot per Table 1-1 of [26]: 119 lb/ft  
 Length: 174.5 in.



AREVA Federal Services LLC

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 39 of 56

Weight:  $(174.5/12)(119) = 1,730 \text{ lb}$

CG Z coordinate:  $19/2 = 9.5 \text{ in.}$

CG X coordinate:  $(174.5/2 - 31.75) = 55.5 \text{ in.}$

**I-Beam 1.5 THK "Boxing" Plate** (NOTE: Holes and Tubing for the railcar pins are neglected.)

I-beam Height: 19 inches per Table I-1 of [26]

I-beam Flange Thickness: 1.06 inches per Table I-1 of [26]

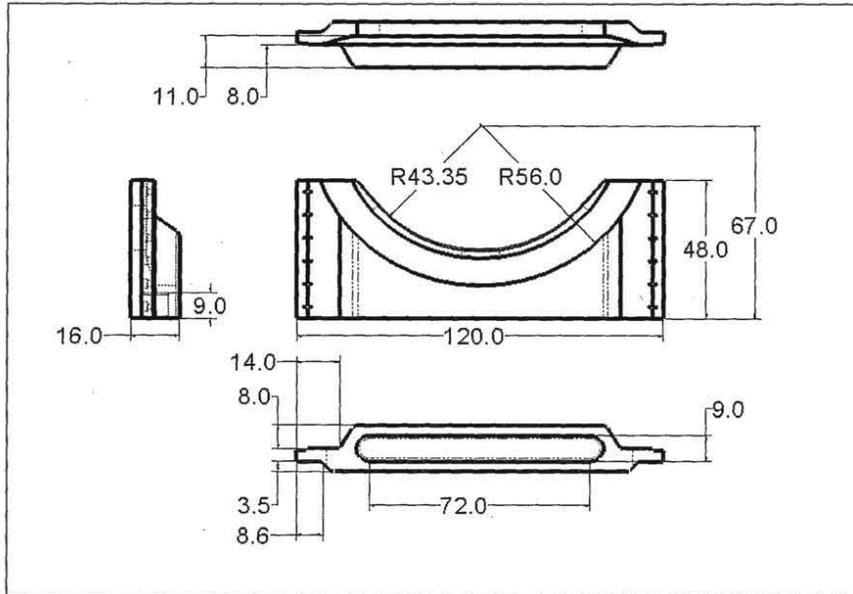
Weight:  $1.5(19 - (2)(1.06))(174.5)(.28) = 1,237 \text{ lb}$

CG Z coordinate:  $19/2 = 9.5 \text{ in.}$  (Centered on I-beam)

CG X coordinate:  $(174.5/2 - 31.75) = 55.5 \text{ in.}$

**Front Saddle (see sketch, some features neglected in weight estimate)**

The Front Saddle is a 16 inch thick casting that is 120 inches wide and 48 inches tall. It is designed to interface with the 86.7 inch diameter upper forging and shear key of the Magnatran<sup>®</sup>, while at the same time clearing the neutron shield, fins, and impact limiter. The following sketch contains the primary dimensions. The volume is estimated by subtracting basic shapes from the 120 x 16 x 48 envelope.

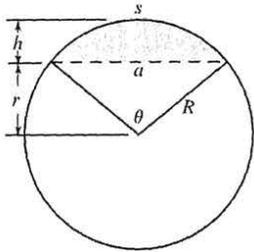




**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

Block volume:  $48.0 \times 16.0 \times 120 = 92,160 \text{ in.}^3$   
 Bottom cut-out volume (approx. as rectangular area):  
 $72 \times 9 \times 9 = 5,832 \text{ in.}^3$   
 Side cut-out volume (approx. as rectangular areas):  
 $2(14 \times 8 + 3.5 \times 8.6)(48) = 13,642 \text{ in.}^3$   
 Circular segment area:



$$A_1 = R^2 \cos^{-1}\left(\frac{r}{R}\right) - r\sqrt{R^2 - r^2}$$

$$A_1 = 1,359 \text{ in.}^2$$

where the radius of the segment is 43.35 in. and the height of the center of the circle above the top of the saddle is  $(67 - 48 = 19 \text{ in.})$  as shown on the sketch above.

The saddle cut-out volume is:  $1359(16) = 21,744 \text{ in.}^3$

The area cutout for the fins and neutron shield (cutout circular segment cutout on the front saddle with a 56 inch radius that is approximately 8 inches deep). It has an area equal to  $A_2 - A_1$ , where  $A_1$  is the saddle cutout area above, and  $A_2$  is:

$$A_2 = (56^2) \cos^{-1}(19/56) - 19\sqrt{56^2 - 19^2} = 2,840 \text{ in.}^2$$

The fin and neutron shield cut-out volume is:  $8(2,840 - 1,359) = 11,848$

The bounding weight of the saddle is:  $.28(92,160 - 5832 - 13,642 - 21,744 - 11,848) = 10,946 \text{ lb}$

The centroid of the part is conservatively placed at the center of the part. This simplification is appropriate since this bounds the actual cg Z coordinate and will give an average X coordinate value which is sufficient for the proof-of-concept.

CG Z coordinate:  $48/2 + .5 = 24.5 \text{ in.}$  (saddle is raised .5 inches above bottom of cradle for clearance during cradle assembly)

CG X coordinate (see first two sketches):  $186.5 - 16/2 - 31.75 = 146.75 \text{ in.}$

**Bolting Plate:** (see sketch, holes neglected)

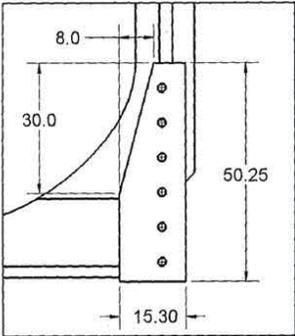
Thickness: 4 in.

$$\text{Weight: } .28(4)(15.3 \times 50.25 - .5(30 \times 8)) = 726 \text{ lb}$$

CG Z coordinate:  $50.25/2 = 25.13 \text{ in.}$

CG X coordinate (see first sketch):

$$174.5 - 31.75 + 4/2 = 144.75 \text{ in.}$$





**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

**Shear Box (see Sketch)**

The box section weight is conservatively calculated using the box section area to the right for the full length between the I-beam webs (as shown Figure 5-10)

Area:  
 $3(35.5) + 2(1)(7.5) + (33.5)(1)$   
 $= 155 \text{ in.}^2$

Length:  $93.5 + 11.3 = 104.8 \text{ in.}$

Weight:  $.28(155)(104.8) = 4,548 \text{ lb}$

CG Z coordinate:  
 $1 + 10.5/2 = 6.3 \text{ in.}$

CG X coordinate:  
 $44.75 + 35.5/2 = 62.5 \text{ in.}$

**Top Plate: (see Sketch)**

Thickness: 3 in.

Weight:  $.28(3)(166.8 \times 18)$   
 $= 2,522 \text{ lb}$

CG Z coordinate:  
 $(78 + 50.25)/2 - 18/2 = 55.13 \text{ in.}$

CG X coordinate:  
 $164.5/2 - 21.75 = 60.5 \text{ in.}$

**Gusset Plate:**

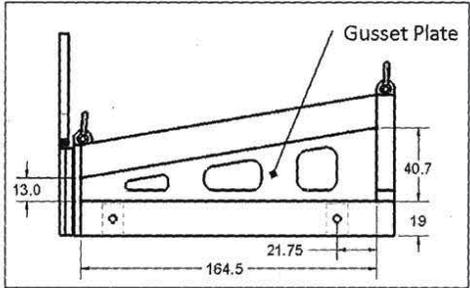
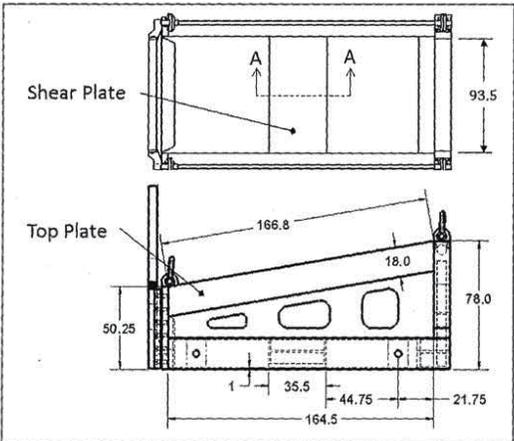
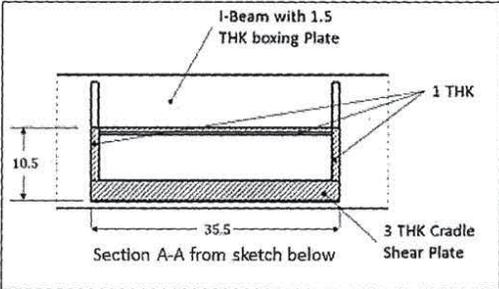
(see Sketch right, holes neglected)

Thickness: 1 in.

Weight:  $(.28)(1)(164.5) \times ((13 + 40.7)/2) = 1,237 \text{ lb.}$

CG Z coordinate:  
 $19 + (13 + 40.7)/2 = 45.9 \text{ in.}$

CG X coordinate (nominal):  
 $164.5/2 - 21.75 = 60.5 \text{ in.}$

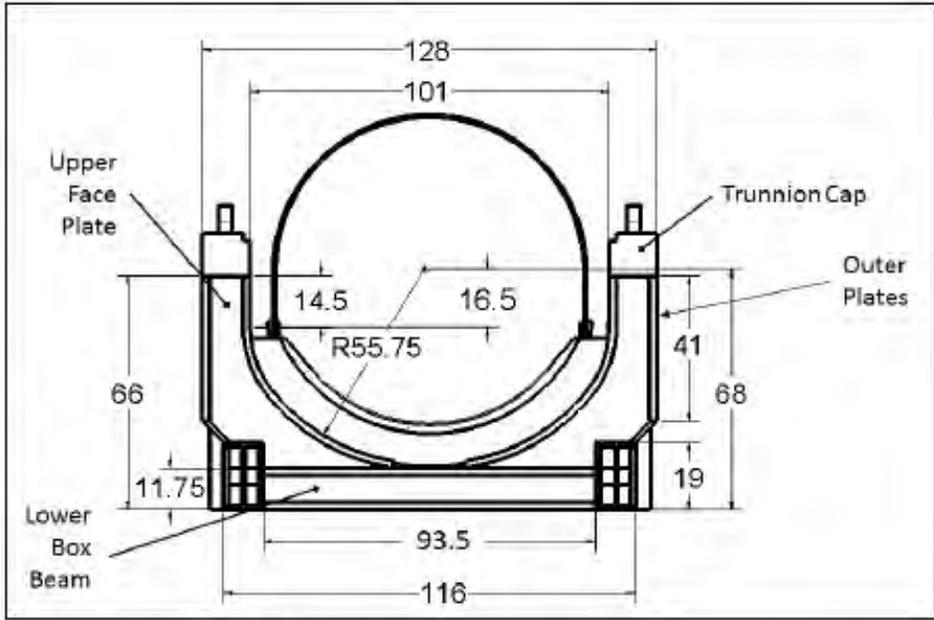




AREVA Federal Services LLC

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
 Doc./Rev.: CALC-3015134-000  
 Project: 00225.03.0050 - DOE Atlas Railcar

**Trunnion Tower Components:**



**Trunnion Tower Upper Face Plates**

Thickness: 2 inches

Area of both right and left plates (conservative approx.):

$$128(66 - 11.75) - 101(14.5) - (55.75^2 \cos^{-1}(16.5/55.75) - (16.5)\sqrt{55.75^2 - 16.5^2}) = 2,410 \text{ in}^2$$

Weight (per plate):  $.28(2)(2,410/2) = 675 \text{ lb.}$

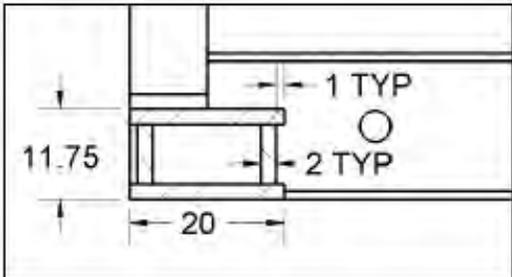
CG Z coordinate (conservative approximation):  $(66 + 11.75)/2 = 38.9 \text{ in.}$

CG X coordinate (All 4 plates will be installed such that the cg is centered on the Trunnion Tower):

$$-21.75 - 10/2 = -26.75 \text{ in.}$$

**Trunnion Tower Lower Box Beam**

The lower box beam cross section is shown in the cross section in the sketch to the right:





**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 43 of 56**

Length: 93.5  
Area:  $2(20)(2) + (11.75 - 4)(2)(2) = 111 \text{ in.}$   
Weight:  $.28(111)(93.5) = 2,906 \text{ lb}$   
CG Z coordinate:  $11.75/2 = 5.9 \text{ in.}$   
CG X coordinate:  $-21.75 \text{ in.}$

**Outside Connecting Trunnion Plates (includes vertical and 45 degree plates)**

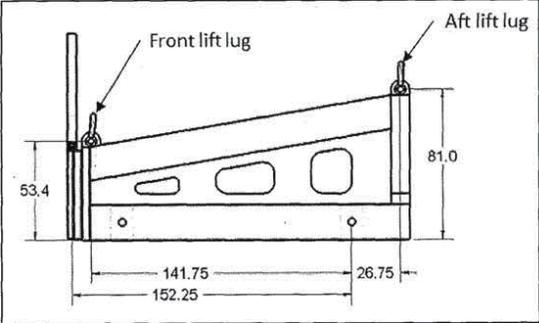
Thickness: 2 in.  
Length:  $41 + 6(\sqrt{2}) = 49.5 \text{ in.}$   
Width: 10 in.  
Weight:  $.28(2)(49.5)(10) = 277 \text{ lb.}$   
CG Z coordinate:  $19 + (66 - 19)/2 = 42 \text{ in.}$   
CG X coordinate (Centered on 10 inch wide Trunnion Tower):  $-26.75 \text{ in.}$

**Trunnion Tower Inner Curved Plate**

Thickness: 2 in.  
Width: 10 in.  
Curved linear length:  $(14.5) + 1/4(2\pi(55.75)) = 102 \text{ in.}$   
Weight:  $.28(2)(10)(102) = 571$   
CG Z coordinate (approximated as being half way up the curved section):  $68 - .5(55.75) = 40.13 \text{ in.}$   
CG X coordinate (Centered on 10 inch wide Trunnion Tower):  $-26.75 \text{ in.}$

**Trunnion Tower Cap:**

Steel Block with the following nominal dimensions: 10 in. x 12 in. x 13.5 in.  
Weight:  $.28(10)(12)(13.5) = 454 \text{ lb}$   
CG Z coordinate:  $66 + 12/2 = 72 \text{ in.}$   
CG X coordinate (Centered on 10 inch wide Trunnion Tower):  $-21.75 - 10/2 = -26.75 \text{ in.}$





**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

Page 44 of 56

**Lift Lugs**

The lift lugs are 12 inch long 4 inch thick plates that are approximately 8 inches tall.

Weight:  $.28(12)(4)(8) = 108 \text{ lb.}$

Front CG Z coordinate:  $53.4 \text{ in.}$

Front CG X coordinate:  $141.75 \text{ in.}$

AFT CG Z coordinate:  $81 \text{ in.}$

AFT CG X coordinate:  $-26.75 \text{ in.}$

**Front Strap**

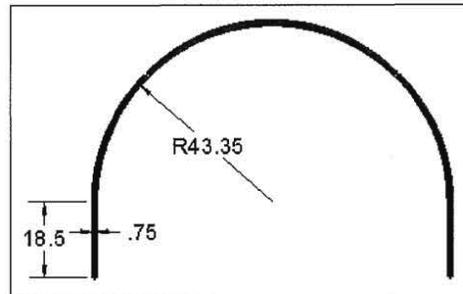
The front strap is made from a 5 inch wide .75 THK plate that is bent to interface the 86.7 inch diameter upper forging of the NAC Magnatran®.

Length:  $2(18.5) + \pi(43.55) = 173.8 \text{ in.}$

Weight:  $.28(.75)(5)(173.8) = 182 \text{ lb}$

CG Z coordinate:  $48 + 18.5 + 43.35/2 = 88.2 \text{ in.}$

CG X coordinate:  $152.25 \text{ in.}$



**Personnel Barrier**

The personnel barrier is NOT explicitly designed. A rough weight estimate is done using .125 THK expanded aluminum with an opening percentage of 65%. This expanded metal spans the distance between the impact limiters and covers the entire cask with radius of 62 inches as shown on SAR Drawing 71160-511, Rev. 1NP in [16]. The 214 inch cask length (see drawing 71160-502, Rev. 3NP of [16]) is conservatively used as the distance between the impact limiters. The density of aluminum is  $.1 \text{ lb/in}^3$ .

Thickness:  $.125 \text{ in.}$

Profile Length:  $2(68) + \pi(62) = 331 \text{ in.}$

Length:  $214 \text{ in.}$

Weight:  $(.65)(.1)(.125)(214)(331) = 575 \text{ lb}$

CG Z coordinate (conservatively assumed to be at cask cg height above bottom of skid):  $67.5 \text{ in.}$   
 (package cg height per [4])

CG X coordinate (at center of package):  $214/2 - 17.7 - 26.75 = 62.6 \text{ in.}$

A bounding value of 600 lb. will be used for the personnel barrier. The other personnel barrier components are also planned to be made from aluminum and will have a negligible weight.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 45 of 56

**Table B-1: NAC Cradle Component Weight Summary**

Item Description	QTY	Individual Component Weight	CG <sup>(1)</sup> (Z)	CG <sup>(2)</sup> (X)
I-beams	2	1,730	9.5	55.5
I-beam plates	4	1,237	9.5	55.5
Front saddle	1	10,946	24.5	146.75
Vertical bolting plate	2	726	25.13	144.75
Shear box plates	1	4,548	6.3	62.75
Top plate	2	2,522	55.13	60.5
Gussets	2	1,237	45.9	60.5
Trunnion tower upper face plates	4	675	38.9	-26.75
Trunnion tower lower box beam	1	2,906	5.9	-21.75
Trunnion tower outside connecting plates (vertical)	2	277	42	-26.75
Trunnion tower outside plates (Curved)	1	571	40.13	-26.75
Rear trunnion tower cap	2	454	72	-26.75
Front strap	1	182	88.2	152.25
Front lift lugs	2	108	53.4	141.75
AFT lift lugs	2	108	81	-26.75
Personnel barrier	1	600	67.5	62.6
<b>Cradle Totals</b>		<b>41,725</b>	<b>27</b>	<b>70</b>

Notes: 1) Vertical cg height is measured from the bottom of the cradle

2) Horizontal cg distance is measured from pinhole centerline closet to trunnion towers

The estimated nominal cradle weight above is rounded to 42,000 lb. A variance of ±10% is used to account for any changes during the final design of the NAC cradles. Thus, the NAC cradles are expected to weigh between 37,800 to 46,200 lb.

The cg offset along the longitudinal length of the cradle (x axis) to the center of the pins is nominally +8.3 inches (= 125/2 - 70). To account for any differences in the final design stage, the cg is limited to ±10 inches from the center point of the attachment pin locations (i.e. 125/2 ± 12 = 52.5 and 72.5 in.). The vertical offset of the cg is limited to 27.5 inches from the railcar deck (including +.5 inches for the railcar attachment mechanism). This limitation is justified due to several conservative approximations that were made in this calculation.

The following table calculates the combined cg for the NAC packages for use in Section 5.1 at the cradle nominal weight of 42,000 lb. Package weight, package cg values, and distance of lower trunnions



**AREVA Federal Services LLC**

**AREVA** Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 46 of 56

from cask bottom are per Tables 4-2 through 4-5. The distance from the lower trunnions to the rear tie-down pin is 26.75 inches for the Magnatran<sup>®</sup> and NAC-UMS<sup>™</sup> cradles, and 16.1 inches for the shorter NAC-STC<sup>™</sup> cradle per drawing [4].

**Table B-2: NAC Package and Cradle Combined Weight and CG Values**

<b>Magnatran<sup>®</sup></b>	
Combined weight (kips)	$312 + 42 = 354 \text{ kip}$
Vertical cg from bottom of cradle <sup>(1,2)</sup> , Z (in)	$\frac{312(67.5) + 42(27)}{354} = 62.5 \text{ in.}$
Minimum Combined CG distance from rear cradle pins, X (in)	$\frac{312(102 - 17.7 - 26.75) + 42(52.5)}{354} = 57 \text{ in.}$
Maximum Combined CG distance from rear cradle pins, X (in)	$\frac{312(108 - 17.7 - 26.75) + 42(72.5)}{354} = 65 \text{ in.}$
<b>NAC-STC<sup>™</sup></b>	
Combined weight (kips)	$254.6 + 42 = 297 \text{ kip}$
Vertical cg from bottom of cradle <sup>(1,2)</sup> , Z (in)	$\frac{254.6(67.5) + 42(27)}{297} = 61.5 \text{ in.}$
Minimum Combined CG distance from rear cradle pins, X (in)	$\frac{254.6(96 - 18.15 - 16.1) + 42(52.5)}{297} = 60 \text{ in.}$
Maximum Combined CG distance from rear cradle pins, X (in)	$\frac{254.6(99 - 18.15 - 16.1) + 42(72.5)}{297} = 66 \text{ in.}$
<b>NAC-UMS<sup>™</sup></b>	
Combined weight (kips)	$256 + 42 = 298 \text{ kip}$
Vertical cg from bottom of cradle <sup>(1,2)</sup> , Z (in)	$\frac{256(67.5) + 42(27)}{298} = 62.0 \text{ in.}$
Minimum Combined CG distance from rear cradle pins, X (in)	$\frac{256(106 - 17.6 - 26.75) + 42(52.5)}{298} = 60 \text{ in.}$
Maximum Combined CG distance from rear cradle pins, X (in)	$\frac{256(108.5 - 17.6 - 26.75) + 42(72.5)}{298} = 65 \text{ in.}$

Note: 1) The 67.5 inch package cg height is the same as the package centerline height on drawing [4].  
 2) Value rounded to the nearest half inch



AREVA Federal Services LLC

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

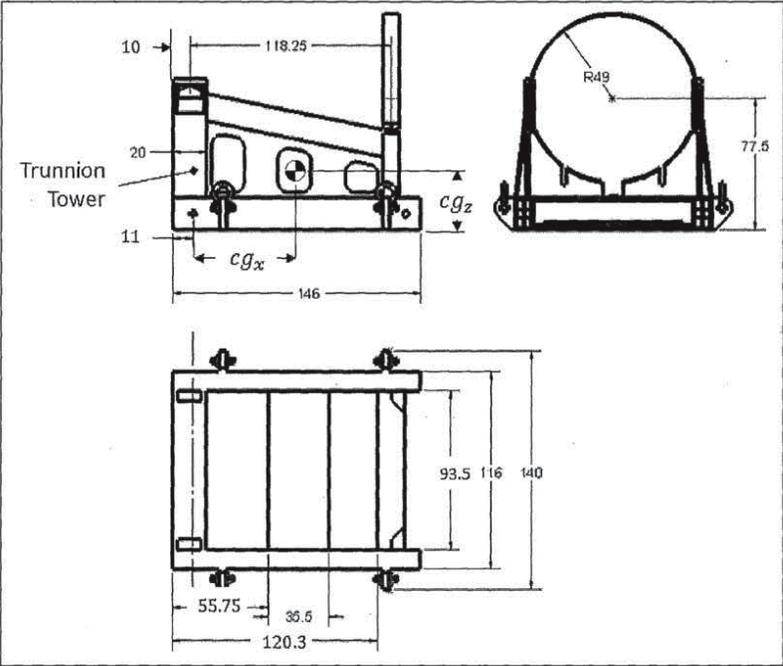
Page 47 of 56

B.2 TN-68 Cradle Weight Estimate

The following calculations estimate the bounding weight for the TN-68 cradled design. Calculations are made for individual components and summarized in Tables B-3 and B-4. This is done since the TN-68 cradle is significantly smaller than the NAC designs and does not require a heavy front saddle to react the longitudinal loads.

The same methodology applied to the NAC cradle weight estimates is applied to the TN-68 cradle

- Some features/components are neglected that have a negligible impact on the weight estimation.
- Where sufficient detail is not provided by drawing [5], sketches are provided in this appendix as required
- Item weights and centroids are calculated individually then summed and evaluated in Tables B-3 and B-4
- The cradle center of gravity is measured from the pin location closet to trunnion towers (labeled the x coordinate) and from the bottom of the cradle I-beam (labeled the z coordinate)
- Steel density is taken as .28 lb/in<sup>3</sup> and the density of aluminum is taken as .1 lb/in<sup>3</sup>





**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

Page 48 of 56

**W19×119 Structural I-Beam** (NOTE: Holes and Tubing for the railcar pins are neglected.)

Weight per foot per Table 1-1 of [26]: 119 lb/ft

Length: 146 in.

Weight:  $(146/12)(119) = 1,447$  lb

CG Z coordinate:  $19/2 = 9.5$  in.

CG X coordinate:  $(146/2 - 11) = 62$  in.

**I-Beam 1.5 THK "Boxing" Plate**

I-beam Height: 19 inches per Table 1-1 of [26]

I-beam Flange Thickness: 1.06 inches per Table 1-1 of [26]

Weight:  $1.5(19 - (2)(1.06))(146)(.28) = 1,035$  lb

CG Z coordinate (Centered on I-beam): 9.5 in.

CG X coordinate:  $(146/2 - 11) = 62$  in.

**Front Saddle W14×233 Structural I-Beam**

Weight per foot per Table 1-1 of [26]: 233 lb/ft

Length: 93.4 in.

Weight:  $(93.4/12)(233) = 1,814$  lb

(I-beam height is 16 inches, and width is 15.9 inches per Table 1-1 of [26])

CG Z coordinate:  $19 - 16/2 = 11$  in.

CG X coordinate:  $(120.3 - 11 + 15.9/2) = 117.25$  in.

**Front Saddle Vertical Side Plates**

Thickness: 2 in.

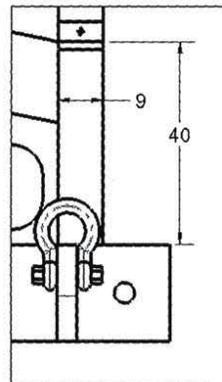
Width: 9 in.

Length: 40 in.

Weight:  $.28(9)(40)(2) = 202$  lb

CG Z coordinate:  $19 + 40/2 = 39$  in.

CG X coordinate:  $118.25 + 10 - 11 = 117.25$  in.





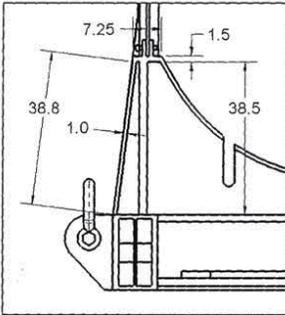
AREVA Federal Services LLC

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
 Doc./Rev.: CALC-3015134-000  
 Project: 00225.03.0050 - DOE Atlas Railcar

**Front Saddle Lateral Gussets:**

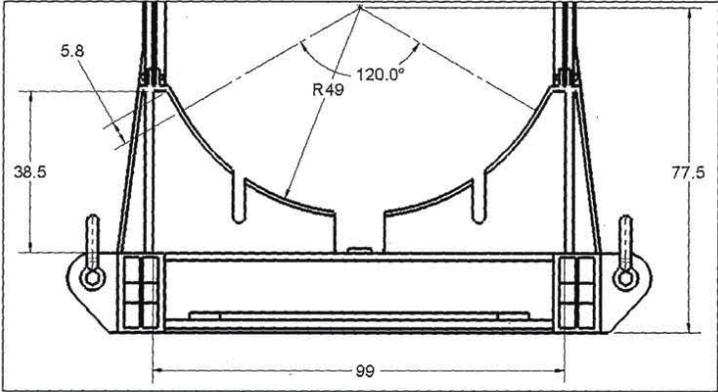
(Only Evaluating outside plate, small triangular plate neglected)

Thickness: 1 in.  
 Width: 9 in.  
 Length: 38.8 in.  
 Weight: .28(9)(38.8)(1) = 98 lb  
 CG Z coordinate: 19 + 38.5/2 = 38.25 in.  
 CG X coordinate: 117.25 in.



**Front Saddle Vertical Support**

Vertical plate supporting curved saddle plate; neglecting cutouts for tie-rods



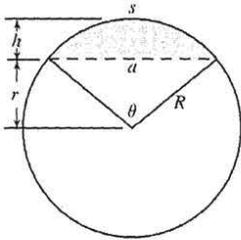
Thickness: 1 in.  
 Rectangular Area: 38.5(99) = 3811.5 in<sup>2</sup>  
 Circular Segment Area:

$$A_1 = R^2 \cos^{-1} \left( \frac{r}{R} \right) - r \sqrt{R^2 - r^2}$$

$$A = 1,867 \text{ in.}^2$$

where the radius of the segment is 49 in. and the height of the center of the circle above the top of the saddle is (58.5-38.5 = 20 in.) as shown on the sketch above.

Weight: .28(1)(3,811.5 - 1,867) = 545 lb





**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
**Doc./Rev.:** CALC-3015134-000  
**Project:** 00225.03.0050 - DOE Atlas Railcar

CG Z coordinate (conservatively half way up):  $19 + 38.5/2 = 38.25 \text{ in.}$   
 CG X coordinate:  $118.25 + 10 - 11 = 117.25 \text{ in.}$

**Front Saddle Curved Plates**

(Shown in sketch for front saddle vertical plate; neglecting cutouts for tie-rods)  
 Thickness: 1 in.

Width: 9 in.  
 Length:  $2(5.8) + 2\pi(49)(120/360) = 114 \text{ in}$   
 Weight:  $.28(1)(9)(114) = 287 \text{ lb}$

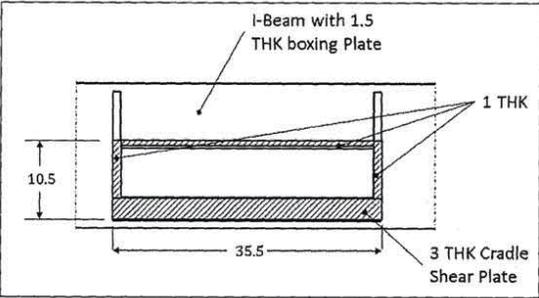
CG Z coordinate (conservatively half way up):  $((77.5 - 49) + (19 + 38.5))/2 = 43 \text{ in.}$   
 CG X coordinate:  $118.25 + 10 - 11 = 117.25 \text{ in.}$

**Shear Box (see first sketch for position)**

The box section weight is conservatively calculated using the box section area to the right for the full length between the I-beam webs (as shown Figure 5-10)

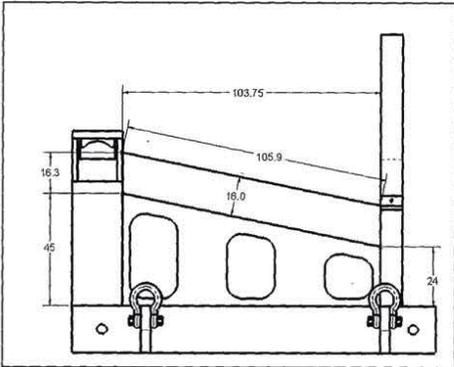
Area:  
 $3(35.5) + 2(1)(7.5) + (33.5)(1)$   
 $= 155 \text{ in.}^2$

Length:  $93.5 + 11.3 = 104.8 \text{ in.}$   
 Weight:  $.28(155)(104.8) = 4,548 \text{ lb}$   
 CG Z coordinate:  $1 + 10.5/2 = 6.3 \text{ in.}$   
 CG X coordinate:  $55.75 - 11 + 35.5/2 = 62.5 \text{ in.}$



**Top Plate**

Thickness: 2 in.  
 Width: 16 in.  
 Length: 105.9 in.  
 Weight:  $.28(2 \times 16 \times 105.9) = 949 \text{ lb}$   
 CG Z coordinate:  
 $19 + (45 + 24)/2 + 16.3/2 = 61.7 \text{ in.}$   
 CG X coordinate:  
 $20 - 11 + 103.75/2 = 60.9 \text{ in.}$





AREVA Federal Services LLC

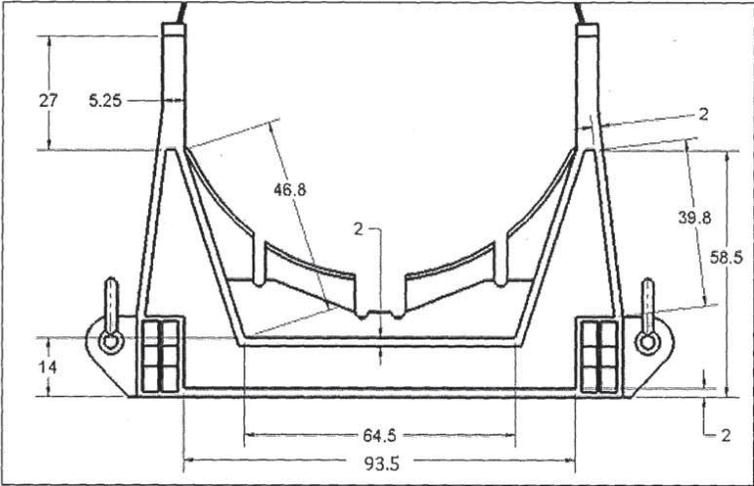
Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation  
Doc./Rev.: CALC-3015134-000  
Project: 00225.03.0050 - DOE Atlas Railcar

**Gusset Plate**

The holes in the side gusset plate are neglected  
Thickness: 1 in.  
Average Height:  $(45 + 24)/2 = 34.5$  in.  
Length: 103.75 in.  
Weight:  $.28(1 \times 34.5 \times 103.75) = 1,002$  lb  
CG Z coordinate:  $19 + (45 + 24)/2 = 53.5$  in.  
CG X coordinate:  $20 - 11 + 103.75/2 = 60.9$  in.

**Trunnion Tower Bottom Plate**

Neglecting the bottom cut-out for the railcar tie-down pin plates.  
Thickness: 2 in.  
Width: 20 in.  
Length: 93.5 in.  
Weight:  $.28(2)(20)(93.5) = 1,047$  lb.  
CG Z coordinate: 1 in.  
CG X coordinate:  $20/2 - 11 = -1$  in.





**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 52 of 56

**Trunnion Tower Outside Plates (see sketch above)**

Thickness: 2 in.

Width: 20 in.

Length: 39.8 in.

Weight:  $.28(2)(20)(39.8) = 446 \text{ lb.}$

CG Z coordinate:  $(58.5 + 19)/2 = 38.8 \text{ in.}$

CG X coordinate:  $-1 \text{ in.}$

**Trunnion Tower Lower Horizontal Plate (see sketch above)**

Thickness: 2 in.

Width: 20 in.

Length: 64.5 in.

Weight:  $.28(2)(20)(64.5) = 722 \text{ lb.}$

CG Z coordinate:  $14 - 2/2 = 13 \text{ in.}$

CG X coordinate:  $-1 \text{ in.}$

**Trunnion Tower Inside Plates (see sketch above)**

Thickness: 2 in.

Width: 20 in.

Length: 46.5 in.

Weight:  $.28(2)(20)(46.8) = 524 \text{ lb.}$

CG Z coordinate:  $(58.5 + 14)/2 = 36.3 \text{ in.}$

CG X coordinate:  $-1 \text{ in.}$

**Trunnion Tower Forward /Aft Face Plates**

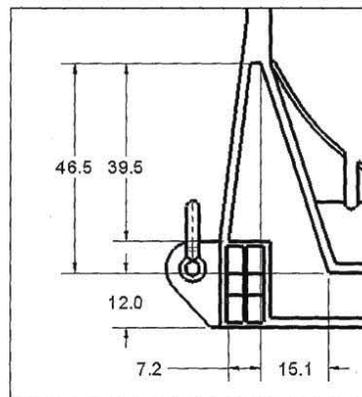
Approximated by a lower rectangle and four right triangles

Thickness: 1 in

Rectangular Area:  $93.5(12 - 2) = 935 \text{ in}^2$

Area of two outer triangles:  $39.5 \times 7.2 = 284.4$

Area of two inner triangles:  $46.5 \times 15.1 = 702.1$





**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 53 of 56

Weight:  $.28(1)(935 + 284.4 + 702.1) = 538 \text{ lb}$

CG Z coordinate of rectangle:  $2 + 10/2 = 7 \text{ in.}$

CG Z coordinate of outer triangles:  $19 + 1/3 \times (39.5) = 32.2 \text{ in.}$

CG Z coordinate of inner triangles:  $12 + 1/3 \times (46.5) = 27.5 \text{ in.}$

Total CG Z:

$$\frac{935(7) + 284.4(32.2) + 702.1(27.5)}{(935 + 284.4 + 702.1)} = 18.2 \text{ in.}$$

CG X coordinate (Average of the forward & AFT plates):

$$20/2 - 11 = -1 \text{ in.}$$

**Trunnion Tower Cap**

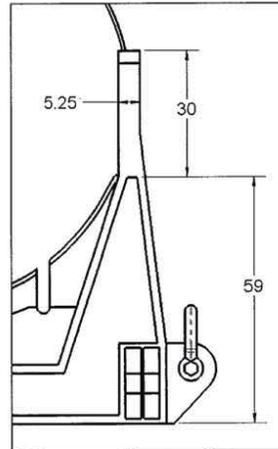
Neglecting machined features to bound the weight of all trunnion interface components.

Using average thickness: 5.25 in.

Weight:  $.28(5.25)(30)(20) = 882 \text{ lb}$

CG Z coordinate:  $59 + 30/2 = 74 \text{ in.}$

CG X coordinate:  $20/2 - 1 = -1 \text{ in.}$



**Front Strap**

The front strap is made from a 9 inch wide .75 THK plate that is bent to interface the 98 inch diameter of the TN-68 neutron shield.

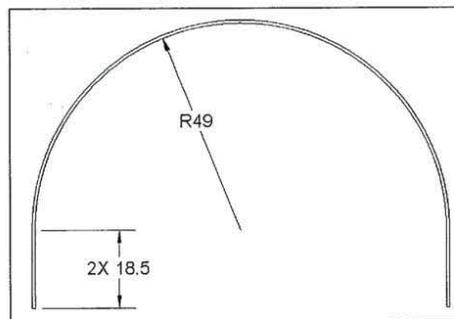
Length:  $2(18.5) + \pi(49) = 190.9 \text{ in.}$

Weight:  $.28(.75)(9)(190.9) = 361 \text{ lb}$

CG Z coordinate (arc center at package cg height per drawing [4]):

$$77.5 + 49/2 = 102 \text{ in.}$$

CG X coordinate: 117.25 in.





**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015134-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 54 of 56**

**Personnel Barrier:**

The Personnel Barrier is only required to extend between the impact limiters up to the centerline of the cask. The weight will be estimated by using expanded aluminum .125 THK. An opening percentage is specified as 65% to match the NAC cradle design since nothing is specified in the SAR [21]. The density of aluminum is .1 lb/in<sup>3</sup>.

Length (conservatively using package length per [21]): 197.25 *in.*

Height: 77.5 *in.*

Weight:  $(.1 \times .65)(.125)(197.25)(77.5) = 124 \text{ lb}$

CG Z coordinate:  $77.5/2 = 38.75 \text{ in.}$

CG X coordinate (at center of package):  $197.25/2 - 27.4 - 1 = 70.2 \text{ in.}$

A bounding value of 200 lb. will be used for each side personnel barrier. The other personnel barrier components are also planned to be made from aluminum and will have a negligible weight.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 55 of 56

**Table B-3: TN-68 Cradle Component Weight Summary**

Item Description	QTY	Individual Component Weight	CG (Z)	CG (X)
I-beams, W18x119	2	1,447	9.5	62
I-beam plates	4	1,035	9.5	62
Front saddle I-beam, W14x233	1	1,814	11	117.25
Front saddle vertical side plates	2	202	39	117.25
Front saddle lateral gussets	2	98	38.25	117.25
Front saddle vertical support	1	545	38.25	117.25
Front saddle curved plate	1	287	43	117.25
Shear Box	1	4,548	2.5	62.5
Top plate	2	949	61.7	60.9
Gusset plate	2	1,002	53.5	60.9
Trunnion tower bottom plate	1	1,047	1	-1
Trunnion tower outside plates	2	446	38.8	-1
Trunnion tower lower horizontal plate	1	722	13	-1
Trunnion tower inside plates	2	524	36.3	-1
Trunnion tower forward/aft face plates	2	538	18.2	-1
Trunnion tower cap	2	882	74	-1
Front Strap	1	361	102	117.25
Personnel barrier	2	200	38.75	70.2
<b>Totals</b>		<b>26,040</b>	<b>26</b>	<b>54</b>

The estimated nominal cradle weight above is rounded to 27,000 lb. A variance of ±10% is used to account for any changes during the final design of the TN-68 cradle. Thus, the TN-68 cradle is expected to weight between 24,300 to 29,700 lb.

The cg offset from the center of the pins is nominally -8.5 inches ( $= 125/2 - 54$ ). To account for any differences in the final design stage, the cg is limited to ±12 inches from the center point of the attachment pin locations (i.e.  $125/2 \pm 12 = 52.5$  &  $72.5$  in.). The vertical offset of the cg is limited to 26.5 inches from the railcar deck (including +.5 inches for the railcar attachment mechanism). This limitation is justified due to several conservative approximations that were made during the calculation above.

The following calculates the combined cg for the NAC packages for use in Section 5.1 at the cradle nominal weight of 27,000 lb. Package weight, cg location from cask bottom, and distance of lower



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 2 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015134-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 56 of 56

trunnions from cask bottom are per Table 4-6. The distance from the lower trunnions to the rear tie-down pin is 1 inch (see drawing [5]).

**Table B-4: TN-68 Package and Cradle Combined Weight and CG Values**

Combined weight (kips)	$272 + 27.0 = 299 \text{ kip}$
Vertical cg from bottom of cradle <sup>(1,2)</sup> , Z (in)	$\frac{272(77.5) + 27.0(26)}{299} = 73.0 \text{ in.}$
Minimum Combined CG distance from rear cradle pins, X (in)	$\frac{272(97 - 27.4 - 1) + 27.0(52.5)}{299} = 67 \text{ in.}$
Maximum Combined CG distance from rear cradle pins, X (in)	$\frac{272(97 - 27.4 - 1) + 27.0(72.5)}{299} = 69 \text{ in.}$

Note: 1) The 77.5 inch package cg height is the same as the package centerline height on drawing [5].  
 2) Value rounded to the nearest half inch

## Appendix A.2.3 – Compliance Matrix

### REQUIREMENTS FOR CRADLE DESIGN FROM EIR-3014611, "DESIGN BASIS REQUIREMENTS DOCUMENT (DBRD) FOR THE DOE ATLAS RAILCAR," REV 4<sup>1</sup>

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
Family No. 2: Casks covered: NAC: MAGNATRAN, NAC-STC, NAC-UMS, AREVA: TN-68			
2.1	<b>Regulatory Requirements</b> Comply with AAR 2043	For the cradles the AAR requirements are called out below	Y
2.2	<b>Functional Requirements</b>		
2.2.2	<i>Cradle Functional Requirements</i>		
2.2.2.1	During transport, a transportation cask must rest on a cradle on top of the cask railcar deck.	All cradles interface with the rail car attachments that comply with this requirement.	Y
2.2.2.2	Conceptual cask cradle designs must accommodate the cask designs listed above and interface with cradle as indicated in the cask SARs.	All casks in the family are evaluated.	Y
2.2.2.3	The conceptual cradle designs shall not be final designs or prototypes.	The conceptual design has sufficient margin to allow for specific design requirements.	Y
2.2.2.3.a	Conceptual design shall have a plus or minus 10% weight envelope evaluated.	The weight envelope evaluated allows for refinement of the design in the final design	Y
2.2.2.3.b	Center of gravity for the cradle shall be calculated and used to demonstrate the combined CG is met for the cask rail car and cradle of 98 inches or less. CG and loading distributions shall be detailed sufficiently to support railcar design and testing.	The CG for each cask cradle is calculated. The combined CG for the rail car and loaded cradles are shown in the rail car attachment calculation CALC-3015276. All are less than the 98 inch limit.	Y
2.2.2.3.c	Cradle shall be capable of handling the loads specified in Section 2.2.2.13 ( Rule 88 loads)	The cradles are demonstrated to meet Rule 88 loadings for all casks within the family.	Y
2.2.2.3.d	Cradle shall be capable in the final design to handle a fatigue evaluation per AAR rules.	The weight margin allowed for the cradle and the design loading for compliance with Rule 88 ensures that there is sufficient margin for the detailed design to comply with the fatigue evaluation require by AAR-2043 which references AAR M-1001.	Y
2.2.2.3.e	Cradle designs shall have hard dimensions for interface to rail car to ensure ability to be attached to rail car.	The rail car interface dimensions are tolerance to ensure fit up.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
2.2.2.4	The conceptual cradle design shall determine the height of the cask center of gravity above the railcar deck, the weight on each axle, etc. as necessary to perform the analysis and provide simulate cradle test weights and supporting information needed for testing the railcar.	Required parameters for testing the rail car are provided in the families individual calculations and in the attachment design calculations.	Y
2.2.2.6	When rotation is necessary, the cradle will include the required hardware, such as trunnion supports.	The cradles where appropriate allow for rotation of the cask in the cradle.	Y
2.2.2.7	The cradles will be tall enough and open-ended so that the impact limiters can be attached to a cask after the cask is secured to the cradle.	The cradle design allows installation of impact limiters after the cask is secured to the cradle.	Y
2.2.2.8	Each cask design will need a cradle designed to position the center of gravity low for stability during transport, but the cradle design will position the impact limiter with a clearance of at least one inch above the cask car deck.	Adequate clearance is allowed for installation of the impact limiters.	Y
2.2.2.9	The cask car (including a cradle and a cask) and buffer car clearances shall fit within AAR Plate C [3], except when loaded with the casks that are more than 128 inches wide (Same as Requirement 2.2.1.12 above).	All cask cradle combinations for the family allow Plate C requirements to be met except for the TN-68 cask which has impact limiters of 144 inches.	Y
2.2.2.10	Demonstrate that bonding weights both min and max meet a combined CG of 98 inches for the railcar, skid and fully loaded and empty cask.(personnel shield, impact limiters etc.)An alternative to adding ballast weight to the railcar may include requiring that the transport cradle for the lighter cask be designed to provide the ballast.	The CG for each cask cradle is calculated. The combined CG for the rail car and loaded cradles are shown in the rail car attachment calculation CALC-3015276. All are less than the 98 inch limit.	Y
2.2.2.11	The various cradles will be designed to fit a standard attachment mechanism. Tolerance to ensure.	Fit the common attachments on the rail car.	Y
2.2.2.12	During loading operations, the cradle may be attached to the railcar first, followed by putting the cask on the cradle, but sometimes the cask will be on the cradle first. In that case, both the cradle and cask together will be hoisted onto the railcar deck. Lifting points permit this handling of the cask	Designs permit loading separately or with the cask on the cradle.	Y
2.2.2.13	The cask railcar shall incorporate a standardized attachment capability for coupling the cask cradle to the railcar. This attachment must be capable of securely attaching loads of up to the maximum cask	Attachments meet rule 88 load requirements.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	weight and the weight cradle. in accordance with the requirements of AAR Rule 88 A16c(3) [7].		
2.2.2.13	AAR Rule 88 A16c(3) does not specify if the securement system loading requirements are to be applied separately or simultaneously. Per direction from KASGRO (via the AAR EEC) transportation loading is not simultaneous and is applied separately. Also gravity is not applied in the vertical up or down accelerations, so +/- 2 g vertical only. Rule 88 A.16.C requires the following tie down loads (g force to yield):	Analyzed according to the direction of the AAR.	
2.2.2.13.a	7.5g Longitudinal	Met for all cradles and casks.	Y
2.2.2.13.b	2g Vertical	Met for all cradles and casks.	Y
2.2.2.13.c	2g Lateral	Met for all cradles and casks.	Y
	<b>Operational Requirements</b>		
	The cradle must accommodate the camber in the rail car.	Interfaces allows for the camber.	Y
	Have clearances to install and remove impact limiters on the rail car.	Clearance provided.	Y
	Features and clearances to load the cask into the cradle on and off the railcar and to be able to load the cradle with the impact limiters and personnel shield if required in place, on rail car.	Features and clearances permits loading with or without the personnel barrier in place to allow for intermodal transfers.	Y
	Operational Steps. Can it be used and how? The loading and unloading steps requested should address that.	Complies with loading procedures.	Y
	<b>Maintenance Requirements</b>		
	Since none of the designs use corrosion resistance material, the life expectancy would be dependent on corrosion control by the use of "high quality weather resistant coatings". Strip and repaint as required. Use wear pads to minimize loss of coatings.	Wear pads and coatings adequately applied	Y
	<b>Additional Design Considerations</b>		
	The cask cradles should be designed to support the cask for lifting on and off the railcar (with or without the cask impact limiters installed) as specified in Section 2.2.2.11 above. Lifting attachments shall be designed in accordance with ANSI N14.6 (i.e. the	Lifting meets ANSI N14.6.	Y

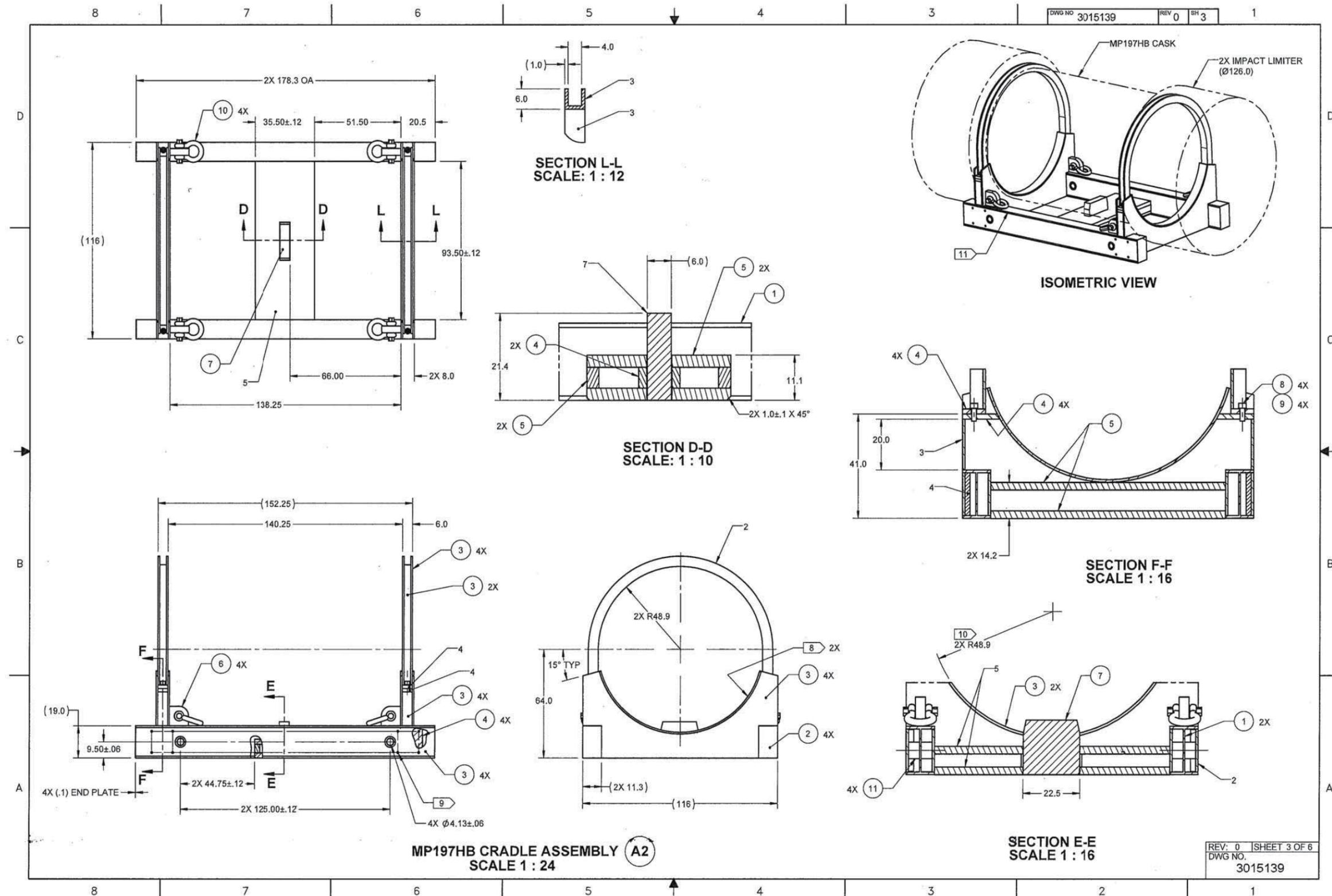
DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	combined maximum tensile stress or the maximum shear stress of all members in the load path shall not exceed smaller of $S_y/3$ or $S_u/5$ . A vertical lift is assumed (requiring the use of a spreader beam/frame). All lift points are assumed to support the load equally for the conceptual design. The lift points should be designed such that the personnel barrier is not removed to lift the cradle when loaded with a package. A dynamic load factor of 1.15 shall be included per the recommendations of CMAA Specification No. 70 [12].		
	For cradle attachment points, the attachment mechanism (pin/bolt) should be removable and shall be sized for manual handling (less than 50 lbs.) or provisions should be designed for mechanically assisted insertion.	Attachments pins have mechanisms for handling	Y
	The bottom of the cradle shall be flat to facilitate placement on a flat surface or intermodal transfer.	Cradle can sit on flat surface.	Y

<sup>1</sup>Approved calculation performed to DBRD Revision 3; all pertinent calculation references are carried forward in Revision 4.

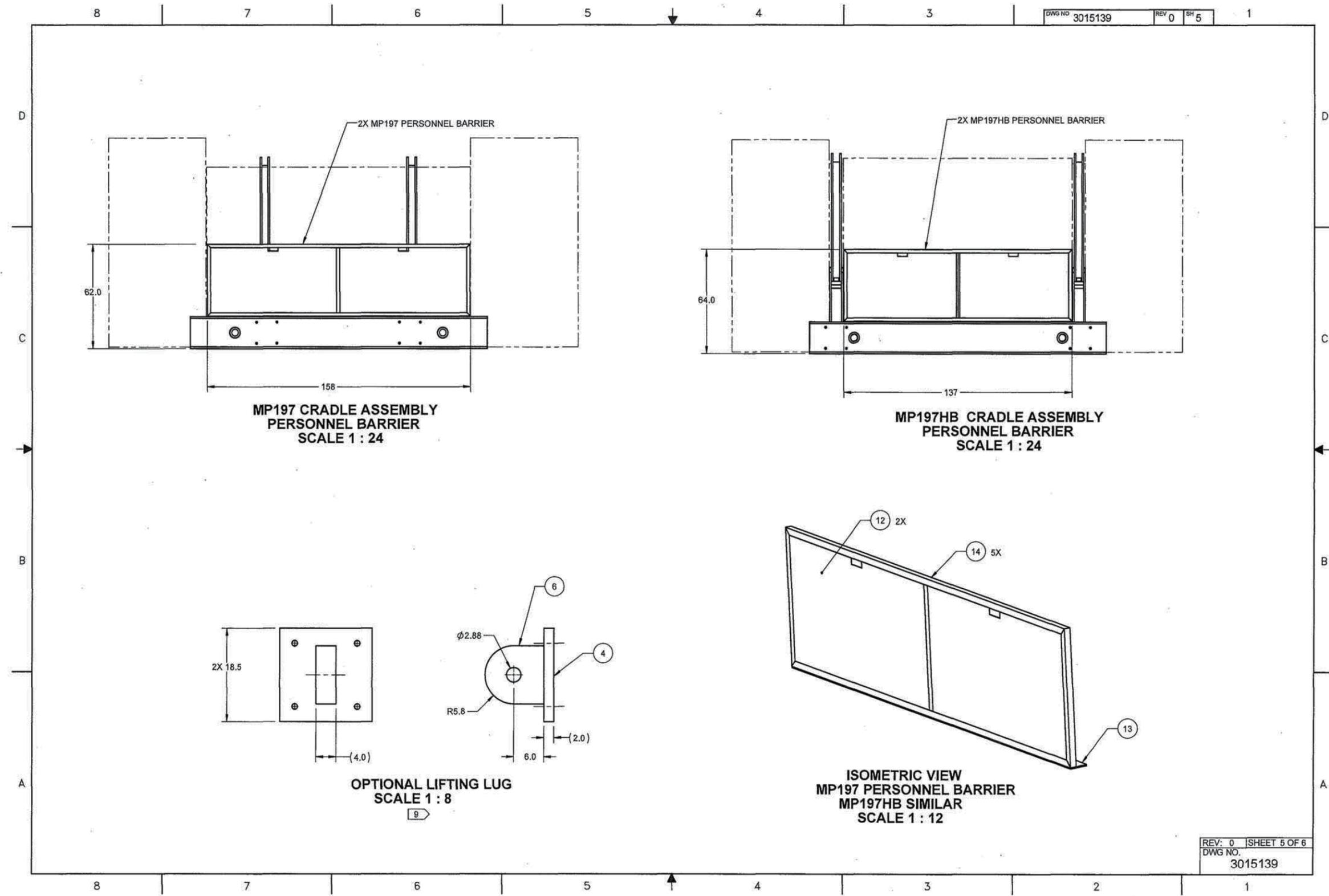
## APPENDIX A.3 – FAMILY 3 CRADLE



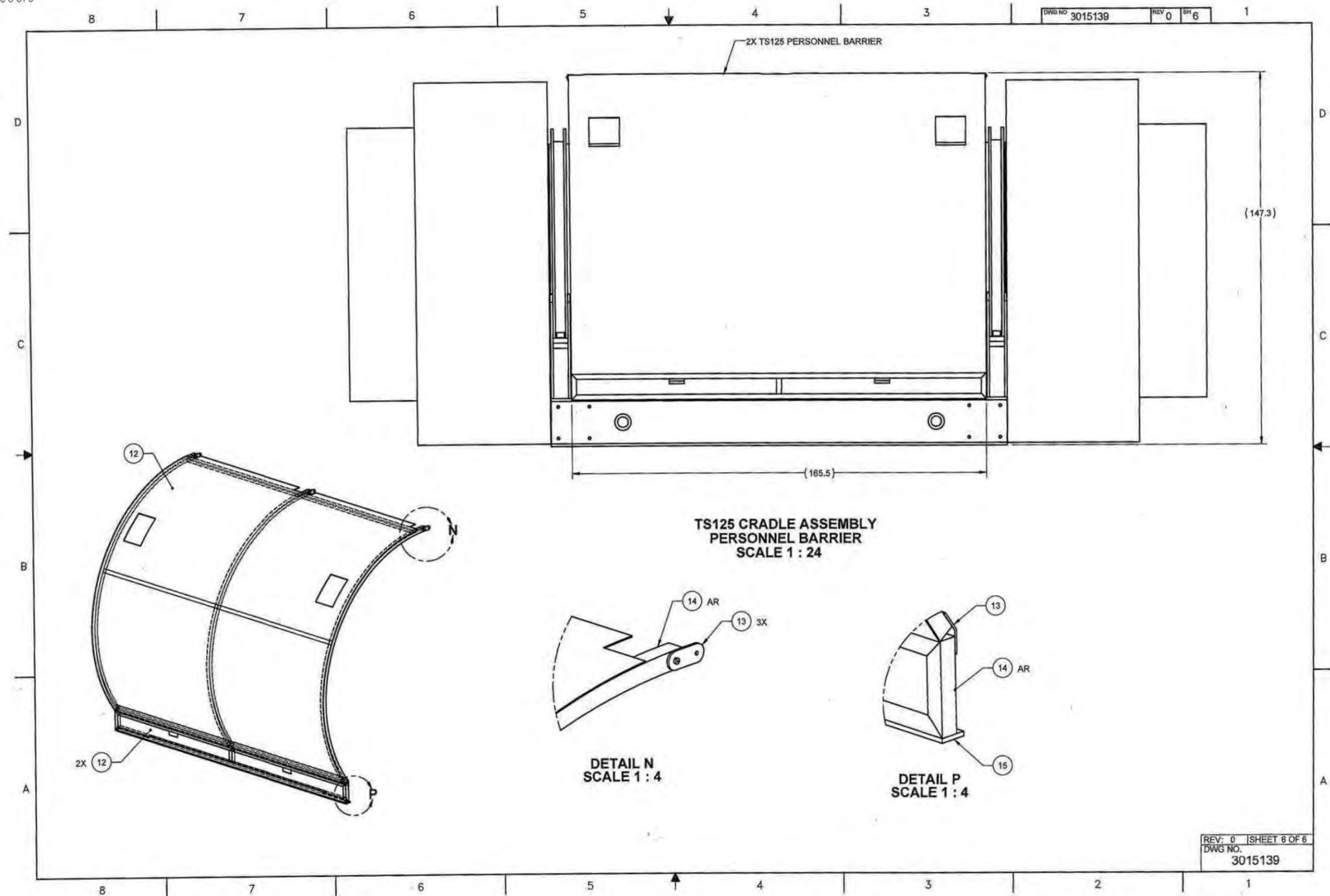






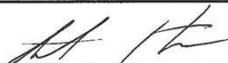


DWG-3015139-000  
Page 6 of 6



## Appendix A.3.2 – Structural Calculation

CALC-3015135-000  
 Page 1 of 40

	AREVA Federal Services LLC		
	CALCULATION		
Document No.:	CALC-3015135	Rev. No.	000
		Page 1 of 40	
Project No.:	00225.03.0050	Project Name:	DOE Atlas Rail Car
Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation			
<b>Summary:</b> This calculation is used to verify the sizing of components for the MP197, MP197HB, and TS125 Atlas Railcar cradles and to present the connection loads to the railcar.			
Contains Unverified Input / Assumptions: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>			
Software Utilized: Microsoft Excel Software Active in AFS EASI: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/> Error Reports & Associated Corrective Actions Reviewed: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>		Version: 14.0.7165.5000 (32-bit)	Storage Media: Yes: <input checked="" type="checkbox"/> No: <input type="checkbox"/>  Location: COLDStor
	Printed Name	Signature	Date
Preparer:	D. Wick		6-29-2016
Checker:	S. Bear		6-29-2016
Approver:	D. Hillstrom		6/29/16
Other:	S. Klein		6/29/16

AFS-EN-FRM-002 Rev. 07 (Effective April 21, 2015)  
 Reference: AFS-EN-PRC-002

AREVA  
 June 30, 2016  
 Records Management



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 2 of 40

**Revision History**

Rev.	Changes
0	Initial Issue



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 3 of 40**

**Table of Contents**

LIST OF TABLES ..... 4

LIST OF FIGURES ..... 5

1.0 PURPOSE ..... 6

2.0 METHODOLOGY ..... 6

    2.1 Acceptance Criteria ..... 7

    2.2 Margin of Safety ..... 7

3.0 ASSUMPTIONS ..... 7

    3.1 Unverified Inputs/Assumptions ..... 7

    3.2 Justified Assumptions ..... 7

4.0 DESIGN INPUTS ..... 8

    4.1 Transportation Package Design Inputs ..... 8

    4.2 Material Properties ..... 9

5.0 CALCULATIONS ..... 9

    5.1 Allowable Stresses ..... 9

    5.2 Cradle Weight Analysis ..... 10

    5.3 Railcar Loads ..... 10

    5.4 MP197 Cradle Structural Analysis ..... 15

        5.4.1 Saddle Tower Stresses ..... 15

        5.4.2 Main Longitudinal Beam Sizing ..... 19

        5.4.3 Tie-Down Restraint Loading ..... 20

        5.4.4 Longitudinal Restraint Loads ..... 22

        5.4.5 Lifting Points ..... 26

    5.5 Fatigue ..... 36

6.0 COMPUTER SOFTWARE USAGE (IF SOFTWARE IS USED) ..... 37

    6.1 Non-Engineering Application Software ..... 37

7.0 RESULTS/CONCLUSIONS ..... 37

    7.1 Include results of applicable literature searches or other applicable background data ..... 37

8.0 REFERENCES ..... 38

APPENDIX A : CUT SHEETS ..... 39



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 4 of 40

**List of Tables**

Table 4.1-1: Package Design Inputs ..... 8  
Table 4.2-1: Material Properties ..... 9  
Table 5.2-1: Cradle Weight and CG Position ..... 10  
Table 5.3-1: Package Reaction Force Calculation Variables ..... 12  
Table 5.3-2: Loads for Each Load Case (kip) ..... 12  
Table 5.3-3: Maximum Railcar Loading (kip) ..... 12  
Table 5.4-1: Longitudinal Loading Data ..... 16  
Table 5.4-2: Longitudinal Loading Loads on Saddle Tower ..... 16  
Table 5.4-3: Saddle Tower Weld Loads ..... 17  
Table 5.4-4: Longitudinal Loading Bending Load on Saddle Tower Support ..... 19  
Table 5.4-5: Bending Loads on Main Beam ..... 20  
Table 5.4-6: Tie-Down Restraint Loading ..... 22  
Table 5.4-7: Shear Key Stress Variables ..... 23  
Table 5.4-8: Shear Key Stress Results ..... 23  
Table 5.4-9: Shear Key Support Box Stress ..... 25  
Table 5.4-10: Longitudinal Restraint Weld Stress ..... 26  
Table 5.4-11: Lifting Loads on Saddle Tower Support ..... 30  
Table 6.1-1: Computer File Listing ..... 37



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 5 of 40

**List of Figures**

Figure 5.3-1: Package and Cradle Longitudinal Loads Free Body Diagram (FBD)..... 13  
Figure 5.3-2: Package and Cradle Lateral Loads FBD..... 13  
Figure 5.3-3: Package and Cradle Vertical Loads FBD..... 14  
Figure 5.3-4: Railcar Load Attachment Features and Locations..... 15  
Figure 5.4-1: Package Longitudinal Reaction Forces on Cradle..... 30  
Figure 5.4-2: Package Vertical forces on Cradle..... 31  
Figure 5.4-3: Longitudinal Loading Tower Compressive Stress ..... 31  
Figure 5.4-4: Longitudinal Load Tower Support Bending Stress ..... 32  
Figure 5.4-5: MP197 Main Beam Loading FBD..... 32  
Figure 5.4-6: MP197HB and TS125 Main Beam Loading FBD..... 33  
Figure 5.4-7: Shear Key FBD..... 33  
Figure 5.4-8: Shear Key Support Box FBD ..... 34  
Figure 5.4-9: Lifting Free Body Diagram ..... 34  
Figure 5.4-10: Typical Lifting Hole FBD ..... 35  
Figure 5.4-11: Lifting Section FBD ..... 35



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 6 of 40

## 1.0 PURPOSE

The United States Department of Energy (DOE) is laying the groundwork for implementing an integrated nuclear waste management system. This includes preparing for future large-scale transport of spent nuclear fuel (SNF), high-level radioactive waste (HLW), and Greater-Than-Class-C (GTCC) waste; since transport will be a necessary component of any integrated nuclear waste management system. With this project the DOE will provide for the transportation of SNF (GTCC is transported similarly to SNF) and HLW by means of a specific railcar to carry SNF and HLW casks. The proposed design is currently known as the Atlas railcar.

A number of transportation packages have been proposed for use in transportation. The focus of this analysis is for a set of cradles designed for one family of transportation packages consisting of the AREVA TN MP197 and MP197HB as well as the Fuel Solutions TS125 (hereafter described as the Family 3 cradles). The packages within this family are designed to directly rest upon two saddles and utilize a shear key receptacle to restrain the package against axial motion. Each package in this family differs in the size and location of the mounting points necessitating three separate cradle designs; one for each package of this family. This calculation provides an analysis of the bounding cradle weights and railcar loads as well as scoping of the conceptual design cradle components.

Sizing of the components and structures for each railcar cradle of this family is dependent on publicly available information for each of the packages. This information is generally limited to the maximum transportation weight and the nominal external package dimensions. While the design information is limited there is still enough available to produce a fairly good conceptual design of the cradle; one that allows us to predict the location and magnitude of the railcar loads based on the predicted weight and dimensions. This calculation will show that the conceptual design of each cradle from this family will support packages during transport. Railcar support loads will also be provided.

The DOE Atlas Cask railcar (and by extension to subsystems the package cradles) must be designed and built to satisfy the requirements of Association of American Railroads (AAR) Standard S-2043 [1], [2]. Application of this standard to the conceptual design analyses is described in Section 2.0.

## 2.0 METHODOLOGY

The weight and CG of each of the three cradle variations is calculated based on the initial family conceptual cradle design drawing [3]. This information will be presented in an accompanying spreadsheet (see Section 6.0) and the results presented in Section 5.2. The combined weight and CG information will be used with the package information to calculate the railcar loads based on the AAR Standards. The design loads on the cradle, taken separately, are 7.5g longitudinally, 2g laterally, and 2g vertically (7.5g/2g/2g) [4]. These loads are provided to the railcar vendor to support their analysis of the railcar.

The conceptual design of each cradle will be evaluated to provide good assurance that a design can be made to support the applied loads. Each cradle will be required to support the 7.5g/2g/2g loads taken individually. In addition, it will be shown that lifting load path components in the cradle can support the combined load of the cradle and package to support transfer between modes of transportation.

The fatigue capability of the design will be explored to provide reasonable assurance that the individual members of the cradle will support the fatigue loads of chapter 7 of M-1001[2] for the design life of the cradle. An analysis of the final design will be required to cover weld details and any design changes that are made at that stage.

Throughout this calculation, analysis of the MP197 cradle will be explicitly performed; followed by a summary of the results for the remaining cradles as required. Analysis of the shackle lift points will be performed using the combined weight of the bounding package and cradle combination for this analysis.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 7 of 40

**2.1 Acceptance Criteria**

Stresses for the tie-down components shall be compared to the allowable stresses. The allowable stress for tie-down components of the cradle is yield stress for tensile and compressive stresses, and six-tenths of yield stress for shear stresses [4].

Based on N14.6 [5] the lifting components shall support one-third of yield stress and one-fifth of ultimate stress of the base material. Shear stresses and weld stresses shall be one-third of the yield strength or one-fifth of the ultimate strength (as appropriate) multiplied against a shear factor of six-tenths [4].

The shackles used in this design are meet ASME B30.26 requirements and have a minimum ultimate load of 5.0 times their working load limit. The cradle lift points were sized to for an 85 metric ton Crosby G-2140 alloy bolt type shackle (Stock No. 1021174, see Appendix A). This shackle already meets the 3/5 requirement based on manufacturer's data. Loads on the shackles shall be less than their Working Load Limit (WLL).

**2.2 Margin of Safety**

A margin of safety is used to indicate the degree of confidence in the allowable loads and stresses. For acceptance the margin of safety must be greater or equal to zero. The margin of safety of component stresses is calculated as:

$$MS = \frac{\text{Allowable Stress}}{\text{Actual Stress}} - 1 \geq 0$$

For load the margin of safety is calculated as:

$$MS = \frac{\text{Allowable Load}}{\text{Actual Load}} - 1 \geq 0$$

**3.0 ASSUMPTIONS**

**3.1 Unverified Inputs/Assumptions**

There are no unverified assumptions in this calculation.

**3.2 Justified Assumptions**

1. Mating points between the cradle and the package are estimated based on publicly available data for this conceptual design. Nominal dimension are adequate for this analysis. Verification of each package's interface dimensions will be required prior to final design of a cradle.
2. Longitudinal loading on the saddle towers is assumed to be negligible. This load is not explicitly analyzed, but support from the shackle lift lugs should accommodate this load. However, it is recommended to shim the contact points between longitudinal load connections between the package and the cradle as well as the cradle to the railcar to prevent this load case from occurring.
3. A four-point vertical lift is used in this analysis. This assumption is justified in that lifting systems can be designed to support equal loads at all four lift points.
4. All welds are assumed to be full penetration. Detailed design may alter the weld configuration as appropriate.
5. No rotation hardware is included in this design. The TN packages are stored and transported horizontally. The fuel solutions package may be rotated from using a separated rotating frame. If designed and used, the rotating frame would attach to the cradle at the rear railcar pin holes.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 8 of 40**

**4.0 DESIGN INPUTS**

**4.1 Transportation Package Design Inputs**

Design inputs for the AREVA TN MP197 and 197HB are from the Certificate of Compliance (CoC) [6] and the non-proprietary version of the Safety Analysis Report (SAR) [7]. Design inputs for the Energy Solutions TS125 package are from the Certificate of Compliance (CoC) [8] and the non-proprietary version of the Safety Analysis Report (SAR) [9]. All documents are publically released documents and available online at the RAMPAC [10] and ADAMS Public Documents [11] websites. Necessary but omitted details are derived from the available documents using scaling of figures or estimations and noted. Other than the CG position the values are also listed in Attachment A of the Statement of Work (SOW) [1]. The design characteristics for each package are summarized in Table 4.1-1.

**Table 4.1-1: Package Design Inputs**

Characteristic	AREVA TN MP197	AREVA TN MP197HB	Energy Solutions TS125
Maximum Package Weight (kip)	265.1	303.6 <sup>(1)</sup>	285
Package Length (in)	281.25	271.25	342.4
Package Diameter (in)	122.0	126.0	143.5
Cask Length (in)	208.0	210.25	210.4
Cask Diameter at Supports (in)	91.5	97.75	94.2
Maximum Cask Diameter (in)	-	104.75 <sup>(2)</sup>	---
Cask Support Separation (in)	88.0 <sup>(3)</sup>	146.25 <sup>(3)</sup>	174.0 <sup>(4)</sup>
Cask Longitudinal CG (in)			
minimum	--	103.5 <sup>(5)</sup>	100.2 <sup>(6)</sup>
maximum	--	105.75 <sup>(5)</sup>	103.2 <sup>(6)</sup>
nominal (average)	102.85 <sup>(5)</sup>	104.63	101.7
Cask Radial CG (in)	At axis	At axis	At axis

- Notes:
1. The weight of the MP197HB is found in Table A.1-1 of the SAR [7]. This value differs from the value originally found in Attachment A of the SOW.
  2. The maximum cask diameter specified for the MP197HB is the outer extension of the removable fin structure.
  3. Estimated based on the inspection of SAR figures (Chapter 1 for MP197 and Section A.4 for the MP197HB.)
  4. The cask support separation of the TS125 package is based on the cradle support thickness [3] and the separation of the impact limiters. Contact with the cask occurs on a raised boss surface 3-inches across on each saddle with a support separation of 178.4 inches (Section 2.5.2.3 of [9]).
  5. Measured from the base of the cask. See SAR Section 2.2 for the MP197 and Section A.2.1.3 for the MP197HB.
  6. Measured from the base of the cask. (See Table 2.2-1 of the SAR [9]).



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 9 of 40**

**4.2 Material Properties**

The material properties listed in Table 4.2-1 are used in the design. The yield and ultimate stresses are the minimum values found in the ASTM standards [12]. Material density is from ASME B&PV Code Section II, Part D Table PRD [13]. The structure is primarily ASTM A514, high yield strength, quenched and tempered alloy steel plate, suitable for welding. This material is suitable for use in low temperature applications and performance can be assured through testing such as a Charpy V-notch impact test. Brittle fracture will be investigated during detailed design [4].

**Table 4.2-1: Material Properties**

Material	Yield Stress (ksi)	Ultimate Stress (ksi)	Density (lb/in <sup>3</sup> )
ASTM A514			0.280
thickness ≤ 2 1/2 in	100	110	
thickness 2 1/2 to 6 in	90	100	
ASTM A540 B24 CL 1	150	165	
ASTM A705 or ASTM A564 XM-16 H900	220	235	
ASTM A992	50	65	

**5.0 CALCULATIONS**

**5.1 Allowable Stresses**

The allowable minimum yield strength and ultimate strength of ASTM A514 is 90 and 100 ksi respectively. The minimum yield and ultimate stress for ASTM A992 is 50 and 65 ksi respectively.

The tie-down loading stresses for the 7.5g/2g/2g load cases are compared directly against yield stress. Based on N14.6-1993[5] the lifting stresses are compared against an allowable of one-third yield stress and one-fifth ultimate stress. All materials, except for the A992 Beams, within the load path or the tie-downs are ASTM A514. The allowable stresses are:

- Tie-down component allowable stress:  $S_{A514T} = S_{yA514} = 90$  ksi
- Tie-down component allowable shear stress:  $S_{A514TS} = 0.6S_{yA514} = 54$  ksi
- ASTM A992 section allowable stress:  $S_{A992} = S_{y992} = 50$  ksi
- ASTM A992 section allowable shear stress:  $S_{A992S} = 0.6S_{y992} = 30$  ksi
- Lifting allowable stress:  $S_{A514L} = \min\left(\frac{S_{yA514}}{3}, \frac{S_{uA514}}{5}\right) = 20$  ksi
- Lifting allowable shear stress:  $S_{A514LS} = 0.6 \times \min\left(\frac{S_{yA514}}{3}, \frac{S_{uA514}}{5}\right) = 12$  ksi
- ASTM A540 fastener allowable stress:  $S_{A540} = S_{yA540} = 150$  ksi
- Shear key allowable stress:  $S_{AXM16} = S_{yXM16} = 220$  ksi
- Shear key allowable shear stress:  $S_{AXM16S} = 0.6S_{yXM16} = 132$  ksi



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 10 of 40**

**5.2 Cradle Weight Analysis**

The weight of each cradle is determined using classical hand calculations and a spreadsheet to facilitate processing of the analysis. The cradle designs are found in drawing DWG-3015139 [3]. The calculation of the nominal weight and vertical CG of each cradle is performed in the file calc-3015135-000 weight.xlsx (see Section 6.0) with a bounding weight and vertical CG position presented in Table 5.2-1. Each cradle is symmetrically designed so that the longitudinal and lateral CG positions occur in the geometric center.

**Table 5.2-1: Cradle Weight and CG Position**

Characteristic	MP197	MP197HB	TS125
Cradle Weight (kip)	26.0	26.0	30.0
Vertical CG Position (in)	17.0	17.5	24.5

**5.3 Railcar Loads**

See Figure 5.3-4 showing rail car load attachment features. The package and cradle are subjected to loads of 7.5g longitudinally and 2g both laterally and vertically. Analysis of the 2g vertical load on the cradle bounds the 1g dead-weight load with a safety margin of 2 to yield. Therefore explicit analysis of the 1g load is not included. This analysis takes the loads individually, and not simultaneous, to determine the maximum connection loads on the railcar [4]. Also, in accordance with the DBRD, gravity is not included as a separate force in railcar load cases. Longitudinal loads are transferred to the railcar by the shear block from the central weldment of the cradle. No longitudinal loads are transmitted through the pin attachment points by design due to assembly fit-up tolerances [14]. Vertical loads are transferred through four pins to pin blocks. Lateral loads are transferred to the railcar directly to the pin blocks. Each load case is taken separately to determine the maximum load on each component. The loads are calculated based on the combined package and cradle weight. For the MP197 package:

- Package weight:  $W_{PKG} = 265.1$  kip
- Cradle weight:  $W_{CD} = 26.0$  kip (bounding weight)
- Combined weight:  $W = W_{PKG} + W_{CD} = 291.1$  kip

The locations of the CGs below are conservatively taken from the bottom surface of the cradle. There is a 1.0 inch gap between the bottom of the cradle and the lowest point of the package impact limiter. The CG is one-half of the package impact limiter diameter found in Table 4.1-1 plus the 1.0 inch gap.

- Package CG height (from bottom of cradle):  $H_{CRP} = \frac{1}{2}(122.0 \text{ in}) + 1.0 \text{ in} = 62.0 \text{ in}$
- Cradle CG height:  $H_{CGC} = 17.0 \text{ in}$
- Combined CG height:  $H_{CG} = \frac{(W_{PKG}H_{CRP} + W_{CD}H_{CGC})}{W} = 58.0 \text{ in}$
- Longitudinal pin separation:  $L_{lon} = 125.0 \text{ in}$
- Lateral pin separation:  $L_{lat} = 116.0 \text{ in} - 11.25 \text{ in} = 104.8 \text{ in}$
- Cask Length:  $L_{csk} = 208.0 \text{ in}$
- Nominal CG position from cask bottom:  $L_{cgn} = 102.85 \text{ in}$
- Difference from geometric center:  $\Delta_{gc} = \frac{1}{2}L_{csk} - L_{cgn} = 1.15 \text{ in}$
- Longitudinal CG from forward pins:  $L_{cg} = \frac{1}{2}L_{lon} - \Delta_{gc} = 61.4 \text{ in}$



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 11 of 40**

Longitudinal load:	$F_{LON} = 7.5W = 2,183 \text{ kip}$
Vertical load:	$F_{VER} = 2W = 582.2 \text{ kip}$
Lateral load:	$F_{LAT} = 2W = 582.2 \text{ kip}$

Longitudinal Loading Induced Pin Load

The schematic for the loads is shown in Figure 5.3-1. The system equilibrium equations are:

Sum of moments at front pin:	$\Sigma M_F = H_{cg}(F_{LON}) - L_{lon}(2R_B) = 0$
Sum of vertical forces:	$\Sigma F_z = 2R_F - 2R_B = 0$
Sum of longitudinal forces:	$\Sigma F_x = R_{SK} - F_{LON} = 0$

The loads on the railcar from the equilibrium equations are:

Rear pin load:	$R_B = \frac{H_{cg}}{2L_{lon}} F_{LON} = 506.5 \text{ kip}$
Front pin load:	$R_F = R_B = 506.5 \text{ kip}$
Shear block load:	$R_{SK} = F_{LON} = 2,183 \text{ kip}$

Lateral Loading Induced Pin Load

The schematic for the lateral load is shown in Figure 5.3-2. The system equilibrium equations are:

Sum of moments at left-hand side pin:	$\Sigma M_L = H_{cg}F_{lat} - L_{lat}(2R_R) = 0$
Sum of lateral forces:	$\Sigma F_y = 2R_{SB} - F_{LAT} = 0$
Sum of vertical forces:	$\Sigma F_z = 2R_L - 2R_R = 0$

The loads on the railcar from the equilibrium equations are:

Right pin loads:	$R_R = \frac{H_{cg}}{2L_{lat}} F_{LAT} = 161.1 \text{ kip}$
Left pin loads:	$R_L = R_R = 161.1 \text{ kip}$
Pin block shear load:	$R_{SB} = \frac{1}{2} F_{LAT} = 291.1 \text{ kip}$

Vertical Loading Induced Pin Load (Direction can be up or down)

The schematic for the vertical load is shown in Figure 5.3-3. The system equilibrium equations are:

Sum of moments at front pin:	$\Sigma M_f = L_{cg}(F_{VER}) - L_{lon}(2R_B) = 0$
Sum of vertical forces:	$\Sigma F_z = F_{VER} - 2R_F - 2R_B = 0$

The loads on the railcar from the equilibrium equations are:

Rear pin load:	$R_B = \frac{L_{cg}}{2L_{lon}} F_{VER} = 143.0 \text{ kip}$
Front pin load:	$R_F = \frac{1}{2} F_{VER} - R_B = 148.1 \text{ kip}$

The input variables and calculated reaction forces are shown in Table 5.3-1 through Table 5.3-3 for all three packages and load cases.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 12 of 40

**Table 5.3-1: Package Reaction Force Calculation Variables**

Package	Weight (kip)			CG Position (in) <sup>(1)</sup>		
	Package, W <sub>PKG</sub>	Cradle, W <sub>CD</sub>	Combined, W	Package, H <sub>egp</sub>	Cradle, H <sub>egc</sub>	Combined, H <sub>cg</sub>
MP197	265.1	26.0	291.1	62.0	17.0	58.0
MP197HB	303.6	26.0	329.6	64.0	17.5	60.3
TS125	285.0	30.0	315.0	72.8	24.5	68.2

Notes: (1) The vertical CG position of the package and cradle are measured from the bottom surface of the cradle.

**Table 5.3-2: Loads for Each Load Case (kip)**

Package	Longitudinal Load Case		Lateral Load Case		Vertical Load Case	
	Vertical Pin Loads (+/-)	Shear Block Load	Vertical Pin Loads (+/-)	Lateral Block Load	Front Pin Loads	Rear Pin Loads
MP197	506.5	2,183	161.1	291.1	143.0	148.1
MP197HB	596.2	2,472	189.6	329.6	163.5	166.1
TS125	644.6	2,363	205.0	315.0	148.7	166.3

**Table 5.3-3: Maximum Railcar Loading (kip)**

Location/Load	MP197	MP197HB	TS125
Pin Blocks			
Vertical (+z)	506.5	596.2	644.6
Vertical (-z)	506.5	596.2	644.6
Lateral (y)	291.1	329.6	315.0
Shear Block			
Axial (x)	2,183	2,472	2,363

Note: See Figure 5.3-4 for the locations railcar loads are applied.



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 13 of 40

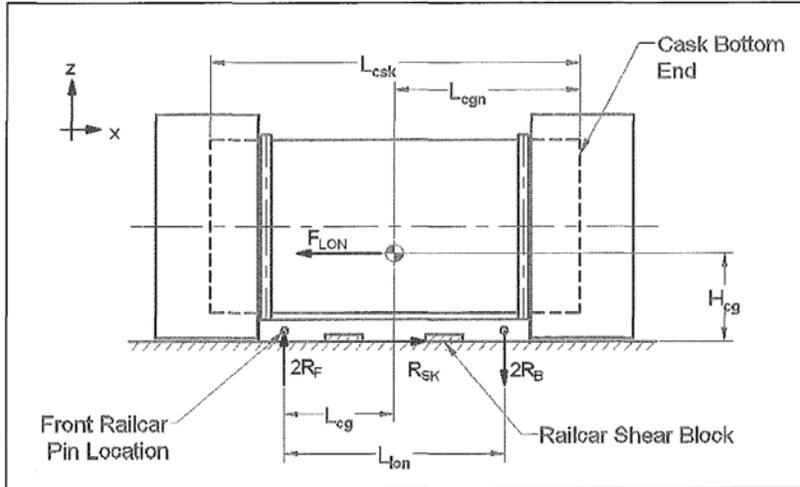


Figure 5.3-1: Package and Cradle Longitudinal Loads Free Body Diagram (FBD)

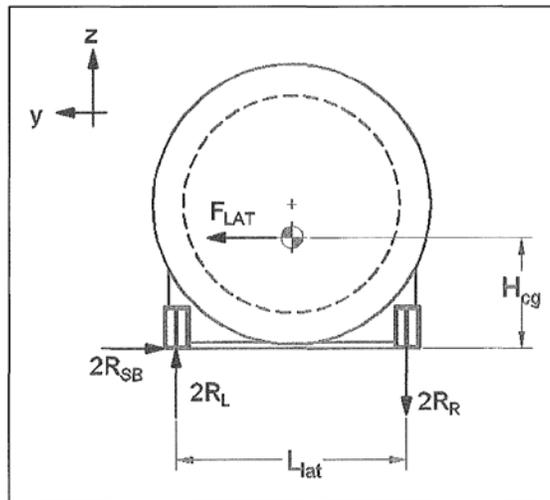


Figure 5.3-2: Package and Cradle Lateral Loads FBD



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

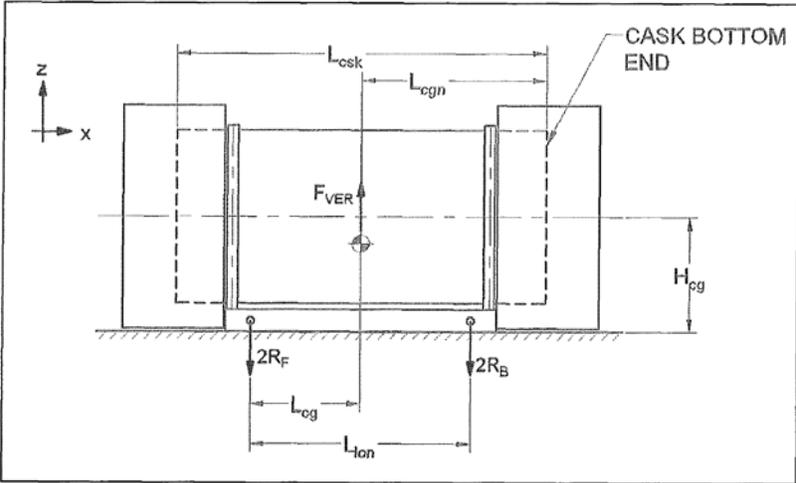


Figure 5.3-3: Package and Cradle Vertical Loads FBD



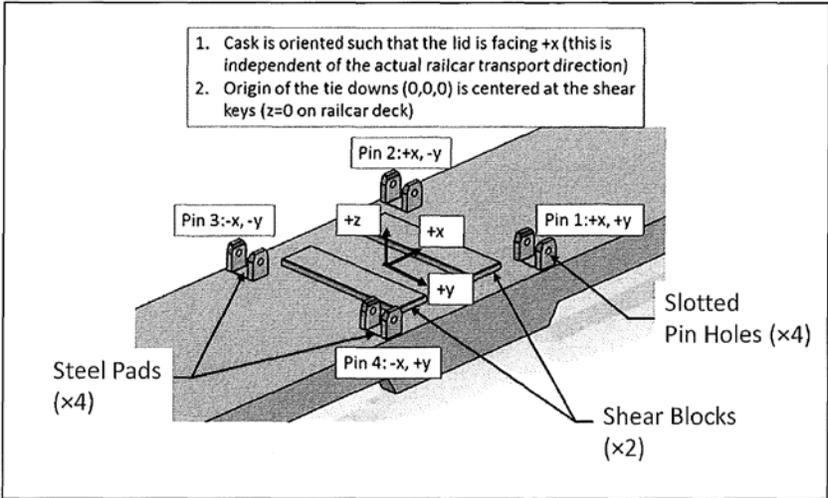
**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 15 of 40**



**Figure 5.3-4: Railcar Load Attachment Features and Locations**

**5.4 MP197 Cradle Structural Analysis**

**5.4.1 Saddle Tower Stresses**

**5.4.1.1 Longitudinal Loads on Saddle Tower**

The longitudinal load case presents the highest loads on the cradle saddle towers due to the internal reactions to the induced pin loads derived earlier. The forward saddle tower takes a downward (compressive) load while the rear saddle tower supports an upward (tensile) load. The towers are short columns with compact sections and therefore no buckling is expected. There will be some longitudinal loading due to delayed contact with the shear block contact due to friction if there is a gap, but these are assumed to be negligible [Justified Assumption 2]. An explicit analysis of the MP197 cradle is shown with tabulated results for the remaining cradles included at the end of each section.

**5.4.1.1.1 Compressive/Tensile Load**

The compressive load is taken across the full width of the saddle tower. The longitudinal load is 7.5 times the weight and directly countered by the cradle shear key with a couple load on the saddle towers (See Figure 5.4-1).

Package weight:	$W = 265.1 \text{ kip}$
Package radius:	$R = 45.75 \text{ in}$
Saddle separation:	$L_{ton} = 88.0 \text{ in}$
Sum of moments:	$\Sigma M: R_b = R_f = 7.5W \frac{R}{L_{ton}} = 1,034 \text{ kip}$
Tower load:	$F = R_f = 1,034 \text{ kip}$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 16 of 40

Width of tower:	$w_t = 112$ in
Thickness of cradle tower:	$t_t = 8.0$ in
Thickness of tower plates:	$t_{pl} = 1.0$ in
Stress area:	$A = w_t t_t - (w_t - 2t_{pl})(t_t - 2t_{pl}) = 236$ in <sup>2</sup>
Compressive stress on tower:	$\sigma_A = \frac{F}{A} = 4.38$ ksi
Allowable stress:	$S_A = S_{A514T} = 90$ ksi
Margin of safety:	$MS = \frac{S_A}{\sigma_A} - 1 = +19.5$

The variable characteristics of the cradle and the calculated stresses are shown in Table 5.4-1 and Table 5.4-2 for each package. The margin of safety is positive in all cases showing that the section can support the applied loads.

**Table 5.4-1: Longitudinal Loading Data**

Package	Cask Radius, R (in)	Saddle Separation, L <sub>lon</sub> (in)	Tower Width, w <sub>t</sub> (in)	Package Weight, F (kip)
MP197	45.75	88.0	112	265.1
MP197HB	48.88	146.3	116	303.6
TS125	47.10	174.0	116	285.0

**Table 5.4-2: Longitudinal Loading Loads on Saddle Tower**

Package	Tower Loads, R <sub>f</sub> and R <sub>b</sub> (kip)	Stress, $\sigma_A$ (ksi)	Margin of Safety
MP197	1,034	4.38	19.5
MP197HB	761.0	3.12	27.8
TS125	579.0	2.37	37.0

Note that the tensile load on the rear saddle tower is the same magnitude as the compressive load on the front tower. When in tension the loads are transmitted directly through the tower plates to the side rails through full penetration welds. Due to the location of the loads on the side of the tower they may be analyzed in direct shear.

Width of beam (W18X119):	$w_b = 11.3$ in
Width of cradle:	$w_c = 116.0$ in
Width of tower:	$w_t = 8.0$ in
Weld section length:	$b_w = w_b - (w_c - w_t) = 9.3$ in
Weld section height (W18X119):	$d_w = 19.0$ in
Weld thickness:	$t_w = t_{pl} = 1.0$ in



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 17 of 40

Weld area:  $A_w = 2t_w(b_w + d_w) = 56.6 \text{ in}^2$

Weld stress:  $\tau_w = \frac{F}{2A_w} = 9.13 \text{ ksi}$

Tie-down component allowable shear stress:  $S_A = S_{A992S} = 30 \text{ ksi}$

Margin of safety:  $MS = \frac{S_A}{\tau_w} - 1 = 2.29$

The pertinent information for the weld analysis is presented in Table 5.4-3. The weld area is shown to support the applied shear load.

**Table 5.4-3: Saddle Tower Weld Loads**

Package	$b_w$ (in)	$A_w$ (in <sup>2</sup> )	$\tau_w$ (ksi)	MS
MP197	9.3	56.6	9.13	2.29
MP197HB	11.3	60.6	6.28	3.78
TS125			4.78	5.28

**5.4.1.1.2 Bending Load due to Moment**

Calculation of the bending stresses due to the tower load is computed across the width of the tower as a simply supported distributed load. Conservatively the bending analysis is limited to the cross-section of the tower designed to support the applied load; the section between the outer surfaces of the two 3-inch thick horizontal plates at the base of each tower (see Figure 5.4-4). The actual cross section increases, following the curve of the saddle, and continuing on through the saddle bolt plates and saddle walls.

Section height:  $d_{xc} = 15.3 \text{ in}$

Horizontal plate thickness:  $t_{hp} = 3.0 \text{ in}$

Beam section length:  $w_b = w_t = 112.0 \text{ in}$

Maximum bending moment:  $M = \frac{Fw_b}{8} = 14.5 \times 10^3 \text{ in} - \text{kip}$

Cross section area:  $A_{xc} = t_d d_{xc} - (t_t - 2t_{pl})(d_{xc} - 2t_{hp}) = 66.6 \text{ in}^2$

Cross section moment of inertia:  $I_{xc} = \frac{1}{12}t_d(d_{xc})^3 - \frac{1}{12}(t_t - 2t_{pl})(d_{xc} - 2t_{hp})^3$   
 $I_{xc} = 1.986 \times 10^3 \text{ in}^4$

Max fiber length:  $c = \frac{1}{2}d_{xc} = 7.65 \text{ in}$

Bending stress:  $\sigma_b = \frac{Mc}{I_{xc}} = 55.9 \text{ ksi}$

Allowable stress:  $S_A = S_{A514T} = 90 \text{ ksi}$

Margin of safety:  $MS = \frac{S_A}{\sigma_b} - 1 = 0.61$

Shear stress:  $\tau = \frac{F}{A_{xc}} = 15.5 \text{ ksi}$

Allowable stress:  $S_A = S_{A514TS} = 54 \text{ ksi}$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 18 of 40

Margin of safety:  $MS = \frac{S_A}{\tau} - 1 = 2.48$

The moment of inertia at the transition to the built-up section of I-beam is also of concern. The section up to the top surface of the saddle bolt plate and within the eight-inch width of the saddle tower is considered. To demonstrate that the connecting welds are more than adequate to support the load the maximum moment will be used to calculate the stress. Dimensions can be found in Zone C3 on Sheets 2, 3, and 4 of the drawing [3].

Section height:  $d_s = 42.0$  in

Flange thickness:  $t_f = 1.06$  in

Bolt Plate thickness:  $t_{bp} = 2.0$  in

End Plate length:  $t_{ep} = 21.0$  in

Lower flange centroid height:  $h_{f1} = \frac{1}{2}t_f = 0.53$  in

Upper flange centroid height:  $h_{f2} = d_w - \frac{1}{2}t_f = 18.5$  in

Side plate centroid height:  $h_{sp} = d_w + \frac{1}{2}h_{ep} = 29.5$  in

Bolt plate centroid height:  $h_{bp} = d_s - \frac{1}{2}t_{bp} = 41.0$  in

Flange area:  $A_f = t_f t_f = 8.5$  in<sup>2</sup>

Side plate area:  $A_{sp} = t_{pl} h_{sp} = 21.0$  in<sup>2</sup>

Bolt plate area:  $A_{bp} = t_t t_{bp} = 16.0$  in<sup>2</sup>

Section Area:  $A_s = 2A_f + 2A_{sp} + A_{bp} = 75.0$  in<sup>2</sup>

Section centroid height:  $\bar{y} = \frac{A_f(h_{f1} + h_{f2}) + 2A_{sp}h_{sp} + A_{bp}h_{bp}}{A_s} = 27.4$  in

Lower flange moment of inertia:  $I_{f1} = \frac{1}{12}t_f t_f^3 + A_f(h_{f1} - \bar{y})^2 = 6.138 \times 10^3$  in<sup>4</sup>

Upper flange moment of inertia:  $I_{f2} = \frac{1}{12}t_f t_f^3 + A_f(h_{f2} - \bar{y})^2 = 0.674 \times 10^3$  in<sup>4</sup>

Side plate moment of inertia:  $I_{sp} = 2 \left[ \frac{1}{12}t_{pl} h_{ep}^3 + A_{sp}(h_{sp} - \bar{y})^2 \right] = 1.729 \times 10^3$  in<sup>4</sup>

Bolt plate moment of inertia:  $I_{bp} = \frac{1}{12}t_t t_{bp}^3 + A_{bp}(h_{bp} - \bar{y})^2 = 2.965 \times 10^3$  in<sup>4</sup>

Section moment of inertia:  $I_s = I_{f1} + I_{f2} + I_{sp} + I_{bp} = 11.506 \times 10^3$  in<sup>4</sup>

Max fiber length:  $c = \text{maximum}(d_s - \bar{y}, \bar{y}) = 27.4$  in

Bending stress:  $\sigma_b = \frac{Mc}{I_s} = 34.5$  ksi

Allowable stress:  $S_A = S_{A992} = 50$  ksi

Margin of safety:  $MS = \frac{S_A}{\sigma_b} - 1 = 0.45$

Shear stress:  $\tau = \frac{F}{A_s} = 13.8$  ksi

Allowable stress:  $S_A = S_{A992S} = 30$  ksi



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 19 of 40**

Margin of safety:  $MS = \frac{S_A}{\tau} - 1 = 1.17$

The section height of the each cradle and the resultant stresses are shown in Table 5.4-4. The margin of safety is positive in all cases showing that the section can support the applied loads. No additional build-up of the section should be required.

**Table 5.4-4: Longitudinal Loading Bending Load on Saddle Tower Support**

Package	Section Height (in)	Bending Load, $\sigma_b$		Shear Load, $\tau$	
		Stress (ksi)	Margin of safety	Stress (ksi)	Margin of Safety
Simplified Section through Saddle Tower					
MP197	15.3	55.9	0.61	15.5	2.48
MP197HB	14.2	47.8	0.88	11.8	3.58
TS125	18.6	23.7	2.80	7.91	5.83
Section with A992 W18X119 built-up Beam <sup>(1)</sup>					
MP197	42.0	34.5	0.45	13.8	1.17
MP197HB	40.0	28.3	0.77	10.4	1.88
TS125	40.0	21.6	1.31	7.93	2.78

Notes: 1. Based on the maximum moment rather than actual moment at the cross section.

**5.4.2 Main Longitudinal Beam Sizing**

There are two beams running the longitudinal length of the package that are pinned and transfer cradle loads to the railcar deck. The beams are resting on pads located at the pin attachment blocks and raised above the railcar deck and are therefore simply supported. Two reinforced W18x119 structural members are proposed by the conceptual design to support the expected loads. Conservatively, the analysis omits the reinforcing plates. The loads on the beam consist of the pin loads described in Section 5.3 and the package loads on the saddles from Section 5.4.1.1. See Figure 5.4-5 for the free body diagram.

Package weight:	$W = 265.1 \text{ kip}$
Longitudinal pin separation:	$x_p = 125 \text{ in}$
Longitudinal saddle separation:	$x_s = 88.0 \text{ in}$
Cask support radius:	$R = 45.75 \text{ in}$
Maximum rear saddle load:	$A_B = 1,034 \text{ kip}$ ( $R_B$ from Section 5.4.1.1),
Maximum front saddle load:	$A_F = 1,034 \text{ kip}$ ( $R_F$ from Section 5.4.1.1)
Pin-to-saddle separation:	$x_o = \frac{1}{2}(x_p - x_s) = 18.5 \text{ in}$
Maximum rear railcar pin load:	$R_B = 505.9 \text{ kip}$ ( $R_B$ from Section 5.3)
Maximum front railcar pin load:	$R_F = 505.9 \text{ kip}$ ( $R_F$ from Section 5.3)
Maximum moment:	$M_{\max} = R_F x_o = 9.370 \times 10^3 \text{ in} - \text{kip}$
Section moment of inertia:	$I_w = 2,190 \text{ in}^4$ (For AISC W18x119 W section beam)
Section height:	$d_w = 19.0 \text{ in}$ (For AISC W18x119 W section beam)



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 20 of 40**

Maximum stress distance:	$c_w = \frac{1}{2}d_w = 9.50 \text{ in}$
Maximum bending stress:	$\sigma = \frac{M_{mx}c_w}{I_w} = 40.6 \text{ ksi}$
Allowable stress:	$S_A = S_{A992} = 50 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma} - 1 = 0.23$

For the MP197HB and TS125 the calculation is slightly different due to the pin and saddle positions (see Figure 5.4-6). Calculating for the MP197HB:

Package weight:	$W = 303.6 \text{ kip}$
Longitudinal pin separation:	$x_p = 125 \text{ in}$
Longitudinal saddle separation:	$x_s = 146.3 \text{ in}$
Cask support radius:	$R = 48.88 \text{ in}$
Maximum rear saddle load:	$A_B = 761.0 \text{ kip}$ ( $R_B$ from Section 5.4.1.1),
Maximum front saddle load:	$A_F = 761.0 \text{ kip}$ ( $R_F$ from Section 5.4.1.1)
Pin-to-saddle separation:	$x_o = \frac{1}{2}(x_s - x_p) = 10.6 \text{ in}$
Maximum rear railcar pin load:	$R_B = 596.2 \text{ kip}$ ( $R_B$ from Section 5.3)
Maximum front railcar pin load:	$R_F = 596.2 \text{ kip}$ ( $R_F$ from Section 5.3)
Maximum moment:	$M_{mx} = \frac{1}{2}A_Fx_o = 4.033 \times 10^3 \text{ in-kip}$
Maximum bending stress:	$\sigma = \frac{M_{mx}c_w}{I_w} = 17.5 \text{ ksi}$
Allowable stress:	$S_A = S_{A992} = 50 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma} - 1 = 1.86$

The results are shown in Table 5.4-5. The margin of safety is positive in all cases showing that the section can support the applied loads.

**Table 5.4-5: Bending Loads on Main Beam**

Package	Moment (in-kip)	Bending Stress (ksi)	Margin of safety
MP197	$9.370 \times 10^3$	40.6	0.23
MP197HB	$4.033 \times 10^3$	17.5	1.86
TS125	$7.093 \times 10^3$	30.8	0.62

**5.4.3 Tie-Down Restraint Loading**

The bounding load on the tie-down restraint is due to the 7.5g longitudinal load. The tie-down restraint is a steel band, U-shaped with a constant thickness of 1.0 inches. The tie-down is secured to the frame using two 2.50-inch diameter fasteners placed in tension.

Tower load:	$F = 1,034 \text{ kip}$
-------------	-------------------------



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 21 of 40

Tensile load:	$T = \frac{1}{2}F = 517.0 \text{ kip}$
Width of band:	$w_b = 6.0 \text{ in}$
Thickness of plate:	$t_b = 1.0 \text{ in}$
Height of cross section:	$h_b = 4.0 \text{ in}$
Tensile area of band:	$A_{TB} = w_b h_b - (w_b - 2t_b)(h_b - t_b) = 16.0 \text{ in}^2$
Tensile stress:	$\sigma_B = \frac{T}{A_{TB}} = 32.3 \text{ ksi}$
Allowable stress:	$S_A = S_{A514T} = 90 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma_B} - 1 = 1.79$

The fastener is calculated from the minimum pitch diameter using the tensile area formula for steels over 100,000 psi in ultimate strength (page 1490 of the Machinery's Handbook [15]). The thread analyzed is for a 2-1/2 inch bolt with eight threads per inch; but any standard 2-1/2 inch thread size will work.

Fastener minimum pitch diameter:	$E_{smin} = 2.4082 \text{ in}$
Number of threads per inch:	$n = 8$
Tensile area of fastener:	$A_F = 3.1416 \left( \frac{E_{smin}}{2} - \frac{0.1623n}{n} \right)^2 = 4.408 \text{ in}^2$
Tensile stress of fastener:	$\sigma_F = \frac{T}{A_F} = 117.4 \text{ ksi}$
Allowable stress:	$S_A = S_{A540} = 150 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma_F} - 1 = 0.28$

The loads and stress results for the cradle tie-down restraint are shown in Table 5.4-6 for each package. The margin of safety is positive in all cases showing that the section can support the applied loads.

Since the base metal has a much lower stress limit than the bolting material Tear-out of the threaded hole is checked. The shear area formula and thread sizing information is from the Machinery's Handbook [15]. For the MP197 package the thread tear-out stress is:

Length of thread engagement:	$L_e = 2.0 \text{ in}$
Bolt thread minimum major diameter <sup>1</sup> :	$D_{smin} = 2.4751 \text{ in}$
Hole maximum pitch diameter:	$E_{nmax} = 2.4294 \text{ in}$
Internal thread shear area:	$A_S = 3.1416nL_e D_{smin} \left[ \frac{1}{2n} + 0.57735 * (D_{smin} - E_{nmax}) \right]$
	$A_S = 11.06 \text{ in}^2$
Shear stress:	$\tau = \frac{T}{A_S} = 46.7 \text{ ksi}$
Allowable stress:	$S_A = S_{A514TS} = 54 \text{ ksi}$

<sup>1</sup> This case is using the minimum external thread major diameter for unfinished hot-rolled material not including standard fasteners with rolled threads from the Machinery's handbook.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 22 of 40

Margin of safety:  $MS = \frac{S_A}{\tau} - 1 = 0.16$

The positive margin of safety shows that the base material will support the applied load. An improvement in tear-out could be made to increase the margin by adding a backing plate to the threaded hole. Since the tensile load is much greater on the MP197 cradle this analysis bounds that of the MP197HB and TS125 cradles.

**Table 5.4-6: Tie-Down Restraint Loading**

Package	Tensile Load (kip)	Band		Fastener	
		Tensile Stress (ksi)	Margin of Safety	Tensile stress (ksi)	Margin of Safety
MP197	517.0	32.3	1.79	117.4	0.28
MP197HB	380.5	23.8	2.78	86.4	0.74
TS125	289.5	18.1	3.97	65.8	1.28

**5.4.4 Longitudinal Restraint Loads**

The longitudinal load is directly reacted by the shear key which is connected to the cradle through the cradle shear box. The longitudinal load on the cradle is supported along the length of the shear box by the railcar attachment shear block. A couple-moment is applied to the section and the end welds. The load produces a moment on the shear box and the connecting welds.

**5.4.4.1 Shear Key Bending and Shear Stress**

The shear key supports the 7.5g longitudinal cask restraint load near its top end. The bottom end is supported by the shear key support box. The shear key is modeled as a cantilever beam. The length of this support is equal to the height of the shear key support box. See Figure 5.4-7 for the free body diagram and Table 5.4-7 for the variables used for each of the three cradles.

Package weight:	$W = 265.1 \text{ kip}$
Shear key load:	$F_{SK} = 7.5W = 1,988 \text{ kip}$
Shear key elevation:	$h_k = 22.1 \text{ in}$
Shear key restraint height:	$d_k = 15.5 \text{ in}$
Shear key width:	$y_k = 22.5 \text{ in}$
Shear key thickness:	$x_k = 6.0 \text{ in}$
Sum of moments:	$\Sigma M_2 = h_k F_{SK} - d_k R_1 = 0$
Top plate reaction force:	$R_1 = \frac{h_k}{d_k} F_{SK} = 2,835 \text{ kip}$
Sum of forces:	$\Sigma F = F_{SK} + R_2 - R_1 = 0$
Bottom plate reaction force:	$R_2 = R_1 - F_{SK} = 847 \text{ kip}$
Maximum shear force:	$V = R_1 = 2,835 \text{ kip}$
Maximum moment:	$M = (h_k - d_k) F_{SK} = 13,121 \text{ in} - \text{kip}$
Maximum stress distance:	$c_k = \frac{1}{2} x_k = 3.0 \text{ in}$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 23 of 40

Section area:	$A_k = y_k x_k = 135 \text{ in}^2$
Section moment of inertia:	$I_k = \frac{1}{12} y_k x_k^3 = 405 \text{ in}^4$
Shear stress:	$\tau_k = \frac{V}{A_k} = 21.0 \text{ ksi}$
Allowable stress:	$S_A = S_{yXM16S} = 132 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\tau_k} - 1 = 5.29$
Bending stress:	$\sigma = \frac{M C_k}{I_k} = 97.2 \text{ ksi}$
Allowable stress:	$S_A = S_{yXM16} = 220 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma} - 1 = 1.26$

The loads and stress results for the shear key support box stress are shown in Table 5.4-8 for each package. The margin of safety is positive in all cases showing that the section can support the applied loads. Note that the margin on the TS125 package is positive, but quite small. The shear key support box could be modified to increase the margin with minimal weight increase by increasing its elevation and reducing the length of the shear key.

**Table 5.4-7: Shear Key Stress Variables**

Package	Elevation, $h_k$ (in)	Restraint Height, $d_k$ (in)	Restraint thickness, $x_k$ (in)	Restraint width, $y_k$ (in)	Shear Key Load, $F_{sk}$ (kip)
MP197	22.1	15.5	6.0	22.5	1,988
MP197HB	21.4	11.1			2,277
TS125	31.6	18.5			2,138

**Table 5.4-8: Shear Key Stress Results**

Package	Shear Stress, $\tau_k$ (ksi)	Margin of Safety	Bending Stress, $\sigma$ (ksi)	Margin of Safety
MP197	21.0	5.29	97.2	1.26
MP197HB	32.5	3.06	174	0.26
TS125	27.1	3.87	207	0.06

**5.4.4.2 Shear Key Support Box Stress**

The shear key support box is intended to be in contact with the railcar shear support block over its full length. The stresses in the shear key support box are due to the torsional loading from the load applied from the package to the cradle weldment. See Figure 5.4-8 for the Free Body Diagram.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 24 of 40**

Shear key load:	$F_{SK} = 1,988 \text{ kip}$ (Section 5.4.4.1)
Shear key elevation:	$h_k = 22.1 \text{ in}$
Shear key restraint height:	$d_k = 15.5 \text{ in}$
Shear key restraint beam width:	$b_k = 35.5 \text{ in}$
Shear key restraint beam wall thickness:	$t_k = 3.0 \text{ in}$
Shear key load arm length:	$l_k = h_k - \frac{1}{2}d_k = 14.4 \text{ in}$
Applied torsion:	$T = \frac{1}{2}l_k F_{SK} = 14.26 \times 10^3 \text{ in} \cdot \text{kip}$
Shear load:	$V = F_{SK} = 1,988 \text{ kip}$
Vertical chord distance:	$c_z = \frac{1}{2}d_k = 7.75 \text{ in}$
Horizontal chord distance:	$c_x = \frac{1}{2}b_k = 17.9 \text{ in}$
Cross sectional area:	$A = d_k b_k - (d_k - 2t_k)(b_k - 2t_k) = 270.0 \text{ in}^2$
Moment of inertia x-x:	$I_{xx} = \frac{1}{12} [b_k d_k^3 - (b_k - 2t_k)(d_k - 2t_k)^3]$ $I_{xx} = 8.909 \times 10^3 \text{ in}^4$
Moment of inertia z-z:	$I_{zz} = \frac{1}{12} [d_k b_k^3 - (d_k - 2t_k)(b_k - 2t_k)^3]$ $I_{zz} = 37.464 \times 10^3 \text{ in}^4$
Polar Moment of inertia:	$J = I_{xx} + I_{zz} = 46.373 \times 10^3 \text{ in}^4$
Horizontal torsional stress component:	$\tau'_x = \frac{T c_z}{J} = 2.38 \text{ ksi}$
Shear Stress:	$\tau'_y = \frac{V}{A} = 7.36 \text{ ksi}$
Vertical torsional stress component:	$\tau'_z = \frac{T c_x}{J} = 5.48 \text{ ksi}$
Combines shear stress:	$\tau = \sqrt{(\tau'_x + \tau'_z)^2 + \tau'_y^2} = 11.2 \text{ ksi}$
Allowable shear stress:	$S_A = S_{A514TS} = 54 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\tau} - 1 = 3.82$

The loads and stress results for the shear key support box stress are shown in Table 5.4-9 for each package. The margin of safety is positive in all cases showing that the section can support the applied loads.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 25 of 40**

**Table 5.4-9: Shear Key Support Box Stress**

Package	Shear Key Elevation, $h_k$ (in)	SK Restraint Height, $d_k$ (in)	SK Restraint Width, $b_k$ (in)	Shear Key Load, $F_{sk}$ (kip)	Shear Stress, $\tau$ (ksi)	Margin of Safety
MP197	22.1	15.5	35.5	1,988	11.2	3.82
MP197HB	21.4	11.1		2,277	15.5	2.48
TS125	31.6	18.5		2,138	13.7	2.94

**5.4.4.3 Weld Stress**

The minimum weld size connecting the shear key restraint should have an effective throat of 1.0-inches. Since the load path is from the shear key directly through the shear key support box to the railcar structure these loads will only be seen if the railcar support is unconnected. The calculation below demonstrates that this size of weld will support the loads.

Effective throat:  $t_w = 1.0$  in

Cross sectional area:  $A = d_k b_k - (d_k - 2t_w)(b_k - 2t_w) = 98.0$  in<sup>2</sup>

Moment of inertia x-x:  $I_{xx} = \frac{1}{12} [b_k d_k^3 - (b_k - 2t_w)(d_k - 2t_w)^3]$   
 $I_{xx} = 4.148 \times 10^3$  in<sup>4</sup>

Moment of inertia z-z:  $I_{zz} = \frac{1}{12} [d_k b_k^3 - (d_k - 2t_w)(b_k - 2t_w)^3]$   
 $I_{zz} = 15.493 \times 10^3$  in<sup>4</sup>

Polar Moment of inertia:  $J = I_{xx} + I_{yy} = 19.641 \times 10^3$  in<sup>4</sup>

Horizontal torsional stress component:  $\tau'_x = \frac{M_{Cz}}{J} = 5.63$  ksi

Shear Stress:  $\tau''_x = \frac{V}{A} = 20.29$  ksi

Vertical torsional stress component:  $\tau'_z = \frac{M_{Cx}}{J} = 12.93$  ksi

Combines shear stress:  $\tau = \sqrt{(\tau'_x + \tau''_x)^2 + \tau'_z{}^2} = 29.0$  ksi

Allowable shear stress:  $S_A = S_{A514TS} = 54$  ksi

Margin of safety:  $MS = \frac{S_A}{\tau} - 1 = 0.86$

The loads and stress results for the weld are shown in Table 5.4-10 for each package. The margin of safety is positive in all cases showing that the section can support the applied loads.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

**Table 5.4-10: Longitudinal Restraint Weld Stress**

Package	Weld Stress, $\tau$ (ksi)	Margin of Safety
MP197	29.0	0.86
MP197HB	38.9	0.39
TS125	35.0	0.54

**5.4.5 Lifting Points**

Lifting is assumed to be performed with a four-point lifting frame. The frame may be lifted from either the four lift plates of the weldment or an optional bolt-on lift lug. Since all three cradles have the same lifting plate design the bounding load of the MP197HB and cradle will be used for this analysis. The load is equalized between all four lift points and completely vertical [4]. A dynamic load factor of 1.15 is used based on CMAA Specification No. 70-2004 [16]. See Figure 5.4-9 for the free body diagram.

- Weight to lift:  $W = 329.6$  kip
- Dynamic Load factor:  $DLF = 1.15$
- Weight per lift point:  $P = \frac{1}{4}W \times DLF = 94.8$  kip

The plate is 4.00 inches thick with a 2.88-inch shackle hole. The stresses in the plate due to the lifting forces applied by the shackle pins are calculated below. See Figure 5.4-10 for details.

- Hole diameter:  $D_h = 2.88$  in
- Shackle pin diameter:  $D_p = 2.75$  in (Crosby G-2140, S/N 1021174 [17])
- Width of plate:  $w_p = 11.5$  in
- Plate thickness:  $t = 4.0$  in
- Plate radius/hole offset:  $R = \frac{1}{2}w_p = 5.75$  in

Tensile Load

The tensile load area is perpendicular to the line of action passing through the center of the hole (the minimum cross sectional area).

- Tensile stress area:  $A_t = (w_p - D_h)t = 34.5$  in<sup>2</sup>
- Tensile stress:  $\sigma_t = \frac{P}{A_t} = 2.75$  ksi
- Allowable stress:  $S_A = S_{A514L} = 20$  ksi
- Margin of safety:  $MS = \frac{S_A}{\sigma_t} - 1 = 6.27$

Single Plane Tensile Rupture Load

The tensile stress area for single-plane tensile loading is parallel to the line of action, between the hole and the outer surface of the plate toward the direction of the load.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 27 of 40**

Tensile stress area:	$A_r = (R - D_h)t = 11.5 \text{ in}^2$
Rupture stress:	$\sigma_r = \frac{P}{A_r} = 8.24 \text{ ksi}$
Allowable stress:	$S_A = S_{A514L} = 20 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma_r} - 1 = 1.43$

Double Plane Shear Load

The double plane shear stress is parallel to the line of action, between the hole and the outer surface, but at the pin diameter of the hole. Phi is the angle used to calculate the length of the shear plane based on the ratio of the pin-to-hole diameter [18].

Angle:	$\phi = 55 \frac{D_p}{D_h} = 52.5^\circ$
Double shear plane area:	$A_v = 2 \left[ (R - D_h) + \frac{D_p}{2} (1 - \cos\phi) \right] t = 27.3 \text{ in}^2$
Shear stress:	$\tau_{ds} = \frac{P}{A_v} = 3.47 \text{ ksi}$
Allowable stress:	$S_A = S_{A514LS} = 12 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\tau_{ds}} - 1 = 2.46$

Bearing Load

Failure due to bearing load on the lug is conservatively checked against the lifting base metal allowable.

Bearing area:	$A_p = tD_p = 11.0 \text{ in}^2$
Bearing stress:	$\sigma_p = \frac{P}{A_p} = 8.62 \text{ ksi}$
Allowable stress:	$S_A = S_{A514L} = 20 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma_p} - 1 = 1.32$

The margins of safety are positive; therefore the lift lug is adequately sized for the design loads. The MP197HB analysis bounds the other two cradle designs.

Lift Lug Stresses

There is a bending load on the lift points due to the offset pick-point position. The bending stress in the bolt-on lugs will bound that of the weldment lugs due to the slightly larger moment-arm and smaller weld. The moment arm to the weld is the offset length from the lug base to the pick-point minus the base plate thickness of two inches. The weld connecting the lift lug to its base plate is assumed to be a full penetration weld. The load stresses will be checked against the base metal stress and combined with the shear allowable stress to account for the load on the weld.

Moment-arm to lift point from cradle:	$L_p = 8.0 \text{ in}$
Moment-arm to lug weld:	$L_w = L_p - 2.0 \text{ in} = 6.0 \text{ in}$
Bending moment:	$M = L_w P = 568.8 \text{ in} - \text{kip}$
Plate area:	$A = 2Rt = 46.0 \text{ in}^2$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 28 of 40

Plate Moment of inertia:	$I = \frac{1}{12} t(2R)^3 = 507.0 \text{ in}^4$
Bending stress:	$\sigma_b = \frac{MR}{I} = 6.45 \text{ ksi}$
Shear stress:	$\tau = \frac{P}{A} = 2.06 \text{ ksi}$
Combined stress:	$\tau_c = \left[ \left( \frac{\sigma_b}{2} \right)^2 + \tau^2 \right]^{1/2} = 3.83 \text{ ksi}$
Allowable stress:	$S_A = S_{A514LS} = 12 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\tau_{ds}} - 1 = 2.13$

Note that sizing of the lug plate fasteners shall be accomplished during detailed design. From the drawing [3] the fastener hole pattern must be at least twice the radius of the lug plate and that the number of fasteners is four. The loads the fasteners must support are:

Minimum bolt pattern separation:	$x_B = 2R = 11.5 \text{ in}$
Number of fasteners:	$n_f = 4$
Summation of moments:	$\Sigma M = PL_P - x_B 2R_B = 0$
Fastener tensile force:	$R_B = \frac{L_P}{2x_B} P = 33.0 \text{ kip}$
Fastener shear load:	$V_B = \frac{P}{n_f} = 23.7 \text{ kip}$
Minimum fastener stress diameter:	$D_f = 1.50 \text{ in}$
Nominal fastener stress area:	$A_f = \frac{\pi}{4} D_f^2 = 1.77 \text{ in}^2$
Tensile stress:	$\sigma_t = \frac{R_B}{A_f} = 18.6 \text{ ksi}$
Allowable tensile (no shear):	$F_t = 33.0 \text{ ksi}$
Shear stress:	$\tau = \frac{V_B}{A_f} = 13.4 \text{ ksi}$
Allowable shear stress:	$F_v = 0.6F_t = 19.8 \text{ ksi}$
Shear margin of safety:	$MS = \frac{F_v}{\tau} - 1 = 0.48$
Allowable tensile stress <sup>2</sup> :	$F'_t = \sqrt{F_t^2 - 2.60\tau^2} = 24.9 \text{ ksi}$
Tensile margin of safety:	$MS = \frac{F'_t}{\sigma_t} - 1 = 0.34$

A minimum diameter of 1.50 inches is required for each fastener. Detailed design sizing will require a check of the thread tear-out to determine the hole depth into the reinforced section of beam.

Shackles

The cask sling shackles connect the cask slings to the cradle. The cask sling shackles are Crosby G-2140 shackles with a WLL of 85 metric tons. The vendor utilizes a safety factor of 5.4 for this particular shackle which is accounted for in the allowable load calculated below.

<sup>2</sup> Tensile allowable reduced using Equation 3-43 from ASME BTH-1-2014[18] for combined tension and shear on fasteners.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 29 of 40**

Shackle load:	$P = 82.2 \text{ kip} = 47.4 \text{ ton}$
Shackle rating:	$F_R = 85.0 \text{ tonne} = 93.7 \text{ ton}$
Allowable load:	$F_A = F_R = 93.7 \text{ ton}$
Margin of safety:	$MS = \frac{F_A}{P} - 1 = 0.98$

The margin of safety is positive; therefore the shackle is adequately sized for the design loads. The MP197HB analysis bounds the other two cradle designs.

**5.4.5.1 Lifting Loads on Saddle Tower**

The lifting load is less than the maximum operational load, but provisions are provided for the attachment of lifting brackets on the outside of the main rail beams. The extension of the lift point of the lifting brackets should be limited to six inches without further review of the design. See Figure 5.4-11 for a sketch of the lifting section. The beam properties remain the same as found in Section 5.4.1.1.2. The lifting stresses are compared against an allowable of one-third yield stress and one-fifth ultimate stress.

Weight to lift (MP197 and Cradle):	$W = 291.1 \text{ kip}$
Lifting Loads:	$F_l = \frac{1}{4}W \times DLF = 83.7 \text{ kip}$
Cradle width:	$w_c = 116 \text{ in}$
Lift point extension offset:	$l_p = 6.0 \text{ in}$
Lift point separation:	$w_{lp} = w_c + 2l_p = 128 \text{ in}$
Tower width:	$w_t = 112 \text{ in}$
Maximum bending moment [19] <sup>3</sup> :	$M = \frac{F_l(w_{lp}-w_t)}{2} + \frac{F_l w_t}{2} = 2.846 \times 10^3 \text{ in} - \text{kip}$
Bending stress:	$\sigma_b = \frac{Mc}{I_{xc}} = 11.0 \text{ ksi}$
Allowable stress:	$S_A = S_{A514L} = 20 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\sigma_b} - 1 = 0.82$
Shear stress:	$\tau = \frac{F_l}{A_{xc}} = 1.26 \text{ ksi}$
Allowable stress:	$S_A = S_{A514LS} = 12 \text{ ksi}$
Margin of safety:	$MS = \frac{S_A}{\tau} - 1 = 8.5$

The resultant stresses are shown in Table 5.4-11 for each package. The margin of safety is positive; therefore the component is adequately sized for the design loads.

<sup>3</sup> Section 8.1, Beam Diagrams and Formulas, Case 3C.



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 30 of 40

Table 5.4-11: Lifting Loads on Saddle Tower Support

Package	Weight (kip)	Lifting Load (kip)	Bending Load, $\sigma_b$		Shear Load, $\tau$	
			Stress (ksi)	Margin of safety	Stress (ksi)	Margin of Safety
MP197	291.1	83.7	11.0	0.82	1.26	8.5
MP197HB	329.6	94.8	14.4	0.39	1.47	7.2
TS125	315.0	90.6	9.0	1.22	1.24	8.7

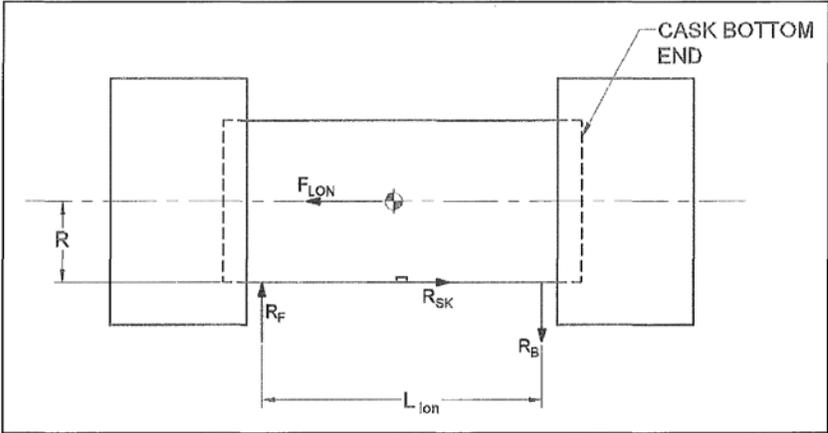


Figure 5.4-1: Package Longitudinal Reaction Forces on Cradle



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 31 of 40

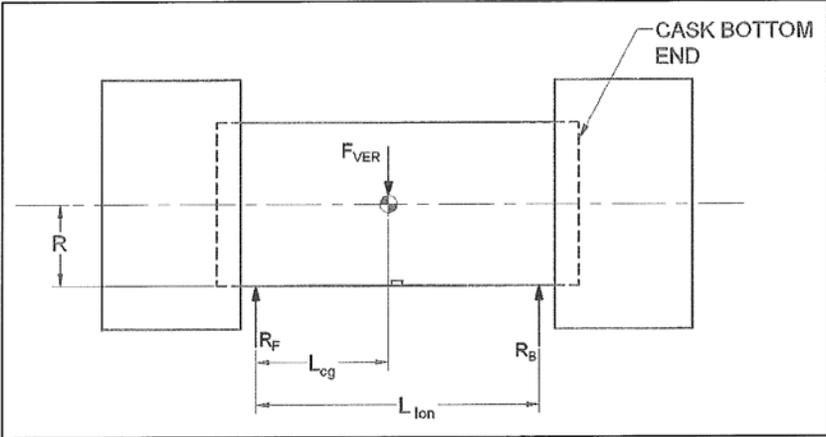


Figure 5.4-2: Package Vertical forces on Cradle

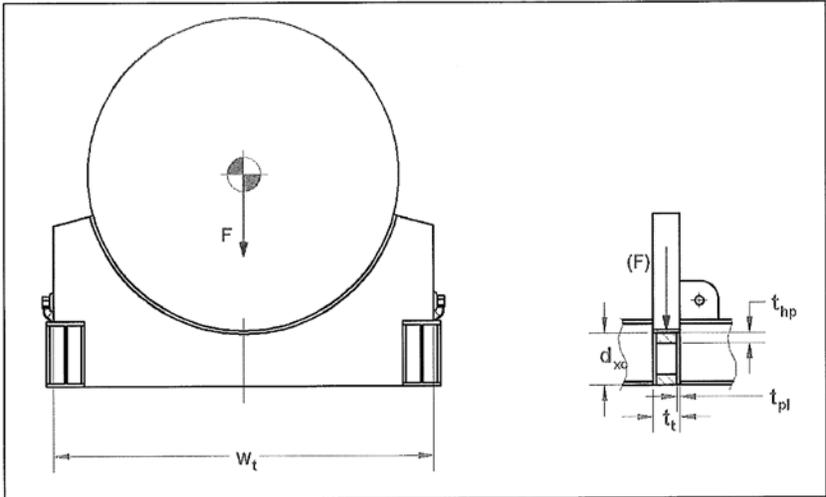


Figure 5.4-3: Longitudinal Loading Tower Compressive Stress



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 32 of 40

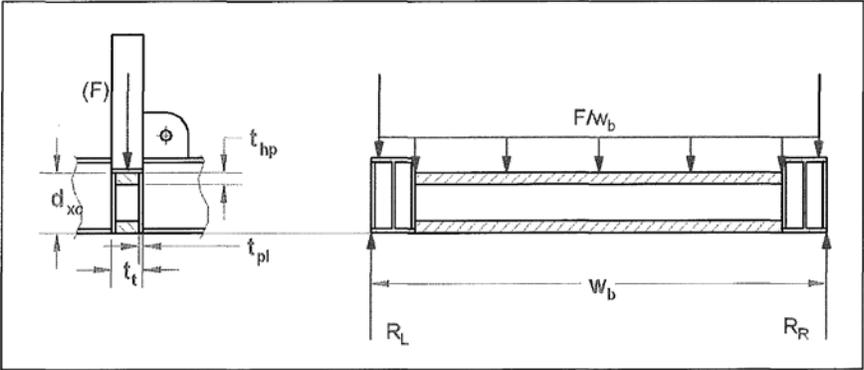


Figure 5.4-4: Longitudinal Load Tower Support Bending Stress

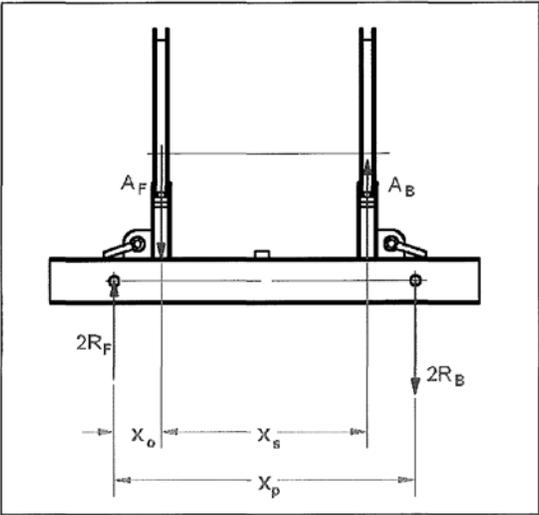


Figure 5.4-5: MP197 Main Beam Loading FBD



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 33 of 40

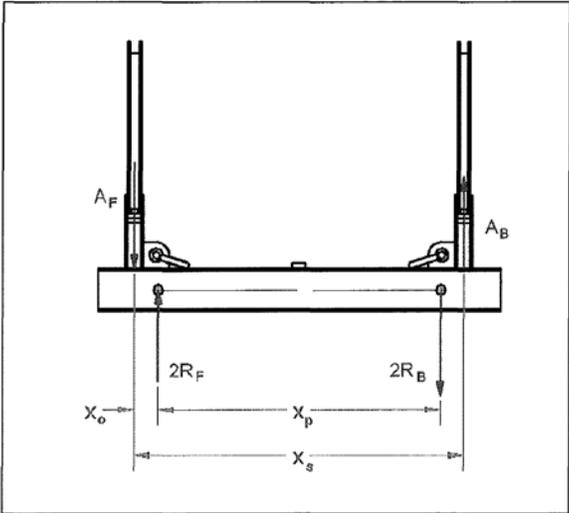


Figure 5.4-6: MP197HB and TS125 Main Beam Loading FBD

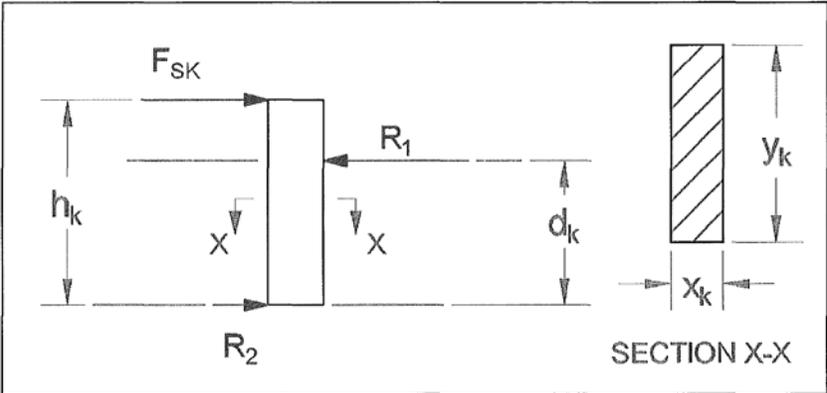


Figure 5.4-7: Shear Key FBD



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 34 of 40

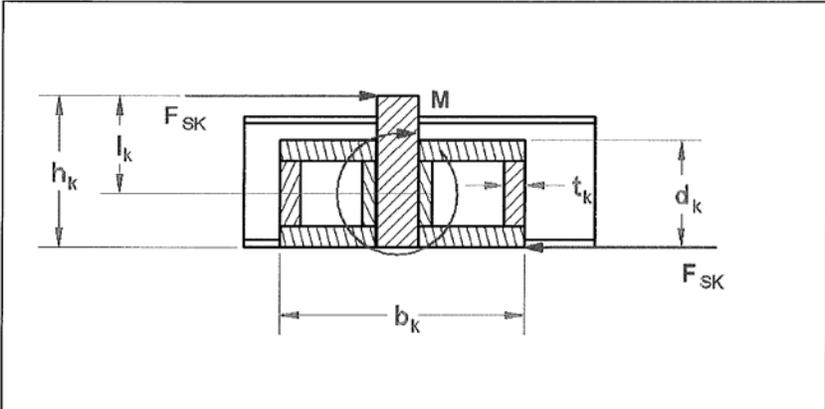


Figure 5.4-8: Shear Key Support Box FBD

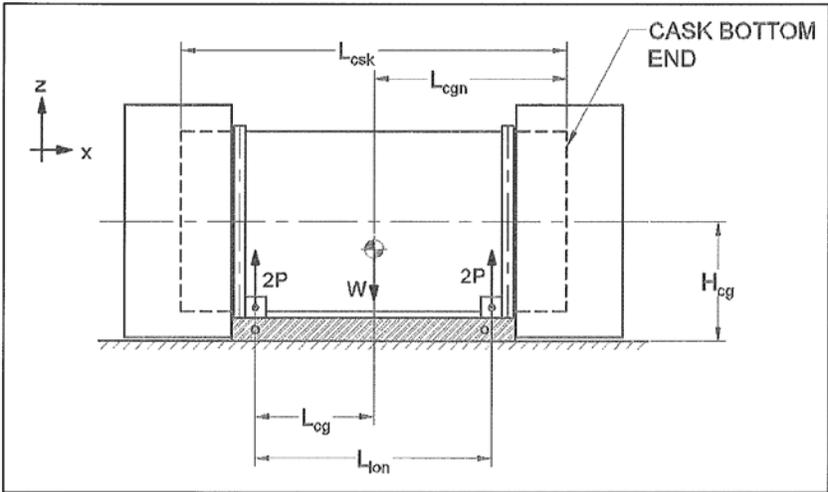


Figure 5.4-9: Lifting Free Body Diagram



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 35 of 40

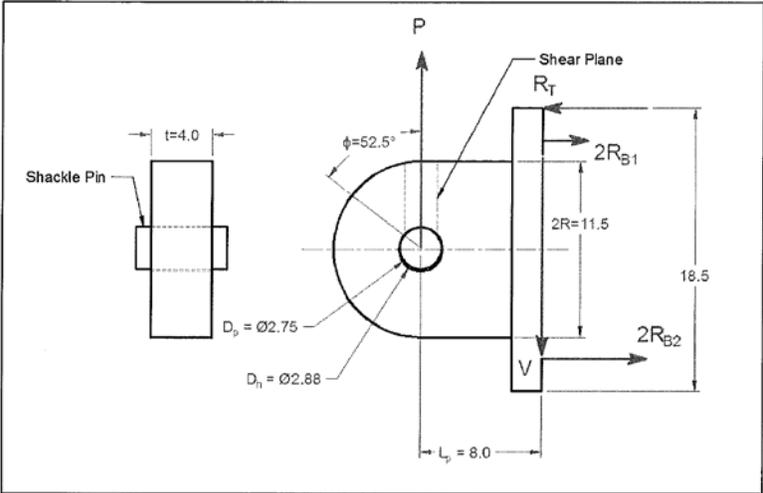


Figure 5.4-10: Typical Lifting Hole FBD

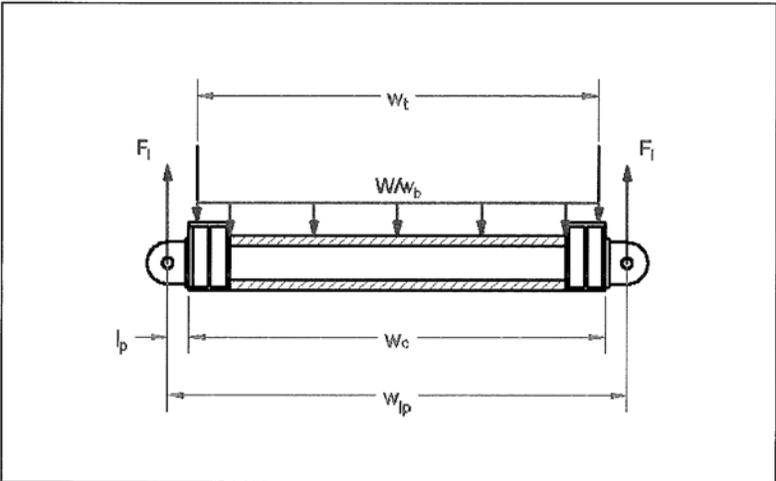


Figure 5.4-11: Lifting Section FBD



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 36 of 40

**5.5 Fatigue**

The cradles are expected to perform service for up to 50 years and not expected to travel more than 3,000,000 miles per Section 7.1.2.1 of M-1001[2]. While this period of performance is not expected to be maintenance free it is reasonable to assume that the structure would perform its support function without major component failure. This analysis presents a cursory examination of the fatigue loading over this lifespan. The detailed fatigue analysis can only be done on the final design of the cradles.

An example of the accepted method for calculating fatigue life is shown in Chapter 7 of the M-1001. From the example case Table 7-3 it can be seen, for an unspecified car, that 97 percent of the vertical fatigue loading is due to stress ranges under 0.3g. As this is from an example case it is assumed to be normal in comparison to other railcar response curves. Since a majority of the fatigue loading is within this range the fatigue life, the cradle is assumed to be defined by these loads.

The basic cradle structural analysis demonstrates that a bounding acceleration load of 2g in the vertical direction can be supported compared against yield stress. This is equivalent to using an allowable stress of 1/2 yield stress under normal gravity loading. All of the cradle analyses show that this yield criterion is met.

If we assume that the stress variation due to cyclic loading is no more than +/- 0.2g (or a range of 0.4g), and that the allowable stress is 1/2 yield at one gravity, the minimum and maximum stress that will be found in any component with a yield stress of 50 ksi due to cyclic loading will be due to the variable stress. This stress is:

Mean Stress:	$S = \frac{1}{2} 50 \text{ ksi} = 25 \text{ ksi}$
Variable Stress:	$S_v = 0.2\sigma_m = 5 \text{ ksi}$
Maximum Stress:	$S_{mx} = 30 \text{ ksi}$
Minimum Stress:	$S_{mn} = 20 \text{ ksi}$
Stress Ratio:	$R = \frac{S_{mn}}{S_{mx}} = \frac{2}{3}$

The stress that produces failure in steel at 2,000,000 cycles can be computed from cases in Table 7.55 of Chapter 7 of M-1001. This table presents values for determining the fatigue properties of the Modified Goodman Diagram (MGD) for a particular member. As an example, for an A992 beam the allowable stress is 50 ksi. From Table 7.55, Fig. No. 7.4.1.8 the following information is available:

Y intercept of MGD:	$b = 26 \text{ ksi}$
MGD Slope:	$m = 0.9$
S-N Curve Slope:	$k = 0.16$
Cycles at Fatigue Stress $S_e$ :	$N_e = 2 \times 10^6 \text{ cycles}$

The stress at which the beam is expected to fail at two million cycles is:

Fatigue Stress (at $N_e$ ):	$S_e = \frac{b}{1-mR} = 65 \text{ ksi}$
-----------------------------	---

Since the Fatigue Limit is greater than the maximum load the S-N curve slope is half the value above.

Cycles to failure:	$N = \frac{N_e}{\left(\frac{S_{mx}}{S_e}\right)^k} = 31.5 \times 10^9 \text{ cycles}$
--------------------	---



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 37 of 40**

For a 50 year life the rail car is expected to cover 3,000,000 miles. Assuming a cyclic rate of  $\beta = 300$  cycles per mile (based on the example of Section 7.2.4.1.1.2 of M-1001<sup>4</sup>) the expected life will be:

$$\text{Life} = \frac{N}{\beta} = (31.5 \times 10^9 \text{ cycles}) / (300 \text{ cycles/mile}) = 105 \times 10^6 \text{ miles}$$

The life prediction for this component is much larger than the required lifespan for the component, therefore it is reasonable to say that it will support fatigue loading without any modification. Similar analysis performed on an axially loaded flat plate for material with a 50 ksi yield stress limit shows improved fatigue life in comparison to the beam section.

Not that these examples correspond to non-welded or rolled sections only and welded or built-up sections will possess a lower endurance limit resulting in a reduced life expectancy. Therefore, the final design will require a rigorous fatigue analysis for all welds and built-up sections. Components such as the pinhole liners and attachments, and the personnel barriers due not significantly contribute to the overall weight of the cradles. The lifting provisions are not cyclically loaded and will not change. Therefore the detailed design will remain similar to the conceptual design and there are no expected changes in the structural components. It can be safely concluded that there will be no significant change to bounding cradle design weights due to questions about fatigue.

**6.0 COMPUTER SOFTWARE USAGE (IF SOFTWARE IS USED)**

**6.1 Non-Engineering Application Software**

Computer software was limited to use of Microsoft Excel. The computation was run using Microsoft Excel Version 14.0.7165.5000 (32-bit) on a Lenovo Think Station Model S30, labeled DWICK1.adom.ad.corp, running Windows 7 Enterprise with service pack 1 installed. The one file was generated for this calculation to calculate the cradle weights and the vertical location of the center of gravity is listed in Table 6.1-1.

**Table 6.1-1: Computer File Listing**

Filename	Description	Date and Time	Size
CALC-3015135-000.xlsx	Weight and CG Spreadsheet	3/7/2016 12:00 PM	46 kB

**7.0 RESULTS/CONCLUSIONS**

The results of the analyses in this calculation demonstrated that the package cradles are designed to support the applied loads. The minimum factor of safety is 0.06 due to the bending moment of the shear key in the TS125 package. With additional information on this package this margin could be improved by restructuring the shear key support. Note that a four-point lift must be used when lifting the combined package and cradle.

The weight and CG for the package and cradle can be found in Table 5.3-1. The railcar reaction forces are found in Table 5.3-2 with the maximum values summarized in Table 5.3-3.

**7.1 Include results of applicable literature searches or other applicable background data**

This analysis was not performed to provide the results of a literature search.

<sup>4</sup> Note the percent load spectrum is based on an average frequency of 354.6 cycles/mile.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

Page 38 of 40

**8.0 REFERENCES**

The following references were used in this analysis:

1. Department of Energy Contract DE-NE0008390; Part 1, Section C, "Statement of Work."
2. Association of American Railroads, "Manual of Standards and Recommended Practices, Section C – Car Construction Fundamentals and Details", Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material."
3. DWG-3015139-000, "Atlas Railcar Cradle Family 3 Conceptual Drawing," AREVA Federal Services
4. EIR-3014611-003, "Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar," AREVA Federal Services.
5. ANSI N14.6-1993, "American National Standard for Radioactive materials–Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 kg) or More," ANSI, New York, NY.
6. Certificate Number 9302, "Certificate of Compliance for Radioactive Material Packages, Package Identification Number USA/9302/B(U)F-96," Rev 7, U.S. Nuclear Regulatory Commission.
7. Docket No. 71-9302, "NUHOMS<sup>®</sup>-MP197 Transportation Package safety Analysis Report," Revision 17, non-proprietary version, AREVA TN
8. Certificate Number 9276, "Certificate of Compliance for Radioactive Material Packages, Package Identification Number USA/9276/B(U)F-96," Rev 4, U.S. Nuclear Regulatory Commission.
9. Docket No. 71-9276, "Fuel Solutions<sup>™</sup> TS125 Transportation Cask Safety Analysis Report," Revision 6, BNLF Fuel Solutions Corporation
10. <https://rampac.energy.gov/>, DOE Office of Environmental Management Radioactive Material Packaging (RAMPAC) website, last accessed on 12/31/2015.
11. <http://www.nrc.gov/reading-rm/adams.html>, Agencywide Documents Access and Management Systems (ADAMS) Public Documents website,
12. ASTM Annual Book of Standards, Section One, "Iron and Steel Products," Volume 01, ASTM International, 2012.
13. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section II, Part D, "Properties (Customary)," 2015.
14. DWG-3015278-000, "Atlas Railcar Cradle Attachment Conceptual Drawing," AREVA Federal Services.
15. Oberg, Erik et al, "Machinery's Handbook," 26<sup>th</sup> edition, Industrial Press Inc, New York, NY, 2000.
16. CMAA Specification No. 70-2004, "Specifications for Top Running Bridge & Gantry Type Multiple Girder Electric Overhead Traveling Cranes," Crane Manufacturers Association of America, Inc., Charlotte, NC.
17. The Crosby Group, 2801 Dawson Rd, Tulsa, OK 74110, <http://www.thecrosbygroup.com>, last accessed on 1/28/2016 (See Appendix A for vendor data).
18. ASME BTH-1–2014, "Design of Below-the-Hook Lifting Devices," ASME.
19. Blodgett, Omer W., "Design of Welded Structures." The James F. Lincoln Arc Welding Foundation, Cleveland, OH, 1966.

CALC-3015135-000  
Page 39 of 40



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015135-000

**Project:** 00225.03.0050 - DOE Atlas Rail Car

**Page 39 of 40**

---

**APPENDIX A: CUT SHEETS**



AREVA Federal Services LLC

Title: Atlas Railcar Family 3 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015135-000

Project: 00225.03.0050 - DOE Atlas Rail Car

## Crosby® Alloy Bolt Type Shackles



**APPLICATION INSTRUCTIONS**  
SEE PAGE 89 OF THE GENERAL CATALOG

**G-2140 / S-2140 ALLOY BOLT TYPE ANCHOR SHACKLES**

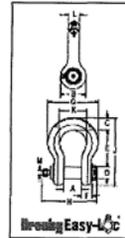
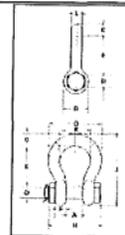


G-2140 meets the performance requirements of Federal Specification QQ-C-211, Type IVA, Grade B, Class 2, except for those provisions required of the entrance. For additional information, see page 141.



**G-2140E Alloy Bolt Type Anchor Shackle**

- Quenched and Tempered.
- Alloy bows, Alloy bolts.
- Forged Alloy Steel 30 thru 200 metric tons, Cast Alloy Steel 250 thru 400 metric tons. Meets performance requirements of Grade 8 shackles.
- Working Load Limit is permanently shown on every shackle.
- 30, 40, 55, and 85 metric ton shackle bows are available galvanized or self colored with pins that are galvanized and painted red.
- 120, 150, 175 metric ton shackle bows are hot-dip galvanized; pins are Dimetcoated® and painted red.
- 200, 250, 300 and 400 metric ton shackle bows are Dimetcoated®; pins are Dimetcoated® and painted red.
- All sizes are **RFID EQUIPPED**.
- Approved for use at -40 degree C (-40 degree F) to 204 degree C (400 degree F).
- Shackles are Quenched and Tempered and can meet DNV impact requirements of 42 joules (31 ft.-lbs.) at -20 degree C (-4 degree F).
- All sizes are individually proof tested to 2.0 times the Working Load Limit.
- Refer to page 85 for Crosby COLD TUFF shackles that meet the additional requirements of DNV rules for certification of lifting applications - Loose Gear.
- Shackles 200 metric tons and larger are provided as follows:
  - Serialized Pin and Bow
  - Material Certification (Chemical)
  - Magnetic Particle Inspected.
  - Certification must be requested at time of order.
- Meets or exceeds all requirements of ASME B30.26 including identification, ductility, design factor, proof load and temperature requirements. Importantly, these shackles meet other critical performance requirements including impact properties and material traceability, not addressed by ASME B30.26.
- Type Approval and certification in accordance with ABS 2006 Steel Vessel Rules 1-T-17.7, and ABS Guide for Certification of Cranes.
- Look for the Red Pin®... the mark of genuine Crosby quality.



**G-2140E / S-2140E Crosby® Alloy Bolt Type Shackles**

Nominal Shackle Size (in.)	Working Load Limit (k)	Stock No.		Weight Each (lbs.)	Dimensions (in.)													Tolerance +/-	
		G-2140E	S-2140E		A	B	C	D +/- .02	E	F	G	H	J	K	L	M	A	E	
4-3/4	1200	1021422	-	452	7.25	10.50	5.00	4.75	15.19	4.58	20.84	23.11	27.81	11.00	4.75	1.75	0.25	0.25	
6"	1250	1021442	-	524	8.60	12.00	5.63	5.00	18.50	4.48	23.63	24.28	32.63	13.00	5.00	1.75	0.25	0.25	
6"	1300	1021460	-	791	10.88	15.00	6.25	8.00	18.74	4.89	24.76	25.45	34.78	13.00	5.88	1.75	0.25	0.25	

**G-2140 / S-2140 Crosby® Alloy Bolt Type Shackles**

Nominal Shackle Size (in.)	Working Load Limit (k)	Stock No.		Weight Each (lbs.)	Dimensions (in.)													Tolerance +/-	
		G-2140	S-2140		A	B	C	D +/- .02	E	F	G	H	J	K	L	A	E		
3/8	2	1021015	-	0.33	0.66	0.91	0.38	0.44	1.44	0.33	1.78	2.17	2.29	1.03	0.39	0.06	0.13		
7/16	2.2/3	1021020	-	0.49	0.75	1.05	0.25	0.50	1.69	0.41	2.03	2.51	2.81	1.19	0.44	0.06	0.13		
1/2	3.1/3	1021029	-	0.79	0.51	1.18	0.50	0.64	1.88	0.46	2.31	2.80	3.28	1.31	0.50	0.06	0.13		
5/8	5	1021038	-	1.08	1.05	1.50	0.69	0.77	2.38	0.58	2.94	3.50	4.19	1.69	0.63	0.06	0.13		
3/4	7	1021047	-	2.72	1.25	1.81	0.81	0.89	2.81	0.69	3.50	4.15	4.87	2.00	0.75	0.06	0.25		
7/8	9.1/2	1021056	-	3.95	1.44	2.09	0.97	1.02	3.31	0.81	4.03	4.82	5.89	2.28	0.88	0.06	0.25		
1	12.1/2	1021065	-	5.66	1.69	2.39	1.05	1.15	3.75	0.92	4.69	5.59	6.58	2.59	1.00	0.06	0.25		
1 1/8	15	1021074	-	8.57	1.81	2.69	1.25	1.25	4.25	1.04	5.16	5.90	7.17	2.81	1.13	0.06	0.25		
1 1/4	18	1021083	-	11.7	2.03	3.00	1.38	1.40	4.69	1.10	5.75	6.69	8.25	3.25	1.29	0.06	0.25		
1 3/8	21	1021092	-	15.8	2.25	3.31	1.50	1.63	6.25	1.28	6.38	7.21	9.16	3.69	1.42	0.13	0.25		
1 1/2	30	1021100	1021109	19.8	2.38	3.67	1.62	1.63	6.75	1.39	6.85	7.73	10.00	3.88	1.50	0.13	0.25		
1 3/4	40	1021138	1021147	33.8	2.88	4.19	2.25	2.00	7.00	1.75	8.81	9.30	12.34	5.00	1.84	0.13	0.25		
2	55	1021156	1021165	49.9	3.25	4.81	2.40	2.25	7.75	2.00	10.16	10.41	13.65	5.75	2.08	0.13	0.25		
2-1/2	85	1021172	1021183	103	4.15	5.81	3.12	2.75	13.50	2.62	13.75	13.88	17.90	7.25	2.71	0.25	0.25		
3	120	1021190	-	162	5.00	6.50	3.63	3.25	13.00	3.00	14.62	15.13	21.50	7.88	3.12	0.25	0.25		
3-1/2	160	1021216	-	266	5.25	8.00	4.38	3.75	14.63	3.75	17.00	17.60	24.88	9.00	3.62	0.25	0.25		
4	175	1021250	-	332	5.50	9.00	4.56	4.25	14.60	4.00	18.00	20.37	25.68	10.00	4.00	0.25	0.25		
4"	1400	1021478	-	1900	8.25	14.00	7.25	7.00	22.50	6.60	28.00	28.68	40.25	13.00	6.00	0.25	0.25		

\*Note: Maximum Proof Load is 2.0 times the Working Load Limit. Minimum Ultimate Load is 4 times the Working Load Limit on 300 thru 400 metric Tons. For sizes 30 thru 175 metric Tons, Minimum Ultimate Load is 5.4 times the Working Load Limit. \*\*Cast Alloy Steel. † Furnished with Round Head Bolts with an eyebolt for handling. For Working Load Limit reduction due to side loading applications, see page 91.

### Appendix A.3.3 – Compliance Matrix

#### REQUIREMENTS FOR CRADLE DESIGN FROM EIR-3014611, "DESIGN BASIS REQUIREMENTS DOCUMENT (DBRD) FOR THE DOE ATLAS RAILCAR," REV 4<sup>1</sup>

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
<b>Family No. 3: TN: MP-197, MP-197HB, Energy Solutions TS125</b>			
2.1	<b>Regulatory Requirements</b> Comply with AAR 2043	For the cradles the AAR requirements are called out below	Y
2.2	<b>Functional Requirements</b>		
2.2.2	<i>Cradle Functional Requirements</i>		
2.2.2.1	During transport, a transportation cask must rest on a cradle on top of the cask railcar deck.	All cradles interface with the rail car attachments that comply with this requirement.	Y
2.2.2.2	Conceptual cask cradle designs must accommodate the cask designs listed above and interface with cradle as indicated in the cask SARs.	All casks in the family are evaluated.	Y
2.2.2.3	The conceptual cradle designs shall not be final designs or prototypes.	The conceptual design has sufficient margin to allow for specific design requirements.	Y
2.2.2.3.a	Conceptual design shall have a plus or minus 10% weight envelope evaluated.	The weight envelope evaluated allows for refinement of the design in the final design	Y
2.2.2.3.b	Center of gravity for the cradle shall be calculated and used to demonstrate the combined CG is met for the cask rail car and cradle of 98 inches or less. CG and loading distributions shall be detailed sufficiently to support railcar design and testing.	The CG for each cask cradle is calculated. The combined CG for the rail car and loaded cradles are shown in the rail car attachment calculation CALC-3015276. All are less than the 98 inch limit.	Y
2.2.2.3.c	Cradle shall be capable of handling the loads specified in Section 2.2.2.13 ( Rule 88 loads)	The cradles are demonstrated to meet rule 88 loadings for all casks within the family.	Y
2.2.2.3.d	Cradle shall be capable in the final design to handle a fatigue evaluation per AAR rules.	The weight margin allowed for the cradle and the design loading for compliance with Rule 88 ensures that there is sufficient margin for the detailed design to comply with the fatigue evaluation require by AAR-2043 which references AAR M-1001.	Y
2.2.2.3.e	Cradle designs shall have hard dimensions for interface to rail car to ensure ability to be attached to rail car.	The rail car interface dimensions are tolerance to ensure fit up.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
2.2.2.4	The conceptual cradle design shall determine the height of the cask center of gravity above the railcar deck, the weight on each axle, etc. as necessary to perform the analysis and provide simulate cradle test weights and supporting information needed for testing the railcar.	Required parameters for testing the rail car are provided in the families individual calculations and in the attachment design calculations.	Y
2.2.2.5	When rotation is necessary, the cradle will include the required hardware, such as trunnion supports.	None of these casks require rotational capability in the cradle.	Y
2.2.2.6	The cradles will be tall enough and open-ended so that the impact limiters can be attached to a cask after the cask is secured to the cradle.	The cradle design allows installation of impact limiters after the cask is secured to the cradle.	Y
2.2.2.7	Each cask design will need a cradle designed to position the center of gravity low for stability during transport, but the cradle design will position the impact limiter with a clearance of at least one inch above the cask car deck.	Adequate clearance is allowed for installation of the impact limiters.	Y
2.2.2.8	The cask car (including a cradle and a cask) and buffer car clearances shall fit within AAR Plate C [3], except when loaded with the casks that are more than 128 inches wide (Same as Requirement 2.2.1.12 above).	The MP-197 and the MP-197HB are compliant to Plate C. Due to the larger impact limiter for the TS125 of 143 inches it is greater than Plate C.	Y
2.2.2.9	Demonstrate that bonding weights both min and max meet a combined CG of 98 inches for the railcar, skid and fully loaded and empty cask.(personnel shield, impact limiters etc.) An alternative to adding ballast weight to the railcar may include requiring that the transport cradle for the lighter cask be designed to provide the ballast.	Cradles as designed meet the combined CG.	Y
2.2.2.10	The various cradles will be designed to fit a standard attachment mechanism. Tolerance to ensure.	Fit the common attachments on the rail car.	Y
2.2.2.11	During loading operations, the cradle may be attached to the railcar first, followed by putting the cask on the cradle, but sometimes the cask will be on the cradle first. In that case, both the cradle and cask together will be hoisted onto the railcar deck. Lifting points permit this handling of the cask	Designs permit loading separately or with the cask on the cradle.	Y
2.2.2.12	The cask railcar shall incorporate a standardized attachment capability for coupling the cask cradle to the railcar. This attachment must be capable of securely attaching loads of up to the maximum cask	Attachments meet rule 88 load requirements.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	weight and the weight cradle in accordance with the requirements of AAR Rule 88 A16c(3) [7].		
2.2.2.13	AAR Rule 88 A16c(3) does not specify if the securement system loading requirements are to be applied separately or simultaneously. Per direction from KASGRO (via the AAR EEC) transportation loading is not simultaneous and is applied separately. Also gravity is not applied in the vertical up or down accelerations, so +/- 2 g vertical only. Rule 88 A.16.C requires the following tie down loads (g force to yield):	Analyzed according to the direction of the AAR.	
2.2.2.13.a	7.5g Longitudinal	Met for all cradles and casks.	Y
2.2.2.13.b	2g Vertical	Met for all cradles and casks.	Y
2.2.2.13.c	2g lateral	Met for all cradles and casks.	Y
	<b>Operational Requirements</b>		
	The cradle must accommodate the camber in the rail car.	Interfaces allows for the camber.	Y
	Have clearances to install and remove impact limiters on the rail car.	Clearance provided.	Y
	Features and clearances to load the cask into the cradle on and off the railcar and to be able to load the cradle with the impact limiters and personnel shield if required in place, on rail car.	Features and clearances permits loading with or without the personnel barrier in place to allow for intermodal transfers	Y
	Operational Steps. Can it be used and how? The loading and unloading steps requested should address that.	Complies with loading procedures	Y
	<b>Maintenance Requirements</b>		
	Since none of the designs use corrosion resistance material, the life expectancy would be dependent on corrosion control by the use of "high quality weather resistant coatings". Strip and repaint as required. Use wear pads to minimize loss of coatings.	Wear pads and coatings adequately applied	Y
	<b>Additional Design Considerations</b>		
	The cask cradles should be designed to support the cask for lifting on and off the railcar (with or without the cask impact limiters installed) as specified in Section 2.2.2.11 above. Lifting attachments shall be designed in accordance with ANSI N14.6 (i.e. the combined maximum tensile stress or the	Lifting meets ANSI N14.6.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	<p>maximum shear stress of all members in the load path shall not exceed smaller of <math>S_y/3</math> or <math>S_u/5</math>. A vertical lift is assumed (requiring the use of a spreader beam/frame). All lift points are assumed to support the load equally for the conceptual design. The lift points should be designed such that the personnel barrier is not removed to lift the cradle when loaded with a package. A dynamic load factor of 1.15 shall be included per the recommendations of CMAA Specification No. 70 [12].</p>		
	<p>For cradle attachment points, the attachment mechanism (pin/bolt) should be removable and shall be sized for manual handling (less than 50 lbs.) or provisions should be designed for mechanically assisted insertion.</p>	<p>Attachments pins have mechanisms for handling</p>	<p>Y</p>
	<p>The bottom of the cradle shall be flat to facilitate placement on a flat surface or intermodal transfer.</p>	<p>Cradle can sit on flat surface.</p>	<p>Y</p>

<sup>1</sup>Approved calculation performed to DBRD Revision 3; all pertinent calculation references are carried forward in Revision 4.

## APPENDIX A.4 – FAMILY 4 CRADLE

	8	7	6	5	4	3	1
						DWG NO 3015140	REV 0 SH 1

**NOTES, UNLESS OTHERWISE SPECIFIED:**

1. CONCEPTUAL DESIGN ASSUMES ALL WELDS ARE FULL PENETRATION UNLESS OTHERWISE NOTED. ALL WELDS WILL BE FURTHER SPECIFIED IN A FINAL DESIGN.
2. FABRICATION SHALL BE PERFORMED IN ACCORDANCE WITH AWS D1.1.
3. DIMENSIONS WITH TOLERANCES SPECIFIED ARE RAILCAR INTERFACE DIMENSIONS AND SHOULD BE CONSIDERED DURING FINAL CRADLE DESIGN.
4. ALL SURFACES OF THE CRADLE WELDMENT, EXCEPT FOR PIN HOLES, PINS AND THREADED HOLES, SHALL BE BLAST CLEANED PER SSP-SP-10 AND COATED WITH SELF-PRIMING ENAMEL, 2 COATS. THE NON-PAINTED CRADLE WELDMENT SURFACES SHALL BE LIGHTLY COATED WITH NUCLEAR GRADE "NEVER-SEEZ" GREASE.
5. ATTACHMENTS FOR PERSONNEL BARRIER TO THE CRADLE ARE TO BE DEFINED DURING THE FINAL DESIGN.
6. THE ADDITION OF ALIGNMENT MARKS BETWEEN THE CRADLE AND RAILCAR INTERFACE SHOULD BE CONSIDERED IN THE DETAILED DESIGN TO SUPPORT LOADING OPERATIONS.
7. ALTERNATE MATERIAL (PLATE, BAR, OR FORGING) HAVING THE SAME CHEMICAL COMPOSITION WITH MECHANICAL PROPERTIES EQUAL TO OR GREATER THAN THOSE SPECIFIED MAY BE USED WITH THE APPROVAL OF THE DESIGN AUTHORITY.
8. ALL FILLETS OR INTERNAL RADII AND OUTSIDE CORNERS SHALL BE NO GREATER THAN 0.12 IN. UNLESS OTHERWISE SPECIFIED.
9. A SET OF LIFTING LINKAGE SHALL BE USED FOR VERTICAL LIFTING AT THE FOUR LIFTING POINTS PROVIDED.

LIST OF MATERIALS				
QTY	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION
X	A1		MP187 CRADLE ASSEMBLY	
61	1		PLATE, 1 THK	ASTM A572, GR 50 OR EQUIV
4	2		W18X119	ASTM A992
4	3		FORGING	100 KSI MIN YIELD
1	4		PLATE, 6.0 X 23.3 X 26.9	ASTM A514
2	5		PLATE, 3 1/2 THK	ASTM A572, GR 50
12	6		PLATE, 1 1/2 THK	ASTM A572, GR 50
4	7		PLATE, 2 THK	ASTM A572, GR 50
4	8		PLATE, 1/2 THK	ASTM A572, GR 50
2	9		RUBBER, 1 THK	80 DURO
4	10		SQ BAR, 6 X 6 X 8	ASTM A514
6	11		RUBBER, 1/2 THK	80 DURO
3	12		PLATE, 1/4 THK	ASTM A572, GR 50
4	13		SIDE SCREEN MESH, 50% OPEN AREA	STAINLESS STEEL
4	14	2994T69	HOIST RING, 3/4-10 UNC, 5000 WLL	McMASTER-CARR OR EQUIV
4	15		PLATE, 4 THK	ASTM A572, GR 50 OR EQUIV
4	16		BUILD-UP ANGLE, 6 X 8 X 1.5	ASTM A572, GR 50
6	17		PLATE, 1 THK	ASTM A514
12	18	98404A515	BALL LOCK PIN, Ø.50 X 3.5 LG	McMASTER-CARR OR EQUIV
4	19		BAR, Ø2.5 X 10.5 LG	ASTM A311, GR 1144 CLASS B
4	20	91268A958	HEX BOLT, 1 1/2-6 UNC X 5 LG	McMASTER-CARR OR EQUIV
4	21	94895A041	HEX NUT, 1 1/2-6 UNC	McMASTER-CARR OR EQUIV
AR	22		TUBE, 2 X 2 X .125 WALL	STAINLESS STEEL
4	23		BAR, Ø6.5	ASTM A276, TYPE 304

**ISOMETRIC VIEW**

**AREVA**  
July 6, 2016  
Records Management

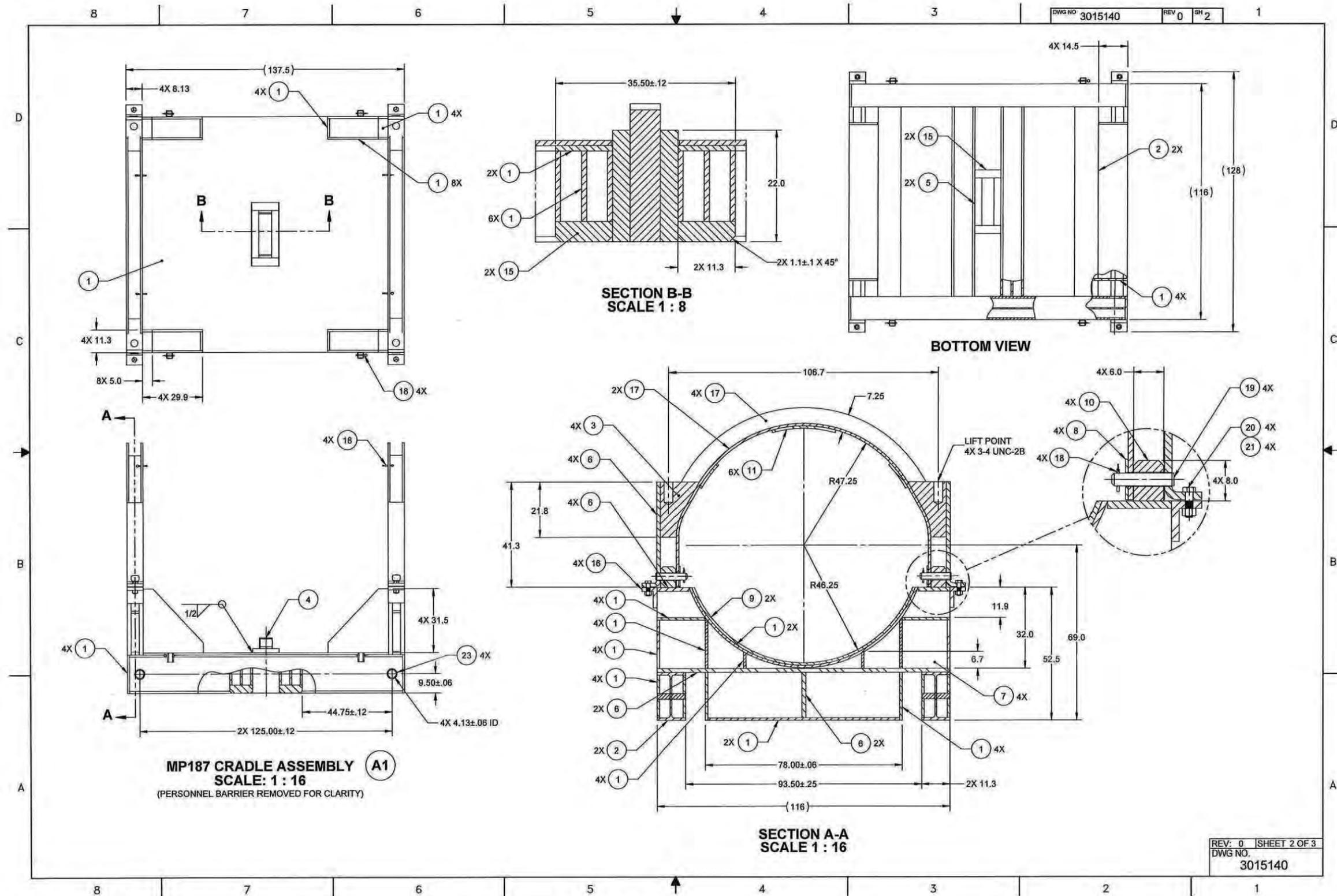
REV	DESCRIPTION	DRAWN	CHECKER	VERIFIED
REVISION HISTORY				
	NAME/SIGNATURE	DATE		
EM	<i>[Signature]</i>	6/30/16		
RE	<i>[Signature]</i>	6/29/16		
TECH CHK	<i>[Signature]</i>	6-29-16		
DFTG CHK	<i>[Signature]</i>	6-29-16		
NEXT ASSY	FINAL ASSY	DRAWN	R. LE	6/29/16

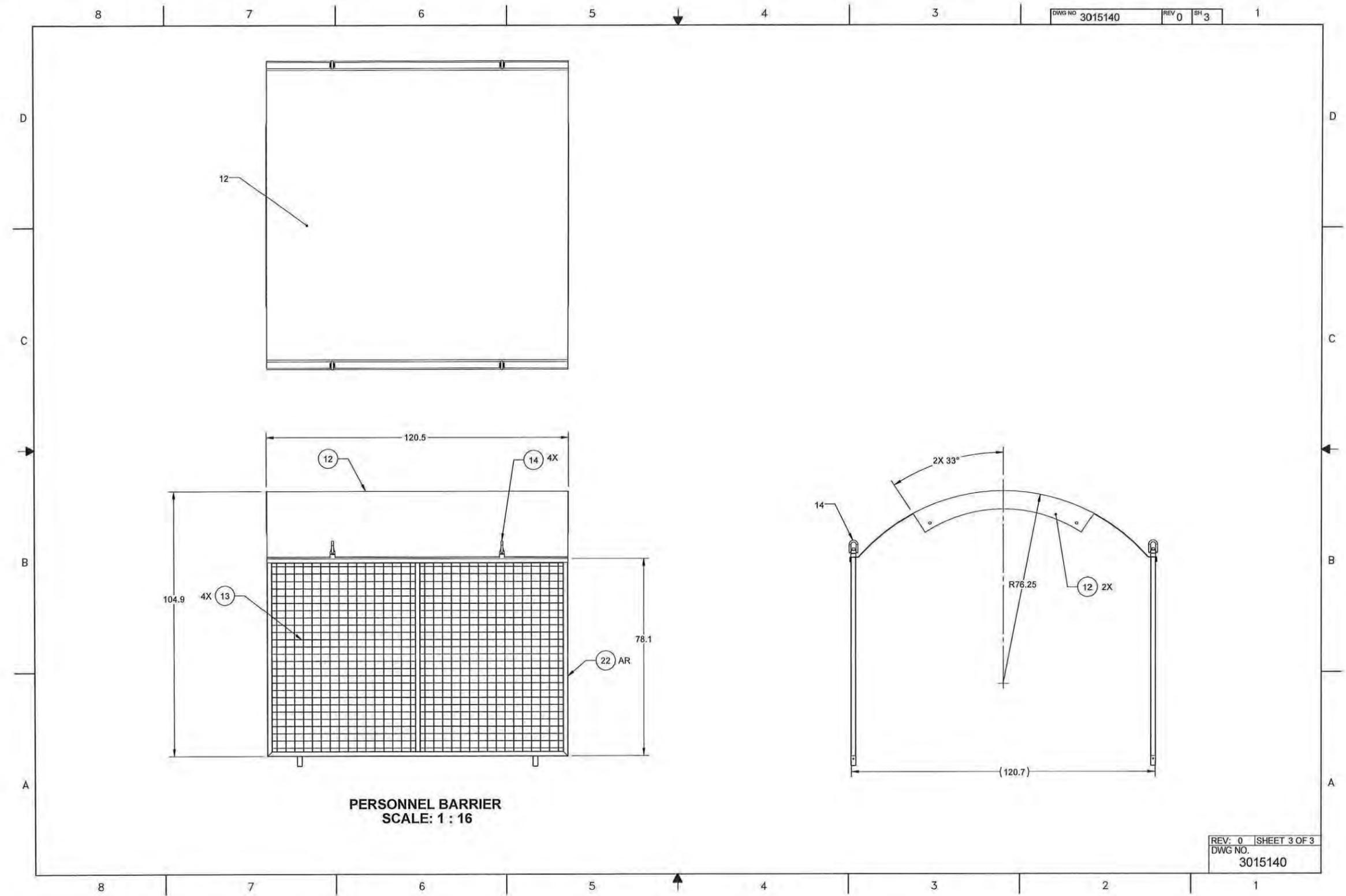
UNLESS OTHERWISE SPECIFIED:  
INTERPRET DRAWINGS & TOLERANCES PER ASME Y14.5-2009  
(REVISION OF ASME Y14.5M-1994)  
INTERPRET WELD CALLOUTS PER ANSI/AWS A2.4  
DIMENSIONS ARE IN INCHES

**AREVA** Federal Services LLC  
Packaging Projects  
Federal Way, WA 98003

DWG TITLE  
**ATLAS RAILCAR CRADLE FAMILY 4  
CONCEPTUAL DRAWING**

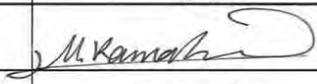
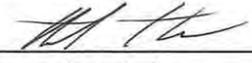
SCALE: SHOWN WT. - LBS  
REV: 0 SHEET 1 OF 3  
DWG NO.  
**3015140**  
CADFILE: 3015140.SLDDRW  
DWG-3015140-000





## Appendix A.2.4 – Structural Calculation

CALC-3015136-000  
 Page 1 of 26

	<b>AREVA Federal Services LLC</b>		
	<b>CALCULATION</b>		
<b>Document No.:</b>	CALC-3015136	<b>Rev. No.</b>	000 <span style="float: right;">Page 1 of 26</span>
<b>Project No.:</b>	00225.03.0050	<b>Project Name:</b>	DOE Atlas Railcar
<b>Title:</b>	Atlas Railcar Family 4 Conceptual Cradle Structural Calculation		
<b>Summary:</b>			
<p>The Atlas Railcar Family 4 Cradle Assembly conceptual design has been evaluated in this document. As the result of this evaluation, it is found that the design is structurally sound and it can withstand all the loads in accordance with the DBRD [2].</p>			
<b>Contains Unverified Input / Assumptions:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>			
<b>Software Utilized:</b> MS Excel <b>Software Active in AFS EASI:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/> <b>Error Reports &amp; Associated Corrective Actions Reviewed:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>	<b>Version:</b> 2010	<b>Storage Media:</b> Yes: <input checked="" type="checkbox"/> No: <input type="checkbox"/>  <b>Location:</b> COLDstor	
	<b>Printed Name</b>	<b>Signature</b>	<b>Date</b>
<b>Preparer:</b>	M. Kamalian		6/29/16
<b>Checker:</b>	D. Wick		6/29/16
<b>Approver:</b>	D. Hillstrom		6/30/16
<b>Other:</b>	S. Klein		6/30/16

AFS-EN-FRM-002 Rev. 07 (Effective April 21, 2015)  
 Reference: AFS-EN-PRC-002

**AREVA**  
**July 6, 2016**  
**Records Management**



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015136-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 2 of 26**

**Revision History**

Rev.	Changes
000	Initial release



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 3 of 26

**Table of Contents**

	Page
REVISION HISTORY .....	2
LIST OF TABLES .....	5
LIST OF FIGURES .....	6
1.0 PURPOSE .....	7
2.0 METHODOLOGY .....	8
2.1 Interface Conditions .....	8
2.2 Loading Conditions .....	8
2.3 Margin of Safety .....	8
3.0 ASSUMPTIONS .....	8
3.1 Unverified Inputs/Assumptions .....	8
3.2 Justified Assumptions .....	8
4.0 DESIGN INPUTS .....	9
4.1 Loads and Centers of Gravity (CG) .....	9
4.1.1 Cask and Cradle .....	9
4.1.2 Tie-Down Loads .....	9
4.1.3 Dynamic Factor .....	9
4.2 Materials Properties .....	10
5.0 CALCULATIONS .....	10
5.1 System General Descriptions .....	10
5.1.1 Cradle Base .....	10
5.1.2 Lower Tie-Down (saddle) .....	11
5.1.3 Upper Tie-Down .....	12
5.1.4 Sun Shield and Personnel Barrier .....	13
5.2 Determine Bounding Tie-Down Loads to the Railcar .....	14
5.2.1 Longitudinal Load .....	14
5.2.2 Lateral Load .....	15
5.2.3 Vertical Load .....	15
5.2.4 Summary of the Tie-Down Loads to the Railcar .....	15
5.3 Determine Bounding Load to Tie-Downs Connection .....	16
5.3.1 Longitudinal Load .....	16
5.3.2 Lateral Load .....	16
5.3.3 Vertical Load .....	18
5.4 Stresses on the Tie-Downs Connection Members .....	18
5.4.1 Stress on the Tie-Downs Retainer Pin .....	19
5.4.2 Stress on the Upper Tie-Down Side Supporting Plates .....	19
5.4.3 Stress on the Lower Tie-Down Post .....	20



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015136-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 4 of 26**

**Table of Contents**  
(continued)

	<b>Page</b>
5.5 Other Evaluations.....	20
5.5.1 Critical Members affected by the Lifting Load .....	20
5.5.2 Critical Members affected by 7.5g Longitudinal Tie-Down Load.....	21
5.5.3 Critical Members affected by 2g Lateral Tie-Down Load.....	23
5.5.4 Critical Members affected by 2g Vertical Tie-Down Load .....	23
6.0 RESULTS/ CONCLUSIONS .....	24
6.1 Results of Applicable Literature Searches and Other Applicable Background Data .....	24
7.0 REFERENCES .....	25
APPENDIX A : WEIGHT AND CG CALCULATIONS.....	26

CALC-3015136-000  
Page 5 of 26



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015136-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 5 of 26**

---

**List of Tables**

	<b>Page</b>
Table 4-1: Cask and Cradle Weights and CGs.....	9
Table 4-2: Material Properties.....	10
Table 5-1: Summary of Tie-Down Loads to the Railcar.....	16



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015136-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 6 of 26**

**List of Figures**

	<b>Page</b>
Figure 1-1: Family 4 Cradle Assembly Conceptual Design .....	7
Figure 5-1: Cradle Base (top plate transparent for clarity) .....	11
Figure 5-2: Lower Tie-Down (Saddle) .....	12
Figure 5-3: Upper Tie-Down .....	13
Figure 5-4: Personnel Barrier and Sun Shield .....	13
Figure 5-5: Pin Locations and Acceleration Directions .....	14
Figure 5-6: Longitudinal Load to Railcar FBD .....	14
Figure 5-7: Lateral Load to Railcar FBD .....	15
Figure 5-8: Longitudinal Load to Cradle .....	16
Figure 5-9: Lateral Load Distribution on the Tie-Downs .....	17
Figure 5-10: Lateral Load on Upper Tie-Downs .....	18
Figure 5-11: Tie-Downs Loads .....	19
Figure 5-12: Lifting Lug .....	20
Figure 5-13: Cask and Cradle Shear Keys .....	22
Figure 5-14: Longitudinal Load on Cask Shear Key .....	22
Figure 5-15: Bounding Load on Upper Tie-Down .....	23
Figure 5-16: Load on the Box Section A-A .....	24



AREVA Federal Services LLC

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 7 of 26

### 1.0 PURPOSE

The Atlas Railcar Family 4 Cradle Assembly conceptual design (cradle), exclusively designed for the transport of Multi-Purpose cask 187 (MP187), is one of the four (4) family cradle designs. It is designed to serve under phase 1 (conceptual design phase) of the US Department of Energy (DOE) integrated nuclear waste management disposition system, called DOE Atlas Railcar Project [1]. The driving size limitations and design boundaries are delineated in the Design Basis Requirements Document (DBRD) [2]. The purpose of this document is to evaluate the structural integrity of the MP187 cradle under the loads specified in the following subsections, in accordance with the DBRD [2]. Additionally, the height and vertical CG from the bottom of the cradle and associated loads to the railcar at the pin locations will be determined and provided for the testing purpose of the railcar. The conceptual design is shown in Figure 1-1 and drawing 3015140 [8].

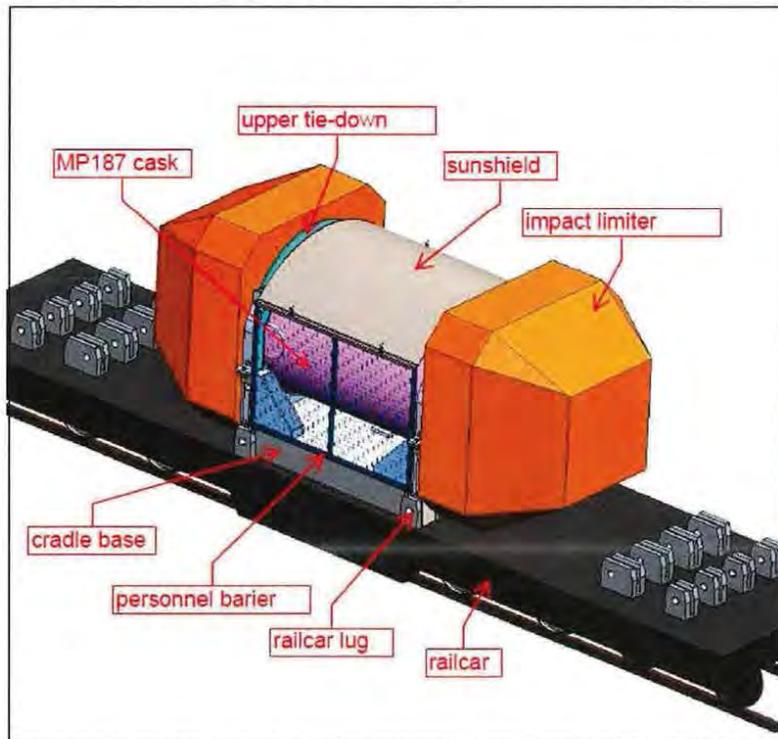


Figure 1-1: Family 4 Cradle Assembly Conceptual Design



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 8 of 26

**2.0 METHODOLOGY**

Hand calculation will be used in this document to demonstrate that the cradle can support the applied loads. Allowable stresses are calculated using the given accelerations loads per the DBRD [2] against yield strength of the materials. Steel Construction Manual of AISC may be used as a guide also [3]. Because the design is merely conceptual, only the main or critical components and connections in the load path are evaluated in this document. The interfaces and loading conditions are as follows.

**2.1 Interface Conditions**

There are two (2) major interface conditions:

- 1- Loaded Cradle-to-Railcar interface: The total loaded cradle will be used in this case.
- 2- Cask-to-Cradle interface: Only the load from the cask will be applied to the affected members in this case.
- 3- No cask rotation on the cradle is required for the MP187 loading condition.

**2.2 Loading Conditions**

There are three (3) loading conditions to be evaluated:

- 1- **Lifting Load:** The load will be distributed equally between all four (4) lifting points in accordance with DBRD [2]. ANSI N14.6 [4] will be used in this evaluation since the payload is higher than 10,000 lb.
- 2- **Tie-Down Loads:** The accelerations in the design input section of this document will apply individually per DBRD [2]. The stresses resulting from the applied loads are then compared against the allowable yield stresses of the components in accordance with Section 2.2.2-13 of the DBRD [2]. Analysis of the 2g vertical load bounds the 1g dead weight load.
- 3- **Fatigue Load:** Family 3 cradle conceptual design calculation [5] covers the fatigue evaluation for all other cradle designs including this design.

**2.3 Margin of Safety**

The margin of safety in this calculation is defined as the allowable load divided by the applied load to be greater than 1 or:

$$MS = (\text{allowable load} / \text{applied load}) - 1 > 0$$

**3.0 ASSUMPTIONS**

**3.1 Unverified Inputs/Assumptions**

All inputs are referenced against verifiable sources. There are no unverified inputs or assumptions used in this document.

**3.2 Justified Assumptions**

- 1- It is assumed that the loads are uniformly applied where shown in this document. This is considered as a standard practice.
- 2- It is assumed that the materials used in this design have no defects per the procurement standard practice; therefore their properties are accurate per the published codes and standards referenced in this document.
- 3- It is assumed that the materials are inherently homogeneous throughout; hence strengths of materials are uniform. This is justified based on the procurement standard practice.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 9 of 26

- 4- It is assumed that the lift occurs through four (4) points and is equally balanced. This is a standard practice.
- 5- All welds are assumed to be either full or partial penetration with full strength as adjoining component. Where a full or partial penetration weld is not possible, it is assumed there will be adequate weld such that the strength of the weld is equal or greater than the full strength as adjoining component. Welds will be fully evaluated in the final design.

**4.0 DESIGN INPUTS**

**4.1 Loads and Centers of Gravity (CG)**

**4.1.1 Cask and Cradle**

The CG and the maximum allowable transportation weight for the cask come from Section 2.5.2 of MP187 SAR [6]. The weight and CG for the cradle assembly come from the details in Appendix A.1. The combined cradle and cask weight and CG is computed below and the result is recorded in Table 4-1.

From Appendix A1:  $W_c = 36.8$  kip  $CG \text{ of Cradle} = 27.2$  in.

From the MP187 SAR:  $W_{cask} = 280$  kip  $CG \text{ of cask} = 69$  in.

Combined weight:  $W_t = 280 + 36.8 = 316.8$  kips

Rounded up combined CG:  $Z_t = [36.8(27.2) + 280(69)] / 316.8 = 64.2$  in

A conservative rounded up total weight of 320 kips will be used in this document where applicable.

**Table 4-1: Cask and Cradle Weights and CGs**

Component	Weight (kip)	Vertical CG from cradle bottom (in)	Ref.
MP187 (cask)	280	69.0	SAR [6]
Cradle Assembly	36.8	27.2	Appendix A
Cask + Cradle Assembly	316.8	64.2	Sec. 4.1.1

**4.1.2 Tie-Down Loads**

The following accelerations will be applied individually in the evaluations of the cradle components for the tie-down loading in accordance with [2].

- $\pm 7.5g$  Longitudinal (axial)
- $\pm 2g$  Vertical
- $\pm 2g$  Lateral

**4.1.3 Dynamic Factor**

A dynamic factor of 1.15 will also be applied to the lifting load per the DBRD [2]



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 10 of 26

**4.2 Materials Properties**

The materials properties listed in Table 4-2 are from ASTM Standards [7].

**Table 4-2: Material Properties**

ASTM Code	Yield (ksi)	N14.6 lifting based on yield (ksi)	Tensile (ksi)	N14.6 lifting based on ultimate (ksi)
A572, Gr 50	$S_y = 50$	$50/3 = 16.67$	$S_u = 65$	$65/5 = 13$
A514 up to 2.5" thick	$S_y = 100$	$100/3 = 33.33$	$S_u = 110$	$110/5 = 22$
A514 2.5" to 6" thick	$S_y = 90$	$90/3 = 30$	$S_u = 100$	$100/5 = 25$
A311, Gr. 1144, Class B	$S_y = 100$	$100/3 = 33.33$	$S_u = 115$	$115/5 = 23$

- The density of steel materials used in this document is per Table 17-12 of [3].
- The unit weight of the wide flange W18x119 is from [3].
- Allowable shear stress: 60% of materials yield or ultimate stress will be used, where applicable per [3].

**5.0 CALCULATIONS**

In addition to a general system description and analysis below, the following evaluations are presented to determine the loads to the railcar as well as to demonstrate that the critical members and connections of the cradle assembly are capable of supporting the MP187 under various loading conditions.

- 1- System General Descriptions
- 2- Loads to the Railcar Evaluations
- 3- Determine Bounding Load to Tie-Downs Connection
- 4- Stresses on the Tie-Down Connecting Members
- 5- Other Evaluations due to all Loads
  - Critical Members affected by the Lifting Load
  - Critical Members affected by 7.5g Longitudinal Load
  - Critical Members affected by 2g Lateral Load
  - Critical Members affected by 2g Vertical Load

**5.1 System General Descriptions**

The Atlas Family 4 cradle assembly conceptual design consists of the following main components (subassemblies) as shown in [8] and described below.

**5.1.1 Cradle Base**

The cradle base provides the interfaces with the railcar as well as the cask. With the railcar, it is restrained at four (4) pin locations to react to the tie-down loads. It also interfaces with two (2) shear keys on the railcar to support



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

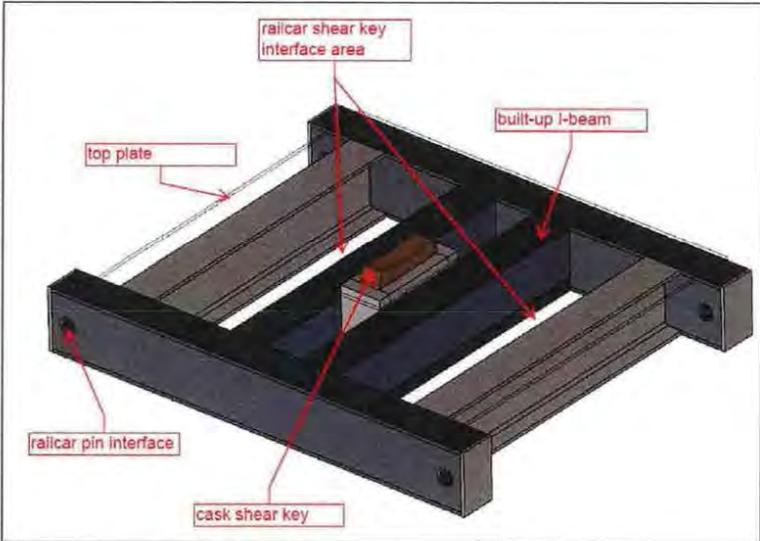
Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 11 of 26

the longitudinal shear loads. With the cask, the cradle base interfaces with a shear key at the center to resist the longitudinal load only. Laterally, the cradle upper and lower tie-downs will resist the cask's load and the railcar lugs will resist the load from loaded cradle.

All members are made of high strength low alloy steel. The two (2) main side beams as well as the four (4) cross beams are built from W18x119 wide flanges or Built-up I-beam with one inch side plates reinforced with full or partial penetration welds. A one inch thick plate covers and connects all these members at the top with welds to form a rectangular body shown in Figure 5-1. The shear key with its reinforcement plates are then welded at the center for the interface between the cask and the cradle. The shear key is similar in design to that shown in the MP187 SAR [6]. The concept of this subassembly is shown on sheet 2 of [8].



**Figure 5-1: Cradle Base (top plate transparent for clarity)**

**5.1.2 Lower Tie-Down (saddle)**

Two (2) saddles provide the nesting areas for the cask to rest on. Each saddle is eight (8) inches wide and is welded on top at the end of the skid base. In addition to the interior strut reinforcement members, it consists of two (2), 2-inch welded plates that will carry the cask's load to the ground statically. Each saddle includes two posts at the top to engage with the upper tie-downs. The upper tie-downs slip over the six (6) inch square posts and 2.5 inch pins will secure the tie-downs around the cask to the cradle base. The conceptual design is shown in Figure 5-2 with more detail on sheet 2 of the conceptual design drawing [8].



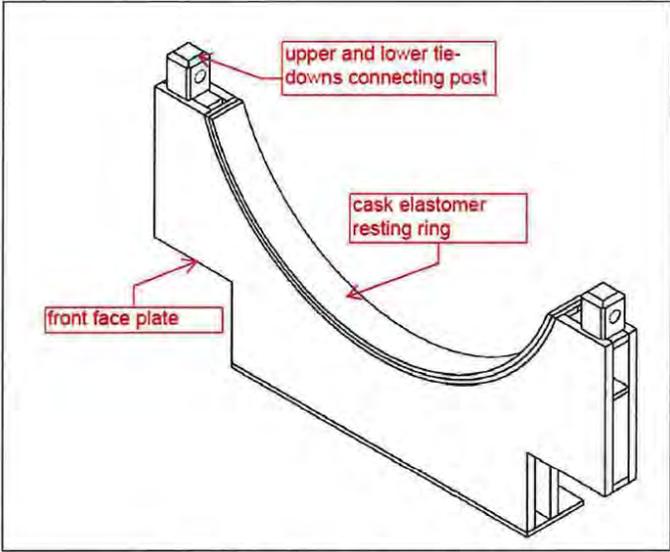
**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 12 of 26



**Figure 5-2: Lower Tie-Down (Saddle)**

**5.1.3 Upper Tie-Down**

The two upper tie-downs are designed, mainly, to minimize the cask movement vertically. Each upper tie-down is built to form a 6 x 8 C-channel, curved to nest around the upper portion of the cask, and will provide clearance for the cask's side trunnions. As mentioned above, the upper tie-downs will slip over the posts of the lower tie-downs and the 2.5 inch pins are sized to secure them in through 1.5 inch thick side plates. Because of the imperfect cask circular body, it is necessary to draw the upper tie-down onto the lower tie-down to match the pin holes. For this reason a 1.5 bolt will be used on each side of each tie-down. The rubber liner on the upper tie-down is designed to compress against the cask as the bolts are tightened sufficiently to allow the upper tie-down pin hole to align with the lower tie-down pin hole.

Each upper tie-down includes an outer 1.5 thick plate welded to the lower portion of the C-channel to add stiffness around the bent portion which is not in contact with the cask. This plate adds rigidity to the C-channel at the highest stress location due to the bounding load computed below. The plate is also welded to the lift lugs at the top to provide support for vertical lifting. At the bottom this plate is bent outwards to provide a surface to the 1.5 inch diameter bolt mentioned above.



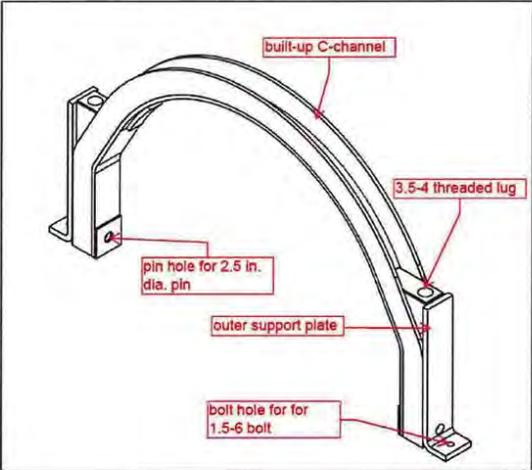
**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

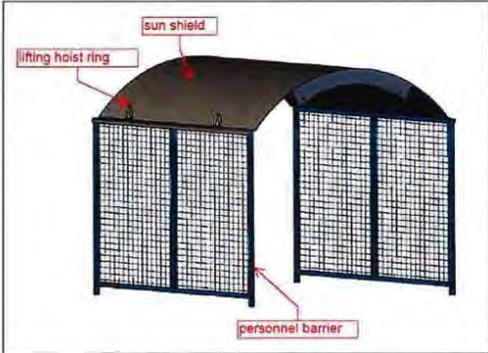
Page 13 of 26



**Figure 5-3: Upper Tie-Down**

**5.1.4 Sun Shield and Personnel Barrier**

The personnel barrier assembly consists of a curved 1/4 inch thick plate as a shade provider and two (2) side metal screens as personnel barriers. The personnel barrier is made from two (2) inch stainless steel tubing framed around a mesh of 1/4 inch welded stainless steel rods. The entire assembly is lifted by the four (4) hoist rings rated for 5,000 lbs. each. The personnel barrier is secured onto the cradle assembly via ball lock pins.



**Figure 5-4: Personnel Barrier and Sun Shield**



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

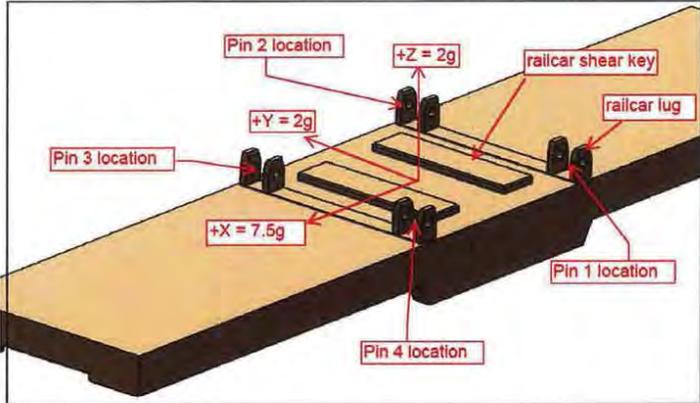
Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 14 of 26

**5.2 Determine Bounding Tie-Down Loads to the Railcar**

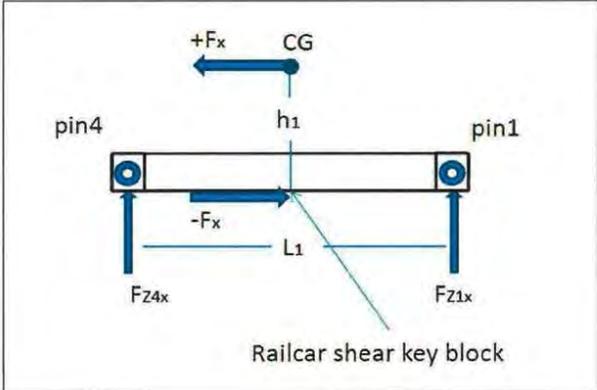
The tie-down loads directions and pin locations are shown in Figure 5-5.



**Figure 5-5: Pin Locations and Acceleration Directions**

**5.2.1 Longitudinal Load**

The 7.5 longitudinal acceleration results in a shear force that is resisted by the railcar shear key and a moment on each pin. The free body diagram is shown in



**Figure 5-6: Longitudinal Load to Railcar FBD**



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 15 of 26

The load:  $F_x = 7.5(320 \text{ kip}) / 2 = 1200 \text{ kip}$   
 Vertical moment arm:  $h_1 = Z_t = 64.2 \text{ in.}$   
 Distance between the pins:  $L_1 = 125.0 \text{ in.}$   
 $\sum M_{pin4} = 0$   $F_{z1x} = F_x(h_1) / L_1 = 1200(64.2) / 125 = 616.3 \text{ kip}$   
 $\sum F_x = 0$   $F_x = -F_x = -1200 \text{ kip}$

**5.2.2 Lateral Load**

Similarly, the 2g lateral load will be resisted by the two lugs on the railcar. The reaction will occur at the base of the cradle.

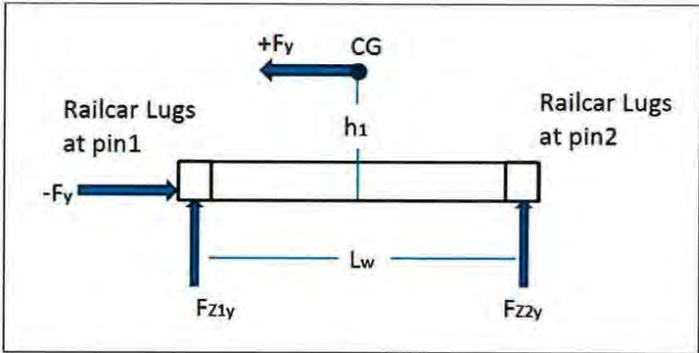


Figure 5-7: Lateral Load to Railcar FBD

The load:  $F_y = 2(320 \text{ kip}) / 2 = 320 \text{ kip}$   
 Distances:  
 Vertical moment arm:  $h_1 = 64.2 \text{ in.}$   
 Distance between the pins:  $L_w = 104.75 \text{ in.}$   
 $\sum M_{pin2} = 0$   $F_{z1y} = F_y(h_1) / L_w = 320(64.2) / 104.75 = 196.1 \text{ kip}$   
 $\sum F_y = 0$   $F_y = -F_y = -320 \text{ kip}$

**5.2.3 Vertical Load**

The result of the 2g vertical force as follows:

The load:  $F_z = 2(320 \text{ kip}) / 4 = 160 \text{ kip}$

**5.2.4 Summary of the Tie-Down Loads to the Railcar**

The summary of the tie-down loads to the railcar is listed in Table 5-1.



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 16 of 26

**Table 5-1: Summary of Tie-Down Loads to the Railcar**

Acceleration	Load to the Railcar (kip)
7.5g Longitudinal double shear on any pin location	$\pm Fz = 616.3$
7.5g Longitudinal on railcar shear key	$\pm Fx = 1200$
2g Lateral on any railcar lug	$\pm Fy = 320$

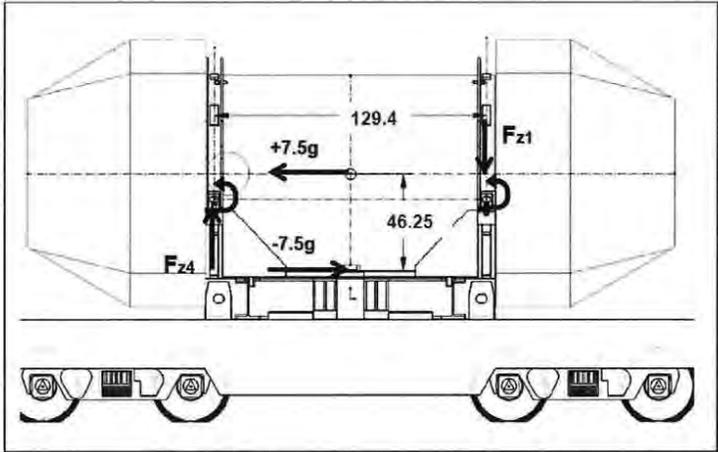
**5.3 Determine Bounding Load to Tie-Downs Connection**

In this evaluation, the lifting load and the loads from the tie-downs in each direction are compared and the bounding load will be used to determine the stresses on the upper and lower tie-down members.

**5.3.1 Longitudinal Load**

The load includes a 7.5g tie-down load that is resisted by the cask's shear key and a moment that is applied to the pin connection between the upper and lower tie-downs. In this section, only the load on the pin connection will be determined, hence summing the moment around the left pin:

$\sum M_{pin} = 0 \quad 7.5g (280 \text{ kip} / 2) (46.25 \text{ in}) = Fz1(129.4 \text{ in}), \quad Fz1 = 375.3 \text{ kips}$



**Figure 5-8: Longitudinal Load to Cradle**

**5.3.2 Lateral Load**

The lateral load includes a 2g tie-down load that is resisted in part by the upper tie-down and partly by the lower tie-down. Structurally the lower tie-down is stronger than the upper tie-down and since the portion of the load that is acting on the upper tied-down is greater than the lower portion of the load, considering linear distribution as shown in Figure 5-9, thus the upper tie-down stresses bound the lower tie-down. Therefore, first the ratio of the load that is carried by the upper tie-downs needs to be determined, hence.



**AREVA Federal Services LLC**

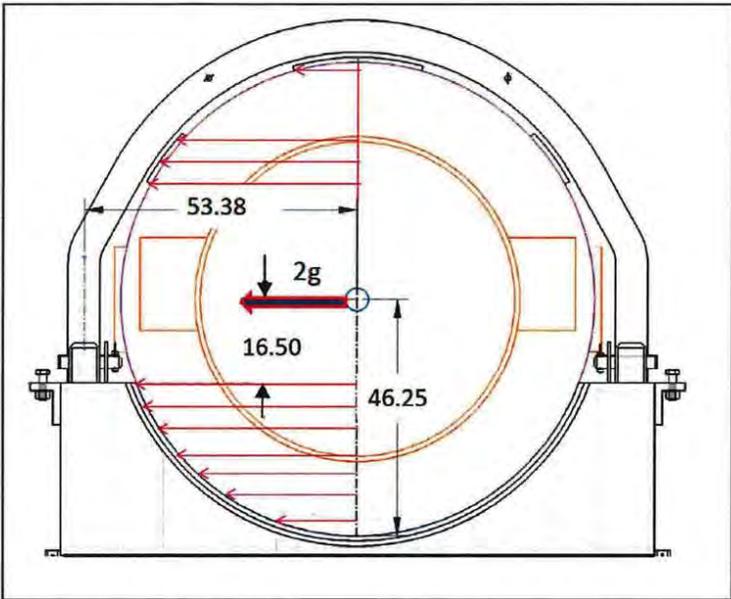
Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 17 of 26

The lower tie-down lateral reaction point is 16.5 inches down from the cg location, therefore:  
 The load on the bottom tie-down =  $(280 \text{ kip}/2) - [280 \text{ kip} (16.50/92.5)] = 90 \text{ kip}$   
 The load on the upper tie-down =  $(280 - 90) \text{ kip} = 190 \text{ kip}$



**Figure 5-9: Lateral Load Distribution on the Tie-Downs**

For the upper tie-downs, as shown in Figure 5-10, conservatively it is assumed a maximum moment arm which is at the highest point of contact between the cask and the upper tie-down to the pin location.

Moment arm =  $46.25 + 7.45 = 53.7 \text{ in.}$

For the upper portion of the load:

$$\sum M_{pin2} = 0 \quad 2g (190 \text{ kip}/2)(53.7 \text{ in}) = Fz1l (2 \times 53.38 \text{ in}) \quad Fz1l = 95.6 \text{ kips}$$

$$\text{Lateral shear reaction:} \quad Fy1l = 2 (190 \text{ kip}/2) = 190 \text{ kip}$$

$$\text{The resultant:} \quad Fz1y = \sqrt{95.6^2 + 190^2} \quad \mathbf{Fz1y = 212.7 \text{ kip}}$$



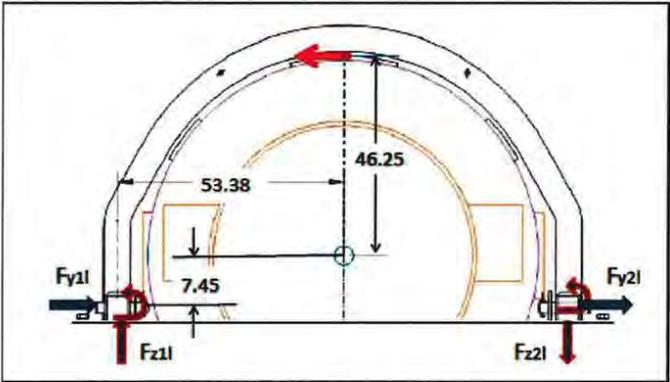
**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 18 of 26



**Figure 5-10: Lateral Load on Upper Tie-Downs**

**5.3.3 Vertical Load**

There are two (2) vertical loads to consider, the tie-down 2g vertical load and the lifting load, hence:

**5.3.3.1 2g Vertical Load**

The 2g vertical acceleration results in reactions forces as follows:  $Fz1z = 2g (280 \text{ kip} / 4) = 140 \text{ kip}$

**5.3.3.2 Vertical Lifting Load**

For lifting, the lifting lugs are designed directly above the tie-down connections so that there is no eccentricity. Based on Table 4-2, the ultimate stress allowable for all materials is bounding. In order to compare the bounding load in the system, five (5) times the loaded cradle is considered to account for the allowable based on the bounding tensile stress against the ultimate stress of the materials in accordance with the lifting requirements of ANSI N14.6 [4]. Additionally, a load factor of 1.15 will be added, hence:

$$Fliftu = 5(1.15)(320 \text{ kip}) / 4 = 460 \text{ kip}$$

**5.4 Stresses on the Tie-Downs Connection Members**

Between all the loads in Sections 5.3.1, 5.3.2, and 5.3.3, the vertical lifting load is the highest load and therefore will be used for the evaluations of the members associated in connection between the upper and the lower tie-downs per Figure 5-11.



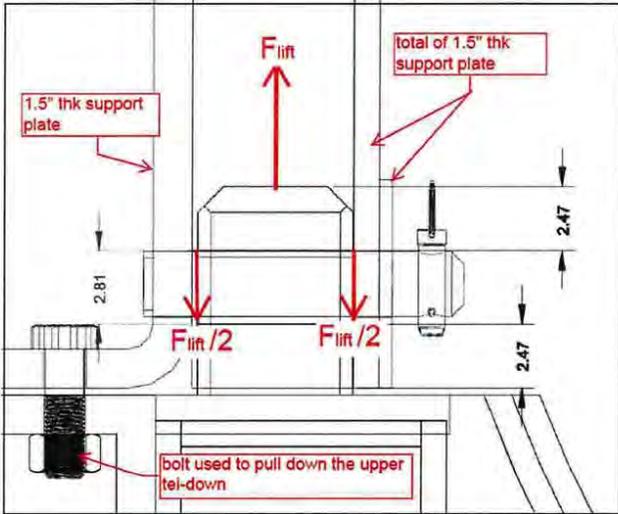
**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 19 of 26



**Figure 5-11: Tie-Downs Loads**

**5.4.1 Stress on the Tie-Downs Retainer Pin**

The applied load from Section 5.3.3.2:  $F_{pin} = F_{liftu} = 460 \text{ kip}$   
 The pin is in double shear and made of A311, Gr. 1144, Class B with  $S_u = 115 \text{ ksi}$ .  
 The pin is sized for 2.5 in. dia. with an area of:  $A_{pin} = \pi (2.5 / 2)^2 = 4.9 \text{ in}^2$   
 The applied double shear stress on the pin:  $F_{app} = 460 \text{ kip} / (2 \times 4.9 \text{ in}^2) = 46.9 \text{ ksi}$   
 Allowable shear force on the pin:  $S_{pin} = 0.6 S_u = 0.6 \times 115 \text{ ksi} = 69 \text{ ksi}$   
 The Margin of Safety:  $MS_{pin} = (69 / 46.9) - 1 = 0.47 \quad \text{OK}$

**5.4.2 Stress on the Upper Tie-Down Side Supporting Plates**

Each side of the pin is supported with a 1.5 inch thick plate by 8 inches wide, made from ASTM A514 with  $S_u = 110 \text{ ksi}$ . The tear out area of these plates bounds all other areas under this load, hence.  
 The Applied Load:  $F_{plate} = F_{liftu} / 2 = 460 \text{ kip} / 2 = 230 \text{ kip}$   
 Plate tear out area with edge distance of 2.47 in.:  $A_{plate} = 2(1.5 \text{ in})(2.47 \text{ in}) = 7.41 \text{ in}^2$   
 The applied shear stress:  $F_{app} = 230 \text{ kip} / (7.41 \text{ in}^2) = 31 \text{ ksi}$   
 Allowable shear force:  $S_{plate} = 0.6 \times S_u = 0.6 \times 110 \text{ ksi} = 66 \text{ ksi}$   
 The Margin of Safety:  $MS_{plate} = (66 / 31) - 1 = 1.1 \quad \text{OK}$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 20 of 26

**5.4.3 Stress on the Lower Tie-Down Post**

The lower tie-down post is 6 x 6 x 8 tall, made from ASTM A514 with  $S_u = 100$  ksi.

The Applied Load:	$F_{post} = F_{lift} = 460$ kip
Post tear out edge distance with 2.81 in dia. hole:	$edge = (6 - 2.81) / 2 = 1.6$ in
The tear out area:	$A_{post} = 2(1.6 \times 6) = 19.2$ in <sup>2</sup>
The applied shear stress:	$F_{app} = 460 \text{ kip} / (19.2 \text{ in}^2) = 24$ ksi
Allowable shear force:	$S_{plate} = 0.6 \times S_u = 0.6 \times 100 \text{ ksi} = 60$ ksi
The Margin of Safety:	$MS_{post} = (60 / 24) - 1 = 1.5$ <b>OK</b>

**5.5 Other Evaluations**

**5.5.1 Critical Members affected by the Lifting Load**

Each upper tie-down includes two (2) lifting lugs, shown in Figure 5-12. Each lug includes a 3-4 UNC, 2B by minimum of 4 inches long threads. A lifting device such as a hoist ring with minimum Working Load Limit (WLL) of 85 kips with a safety margin of 5 to 1 shall be used. Each lug will carry 1/4 of the total load of 320 kip, which is 80 kip. The welds are full penetration or equivalent in area where full penetration is not possible. Due to having long stretch of welds all around the lug the stress on this weld group is not bounding as compare to the stress on the internal threads, hence the provisions ANSI N14.6 will apply to the internal threads in addition to a load factor 1.15:

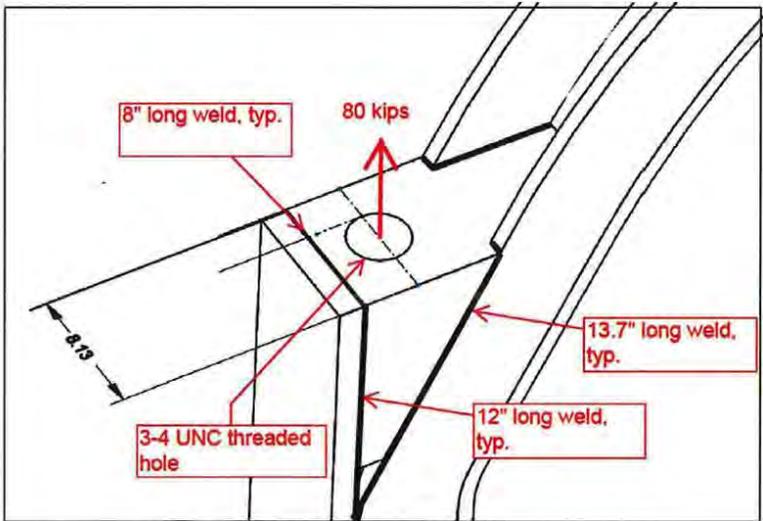


Figure 5-12: Lifting Lug



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015136-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 21 of 26**

3 times the load on yield stress:  $F_{3lift} = 1.15 \times 3 \times 320 \text{ kip} / 4 = 276 \text{ kip}$

5 times the load on ultimate stress:  $F_{5lift} = 1.15 \times 5 \times 320 \text{ kip} / 4 = 460 \text{ kip}$

The material is ASTM A514 with yield stress of 90 ksi and ultimate stress of 100 ksi.

The allowable shear on the threads based on yield:  $S_{yallow} = 0.6 \times 90 \text{ ksi} = 54 \text{ ksi}$

The allowable shear on the threads based on ultimate:  $S_{ualow} = 0.6 \times 100 \text{ ksi} = 60 \text{ ksi}$

The ratio for yield:  $276 / 54 = 5.1 \text{ in}^2$  for ultimate:  $460 / 60 = 7.7 \text{ in}^2$

Therefore the ultimate criteria will be used in the following.

The shear and tensile area for 3-4 UNC, class 2B threads from Product Engineering, Nov. 1961:  $A_t = 7.29 \text{ in}^2/\text{in}$ .

The area for minim of 4 inches:  $A_{th} = 7.29 \times 4.0 = 29.2 \text{ in}^2$

Margin of Safety:  $MSt = (29.2 / 7.7) - 1 = 2.8 \text{ OK}$

**5.5.2 Critical Members affected by 7.5g Longitudinal Tie-Down Load**

**5.5.2.1 Loaded Cradle to the Railcar**

The 7.5g tie-down load causes a shear load to the railcar that is resisted by the railcar cask shear keys on the deck of the railcar (see Figure 5-13) and a moment on the four (4) inch pins at the connection points between the railcar and the cradle.

The shear force from the railcar shear key is reacted at the bottom by a 4 inch thick x 93.5 inches long plate at the bottom of a built-up I-beam. The moment, however, results in a vertical shear force on each pin which is evaluated in [9] based on the bounding load from all Atlas cradle family conceptual designs.

**5.5.2.2 Cask to Cradle**

The 7.5g tie-down load in either longitudinal direction will result in a shear force resisted by the cask shear key at the top center of the cradle and a moment. The shear key is full penetration welded all around to the center piece of the cradle with four (4) inch thick supporting plates welded all the way down to cradle. The cask shear key shown in Figure 5-13 and the load diagram is shown in Figure 5-14.

The shear key is a six (6) inches thick by 26.9 inches long by 23.3 wide with a taper on top to reduce the width no less than 20 inches. The shear key bears the entire cask load which is conservatively rounded up to 280 kips. The contact point on the shear key from the cask is 1.25 inches above the shear key support.

The reaction load at the contact point of the cradle and the cask:  $F_{shear} = 7.5 \times 280 \text{ kip} = 2100 \text{ kip}$

The moment on the shear key:  $M_{key} = 2100 \text{ kip} (1.25 \text{ in}) = 2625 \text{ in.kip}$

The moment of inertia:  $I_{key} = (1/12) (20)(6)^3 = 360 \text{ in}^4$

Distance to maximum stress:  $c = (1/2) (6.0) = 3.0 \text{ in}$ .

The stress due to moment:  $F_{keym} = (M_{key})(c) / I_{key} = [2625 (3.0)] / 360 = 21.9 \text{ ksi}$

Stress area:  $A_{sh} = 6.0 (20.0) = 120 \text{ in}^2$

The stress due shear:  $F_{keys} = F_{shear} / A_{sh} = 2100 / 120 = 17.5 \text{ ksi}$



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 22 of 26

The total stress:  $F_{key} = \sqrt{(F_{keym}/2)^2 + F_{keys}^2} = \sqrt{(21.9/2)^2 + 17.5^2} = 20.6 \text{ ksi}$

The allowable shear for 6 inch, A514 material:  $S_{y514} = 0.6x 90 = 54 \text{ ksi}$

Margin of Safety:  $MS_{key} = (54 / 20.6) - 1 = 1.6$  **OK**

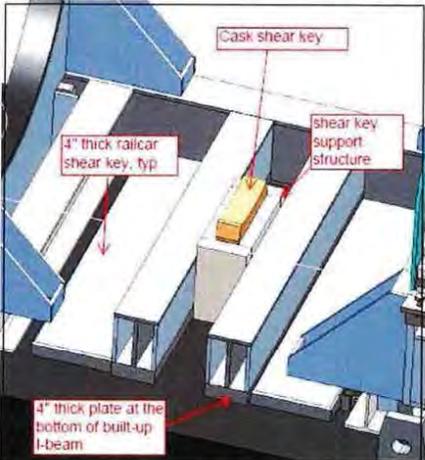


Figure 5-13: Cask and Cradle Shear Keys

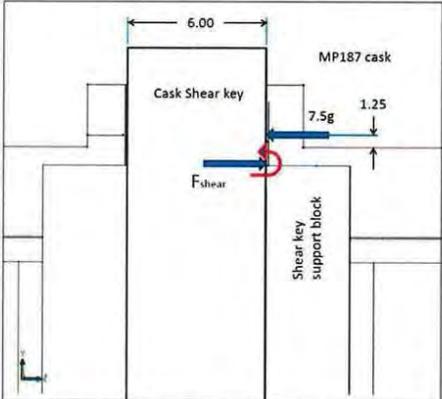


Figure 5-14: Longitudinal Load on Cask Shear Key



**AREVA Federal Services LLC**

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 23 of 26

**5.5.3 Critical Members affected by 2g Lateral Tie-Down Load**

**5.5.3.1 Loaded Cradle to the Railcar**

The lateral load to railcar is resisted by the railcar lugs evaluated in [9].

**5.5.3.2 Cask to Cradle**

The 2g tie-down load in either lateral direction is not resisted by the center shear key rather it is resisted by tie-downs. However, the stresses on the pin connection members between the upper and the lower tie-downs are bounded by those determined in Section 5.3.

**5.5.4 Critical Members affected by 2g Vertical Tie-Down Load**

**5.5.4.1 Loaded Cradle to the Railcar**

The vertical load to railcar is resisted by the railcar pins evaluated in [9].

**5.5.4.2 Cask to Cradle**

The 2g tie-down vertical load is resisted by the pin at interface between the upper and the lower tie-downs. The upper tie-down structure prevents the package from rising vertically from the cradle. This cannot occur during lifting. Bending stresses in the upper tie-down only occur when they are resisting the upward loads. The 375.3 kip from Section 5.3.1 seen at the pin connection due to the 7.5g longitudinal load case is the bounding load.

There is one primary area of concern for high stresses. It is where the tie-down transitions from the solid cross-section to the lower boxed section A-A shown in Figure 5-15. Since the support at the tie-down due to the cask separates at approximately 37° up from the center of the cask the load can be applied to the section from here. This section may be seen as a cantilever beam. Figure 5-16 shows the cross section A-A.

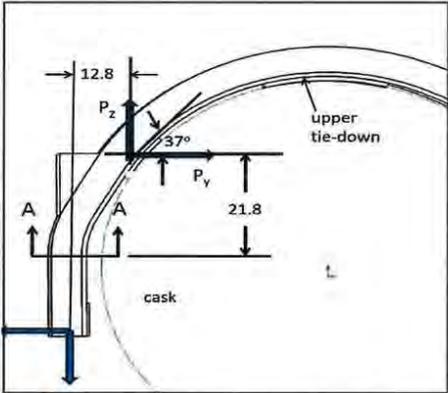


Figure 5-15: Bounding Load on Upper Tie-Down



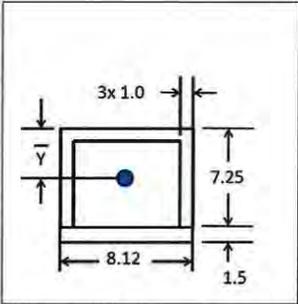
**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015136-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 24 of 26**



**Figure 5-16: Load on the Box Section A-A**

$P_z = 375.3 \text{ kip}$   
 $P_y = (P_z) \tan(37^\circ) = 282.8 \text{ kip}$   
 $M_g = P_z (12.8) - P_y (21.8) = -1361 \text{ in.kip}$   
 $A_1 = 7.25(1)(2) = 14.5 \text{ in}^2$       $A_2 = (8.12-2)(1) = 6.12 \text{ in}^2$       $A_3 = (8.12)(1.5) = 12.18 \text{ in}^2$   
 $Y_1 = 7.25 / 2 = 3.63 \text{ in}$       $Y_2 = 1 / 2 = 0.50 \text{ in}$       $Y_3 = (1.5 / 2) + 7.25 = 8.00 \text{ in}$   
 $\bar{Y} = \frac{\sum A_i \bar{Y}_i}{\sum A_i} = 4.67 \text{ in}$       $h = 1.5 + 7.25 = 8.75 \text{ in}$       $c = \max(\bar{Y}, h - \bar{Y}) = 4.67 \text{ in}$   
 $I = 2(1/12)(1.0)(7.25)^3 + (14.50)(4.67-3.63)^2 + (1/12)(6.12)(1.0)^3 + (6.12)(0.50-4.67)^2 + (1/12)(8.12)(1.5)^3 + (12.18)(4.67-8.0)^2 = 323.63 \text{ in}^4$   
 $S_b = M_c / I = (-1361) (4.67) / 323.63 = 19.64 \text{ ksi}$   
 Allowable stress      $S_a = 100 \text{ ksi}$   
 Margin of Safety:      $MS = (100 / 19.64) - 1 = 4.09$      **OK**

**6.0 RESULTS/ CONCLUSIONS**

The Atlas Railcar Family 4 Cradle conceptual design has been structurally evaluated in this document. As the result of this evaluation, it is found that the design is structurally sound and it can withstand all the applied loads. In this document, only the weakest failure modes in the load paths were identified and analyzed. A more detailed structural evaluation will be required for a comprehensive calculation package should fabrication of this cradle assembly be necessary. According to the above evaluations, the least margin of safety found is +0.47 from Section 5.4.1. The methods used for the allowables are from ANSI N14.6 [4] for lifting and to yield stress of the materials for all others. Note that a four (4) point vertical lift must be used when lifting the entire loaded cradle. The weight and CG for the package and cradle can be found in Table 4-1. The railcar reaction forces are found in Table 5-1.

**6.1 Results of Applicable Literature Searches and Other Applicable Background Data**

None



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

**Doc./Rev.:** CALC-3015136-000

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 25 of 26**

---

**7.0 REFERENCES**

1. Department of Energy: *Contract DE-NE0008390, Part 1, Section C, Statement of Work.*
2. AREVA Federal Services LLC: *PKG-DBR-019, Design Basis Requirement Document (DBRD) for the DOE ATLAS Railcar Project, Rev 3.*
3. American Institute of Steel Construction Inc. (AISC): *Steel Construction Manual, 13<sup>th</sup> edition.*
4. American National Standard Institute (ANSI N14.6-1993): *Special Lifting Devices for Shipping Containers weighing 10 000 Pounds (4500 kg) or More.*
5. AFS Document Number CALC-3015135: *Atlas Railcar Family 3 Conceptual Cradle Structural Calculation.*
6. NUHOMS® -MP187 Multi-Purpose Cask: *Safety Analysis Report, Rev. 17, Docket 71-9255.*
7. ASTM International Standards: *Annual Book of ASTM Standards, 2012.*
8. DWG-3015140-000: *Atlas Railcar Cradle Family 4 Conceptual Drawing, AREVA Federal Services LLC.*
9. AFS Document Number CALC-3015276-000: *Atlas Railcar Cradle Attachment Structural and Combined Center of Gravity Calculation.*



AREVA Federal Services LLC

Title: Atlas Railcar Family 4 Conceptual Cradle Structural Calculation

Doc./Rev.: CALC-3015136-000

Project: 00225.03.0050 - DOE Atlas Railcar

Page 26 of 26

APPENDIX A: WEIGHT AND CG CALCULATIONS

A.1 Cradle Assembly Weight and CG Calc

Unit of weights:		W18x 119 per AISC	119	lbs/ft	or	9.91667	lbs/in			
		steel per ASTM A6	0.284	lbs/in^3						
Assembly	part description	qty.	length (in)	width (in)	height (in)	thk (in)	(voids) (in^2)	wt. (lb)	CG from btm (in)	
Cradle Assem (A1)	W18x 119 main beam	2.0	135.5	11.3	19.0			2687.4	9.5	
	main beam side plates	4.0	135.5		16.9	1.0		2601.4	9.5	
	end caps	4.0		11.3	19.0	1.0		243.9	9.5	
	build-up i-beam btm plate	2.0	93.5	11.3		4.0	1.2	2336.8	2.0	
	build-up i-beam vertical plates	8.0	93.5		14.0	1.0		2974.0	11.0	
	build-up i-beam top plate	2.0	93.4	11.3		1.0		599.5	18.5	
	W18x 119 cross beams	2.0	93.5	11.3	19.0			1854.4	9.5	
	cradle top plate	1.0	121.5	116.0	1.0		408.2	3886.8	19.5	
	shear key	1.0		23.3	26.9	6.0		1069.8	13.5	
	shear key support plate, long	2.0	23.4		22.0	3.5		1007.7	11.0	
	shear key support plate short	2.0	13.0		22.0	4.0		649.8	11.0	
	front and back lower tie-down plates	4.0	116.0		69.0	2.0	4732.2	7433.5	22.2	
	lower tie-down radius plate	2.0	118.0	8.0		1.0		536.2	32.2	
	saddle top plates	4.0	9.8	4.0		1.5		66.8	51.8	
	top inner horizontal plates	4.0	19.0	4.0		1.0		86.3	40.1	
	saddle mid bottom plate, long	2.0	116.0	4.0	1.5			395.3	19.8	
	mounting pin bar	4.0	6.0	6.0	8.0			327.2	56.5	
	bottom horizontal plate	2.0	76.0	14.5	1.0			625.9	0.5	
	4 upper long vertical plate	8.0	19.1	4.0		1.0		173.9	30.1	
	2 upper short vertical plate	4.0	6.7	4.0		1.0		30.4	23.9	
	bottom end plates	4.0	19.5		19.0	1.0		420.9	9.5	
	lower vertical support plate	2.0	18.0	4.0		1.5		61.3	10.0	
	gusset plate	8.0	29.9		29.9	1.0		1321.2	31.9	
	gusset end plate	8.0	9.3		5.0	1.0		0.3	22.5	
	upper tie down front plate	4.0	205.6	6.3		1.0		1459.8	94.8	
	upper tie down radius plate+lift lugs	2.0	180.6	8.0		1.0		1420.6	92.3	
	upper tiedown side reinforcer plate	4.0	47.3	8.0		1.5		644.8	74.1	
	top shield plate	1.0	148.2	124.0		0.3		1304.8	118.9	
	angle	4.0	8.1	6.0	8.0	1.5		193.9	49.7	
	2.5" pin	4.0	13.0			2.5		72.5	56.8	
	barrier assembly	2.0	131.2		78.4	0.1		321.5	63.7	
	<b>Total</b>								<b>36809</b>	<b>27.2</b>

- Total CG = Sum (each item wt. times it's cg) / Total weight
- Excel worksheet MP187 Cradle Weight Calc is located in COLDStor.

### Appendix A.4.3 – Compliance Matrix

#### REQUIREMENTS FOR CRADLE DESIGN FROM EIR-3014611, "DESIGN BASIS REQUIREMENTS DOCUMENT (DBRD) FOR THE DOE ATLAS RAILCAR," REV 4<sup>1</sup>

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
<b>Family No. 4: TN: MP-187</b>			
2.1	<b>Regulatory Requirements</b> Comply with AAR 2043	For the cradle the AAR requirements are called out below.	Y
2.2	<b>Functional Requirements</b>		
2.2.2	<i>Cradle Functional Requirements</i>		
2.2.2.1	During transport, a transportation cask must rest on a cradle on top of the cask railcar deck.	The cradle interfaces with the rail car attachments that comply with this requirement.	Y
2.2.2.2	Conceptual cask cradle designs must accommodate the cask designs listed above and interface with cradle as indicated in the cask SARs.	The cask cradle is evaluated.	Y
2.2.2.3	The conceptual cradle designs shall not be final designs or prototypes.	The conceptual design has sufficient margin to allow for specific design requirements.	Y
2.2.2.3.a	Conceptual design shall have a plus or minus 10% weight envelope evaluated.	The weight envelope evaluated allows for refinement of the design in the final design.	Y
2.2.2.3.b	Center of gravity for the cradle shall be calculated and used to demonstrate the combined CG is met for the cask rail car and cradle of 98 inches or less. CG and loading distributions shall be detailed sufficiently to support railcar design and testing.	The CG for the cask cradle is calculated. The combined cg for the rail car and loaded cradle is shown in the rail car attachment calculation CALC-3015276. It is less than the 98 inch limit.	Y
2.2.2.3.c	Cradle shall be capable of handling the loads specified in Section 2.2.2.13 ( Rule 88 loads)	The cradle is demonstrated to meet Rule 88 loadings for the cask.	Y
2.2.2.3.d	Cradle shall be capable in the final design to handle a fatigue evaluation per AAR rules.	The weight margin allowed for the cradle and the design loading for compliance with Rule 88 ensures that there is sufficient margin for the detailed design to comply with the fatigue evaluation require by AAR-2043 which references AAR M-1001.	Y
2.2.2.3.e	Cradle designs shall have hard dimensions for interface to rail car to ensure ability to be attached to rail car.	The rail car interface dimensions are tolerance to ensure fit up.	Y
2.2.2.4	The conceptual cradle design shall determine the height of the cask center of gravity above	Required parameters for testing the rail car are provided in the families	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	the railcar deck, the weight on each axle, etc. as necessary to perform the analysis and provide simulate cradle test weights and supporting information needed for testing the railcar.	individual calculations and in the attachment design calculations.	
2.2.2.5	When rotation is necessary, the cradle will include the required hardware, such as trunnion supports.	None of these casks require rotational capability in the cradle.	Y
2.2.2.6	The cradles will be tall enough and open-ended so that the impact limiters can be attached to a cask after the cask is secured to the cradle.	The cradle design allows installation of impact limiters after the cask is secured to the cradle.	Y
2.2.2.7	Each cask design will need a cradle designed to position the center of gravity low for stability during transport, but the cradle design will position the impact limiter with a clearance of at least one inch above the cask car deck.	Adequate clearance is allowed for installation of the impact limiters.	Y
2.2.2.8	The cask car (including a cradle and a cask) and buffer car clearances shall fit within AAR Plate C [3], except when loaded with the casks that are more than 128 inches wide (Same as Requirement 2.2.1.12 above).	The MP-187 is compliant to Plate C.	Y
2.2.2.9	Demonstrate that bonding weights both min and max meet a combined CG of 98 inches for the railcar, skid and fully loaded and empty cask.(personnel shield, impact limiters etc.) An alternative to adding ballast weight to the railcar may include requiring that the transport cradle for the lighter cask be designed to provide the ballast.	The cradle is designed to meet the combined CG.	Y
2.2.2.10	The various cradles will be designed to fit a standard attachment mechanism. Tolerance to ensure.	Fit the common attachments on the rail car.	Y
2.2.2.11	During loading operations, the cradle may be attached to the railcar first, followed by putting the cask on the cradle, but sometimes the cask will be on the cradle first. In that case, both the cradle and cask together will be hoisted onto the railcar deck. Lifting points permit this handling of the cask	Designs permit loading separately or with the cask on the cradle.	Y
2.2.2.12	The cask railcar shall incorporate a standardized attachment capability for coupling the cask cradle to the railcar. This attachment must be capable of securely attaching loads of up to the maximum cask weight and the weight cradle in accordance with the requirements of AAR Rule 88 A16c(3)	Attachments meet rule 88 load requirements.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	[7].		
2.2.2.13	AAR Rule 88 A16c(3) does not specify if the securement system loading requirements are to be applied separately or simultaneously. Per direction from KASGRO (via the AAR EEC) transportation loading is not simultaneous and is applied separately. Also gravity is not applied in the vertical up or down accelerations, so +/- 2 g vertical only. Rule 88 A.16.C requires the following tie down loads (g force to yield):	Analyzed according to the direction of the AAR.	
2.2.2.13.a	7.5g Longitudinal	Met for this cradle a and cask.	Y
2.2.2.13.b	2g Vertical	Met for this cradle a and cask.	Y
2.2.2.13.c	2g lateral	Met for this cradle a and cask.	Y
	<b>Operational Requirements</b>		
	The cradle must accommodate the camber in the rail car.	Interfaces allows for the camber.	Y
	Have clearances to install and remove impact limiters on the rail car.	Clearance provided.	Y
	Features and clearances to load the cask into the cradle on and off the railcar and to be able to load the cradle with the impact limiters and personnel shield if required in place, on rail car.	Features and clearances permits loading with or without the personnel barrier in place to allow for intermodal transfers	Y
	Operational Steps. Can it be used and how? The loading and unloading steps requested should address that.	Complies with loading procedures.	Y
	<b>Maintenance Requirements</b>		
	Since none of the designs use corrosion resistance material, the life expectancy would be dependent on corrosion control by the use of "high quality weather resistant coatings". Strip and repaint as required. Use wear pads to minimize loss of coatings.	Wear pads and coatings adequately applied.	Y
	<b>Additional Design Considerations</b>		
	The cask cradles should be designed to support the cask for lifting on and off the railcar (with or without the cask impact limiters installed) as specified in Section 2.2.2.11 above. Lifting attachments shall be designed in accordance with ANSI N14.6 (i.e. the combined maximum tensile stress or the maximum shear stress of all members in the load path shall not exceed smaller of $S_y/3$ or	Lifting meets ANSI N14.6.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	Su/5). A vertical lift is assumed (requiring the use of a spreader beam/frame). All lift points are assumed to support the load equally for the conceptual design. The lift points should be designed such that the personnel barrier is not removed to lift the cradle when loaded with a package. A dynamic load factor of 1.15 shall be included per the recommendations of CMAA Specification No. 70 [12].		
	For cradle attachment points, the attachment mechanism (pin/bolt) should be removable and shall be sized for manual handling (less than 50 lbs.) or provisions should be designed for mechanically assisted insertion.	Attachments pins have mechanisms for handling.	Y
	The bottom of the cradle shall be flat to facilitate placement on a flat surface or intermodal transfer.	Cradle can sit on flat surface.	Y

<sup>1</sup>Approved calculation performed to DBRD revision 3; all pertinent calculation references are carried forward in revision 4.

## APPENDIX A.5 – CRADLE TO RAILCAR INTERFACE

Appendix A.

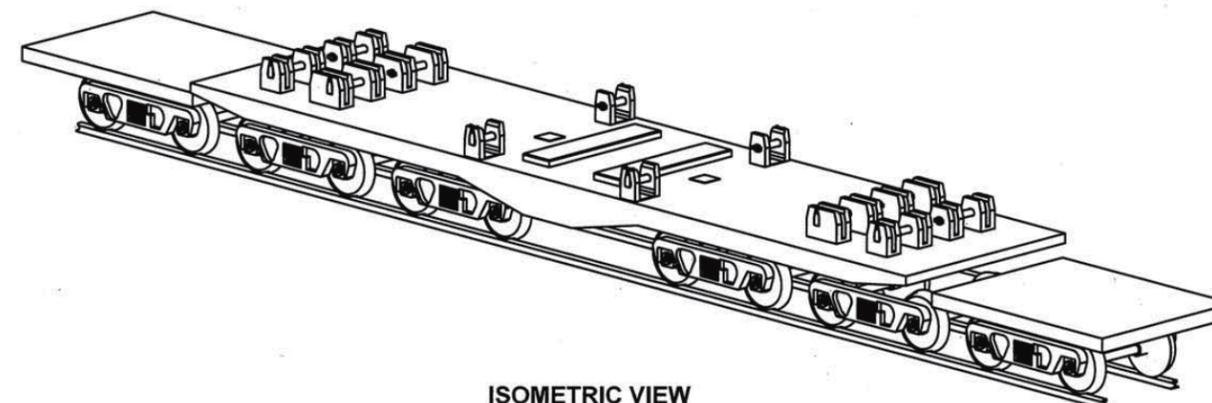
DWG-3015278-001  
Page 1 of 7

S/D		QTY A2	QTY A1	ITEM NO	PART NO	DESCRIPTION	SPECIFICATION
				A1		CRADLE ATTACHMENT COMPONENTS	
				A2		CONCEPTUAL PIN LOADING WELDMENT	
			1	1		ATLAS RAILCAR	
			12	2		BAR, .25 THK X 9.0 X 1.5	ASTM A276, TYPE 304
		12	-	3		PLATE, .25 THK X 8 X 19.2	ASTM A240, TYPE 304
			12	4		PLATE, .25 THK X 4.0 X 10	ASTM A240, TYPE 304
			2	5		PLATE, .38 THK X 12. X 12	ASTM A240, TYPE 304
			4	6		PLATE, .50 THK X 9.0 X 12	ASTM A240, TYPE 304
			4	7		PLATE, 4.0 THK X 12 X 18	ASTM A572, GR 50
			4	8		PLATE, 4.0 THK X 12 X 18	ASTM A572, GR 50
			2	9		PLATE, 4.0 THK X 21 X 90	ASTM A572, GR 50
			4	10		PLATE, 11 THK X 16 X 18	ASTM A572, GR 50
			4	11		PLATE, 11 THK X 16 X 18	ASTM A572, GR 50
			2	12		PLATE, LEFT 11.0 THK X 24 X 18	ASTM A572, GR 50
			2	13		PLATE, RIGHT 11 THK X 24 X 18	ASTM A572, GR 50
			4	14		PLATE, 11 THK X 24 X 18	ASTM A572, GR 50
			4	15		ROUND, Ø4.0 X 20.7	ASTM A564, TYPE 630, CONDITION H1100
			8	16		ROUND, Ø4.0 X 37.2	ASTM A564, TYPE 630, CONDITION H1100
		12	-	17		PIPE, 5.0 SCHEDULE 40 X 40.0	ASTM A312, TYPE 304
			36	18		SHCS, 5/8-11 UNC X 1.25	SS

**NOTES, UNLESS OTHERWISE SPECIFIED:**

- FABRICATE PER AWS D15.1.
- ALL LUG AND SHEAR KEY WELDS ARE CRITICAL WELDS AS DEFINED BY AAR S-2043.
- VISUALLY INSPECT (VT) ALL WELDS PER AWS D15.1, CLAUSE 17.2 AND USE CLASS 1 ACCEPTANCE CRITERIA. ALL INSPECTIONS MUST BE PERFORMED BY AN AWS CERTIFIED INSPECTOR.
- MAGNETIC PARTICLE (MT) DYE PENETRANT OR ULTRASONIC INSPECTION SHALL BE PERFORMED ON ALL WELDS BETWEEN RAILCAR DECK AND CRADLE ATTACHMENT COMPONENTS (EXCEPT ITEM 5 AND 6) PER AWS D15.1 CLAUSE 17.66, 17.5 OR 17.4 RESPECTIVELY. USE CLASS A ACCEPTANCE CRITERIA. ALL INSPECTIONS MUST BE PERFORMED BY AN AWS CERTIFIED INSPECTOR.
- ALTERNATE WELD DETAILS ARE ACCEPTABLE IF THEY MEET OR EXCEED THE STRENGTH OF THOSE SPECIFIED.
- PERFORM WELD INSPECTIONS SPECIFIED IN NOTE 4 ON 10% OF WELDS BETWEEN THE RAIL CAR DECK AND ITEM 3. USE ACCEPTANCE CRITERIA FOR CLASS 2 WELDS. ALL INSPECTIONS MUST BE PERFORMED BY AN AWS CERTIFIED INSPECTOR.
- APPLY ALL HOLES AND THREADED HOLE LOCATIONS AFTER WELDING.
- APPLY A STAINLESS STEEL FACING TO THESE SURFACES. THE FACING MAY BE CLADDING OR WELD OVERLAY THAT IS AT LEAST .05 INCHES THICK AND NO GREATER THAN .13 INCHES THICK. THE DIMENSIONS OF OPENINGS AND LOCATIONS MUST BE MET AFTER THE FACING IS APPLIED. FOR PIN HOLES/SLOTS STAINLESS STEEL SHIM STOCK MAY BE USED AND TACKED IN PLACE.
- FABRICATE FROM THREE PIECES USING FULL PENETRATION WELDS. PERFORM VT AND MT PER GENERAL NOTE 3 AND 4.
- CONCEPTIONAL PIN LOADING COMPONENTS.
- PIN AND INSIDE SURFACE OF PIN HOLES SHALL BE CLEANED AND COATED WITH PURE NICKEL NUCLEAR GRADE 'NEVER SEEZ' GREASE.



**ISOMETRIC VIEW**

AREVA  
September 1, 2016  
Records Management

1	SEE ECN NO. 3015278R0-E1	P.P. 8/31/16	M. Kamalian	S. Klein
REV	DESCRIPTION	DRAWN	CHECKER	VERIFIED
REVISION HISTORY				
	NAME/SIGNATURE	DATE		
	EM D. HILLSTROM	7/13/16		
	RE S. KLEIN	7/13/16		
	TECH CHK C. TEMUS	7/13/16		
	DFTG CHK M. KAMALIAN	7/13/16		
	DRAWN P. PIKULIN	7/7/16		
NA	NA			
NEXT ASSY	FINAL ASSY			
THIRD ANGLE PROJECTION				

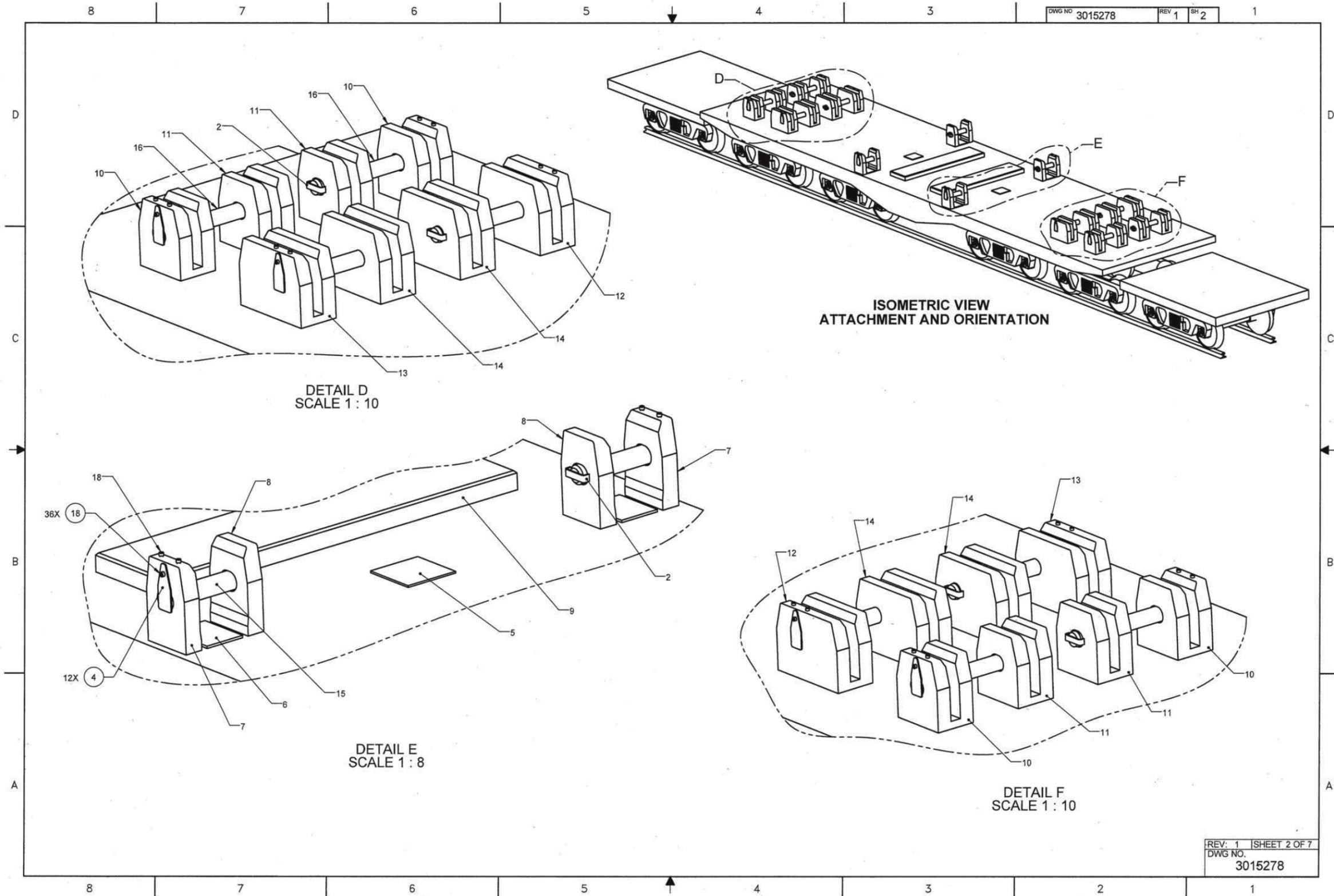
UNLESS OTHERWISE SPECIFIED:  
INTERPRET DRAWINGS & TOLERANCES PER ASME Y14.5-2009  
(REVISION OF ASME Y14.5M-1994)  
INTERPRET WELD CALLOUTS PER ANS/AWS A2.4  
DIMENSIONS ARE IN INCHES

**AREVA** Federal Services LLC  
Packaging Projects  
Federal Way, WA 98003

DWG TITLE: **ATLAS RAILCAR  
CRADLE ATTACHMENT COMPONENTS**

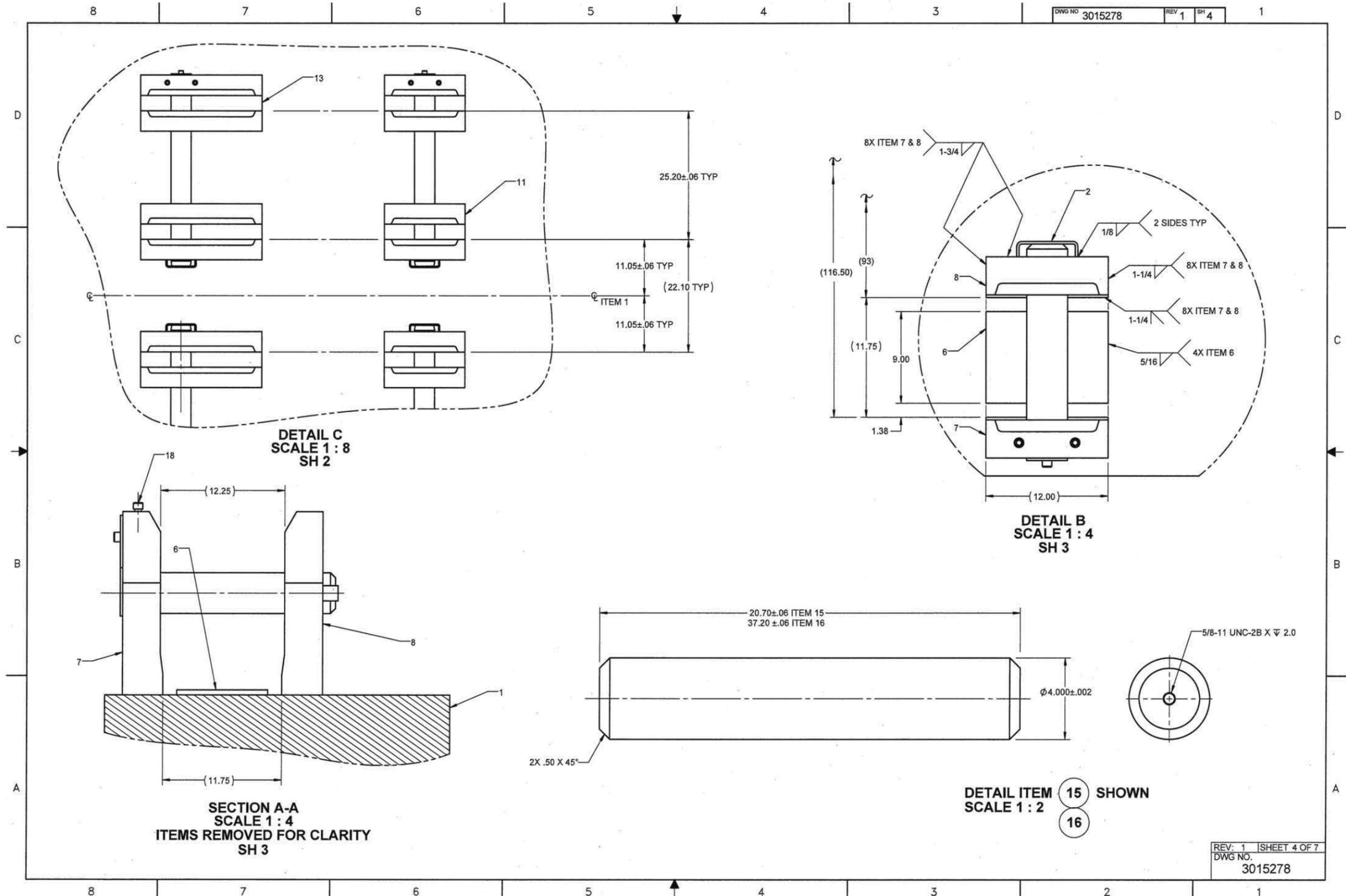
SCALE: SHOWN | WT. ~  
REV: 1 | SHEET 1 OF 7  
DWG NO. 3015278  
DWG SIZE D  
CADFILE: 3015278.SLDORW

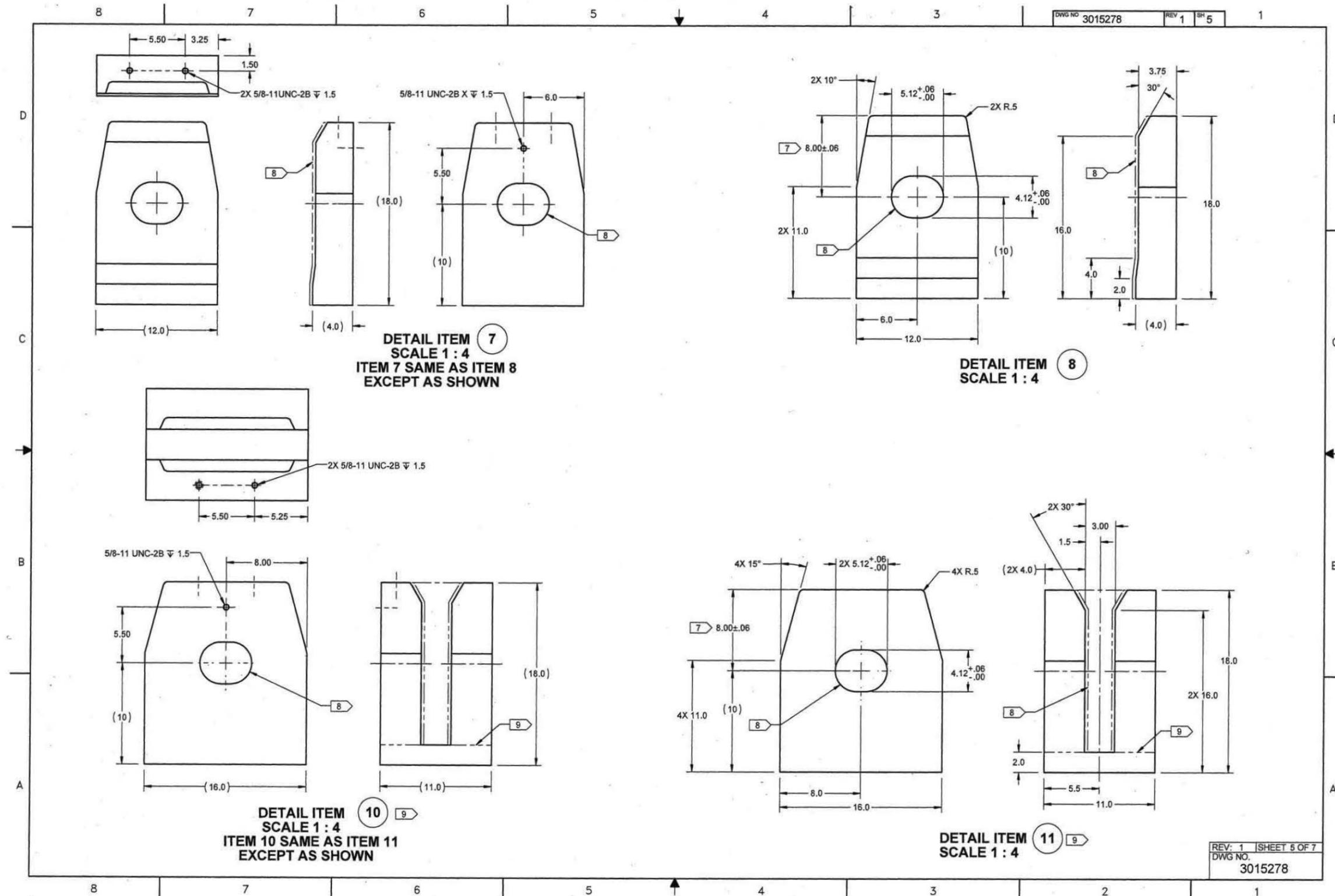
DWG-3015278-001  
 Page 2 of 7

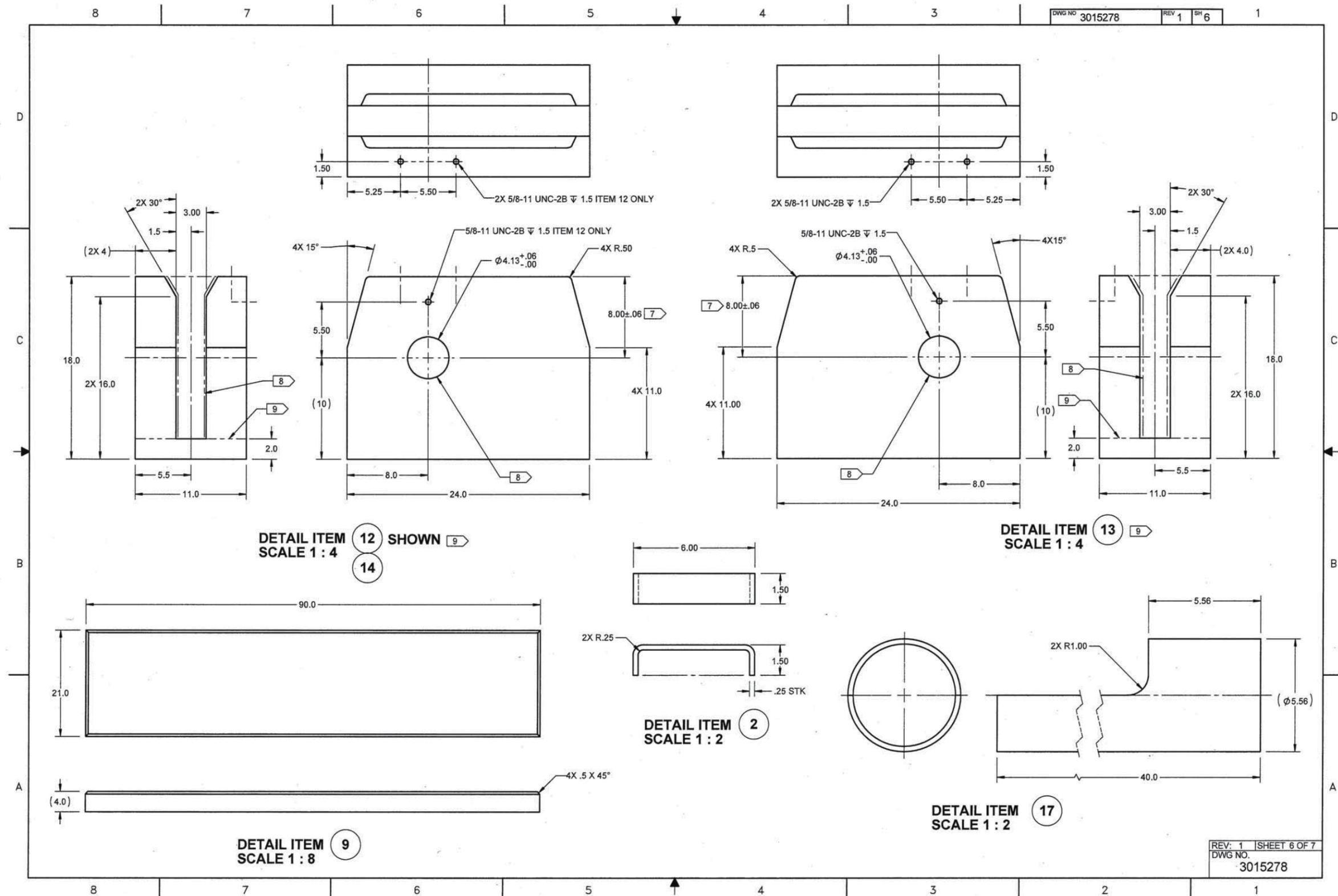




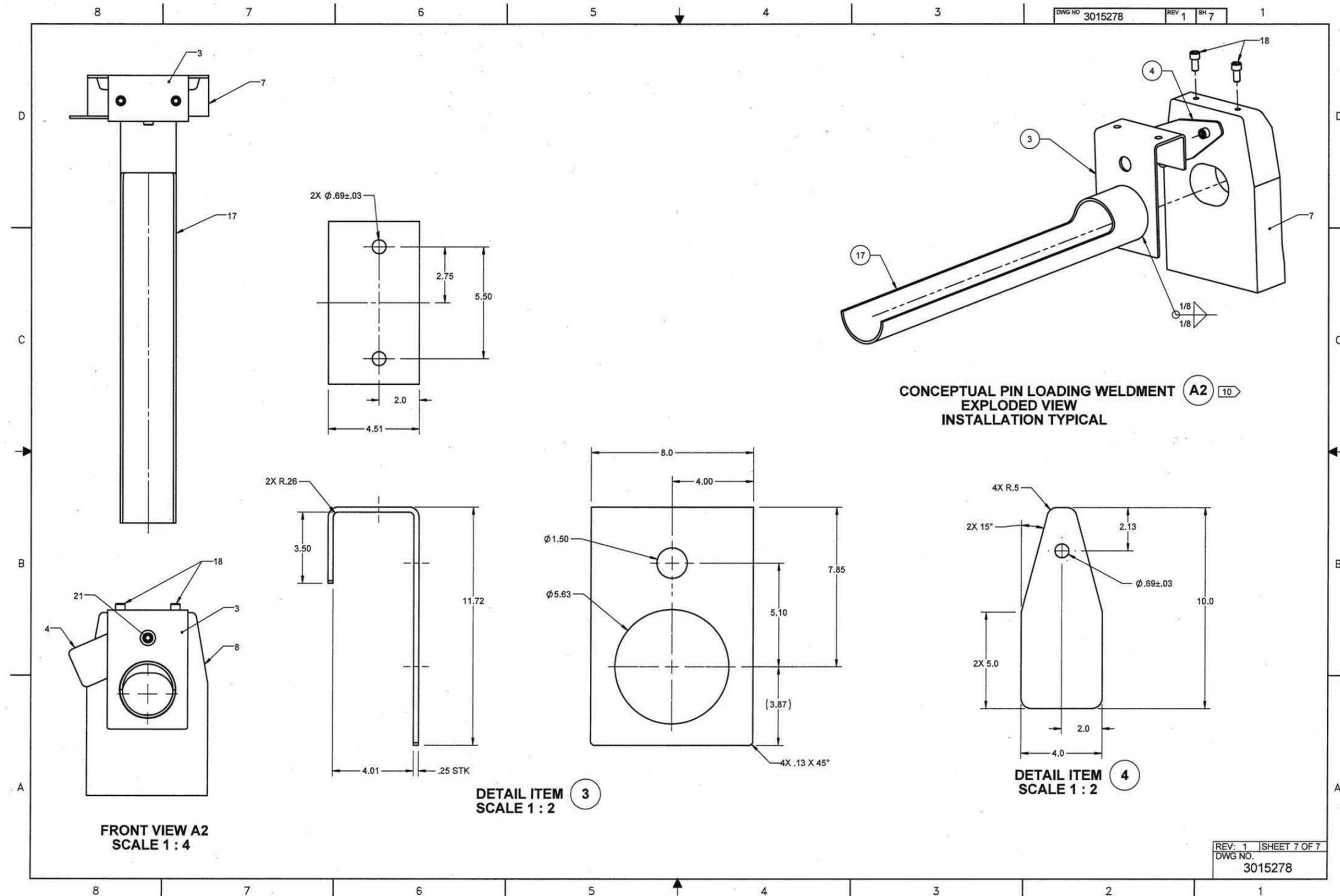
DWG-3015278-001  
 Page 4 of 7







DWG-3015278-001  
 Page 7 of 7



## Appendix A.5.2 – Supporting Calculation

CALC-3015276-001  
 Page 1 of 43

	<b>AREVA Federal Services LLC</b>		
	<b>CALCULATION</b>		
<b>Document No.:</b>	CALC-3015276	<b>Rev. No.</b>	001 <span style="float: right;"><b>Page 1 of 43</b></span>
<b>Project No.:</b>	00225.03.0050	<b>Project Name:</b>	DOE Atlas Railcar
<b>Title:</b>	Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation		
<b>Summary:</b>			
<p>This calculation contains the structural evaluation of the Atlas Railcar standardized attachment components. This calculation also calculates the combined center of gravity (cg) and weight for the railcar, cradles and packages.</p> <p>This document is not safety related.</p>			
<b>Contains Unverified Input / Assumptions:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>			
<b>Software Utilized:</b> None <b>Software Active in AFS EASI:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/> <b>Error Reports &amp; Associated Corrective Actions Reviewed:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>		<b>Version:</b> N/A	<b>Storage Media:</b> Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>  <b>Location:</b> N/A
	<b>Printed Name</b>	<b>Signature</b>	<b>Date</b>
<b>Preparer:</b>	S. Klein		8/30/16
<b>Checker:</b>	A. Ross		30 August 16
<b>Approver:</b>	D. Hillstrom		8/30/16
<b>Other:</b>			

AFS-EN-FRM-002 Rev. 07 (Effective April 21, 2015)  
 Reference: AFS-EN-PRC-002

**AREVA**  
**August 31, 2016**  
**Records Management**

CALC-3015276-001  
Page 2 of 43



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 2 of 43**

**Revision History**

Rev.	Changes
000	Initial issue
001	Revised to update railcar to 12 axle design.



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 3 of 43

**Table of Contents**

LIST OF TABLES ..... 4

LIST OF FIGURES ..... 5

1.0 PURPOSE ..... 6

    1.1 Project Background ..... 6

    1.2 Calculation Purpose ..... 6

    1.3 Atlas Railcar Standardized Attachment Components ..... 6

2.0 METHODOLOGY ..... 7

    2.1 Acceptance Criteria ..... 7

    2.2 Margin of Safety ..... 8

3.0 ASSUMPTIONS ..... 8

    3.1 Unverified Inputs/Assumptions ..... 8

    3.2 Justified Assumptions ..... 8

4.0 DESIGN INPUTS ..... 8

    4.1 Transportation Package Design Inputs ..... 8

    4.2 Material Properties ..... 12

5.0 CALCULATIONS ..... 13

    5.1 Allowable Stresses ..... 13

    5.2 Standardized Attachment Components ..... 13

    5.3 Cradle Weight ..... 32

    5.4 Combined cg and Railcar Weight ..... 33

    5.5 Attachment Components Cask Interface ..... 38

    5.6 Fatigue ..... 39

6.0 COMPUTER SOFTWARE USAGE (IF SOFTWARE IS USED) ..... 40

7.0 RESULTS/CONCLUSIONS ..... 41

    7.1 Standardized Attachment Components ..... 41

    7.2 Standardized Attachment Components Welds ..... 41

    7.3 Combined cg and Railcar Weight ..... 42

    7.4 Literature Search and other Background Data ..... 42

8.0 REFERENCES ..... 42



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 4 of 43**

**List of Tables**

Table 4-1: Initial Tie-Down Loading Inputs (kips).....9  
Table 4-2: Final Tie-Down Loading Inputs (kips) .....10  
Table 4-3: Cask Design Inputs.....11  
Table 4-4: Cradle Design Inputs .....12  
Table 4-5: Material Properties.....12  
Table 5-1: Adjusted Cradle Weights .....33  
Table 5-2: Combined CG Height, 195,000 lb. Railcar.....34  
Table 5-3: Combined CG Height, 200,000 lb. Railcar.....35  
Table 5-4: Combined CG Height, 205,000 lb. Railcar.....36  
Table 5-5: Total cg's and Margin to 98 inches .....37  
Table 5-6: Total Weight and Margin to 789,000 pounds .....38  
Table 5-7: Bounding Required Impact Limiter Clearance .....39  
Table 7-1: Margins of Safety.....41  
Table 7-2: Required Weld Strength and Size .....41  
Table 7-3: Total cg's and Weight .....42



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity  
Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 5 of 43**

---

**List of Figures**

Figure 1-1: Atlas Railcar Standardized Attachment Components..... 7  
Figure 5-1: Center Pin Attachment Block..... 14  
Figure 5-2: Center Pin Attachment Block Weld Group ..... 17  
Figure 5-3: Shear Blocks ..... 20  
Figure 5-4: Outer Pin Attachment Block Nomenclature ..... 22  
Figure 5-5: Inboard Outer Pin Attachment Block ..... 23  
Figure 5-6: Inboard Outer Pin Block Leg Beam ..... 24  
Figure 5-7: Outboard Outer Pin Attachment Block ..... 26  
Figure 5-8: Outer Pin Attachment Block Weld ..... 28  
Figure 5-9: Attachment Pin Connection (Item 15)..... 29  
Figure 5-10: Attachment Pin Bending ..... 30  
Figure 5-11: Attachment Pin Connection (Item 16)..... 31



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 6 of 43**

## 1.0 PURPOSE

### 1.1 Project Background

The United States Department of Energy (DOE) is laying the groundwork for implementing an integrated nuclear waste management system. This includes preparing for future large-scale transport of spent nuclear fuel (SNF), high-level waste (HLW), and Greater-Than-Class-C (GTCC) waste; since transport will be a necessary component of any integrated nuclear waste management system. With this project the DOE will provide for the transportation of SNF (GTCC is transported similarly to SNF) and HLW by means of a specific railcar (named by the DOE as the Atlas railcar) to carry SNF and HLW casks.

As part of this project, DOE has contracted with AREVA Federal Services (AFS) to design the Atlas railcar including standardized attachment components (railcar tie-down interface), and transport package conceptual cradle designs for the 15 SNF transportation casks (herein referred to as "packages") listed in Attachment A of the Statement of Work (SOW) [1].

The DOE Atlas railcar (and by extension to subsystems, the package cradles) must be designed and built to satisfy the requirements of Association of American Railroads (AAR) Standard S-2043 [2] and the AFS Design Basis Requirements Document (DBRD) [3]. Application of this standard to the conceptual design analyses is described in Section 2.0. The standardized attachment components are part of the railcar and must also meet the AAR S-2043 requirements.

AFS has chosen to divide the 15 packages into 4 families based on the package tie-down methods. The packages contained in each of these four families are listed below:

- Family 1 TN-32B, TN-40, TN-40HT, HI-STAR 60, HI-STAR 100, HI-STAR 100HB (also referred to as HI-STAR HB), and the HI-STAR 180.
- Family 2 MAGNATRAN<sup>®</sup>, NAC-STC<sup>™</sup>, NAC-UMS UTC<sup>™</sup>, and the TN-68.
- Family 3 MP-197, MP-197HB, and the TS125.
- Family 4 MP-187.

### 1.2 Calculation Purpose

This calculation contains the structural evaluation of the Atlas Railcar standardized attachment components. This calculation also calculates the combined center of gravity (cg) and weight for the railcar, cradles and packages.

### 1.3 Atlas Railcar Standardized Attachment Components

The Atlas Railcar Standardized Attachment Components are depicted in AFS Drawing DWG-3015278 [4] and are shown in Figure 1-1 below. There are four center pin attachment blocks welded to the railcar that are used for cradle designs in families 1 through 4. The cradles are secured laterally and vertically using four attachment pins inserted through the center pin attachment blocks. Longitudinal support for cradle families 2 through 4 is provided by shear blocks welded to the railcar. Family 1 cradles are supported longitudinally by end stop assemblies attached to the railcar using the outer sixteen attachment blocks. The end stop assemblies are pinned in place.

CALC-3015276-001  
Page 7 of 43



AREVA Federal Services LLC

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 7 of 43

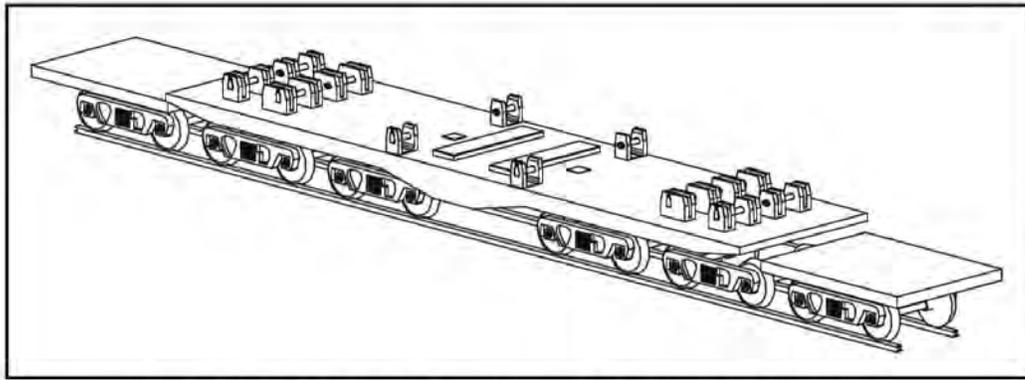


Figure 1-1: Atlas Railcar Standardized Attachment Components

## 2.0 METHODOLOGY

The conceptual design of each cradle was evaluated to determine the tie-down loads applied to the railcar via the standardized attachment components. Each cradle is required to support the 7.5g/2g/2g tie-down loads taken individually per Section 2.2.2.13 of the DBRD [3]. The bounding loads from the 15 package designs and associated conceptual cradle designs are applied to the standardized attachment components and the bounding loads are shown in Section 4.0.

This calculation uses manual calculations to evaluate the standardized attachment components including the pin attachment blocks, the shear blocks and the attachment pins shown in AFS drawing DWG-3015278 [4]. Material properties are taken at 100 °F per the DBRD [3].

The combined cg and weight of the railcar and load is determined using the package weights and vertical cg locations, calculated weights and vertical cg locations of the conceptual cradle designs, and the railcar deck height and railcar vertical cg location provided by KASGRO [6].

The fatigue capability of the design will be explored to provide reasonable assurance that the attachment components will support the fatigue loads of Chapter 7 of M-1001[28] for the design life of the railcar. The fatigue analysis of the railcar should cover the weld details between the attachment components and the railcar.

### 2.1 Acceptance Criteria

Stresses for the attachment components shall be compared to the allowable stresses. The allowable stress for the standardized attachment components is yield strength for tensile and compressive stresses per Section 2.2.2.13 of [3], and 0.6 of yield stress for shear stresses. Where necessary, stresses will be combined to determine the von Mises stress per equation 6-18 of [7] shown below and compared to the allowable tensile stress.

$$\sigma_v = \sqrt{\sigma_x^2 + 3\tau_{xy}^2}$$

Per Section 2.2.1.1 of [3], the cask car and buffer car must comply with the AAR's Manual of Standards and Recommended Practices which includes M-1001. Per Section 2.1.3 of M-1001, the combined cg of a fully loaded car must be less than 98 inches. The combined weight of the railcar, cradle and loaded cask must be less than



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 8 of 43**

65,750 pounds per axle (789,000 pound loaded car limit) per AFS-IN-16-0039 [6]. The term “loaded car” is defined in Section 11.0 of S-2043 [2]

The attachment components must allow for impact limiter removal for all 15 of the packages listed in Attachment A of the SOW [1].

**2.2 Margin of Safety**

A margin of safety is used to indicate the degree of confidence in the allowable loads and stresses. For acceptance the margin of safety must be greater or equal to zero. The margin of safety of component stresses is calculated as:

$$MS = \frac{\text{Allowable Stress}}{\text{Actual Stress}} - 1 \geq 0$$

Additional design confidence and increased conservatism is provided from 10% increase in load discussed in Section 4.1. All calculated margins of safety greater than or equal to zero include this additional factor.

**3.0 ASSUMPTIONS**

**3.1 Unverified Inputs/Assumptions**

None.

**3.2 Justified Assumptions**

None.

**4.0 DESIGN INPUTS**

**4.1 Transportation Package Design Inputs**

Design inputs for the tie-down loading are taken from the following calculations:

1. Atlas Railcar Family 1 Conceptual Cradle Structural Calculation [10]
2. Atlas Railcar Family 2 Conceptual Cradle Structural Calculation [11]
3. Atlas Railcar Family 3 Conceptual Cradle Structural Calculation [12]
4. Atlas Railcar Family 4 Conceptual Cradle Structural Calculation [13]

The tie-down loadings for each cask family were taken from the above calculations and compiled to list the maximum loading value at each attachment point as shown in Table 4-1.



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 9 of 43

**Table 4-1: Initial Tie-Down Loading Inputs (kips)**

	Pin Block 1 <sup>(1)</sup>	Pin Block 2 <sup>(1)</sup>	Pin Block 3 <sup>(1)</sup>	Pin Block 4 <sup>(1)</sup>
vertical (+z)	664	664	664	664
vertical (-z)	664	664	664	664
lateral (y) <sup>(3)</sup>	407	407	407	407
	<b>Shear Block<sup>(1)</sup></b>			
axial (x)	2,655			
	Pin Block 5-8 <sup>(2)</sup>	Pin Block 9-12 <sup>(2)</sup>	Pin Block 13-16 <sup>(2)</sup>	Pin Block 17-20 <sup>(2)</sup>
Axial (+x)	0	635	635	0
Axial (-x)	0	635	635	0
vertical (+z)	753	753	753	753
vertical (-z)	753	753	753	753
lateral (y)	14	14	14	14

Notes:

1. The bounding vertical and axial loads are from the MAGNATRAN package per Table 6-1 of [11]. The bounding lateral load is from Table 2.2 of HI-STAR 180 [10].
2. The bounding loads for Pin Blocks 5-20 are taken from Table 2.2 of [10]
3. The maximum lateral load is from the HI-STAR 180 package per [10]. The lateral loading results in a combined loading at one pin location. The maximum vertical load from any lateral load case is 210 kips from Table 2.2 of [10].

The standardized attachment components will be fabricated and attached to the Atlas railcar. These attachment points must accommodate both the conceptual and the final cradle designs for all 15 packages listed in the SOW. The conceptual cradle designs are not final and some small changes are anticipated in the final cradle design (to be performed at a later date). Therefore, an additional factor of 1.1 was added to the loadings to provide increased conservatism in the attachment component design. Final tie-down loading inputs are shown in Table 4-2.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 10 of 43**

**Table 4-2: Final Tie-Down Loading Inputs (kips)**

	Pin Block 1	Pin Block 2	Pin Block 3	Pin Block 4
vertical (+z)	730	730	730	730
vertical (-z)	730	730	730	730
lateral (y) <sup>(1)</sup>	448	448	448	448
	<b>Shear Block</b>			
axial (x)	2,921			
	<b>Pin Block 5-8</b>	<b>Pin Block 9-12</b>	<b>Pin Block 13-16</b>	<b>Pin Block 17-20</b>
Axial (+x)	0	699	699	0
Axial (-x)	0	699	699	0
vertical (+z)	828	828	828	828
vertical (-z)	828	828	828	828
lateral (y)	15	15	15	15

Notes: 1. The adjusted maximum vertical load to be combined with the lateral load in the lateral load case is  $210(1.1) = 231$  kips

To calculate the combined weight and center of gravity location, the maximum (loaded) cask weight, cask vertical cg location, minimum cradle weight, cradle vertical cg location as well as the railcar weight, deck height (when loaded) and railcar vertical cg location are required. The cask weights and cg locations are shown in Table 4-3. Cradle design inputs are shown in Table 4-4.

CALC-3015276-001  
 Page 11 of 43



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 11 of 43**

**Table 4-3: Cask Design Inputs**

Cask	Family	Maximum (Loaded) Cask Weight, lb	Minimum (Empty) Cask Weight, lb <sup>(2)</sup>	Cask Vertical cg from railcar deck, in <sup>(3)</sup>	Reference
NAC-STC	2	254,600	188,767	67.50+0.5 = 68.00	Table B-2 of [11]
NAC-UMS UTC	2	256,000	178,798	67.50+0.5 = 68.00	Table B-2 of [11]
MAGNATRAN	2	312,000	208,000	67.50+0.5 = 68.00	Table B-2 of [11]
HI-STAR 100	1	279,893	179,710	69.75+0.5 = 70.25	Table 4.1 of [10]
HI-STAR 100HB	1	187,200	-	69.75+.05 = 70.25	Table 4.1 of [10]
HI-STAR 180	1	308,647	<308,647	64.50+0.5 = 65.00	Table 4.1 of [10]
HI-STAR 60	1	164,000	<164,000	59.63+0.5 = 60.13	Table 4.1 of [10]
MP187	4	271,300 <sup>(1)</sup>	190,200	69.00+0.5 = 69.50	Table 4.1 of [13]
MP197	3	265,100	176,710	62.00+0.5 = 62.50	Table 5.3-1 of [12]
MP197HB	3	303,600	179,000	64.00+0.5 = 64.50	Table 5.3-1 of [12]
TN-32B	1	263,000	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN-40	1	271,500	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN40HT	1	242,343	-	72.5+0.5 = 73.00	Table 4.1 of [10]
TN-68	2	272,000	<272,000	77.50+0.5 = 78.00	Table B-4 of [11]
TS125	3	285,000	196,118	72.80+0.5 = 73.30	Table 5.3-1 of [12]

**Notes:**

1. The loaded cask and empty cask weight is taken from the DOE SOW Attachment A [1]. The weight used in the calculation was a bounding weight and should not be used here.
2. The empty cask weights are taken from the DOE SOW Attachment A [1].
3. The cg is increased by 0.5 inches due to the standardized attachment components shim plate.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 12 of 43**

**Table 4-4: Cradle Design Inputs**

Cask	Family	Nominal Cradle Weight, lb	Cradle Vertical cg from railcar deck, in <sup>(1)</sup>	Reference
NAC-STC	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
NAC-UMS UTC	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
MAGNATRAN	2	42,000	27+0.5 = 27.5	Table B-1 of [11]
HI-STAR 100	1	67,200 <sup>(2)</sup>	51.5+0.5 = 52.0	Table 6.1 of [10]
HI-STAR 100HB	1	68,800 <sup>(2)</sup>	58.3+0.5 = 58.8	Table 6.1 of [10]
HI-STAR 180	1	54,200 <sup>(2)</sup>	54.6+0.5 = 55.1	Table 6.1 of [10]
HI-STAR 60	1	61,000 <sup>(2)</sup>	53.5+0.5 = 54.0	Table 6.1 of [10]
MP187	4	36,800	27.2+0.5 = 27.7	Table 4-1 of [13]
MP197	3	26,000	17 +0.5 = 17.5	Table 5.3-1 of [12]
MP197HB	3	26,000	17.5+0.5 = 18.0	Table 5.3-1 of [12]
TN-32B	1	70,200 <sup>(2)</sup>	47.0+0.5 = 47.5	Table 6.1 of [10]
TN-40	1	70,200 <sup>(2)</sup>	46.5+0.5 = 47.0	Table 6.1 of [10]
TN40HT	1	70,200 <sup>(2)</sup>	46.5+0.5 = 47.0	Table 6.1 of [10]
TN-68	2	27,000	26 +0.5 = 26.5	Table B-3 of [11]
TS125	3	30,000	24.5 +0.5 = 25.0	Table 5.3-1 of [12]

- Notes:
1. The cg is increased by 0.5 inches due to the standardized attachment components shim plate.
  2. The central cradle weight is added to the end stop weight to calculate to total nominal cradle weight.

**4.2 Material Properties**

The material properties listed in Table 4-5 are used in the design. The yield and ultimate strengths are the minimum values found in the ASTM standards [14] and [15]. Material density is from ASME B&PV Code Section II, Part D Table PRD [16]. The structure is primarily ASTM A574, Grade 50, high-strength low-alloy columbium-vanadium structural steel. Material properties at 100 °F are used. The attachment pins are constructed from ASTM A564, Type 630, Condition H1100, hot-rolled and cold-finished age-hardening stainless steel.

**Table 4-5: Material Properties**

Material	Yield Stress (ksi)	Ultimate Stress (ksi)	Density (lb/in <sup>3</sup> )
ASTM A572, Grade 50	50	65	.280
ASTM A564, Type 630, Condition H1100	115	140	



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 13 of 43**

**5.0 CALCULATIONS**

**5.1 Allowable Stresses**

The allowable minimum yield strength and ultimate strength of ASTM A572, Grade 50 is 50 ksi and 65 ksi respectively [14]. The minimum yield and ultimate stress for ASTM A564, Type 630, Condition H1100 is 115 ksi and 140 ksi respectively [15].

The tie-down loading stresses for the 7.5/2/2g load cases are compared directly against yield strength. The pin attachment blocks and shear blocks are ASTM A572, Grade 50. The attachment pins are ASTM A564, Type 630, Condition H1100. The allowable stresses are:

Attachment Block/Shear Block allowable stress:  $S_{AT} = S_y = 50 \text{ ksi}$

Attachment Block/Shear Block allowable shear stress:  $S_{AS} = 0.6S_y = 30 \text{ ksi}$

Attachment Pin allowable stress:  $S_{A564} = S_{y564} = 115 \text{ ksi}$

**5.2 Standardized Attachment Components**

The following components are evaluated to determine the adequacy of the attachment component design:

- Center Pin Attachment Blocks
- Shear Blocks
- Outer Pin Attachment Blocks
- Attachment Pin

**5.2.1 Center Pin Attachment Blocks**

The center pin attachment blocks (Item 7 and 8 of [4]) are shown in Figure 5-1 and are used to secure the cradles to the railcar. The pin blocks are subjected to lateral and vertical tie-down loads. Using the bounding loads from Table 4-2 the tie-down loading is:

Center pin block (CPB) lateral tie-down load,  $F_{CPB\_lat} = 448 \text{ kip}$  and the vertical load from lateral tie-down load,  $F_{CPB\_vlat} = 231 \text{ kip}$  (load is shared by two blocks, Item 7 and 8 of [4]) is taken from Section 4.1 (Note 1 following Table 4-2).

Center pin block vertical tie-down load,  $F_{CPB\_v} = 730 \text{ kips}$  (load is shared by two blocks, Item 7 and 8 of [4]).

As shown in Section 5.2.7, the load on the attachment pin which is applied to the center pin attachment blocks is not shared equally. The load can be offset in either direction. The maximum load distribution is  $379.5/730 = .52$ .



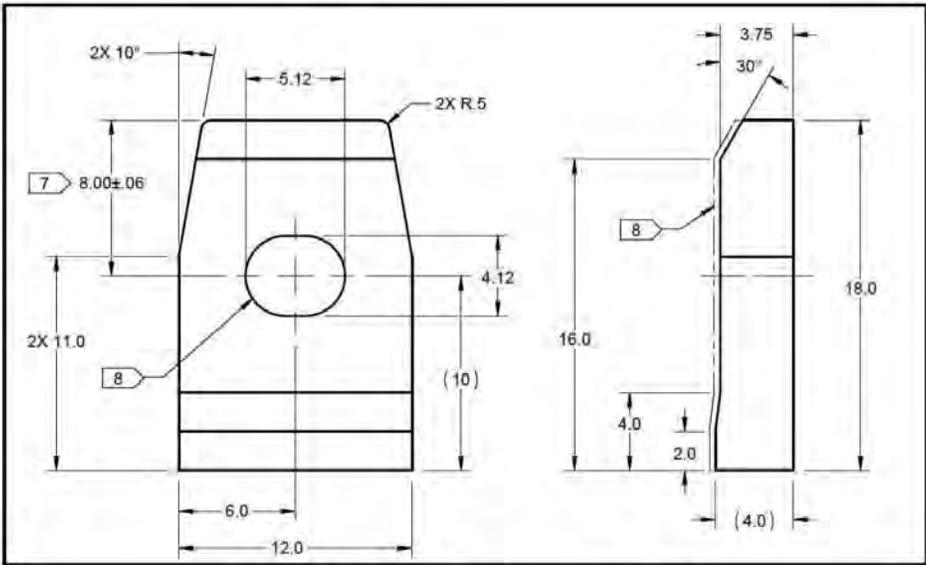
**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 14 of 43



**Figure 5-1: Center Pin Attachment Block**

**Center Pin Attachment Blocks - Vertical Load**

The center pin attachment blocks are subjected to tension loading, shear tear-out, and bearing from the vertical tie-down load.

Tensile loading

The minimum tensile area is located at the hole center and is:

$$A = (12.00 - 5.12)(3.62) = 24.9 \text{ in}^2$$

where the block length is 12.00 inches, the slotted hole length is 5.12 inches and the block thickness is 3.75-0.13 = 3.62 inches (maximum stainless steel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected) at the hole per the drawing dimensions [4]. The tensile stress is:

$$\sigma = \frac{F_{CPB_v}}{A} = \frac{730(.52)}{24.9} = 15.2 \text{ ksi}$$

From Section 5.1, the allowable tensile stress,  $S_{AT} = 50 \text{ ksi}$ . The margin of safety is:

$$MS = \frac{50}{15.2} - 1 = +2.29$$

Shear tear-out

The pin block is subjected to shear-tear out from vertical loading. The shear tear-out area is conservatively calculated using twice the straight line distance:

CALC-3015276-001  
 Page 15 of 43



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 15 of 43

$$A = (2) \left( 16.0 - 10.0 - \frac{4.12}{2} \right) (3.62) = 28.5 \text{ in}^2$$

where the height of the pin block chamfer is 16.0 inches, the height of the slotted hole is 10.0 inches, the slot diameter is 4.12 inches and the thickness of the block is 3.62 inches (see discussion above) per the drawing dimensions [4]. Conservatively, this neglects the material at less than the full 3.75 inch thickness. The shear tear-out stress is:

$$\tau = \frac{F_{CPB_v}}{A} = \frac{730(.52)}{28.5} = 13.3 \text{ ksi}$$

From Section 5.1, the allowable shear stress,  $S_{AS} = 30$  ksi. The margin of safety is:

$$MS = \frac{30}{13.3} - 1 = +1.26$$

Bearing stress

The pin attachment block features a slotted hole that interfaces with the round attachment pin. However, there is no normal loading condition that will exceed the weight of the cask and cradle to load the pin and attachment block and therefore bearing is not a concern for normal loading. The tie-down loading will load the pin; however bearing is not considered a failure and will not be evaluated here.

**Center Pin Attachment Blocks - Lateral Load**

The center pin attachment blocks are subjected to shear and bending from the lateral load. There is also combined stress from the vertical load created from the lateral load moment. The pin attachment blocks support the lateral load at their base. The blocks have a 4.00 inch thick boss that extends 2 inches up the 18 inch high block. This boss face with the opposite pin block boss face create the 11.75 inch opening for cradle I-beam insertion. The lateral load results in a shear stress at the base of the block as well as a bending stress from the 2 inch high contact region. The moment is applied at the center of the contact or 1.25 inches (2.0 contact region and 0.5 inch high pad on railcar deck (2-0.5)/2+0.5 = 1.25 inches) from the railcar deck. Due to the moment and resisting load created by the lateral load being applied at the package cg, there is also a vertical load on the pin block. The tensile load is added to the bending stress and then combined with the shear stress to determine the combined stress. The combined tension and shear is also checked at the hole location.

The center pin block (CPB) lateral load,  $F_{CPB_{lm}} = 448$  kip

The CPB vertical load from lateral tie-down load,  $F_{CPB_{vlm}} = 231$  kip (load is shared by two blocks) is taken from Section 4.1.

At Block Base

The pin block is subjected to shear, bending, and tension at the base. The base cross-section area is:

$$A = (12.00)(3.87) = 46.4 \text{ in}^2$$

where the width of the attachment block is 12.00 inches, and the thickness of the block at the base is 4.00-0.13 = 3.87 inches (maximum stainless steel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected) per [4]. The moment of inertia at the base is:

$$I = \frac{1}{12} (12.00)(3.87)^3 = 58.0 \text{ in}^3$$



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 16 of 43**

The tensile stress is:

$$\sigma = \frac{F_{CPB_{\text{vlat}}}(,52)}{A} = \frac{231(,52)}{46.4} = 2.59 \text{ ksi}$$

The shear stress is:

$$\tau = \frac{F_{CPB_{\text{lat}}}}{A} = \frac{448}{46.4} = 9.66 \text{ ksi}$$

The bending moment is:

$$M = (F_{CPB_{\text{lat}}})(1.25) = (448)(1.25) = 560 \text{ in} - \text{kip}$$

The bending stress is:

$$\sigma_b = \frac{My}{I} = \frac{560(\frac{4.00}{2})}{58.0} = 19.3 \text{ ksi}$$

where the overall thickness is conservatively used. The combined stress is:

$$\sigma_v = \sqrt{\sigma_x^2 + 3\tau_{xy}^2} = \sqrt{(2.59 + 19.3)^2 + 3(9.66)^2} = 27.6 \text{ ksi}$$

From Section 5.1, the allowable tensile stress,  $S_{AT} = 50$  ksi. The margin of safety is:

$$MS = \frac{50}{27.6} - 1 = +0.81$$

**5.2.2 Center Pin Attachment Block Welds**

The welds shown on the drawing are representative of a possible weld configuration. Weld force and weld size required are determined in this calculation. The center pin attachment blocks are welded to the railcar using a 1-3/4 fillet weld on the 3 outboard sides and a 1-1/4 groove weld on the inside face [4]. The weld is evaluated using the weld as a line technique to determine the required weld size. The weld is loaded separately from the vertical and lateral tie-down loading with the lateral loading producing a combined load. Both load cases will be evaluated to determine the bounding required weld size. The weld group is shown in Figure 5-2. The vertical load shown below is applied separately:

Center pin block vertical load,  $F_{CPB_v} = 730$  kips (load is shared by two blocks)

The longitudinal and lateral loads shown below are applied simultaneously:

The center pin block (CPB) lateral load,  $F_{CPB_{\text{lat}}} = 448$  kip

The CBP vertical load from lateral tie-down load,  $F_{CPB_{\text{vlat}}} = 231$  kip (load is shared by two blocks)



AREVA Federal Services LLC

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 17 of 43

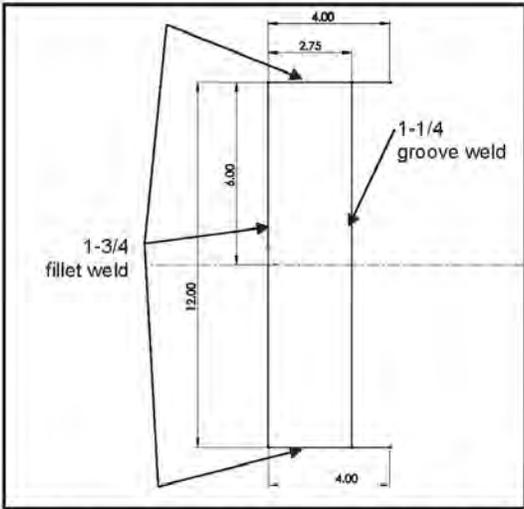


Figure 5-2: Center Pin Attachment Block Weld Group

Weld properties are shown in the table below:

Weld Group	Weld Area ( $A_{w_i}$ )	Weld centroid, $x_i$	$A_{w_i}x_i$
Group 1 1-1/4 fillet	$4+12+4 = 20$ inches	$\bar{x}_1 = \frac{4^2}{2(4) + 12} = 0.8$ inches	$20(0.8) = 16$ in <sup>2</sup>
Group 2 1-1/4 groove	12 inches	$\bar{x}_2 = 2.75$ inches	$12(2.75) = 33$ in <sup>2</sup>
Total	$A_{w_c} = 32$ in		$49$ in <sup>2</sup>

The combined weld group centroid is:

$$x_c = \frac{\sum A_{w_i}x_i}{A_{w_c}} = \frac{49 \text{ in}^2}{32 \text{ in}} = 1.53 \text{ in}$$

The weld moment of inertial is calculated using Table 9-3 of [7] and shown in the table below:

CALC-3015276-001  
 Page 18 of 43



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 18 of 43

Weld Group	Moment of Inertia ( $I_{w_i}$ )	$A_{w_i}d^2$
Group 1 1-1/4 fillet	$I_{w_1} = \frac{2(4.00)^3}{3} - 2(4.00)^2(0.8) + (12.00 + 2(4.00))(0.8)^2$ $= 29.87 \text{ in}^3$	$= 20(1.53 - 0.8) = 14.6$
Group 2 1-1/4 groove	$I_{w_2} = 0$	$= 12(2.75 - 1.53) = 14.64$

The combined weld moment of inertia is:

$$I_c = \sum (I_{w_i} + A_{w_i}d^2) = 59.11 \text{ in}^4$$

The weld section modulus is:

$$S_w = \frac{I_c}{4.00 - x_c} = \frac{59.11}{4.00 - 1.53} = 23.9 \text{ in}^3$$

Weld required by vertical loading

Center pin block vertical load,  $F_{CPB_v} = 730$  kips (load is shared by two blocks)

Weld shear force from vertical load:

$$F_{w1} = \frac{F_{CPB_v}(.52)}{A_w} = \frac{730(.52)}{32.0} = 11.9 \text{ kip/in}$$

From Section 5.1, the allowable shear stress,  $S_{AS} = 30$  ksi. The required weld throat is:

$$\omega = \frac{\text{actual force}}{\text{allowable stress}} = \frac{11.9 \text{ kip/in}}{30 \text{ kip/in}^2} = 0.40 \text{ in}$$

The actual weld throat is:

$$\omega_1 = 0.707(1.75) = 1.24 \text{ in}$$

$$\omega_2 = 1.25 - 0.125 = 1.125 \text{ in}$$

where the groove weld size is reduced by 1/8 per AWS D15.1, Clause 7.1.1 [17]. The margin of safety is:

$$MS = \frac{1.125}{0.40} - 1 = +1.81$$

Weld required by lateral loading

The center pin block (CPB) lateral load,  $F_{CPB,lat} = 448$  kip

The CBP vertical load from lateral tie-down load,  $F_{CPB_v,lat} = 231$  kip (load is shared by two blocks)

Weld shear force from lateral load:

$$F_{w,lat} = \frac{F_{CPB,lat}}{A_w} = \frac{448}{32.0} = 14.0 \text{ kip/in}$$



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 19 of 43**

where the weld area,  $A_w = 27.0$  in, is taken from above. The weld shear force from vertical load:

$$F_{w,v} = \frac{F (.52)}{A_w} = \frac{231(.52)}{32.0} = 3.75 \text{ kip/in}$$

The weld shear force from bending moment is:

$$F_{w,b} = \frac{M}{S_w} = \frac{560}{23.9} = 23.4 \text{ kip/in}$$

where the bending moment,  $M = 560$  in-kips, is taken from Section 5.2.1, and the weld section modulus,  $S_w = 23.9$  from above. The resultant weld force is:

$$F_{w,r} = \sqrt{(F_{w,lat})^2 + (F_{w,v} + F_{w,b})^2} = 30.5 \text{ kip/in}$$

From Section 5.1, the allowable shear stress,  $S_{AS} = 30$  ksi. The required weld throat is:

$$\omega = \frac{\text{actual force}}{\text{allowable stress}} = \frac{30.5 \frac{\text{kip}}{\text{in}}}{30 \frac{\text{kip}}{\text{in}^2}} = 1.02 \text{ in}$$

The actual weld throat is:

$$\omega_1 = 0.707(1.75) = 1.24 \text{ in}$$

$$\omega_2 = 1.25 - 0.125 = 1.125 \text{ in}$$

where the groove weld size is reduced by 1/8 per AWS D15.1, Clause 7.1.1 [17]. The margin of safety is:

$$MS = \frac{1.125}{1.02} - 1 = +0.10$$

**5.2.3 Shear Blocks**

The shear blocks (Item 9 of [4]) are shown in Figure 5-3 and are used to react the axial tie-down loads from the cradles. The shear blocks are subjected to the longitudinal load only. Using the bounding loads from Table 4-2, the loading is:

Shear block (SB) longitudinal load,  $F_{SB, long} = 2,921$  kip



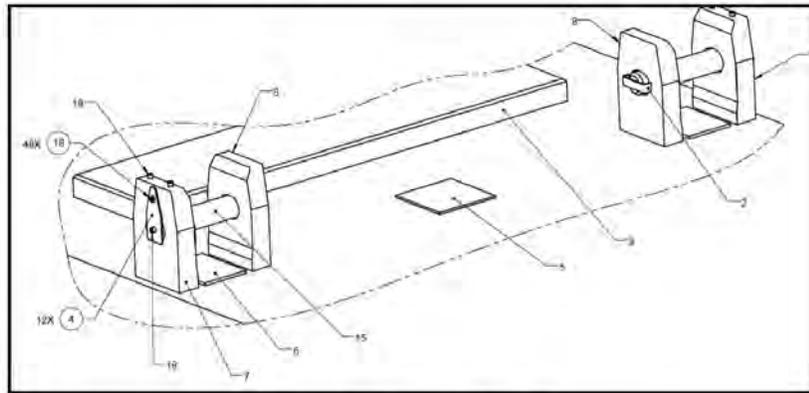
**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 20 of 43



**Figure 5-3: Shear Blocks**

The shear blocks are subjected to shear from the longitudinal load. The shear area is:

$$A = (90.00)(21.00) = 1,890 \text{ in}^2$$

where the shear block width is 90.00 inches and the shear block length is 21.00 inches per the drawing dimensions [4]. The shear stress is:

$$\tau = \frac{F_{SB\_long}}{A} = \frac{2,921}{1,890} = 1.55 \text{ ksi}$$

From Section 5.1, the allowable shear stress,  $S_{AS} = 30$  ksi. The margin of safety is:

$$MS = \frac{30}{1.55} - 1 = +18.4$$

**5.2.4 Shear Blocks Weld**

The welds shown on the drawing are representative of a possible weld configuration. Weld force and size required are determined in this calculation. The shear blocks are welded to the railcar using a 1 inch all-around fillet weld [4]. The weld is evaluated using the weld as a line technique to determine the required weld size. The weld is loaded from the longitudinal tie-down loading

Shear block longitudinal load,  $F_{SB\_long} = 2,921$  kips

The weld area is:

$$A_w = 2(90.00 + 21.00) = 222 \text{ in}$$

where the width of the shear block is 90.00 inches and the length of the shear block is 21.00 inches at the base per [4]. The weld section modulus is:

$$S_w = bd + \frac{d^2}{3} = (90.00)(21.00) + \frac{21.0^2}{3} = 2,037 \text{ in}^2$$

where the width,  $b = 90.00$  inches and the length,  $d = 21.0$  inches per [4] and the section modulus is calculated using Table 4 of Section 6.3 of [17]. Weld shear force from longitudinal load:



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 21 of 43**

$$F_{w\_long} = \frac{F_{SB\_long}}{A_w} = \frac{2,921}{222} = 13.2 \text{ kip/in}$$

The weld shear force from bending moment is:

$$F_{w\_b} = \frac{M}{S_w} = \frac{11,684}{2,037} = 5.74 \text{ kip/in}$$

where the bending moment,  $M = 11,684$  in-kips, is taken from Section 5.2.3. The resultant weld force is:

$$F_{w\_r} = \sqrt{(F_{w\_long})^2 + (F_{w\_b})^2} = \sqrt{13.2^2 + 5.74^2} = 14.4 \text{ kip/in}$$

From Section 5.1, the allowable shear stress,  $S_{AS} = 30$  ksi. The required weld throat is:

$$\omega = \frac{\text{actual force}}{\text{allowable stress}} = \frac{14.4 \text{ kip/in}}{30 \text{ kip/in}^2} = 0.48 \text{ in}$$

The actual weld throat is:

$$\omega_a = 0.707(1) = 0.707 \text{ in}$$

The margin of safety is:

$$MS = \frac{0.707}{0.48} - 1 = +0.47$$

**5.2.5 Outer Pin Attachment Blocks**

The outer pin attachment blocks are used to secure the end stops to the railcar. The inboard outer pin attachment blocks (Item 12-14 of [4], P9-P12 and P13-P16) are subjected to a combined longitudinal and vertical load from the longitudinal tie-down load and a lateral and vertical load from a separately applied lateral tie-down load. The outboard outer pin attachment blocks (Item 10-11 of [4], P5-P8 and P17-P20) are subjected to vertical and lateral loading only; each applied separately.

The lateral load on the outer pin attachment blocks due to the lateral tie-down load is small and is bounded by the lateral load on the center pin attachment blocks. The center pin attachment blocks are subjected to a much higher lateral load, have a shorter length and have the larger size slotted hole.

**Inboard Outer Pin Attachment Blocks**

The blocks are subjected to longitudinal and vertical loads. These loads are applied simultaneously. Using the bounding loads from Table 4-2, the loading is:

Inboard outer pin block (IOPB) longitudinal load,  $F_{IOPB\_long} = 699$  kip

Inboard outer pin block (IOPB) vertical load,  $F_{IOPB\_y} = 828$  kip

The combined load is:

$$F_{IOPB\_c} = \sqrt{699^2 + 828^2} = 1084 \text{ kip}$$



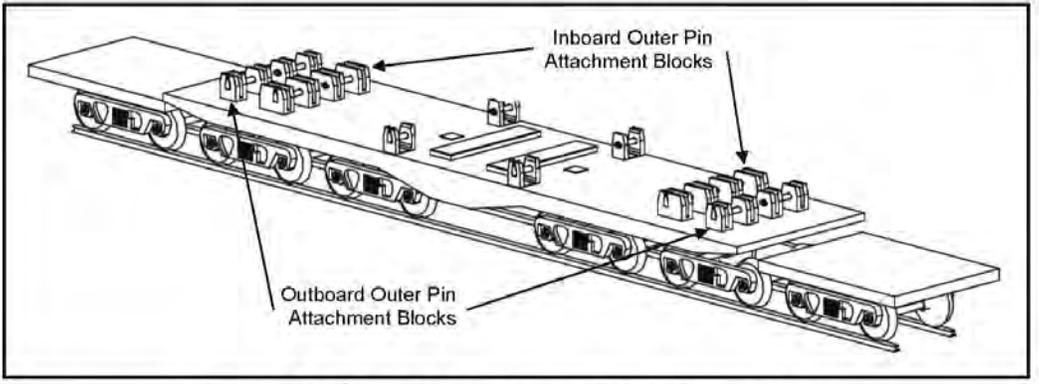
**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 22 of 43



**Figure 5-4: Outer Pin Attachment Block Nomenclature**

The inboard outer pin attachment blocks (See Figure 5-5) are subjected to tension loading, shear tear-out, and bending from the combined longitudinal and vertical loads.

Tension Loading

The minimum tensile area at the hole center and is:

$$A = 2(24.00 - 4.13)(3.87) = 154 \text{ in}^2$$

where the block length is 24.00 inches, the slotted hole width is 4.13 inches and the block leg thickness is 4.0-13 = 3.87 inches (maximum stainless steel facing of 0.13 inches allowed per flag note 8 of [4] is conservatively neglected), and there are two block legs per the drawing dimensions [4]. Conservatively applying the combined load in the vertical direction, the tensile stress is:

$$\sigma = \frac{F_{OOPB,c}}{A} = \frac{1084}{154} = 7.04 \text{ ksi}$$

From Section 5.1, the allowable tensile stress,  $S_{AT} = 50$  ksi. The margin of safety is:

$$MS = \frac{50}{7.04} - 1 = +6.10$$



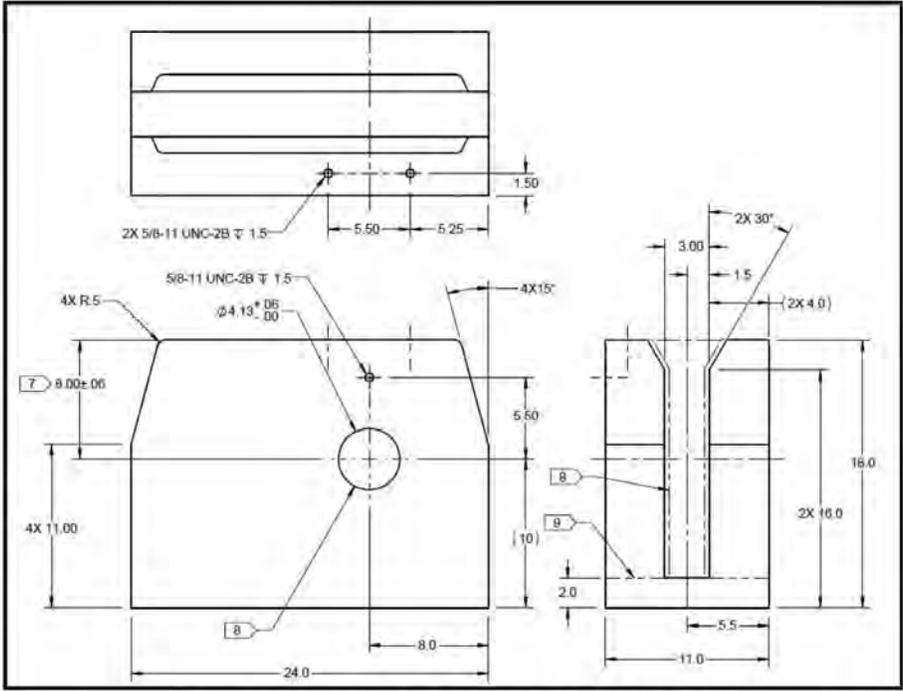
**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 23 of 43



**Figure 5-5: Inboard Outer Pin Attachment Block**

Shear tear-out

The pin block is subjected to shear-tear out from vertical loading. The shear tear-out area is conservatively calculated using twice the straight line distance:

$$A = 2(2) \left( 16.0 - 10.0 - \frac{4.13}{2} \right) (3.87) = 60.9 \text{ in}^2$$

where the height of the pin block chamfer is 16.0 inches, the center of the hole is 10.0 inches, the hole diameter is 4.13 inches and the thickness of the block leg is 3.87 inches (as discussed above), and there are two legs per [4]. Conservatively, this neglects the material at less than the full 4.0 inch thickness. Conservatively applying the combined load in the vertical direction, the shear tear-out stress is:

$$\tau = \frac{F_{IOPB_C}}{A} = \frac{1084}{60.9} = 17.8 \text{ ksi}$$

From Section 5.1, the allowable tensile stress,  $S_{AS} = 30$  ksi. The margin of safety is:

$$MS = \frac{30}{17.8} - 1 = +0.69$$



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 24 of 43**

Bending

The inboard outer pin blocks are subjected to simultaneous bending and shear from the longitudinal and vertical load. There are two sections of interest. The bottom of each pin block leg (supports half the load as a cantilever beam with vertical end and eccentric axial loads) and the base of the pin block (whole load, largest moment arm).

The leg of the inboard outer pin block is evaluated as a cantilever beam, see Figure 5-8. As shown in Section 5.2.7, the load on each leg is not shared equally. The load can be offset in either direction. The maximum load distribution is  $632.3/1084 = .583$ .

Inboard outer pin block (IOPB) longitudinal load applied to single leg,  $F_{leg\_long} = 699 (.583) = 407.5$  kip

Inboard outer pin block (IOPB) vertical load,  $F_{leg\_v} = 828 (.583) = 482.7$  kip

The cross-sectional area at the leg base is:

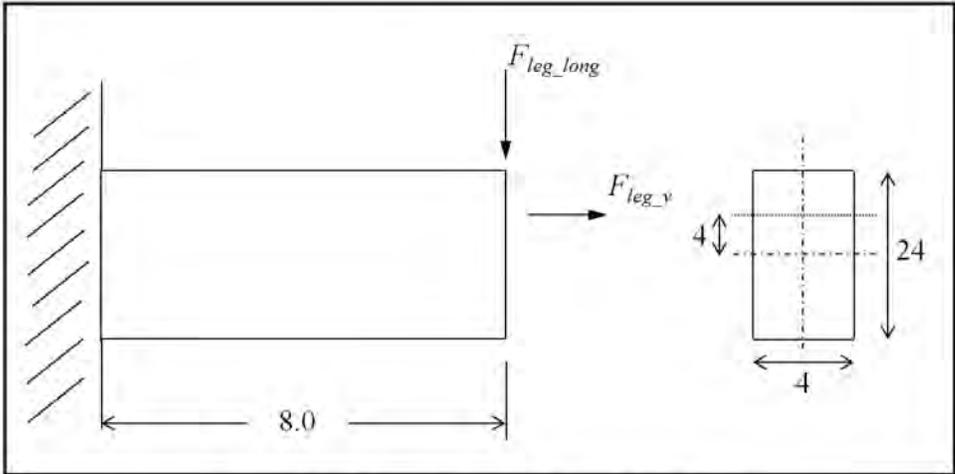
$$A = (24.0)(3.87) = 92.9 \text{ in}^2$$

where the length of the inboard outer pin block is 24.0 inches, and the thickness of the leg is 3.87 inches. The moment of inertia at the leg base is:

$$I = \frac{1}{12} (3.87)(24.0)^3 = 4,458 \text{ in}^3$$

The shear stress at the base is:

$$\tau = \frac{F_{leg\_long}}{A} = \frac{407.5}{92.9} = 4.39 \text{ ksi}$$



**Figure 5-6: Inboard Outer Pin Block Leg Beam**



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 25 of 43**

The tensile stress is:

$$\sigma = \frac{F_{leg,v}}{A} = \frac{482.7}{92.9} = 5.20 \text{ ksi}$$

The bending moment from the longitudinal load is

$$M = (F_{leg,long})(8.0) = (407.5)(8.0) = 3,260 \text{ in} - \text{kip}$$

where moment arm is taken from the center of the pin hole to the base of the leg (10.0 - 2.0 = 8.0 inches). The bending stress is:

$$\sigma_{b,long} = \frac{My}{I} = \frac{3,260(\frac{24}{2})}{4,458} = 8.78 \text{ ksi}$$

The bending moment from the vertical load is

$$M = (F_{leg,v})(4.0) = (482.7)(4.0) = 1,931 \text{ in} - \text{kip}$$

where moment arm is calculated as 24.0/2 - 8.00 = 4.0 inches. The bending stress is:

$$\sigma_{b,v} = \frac{My}{I} = \frac{1,931(\frac{24}{2})}{4,458} = 5.20 \text{ ksi}$$

The combined stress is:

$$\sigma_v = \sqrt{\sigma_x^2 + 3\tau_{xy}^2} = \sqrt{(5.20 + 8.78 + 5.20)^2 + 3(4.39)^2} = 20.6 \text{ ksi}$$

From Section 5.1, the allowable tensile stress,  $S_{AT} = 50$  ksi. The margin of safety is:

$$MS = \frac{50}{20.6} - 1 = +1.43$$

The evaluation of the base of the inboard outer pin block is bounded by the weld evaluation in Section 5.2.6.

**Outboard Outer Pin Attachment Block**

The outboard outer pin blocks (See Figure 5-7) are subjected to vertical loading from the longitudinal tie-down load on the end stop and lateral loading from the lateral tie-down load on the end stop. The bounding vertical load is taken by the pin block.

Tensile/Compressive loading

The minimum cross-sectional area at the slotted hole center and is:

$$A = 2(16.00 - 5.12)(3.87) = 84.2 \text{ in}^2$$

where the block length is 16.00 inches, the slotted hole length is 5.12 inches and the block leg thickness is 3.87 inches, and there are two legs per the drawing dimensions [4]. The stress is:

$$\sigma = \frac{P}{A} = \frac{828}{84.2} = 9.83 \text{ ksi}$$

where the maximum vertical load is 828 kips per Table 4-2. From Section 5.1, the allowable tensile stress,  $S_{AT} = 50$  ksi. The margin of safety is:



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

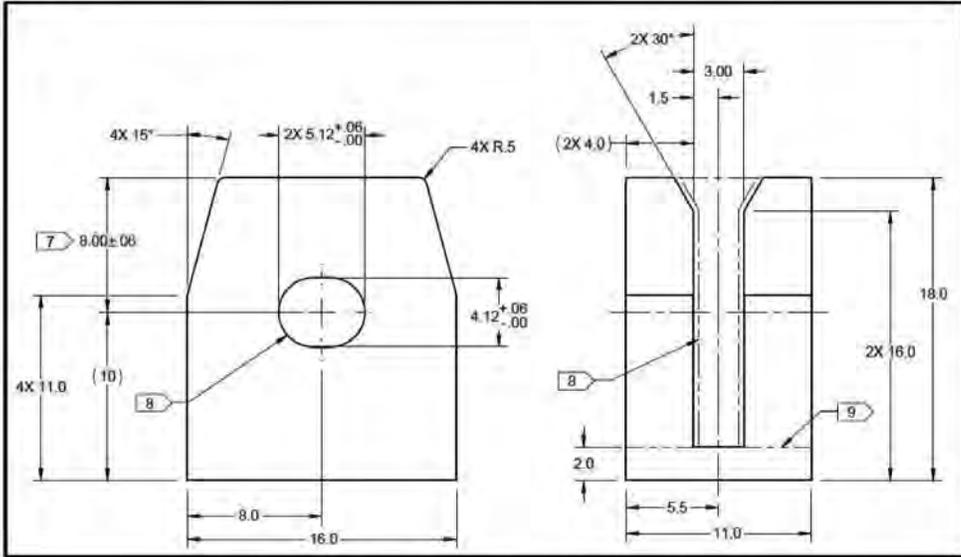
Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 26 of 43

$$MS = \frac{50}{9.83} - 1 = +4.09$$

The lateral loading is bounded by the evaluation of the center pin attachment blocks in Section 5.2.1. The center pin attachment blocks are subjected to a much higher lateral load, have a shorter length and have the same size slotted hole.



**Figure 5-7: Outboard Outer Pin Attachment Block**

**5.2.6 Outer Pin Attachment Block Welds**

The Inboard and outboard block welds are considered separately due to their different loading and weld geometry.

Inboard Outer Pin Attachment Block Welds

The loads on the inboard pin attachment block (Item 12-14 of [4], P9-P12 and P13-P16) welds are taken from Section 5.2.5. The welds shown on the drawing are representative of a possible weld configuration. Weld force and size required are determined in this calculation. The inboard outer pin attachment blocks are welded to the railcar using an all-around 3/4 groove weld with a 1-1/4 fillet weld cover [4]. The weld is evaluated using the weld as a line technique to determine the required weld size. The longitudinal and lateral loads shown below are applied simultaneously.

Inboard outer pin block (IOPB) longitudinal load,  $F_{IOPB\_long} = 699$  kip

Inboard outer pin block (IOPB) vertical load,  $F_{IOPB\_v} = 828$  kip

The inboard outer pin blocks are also subjected to a separately applied lateral load

Inboard outer pin block (IOPB) lateral load,  $F_{IOPB\_lat} = 15$  kip

CALC-3015276-001  
 Page 27 of 43



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 27 of 43**

The lateral load is small and is bounded by the lateral load on the center pin attachment block welds evaluated in Section 5.2.2. The center pin attachment block welds are subjected to a much higher lateral load, have a smaller weld area and footprint.

The weld area is:

$$A_w = 2(24.00 + 11.00) = 70.0 \text{ in}$$

where the length of the block is 24.00 inches and the width of the block base is 11.00 inches per [4]. The weld section modulus is:

$$S_w = bd + \frac{d^2}{3} = (11.00)(24.00) + \frac{24.00^2}{3} = 456 \text{ in}^2$$

where the width, b = 11.00 inches and the thickness, d = 24.00 inches per [4]. Weld shear force from longitudinal load:

$$F_{w\_long} = \frac{F_{IOPB\_long}}{A_w} = \frac{699}{70.0} = 9.99 \text{ kip/in}$$

The weld shear force from vertical load:

$$F_{w\_v} = \frac{F_{IOPB\_v}}{A_w} = \frac{828}{70.0} = 11.8 \text{ kip/in}$$

The bending moment from the longitudinal load is

$$M = (F_{IOPB\_long})(10.0) = (699)(10.0) = 6,990 \text{ in - kip}$$

where moment arm is taken from the center of the pin hole to the base =10.0 inches from [4]. The weld shear force from bending moment due to the longitudinal load is:

$$F_{w\_b1} = \frac{M}{S_w} = \frac{6,990}{456} = 15.3 \text{ kip/in}$$

The bending moment from the vertical load is

$$M = (F_{IOPB\_v})\left(\frac{24.00}{2} - 8\right) = (828)(4) = 3,312 \text{ in - kip}$$

where moment arm is taken from the center of the block to the pin hole [4]. The weld shear force from bending moment due to the vertical load is:

$$F_{w\_b2} = \frac{M}{S_w} = \frac{3,312}{456} = 7.26 \text{ kip/in}$$

The resultant weld force is:

$$F_{w\_r} = \sqrt{(F_{w\_long})^2 + (F_{w\_v} + F_{w\_b1} + F_{w\_b2})^2} = 35.8 \text{ kip/in}$$

From Section 5.1, the allowable shear stress,  $S_{AS} = 30$  ksi. The required weld throat is:

$$\omega = \frac{\text{actual force}}{\text{allowable stress}} = \frac{35.8 \text{ kip/in}}{30 \text{ kip/in}^2} = 1.19 \text{ in}$$

The actual weld throat is the minimum of:

$$\omega_n = 1.06 + 0.27 = 1.33 \text{ in}$$

CALC-3015276-001  
 Page 28 of 43



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

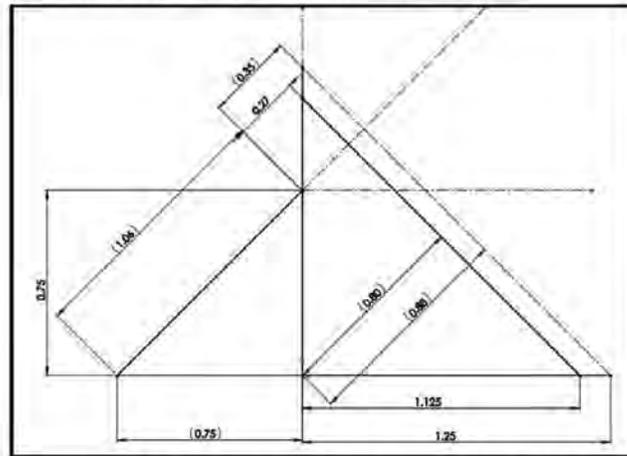
Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 28 of 43

$$a_D = 0.75 + 0.80 = 1.55 \text{ in}$$

where the weld throat is taken as the least distance from the weld root to the weld edge as shown in Figure 5-8 and the groove weld size is reduced by 1/8 per AWS D15.1, Clause 7.1.1 [17].



**Figure 5-8: Outer Pin Attachment Block Weld**

The margin of safety is:

$$MS = \frac{1.33}{1.19} - 1 = +0.12$$

Outboard Outer Pin Attachment Block Welds

The outboard outer pin attachment blocks (Item 10-11 of [4], P5-P8 and P17-P20) support compressive vertical loading and lateral loading. The lateral load is small (15 kip) and is bounded by the center pin attachment weld evaluation in Section 5.2.2. The vertical load on the outboard pin attachment block welds are taken from Section 5.2.5. The welds shown on the drawing are representative of a possible weld configuration. Weld force and size required are determined in this calculation. The outboard outer pin attachment blocks are welded to the railcar using an all-around 1-1/4 fillet weld [4]. The weld is evaluated using the weld as a line technique to determine the required weld size.

Inboard outer pin block (IOPB) vertical load,  $F_{IOPB,v} = 828 \text{ kip}$

The weld area is:

$$A_w = 2(16.00 + 11.00) = 54.0 \text{ in}$$

where the width of the block is 11.00 inches and the length of the block is 16.00 inches per [4]. The weld shear force from vertical load:

$$F_{w1} = \frac{F_{IOPB,v}}{A_w} = \frac{828}{54.0} = 15.3 \text{ kip/in}$$

From Section 5.1, the allowable shear stress,  $S_{AS} = 30 \text{ ksi}$ . The required weld throat is:



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 29 of 43

$$\omega = \frac{\text{actual force}}{\text{allowable stress}} = \frac{15.3 \text{ kip/in}}{30 \text{ kip/in}^2} = 0.51 \text{ in}$$

The actual weld throat is:

$$\omega_a = 0.707(1.25) = 0.88 \text{ in}$$

The margin of safety is:

$$MS = \frac{0.88}{0.51} - 1 = +0.73$$

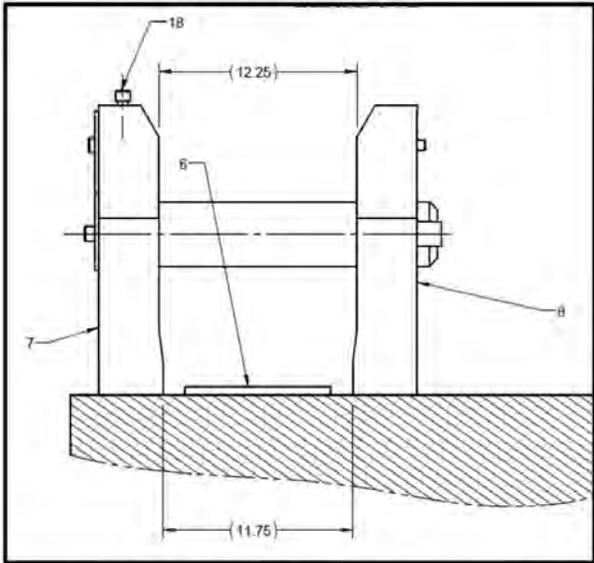
**5.2.7 Attachment Pin**

The attachment pins used by the center pin attachment blocks (Item 15 of [4]) are used to secure the cradles to the railcar. They are inserted through the center pin attachment blocks and the holes in the cradle main beams. The attachment pins used by the outer pin attachment blocks (Item 16 of [4]) to secure the end stop assemblies are double length and are used to secure both legs of the end stop. However the loading condition on each pin is the same for each location (double or single).

Pin at Center Pin Attachment Block

The maximum load on the attachment pin at the center pin attachment blocks is from the vertical tie-down load taken from Section 5.2.1:

$$F_{pin,v} = F_{CPB,v} = 730 \text{ kip}$$



**Figure 5-9: Attachment Pin Connection (Item 15)**

The pin is subjected to shear and bending from the gap between the center pin attachment blocks and the cradle beams. The pin cross sectional area is:



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 30 of 83**

$$A = \frac{\pi}{4}(4.00)^2 = 12.6 \text{ in}^2$$

where the pin diameter is 4.00 inches from [4]. The pin section modulus is:

$$S = \frac{\pi}{32}(4.00)^3 = 6.28 \text{ in}^3$$

Using Table 42, Case 5 of [17] and conservatively assuming the gap is maximized toward one end leaving only a 0.25 inch gap due to the boss at the block bottom, the load P is:

$$P = (F_{pin})/2 = 730/2 = 365 \text{ kip}$$

As shown on Figure 5-10, the reactions R1 and R2 are:

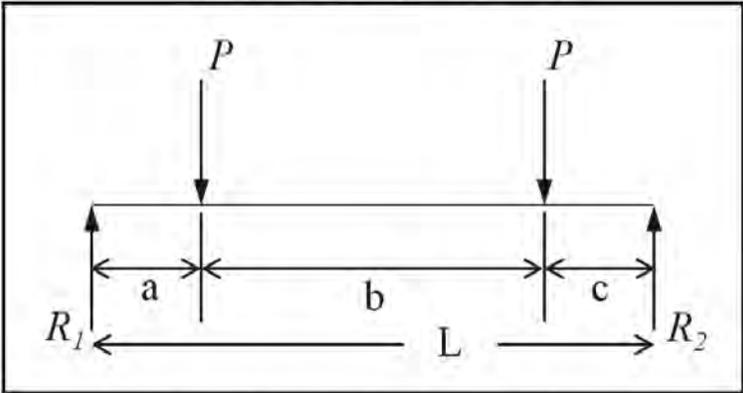
$$R_1 = \frac{P(L - a + c)}{L} = \frac{365(12.25 - 0.735 + 0.25)}{12.25} = 350.5 \text{ kip}$$

$$R_2 = \frac{P(L - c + a)}{L} = \frac{365(12.25 - 0.25 + 0.735)}{12.25} = 379.5 \text{ kip}$$

where the opening between the center pin attachment blocks is,  $L = (11.75 + 0.25 + 0.25) = 12.25$  inches per [4], the connecting cradle I-beam is W18x119 per [20], [21], [22], [23] and [24], per [25], the width  $b = 11.265$ , the length  $a = 12.25 - 11.265 - 0.25 = 0.735$  inches and the length  $c = 0.25$  inches. The bending moments are:

$$M_1 = R_1 a = 350.5(0.735) = 257.6 \text{ in} - \text{kip}$$

$$M_2 = R_2 c = 379.5(0.25) = 94.9 \text{ in} - \text{kip}$$



**Figure 5-10: Attachment Pin Bending**

The shear stress is:

$$\tau = \frac{\text{MAX}(R_1, R_2)}{A} = \frac{379.5}{12.6} = 30.1 \text{ ksi}$$

The bending stress is:

CALC-3015276-001  
 Page 31 of 43



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 31 of 43**

$$\sigma_b = \frac{MAX(M_1, M_2)}{S} = \frac{257.6}{6.28} = 41.0 \text{ ksi}$$

The von Mises stress is:

$$\sigma_v = \sqrt{(\sigma_x)^2 + 3\tau_{xy}^2} = \sqrt{(41.0)^2 + 3(30.1)^2} = 66.3 \text{ ksi}$$

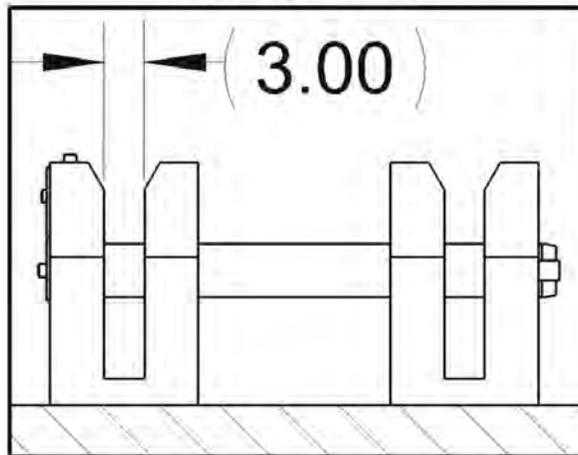
From Section 5.1, the allowable tensile stress,  $S_{AT} = 115$  ksi. The margin of safety is:

$$MS = \frac{115}{66.3} - 1 = +0.73$$

Pin at Outer Pin Attachment Block

The maximum load on the attachment pin used at the outer pin attachment block is taken from Section 5.2.5 as:

$$F_{pin_o} = F_{IOPB_c} = 1084 \text{ kip}$$



**Figure 5-11: Attachment Pin Connection (Item 16)**

The pin is subjected to shear and bending from the gap between the outer pin attachment blocks and the end stop plates. The pin cross sectional area is:

$$A = \frac{\pi}{4}(4.00)^2 = 12.6 \text{ in}^2$$

where the pin diameter is 4.00 inches from [4]. The pin section modulus is:

$$S = \frac{\pi}{32}(4.00)^3 = 6.28 \text{ in}^3$$

Again using Table 42, Case 5 of [17] the load P is:

$$P = (F_{pin})/2 = 1084/2 = 542 \text{ kip}$$

As shown on Figure 5-10, the reactions R1 and R2 are:



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 32 of 43**

$$R_1 = \frac{P(L - a + c)}{L} = \frac{542(3.00 - 0 + 0.50)}{3.00} = 632.3 \text{ kip}$$

$$R_2 = \frac{P(L - c + a)}{L} = \frac{542(3.00 - 0.50 + 0)}{3} = 451.7 \text{ kip}$$

where the opening between the outer pin attachment blocks is,  $L = 3.00$  inches per [4], the connecting end stop plates are  $2.00 + .25 + .25$  inches (Items 4(2x) and 5 of [20]) wide,  $b = 2.50$  inches, the length  $a = 3.00 - 2.50 - 0.50 = 0$  inches and the length  $c = 0.50$  inches. The bending moments are:

$$M_1 = R_1 a = 632.3(0) = 0 \text{ in - kip}$$

$$M_2 = R_2 c = 451.7(0.50) = 225.9 \text{ in - kip}$$

The shear stress is:

$$\tau = \frac{MAX(R_1, R_2)}{A} = \frac{632.3}{12.6} = 50.2 \text{ ksi}$$

The bending stress is:

$$\sigma_b = \frac{MAX(M_1, M_2)}{S} = \frac{225.9}{6.28} = 36.0 \text{ ksi}$$

The von Mises stress is:

$$\sigma_v = \sqrt{(\sigma_x)^2 + 3\tau_{xy}^2} = \sqrt{(36.0)^2 + 3(50.2)^2} = 94.1 \text{ ksi}$$

From Section 5.1, the allowable tensile stress,  $S_{AT} = 115$  ksi. The margin of safety is:

$$MS = \frac{115}{94.1} - 1 = +0.22$$

**5.3 Cradle Weight**

Weights for the conceptual cradle designs are listed in Table 4-4. To bound the dynamic response of the railcar and any changes in the future final cradle designs, a range of  $\pm 10\%$  is added to the cradle weight. The nominal, maximum, and minimum cradle weights are shown in Table 5-1 below:



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 33 of 43

**Table 5-1: Adjusted Cradle Weights**

Cask	Family	Nominal Cradle Weight, lb	Maximum Cradle Weight, lb	Minimum Cradle Weight, lb
NAC-STC	2	42,000	46,200	37,800
NAC-UMS UTC	2	42,000	46,200	37,800
MAGNATRAN	2	42,000	46,200	37,800
HI-STAR 100	1	67,200	73,920	60,480
HI-STAR 100HB	1	68,800	75,680	61,920
HI-STAR 180	1	54,200	59,620	48,780
HI-STAR 60	1	61,000	67,100	54,900
MP187	4	36,800	40,480	33,120
MP197	3	26,000	28,600	23,400
MP197HB	3	26,000	28,600	23,400
TN-32B	1	70,200	77,220	63,180
TN-40	1	70,200	77,220	63,180
TN40HT	1	70,200	77,220	63,180
TN-68	2	27,000	29,700	24,300
TS125	3	30,000	33,000	27,000

**5.4 Combined cg and Railcar Weight**

In order to meet the combined cg requirement of 98 inches, required by Rule 89 of the AAR Field Manual of the AAR Interchange Rules [8], the railcar weight must be considered. The required railcar weight is determined using the package weights and vertical cg locations, the conceptual cradle designs calculated weights and vertical cg locations, and the railcar deck height and railcar vertical cg location provided by KASGRO [6].

The total cg of the cask, cradle and railcar is shown in the following table. The unloaded railcar deck height was provided by KASGRO to be 60.0 inches [6]. This value is lower when under load. Per KASGRO, the loaded deck height from the rails is 55.875 inches [6]. Conservatively, the unloaded deck height of 60.0 inches will be used. This value was used to adjust the cask and cradle cg's provided in Table 4-3 and Table 4-4. The railcar cg (unloaded condition) is 35.10 inches from the rails [6]. To calculate the worst case cg for each cask and cradle combination, the maximum cask weight is used from Table 4-3 and the minimum cradle weight is used from Table 5-1. The total cg is calculated as follows:

$$total\ cg = \frac{Railcar\ Weight \times Railcar\ cg + Cradle\ Weight \times Cradle\ cg + Cask\ Weight \times Cask\ cg}{Total\ Weight}$$

The combined total cg's are calculated and shown in Table 5-2, Table 5-3 and Table 5-4 below. Three railcar weights are considered, 195,000 lb., 200,000 lb. and 205,000 lb.. These weights were selected based on the range provided by KASGRO. The minimum railcar weight of 195,000 lb. was selected to provide the minimum required railcar weight needed to meet the cg limit with an acceptable margin. The allowable cg is 98 inches per Section 2.1. The cg margins for each of the casks are calculated in Table 5-5. The bounding cask is the TN-68 which has a margin of 98-94.61 = 3.39 inches for a 195,000 lb. railcar.

The maximum railcar weight of 205,000 lb. was selected to meet the maximum allowed combined weight. The maximum combined weight of the railcar, cradle and loaded cask must be less than 65,750 pounds per axle



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 34 of 43

(789,000 pound loaded car limit) per AFS-IN-16-0039 [6]. The maximum combined weight is calculated using the maximum cask weight from Table 4-3, the maximum cradle weight from Table 5-1 and the railcar weight. Maximum weights are shown in Table 5-6 below. The minimum margin is 215,733 pounds for the HI-STAR 180 loaded on a 205,000 pound railcar.

**Table 5-2: Combined CG Height, 195,000 lb. Railcar**

Cask	Family	Cask cg <sup>(1)</sup> , in	Max Cask Weight, lb	Cradle cg <sup>(1)</sup> , in	Min Cradle Weight, lb	Total Weight <sup>(2)</sup> , lb	Total cg <sup>(1)</sup> , in
NAC-STC	2	128.00	254,600	87.50	37,800	487,400	87.69
NAC-UMS UTC	2	128.00	256,000	87.50	37,800	488,800	87.81
MAGNATRAN	2	128.00	312,000	87.50	37,800	544,800	91.94
HI-STAR 100	1	130.25	279,893	112.00	60,480	535,373	93.53
HI-STAR 100HB	1	130.25	187,200	118.80	61,920	444,120	86.88
HI-STAR 180	1	125.00	308,647	115.10	48,780	552,427	92.39
HI-STAR 60	1	120.13	164,000	114.00	54,900	413,900	79.26
MP187	4	129.50	271,300	87.70	33,120	499,420	89.87
MP197	3	122.50	265,100	77.50	23,400	483,500	85.07
MP197HB	3	124.50	303,600	78.00	23,400	522,000	89.02
TN-32B	1	133.00	263,000	107.50	63,180	521,180	93.28
TN-40	1	133.00	271,500	107.00	63,180	529,680	93.86
TN40HT	1	133.00	242,343	107.00	63,180	500,523	91.58
TN-68	2	138.00	272,000	86.50	24,300	491,300	<b>94.61</b>
TS125	3	133.30	285,000	85.00	27,000	507,000	92.96

Notes:

1. A value of 60.0 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight

CALC-3015276-001  
 Page 35 of 43



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 35 of 43

**Table 5-3: Combined CG Height, 200,000 lb. Railcar**

Cask	Family	Cask cg <sup>(1)</sup> , in	Max Cask Weight, lb	Cradle cg <sup>(1)</sup> , in	Min Cradle Weight, lb	Total Weight <sup>(2)</sup> , lb	Total cg <sup>(1)</sup> , in
NAC-STC	2	128.00	254,600	87.50	37,800	492,400	87.16
NAC-UMS UTC	2	128.00	256,000	87.50	37,800	493,800	87.27
MAGNATLAN	2	128.00	312,000	87.50	37,800	549,800	91.42
HI-STAR 100	1	130.25	279,893	112.00	60,480	540,373	92.99
HI-STAR 100HB	1	130.25	187,200	118.80	61,920	449,120	86.30
HI-STAR 180	1	125.00	308,647	115.10	48,780	557,427	91.88
HI-STAR 60	1	120.13	164,000	114.00	54,900	418,900	78.73
MP187	4	129.50	271,300	87.70	33,120	504,420	89.33
MP197	3	122.50	265,100	77.50	23,400	488,500	84.56
MP197HB	3	124.50	303,600	78.00	23,400	527,000	88.51
TN-32B	1	133.00	263,000	107.50	63,180	526,180	92.73
TN-40	1	133.00	271,500	107.00	63,180	534,680	93.31
TN40HT	1	133.00	242,343	107.00	63,180	505,523	91.02
TN-68	2	138.00	272,000	86.50	24,300	496,300	<b>94.01</b>
TS125	3	133.30	285,000	85.00	27,000	512,000	92.39

Notes:

1. A value of 60.0 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight

CALC-3015276-001  
 Page 36 of 43



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 36 of 43

**Table 5-4: Combined CG Height, 205,000 lb. Railcar**

Cask	Family	Cask cg <sup>(1)</sup> , in	Max Cask Weight, lb	Cradle cg <sup>(1)</sup> , in	Min Cradle Weight, lb	Total Weight <sup>(2)</sup> , lb	Total cg <sup>(1)</sup> , in
NAC-STC	2	128.00	254,600	87.50	37,800	497,400	86.63
NAC-UMS UTC	2	128.00	256,000	87.50	37,800	498,800	86.75
MAGNATRAN	2	128.00	312,000	87.50	37,800	554,800	90.91
HI-STAR 100	1	130.25	279,893	112.00	60,480	545,373	92.46
HI-STAR 100HB	1	130.25	187,200	118.80	61,920	454,120	85.74
HI-STAR 180	1	125.00	308,647	115.10	48,780	562,427	91.37
HI-STAR 60	1	120.13	164,000	114.00	54,900	423,900	78.22
MP187	4	129.50	271,300	87.70	33,120	509,420	88.79
MP197	3	122.50	265,100	77.50	23,400	493,500	84.06
MP197HB	3	124.50	303,600	78.00	23,400	532,000	88.01
TN-32B	1	133.00	263,000	107.50	63,180	531,180	92.18
TN-40	1	133.00	271,500	107.00	63,180	539,680	92.77
TN40HT	1	133.00	242,343	107.00	63,180	510,523	90.47
TN-68	2	138.00	272,000	86.50	24,300	501,300	<b>93.42</b>
TS125	3	133.30	285,000	85.00	27,000	517,000	91.84

Notes:

1. A value of 60.0 inches is added for the deck height of the railcar. The cg is measured from the rails.
2. Includes railcar weight



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 37 of 43

**Table 5-5: Total cg's and Margin to 98 inches**

Cask	Family	195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
		total cg, in	margin, in	total cg, in	margin, in	total cg, in	margin, in
NAC-STC	2	87.69	10.31	87.16	10.84	86.63	11.37
NAC-UMS UTC	2	87.81	10.19	87.27	10.73	86.75	11.25
MAGNATRAN	2	91.94	6.06	91.42	6.58	90.91	7.09
HI-STAR 100	1	93.53	4.47	92.99	5.01	92.46	5.54
HI-STAR 100HB	1	86.88	11.12	86.30	11.70	85.74	12.26
HI-STAR 180	1	92.39	5.61	91.88	6.12	91.37	6.63
HI-STAR 60	1	79.26	18.74	78.73	19.27	78.22	19.78
MP187	4	89.87	8.13	89.33	8.67	88.79	9.21
MP197	3	85.07	12.93	84.56	13.44	84.06	13.94
MP197HB	3	89.02	8.98	88.51	9.49	88.01	9.99
TN-32B	1	93.28	4.72	92.73	5.27	92.18	5.82
TN-40	1	93.86	4.14	93.31	4.69	92.77	5.23
TN40HT	1	91.58	6.42	91.02	6.98	90.47	7.53
TN-68	2	94.61	<b>3.39</b>	94.01	<b>3.99</b>	93.42	<b>4.58</b>
TS125	3	92.96	5.04	92.39	5.61	91.84	6.16



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 38 of 43**

**Table 5-6: Total Weight and Margin to 789,000 pounds**

Cask	Family	195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
		Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.
NAC-STC	2	495,800	293,200	500,800	288,200	505,800	283,200
NAC-UMS UTC	2	497,200	291,800	502,200	286,800	507,200	281,800
MAGNATRAN	2	553,200	235,800	558,200	210,100	563,200	225,800
HI-STAR 100	1	548,813	240,187	553,813	235,187	558,813	230,187
HI-STAR 100HB	1	457,880	331,120	462,880	326,120	467,880	321,120
HI-STAR 180	1	563,267	<b>225,733</b>	568,267	<b>220,733</b>	573,267	<b>215,733</b>
HI-STAR 60	1	426,100	362,900	431,100	357,900	436,100	352,900
MP187	4	506,780	282,220	511,780	277,220	516,780	272,220
MP197	3	488,700	300,300	493,700	295,300	498,700	290,300
MP197HB	3	527,200	261,800	532,200	256,800	537,200	251,800
TN-32B	1	535,220	253,780	540,220	248,780	545,220	243,780
TN-40	1	543,720	245,280	548,720	240,280	553,720	235,280
TN40HT	1	514,563	274,437	519,563	269,437	524,563	264,437
TN-68	2	496,700	292,300	501,700	287,300	506,700	282,300
TS125	3	513,000	276,000	518,000	271,000	523,000	266,000

Notes:

1. The weight limit of 789,000 pounds is based on a selected limit of 65,750 lb/axle for a 12 axle railcar.
2. The maximum combined weight is the summation of the maximum cradle weight from Table 5-1, the maximum cask weight from Table 4-3, and the provided railcar weight.

**5.5 Attachment Components Cask Interface**

Some of the packages must have their impact limiters installed on the railcar deck. Table 5-7 shows the distance required for impact limiter removal/insertion for the two packages (MP187 and TS125) that are bounding. It can be seen from [4] that the distance between the attachment components is:

$$125 + 2(133.50) - 2(8) = 376 \text{ inches}$$

The minimum required clearance for impact limiter removal is 372 inches for the MP187 from [26]. In this case there is 4 inches of clearance. However, the clearance was calculated assuming the impact limiter has a flat bottom end. In reality all of the cask impact limiters have some taper which provides additional clearance.

CALC-3015276-001  
 Page 39 of 43



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 39 of 43

**Table 5-7: Bounding Required Impact Limiter Clearance**

Family	Cask	Total length (to facilitate removal of impact limiters)
4	MP187	Package Length: 308 inches (see SOW Appendix A [1]) Impact Limiter Overlap: 32 inches (SAR DWG NUH-05-4000NP R9 & DWG NUH-05-4001NP R13 [26]) $=308+ 2(32) = 372$ inches
3	TS125	Package Length: 342.4 inches (see SOW Appendix A [1]) Impact Limiter Overlap: 14.5 inches (SAR Section 2.1.1.1 [27]) $=342.4+ 2(14.5) = 371.4$ inches

**5.6 Fatigue**

The railcar is expected to perform service for up to 50 years and are not expected to travel more than the maximum value of 3,000,000 miles per Section 7.1.2.1 of M-1001 [28]. While this period of performance is not expected to be maintenance free it is reasonable to assume that the structure would perform its support function without major component failure. To this end this analysis presents a cursory examination of the fatigue loading over this lifespan. The detailed fatigue analysis will be included with the evaluation of the railcar.

An example of the accepted method for calculating fatigue life is shown in Chapter 7 of the M-1001. From the example case Figure 7-3 it can be seen that 97 percent of the vertical fatigue loading is due to stress ranges under 0.3g. As this is from an example case it is assumed to be normal in comparison to other railcar response curves. Since a majority of the fatigue loading is within this range the fatigue life of the cradle is assumed to be defined by these loads.

The attachment component structural analysis demonstrates that a bounding acceleration load of 2g in the vertical direction can be supported when compared against yield strength. This is equivalent to using an allowable stress of 1/2 yield stress under normal gravity loading. All of the attachment component analyses show that this yield criterion is met.

If we assume that the stress variation due to cyclic loading is no more than +/- 0.2g (or a range of 0.4g), and that the allowable stress is just met at one gravity, the minimum and maximum stress that will be found in any component with a yield stress of 50 ksi due to cyclic loading will be due to the variable stress. This stress is:

Mean Stress:  $S = \frac{1}{2} 50 \text{ ksi} = 25 \text{ ksi}$   
 Variable Stress:  $S_v = 0.2S = 5 \text{ ksi}$   
 Maximum Stress:  $S_{\text{max}} = 30 \text{ ksi}$   
 Minimum Stress:  $S_{\text{min}} = 20 \text{ ksi}$   
 Stress Ratio:  $R = \frac{S_{\text{min}}}{S_{\text{max}}} = \frac{2}{3}$

The stress that produces failure in steel at 2,000,000 cycles can be computed from cases in Table 7.55 of Chapter 7 of M-1001. This table presents values for determining the fatigue properties of the Modified Goodman Diagram (MGD) for a particular member. As an example, for an A992 beam the allowable stress is 50 ksi. From Table 7.55, Fig. No. 7.4.1.8 the following information is available:

Y intercept of MGD:  $b = 26 \text{ ksi}$



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 40 of 43**

MGD Slope:  $m = 0.9$   
 S-N Curve Slope:  $k = 0.16$   
 Cycles at Fatigue Stress  $S_e$ :  $N_e = 2 \times 10^6$  cycles

The stress at which the beam is expected to fail at two million cycles is:

$$\text{Fatigue Stress (at } N_e\text{): } S_e = \frac{b}{1-mR} = 65 \text{ ksi}$$

Since the Fatigue Limit is greater than the maximum load the S-N curve slope is half the value above.

$$\text{Cycles to failure: } N = \frac{N_e}{\left(\frac{S_{max}}{S_e}\right)^k} = 31.5 \times 10^9 \text{ cycles}$$

For a 50 year life the railcar is expected to cover 3,000,000 miles. Assuming a cyclic rate of  $\beta = 300$  cycles per mile (based on the example of Section 7.2.4.1.1.2 of M-1001) the expected life will be:

$$\text{Life} = \frac{N}{\beta} = (31.5 \times 10^9 \text{ cycles}) / (300 \text{ cycles/mile}) = 105 \times 10^6 \text{ miles}$$

The life prediction for this component is much larger than the required lifespan for the component, therefore it is reasonable to say that it will support fatigue loading without any modification. Similar analysis performed on an axially loaded flat plate for material with a 50 ksi yield stress limit shows improved fatigue life in comparison to the beam section.

**6.0 COMPUTER SOFTWARE USAGE (IF SOFTWARE IS USED)**

No computer software is used in this calculation.



**AREVA Federal Services LLC**

Title: Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

Doc./Rev.: CALC-3015276-001

Project: 00225.03.0050 - DOE Atlas Railcar

Page 41 of 43

**7.0 RESULTS/CONCLUSIONS**

**7.1 Standardized Attachment Components**

The results of the analyses in this calculation demonstrated that the standardized attachment components are adequate to perform required function. The margins of safety for the evaluated components are shown in Table 7-1.

**Table 7-1: Margins of Safety**

Component	Loading	Margin of Safety
Center Pin Attachment Blocks (Section 5.2.1)	Tensile stress from vertical load	+2.29
	Shear tear-out from vertical load	+1.26
	Combined stress from lateral load at base	+0.81
Shear Blocks (Section 5.2.3)	Combined stress from longitudinal load	+18.4
Outer Pin Attachment Blocks (Section 5.2.5)	Tension Stress from combined load	+6.10
	Shear tear-out from combined load	+0.69
	Combined stress at leg	+1.43
	Compression from vertical load	+4.09
Attachment Pin (Section 5.2.7)	Combined stress (minimum)	+0.22

All margins of safety are positive and the components are adequate to support the applied loading.

**7.2 Standardized Attachment Components Welds**

The forces applied to the welds between the attachment components and the railcar deck are taken from Section 5.2.2, Section 5.2.4, and Section 5.2.6 and are shown in Table 7-2.

**Table 7-2: Required Weld Strength and Size**

Weld	Forces Applied to Weld
Center Pin Attachment Block Weld (Section 5.2.2), (Item 7-8 of [4])	730 kip (vertical)
	448 kip (lateral) and 231 kip (vertical)
Shear Blocks Weld (Section 5.2.4), (Item 9 of [4])	2,921 kips (longitudinal)
Outer Pin Attachment Block Welds (Section 5.2.6) – Inboard (Item 10-11 of [4])	699 kip (longitudinal) and 828 kip (vertical)
	15 kip (lateral)
Outer Pin Attachment Block Welds (Section 5.2.6) – Outboard (Item 12-14 of [4])	828 kip (vertical)



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 42 of 43**

**7.3 Combined cg and Railcar Weight**

The bounding combined cg and maximum weight are taken from Table 5-5 and Table 5-6 are shown in Table 7-3.

**Table 7-3: Total cg's and Weight**

Bounding Combined cg and Minimum Margin to 98 Inches							
Cask	Family	195,000 lb. railcar		200,000 lb. railcar		205,000 lb. railcar	
		total cg, in	margin, in	total cg, in	margin, in	total cg, in	margin, in
Maximum Margin = HI-STAR 60	1	79.26	18.74	78.73	19.27	78.22	19.78
Minimum Margin = TN-68	2	94.61	3.39	94.01	3.99	93.42	4.58
Bounding Total Weight and Minimum Margin to 789,000 pounds							
Cask	Family	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.	Max Combined Weight, lb.	margin, lb.
Maximum Margin = HI-STAR 60	1	426,100	362,900	431,100	357,900	436,100	352,900
Minimum Margin = HI-STAR 180	1	563,267	225,733	568,267	220,733	573,267	215,733

**7.4 Literature Search and other Background Data**

A formal literature search was not applicable to this scope of work. All required background information is given under Section I.1, *Project Background*.

**8.0 REFERENCES**

The following references were used in this analysis:

1. Department of Energy Contract DE-NE0008390, Part 1, Section C, *Statement of Work*.
2. Association of American Railroads, *Manual of Standards and Recommended Practices, Section C – Car Construction Fundamentals and Details, Standard S-2043, Performance Specification for Trains Used to Carry High-Level Radioactive Material*, 2009
3. AREVA Federal Services Engineering Information Record, EIR-3014611, *Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar*, Rev. 4.
4. AREVA Federal Services Drawing, DWG-3015278, *Atlas Railcar Cradle Attachment Conceptual Drawing*, Rev. 1.
5. Not Used.
6. AREVA Federal Services, LLC Incoming Document AFS-IN-16-0039, Submitted and Requested Information to AFS for Cask Car, August 9, 2016.
7. Joseph Shigley, Charles Mischke, *Mechanical Engineering Design*, 5th Edition, McGraw-Hill, 2002.
8. Association of American Railroads, *Field Manual of the AAR Interchange Rules*.



**AREVA Federal Services LLC**

**Title:** Atlas Railcar Cradle Attachment and Combined Center of Gravity Calculation

**Doc./Rev.:** CALC-3015276-001

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 43 of 43**

9. Not Used.
10. AREVA Federal Services Calculation, CALC-3015133, *Atlas Railcar Family 1 Conceptual Cradle Structural Calculation*, Rev. 0
11. AREVA Federal Services Calculation, CALC-3015134, *Atlas Railcar Family 2 Conceptual Cradle Structural Calculation*, Rev. 0
12. AREVA Federal Services Calculation, CALC-3015135, *Atlas Railcar Family 3 Conceptual Cradle Structural Calculation*, Rev. 0
13. AREVA Federal Services Calculation, CALC-3015136, *Atlas Railcar Family 4 Conceptual Cradle Structural Calculation*, Rev. 0
14. American Society for Testing and Materials, ASTM A572/A572M, *Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel*, 2007.
15. American Society for Testing and Materials, ASTM A564/A564M, *Standard Specification for Hot-Rolled and Cold-Finished Age-Hardening Stainless Steel Bars and Shapes*, 2010.
16. American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section II, Part D, "Properties (Customary)," 2015.
17. American Welding Society (AWS), Standard D15.1, *Railroad Welding Specification for Cars and Locomotives*, 5th Edition, 2013.
18. Blodgett, Omer, *Design of Weldments*, The James F. Lincoln Arc Welding Foundation, Cleveland Ohio, 1963.
19. The Aluminum Association, *Aluminum Construction Manual*, Section 3, *Engineering Data for Aluminum Structures*, Fifth Edition, December 1986.
20. AREVA Federal Services Drawing, DWG-3015137, *Atlas Railcar, Cradle Family 1, Conceptual Drawing*, Rev. 0
21. AREVA Federal Services Drawing, DWG-3015138, *Atlas Railcar, Cradle Family 2 (NAC), Conceptual Drawing*, Rev. 0
22. AREVA Federal Services Drawing, DWG-3015277, *Atlas Railcar, Cradle Family 2 (TN-68), Conceptual Drawing*, Rev. 0.
23. AREVA Federal Services Drawing, DWG-3015139, *Atlas Railcar, Cradle Family 3, Conceptual Drawing*, Rev. 0
24. AREVA Federal Services Drawing, DWG-3015140, *Atlas Railcar, Cradle Family 4, Conceptual Drawing*, Rev. 0
25. AISC MO16, *Manual of Steel Construction, Allowable Stress Design*, 9th Edition
26. Docket 71-9255, *Safety Analysis Report for the NUHOMS<sup>®</sup>-MP187 Multi-Purpose Cask*, Non-Proprietary Version, Rev 17, July 2003
27. Docket 71-9276, *Fuel Solutions<sup>™</sup> TS125 Transportation Cask Safety Analysis Report*, Non-Proprietary Version, Revision 6, Energy Solutions Spent Fuel Division, Inc., September 2006.
28. Association of American Railroads, *Manual of Standards and Recommended Practices*, Section C, Part II *Design, Fabrication, and Construction of Freight Cars*, M-1001, 2011

## Appendix A.5.3- Compliance Matrix

### REQUIREMENTS FOR CRADLE ATTACHMENT DESIGN FROM EIR-3014611, "DESIGN BASIS REQUIREMENTS DOCUMENT (DBRD) FOR THE DOE ATLAS RAILCAR," REV 4<sup>1</sup>

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
<b>Railcar Attachments: Covers attachment of all families of cradles attached to the Atlas Railcar</b>			
2.1	<b>Regulatory Requirements</b> Comply with AAR 2043	For the attachments the AAR requirements are called out below.	Y
2.2	<b>Functional Requirements</b>		
2.2.2	<i>Cradle Functional Requirements</i>		
2.2.2.1	During transport, a transportation cask must rest on a cradle on top of the cask railcar deck.	The cradles interfaces with the railcar attachments that comply with this requirement.	Y
2.2.2.2	The attachment design must accommodate all the cradles required for the casks covered in Attachment A of the DBRD <sup>1</sup> .	The attachment loads for all cradle cask combinations are evaluated.	Y
2.2.2.3.a	Conceptual design of the attachments must accommodate the maximum weight of each of the cask and cradle combinations .	The weight envelope evaluated allows for refinement of the design in the final design of the cradles.	Y
2.2.2.3.b	Center of gravity for the cradles shall be calculated and used to demonstrate the combined CG is met for the cask railcar and cradle of 98 inches or less. CG and loading distributions shall be detailed sufficiently to support railcar design and testing.	The CG for the cask cradles are calculated. The combined cg for the railcar and loaded cradles are shown in the railcar attachment calculation CALC-3015276. It is less than the 98 inch limit.	Y
2.2.2.3.c	Cradle shall be capable of handling the loads specified in Section 2.2.2.13 (AAR Field Manual Rule 88 loads)	The attachments are demonstrated to meet Rule 88 loadings for the cask.	Y
2.2.2.3.d	The attachments shall be capable in the final design to handle a fatigue evaluation per AAR rules.	The weight margin allowed for the cradle and the design loading for compliance with Rule 88 ensures that there is sufficient margin for the detailed design of the attachments to comply with the fatigue evaluation require by AAR-2043 which references AAR M-1001.	Y
2.2.2.3.e	Cradle designs shall have hard dimensions for interface to railcar attachments to ensure ability to be attached to railcar.	The railcar attachment dimensions are tolerance to ensure fit up.	Y
2.2.2.4	The conceptual cradle design combined with the attachment design shall determine the height of the cask center of gravity above the railcar deck, the weight on each axle, etc. as necessary to perform the analysis and provide	Required parameters for testing the railcar are provided in the families individual calculations and in the attachment design calculation.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	simulate cradle test weights and supporting information needed for testing the railcar.		
2.2.2.6	The cradles will be tall enough and open-ended so that the impact limiters can be attached to a cask after the cask is secured to the cradle.	The cradle design allows installation of impact limiters after the cask is secured to the cradle.	Y
2.2.2.7	Each cask design will need a cradle designed to position the center of gravity low for stability during transport, but the cradle design combined with the attachment design will position the impact limiter with a clearance of at least one inch above the cask car deck.	Adequate clearance is allowed for installation of the impact limiters.	Y
2.2.2.8	The cask car (including a cradle and a cask) and buffer car clearances shall fit within AAR Plate C [3] <sup>1</sup> , except when loaded with the casks that are more than 128 inches wide (Same as Requirement 2.2.1.12 above)	The attachment design allows for the cradles for the casks with impact limiters with a diameter of 128 inches or less to meet Plate C requirements <sup>1,2</sup>	Y
2.2.2.9	Demonstrate that bonding weights both min and max meet a combined CG of 98 inches for the railcar, skid and fully loaded and empty cask. (personnel shield, impact limiters etc.) An alternative to adding ballast weight to the railcar may include requiring that the transport cradle for the lighter cask be designed to provide the ballast.	The cradle is designed to meet the combined CG.	Y
2.2.2.10	The various cradles will be designed to fit a standard attachment mechanism.	Fit the common attachments on the railcar.	Y
2.2.2.11	During loading operations, the cradle may be attached to the railcar first, followed by putting the cask on the cradle, but sometimes the cask will be on the cradle first. In that case, both the cradle and cask together will be hoisted onto the railcar deck. Lifting points permit this handling of the cask	Designs permit loading separately or with the cask on the cradle.	Y
2.2.2.12	The cask railcar shall incorporate a standardized attachment capability for coupling the cask cradle to the railcar. This attachment must be capable of securely attaching loads of up to the maximum cask weight and the weight cradle. in accordance with the requirements of AAR Rule 88 A16c(3) [7].	Attachments meet rule 88 load requirements.	Y
2.2.2.13	AAR Rule 88 A16c(3) does not specify if the securement system loading requirements are to be applied separately or simultaneously. Per direction from KASGRO (via the AAR EEC) transportation loading is not simultaneous and is applied separately. Also gravity is not	Analyzed according to the direction of the AAR.	Y

DBRD Item No.	Requirement	Method of Address	Complies? (Y/N)
	applied in the vertical up or down accelerations, so +/- 2 g vertical only. Rule 88 A.16.C requires the following tie down loads (g force to yield):		
2.2.2.13.a	7.5g Longitudinal	Met for the attachments.	Y
2.2.2.13.b	2g Vertical	Met for the attachments.	Y
2.2.2.13.c	2g lateral	Met for the attachments.	Y
	<b>Operational Requirements</b>		
	The cradle must accommodate the camber in the rail car.	Interfaces allows for the camber.	Y
	Have clearances to install and remove impact limiters on the rail car.	Clearance provided.	Y
	Features and clearances to load the cask into the cradle on and off the railcar and to be able to load the cradle with the impact limiters and personnel shield if required in place, on rail car.	Features and clearances permits loading with or without the personnel barrier in place to allow for intermodal transfers	Y
	Operational Steps. Can it be used and how? The loading and unloading steps requested should address that.	Complies with loading procedures.	Y
	<b>Maintenance Requirements</b>		
	Since none of the designs use corrosion resistance material, the life expectancy would be dependent on corrosion control by the use of "high quality weather resistant coatings". Strip and repaint as required. Use wear pads to minimize loss of coatings.	Wear pads and coatings adequately applied.	Y
	<b>Additional Design Considerations</b>		
	For cradle attachment points, the attachment mechanism (pin/bolt) should be removable and shall be sized for manual handling (less than 50 lbs.) or provisions should be designed for mechanically assisted insertion.	Attachments pins have mechanisms for handling.	Y

<sup>1</sup>Approved calculation performed to DBRD Revision 3; all pertinent calculation references are carried forward in Revision 4.

<sup>2</sup>Currently meets Plate C; pending contract modification to Plate E.

## APPENDIX A.6 – BOUNDING CONDITIONS

## A.6.1 – Summary of Transportation Loads and Size Limits on Atlas Railcar

This document provides the maximum attachment point loading, railcar weight limits, and maximum vertical load on the railcar.

### *Railcar Transportation Loads*

The Atlas Railcar cargo is subjected to transportation loads per Rule 88 A.16.c(3) of the Field Manual of the AAR Interchange Rules. This loading is listed as:

7.5g longitudinal, 2g vertical, 2g lateral

Per KASGRO Rail direction, the loads should be applied individually in pure space (not including gravity).

There are 15 cask designs that must be accommodated by the Atlas railcar. Many of the casks can be supported in similar ways; therefore, the casks were sorted into four families based on their required cradle design. This allowed a minimized number of required cradle designs with each cradle family containing configurations for each cask. The four cradle families were designed to use standardized attachment points to the railcar. These are shown in the below sketch (Section A.6.3). Loadings were calculated at the standardized attachment points and are as follows.

**TABLE A.6-1: MAXIMUM ATTACHMENT POINT LOADING (VALUES ARE KIPS)**

	<b>Pin Block 1</b>	<b>Pin block 2</b>	<b>Pin Block 3</b>	<b>Pin Block 4</b>
vertical (+z)	1,101	1,128	1,133	1,101
vertical (-z)	1,231	1,163	1,167	1,238
lateral (y)	381	381	446	446
	<b>Shear Block</b>			
axial (x)	2,945			
	<b>Pin Block 5-8</b>	<b>Pin Block 9-12</b>	<b>Pin Block 13-16</b>	<b>Pin Block 17-20</b>
axial (+x)	0	593	71	0
axial (-x)	0	71	593	0
vertical (+z)	134	1,055	1,055	134
vertical (-z)	1,033	157	151	1,033
lateral (y)	22	22	22	22

## ***Railcar Weight***

AFS has determined bounding conceptual cradle weights and center of gravity (CG) locations in order to determine the required railcar weight. The railcar weight includes the cradle attachment features. The railcar weight also includes hard points or other features to accommodate stabilizing features for cask placement and rotation. With the change to a 12-axle Atlas railcar, the weight of the railcar has increased which reduced the overall CG. The railcar weight range was provided by KASGRO rail and is listed below:

**Minimum Railcar Weight = 195,000 pounds**

**Maximum Railcar Weight = 205,000 pounds**

The highest CG of the railcar was determined using the minimum railcar weight (195,000 lb) and the margin on the combined CG limit of 98 inches (see “Center of Gravity Limit” discussion below) is 3.39 inches (see Section A.6.4). Using the maximum railcar weight, the margin on the total weight (railcar + cradle + cask) limit of 789,000 pounds (see “Weight Limit” discussion below) is 215,733 pounds (see Section A.6.5). A midpoint railcar weight of 200,000 pounds (220,733-pound margin to weight limit and 3.99 inches to CG limit) is shown in Section A.6.6 - Nominal Railcar Weight.

## ***Center of Gravity Limit***

Per Rule 89.C.1.e of *Field Manual of the AAR Interchange Rules*, the maximum combined center of gravity of the car and load must be less than 98 inches from the top of the rail. Originally, a calculated railcar weight of 190,000 pounds was needed for the 8-axle railcar design to meet the CG requirement due to the TN-40 (and TN-40HT) and TN-68 cask designs. These designs use tie-rods to attach their impact limiters which require additional clearance below the cask body to install. However, after working with the cask vendor to develop a refined conceptual cradle design and operational steps, the CG of the cask was moved down thus lowering the needed 8-axle railcar weight. Note that the CG of the TN-68 is higher than the TN-40 (and TN-40HT) because additional clearance is required in the conceptual cradle design to accommodate rotation of the TN-68 cask on the cradle. With the change to a 12-axle railcar, the railcar weight has increased helping to reduce the overall CG.

## ***Weight Limit***

AFS selected an axle weight limit of 65,750 pounds per axle; therefore, the maximum weight limit for the railcar + cradle + cask is 789,000 pounds (65,750 lb/axle X 12 axle). This load limit was determined in discussions with KASGRO and TTCL. (The AAR EEC utilized the 65,750-pound load limit in the acceptance review of the M-290 railcar during its dynamic modeling and it is assumed that the same limit will be applied to the review of the Atlas cask railcar.)

## ***Maximum Vertical Load***

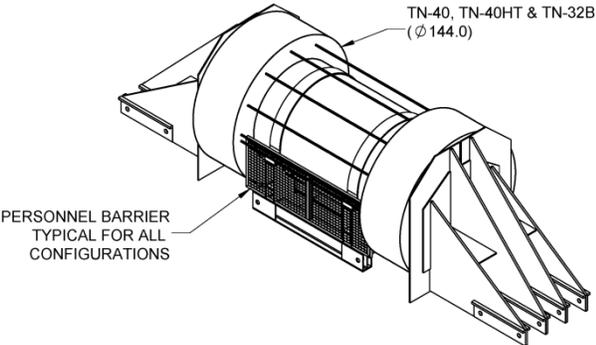
The maximum vertical load is shown below. This load was determined after development of the conceptual cradle designs. This load is the maximum cask + cradle weight that the railcar will need to support. The maximum vertical load is due to the HI-STAR 180 and cradle (values are rounded).

Maximum Vertical Load (maximum cask + cradle) = 380,000 pounds

**A.6.2 – Cradle Families**

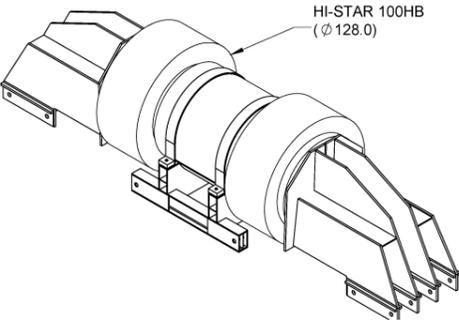
**a) Family 1**

Two axial end stops with two saddles  
 (removable saddles on a single frame)  
 Casks included in Family 1-A:  
 TN-32B, TN-40, TN-40HT, HI-STAR 180



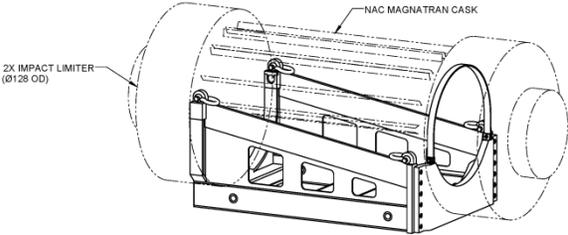
**b) Family 1**

Two axial end stops with a full length saddle  
 Casks included in Family 1-B:  
 HI-STAR 60, HI-STAR 100, HI-STAR 100HB



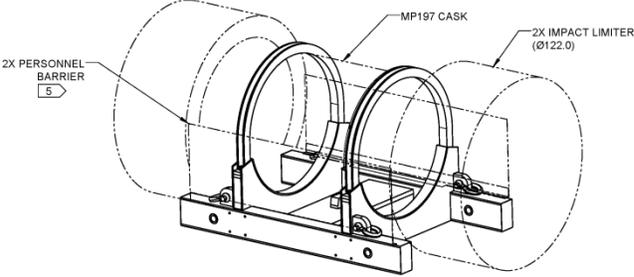
**c) Family 2**

Captured Rear trunnion with top forging shear key or simple front saddle  
 Casks included in Family 2:  
 NAC-STC, NAC-UMS, MAGNATRAN, TN-68



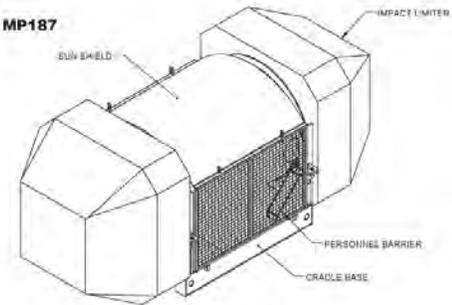
**d) Family 3**

Two saddles with a shear key in the bottom center of the neutron shield (similar saddles on a single frame)  
 Casks included in Family 3:  
 MP198, MP197HB, TS125

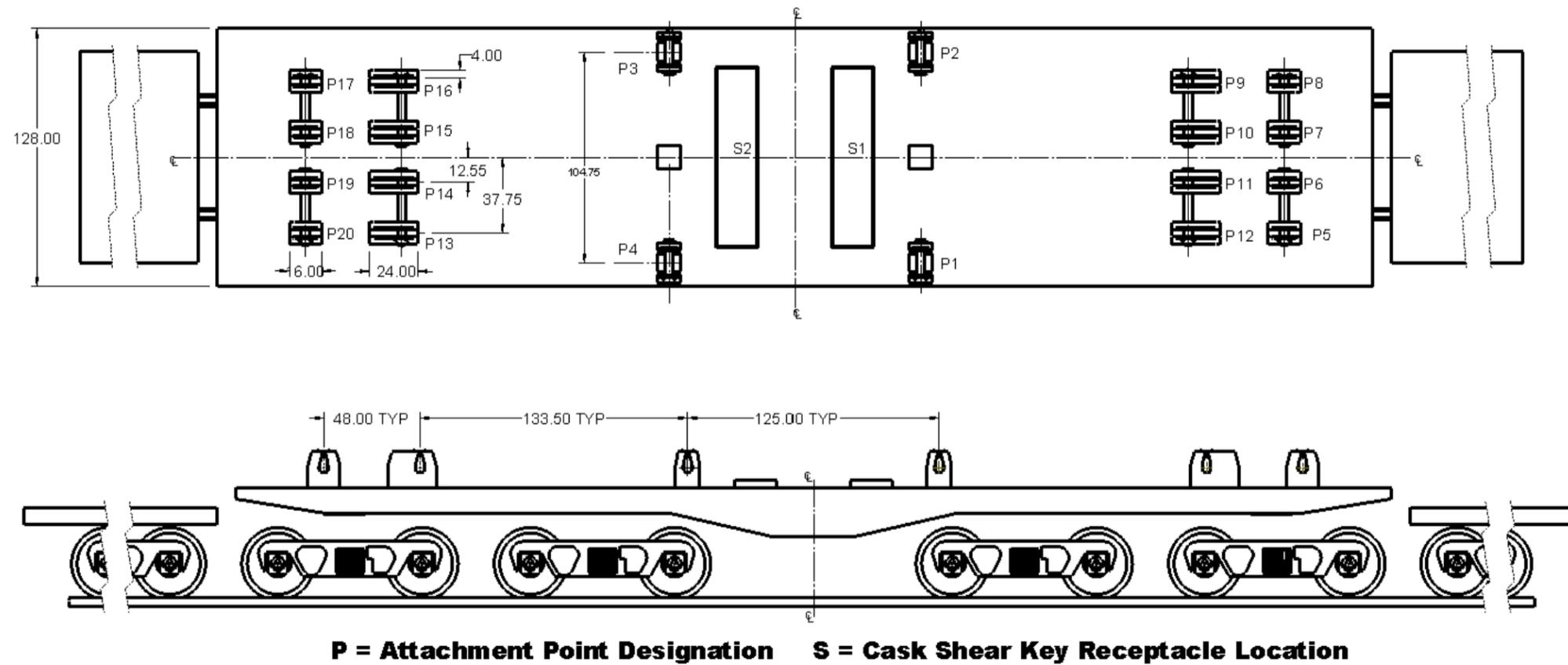


**e) Family 4**

Unique design including many SAR features  
 Casks included in Family 4  
 MP187



### A.6.3 – Railcar Attachment Points and Sizing



**For Information Purposes Only**

## Appendix A.6.4 – Minimum Railcar Weight

### Vertical CG Math

Assumptions			
Railcar Deck Height	60 inches	60.00 unloaded, 55.875 loaded	(from the top of the rail)
Railcar CG	35.1 inches	35.1 unloaded, 33.80 loaded	
Railcar weight	195,000 lb	range of 195,000 to 205,000	65750 per axle 12 axle

Loaded Condition		max cask		min cradle		cask+cradle+railcar		max cradle		cask+cradle+railcar				
Family	Cask	cask cg	cask weight	cradle cg	cradle weight	total weight	total cg	cg allow	cg margin	cradle weight	max weight	w allow	w margin	
2	NAC-STC	128.00	254,600	87.50	37,800	487,400	87.69	98	10.31	46,200	495,800	789000	293,200	
2	NAC-UMS UTC	128.00	256,000	87.50	37,800	488,800	87.81	98	10.19	46,200	497,200	789000	291,800	
2	MAGNATRAN	128.00	312,000	87.50	37,800	544,800	91.94	98	6.06	46,200	553,200	789000	235,800	
1	HI-STAR 100	130.25	279,893	112.00	60,480	535,373	93.53	98	4.47	73,920	548,813	789000	240,187	
1	HI-STAR HB	130.25	187,200	118.80	61,920	444,120	86.88	98	11.12	75,680	457,880	789000	331,120	
1	HI-STAR 180	125.00	308,647	115.10	48,780	552,427	92.39	98	5.61	59,620	563,267	789000	225,733	
1	HI-STAR 60	120.13	164,000	114.00	54,900	413,900	79.26	98	18.74	67,100	426,100	789000	362,900	
4	MP187	129.50	271,300	87.70	33,120	499,420	89.87	98	8.13	40,480	506,780	789000	282,220	
3	MP197	122.50	265,100	77.50	23,400	483,500	85.07	98	12.93	28,600	488,700	789000	300,300	
3	MP197HB	124.50	303,600	78.00	23,400	522,000	89.02	98	8.98	28,600	527,200	789000	261,800	
1	TN-32B	133.00	263,000	107.50	63,180	521,180	93.28	98	4.72	77,220	535,220	789000	253,780	
1	TN-40	133.00	271,500	107.00	63,180	529,680	93.86	98	4.14	77,220	543,720	789000	245,280	
1	TN40HT	133.00	242,343	107.00	63,180	500,523	91.58	98	6.42	77,220	514,563	789000	274,437	
2	TN-68	138.00	272,000	86.50	24,300	491,300	94.61	98	3.39	29,700	496,700	789000	292,300	
3	TS125	133.30	285,000	85.00	27,000	507,000	92.96	98	5.04	33,000	513,000	789000	276,000	
							max	94.61	min	3.39	max	563,267	min	225,733

**Unverified and Assumed Information - For Information Purposes Only**

## Appendix A.6.5 – Maximum Railcar Weight

### Vertical CG Math

Assumptions

Railcar Deck Height                      60 inches                      60.00 unloaded, 55.875 loaded                      (from the top of the rail)  
 Railcar CG                                      35.1 inches                      35.1 unloaded, 33.80 loaded  
 Railcar weight                                205,000 lb                      range of 195,000 to 205,000

65750 per axle  
 12 axle

Loaded Condition		max cask		min cradle		cask+cradle+railcar				max cradle		cask+cradle+railcar	
Family	Cask	cask cg	cask weight	cradle cg	cradle weight	total weight	total cg	cg allow	cg margin	cradle weight	max weight	w allow	w margin
2	NAC-STC	128.00	254,600	87.50	37,800	497,400	86.63	98	11.37	46,200	505,800	789000	283,200
2	NAC-UMS UTC	128.00	256,000	87.50	37,800	498,800	86.75	98	11.25	46,200	507,200	789000	281,800
2	MAGNATRAN	128.00	312,000	87.50	37,800	554,800	90.91	98	7.09	46,200	563,200	789000	225,800
1	HI-STAR 100	130.25	279,893	112.00	60,480	545,373	92.46	98	5.54	73,920	558,813	789000	230,187
1	HI-STAR HB	130.25	187,200	118.80	61,920	454,120	85.74	98	12.26	75,680	467,880	789000	321,120
1	HI-STAR 180	125.00	308,647	115.10	48,780	562,427	91.37	98	6.63	59,620	573,267	789000	215,733
1	HI-STAR 60	120.13	164,000	114.00	54,900	423,900	78.22	98	19.78	67,100	436,100	789000	352,900
4	MP187	129.50	271,300	87.70	33,120	509,420	88.79	98	9.21	40,480	516,780	789000	272,220
3	MP197	122.50	265,100	77.50	23,400	493,500	84.06	98	13.94	28,600	498,700	789000	290,300
3	MP197HB	124.50	303,600	78.00	23,400	532,000	88.01	98	9.99	28,600	537,200	789000	251,800
1	TN-32B	133.00	263,000	107.50	63,180	531,180	92.18	98	5.82	77,220	545,220	789000	243,780
1	TN-40	133.00	271,500	107.00	63,180	539,680	92.77	98	5.23	77,220	553,720	789000	235,280
1	TN40HT	133.00	242,343	107.00	63,180	510,523	90.47	98	7.53	77,220	524,563	789000	264,437
2	TN-68	138.00	272,000	86.50	24,300	501,300	93.42	98	4.58	29,700	506,700	789000	282,300
3	TS125	133.30	285,000	85.00	27,000	517,000	91.84	98	6.16	33,000	523,000	789000	266,000

max 93.42                      min 4.58                      max 573,267                      min 215,733

**Unverified and Assumed Information - For Information Purposes Only**

## Appendic A.6.6 – Nominal Railcar Weight

### Vertical CG Math

Assumptions

Railcar Deck Height 60 inches 60.00 unloaded, 55.875 loaded (from the top of the rail)

Railcar CG 35.1 inches 35.1 unloaded, 33.80 loaded

Railcar weight 200,000 lb range of 195,000 to 205,000 65750 per axle  
12 axle

Loaded Condition		max cask	min cradle	cask+cradle+railcar		max cradle	cask+cradle+railcar						
Family	Cask	cask cg	cask weight	cradle cg	cradle weight	total weight	total cg	cg allow	cg margin	cradle weight	max weight	w allow	w margin
2	NAC-STC	128.00	254,600	87.50	37,800	492,400	87.16	98	10.84	46,200	500,800	789000	288,200
2	NAC-UMS UTC	128.00	256,000	87.50	37,800	493,800	87.27	98	10.73	46,200	502,200	789000	286,800
2	MAGNATRAN	128.00	312,000	87.50	37,800	549,800	91.42	98	6.58	46,200	558,200	789000	230,800
1	HI-STAR 100	130.25	279,893	112.00	60,480	540,373	92.99	98	5.01	73,920	553,813	789000	235,187
1	HI-STAR HB	130.25	187,200	118.80	61,920	449,120	86.30	98	11.70	75,680	462,880	789000	326,120
1	HI-STAR 180	125.00	308,647	115.10	48,780	557,427	91.88	98	6.12	59,620	568,267	789000	220,733
1	HI-STAR 60	120.13	164,000	114.00	54,900	418,900	78.73	98	19.27	67,100	431,100	789000	357,900
4	MP187	129.50	271,300	87.70	33,120	504,420	89.33	98	8.67	40,480	511,780	789000	277,220
3	MP197	122.50	265,100	77.50	23,400	488,500	84.56	98	13.44	28,600	493,700	789000	295,300
3	MP197HB	124.50	303,600	78.00	23,400	527,000	88.51	98	9.49	28,600	532,200	789000	256,800
1	TN-32B	133.00	263,000	107.50	63,180	526,180	92.73	98	5.27	77,220	540,220	789000	248,780
1	TN-40	133.00	271,500	107.00	63,180	534,680	93.31	98	4.69	77,220	548,720	789000	240,280
1	TN4OHT	133.00	242,343	107.00	63,180	505,523	91.02	98	6.98	77,220	519,563	789000	269,437
2	TN-68	138.00	272,000	86.50	24,300	496,300	94.01	98	3.99	29,700	501,700	789000	287,300
3	TS125	133.30	285,000	85.00	27,000	512,000	92.39	98	5.61	33,000	518,000	789000	271,000

max 94.01 min 3.99 max 568,267 min 220,733

**Unverified and Assumed Information - For Information Purposes Only**

## Appendix B – Cask Railcar Concept

APPENDIX B.1 – CASK RAILCAR ILLUSTRATION

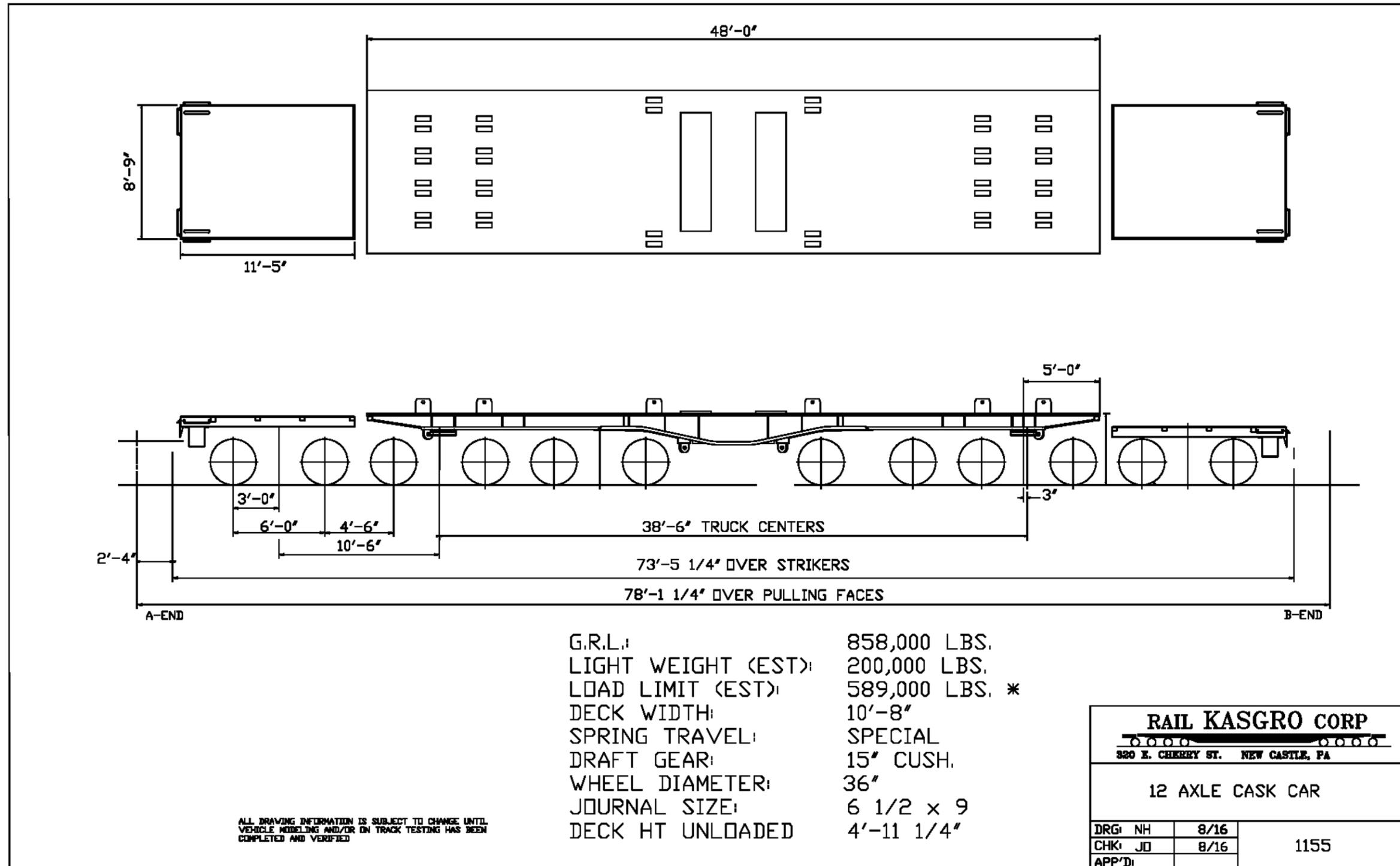


Illustration For Information Purposes Only

## APPENDIX B.2 – CASK RAILCAR DESCRIPTION

The 12-axle cask railcar is designed to transport Department of Energy shipments of spent nuclear fuel using casks transported in cradles and/or saddles. Car design is symmetrical, end to end. The railcar's design, including its trucks, brakes and their components, wheel sets, and safety monitoring system have previously been tested and approved to AAR's EEC to S-2043 Standard.

Extreme Width	10'-8"
Loading Deck Length	48'-0"
Coupled Length	78'-1 1/4"
Length Over Strikers	73'-5 1/4"
Truck Centers	38'-6"
Wheel Size	36"
Journal Size	6 1/2" x 9"
Draft Gear Travel	15"
Gross Rail Load	858,000 pounds
Light Weight (Est.)	200,000 pounds
Load Limit (Est.)	589,000 pounds

## Appendix C – Buffer Railcar Concept

APPENDIX C.1 – BUFFER RAILCAR ILLUSTRATION

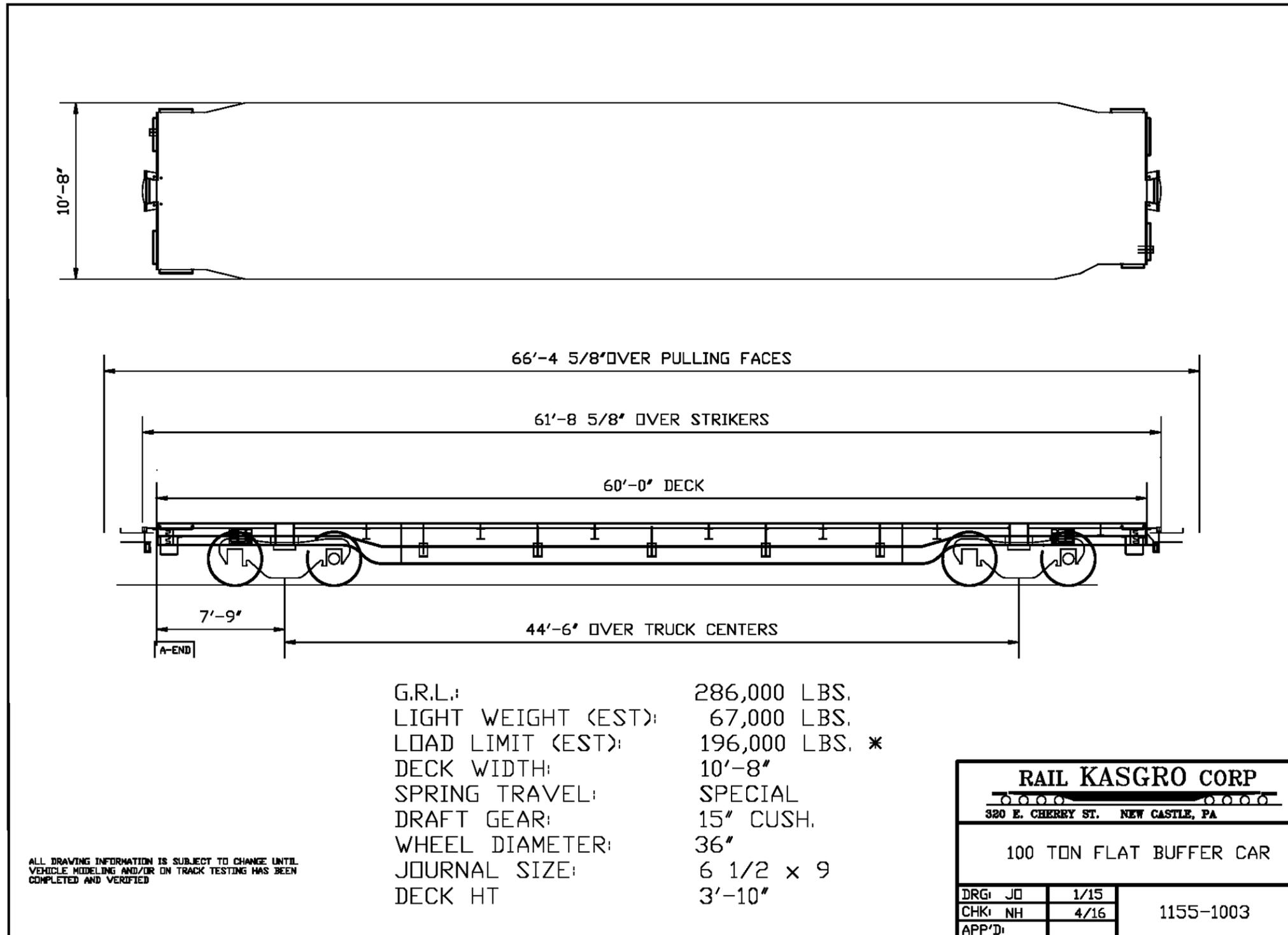


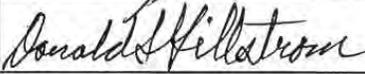
Illustration For Information Purposes Only

## APPENDIX C.2 – BUFFER SUPPORTING DESCRIPTION

The 4-axle buffer FM Flatcar is designed for use in conjunction with 12-axle cask railcars utilized by the Department of Energy for movement of shipments of spent nuclear fuels. The flatcar structural design is symmetrical, end-to-end. Railcar is designed with major components that have previously been tested to AAR S-2043 Standard.

Extreme Width	10'-8"
Loading Deck Length	60'-0"
Coupled Length	66'-4 5/8"
Length Over Strikers	61'-8 5/8"
Truck Centers	44'-6"
Wheel Size	36"
Journal Size	6 1/2" x 9"
Draft Gear Travel	15"
Gross Rail Load	286,000 pounds
Light Weight (Est.)	67,000 pounds
Load Limit (Est.)	196,000 pounds

## Appendix D – General Loading Procedures

	<b>AREVA Federal Services LLC</b>		
	<b>Engineering Information Record</b>		
<b>Document No.:</b>	EIR-3016164	<b>Rev. No.</b>	000 <span style="float: right;"><b>Page 1 of 47</b></span>
<b>Project No.:</b>	00225.03.0050.01	<b>Project Name:</b>	DOE Atlas Railcar
<b>Title:</b> Atlas Railcar Loading Procedures			
<b>Summary:</b> <p>This report provides a collection of general procedures that provide guidance for the loading of casks onto the transportation cradles (cradles), loading of cradles onto the Atlas railcar, and providing insight into the detailed design of the cask cradles and Atlas railcar.</p>			
<b>Contains Unverified Input / Assumptions:</b>		Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>	
	<b>Printed Name</b>	<b>Signature</b>	<b>Date</b>
<b>Preparer:</b>	M. Denton		08/03/2016
<b>Checker:</b>	C. Temus		8/3/2016
<b>Approver:</b>	D. Hillstrom		8/3/16
<b>Other:</b>			

## Atlas Railcar General Loading Procedures

**EIR-3016164-000**

**Prepared by: AREVA Federal Services LLC**



### REVISION LOG

Rev.	Date	Affected Pages	Revision Description
DRAFT-00A	June 22, 2016	All	Initial DRAFT Issue for DOE comment
DRAFT-00B	July 26, 2016	All	Incorporation of DOE comments
000	August 1, 2016	All	Initial document release as approval by DOE

Atlas Railcar General Loading Procedures  
Report No.: EIR-3016164- 000

---

## **DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency, contractor, or subcontractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency, contractor, or subcontractor thereof.

---

Atlas Railcar General Loading Procedures  
July 26, 2016

## TABLE OF CONTENTS

Executive Summary .....	ES-1
<b>1.0 Introduction &amp; Overview .....</b>	<b>1-1</b>
<b>2.0 Methodology .....</b>	<b>2-1</b>
<b>3.0 Assumptions .....</b>	<b>3-1</b>
<b>4.0 Generic Loading Activities.....</b>	<b>4-1</b>
4.1 Receive Railcar and Prepare for Loading.....	4-2
4.2 Remove Empty Transportation Cradle from Railcar (If Necessary).....	4-2
4.3 Prepare Transportation Cradle for Loading.....	4-3
4.4 Load Cask onto Transportation Cradle.....	4-3
4.5 Prepare Cask for Transport.....	4-4
4.6 Secure Cask to Transportation Cradle.....	4-4
4.7 Install Impact Limiters onto Cask.....	4-4
4.8 Install Personnel Barrier onto Transportation Cradle.....	4-5
4.9 Install Loaded Transportation Cradle onto Railcar.....	4-5
4.10 Final Loading Activities.....	4-5
<b>5.0 References.....</b>	<b>5-1</b>
<b>Appendix A – General Loading Procedures.....</b>	<b>A-1</b>
A.1 Receive Railcar and Prepare for Loading.....	A-2
A.1.1 Specific Procedures for Family 1 Cradles.....	A-2
A.2 Remove Empty Transportation Cradle from Railcar (If Necessary).....	A-3
A.3 Prepare Transportation Cradle for Loading.....	A-3
A.3.1 Specific Procedures for Family 1 Casks.....	A-3
A.3.2 Specific Procedures for Family 2 Casks.....	A-4
A.3.3 Specific Procedures for Family 3 Casks.....	A-4
A.4 Load Cask Onto Transportation Cradle.....	A-5
A.4.1 Specific Procedures for Family 1 Casks.....	A-5
A.4.2 Specific Procedures for Family 2 Casks.....	A-5
A.4.3 Specific Procedures for Family 3 Casks.....	A-6
A.4.4 Specific Procedures for Family 4 Casks.....	A-6
A.5 Prepare Cask For Transport.....	A-7
A.5.1 Specific Procedures for Family 1 Casks.....	A-7
A.5.2 Specific Procedures for Family 2 Casks.....	A-7
A.5.3 Specific Procedures for Family 3 Casks.....	A-7
A.6 Secure Cask To Transportation Cradle.....	A-8
A.6.1 Specific Procedures for Family 1 Casks.....	A-8
A.6.2 Specific Procedures for Family 2 Casks.....	A-8
A.7 Install Impact Limiters onto Cask.....	A-9
A.7.1 Specific Procedures for Family 1 Casks.....	A-9
A.7.2 Specific Procedures for Family 2 Casks.....	A-9
A.8 Install Personnel Barrier onto Transportation Cradle.....	A-10
A.8.1 Specific Procedures for Family 1 Casks.....	A-10
A.9 Install Loaded Transportation Cradle onto Railcar.....	A-11
A.9.1 Specific Procedures for Family 1 Casks.....	A-11
A.9.2 Specific Procedures for Family 2 Casks.....	A-11
A.9.3 Specific Procedures for Family 3 Casks.....	A-11
A.9.4 Specific Procedures for Family 4 Casks.....	A-12



Atlas Railcar General Loading Procedures  
Report No.: EIR-3016164- 000

---

*A.10 Final Loading Activities* ..... *A-13*  
    A.10.1 Specific Procedures for Family 1 Casks ..... *A-13*  
**Appendix B – Loading Procedure Applicability Matrix** ..... **B-1**  
**Appendix C – Transportation Cradle Details** ..... **C-1**

**LIST OF FIGURES**

FIGURE 4-1: LOADING ACTIVITIES.....4-1  
FIGURE C-1A: FAMILY 1 CRADLE FOR TN-32B, TN-40, AND TN-40HT CASKS..... C-1  
FIGURE C-1B: FAMILY 1 CRADLE WITH TN-40 CASK ..... C-2  
FIGURE C-1C: FAMILY 1 CRADLE WITH TN-40 CASK READY FOR TRANSPORT..... C-2  
FIGURE C-2: FAMILY 1 CRADLE WITH HI-STAR 60 CASK ..... C-3  
FIGURE C-3: FAMILY 1 CRADLE WITH HI-STAR HB CASK ..... C-3  
FIGURE C-4: FAMILY 1 CRADLE WITH HI-STAR 100 CASK..... C-4  
FIGURE C-5: FAMILY 1 CRADLE WITH HI-STAR 180 CASK..... C-4  
FIGURE C-6A: FAMILY 2 CRADLE FOR TN-68 CASK..... C-5  
FIGURE C-6B: FAMILY 2 CRADLE WITH TN-68 CASK ..... C-5  
FIGURE C-6C: FAMILY 2 CRADLE WITH TN-68 CASK AND PERSONNEL BARRIER..... C-6  
FIGURE C-7A: FAMILY 2 CRADLE FOR NAC-STC CASK ..... C-6  
FIGURE C-7B: FAMILY 2 CRADLE FOR NAC-UMS CASK ..... C-7  
FIGURE C-8A: FAMILY 2 CRADLE FOR MAGNATRAN CASK..... C-7  
FIGURE C-8B: FAMILY 2 CRADLE WITH MAGNATRAN CASK..... C-8  
FIGURE C-8C: FAMILY 2 CRADLE WITH MAGNATRAN CASK & PERSONNEL BARRIER..... C-8  
FIGURE C-9A: FAMILY 3 CRADLE FOR MP197 CASK..... C-9  
FIGURE C-9B: FAMILY 3 CRADLE WITH MP197 CASK ..... C-9  
FIGURE C-10: FAMILY 3 CRADLE FOR MP197HB CASK ..... C-10  
FIGURE C-11: FAMILY 3 CRADLE FOR TS125 CASK..... C-10  
FIGURE C-12A: FAMILY 4 CRADLE FOR MP187 CASK..... C-11  
FIGURE C-12B: FAMILY 4 CRADLE WITH MP187 CASK ..... C-11  
FIGURE C-13: CRADLE ATTACHMENT DETAILS ..... C-12  
FIGURE C-14: SECUREMENT PIN RETENTION FEATURES ..... C-12  
FIGURE C-15: PIN LOADING TRAY INSTALLED..... C-13  
FIGURE C-16: PIN LOADING TRAY WITH PIN RETRACTED ..... C-13

Atlas Railcar General Loading Procedures  
Report No.: EIR-3016164-000

---

**LIST OF TABLES**

TABLE 1-1: CASKS AND TRANSPORTATION CRADLES..... 1-1  
TABLE 3-1: INITIAL CONFIGURATION OF CASKS..... 3-2

## LIST OF ACRONYMS

ALARA	As Low As Reasonably Achievable
CFR	Code of Federal Regulations
CoC	Certificate of Compliance
DOE	Department of Energy
SAR	Safety Analysis Report
USNRC	U.S. Nuclear Regulatory Commission

## EXECUTIVE SUMMARY

This report, Atlas Railcar Loading Procedures, fulfills the Phase 1 deliverable of Department of Energy (DOE) Contract DE-NE-0008390, Part I, Section C related to General Loading Procedures. These procedures include how to load each of the casks in Attachment A of the contract onto the Atlas Cask Railcar, including whether the impact limiters would be attached to the cask before or after the cask is secured to the railcar.

The purpose of this report is not to replace any detailed site-specific or cask-specific loading procedures. Its purpose is to inform the railcar and cask/cradle designers of the strength and versatility needed to accommodate the casks listed in Table 1-1.

This report provides a collection of general procedures that provide guidance for the loading of casks onto the transportation cradles and also the loading of cradles onto the railcar. Whenever possible, the procedures are provided in a general sense and apply to all of the Attachment A casks and cradles. When relevant design differences exist, specific subsections are included that may apply to a particular family of cradles or casks. There are a total of 15 unique casks and 4 cradle designs covered in this report, with each of the casks being assigned to a particular cradle design.

It should be noted that these general loading procedures are based on conceptual designs of the cradles and Atlas railcar, with specific instructions, diagrams, figures, and tables subject to change during final design and fabrication. Also, the loading procedures are intended as a guide to support the development of site-specific loading procedures; therefore, they do not include specific site requirements, inspection requirements, license review requirements, or necessary transport notifications; these items will need to be developed by the specific cask/cradle/Atlas railcar user(s) having responsibility for each subject area at each location where the cask, cradle, or Atlas railcar are used.

## 1.0 INTRODUCTION & OVERVIEW

This report, Atlas Railcar Loading Procedures, fulfills the Phase 1 deliverable of DOE Contract DE-NE-0008390, Part I, Section C related to General Loading Procedures. These procedures include how to load each of the casks in Attachment A of the contract onto the Atlas Railcar (hereafter referred to as railcar), including whether the impact limiters would be attached to the cask before or after the cask is secured to the railcar.

This report provides a collection of general procedures that provide guidance for the loading of casks onto the transportation cradles (hereafter referred to as cradles) and also the loading of cradles onto the railcar. Whenever possible, the procedures are provided in a general sense and they apply to all of the casks and cradles. When relevant design differences exist, specific subsections are included that may apply to a particular family of cradles or casks. There are a total of 15 unique casks and 4 cradle designs covered by this report, with each of the casks being assigned to a particular cradle design. Table 1-1 lists the casks and cradles covered by this report.

**TABLE 1-1: CASKS AND TRANSPORTATION CRADLES**

Cask Model	Cask Manufacturer	Cradle Family	Cradle Features
TN-32B	AREVA TN	Family 1	1) Saddles to support cask 2) Metal straps to secure cask to cradle 3) End stops to resist longitudinal forces
TN-40			
TN-40HT			
HI-STAR 60	Holtec International		
HI-STAR HB			
HI-STAR 100			
HI-STAR 180			
TN-68	AREVA TN	Family 2	1) Captured rear trunnions to support bottom end of cask 2) Saddle to support top end of cask 3) One metal strap to additionally secure cask to cradle 4) Shear blocks on railcar deck and shear key flange integrated into top saddle to resist longitudinal forces for NAC casks
NAC-STC	NAC International		
NAC-UMS			
MAGNATRAN			
MP197	AREVA TN	Family 3	1) Saddles to support cask 2) Metal straps to secure cask to cradle 3) Shear blocks on railcar deck and shear key in center of cask to resist longitudinal forces
MP197HB	EnergySolutions		
FuelSolutions TS125			
MP187	AREVA TN	Family 4	1) Saddles to support cask 2) Metal straps to secure cask to cradle 3) Shear blocks on railcar deck and shear key in center of cask to resist longitudinal forces

*Section 2.0* provides a discussion of the methodology used to generate the loading procedures and also provides a description on the layout of the procedures that are found in *Appendix A*. *Section 3.0* contains the related assumptions that were made when developing these loading procedures. *Section 4.0* includes the generic activities required for loading casks onto the railcar, the order in which these are typically performed, and other activities the procedures are applicable to.

References used throughout this report are included in *Section 5.0*. *Appendix A* includes the loading procedures applicable to the various casks and cradles and is structured so the steps related to individual casks can easily be extracted for use in a standalone procedure. To assist in this, *Appendix B* provides a matrix showing what sections of *Appendix A* are related to which casks. *Appendix C* includes a collection of figures representing the railcar and cradle conceptual designs.

Railroad-related operations are not described in this report, except for high-level activities. Specific activities and associated requirements will be dictated by the railroad and/or site-responsible personnel. Any terminology used in this report, related to rail operations, is not intended to direct railroad operations.

In addition to the railcar, cask, and cradle hardware, it is recommended that the consist have provisions to transport various ancillary equipment and spare parts. While standard tools, rigging, and materials can be obtained at the operation sites, the following ancillary equipment and spare parts are considered specialized and should be transported to the cask/cradle/railcar loading and unloading site:

- Jacks and tie-down devices to stabilize and secure the railcar deck during loading/unloading operations (specifications of jacks and tie-down devices to be generated by railcar designer)
- Wheel chocks to prevent railcar movement once placed
- Pin loading tray(s) (may change during final design of cradles)
- Loaded-cradle lifting devices (for Family 3 cradles) (may change during final design of cradles)
- Spare pins for cradle connection (may change during final design of cradles)
- Spare pins for end stop connect (may change during final design of cradles)

## 2.0 METHODOLOGY

The loading procedures found in *Appendix A* were generated based on information found in Chapter 7 of the applicable Safety Analysis Reports ([1] through [11]), as well as design details found on the conceptual design drawings for the cradles ([12] through [17]). These procedures, which are considered to be general in nature, are not at a level of detail to perform any of the covered activities. As such, prior to conducting loading operations, the procedures provided in *Appendix A* should be used as one of many inputs to site-specific and cask-specific operating procedures.

The loading procedures presented in this report only cover the activities directly related to the railcar and cradle operations. The procedures contained in this report do not address the following activities:

- Loading contents into the cask and preparing the cask for transport
- Performing any required radiation, contamination, or temperature surveys
- Performing any necessary inspections, whether they are related to the cask, cradle, or railcar
- Preparing or installing any required hazard communication, such as shipping papers, placards, markings, and labels
- Installing any security, positional, or performance-monitoring devices, that may be required, onto the cask, cradle, or railcar

To minimize repetition across the casks, the loading procedure steps were consolidated whenever possible to apply to multiple casks and cradles. There are three levels of procedural steps included in *Appendix A*: steps applicable to every cask and every cradle; steps applicable to every cask within a particular cradle family; and steps applicable to individual casks. To extract loading procedures related to a particular cask, *Appendix B* should be utilized to guide the reader as to the applicable sections of *Appendix A*.

The initial configuration of equipment (casks, cradles, and the railcar) will likely be different in a number of cases, depending on the site and shipment constraints. Some of the casks are stored at the sites in a horizontal orientation, which will not necessarily require down-ending prior to loading the railcar, and some casks are stored vertically. Some of the casks will be fully prepared for shipment prior to arrival of the railcar, and other cases will involve receiving an empty cask on the railcar followed by onsite loading of the cask, prior to loading of the railcar. In other cases, where a cask storage site is not rail served, a heavy-haul truck may be required from the site to the railcar. The methodology used in developing *Appendix A* was to provide a general collection of procedures that can be used in multiple scenarios. An example of this is that there are no steps for loading an empty cask onto the railcar, as the procedures for loading a full cask can be used for that activity, with minor alterations. Likewise, steps for unloading a full cask from the railcar are not included as they are basically the reverse order of the loading steps. The procedures provided in *Appendix A* are general in nature and will need to be expanded upon by the individual sites prior to planning for actual operations.

### 3.0 ASSUMPTIONS

The procedures within this report were developed based on the following assumptions:

- 1) The casks have previously been loaded, closed, and prepared for transportation in compliance with the appropriate United States Nuclear Regulatory Commission (USNRC) Certificate of Compliance (CoC) prior to the railcar arrival. This includes, but may not be limited to: verification that the contents are allowable, the appropriate containment boundary leak test has been performed, the cask has been decontaminated to appropriate levels, and all regulatory markings and labels are present on the cask.
- 2) The TN-32B and TN-40HT cask Safety Analysis Reports (SARs), once they are issued, will align with the current TN-40 SAR [1]. While these casks are not yet licensed under 10 CFR Part 71, they are very similar to the TN-40 cask.
- 3) The final MAGNATRAN SAR will not change significantly from the current version [8]. This cask is not yet licensed under 10 CFR Part 71.

The procedures in *Appendix A* are based on the following assumed initial configuration of the equipment:

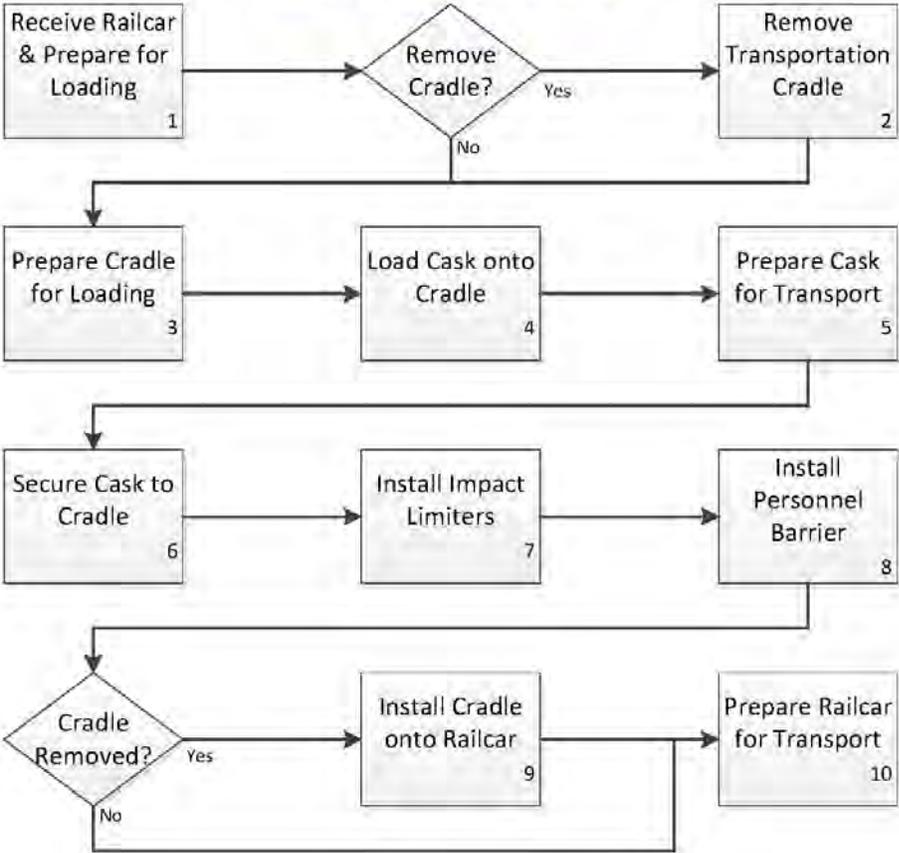
- 1) The railcar arrives at the site with all necessary cradle hardware installed in the approved configuration. In addition, no cask is present on the railcar upon its arrival.
- 2) The cask will have previously been loaded, closed, and prepared for transportation in compliance with the appropriate USNRC CoC prior to the railcar arrival.
- 3) The cask is oriented as listed in Table 3-1. These initial configurations are based on a review of the associated SARs and the typical orientation described in Chapter 7 at the start of the Preparation for Transport steps.

### 4.0 GENERIC LOADING ACTIVITIES

The procedures in this report describe the railcar loading cycle, which begins with a railcar arriving on site and ends once the railcar has been loaded with the cask and prepared for transport. The railcar arrives on site with the appropriate cradle, but without a cask. Operations to perform activities not specifically included in this report, such as how to unload the cask from the railcar, can be inferred by reversing the applicable steps. Unless otherwise stated, the activities may take place on the railcar or on the ground, depending on whether the cradle had previously been removed and is no longer on the railcar.

A flowchart of the loading activities covered by this report is provided in Figure 4-1 and further discussion of the various loading activities is provided in subsequent sections. Procedures for conducting these activities are contained in *Appendix A*.

FIGURE 4-1: LOADING ACTIVITIES



#### 4.1 Receive Railcar and Prepare for Loading

The loading sequence begins with the arrival of an empty railcar at the site with all necessary cradle hardware installed in the approved configuration. While no cask is present on the railcar for this report, the set of activities would be the same if the railcar arrived at the site with an empty cask.

Steps involved in this section include:

- Placement of the railcar and installing the necessary chocks, jacks, and chains. Depending on the site requirements and the operations to be performed on top of the railcar, not all of these activities will necessarily be required. For example, if the cask is to be rotated on top of the railcar, then the jacks will need to be used, as the railcar suspension is not designed to support the concentrated loading of a cask in the vertical orientation.
- Connecting, disconnecting, and removal of (longitudinal) end stops (applicable only to Family 1 cradles).

#### 4.2 Remove Empty Transportation Cradle from Railcar (If Necessary)

The operating procedures in the SARs are written with the assumption that the cask is loaded into the cradle while it is secured to the railcar. This is true for all of the casks covered in this report. While this appears to be the original intent when the safety analysis reports were written, it should be recognized that it may not be the optimal method, nor does it appear to be required by the applicable regulations.

Depending on site characteristics and the specific cask, there may be limitations to how high a cask can be lifted without impact limiters. The maximum height that a cask can be lifted without impact limiters is typically defined in the facility-specific SAR. Exceeding the defined height would likely require implementation of expensive engineering controls. There would likely be additional safety considerations and controls involved in performing loading activities on top of the railcar. Considering the added complexities, it is felt that the optimal location to load the cask into the cradle and install the impact limiters is on the ground.

Each of the cradle designs in this report include features for lifting a fully assembled package (cradle, cask, impact limiters, and personnel barrier), which allows for operational flexibility. The loading procedures in *Appendix A* include steps for loading the cask onto the cradle in both scenarios: on the ground or while the cradle is secured to the railcar.

With minor modifications, the procedures for this activity can also be utilized for other operations involving removal of the cradle from the railcar including: trans-loading between railcars and trailers or when unloading a loaded cask at a destination site. When using these procedures for those purposes, it should be emphasized that the Family 3 cradles have separate lifting lug locations depending on whether or not the cradle is loaded with a cask.

Steps involved in this section, which apply to each and every cask and cradle covered in this report, include:

- Disconnecting the cradle from the railcar
- Rigging to and lifting an empty cradle from the railcar onto the ground for loading a cask

### 4.3 Prepare Transportation Cradle for Loading

The activities in this section pertain to configuring the cradle to accept a cask. The generic loading activity listings provided in this section can also be utilized, with modifications, for operations involving the unloading of a cradle with a cask installed on it. While most of the steps would be applicable, some, such as those related to the impact limiter tie rods, would not be applicable for unloading scenarios.

Steps involved in this section include:

- Removing personnel barrier and cask tie-down straps from the cradle
- Removing trunnion capture covers (applicable only to certain cradles)
- Positioning lower impact limiter tie rods into the cradle (applicable only to certain cradles)
- Attaching separate down-ending tower to the cradle (applicable only to certain cradles)

### 4.4 Load Cask onto Transportation Cradle

The activities in this section pertain to placing the cask into the cradle, whether the cradle is on the ground or on top of the railcar. For some casks starting in the horizontal orientation, this involves lifting the cask and lowering it into the cradle. For the other casks, these activities include lifting a vertically oriented cask, locating the lower trunnions in either the cradle or the down-ending tower, and then rotating the cask to where it is resting in the cradle. When down-ending activities are performed on top of the railcar, the railcar deck must be stabilized by means of jacks and not supported by the suspension system.

The steps included in *Section 4.3* must be performed prior to beginning the following listed activities. The activities listed within this section could also be used to develop cask unloading procedures; although, the steps would be reversed.

Steps involved in this section include:

- Attaching rigging between the crane and the cask
- Lifting the cask and transferring it over the cradle, whether the cradle is on the ground or on top of the railcar
- Removing the cask shear key plug (applicable only to certain casks)
- Removing the cask trunnions and installing trunnion plugs (applicable only to specific casks)
- Lowering the cask into the cradle
- Down-ending the cask into the cradle (applicable only to specific casks)

#### 4.5 Prepare Cask for Transport

The activities in this section pertain to preparing the cask to receive impact limiters and to remove any items prior to transport. While some of these activities could be performed prior to placing the cask in the cradle, these are currently aligned with the SAR sequence of operations.

Steps involved in this section include:

- Removing the cask trunnions and installing trunnion plugs (applicable only to specific casks)
- Installing impact limiter spacers (applicable only to specific casks)
- Installing external fins onto the cask body (applicable only to specific casks)
- Installing trunnion capture covers (applicable only to specific casks)

#### 4.6 Secure Cask to Transportation Cradle

The activities in this section pertain to securing the cask to the cradle with metal tie-down straps. Steps involved in this section include:

- Rigging and lifting/lowering the cask tie-down straps
- Securing the cask tie-down straps to the cradle

#### 4.7 Install Impact Limiters onto Cask

In all cases, it is expected that the impact limiters will be installed once the cask has been loaded onto the cradle. If unique scenarios arise at a site where impact limiters are to be installed onto the cask prior to loading the cask onto the cradle, procedures in *Appendix A* will need to be updated accordingly by the site. It is important to note that some sites and casks may require limited lift heights prior to installing the impact limiters, which will likely influence where the cradle is loaded. The maximum height that a cask can be lifted without impact limiters is typically defined in the site-specific SAR.

While this report does not include procedures for removing the impact limiters from a cask, the procedures within this section could be utilized for such operations, although the steps would be reversed.

Steps involved in this section include:

- Preparations of the cask and/or impact limiters, for specific casks
- Rigging and lifting the impact limiters
- Placing the impact limiters onto the cask
- Securing the impact limiters to the cask

#### 4.8 Install Personnel Barrier onto Transportation Cradle

The activities in this section pertain to installing the personnel barrier, which is part of the cradle. For some of the casks, this step is optional based on whether the dose and temperature surveys require the barrier. For other casks, this is required for all shipments. The installation of the personnel barrier must occur after the cask has been secured in the cradle.

Steps involved in this section include:

- Rigging and lifting the personnel barrier
- Placing the personnel barrier onto the cradle
- Securing the personnel barrier to the cradle

#### 4.9 Install Loaded Transportation Cradle onto Railcar

If the cradle had been previously removed from the railcar (*Section 4.2*), then this activity is needed to lift a loaded cradle onto the railcar and secure it in place. The procedures for this activity, included in *Appendix A*, assume that the cask has already been installed and secured to the cradle and the impact limiters and personnel barrier have also been installed. This set of procedures can also be utilized for intermodal transfers, from (or to) a heavy-haul truck or barge to (or from) the railcar.

Steps involved in this section include:

- Rigging to and lifting a loaded cradle
- Placing the cradle onto the railcar
- Securing the cradle to the railcar by installing pins through the cradle frame and the mating railcar lugs

#### 4.10 Final Loading Activities

This section involves final loading activities that must be completed prior to transporting the loaded railcar. This section does not include other final activities, such as inspections, attaching placards, and radiation surveys.

Steps involved in this section include:

- Rigging to and lifting the end stops (only applicable to Family 1 cradles)
- Placing the end stops onto the railcar (only applicable to Family 1 cradles)
- Securing the end stops to the railcar (only applicable to Family 1 cradles)
- Removing any devices used to position and stabilize the railcar deck

## 5.0 REFERENCES

- [1] AREVA TN, Docket Number 71-9313, TN-40 Transportation Packaging Safety Analysis Report, Rev. 16. It is assumed that this SAR also applies to the TN-32B and TN-40HT casks.
- [2] Holtec International, Docket Number 71-9336, HI-STAR 60 Safety Analysis Report, Rev. 2.
- [3] Holtec International, Docket Number 71-9261, HI-STAR Safety Analysis Report, Rev. 15. This SAR applies to the HI-STAR 100 and HI-STAR HB casks.
- [4] Holtec International, Docket Number 71-9261, HI-STAR 180 Safety Analysis Report, Rev. 6.
- [5] AREVA TN, Docket Number 71-9293, TN-68 Packaging Safety Analysis Report, Rev. 4.
- [6] NAC International, Docket Number 71-9235, NAC-STC Safety Analysis Report, Rev. 15.
- [7] NAC International, Docket Number 71-9270, SAR-UMS® Universal Transport Cask Safety Analysis Report, Rev. 2.
- [8] NAC International, Docket Number 71-9356, MAGNATRAN Transport Cask Safety Analysis Report, Rev. 12A.
- [9] AREVA TN, Docket Number 71-9302, MP197 Transportation Packaging Safety Analysis Report, Rev. 7. This SAR also applies to the MP197HB cask.
- [10] EnergySolutions, Docket Number 71-9276, FuelSolutions™ TS125 Transportation Cask Safety Analysis Report, Rev. 6.
- [11] AREVA TN, Docket Number 71-9255, NUHOMS®-MP187 Multi-Purpose Cask Safety Analysis Report, Rev. 17.
- [12] 3015137, latest revision. Atlas Railcar Cradle Family 1 Conceptual Drawing.
- [13] 3015277, latest revision. Atlas Railcar Cradle Family 2 (TN-68) Conceptual Drawing.
- [14] 3015138, latest revision. Atlas Railcar Cradle Family 2, (NAC) Conceptual Drawing.
- [15] 3015139, latest revision. Atlas Railcar Cradle Family 3 Conceptual Drawing.
- [16] 3015140, latest revision. Atlas Railcar Cradle Family 4 Conceptual Drawing.
- [17] 3015278, latest revision. Atlas Railcar Cradle Attachment Components Conceptual Drawing.
- [18] 1155-811, 200 Ton Flat Cask Car Drawing.
- [19] AFS-16-0110, April 7, 2016. Atlas HLRM Railcar Monthly Status Report for March 2016.

## APPENDIX A – GENERAL LOADING PROCEDURES

The procedures provided in this appendix start with a railcar containing only an empty cradle (no cask) arriving at the site and end once the railcar has been loaded with the cask and prepared for transport. Any operations to unload the cask from the railcar can essentially be inferred by reversing the applicable steps.

Procedures related to railroad-specific operations and any inspections of the casks, cradles, and railcars are not included in this report.

To minimize repetition across the casks, the loading procedure steps are consolidated whenever possible to apply to multiple casks and cradles. The three levels of procedural steps are:

- Steps applicable to every cask and every cradle covered in this report. These are listed under the A.x headings, where x = 1 through 10, depending on the activity.
- Steps applicable to every cask within a particular cradle family. These are listed under the A.x.y headings, where x = 1 through 10, depending on the activity, and y = 1 through 4, depending on the cradle family.
- Steps applicable to individual casks. These are listed under the A.x.y.z headings, where x = 1 through 10, depending on the activity; y = 1 through 4, depending on the cradle family; and z = 1 through 3, depending on the particular cask.

*Appendix B* should be used to guide the reader as to which sections of *Appendix A* are applicable for the specific casks.

*Appendix C* includes figures that can help the reader understand the components being discussed in the following procedural steps.

### **CAUTION**

**Many of the operations are located near the cask and will result in increased worker dose. These activities should be controlled per As Low as Reasonably Achievable (ALARA) practices. The dose rates near the lid and bottom of the cask are likely to be higher than near the cask body. The use of temporary shielding, specialized long-reach tools, and reduced exposure times should be considered during the work planning stages.**

## A.1 Receive Railcar and Prepare for Loading

- 1) Position railcar in the loading location

### **NOTE**

**The following methods to secure and stabilize the railcar may not be necessary for every site and set of activities, although they should be considered during the work planning stage.**

- 2) Place wheel chocks against railcar wheels
- 3) Position vertical jacks under the railcar jacking pads and raise jacks until railcar suspension is unloaded and deck is level
- 4) Install tie-down devices between railcar tie-down lugs and ground and tighten to prevent movement
- 5) For Family 1 cradles, perform additional activities listed in A.1.1

### A.1.1 Specific Procedures for Family 1 Cradles

- 1) Remove devices from all end-stop lifting holes that rendered them inoperable
- 2) Install lifting shackles to the end-stop segment to be removed
- 3) Connect rigging between the crane and the end-stop segment lifting shackles
- 4) Install pin tray at the first connection pin of the end-stop segment to be removed
- 5) Remove pin retention plate securement bolt
- 6) Rotate pin retention plate 90 degrees
- 7) Retract pin into the pin tray
- 8) Remove pin
- 9) Remove pin tray
- 10) Repeat steps 4 through 9 for the other end-stop pins
- 11) Lift end-stop segment and remove from railcar
- 12) Repeat steps 2 through 11 for other end-stop segments

## **A.2 Remove Empty Transportation Cradle from Railcar (If Necessary)**

- 1) Remove devices from cradle lifting lugs that rendered them inoperable
- 2) Install lifting shackles to the cradle lifting lugs
- 3) Connect rigging between the crane and the cradle lifting shackles
- 4) Install pin tray at the first connection pin to be removed from the cradle
- 5) Remove pin retention plate securement bolt
- 6) Rotate pin retention plate 90 degrees
- 7) Retract pin into the pin tray
- 8) Remove pin
- 9) Remove pin tray
- 10) Repeat steps 4 through 9 for other cradle pins
- 11) Lift cradle and remove from railcar
- 12) Place cradle on a level surface

## **A.3 Prepare Transportation Cradle for Loading**

- 1) Install personnel barrier lifting devices
- 2) Install cask tie-down strap lifting devices
- 3) Remove personnel barrier securement hardware from cradle
- 4) Connect rigging between the crane and the personnel barrier and remove it from cradle
- 5) Remove cask tie-down strap securement hardware from cradle
- 6) Connect rigging between the crane and the cask securement straps and remove them from cradle
- 7) For Family 1 cradles, perform additional activities listed in A.3.1
- 8) For Family 2 cradles, perform additional activities listed in A.3.2
- 9) For Family 3 cradles, perform additional activities listed in A.3.3

### **A.3.1 Specific Procedures for Family 1 Casks**

- 1) For TN-32B, TN-40, and TN-40HT casks, perform additional activities listed in A.3.1.1
- 2) For HI-STAR 60 and HI-STAR 180 casks, perform additional activities listed in A.3.1.2

#### **A.3.1.1 Unique Procedures for TN-32B, TN-40, and TN-40HT Casks**

- 1) Place 4 impact limiter lower tie rods into cradle slots
- 2) Place 2 lifting slings on top of tie rods, located under each of the cradle plates. These lifting straps are intended to be used later for lifting the loaded cradle (cradle, cask, impact limiters, and personnel barrier) and must be sized accordingly.

**A.3.1.2 Unique Procedures for HI-STAR 60 and HI-STAR 180 Casks**

- 1) Attach site-provided, down-ending tower to cradle

**A.3.2 Specific Procedures for Family 2 Casks**

- 1) For TN-68 casks, perform additional activities listed in A.3.2.1
- 2) For NAC-STC and NAC-UMS casks, perform additional activities listed in A.3.2.2
- 3) For MAGNATRAN casks, perform additional activities listed in A.3.2.3

**A.3.2.1 Unique Procedures for TN-68 Casks**

- 1) Remove 2 trunnion capture covers
- 2) Place 4 impact limiter lower tie rods into cradle slots

**A.3.2.2 Unique Procedures for NAC-STC and NAC-UMS Casks**

- 1) Verify the front saddle bolts connecting the front saddle to the cradle are tight

**A.3.2.3 Unique Procedures for MAGNATRAN Casks**

- 1) Remove 2 trunnion capture covers
- 2) Verify the front saddle bolts connecting the front saddle to the cradle are tight

**A.3.3 Specific Procedures for Family 3 Casks**

- 1) For TS125 casks, perform additional activities listed in A.3.3.1

**A.3.3.1 Unique Procedures for TS125 Casks**

- 1) If the cask will be down-ended onto the cradle, then attach the site-provided down-ending tower to the cradle

#### **A.4 Load Cask Onto Transportation Cradle**

- 1) For Family 1 cradles, perform activities listed in A.4.1
- 2) For Family 2 cradles, perform activities listed in A.4.2
- 3) For Family 3 cradles, perform activities listed in A.4.3
- 4) For Family 4 cradles, perform activities listed in A.4.4

#### **CAUTION**

**This activity involves hands-on work near higher dose areas of the cask.**

#### **NOTE**

**Prior to lifting a cask without impact limiters, the maximum lift needs to be determined. This height will differ between casks and may even be different between sites using the same cask. Engineering controls, such as crash pads and physical lifting limitations, may need to be implemented prior to performing the lift.**

#### **A.4.1 Specific Procedures for Family 1 Casks**

- 1) For TN-32B, TN-40, and TN-40HT casks, perform activities listed in A.4.1.1
- 2) For HI-STAR 60 and HI-STAR 180 casks, perform activities listed in A.4.1.2
- 3) For HI-STAR HB and HI-STAR 100 casks, perform activities listed in A.4.1.3

##### ***A.4.1.1 Unique Procedures for TN-32B, TN-40, and TN-40HT Casks***

- 1) Attach crane with a spreader bar and slings to cask body
- 2) Lift cask and transfer over the top of the cradle
- 3) Lower cask into cradle, ensuring cask is centered in cradle

##### ***A.4.1.2 Unique Procedures for HI-STAR 60 and HI-STAR 180 Casks***

- 1) Attach crane with a lifting yoke to cask upper trunnions
- 2) Lift cask and transfer over the top of the cradle
- 3) Lower the cask, verifying alignment of lower trunnions, to engage the lower trunnions
- 4) Down-end cask onto cradle
- 5) Remove down-ending tower from cradle

##### ***A.4.1.3 Unique Procedures for HI-STAR HB and HI-STAR 100 Casks***

- 1) Attach crane with a spreader bar and slings to cask body
- 2) Lift cask and transfer over the top of the cradle
- 3) Lower cask into cradle, ensuring cask is centered in cradle

#### **A.4.2 Specific Procedures for Family 2 Casks**

- 1) Attach crane with a lifting yoke to cask upper trunnions

- 2) Lift cask and transfer over the top of the cradle
- 3) Down-end cask onto cradle

#### **A.4.3 Specific Procedures for Family 3 Casks**

- 1) For MP-197 and MP-197HB casks, perform activities listed in A.4.3.1
- 2) For TS125 casks, perform activities listed in A.4.3.2

##### **A.4.3.1 Unique Procedures for MP-197 and MP-197HB Casks**

- 1) Attach crane with a spreader bar and slings to cask upper and lower trunnions
- 2) Lift cask and transfer over the top of the cradle
- 3) Verify shear key plug has been removed from the cask
- 4) Lower cask into cradle, ensuring alignment of the shear key is maintained

##### **A.4.3.2 Unique Procedures for TS125 Casks**

- 1) If the cask is in the vertical orientation, proceed to Step 6
- 2) Attach crane with a horizontal lifting fixture to cask upper trunnions (cables) and bottom cask body (sling)
- 3) Lift cask and position it directly over the top of the cradle
- 4) Verify shear key plug has been removed from the cask
- 5) Lower cask into cradle, ensuring alignment of the shear key is maintained

The following steps are only applicable if the cask is to be down-ended on the cradle:

- 1) Attach crane with a lifting yoke to cask upper trunnions
- 2) Lift cask and position it directly over the top of the cradle
- 3) Verify shear key plug has been removed from the cask
- 4) Down-end cask onto cradle
- 5) Remove down-ending tower from cradle

#### **A.4.4 Specific Procedures for Family 4 Casks**

- 1) Attach crane with a spreader bar and slings to cask body
- 2) Lift cask and transfer over the top of the cradle
- 3) Verify shear key plug has been removed from the cask
- 4) Remove trunnions
- 5) Install trunnion hole plugs
- 6) Lower cask into cradle, ensuring alignment of the shear key

## **A.5 Prepare Cask For Transport**

- 1) For Family 1 cradles, perform activities listed in A.5.1
- 2) For Family 2 cradles, perform activities listed in A.5.2
- 3) For Family 3 cradles, perform activities listed in A.5.3
- 4) There are no activities for Family 4 cradles in this section

### **CAUTION**

**This activity involves hands-on work near higher dose areas of the cask.**

#### **A.5.1 Specific Procedures for Family 1 Casks**

- 1) For TN-32B, TN-40, and TN-40HT casks, perform activities listed in A.5.1.1
- 2) For HI-STAR 180 casks, perform activities listed in A.5.1.2
- 3) There are no activities for the HI-STAR 60, HI-STAR HB, or HI-STAR 100 casks in this section

##### ***A.5.1.1 Unique Procedures for TN-32B, TN-40, and TN-40HT Casks***

- 1) Install top impact limiter spacer

##### ***A.5.1.2 Unique Procedures for HI-STAR 180 Casks***

- 1) Remove trunnions
- 2) Install trunnion hole plugs

#### **A.5.2 Specific Procedures for Family 2 Casks**

- 1) For MAGNATRAN casks, perform activities listed in A.5.2.1
- 2) There are no activities for the TN-68, NAC-STC, or NAC-UMS casks in this section

##### ***A.5.2.1 Unique Procedures for MAGNATRAN Casks***

- 1) Remove upper trunnions
- 2) Install upper trunnion hole plugs

#### **A.5.3 Specific Procedures for Family 3 Casks**

- 1) Remove trunnions
- 2) Install trunnion hole plugs
- 3) For MP-197HB casks, perform additional activities listed in A.5.3.1

##### ***A.5.3.1 Unique Procedures for MP-197HB Casks***

- 1) Install external aluminum fins, if required

## **A.6 Secure Cask To Transportation Cradle**

- 1) Connect rigging between the crane and the cask tie-down strap
- 2) Transfer cask tie-down strap and locate it on the cradle
- 3) Install securement hardware and ensure tie-down strap is secure
- 4) Repeat steps 1 through 3 for other cask tie-down straps, if applicable
- 5) Remove cask tie-down strap lifting devices
- 6) For Family 1 cradles, perform additional activities listed in A.6.1
- 7) For Family 2 cradles, perform additional activities listed in A.6.2

### **A.6.1 Specific Procedures for Family 1 Casks**

- 1) Move lifting strap ends to the top of the cask, ensuring they remain routed under the cradle plates

### **A.6.2 Specific Procedures for Family 2 Casks**

- 1) For TN-68 casks, perform additional activities listed in A.6.2.1
- 2) For MAGNATRAN casks, perform additional activities listed in A.6.2.2

#### **A.6.2.1 Unique Procedures for TN-68 Casks**

- 1) Install 2 trunnion capture covers and related securement hardware

#### **A.6.2.2 Unique Procedures for MAGNATRAN Casks**

- 1) Install 2 trunnion capture covers and related securement hardware

## **A.7 Install Impact Limiters onto Cask**

- 1) For Family 2 cradles, first perform activities listed in A.7.2
- 2) Connect rigging between the crane and the impact limiter
- 3) Install impact limiter onto cask
- 4) Install impact limiter securement hardware
- 5) Disconnect rigging from impact limiter
- 6) Render impact limiter lifting lugs inoperable by installing a bolt, or similar method
- 7) Repeat steps 2 through 6 for other impact limiter
- 8) For Family 1 cradles, perform additional activities listed in A.7.1
- 9) For Family 2 cradles, perform additional activities listed in A.7.2

### **A.7.1 Specific Procedures for Family 1 Casks**

- 1) For TN-32B, TN-40, TN-40HT casks, perform activities listed in A.7.1.1
- 2) For HI-STAR 180 casks, perform activities listed in A.7.1.2

#### **A.7.1.1 Unique Procedures for TN-32B, TN-40, TN-40HT Casks**

- 1) Install remaining impact limiter tie rods and securement hardware between impact limiters

#### **CAUTION**

**To install the lower impact limiter tie rods and associated securement hardware, access between the cradle and cask will be required. The use of long-reach tooling should be considered during this activity.**

#### **A.7.1.2 Unique Procedures for HI-STAR 180 Casks**

- 1) Install at least 1 access tube cover on the top impact limiter

### **A.7.2 Specific Procedures for Family 2 Casks**

- 1) For TN-68 casks, perform activities listed in A.7.2.1
- 2) For NAC-UMS casks, perform activities listed in A.7.2.2

#### **A.7.2.1 Unique Procedures for TN-68 Casks**

- 1) Install shield ring onto cask, if required based on dose
- 2) Install front spacer onto cask
- 3) After performing Step 7 in A.7, install remaining tie rods, and securement hardware, between impact limiters

#### **A.7.2.2 Unique Procedures for NAC-UMS Casks**

- 1) Install lower impact limiter positioner on the cask bottom

## **A.8 Install Personnel Barrier onto Transportation Cradle**

- 1) For Family 1 cradles, perform additional activities listed in A.8.1
- 2) Connect rigging between the crane and the personnel barrier and position on the cradle
- 3) Install personnel barrier securement hardware
- 4) Remove personnel barrier lifting devices
- 5) Install padlocks on all personnel barrier access points

### **A.8.1 Specific Procedures for Family 1 Casks**

- 1) For HI-STAR 60 and HI-STAR 180 casks, perform additional activities listed in A.8.1.1

#### **A.8.1.1 Unique Procedures for HI-STAR 60 and HI-STAR 180 Casks**

- 1) The use of a personnel barrier is optional for HI-STAR 60 and HI-STAR 180 casks, based on the measured dose rates and temperature surveys. The procedural steps in A.8 are not required in the event a personnel barrier for these casks is not required and/or will not be used.

## A.9 Install Loaded Transportation Cradle onto Railcar

- 1) Clean all of the pins and inside surface of pin holes. After cleaning, coat the surfaces with nuclear grade Never Seez
- 2) Prior to performing the following steps, the cradle-specific activities must be performed:
  - For Family 1 cradles, first perform the activities listed in A.9.1
  - For Family 2 cradles, first perform the activities listed in A.9.2
  - For Family 3 cradles, first perform the activities listed in A.9.3
  - For Family 4 cradles, first perform the activities listed in A.9.4
- 3) Lift and position the cradle directly over the top of the railcar
- 4) Lower cradle onto railcar, ensuring alignment with connection pin holes
- 5) Install pin tray at the first location to install a cradle connection pin
- 6) Place cradle connection pin into pin tray
- 7) Rotate pin retention plate 90 degrees
- 8) Slide pin into place through railcar lugs and cradle holes
- 9) Rotate pin retention plate until it is engaged
- 10) Install pin retention plate securement bolt
- 11) Remove pin tray
- 12) Repeat Steps 5 through 11 for all other cradle pins
- 13) Disconnect rigging from cradle-lifting devices
- 14) Disconnect cradle-lifting shackles
- 15) Render cradle-lifting lugs inoperable by installing a bolt, or similar method
- 16) For Family 3 cradles, Step 3 listed in A.9.3.3 must be performed

### A.9.1 Specific Procedures for Family 1 Casks

- 1) Connect crane with spreader bar to the cradle-lifting slings, previously routed under cradle plates (around cask body)

### A.9.2 Specific Procedures for Family 2 Casks

- 1) Connect crane with spreader bar and slings to cradle-lifting devices

### A.9.3 Specific Procedures for Family 3 Casks

- 1) Install loaded cradle-lifting devices onto cradle

#### **NOTE**

**For Family 3 cradles, there are two sets of lifting devices. When lifting a loaded cradle, the removable set of lifting devices must be installed and used. When any lifting device is not in use, they shall be rendered inoperable to avoid misuse.**

Atlas Railcar General Loading Procedures  
Report No.: EIR-3016164-000

---

- 2) Connect crane with spreader bar and slings to loaded cradle-lifting devices
- 3) After performing Steps 2 through 15 in A.9, remove the loaded cradle-lifting devices from the cradle

#### **A.9.4 Specific Procedures for Family 4 Casks**

- 1) Connect crane with spreader bar and slings to cradle-lifting devices

## **A.10 Final Loading Activities**

- 1) Prior to performing the following steps, the cradle-specific activities must be performed:
  - a) For Family 1 cradles, first perform the activities listed in A.10.1
- 2) Remove the previously installed railcar securement devices, i.e., jacks, tie-down devices, etc.

### **A.10.1 Specific Procedures for Family 1 Casks**

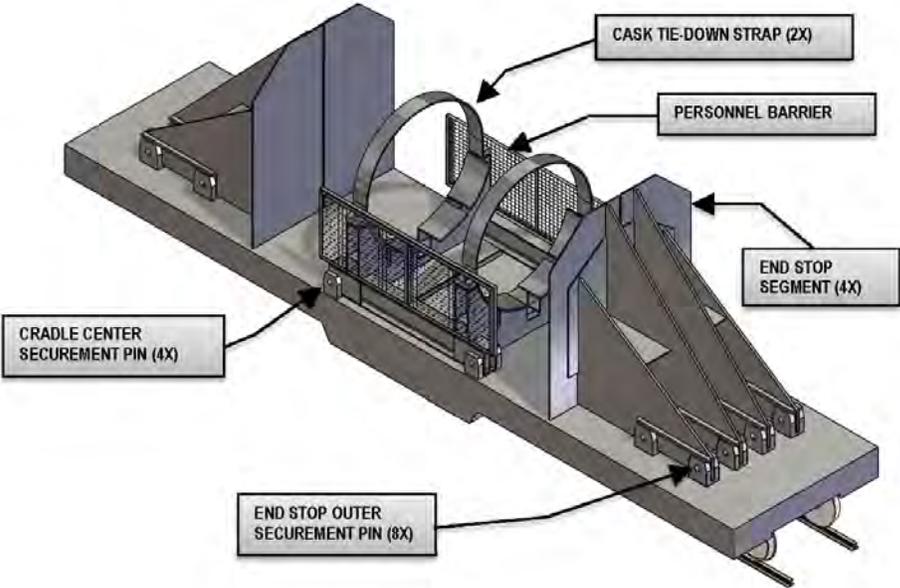
- 1) Clean all of the pins and inside surface of pin holes. After cleaning, coat the surfaces with nuclear grade Never Seez.
- 2) Secure lifting straps within the cradle so that they remain in place, but inoperable, during transit
- 3) Connect rigging between the crane and the end-stop segment to be installed
- 4) Lift and position the end-stop segment directly over the top of the railcar
- 5) Lower end stop onto railcar, ensuring alignment with connection pin holes
- 6) Install pin tray at the first location to install a connection pin
- 7) Place end-stop connection pin into pin tray
- 8) Rotate pin retention plate 90 degrees
- 9) Slide pin into place through railcar lugs and end-stop holes
- 10) Rotate pin retention plate until it is engaged
- 11) Install pin retention plate securement bolt
- 12) Remove pin tray
- 13) Repeat Steps 6 through 12 for all other end-stop connection pins
- 14) Remove lifting shackles from the end-stop segment
- 15) Render end-stop lifting holes inoperable by installing a bolt or similar method
- 16) Repeat Steps 3 through 15 for other end-stop segments
- 17) Install shims between end stops and impact limiters

**APPENDIX B – LOADING PROCEDURE APPLICABILITY MATRIX**

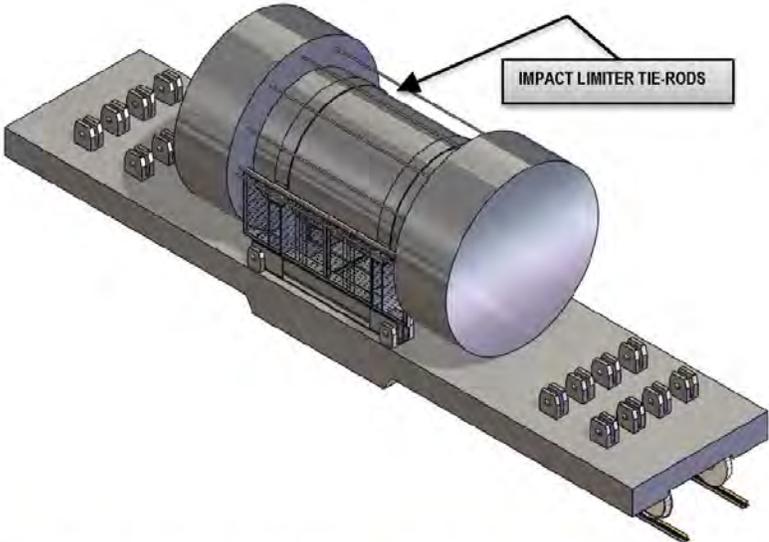
Activity	Cask Cradle Family	TN-32B	TN-40	TN-40HT	HI-STAR 60	HI-STAR HB	HI-STAR 100	HI-STAR 180	TN-68	NAC-STC	NAC- UMS	MAGNA- TRAN	MP-197	MP- 197HB	TS-125	MP-187
		1	1	1	1	1	1	1	2	2	2	2	3	3	3	4
Receive Railcar for Loading		A.1 & A.1.1	A.1 & A.1.1	A.1 & A.1.1	A.1 & A.1.1	A.1 & A.1.1	A.1 & A.1.1	A.1 & A.1.1	A.1	A.1	A.1	A.1	A.1	A.1	A.1	A.1
Remove Transportation Cradle from Railcar		A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2	A.2
Prepare Transportation Cradle for Loading		A.3 & A.3.1.1	A.3 & A.3.1.1	A.3 & A.3.1.1	A.3 & A.3.1.2	A.3	A.3	A.3 & A.3.1.2	A.3 & A.3.2.1	A.3 & A.3.2.2	A.3 & A.3.2.2	A.3 & A.3.2.3	A.3	A.3	A.3 & A.3.3.1	A.3
Load Cask onto Transportation Cradle		A.4.1.1	A.4.1.1	A.4.1.1	A.4.1.2	A.4.1.3	A.4.1.3	A.4.1.2	A.4.2	A.4.2	A.4.2	A.4.2	A.4.3.1	A.4.3.1	A.4.3.2	A.4.4
Prepare Cask for Transport		A.5.1.1	A.5.1.1	A.5.1.1	No activities required	No activities required	No activities required	A.5.1.2	No activities required	No activities required	No activities required	A.5.2.1	A.5.3	A.5.3 & A.5.3.1	A.5.3	No activities required
Secure Cask to Transportation Cradle		A.6 & A.6.1	A.6 & A.6.1	A.6 & A.6.1	A.6 & A.6.1	A.6 & A.6.1	A.6 & A.6.1	A.6 & A.6.1	A.6 & A.6.2.1	A.6	A.6	A.6 & A.6.2.2	A.6	A.6	A.6	A.6
Install Impact Limiters onto Cask		A.7 & A.7.1.1	A.7 & A.7.1.1	A.7 & A.7.1.1	A.7	A.7	A.7	A.7 & A.7.1.2	A.7 & A.7.2.1	A.7	A.7 & A.7.2.2	A.7	A.7	A.7	A.7	A.7
Install Personnel Barrier onto Transportation Cradle		A.8	A.8	A.8	A.8 & A.8.1.1	A.8	A.8	A.8 & A.8.1.1	A.8	A.8	A.8	A.8	A.8	A.8	A.8	A.8
Install Transportation Cradle onto Railcar		A.9 & A.9.1	A.9 & A.9.1	A.9 & A.9.1	A.9 & A.9.1	A.9 & A.9.1	A.9 & A.9.1	A.9 & A.9.1	A.9 & A.9.2	A.9 & A.9.2	A.9 & A.9.2	A.9 & A.9.2	A.9 & A.9.3	A.9 & A.9.3	A.9 & A.9.3	A.9 & A.9.4
Final Loading Activities		A.10 & A.10.1	A.10 & A.10.1	A.10 & A.10.1	A.10 & A.10.1	A.10 & A.10.1	A.10 & A.10.1	A.10 & A.10.1	A.10	A.10	A.10	A.10	A.10	A.10	A.10	A.10

**APPENDIX C – TRANSPORTATION CRADLE DETAILS**

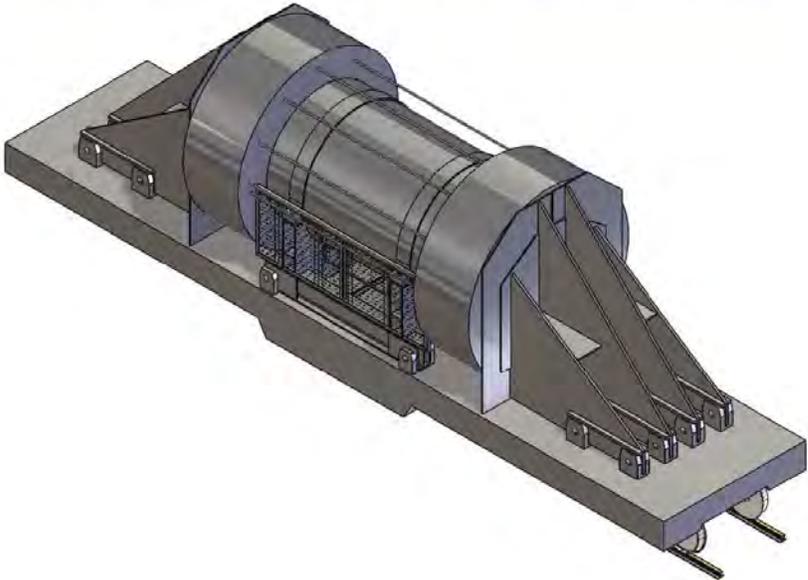
**FIGURE C-1A: FAMILY 1 CRADLE FOR TN-32B, TN-40, AND TN-40HT CASKS**



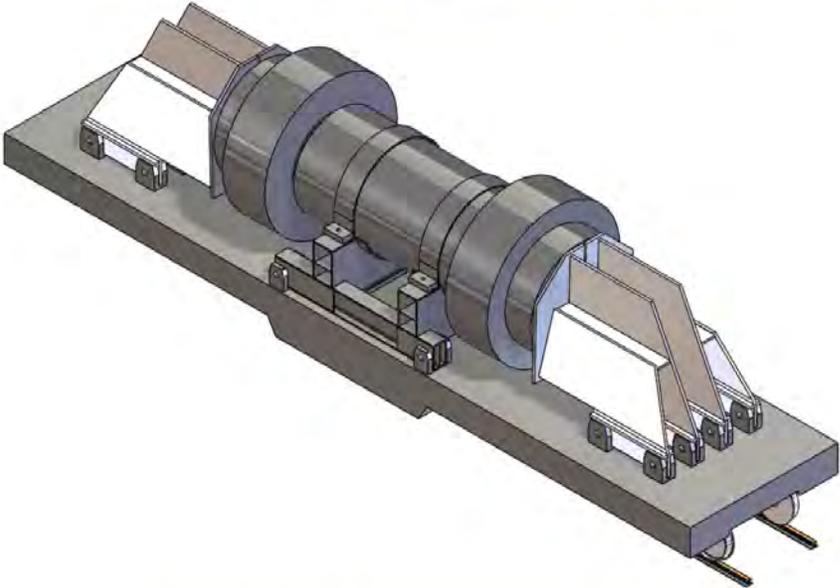
**FIGURE C-1B: FAMILY 1 CRADLE WITH TN-40 CASK**



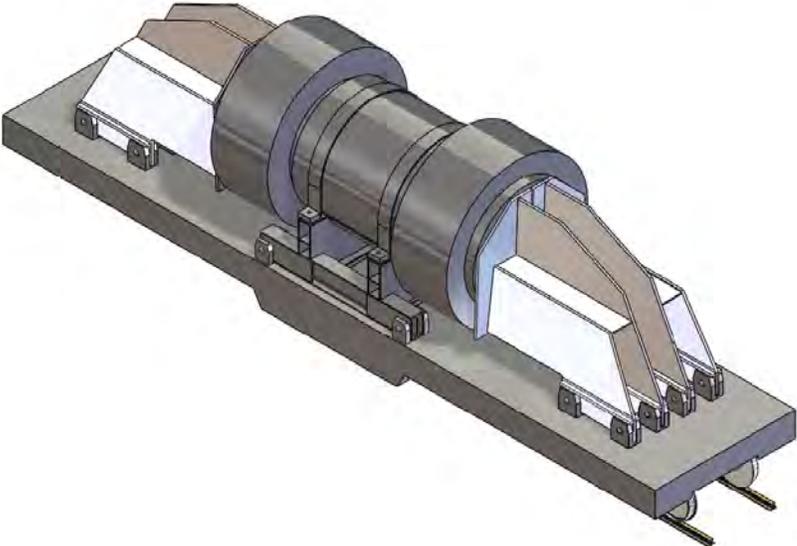
**FIGURE C-1C: FAMILY 1 CRADLE WITH TN-40 CASK READY FOR TRANSPORT**



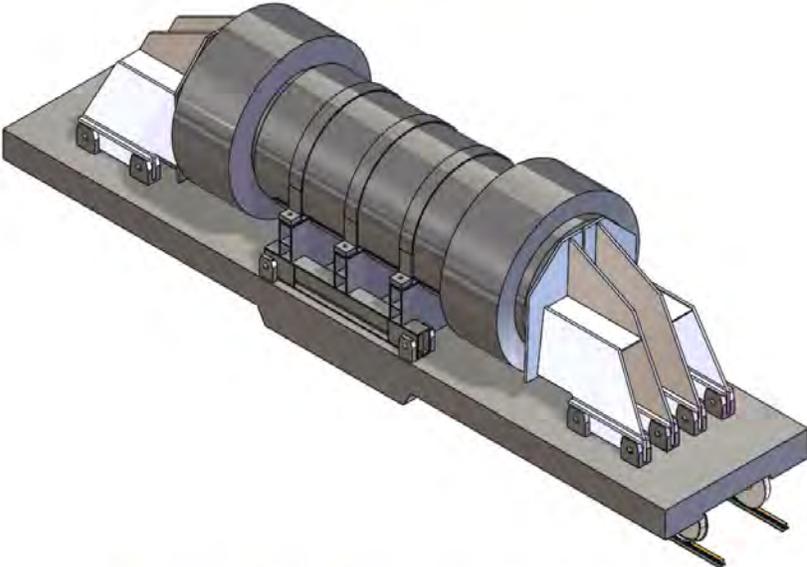
**FIGURE C-2: FAMILY 1 CRADLE WITH HI-STAR 60 CASK**



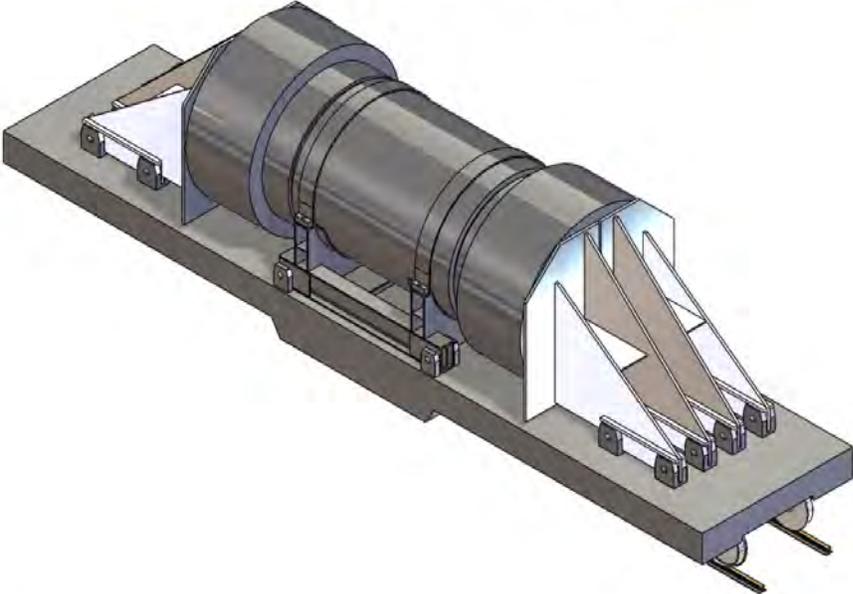
**FIGURE C-3: FAMILY 1 CRADLE WITH HI-STAR HB CASK**



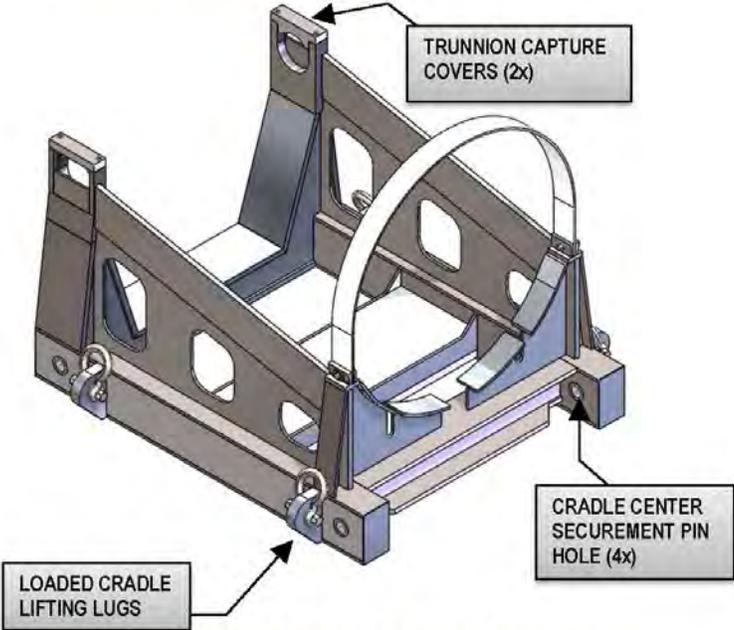
**FIGURE C-4: FAMILY 1 CRADLE WITH HI-STAR 100 CASK**



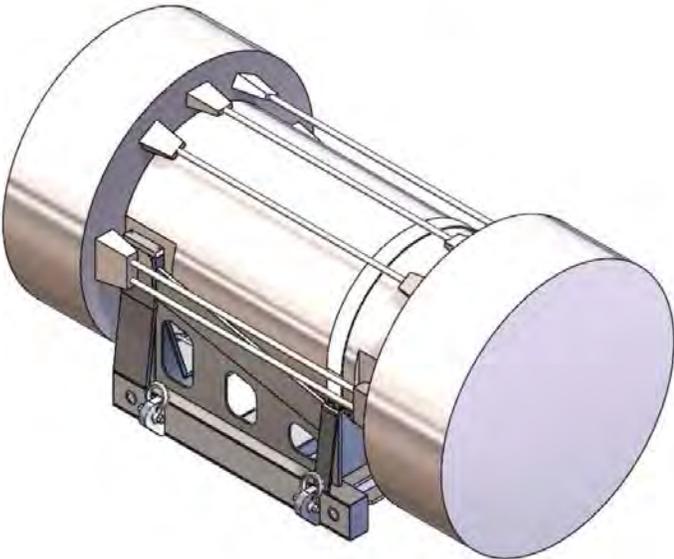
**FIGURE C-5: FAMILY 1 CRADLE WITH HI-STAR 180 CASK**



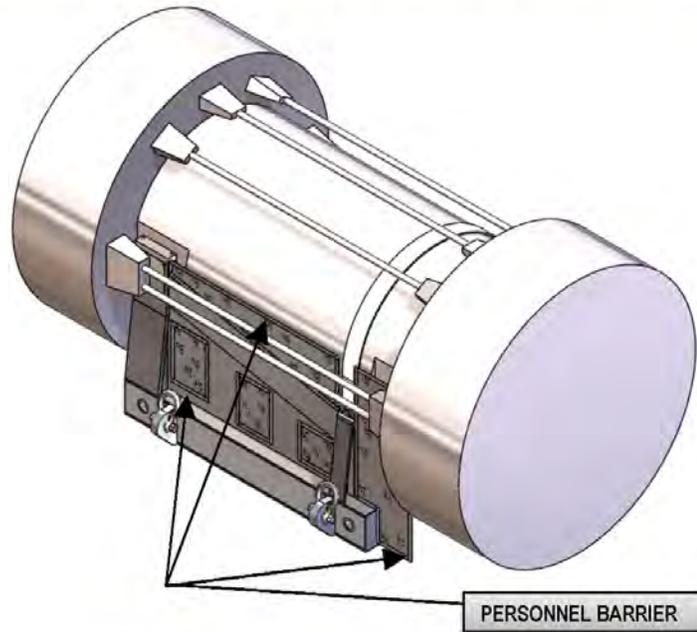
**FIGURE C-6A: FAMILY 2 CRADLE FOR TN-68 CASK**



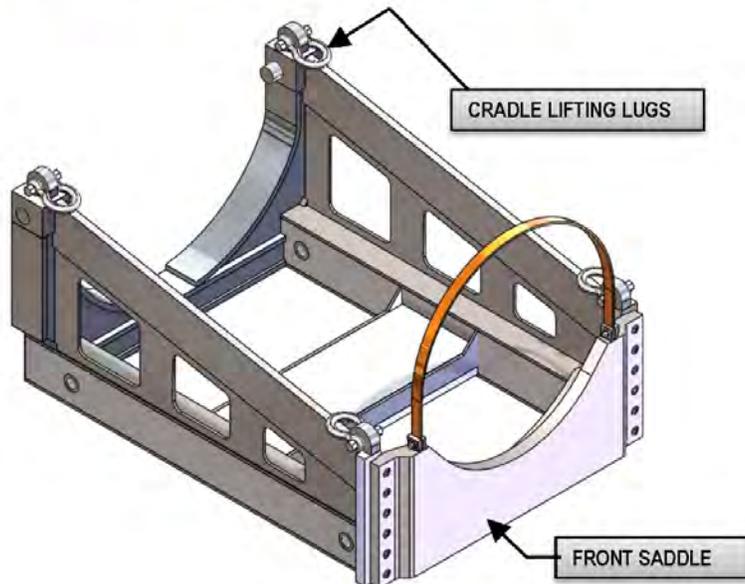
**FIGURE C-6B: FAMILY 2 CRADLE WITH TN-68 CASK**



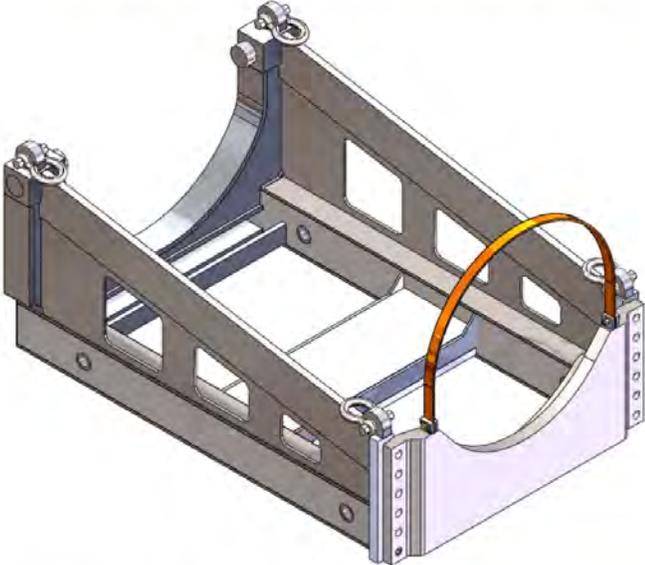
**FIGURE C-6C: FAMILY 2 CRADLE WITH TN-68 CASK AND PERSONNEL BARRIER**



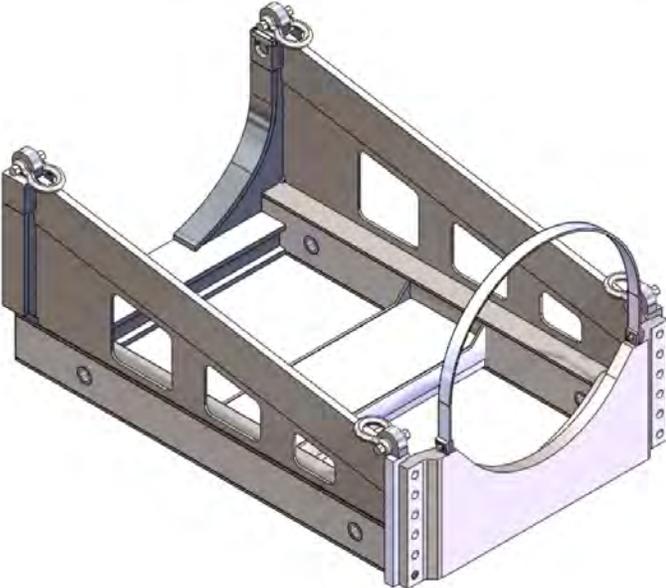
**FIGURE C-7A: FAMILY 2 CRADLE FOR NAC-STC CASK**



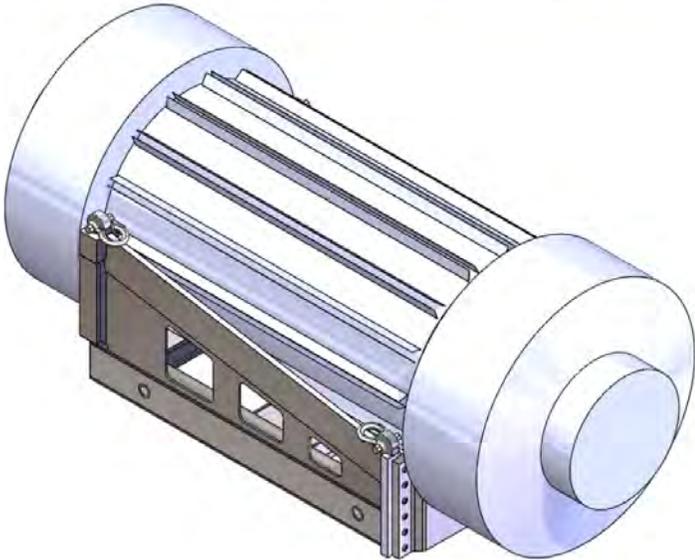
**FIGURE C-7B: FAMILY 2 CRADLE FOR NAC-UMS CASK**



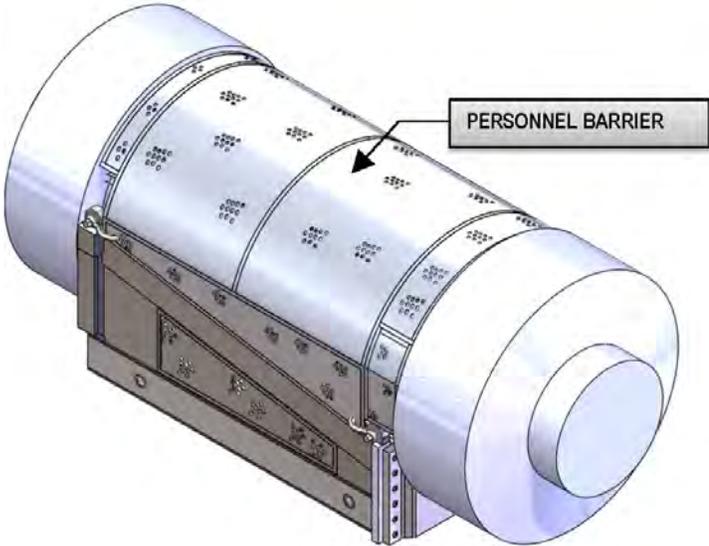
**FIGURE C-8A: FAMILY 2 CRADLE FOR MAGNATRON CASK**



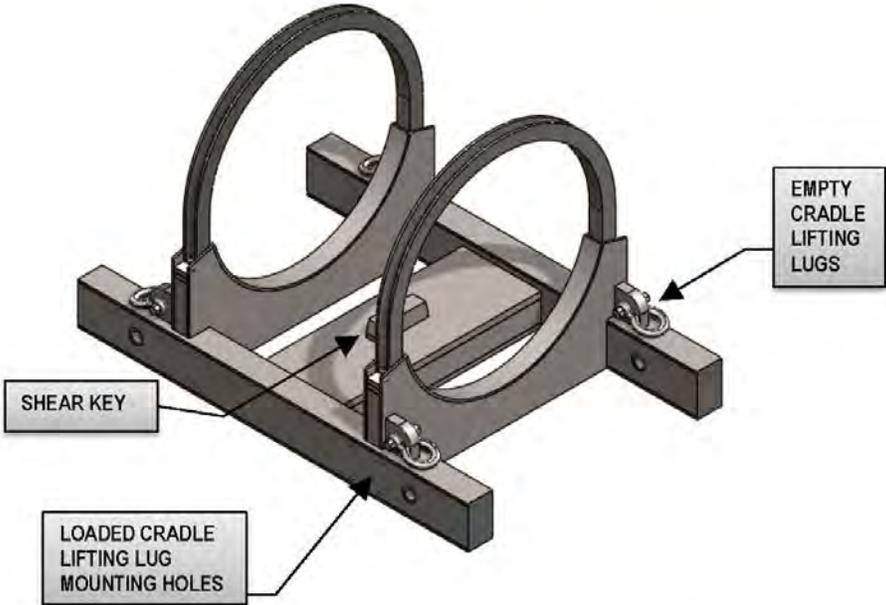
**FIGURE C-8B: FAMILY 2 CRADLE WITH MAGNATRAN CASK**



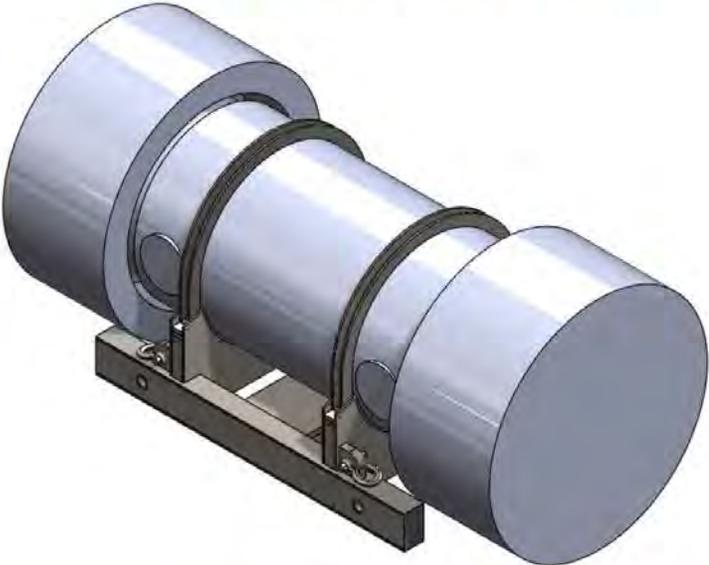
**FIGURE C-8C: FAMILY 2 CRADLE WITH MAGNATRAN CASK & PERSONNEL BARRIER**



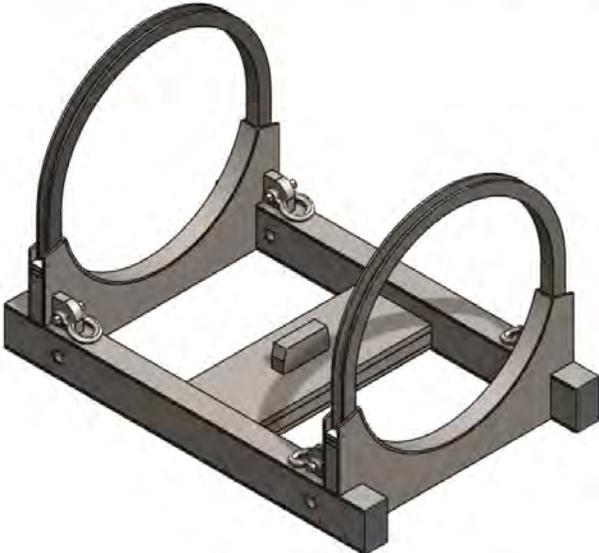
**FIGURE C-9A: FAMILY 3 CRADLE FOR MP197 CASK**



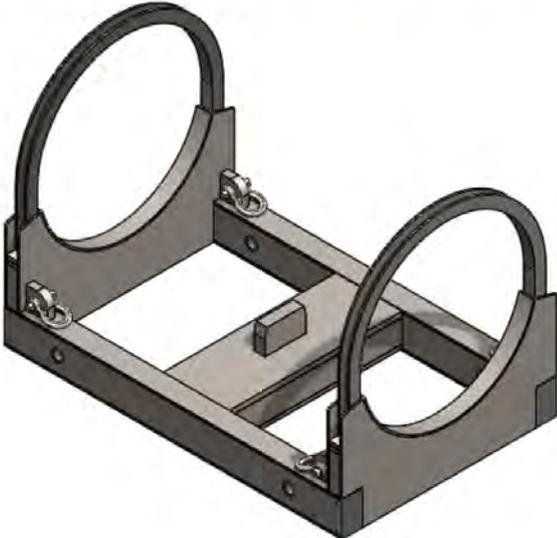
**FIGURE C-9B: FAMILY 3 CRADLE WITH MP197 CASK**



**FIGURE C-10: FAMILY 3 CRADLE FOR MP197HB CASK**



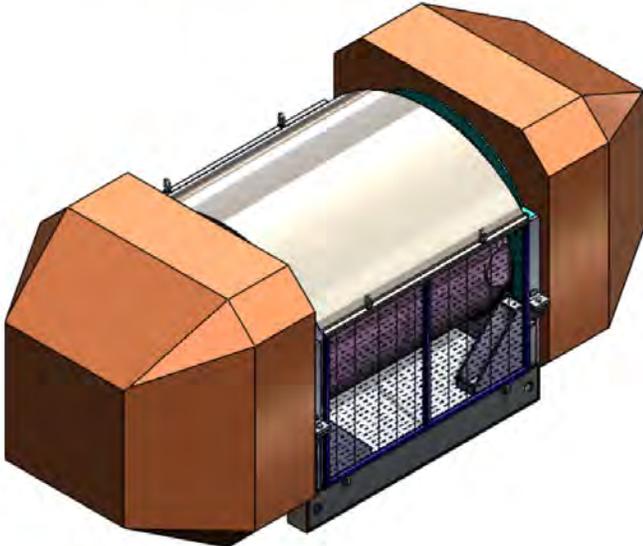
**FIGURE C-11: FAMILY 3 CRADLE FOR TS125 CASK**



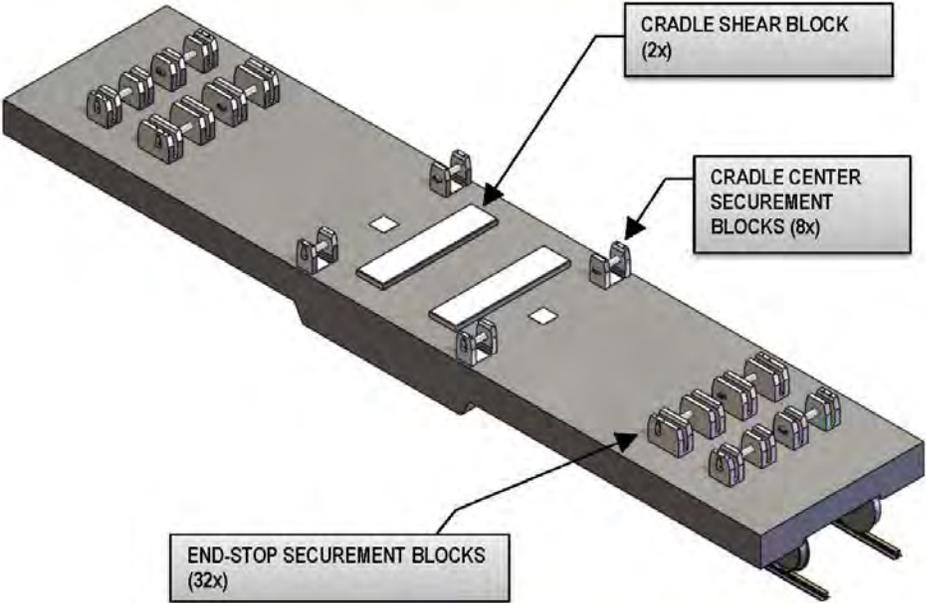
**FIGURE C-12A: FAMILY 4 CRADLE FOR MP187 CASK**



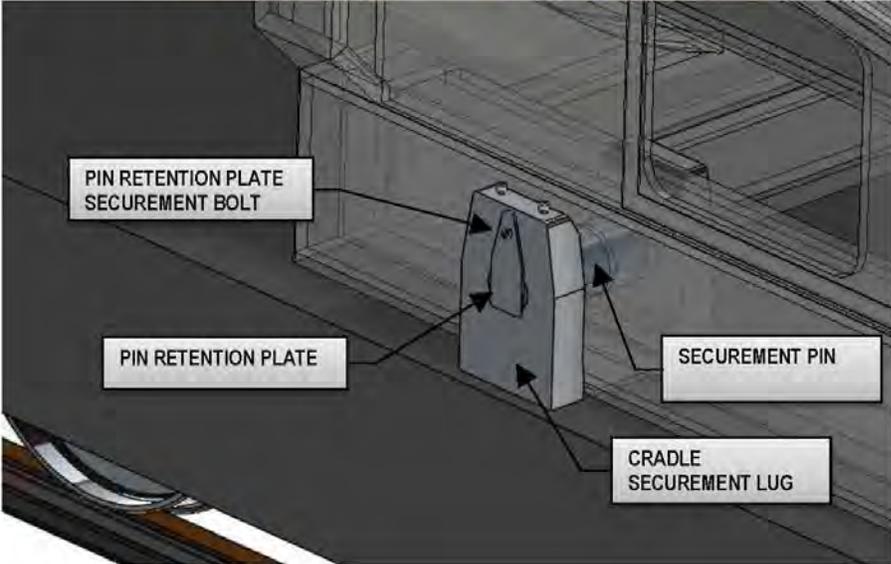
**FIGURE C-12B: FAMILY 4 CRADLE WITH MP187 CASK**



**FIGURE C-13: CRADLE ATTACHMENT DETAILS**



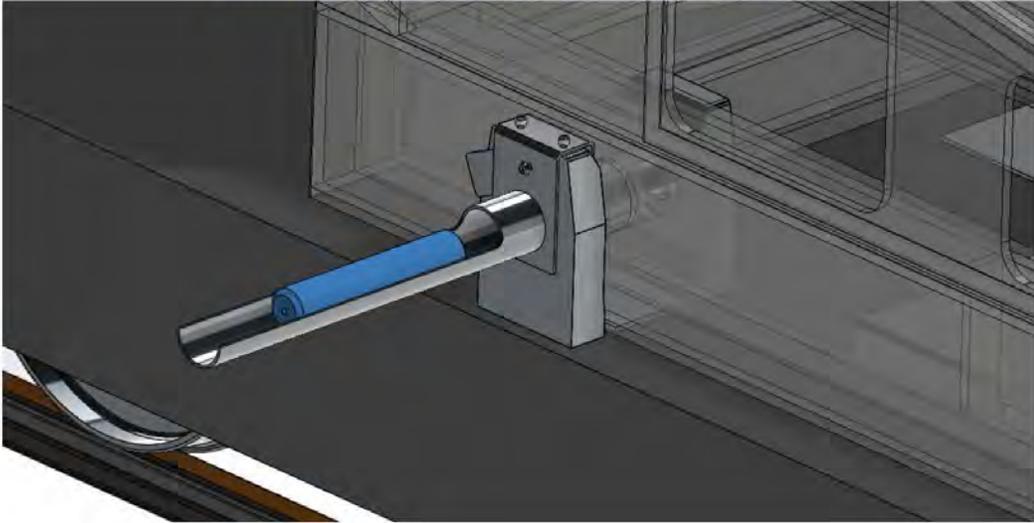
**FIGURE C-14: SECUREMENT PIN RETENTION FEATURES**



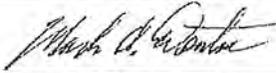
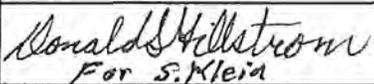
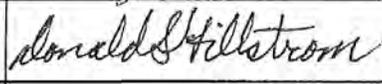
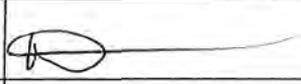
**FIGURE C-15: PIN LOADING TRAY INSTALLED**



**FIGURE C-16: PIN LOADING TRAY WITH PIN RETRACTED**



# Appendix E – CASK & BUFFER RAILCAR FUNCTIONAL & OPERATIONAL REQUIREMENTS DOCUMENT

 <b>AREVA</b>	<b>AREVA Federal Services LLC</b>		
	<b>Engineering Information Record</b>		
Document No.:	EIR-3014611	Rev. No.	004
			Page 1 of 14
Project No.:	00225.03.0050	Project Name:	DOE Atlas Railcar
Title:	Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar		
Summary:	<p>This document contains the design criteria for the DOE Atlas Railcar project.</p> <p>The DBRD is also to be utilized as the Functional and Operational Requirements Document (FORD) deliverable in Phase I of the project.</p> <p>This document is not safety related.</p> <p>Project Document Number: PKG-DBR-019</p>		
Contains Unverified Input / Assumptions: Yes: <input type="checkbox"/> No: <input checked="" type="checkbox"/>			
	Printed Name	Signature	Date
Preparer:	Mark Denton		07/11/2016
Checker:	Slade Klein	 For S. Klein	7/13/16
Approver:	Charles Temus Principle Design Engineer		7/13/16
Approver:	Don Hillstrom Engineering Manager		7/13/16
Approver:	<del>Joe Stringer</del> <sup>TED HENNINGER</sup> Sr. Manager, Engineering		7/20/16
Other:	Bernard Counterman Quality Assurance Engineer		7/18/16
Other:	Mark Denton Project Manager		07/20/2016

AFS-EN-FRM-012 Rev. 02 (Effective April 27, 2015)  
 Refer to AFS-EN-PRC-019



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 2 of 14

**Revision History**

Rev.	Changes
000	Initial Release
001	Complete re-write to incorporate DOE comments and re-format. Acronym list added and sections reserved for operational and maintenance requirements. Revised cradle requirements per AFS-RFI-00225-0004-00.
002	Replacement of revision numbers with "latest revision" in Section 3.0.
003	The following four changes made: 1) Editorial clarifications made throughout document; 2) Clarification added to Section 2.2.2; 3) Added new conceptual cradle specific operational requirements under Section 2.3, and; 4) Additional design requirements added to Section 2.5.
004	The following changes made: 1) Editorial clarifications made throughout document; 2) Added to acronyms table; 3) Added requirement to Section 2.2.1 regarding symmetrical use of cask railcar; 4) Detail added to Section 2.3.1; 5) Detail added to Section 2.4, Added temperature range to Section 2.5, and 6) Added reference items #9 through #19, #23, and renumbered remaining reference items; 7) Added Principal Design Engineer as reviewer to comply with revised Engineering Oversight Plan These changes reflect the DBRD being revised to meet the requirements for the Functional and Operational Requirements Document (FORD) submittal.





**AREVA Federal Services LLC**

**Title:** Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

**Doc./Rev.:** EIR-3014611-004

**Project:** 00225.03.0050 - DOE Atlas Railcar

**Page 4 of 14**

---

**List of Tables**

	<b>Page</b>
Table 1-1: Acronym List.....	5



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 5 of 14

**1.0 INTRODUCTION**

The United States Department of Energy (DOE) is laying the groundwork for implementing an integrated nuclear waste management system. This includes preparing for future large-scale transport of spent nuclear fuel (SNF), high-level waste (HLW), and Greater-Than-Class-C (GTCC) waste; since transport will be a necessary component of any integrated nuclear waste management system. With this project the DOE will provide for the transportation of SNF (GTCC is transported similarly to SNF) and HLW by means of a specific railcar to carry SNF and HLW casks.

This document establishes the design criteria for the DOE Atlas railcar project. The scope of work and deliverables are defined through DOE Contract DE-NE0008390, Part 1, Section C titled "Statement of Work" (SOW) [1], and are discussed in the Engineering Work Plan (EWP) [2]. This document also lists the functional and operational requirements of the cask and buffer railcar designs.

**1.1 Acronyms**

Table 1-1 defines the acronyms used throughout the body of this document.

**Table 1-1: Acronym List**

Acronym	Definition
AAR	Association of American Railroads
CFR	Code of Federal Regulations
DOE	Department of Energy
ECP	Electronically Controlled Pneumatic
EEC	Equipment Engineering Committee
EWP	Engineering Work Plan
FAR	Federal Acquisition Regulation
GTCC	Greater Than Class C
HLRM	High-Level Radioactive Material
HLW	High-Level Waste
L/V	Lateral / Vertical Force Ratio
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
RMS	Root-Mean-Square
SNF	Spent Nuclear Fuel
SOW	Statement of Work

**2.0 DESIGN REQUIREMENTS**

**2.1 Regulatory Requirements**

Per the SOW [1], the DOE Atlas Cask railcar and Buffer railcar must be designed and built to satisfy the requirements of Association of American Railroads (AAR) *Manual of Standards and Recommended Practices* (MSRP) Standard S-2043 titled *Performance Specification for Trains used to Carry High-Level Radioactive*



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 6 of 14

*Material* [3]. This includes the receipt of a notice-to-proceed with the test phase from the AAR Equipment Engineering Committee (EEC) based on modeling of the railcar components, the empty individual Atlas and buffer railcars, the individual loaded Atlas railcar, and a consist (a “consist” is defined in the railroad industry as the coupled vehicles making up the train) of the empty and loaded combinations of the two buffer and Atlas railcars.

Per the DOE Contract, Part 1, Section E [4], the DOE has invoked Federal Acquisition Regulation (FAR) 52.246-11 titled “Higher-Level Contract Quality Requirement”, which requires that the railcar fabricator meet AAR *Manual Standards and Recommended Practices, Section J – Quality Assurance M-1003* [5].

The SOW [1] requires that High-Level Radioactive Material (HLRM), as defined by S-2043 to include SNF and HLW, will be shipped in transport casks certified in accordance with 10CFR71 by the Nuclear Regulatory Commission (NRC). However, the railcar and cask cradle are not licensed by the NRC and 10CFR71 licensing requirements do not apply to this project.

## **2.2 Functional Requirements**

### **2.2.1 Cask/Buffer Railcar Functional Requirements**

The following list of cask/buffer car functional requirements is derived from the SOW [1].

1. The cask railcar and buffer railcars must comply with AAR’s *Manual of Standards and Recommended Practices*, including Standard S-2043 [3].
2. The cask railcar must comply with other applicable standards as specified in the Oak Ridge National Laboratory (ORNL) report, ORNL/TM-2014/596, *AAR S-2043 Cask Railcar System Requirements Document* [6].
3. Standard, commercial off-the-shelf components shall be used to the maximum extent practicable in designing and fabricating the railcars.
4. The cask railcar shall be designed to carry each of the casks identified in Attachment A of the SOW.
5. The cask railcar shall be designed to transport one cask at a time along with one cask cradle.
6. The cask railcar design must include attachment points for the cradles.
7. Some casks may be horizontal when they are placed on the cradle. Other casks may be positioned on the cradle vertically, and may then be rotated to a horizontal position to rest on the cradle. This vertical-to-horizontal operation may be performed on top of the railcar. Therefore, the cask car may be required to support the entire weight of a cask in a vertical position during loading and unloading operations.
8. For a flat-deck railcar design, the length requirement is the total length of the cargo, including the cask with impact limiters attached.
9. For a depressed-deck railcar design, the length requirement is the total length of the cargo plus additional length to accommodate impact limiter installation/removal. This length may be reduced, if the cask can be assembled with impact limiters on the cradle and then lifted onto the railcar.
10. The buffer car will not carry HLRM cargo.
11. The buffer cars may be used to transport some lightweight items, such as tools, spare parts, etc., that are necessary to load/unload the transport casks. The buffer cars may also carry ballast weights, if necessary to maintain the stability of the complete consist. Nothing on the buffer cars, however, shall obstruct the line-of-sight between the escort car and the cask cars.



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 7 of 14

12. The cask car (including a cradle and a cask) and buffer car clearances shall fit within AAR Plate C, except when loaded with the casks that are more than 128 inches wide. Transporting casks that are more than 128 inches wide will require special route analysis. The requirements for Plate C are contained in AAR Standards S-2028, S-2029, and S-2030 [3].
13. Per AAR Manual of Standards and Recommended Practices (MSRP), the cask railcar shall be marked with an "A" and "B" end; however, the railcar is to be symmetrical in its design and operations.

The following list of cask/buffer car functional requirements is derived from ORNL/TM-2014/596 [6].

14. If required by a specific cask's Safety Analysis Report, personnel barriers provide a physical barrier between personnel and the transportation cask body's outer surface and also function to make the railcar a closed transport vehicle as defined by Title 49, Section 173.403, in the Code of Federal Regulations (CFR) [8].
15. It may be necessary to add ballast weight to an AAR Standard S-2043 railcar when it is used to transport a cask with contents that are significantly lighter than the largest and heaviest loaded cask. Requirements for ballast, if needed, will be determined by simulation modeling and testing of the AAR Standard S-2043 railcar.
16. The railcar design must include a simple mechanism to attach the cradle to the deck. (Same as Section 2.2.1.6 above)
17. The design of the cask railcar shall ensure that, in the event of a derailment, the cask car will remain coupled to the railcars fore and aft, the trucks will remain attached to the railcar, and wheel sets will remain attached to the trucks as outlined in Section 4.1.7.1 of AAR Standard S-2043 [3].
18. The cask railcar shall meet brake system design requirements listed in Section 4.4 of AAR Standard S-2043 including the use of an electronically controlled pneumatic (ECP) braking system. To meet Section 4.4 requirements, the braking system must also meet AAR Standards S-401, S-4200, S-4210, S-4220, and S-4230 [3].  
(Note: when approved, AAR S-4300 may be followed in lieu of S-4200.)
19. The cask railcar shall meet System Safety Monitoring requirements listed in Section 4.5 of AAR Standard S-2043 [3] including the capability to continuously monitor location, speed, truck hunting, rocking, wheel flats, bearing condition, ride quality, braking performance, vertical acceleration, lateral acceleration, and longitudinal acceleration.
20. The cask railcar shall be capable of meeting the testing requirements of AAR Standard S-2043 [3], including Section 5.0 "Single-Car Tests" and Section 6.0, "Multiple-Car Tests."  
(Note: testing requirements are further discussed in Section 7 of AAR Standard S-2043.)
21. The cask railcar shall incorporate a standardized attachment capability for coupling the cask cradle to the railcar. This attachment must be capable of securely attaching loads of up to 312,000 lbs. in accordance with the requirements of AAR Rule 88 A16c(3) [7].
22. The cask railcar shall meet the requirements of 49 CFR 210, *Railroad Noise Emission Compliance Regulation*, [8].
23. The cask railcar shall meet the requirements of 49 CFR 215, *Railroad Freight Car Safety Standards*, [8].
24. The cask railcar shall meet the requirements of 49 CFR 221, *Rear End Marking Device—Passenger, Commuter, and Freight Trains*, [8].
25. The cask railcar shall meet the requirements of 49 CFR 224, *Reflectorization of Rail Freight Rolling Stock*, [8].



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 8 of 14

26. The cask railcar shall meet the requirements of 49 CFR 231, *Railroad Safety Appliance Standards* (Specifically 49 CFR 231.6, *Flat Cars*), [8].
27. The cask railcar shall meet the requirements of 49 CFR 232, *Brake System Safety Standards for Freight and Other Non-Passenger Trains and Equipment; End-of-Train Devices* [8].
28. To the extent practicable, the cask railcar shall incorporate standard, commercially available, off-the-shelf components.

### **2.2.2 Conceptual Cradle Design and Functional Requirements**

The following list of conceptual cradle requirements is derived from the SOW [1].

1. During transport, a transportation cask must rest on a cradle on top of the cask railcar deck.
2. Conceptual cask cradle designs must accommodate the 15 cask designs listed in Attachment A of the SOW, as subsequently modified by a contract modification and by AFS Request For Information Number AFS-RFI-00225-0013-00 (see Appendix A).
3. The conceptual cradle designs shall not be final designs or prototypes. DOE only needs cradle design information as it pertains to the performance of the cask car. This SOW requirement has been interpreted by AFS to mean the following conceptual design deliverables are required:
  - a. Calculated conceptual cradle weight(s) supported by a sizing structural calculation(s). This conceptual weight shall include a minimum and maximum weight using  $\pm 10\%$  on the nominal calculated value. The cradle weight shall include any personnel barriers as required.
  - b. Calculated center(s) of gravity of the conceptual cradle(s).
  - c. Maximum loads applied to the railcar under the loading specified in Section 2.2.2.13.
  - d. Preliminary fatigue evaluation(s) to assure the conceptual cradle design(s) are viable.
  - e. Railcar-cradle interface dimensions and tolerances.
4. The conceptual cradle design shall determine the height of the cask center of gravity above the railcar deck, the weight on each axle, etc., as necessary to perform the analysis and provide simulated cradle test weights and supporting information needed for testing of the railcar.
5. When rotation is necessary, the cradle will include the required hardware, such as trunnion supports.
6. The cradles will be tall enough and open-ended so that the impact limiters can be attached to a cask after the cask is secured to the cradle.
7. Each cask design will need a cradle designed to position the center of gravity low for stability during transport, but the cradle design will position the impact limiter with a clearance of at least one inch above the cask car deck.
8. The cask car (including a cradle and a cask) and buffer car clearances shall fit within AAR Plate C contained in AAR Standards S-2028, S-2029, and S-2030 [3], except when loaded with the casks that are more than 128 inches wide (Same as Requirement 2.2.1.12 above).

The following list of cradle functional requirements is derived from ORNL/TM-2014/596 [6].

9. An alternative to adding ballast weight to the railcar may include requiring that the transport cradle for the lighter cask be designed to provide the ballast.
10. The various cradles will be designed to fit a standard attachment mechanism.



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 9 of 14

11. During loading operations, the cradle may be attached to the railcar first, followed by putting the cask on the cradle, but sometimes the cask will be on the cradle first. In that case, both the cradle and cask together will be hoisted onto the railcar deck.
12. The cask railcar shall incorporate a standardized attachment capability for coupling the cask cradle to the railcar. This attachment must be capable of securely attaching loads of up to 312,000 lbs. in accordance with the requirements of AAR Rule 88 A16c(3) [7].
13. Rule 88 A.16.C(3) requires the following tie down loads (g force to yield):
  - a. 7.5g Longitudinal
  - b. 2g Vertical
  - c. 2g lateral

These loads shall be evaluated as a static load with no dynamic load factors applied.

**2.3 Operational Requirements**

**2.3.1 Cask/Buffer Railcar Operational Requirements**

1. For operational status, per project Request For Information (RFI) #14 [9], an “empty cask railcar” shall be a cask railcar with no payload.
2. The Atlas cask railcar and buffer railcar shall be operated within the scope of S-2043 for only those railcar consist configurations approved in writing by the AAR EEC.
3. The Atlas cask and buffer railcar shall meet the operational requirements listed in AAR MSRP S-2043, Appendix B titled “Operating Standard for Trains Used to Carry High-Level Radioactive Material” [3].
4. The cask and buffer railcars shall not be loaded in such a way that they exceed the following performance criteria [10]:

Criterion	Limiting Value	Notes
Maximum car body roll angle	4 degrees	Peak-to-peak
Maximum wheel lateral/vertical force	0.8 L/V	Maximum ratio of lateral/vertical force
Maximum truck side lateral/vertical force	0.5 L/V	Maximum ratio of lateral/vertical force
Minimum vertical wheel load	25%	Minimum
Peak-to-peak car body lateral acceleration	1.3 G	
Maximum car body lateral acceleration	0.75 G	
Lateral car body acceleration standard deviation	0.13 G	Calculated over 1000 ft
Maximum car body vertical acceleration	0.9 G	



AREVA Federal Services LLC

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 10 of 14

Maximum vertical suspension deflection 95% Suspension bottoming not allowed

5. When the cask and buffer railcars are operating under S-2043 requirements, the braking system shall meet the following requirements:
  - Railcars shall have both the electronically controlled pneumatic brake system and the standard freight railcar pneumatic brake system operationally ready;
  - The maximum loaded car brake ratio shall be 16.25% at 65 psi brake cylinder pressure [11];
  - The maximum empty car brake ratio shall be 28.0% at a 30 psi reduction from a 90 psi brake pipe pressure [11];
  - The empty/load changeover should be 60% of the gross rail load in any type train operation [11];
  - The brake shoe force variation within an entire car shall be no more than +/- 8% [11].
6. The cask and buffer railcars shall have remote monitoring systems operational during transport – loaded or empty – with the following being monitored for all railcars in the consist: location, speed, truck hunting, rocking, wheel flats, bearing condition, ride quality/acceleration, braking performance, and vertical/lateral/longitudinal acceleration [12].
7. Other monitoring system requirements include:
  - a) Exception reports will be transmitted to the locomotive and the escort car via the ECP brake system [13].
  - b) A signal requiring train inspection at the next scheduled stop must be transmitted to the train crew when one of the following situations is identified [14]:
    - Hunting-sustained RMS lateral car body acceleration of 0.13 G;
    - Rocking-indication of degraded performance or peak-to-peak roll angles of 4° for 3 cycles;
    - Bearing temperature indicating degraded performance;
    - Wheel flat indications.
  - c) The following situations must trigger a train-stop alarm [13]:
    - Hunting with a RMS lateral car body acceleration of 0.26 G sustained for 10 seconds;
    - Rocking-peak-to-peak roll angles of 5° for 3 cycles;
    - Bearing temperature indicating impending failure;
    - Vertical acceleration with peak vertical car body acceleration of 1.0 G;
    - Lateral acceleration with peak lateral car body acceleration of 0.75 G;
    - Longitudinal acceleration with peak longitudinal car body acceleration of 1.5 G.
  - d) A log of performance exceptions must be compiled at the end of each trip. This log must be transmitted to the appropriate parties that are responsible for the maintenance and operation of this equipment for further evaluation and corrective action [15].
  - e) Raw performance data must be stored for the last 60 minutes of operations for use in troubleshooting exception reports; a method for downloading data must be available during operations [16].



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 11 of 14

- f) The following monitoring parameters shall be transmitted to a home base every 12 hours whether or not the railcar is in HLRM service [17]:
    - Location at beginning and end of each 12-hour period;
    - Histogram of train speed;
    - Histogram of car body acceleration for each axis;
    - Histogram of power supply voltage.
  - g) Performance data will be monitored to identify system degradation. Performance data will be electronically stored on storage media large enough to hold the data from one entire trip. The media shall be removed at the end of the trip and archived [18].
8. Tie-downs and cradle must conform to the *Field Manual of the AAR Interchange Rules*, "Rule 88", Section A.16.c(3), "Securement system specification loads for irradiated fuel casks shipped on flat or gondola cars," and to 10 CFR 71.45.
  9. In Rule 88, static loads must be calculated based on the weight of the cask and the vertical, lateral, or longitudinal acceleration provided.
  10. A railcar inspection must occur before each payload-carrying use of a cask and buffer railcar consist [19]; an inspection checklist is included in the *Atlas Cask and Buffer Railcar Supplemental Maintenance Manual* as Table 2.1 or a transportation service provided may provide an equivalent form superseding Table 2.1..

**2.3.2 Conceptual Cradle Operational Requirements**

1. Conceptual cradle shall accommodate loading and unloading operations of the 15 cask designs listed in Attachment A of the SOW [1] (enclosed as Appendix A).
2. The conceptual cradle designs shall facilitate loading and unloading operations of the Atlas cask railcar when the cradle is in a loaded or unloaded configuration.

**2.4 Maintenance Requirements**

1. The Atlas cask and buffer railcar shall meet the maintenance requirements listed in AAR MSRP S-2043, Appendix A titled "Maintenance Standards and Recommended Practices for Trains Used to Carry High-Level Radioactive Material" [3].
2. Maintenance or repair processes to the cask or buffer railcars must not alter the railcars from the original drawings, specifications, or bill of materials of the Atlas cask and buffer railcars.
3. Welding repairs to the cask or buffer railcars must meet the requirements of AAR MSRP S-2043, Section 4.1.10.4 titled "Special Weld Analysis Requirements for HLRM-Carrying Railcars".
4. Maintenance or repair activities to a cask or buffer railcar must not alter the railcar's performance such that it does not meet the requirements of AAR MSRP S-2043, Section 4.2.2 titled "Car Body Twist Equalization".

The *Atlas Cask and Buffer Railcar Supplemental Maintenance Manual* (included as Appendix A) contains a railcar inspection form and other specific information regarding the maintenance of the Atlas Cask and Buffer railcar.



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 12 of 14

**2.5 Additional Design Considerations**

1. The cask cradles should be designed to support the cask for lifting on and off the railcar (with or without the cask impact limiters installed) as specified in Section 2.2.2.11 above. Lifting attachments shall be designed in accordance with non-critical lifting under ANSI N14.6 [920]. A vertical lift shall be assumed (requiring the use of a spreader beam/frame). Lift points shall be assumed to support the load equally for the conceptual design. The lift points should be designed such that the personnel barrier is not removed to lift the cradle when loaded with a package.
2. For cradle attachment points, the attachment mechanism (pin/bolt) should be removable and shall be sized for manual handling (less than 50 lbs) or provisions should be designed for mechanically assisted insertion.
3. There are no restrictions as to the crane or lifting mechanism size for loading and unloading the cask and cradle on the railcar; however, the cradle design must accommodate the cask specific lifting system. There are no space or facility restrictions associated with the conceptual design of the cask railcar loading and unloading.
4. AAR Rule 88 A16c(3) does not specify if the securement system loading requirements are to be applied separately or simultaneously. Per project memos [1021] and [1122], the each load in AAR Rule 88 A16c(3) shall be applied separately and gravity shall NOT be included in the analysis.
5. The bottom of the cradle shall be flat to facilitate placement on a flat surface or intermodal transfer.
6. Conceptual cradle designs should consider the feasibility of package handling and operations.
7. Corrosion resistance (or coatings) should be considered in the conceptual cradle design.
8. Structural evaluations should be performed using a temperature range of 0 F to 100 F for material properties.  
Cask and buffer railcars shall be designed for a maximum capacity of 71,500 lbs. per axle. Note that operational limits may be different.
9. Cask and buffer railcars shall have a minimum turning radius of 150 ft.

**3.0 REFERENCES**

1. Department of Energy Contract DE-NE0008390; Part 1, Section C, Statement of Work.
2. AREVA Federal Services, LLC EIR-3014612, Engineering Work Plan (EWP) for the DOE ATLAS Railcar, latest revision.
3. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material.
4. Department of Energy, Contract DE- NE0008390; Part 1, Section E, Inspection and Acceptance.
5. Association of American Railroads, Manual of Standards and Recommended Practices, Section J – Quality Assurance M-1003, 2014.
6. ORNL/TM-2014/596, AAR S-2043 Cask Railcar System Requirements Document, Fuel Cycle Research and Development, FCRDNFST-2014-000093 Rev 1, December 2014.
7. Association of American Railroads, Field Manual of the AAR Interchange Rules, 2015.
8. Code of Federal Regulations, Title 49, Chapter II, Federal Railroad Administration, Department of Transportation.



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 13 of 14

9. AREVA Federal Services LLC Request For Information AFS-RFI-00225-0014, Determination of S-2043 Atlas Railcar Empty Condition.
10. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.3.8
11. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.4.2.
12. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.5.4.1.
13. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.5.4.2.1.
14. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.5.4.2.2.
15. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.5.4.2.3.
16. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.5.4.2.4.
17. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.5.4.3.
18. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Section 4.5.4.2.5.
19. Association of American Railroads, Manual of Standards and Recommended Practices, Standard S-2043 titled Performance Specification for Trains used to Carry High-Level Radioactive Material, Appendix A, Section 4.1.1.
- 9.20. American National Standards Institute, ANSI N14.6, for Radioactive Materials – Special Lifting Devices for Shipping Containers Weighing 10 000 Pounds (4500 kg) or More, 1993.
- 10.21. AREVA Federal Services, LLC Incoming Document AFS-IN-16-0001, Clarifications Requested by AREVA for AAR-2043, January 15, 2016.
22. AREVA Federal Services, LLC Incoming Document AFS-IN-16-0002, Clarifications Requested by AREVA for Field Manual of the AAR Interchange Rules, January 15, 2016.
- 11.23. AREVA Federal Services, LLC Request For Information Number AFS-RFI-00225-13-00, approved by DOE March 1, 2016, closed March 7, 2016.  
AREVA Federal Services LLC EIR-3016139, Atlas Railcar Supplemental Maintenance Manual, latest revision.



**AREVA Federal Services LLC**

Title: Design Basis Requirements Document (DBRD) for the DOE Atlas Railcar

Doc./Rev.: EIR-3014611-004

Project: 00225.03.0050 - DOE Atlas Railcar

Page 14 of 14

**APPENDIX A**

(INCLUDES REFERENCES 1 AND 23)

**Nominal Characteristics of Used Nuclear Fuel Transportation Casks  
 (with changes from Contract Modification #2 and Request For Information #13)**

Manufacturer and Model	Length without Impact Limiters (in.)	Length with Impact Limiters (in.)	Diameter without Impact Limiters (in.)	Diameter with Impact Limiters (in.)	Empty Weight with Impact Limiters (lb.)	Loaded Weight with Impact Limiters (lb.)
<b>NAC International</b>						
NAC-STC	193.0	273.7	99.0	128.0	188,767-194,560	241,664-254,589
NAC-UMS UTC	209.3	273.3	92.9	124.0	178,798	248,373-255,022
MAGNATRAN	214.0	322.0	110.0	128.0	208,000	312,000
<b>Holtec International</b>						
HI-STAR 100	203.25	307.5	96.0	128.0	179,710	272,622-279,893
HI-STAR HB	128.0	230.8 <sup>a</sup>	96.0	128.0 <sup>a</sup>	-- <sup>b</sup>	187,200
HI-STAR 180	174.37	285.04	106.30	128.0	< 308,647	308,647
HI-STAR 60	158.94	274.37	75.75	128.0 <sup>a</sup>	<164,000	164,000
<b>AREVA Transnuclear</b>						
MP187	201.5	308.0	92.5	126.75	190,200	265,100-271,300
MP197	208.0	281.25	91.5	122.0	176,710	265,100
MP197HB	210.25	271.25	97.75	126.0	179,000	303,600
TN-32B <sup>c</sup>	184.0	261.0 <sup>d</sup>	97.75	144.0 <sup>a</sup>	-- <sup>d</sup>	263,000 <sup>a</sup>
TN-40	183.75	261.0	99.52	144.0	-- <sup>d</sup>	271,500
TN40HT	183.75	260.9	101.0	144.0	-- <sup>d</sup>	242,343
TN-68	197.25	271.0	98.0	144.0	<272,000	272,000
<b>EnergySolutions</b>						
TS125	210.4	342.4	94.2	143.5	196,118	285,000

Source: Greene, S.R., J.S. Medford, and S.A. Macy, Storage and Transport Cask Data for Used Commercial Nuclear Fuel, 2013 U.S. Edition, Report ATI-TR-13047, August 2013

a. Estimated

b. HI-STAR HB transportation casks are already loaded so they would not be shipped empty.

c. This is the TN-32B that DOE plans to use in the High Burnup Dry Storage Cask Research and Development Project, and ship from North Anna Nuclear Power Plant. The TN-32B does not currently have a transport certificate of compliance. The dimensions and weight with impact limiters for the TN-32B are estimated.

d. TN-40 transportation casks are authorized for single use shipments and would not be shipped empty. TN-32B and TN40HT transportation casks are also assumed to be authorized for single use shipments and would not be shipped empty on an S-2043 cask car.