Update on Development of a U.S. Rail Transport Capability for Spent Nuclear Fuel and High-Level Waste – 17138

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ABSTRACT

The U.S. Department of Energy, Office of Nuclear Energy (DOE-NE) 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) and high-level radioactive waste (HLW) since transport will be a necessary component of an integrated waste management system. This paper provides an overview of the progress to date, and discussion of the path forward, for the current DOE-NE effort related to designing and fabricating prototype railcars for rail transport of SNF from commercial nuclear power reactor sites when a receiving site becomes operational.

INTRODUCTION

The Blue Ribbon Commission on America's Nuclear Future made a series of recommendations to the Secretary of Energy in 2012 regarding the management and eventual disposal of SNF and HLW. [1] One recommendation was to make "prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available." In response to these recommendations, DOE-NE established the Nuclear Fuels Storage and Transportation Planning Project (NFST). The mission of NFST was to lay the groundwork for implementing interim storage, including associated transportation activities. In October 2016 DOE-NE created the Spent Fuel and Waste Disposition (SFWD) Program, which now includes this mission.

Moving commercial SNF from its current locations at reactor sites will require both a receiving site(s) and a transportation capability. The U.S. currently has a very limited capability to move large rail-size casks of SNF. Improved rail transportation capability will be needed to move the SNF, no matter where the final destination is.

The Association of American Railroads (AAR) has published a technical standard developed specifically for railcars used to transport High-Level Radioactive Material (HLRM): *Performance Specification for Trains Used to Carry High-Level Radioactive Material, Standard S-2043*. [2] AAR defines the term HLRM to include SNF and HLW. DOE is in the process of developing prototype railcars that satisfy S-2043.

HLRM from commercial nuclear power plants will need to be shipped in transport casks certified in accordance with 10 CFR Part 71 by the Nuclear Regulatory Commission (NRC). The NRC has certified numerous rail transport cask designs supplied by various manufacturers. These rail transportation casks will weigh between approximately 82 and 207 tons when loaded; additionally, each cask, if transported by rail, would need to be attached to the railcar by a cradle (often called a “skid”) that is expected to weigh between 10 and 20 tons. No existing railcars have been approved as AAR S-2043 compliant for shipping these NRC-certified casks. Therefore, transport of HLRM over the railroad infrastructure in the U.S. in railcars that meet S-2043 will require new railcars to be designed, tested, and approved by the AAR for use.

An effort to design and develop prototypes, conduct necessary testing and secure approval of S-2043 compliant railcars is estimated to take approximately seven to nine years to complete. Approval by the AAR will require extensive full-scale testing of the individual railcars and the complete rail consist.

DOE-NE is currently funding an effort to have industry design and develop S-2043 compliant cask and buffer railcars. The result of this effort will be cask and buffer railcar designs and fabricated prototypes ready for testing. Future activities are envisioned to perform the required testing and obtain approval of the cask and buffer railcars from the AAR.

While a complete transportation system cannot be fully developed until a destination site is known, long lead-time activities necessary for transportation system development such as railcar design and prototype fabrication can be addressed now. DOE’s SFWD is proactively laying the groundwork so that a transportation system capability will be available to ensure safe, secure, and efficient movement of SNF from commercial nuclear power reactor sites in a timely manner when a receiving site becomes operational.

ATLAS RAILCAR DESIGN PROJECT OVERVIEW

The DOE awarded a firm-fixed-price (FFP) contract on August 21, 2015 for the design, associated analysis, and prototype fabrication of cask and buffer railcars to transport HLRM. This was the culmination of 18 months (March 2014 to August 2015) of concerted effort to prepare the solicitation, review and evaluate the proposals, and make the contract award to AREVA Federal Services (AFS).

The new cask railcar design is named *Atlas*. The Atlas Railcar Design Project has three phases under a single multi-year FFP contract, plus two more phases that are not under contract yet. Phase 1 is Mobilization and Conceptual Design, Phase 2 is Preliminary Design, and Phase 3 is Prototype Fabrication and Delivery. Phases 4 and 5 are Single-Car Testing and Multiple-Car Testing, respectively. A description of the major activities in each of the five project phases is provided in this paper. The summary-level project schedule is shown in Fig. 1.

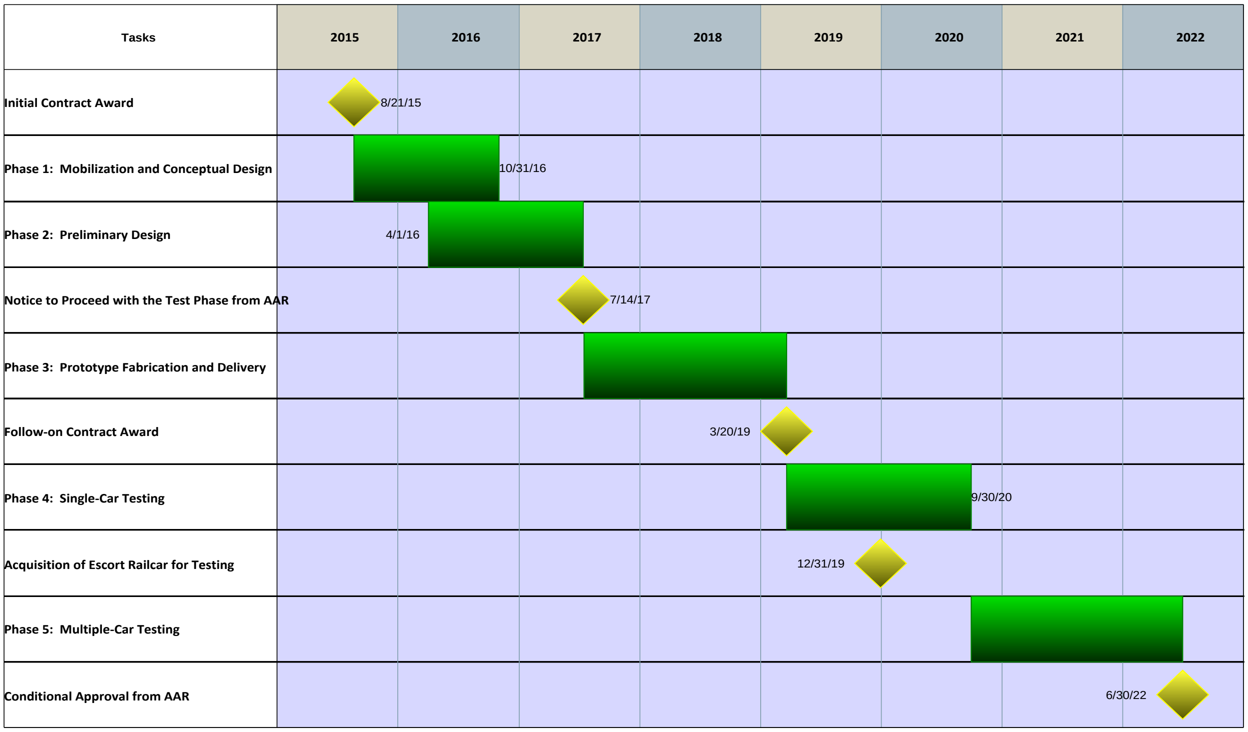

Fig. 1. Schedule for ATLAS Railcar Design Project

Phase 1 was completed at the end of October 2016 [3]. This work included preparation of a number of planning documents for project management, requirements, and engineering, as well as development of cask loading procedures and conceptual design of cask cradles and preparation of conceptual designs for the cask and buffer railcars. Phase 2 was initiated by performing computer modeling for the preliminary cask and buffer railcar designs. During the design analysis and modeling of the eight-axle railcar conceptual design, it was determined that hunting was occurring and that the damping in the trucks was not sufficient to damp out this vibration. To address this issue, the railcar designer made the decision to change to a twelve-axle railcar design. Phase 3 has not yet started.

The first three project phases under the current contract will be completed in March 2019. Follow-on contract(s) will be awarded to conduct the single-car and multiple-car testing of the Atlas prototype railcars to secure railcar design approval. The complete project to design and develop the Atlas cask car and buffer car prototypes, perform the required railcar testing, and obtain design approval from AAR is currently estimated to take approximately seven years, from 2015 to 2022.

The primary contractor for Phases 1 through 3 is AREVA Federal Services, with six supporting subcontractors. The seven organizations and their primary roles on the Atlas Railcar Design Project are as follows:

AREVA Federal Services (AFS): project integrator, conceptual designs of cask cradles and attachment mechanisms.

AREVA-TN (aka Transnuclear): cask-to-cradle-to-Atlas railcar loading procedures, peer review.

KASGRO Rail: overview of the cradle-to-Atlas railcar attachment mechanism design, railcar conceptual and preliminary designs, detailed railcar designs including finite-element modeling, and prototype fabrication. KASGRO Rail is a fabricator of heavy-duty railcars with an AAR-certified quality assurance program. A point of particular importance to the Atlas Railcar Design Project is that KASGRO Rail is the fabricator of the U.S. Navy's M-290 cask railcar, the only AAR S-2043 approved railcar to be manufactured to date.

Transportation Technology Center, Inc. (TTCI): dynamic modeling of railcar designs using the NUCARS computer code and AAR Standard S-2043 submittal expertise.

Stoller Newport News Nuclear (SN3): peer review of Atlas cradle design and loading procedures based on previous experience as cradle designer/fabricator of the U.S. Navy's cask cradle.

MHF Services, Inc.: peer review of Phase 1 cask and cradle design data packages and AAR plate dimensions and cask railcar clearance.

Coghill Communications, Inc.: woman-owned small business responsible for document management.

PHASE 1: RAILCAR CONCEPTUAL DESIGN

The mobilization part of Phase 1 includes typical project management planning activities such as development of a project management plan and other associated plans. Conceptual designs were developed for the cask cradles, cask railcars, and buffer railcars. General loading procedures were developed for each cask and cradle combination. Phase 1 was completed in October 2016. DOE has released the complete Phase 1 Conceptual Design Report (Reference #3).

The Atlas cask railcar is being designed to carry 17 different SNF casks. During transport, a transportation cask must rest on a cradle, often called a skid, on top of the cask railcar deck. The cask railcar is being designed to transport one cask at a time along with one cask cradle. The cask railcar design must include all needed attachment points and a description of how to attach each of the cradles to the deck.

AFS is responsible for interfacing with all the transportation cask vendors to obtain the transportation cask information necessary to design the cask railcar. One result of this collaboration will be conceptual designs of cradles: cradle designs that accommodate each of the 17 casks. These conceptual cradle designs will determine the height of the cask's 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. These conceptual cradle designs, however, will not be carried through to preliminary designs or final designs. DOE does not require final designs or prototypes of any cradles. Cradle designs are being developed in this project to define the railcar design envelope, so DOE only needs cradle design information as it pertains to the performance of the cask railcar.

Cask Railcar Conceptual Design

The initial cask railcar conceptual design was for an eight-axle[a] freight railcar. The process of developing a conceptual design calls for generating basic design information such as dimensions, deck layout, and number and type of trucks and then providing that information to the simulation team for the initial design analysis and modeling that occurs in Phase 2.

During the design analysis and modeling of the eight-axle cask railcar conceptual design, it was determined that hunting was occurring and that the damping in the trucks was not sufficient to damp out this vibration. Hunting is a lateral instability where the wheelsets start rapidly moving from side to side due to high lateral forces that are not sufficiently countered by the damping effects of the overall design. Hunting occurs at what is known as the *critical speed*, and rail vehicle designers must ensure that the critical speed is higher than the speed of operation.

After trying numerous design modifications to the eight-axle conceptual design, it was determined that the hunting issue could not be resolved using this design. Thus, this eight-axle design was abandoned, and the design team is now preparing a twelve-axle cask railcar conceptual design, as shown in Fig. 2, in preparation for Phase 2 analysis and modeling. This new approach is based on a similar design, for another customer, of a cask railcar that has already received AAR approval, so it is anticipated that the Atlas twelve-axle design will satisfy all the requirements of S-2043.

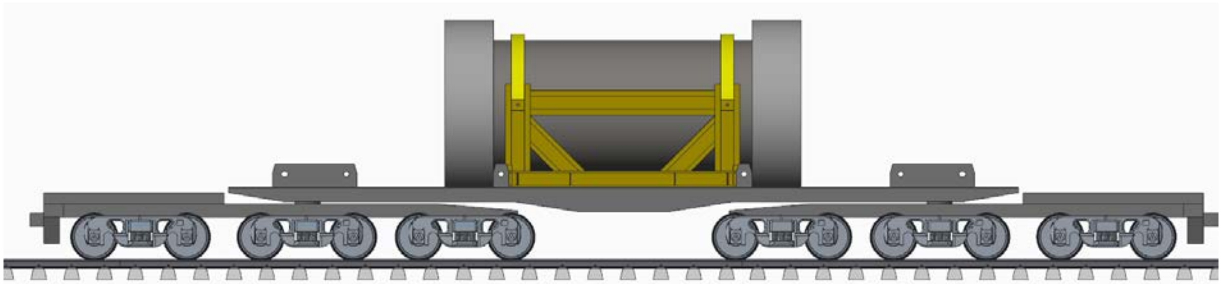

Fig. 2. Atlas Twelve-Axle Railcar Conceptual Design

[a] Terminology note for railcars: a wheelset is an assembly that consists of two wheels fitted to an axle. Two wheelsets connected by two sideframes and a center bolster are called a three-piece freight truck or bogie. Thus, each truck has two axles, so an eight-axle railcar will have four trucks underneath the railcar frame and a twelve-axle railcar will have six trucks.

Buffer Railcar Conceptual Design

Buffer railcars are flatbed cars that are required by regulation (49 CFR 174.85) to separate SNF cask cars from the locomotive and rail escort vehicle (REV). The buffer railcar conceptual design is for a four-axle freight railcar as shown in Fig. 3. The process of developing a conceptual design calls for generating basic design information such as dimensions, deck layout, and number and type of trucks and then providing that information to the simulation team for the initial design analysis and modeling that occurs in Phase 2.

Fig. 3. Buffer Railcar Conceptual Design

This buffer railcar design is based on the design of another railcar for the U.S. Navy, which is also designed to satisfy AAR Standard S-2043. This should reduce the number of issues that occur during the design analysis and preliminary design development.

Cask Cradle Conceptual Designs

SNF casks shipped by rail are secured to the railcar using a cradle, or skid, which attaches to both the cask and railcar deck. Each cradle is custom designed for a particular cask design and must also mate with various attachment mechanisms on the railcar deck. Thus it is an engineering challenge to ensure that the cask-to-cradle-to-railcar design is integrated into a safe and secure means of transporting SNF by rail.

The Atlas railcar is being designed to transport 17 different SNF cask models. This adds complexity to the railcar and cradle designs since these different casks will have different weights and dimensions that must be considered during the conceptual design of the cradle and cradle attachment mechanisms. An important design parameter is the development of the dimensional and payload bounding conditions that will apply to each cask cradle design.

Many of these casks can be attached to the railcar in similar ways; therefore, the casks were sorted into four cradle design families as shown in Table 1 by grouping casks together that can be attached to the railcar in a similar fashion. This allows for the design of four conceptual cradles that will be capable of attaching all 17 casks to the Atlas railcar.

Table 1. Conceptual Cradle Design Families and Casks

Family 1	Family 2	Family 3	Family 4
TN-32B	NAC-STC	MP197	MP187
TN-40	NAC-UMS UTC	MP197HB	
TN-40HT	NAC MAGNATRAN	TS125	
HI-STAR 100	TN-68		
HI-STAR 100HB			
HI-STAR 180			
HI-STAR 60			
HI-STAR 190SL			
HI-STAR 190XL			

All four of the cradle families consist of a central cradle base that attaches to the railcar to resist lateral and vertical forces. Variations between families include how the cradles attach to the casks, whether the casks use an integral shear key, if cask trunnions are used for restraint, and whether end stops are used.

DOE is funding the development of conceptual cradle designs so that the Atlas railcar designers can use these conceptual designs to estimate the centers of gravity and loads on the railcar axles, along with determining other information required to support railcar design analysis and testing. However, DOE will not carry these conceptual cradle designs forward to final designs since this is not necessary to finalize the railcar designs. Each cask vendor will be responsible for developing the final cradle designs and fabricating the cradles for their own SNF casks. The only engineering restriction on the cask vendors, if their casks are to be transported on the Atlas railcar, is to ensure that their cradle designs fit within the dimensional and payload bounding conditions of the Atlas railcar design.

There are three components for the development of conceptual cradle designs for railcars: (1) calculating the payload and size bounding conditions, (2) developing conceptual cradle designs for each SNF cask model, and (3) designing conceptual cradle attachment points on the railcar deck that are able to securely affix all of the cradle designs to the railcar. All three activities are done concurrently and iteratively as the conceptual cradle designs are refined.

General Loading Procedures

General loading procedures were prepared to describe how to load each of the casks onto the Atlas railcar, including whether the impact limiters would be attached to the cask before or after the cask is secured to the railcar. The procedures provide guidance for the loading of casks onto the transportation cradles and the loading of cradles onto the railcar.

These loading procedures are of a very general nature based upon conceptual cradle designs and a conceptual railcar design. The procedures are likely to change as the cradle and Atlas railcar designs evolve. The general nature also precludes providing detailed, site-specific loading procedures or specific instructions, diagrams, or figures regarding these procedures.

These procedures were developed based upon information from the cask safety analysis reports and the conceptual cradle design drawings. The procedures only cover activities related to loading casks onto the railcars and do not address loading contents into the casks, performing any radiation surveys, conducting necessary inspections, or preparing shipping documentation or placarding.

The general loading procedures 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. It is assumed that the railcar arrives on site with the appropriate cradle but without a cask. The cradles are designed so that they can be loaded with a cask when attached to the railcar or when positioned on the ground.

PHASE 2: RAILCAR PRELIMINARY DESIGN

The Phase 2 preliminary design activities are currently underway. This includes performing the required design analysis, modeling and simulation of the railcar designs, preparing preliminary designs of the Atlas and buffer railcars, and submitting a preliminary S-2043 design package to the AAR for review and approval.

The conceptual designs from Phase 1 are being developed further in Phase 2 to include detailed technical descriptions of the railcars, general design drawings, parts lists, and detailed documentation of the design analysis, modeling, and simulation. The final outcome will be a detailed preliminary design package with sufficient information to support fabrication of prototype Atlas and buffer railcars in Phase 3 of the project.

Design Development, Analysis, Modeling, and Simulation

The railcars must be designed to meet AAR Standard S-2043 design requirements in six areas: (1) structural analysis, (2) nonstructural static analysis, (3) dynamic analysis, (4) brake system design, (5) system safety monitoring, and (6) railcar clearance and weight.

Structural analysis of the railcar designs is performed using commercial finite-element analysis (FEA) software that considers a number of load and force combinations, including dead load, live load, coupler load, compressive end load, and impact load as specified in S-2043. The analysis includes an assessment of whether the cask cradles and securement points can withstand specific static, cyclic, and dynamic loads. There are also crashworthiness requirements to ensure that railcar coupling systems, trucks, and wheelsets will not separate from one another in the event of a derailment.

Nonstructural static analysis includes an assessment of truck twist equalization to ensure adequate truck load distribution under statically applied track twist conditions, car body twist equalization to document the amount of wheel unloading during car body twist, like that encountered during negotiation of a spiral, and static curve stability analysis to calculate the amount of wheel unloading in adverse curving scenarios.

Dynamic analysis simulations of the railcars are modeled for 14 areas of track performance. The purpose of the simulations is to provide a realistic basis for evaluation of railcar dynamic performance under less-than-ideal conditions. This demonstrates that the railcar designs provide an adequate margin of safety from structural damage and from any tendency to derail. Each simulation must meet nine performance criteria related to lateral and vertical wheel forces, car body roll angle, and various car body accelerations.

The brake system design must include electronically controlled pneumatic (ECP) brakes, which provide higher braking rates to improve stopping distances, possibly preventing some grade crossing accidents. The ECP brake monitoring system also transmits vital safety-related information (e.g., brake pressure, roller bearing temperature, vibration level, etc.) to the locomotive, which will allow the train crew to stop the consist in the event of equipment malfunction or failure. The ECP brake design is modeled during the dynamic simulations.

The railcar design must include a reliable and robust safety monitoring system designed to prevent derailments caused by equipment degradation or failure. The system must be designed to provide the train crew with real-time monitoring of 11 performance parameters, including railcar location, speed, truck hunting, rocking, wheel flats, bearing condition, ride quality, braking performance, vertical acceleration, lateral acceleration, and longitudinal acceleration.

The railcar designers must provide railcar clearance diagrams for each railcar design and determine bridge loadings for each railcar.

Preliminary S-2043 Design Package Submittal to AAR

The railcar designer is required to submit a preliminary S-2043 design package to the AAR Equipment Engineering Committee (EEC) near the end of Phase 2 of this project. The EEC will perform an in-depth technical review of the railcar designs prior to Phase 3 prototype fabrication. A successful outcome of this review will be a notification from the EEC to proceed with the railcar test phase, which will indicate to the railcar designer that Phase 3 fabrication of the railcar prototypes for testing can begin.

PHASE 3: PROTOTYPE RAILCAR FABRICATION

The Phase 3 prototype fabrication and delivery activities will begin in July 2017 when the preliminary railcar designs are scheduled to be completed and the AAR EEC has provided notification to proceed with the test phase. KASGRO Rail will fabricate one prototype Atlas railcar capable of transporting any of the 17 SNF casks and two prototype buffer railcars in accordance with the AAR-approved preliminary designs developed in Phase 2 of this project. A description of the Phase 3 activities and accomplishments will be included in future updates of this paper.

FUTURE ACTIVITIES

There are future activities (beyond the current contract with AFS) that need to be accomplished in order to have a complete AAR-approved railcar consist to conduct shipments of SNF and HLW. A railcar consist includes two locomotives, one or more Atlas cask railcars, two or more buffer railcars, and an REV.

Obtaining AAR conditional approval to operate the railcar consist will require conducting single-car and multiple-car testing to ensure that the railcars are prepared for operational use. The single-car testing for this project is Phase 4 and the multiple-car testing is Phase 5. The multiple-car testing will require the acquisition of an REV so that the cask car, buffer cars, and REV can be tested in a complete consist configuration.

Phase 4: Single-Car Testing

AAR Standard S-2043 requires completion of a comprehensive set of single-car tests to confirm the results of the design simulations and to ensure that the railcars meet the stringent safety requirements of the standard. The single-car testing is conducted in five major categories: (1) vehicle characterization, (2) nonstructural static tests, (3) static brake tests, (4) structural tests, and (5) dynamic tests.

Vehicle characterization is performed to verify that the components and vehicle as a whole are built as designed. This involves characterizing properties of the railcar body and its suspension using off-track testing methods. Characterization results will aid the railcar designers in estimating performance under conditions that cannot easily be tested. Tests include system-level and component-level stiffness, damping and resonances, twist and roll, pitch and bounce, yaw and sway, and hunting performance. Other tests in this category include truck rotation stiffness and break-away moment, inter-axle longitudinal stiffness, and axle yaw stiffness.

Nonstructural static tests are performed to demonstrate the ability of the railcar to maintain adequate vertical wheel loads in extreme load conditions and poor track geometry environments. Tests include truck twist equalization, car body twist equalization, static curve stability, and horizontal curve negotiation.

Static brake tests include measurement of braking ratios for both ECP-controlled and regular freight operation of the braking systems on the railcar consist. Braking ratio is the braking force of a full brake application of a railcar divided by the total weight of the railcar.

Structural tests are conducted to demonstrate the railcar's ability to withstand the rigorous railroad load environment and to verify the accuracy of the structural analysis modeling. Tests include compressive end loading, coupler vertical loads, jacking, twisting, and impact tests. A minimum of 50 strain gages on the railcar underframe must be monitored and compared to the Finite Element Analysis (FEA) predictions.

Dynamic tests are conducted and the results compared to the dynamic analysis simulations previously performed. Instrumented wheelsets are required and are used to measure dynamic performance in 14 areas of track performance under less-than-ideal conditions. This demonstrates that the railcar designs provide an adequate margin of safety from structural damage and from any tendency to derail. Instrumented wheelsets are railway wheelsets that have been instrumented and calibrated so that they are capable of accurately measuring the dynamic contact forces between the wheel and rail.

Acquisition of Rail Escort Vehicle

The REV is a passenger car that will provide conveyance for armed escorts as required in 10 CFR 73.37 for rail shipments of irradiated reactor fuel. The REV must be included in the consist during the multiple-car testing in order to meet all S-2043 requirements. DOE currently plans to use an REV design that is already being developed for the U.S. Naval Nuclear Propulsion Program. The Navy's REV design will meet all AAR requirements.

Phase 5: Multiple-Car Testing

The multiple-car test train consist must match the anticipated DOE SNF train as closely as possible with a minimum of one of each type of car. It is anticipated that a DOE consist will include two locomotives, one or more Atlas railcars, a minimum of two buffer railcars, and one REV.

The multiple-car tests are designed to verify that the individual cars do not adversely affect the performance of adjacent cars. There are three categories of multiple-car tests, including dynamic, system monitoring, and revenue service tests.

Dynamic tests are performed to measure braking stop distance under various loads and rail conditions, braking performance in curves, ability of the hand brakes to hold the train on a grade, and buff and draft loads in curves. System monitoring tests are conducted on all the train's communications and monitoring systems under normal service conditions and during failure simulations of various components. Revenue service tests are performed to demonstrate acceptable performance under revenue service conditions such as turnouts, crossovers, and on poorly maintained spur tracks.

The Atlas railcar final testing report will be completed in Phase 5 of this project and submitted to the EEC for a final review with a successful outcome resulting in conditional approval to operate the railcars during the conditional approval period. After satisfactory operation of the railcars for approximately 100,000 service miles, the railcar designer will submit a follow-up test report to the EEC for final review. A successful outcome would result in the EEC granting full approval of the Atlas railcar design to the railcar designer.

CONCLUSIONS

This paper documents the successful results achieved to date and the path forward for the DOE Atlas Railcar Design Project. A summary was provided of the ongoing progress on the AFS contract for the design, associated analysis, and prototype fabrication of cask and buffer railcars to transport SNF and HLW. The end result of this project will be the final cask and buffer railcar designs.

During the last year, the Phase 1 conceptual designs were completed. This work included preparation of a number of planning documents for project management, requirements, and engineering, as well as development of cask general loading procedures, conceptual designs of cask cradles, and conceptual designs of the cask and buffer railcars.

Also during the last year, DOE began work on the preliminary designs of Phase 2. This included computer modeling for the preliminary cask and buffer railcar designs. During the design analysis and modeling of the eight-axle railcar conceptual design, it was determined that hunting was occurring and that the damping in the trucks was not sufficient to damp out this vibration. To address this issue, AFS made the decision to change to a twelve-axle design.

Phase 3, which is scheduled to start in July 2017, will include fabrication of one Atlas cask railcar and two buffer railcars.

The report also describes the future testing activities that will be required to obtain AAR conditional approval of the railcar designs. The effort to design and develop railcar prototypes, conduct the necessary testing, and secure approval of S-2043-compliant railcars is estimated to be complete in 2022. AAR approval will require extensive full-scale testing of the individual railcars and the complete railcar consist.

While a complete transportation system cannot be fully developed until a destination site is known, long lead-time activities necessary for transportation system development, such as design and prototype fabrication, can be addressed now. DOE is proactively laying the groundwork so that a transportation system capability will be available to ensure safe, secure, efficient, and timely movement of SNF from commercial nuclear power reactor sites when a receiving site becomes available.

REFERENCES

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