

OPERATING AN ONSITE USED FUEL TRANSPORTATION PROGRAM

G. Pringle and S. Siu

Ontario Power Generation, Nuclear Waste Management Division, Pickering Waste Management Facility, Pickering, Ontario, Canada

glenn.pringle@opg.com, steven.siu@opg.com

1. Dry Storage Container Transporters

Ontario Power Generation (OPG) operates a fleet of custom built vehicles to transfer used nuclear fuel from the wet irradiated fuel bay (IFB) to the used fuel storage facilities. Used nuclear fuel is stored in the IFB for about 10 years to provide sufficient cooling and reduction in radiation fields thus enabling subsequent storage in passive dry storage containers (DSC) at each nuclear site.

Used fuel bundles, contained in modules, are loaded into the metal-jacketed concrete DSC while under water inside the IFB followed by fitting and locking of a closure clamp. After emptying the water, drying and decontamination, the DSC is picked up by a transporter which carries the DSC from the used fuel bay to the dry storage processing and storage buildings. The loaded and clamped DSC's are currently transported over distances of 0.8 to 4 km on site roads and outside the protected area of the power plant in some cases. Movement of the containers outside the crane footprint in the processing shop is also performed by transporter (e.g. movement for inspection, into the painting bay or for final storage). The safety analysis for transport of DSC's includes credible scenarios including collision, fire, natural disaster, tornado, road hazards and is bounded by the scenario of a 2m drop of the container. Nevertheless, every effort is made to protect analysis margins by designing and operating the transporters to maximize reliability. This has additional rewards in maximizing availability and in minimizing the probability of a public relations event should a transporter be stranded en route at the site. Hence DSC transporters are deemed to be a critical system in the dry fuel storage operation.

A DSC transporter is a heavy vehicle (~40 tonnes) utilizing 3-4 axles and which is capable of lifting, placing and transporting the loaded DSC (~80 tonnes) at low speed (nominally 4-12 km/hr). All DSC transporters in the OPG fleet are custom designed vehicles. Due to the heavy gross vehicle weight of the transporters, they are usually powered by a diesel engine which in turn powers a hydraulic drive system.

Presented in this paper is the experience obtained by OPG Nuclear in managing the development, fabrication, operation, maintenance, refurbishment and life cycle of the DSC transporter fleet.

2. Hammant DSC Transporter

The first lift-and-place DSC vehicle built for transporting DSCs at the prototype Used Fuel storage facility in OPG, the Pickering Waste Management Facility (PWMF), was named the Hammant (see Figure 1) after the manufacturer of the vehicle. Designed in 1990, commissioned and placed in service in 1995, it was a custom U frame design with 8 wheels and weighed approximately 40 tonnes (~22'L 11'W 16'H). Four of the six rear wheels were steerable and the driving and braking functions limited to the two front wheels. All 8 wheels were solid, foam filled tires to prevent deflation. The open end of the U frame received the DSC. The Hammant was powered by a 2

stroke, 300 HP diesel engine with maximum speed of 4 km/h. Steering was controlled by a hydraulic motor via a programmable logic controller. The hydraulic system consisted of two closed loops for the drive/brake systems and one open loop to control the lift and place system. A 49.8 Hz radio control unit provided remote operation capability. The lift and place system consisted of 2 lift trunnions, 2 lift arms, 2 lift cylinders and 2 locking cylinders. The safety system consisted of 5 perimeter emergency stops, button, front and back bumper limit switches.

Like most custom “one-off” vehicle designs, the Hammant experienced many different and often repetitious teething and design problems such as hydraulic leaks, hydraulic system (pump) failures, control system malfunctions, lift system failures and steering problems. Several upgrades were made to improve performance and reliability (e.g. upgrading the locking mechanism in the lifting system, upgrading the service and parking brakes and modifying the control logic to correct misalignments in the rear wheels during steering).

However, design issues continued to limit use of the Hammant, necessitating upgrades and eventual procurement of a more suitable transporter design in the Liftking during 2000-2002. The rearward visibility in the Hammant was limited and relied heavily on communication with human spotters. Health concerns were raised in 2000 over the emissions from the two stroke engine when used indoors and the Hammant was restricted from being used in the IFB's. The vehicle was further limited to gentle grades due to concerns over inadequate braking performance on some road grades and then limited to operating on flat surfaces to avoid unequal axle load distribution that would overly stress the steering and suspension components. Finally, uneven trunnion engagement and the resulting potential of a DSC closure clamp being bumped into the lift frame, resulted in the Hammant being restricted to only operation inside the processing and storage buildings where clamps are either not required or the DSC is already welded, respectively. It remained as a backup unit until it was removed from service in 2014 due to the excessive investment required to resolve known design and reliability issues. Over 1000 hours of operation were accumulated in 18 years of operation.



Figure 1 Hammant Transporter

3. Liftking DSC Transporter

Expansion from a single used fuel facility to one at each of three nuclear sites, continuing problems and restrictions with the Hammant and lack of vendor support led to the procurement of transporters of a new design from Liftking Industries in 2002.

The following improvements were included in the Liftking transporters (see Figure 2) in response to previous operational experience. A four stroke diesel engine was specified to reduce emissions; and the control system was upgraded from analog to a digital control system. Walking beams were incorporated in the rear frame to improve axle load distribution via wheel contact with the ground. New features in the Liftking included use of a vehicle lift system to lift and place DSCs. The raised cabin, and a rear-facing drive mode during lift and place operations, improved sightlines sufficiently that the remote control option was rarely used in operation. In addition, steering capability was concentrated in the front wheels only in order to reduce complexity and alignment problems while a seat occupancy switch was added as an additional safety feature.

The first two Liftking transporters experienced teething problems with the lifting cylinders, hydraulic motor, starting system, braking system and control systems. Subsequently, two additional Liftking transporters were built with some minor enhancements including a winter package with a heater for the coolant and battery and an improved lift joint utilizing spherical joints that were more forgiving and less failure prone than the original 'straight through' rigid design (see Figure 2).

Latent defects also appeared. In 2014, the hydraulic system on a Liftking failed because a grinding disc left in the hydraulic tank during manufacture and worked its way over to block the suction line. The pump was refurbished and replaced.

Some additional enhancements were made to all four Liftkings after they were put in service. The braking system was improved to increase the total braking capability. An after treatment device (ATD) was added to the exhaust system to reduce NOX emissions and, most importantly, particulate/PAH and irritant emissions. Dry composite bushings were used to replace the hard bushings in the lift system.

The four Liftking transporters average between 6 to 15 running hours per month and lifetime running hours range from 900 to 1600 hours. After 15 years of service, the Liftking transporters are scheduled to undergo major refurbishment in 2016. A new CANBUS control system with open source components will replace the existing obsolete Vansco units. The control system will be completely rewired. A new starting system will also be added. The open and closed loop hydraulic systems will be overhauled. A new dashboard in the cab will replace the existing rudimentary display. The lift and place system will be inspected and components will be replaced or rebuilt based on the inspection findings.



Figure 2 Liftking

4. GEN4 DSC Transporters

In 2011 OPG commissioned a new design of DSC transporters to provide redundancy during and after the Liftking refurbishment. The design was completed in 2012 and the first transporter was fabricated in 2013. The new transporter was named “GEN4” signifying the fourth generation DSC transporter. A second GEN4 transporter was built in 2015. Changes made in the GEN4 included eliminating the front and rear lift joints by reintroducing a hydraulic arm lift system, using a CANBUS control system with open sourced components to avoid future obsolescence issues and employing 8 wheel vehicle with 2 front and 6 back wheels of which all but 2 rear wheels are capable of steering.

An enhanced active safety system (LED Laser based sensors) was specified to identify proximity to objects and providing markers that can be seen for the video monitors in the cab. An Auxiliary Power Unit was added for emergency operation of the vehicle during major functional failures. The GEN4 DSC transporter was designed to a higher transport maximum speed of 12 km/hr for providing a backup for the TOR vehicle used at the Western site for relatively long transport distances.



Figure 3 (a) Gen4 Transporter and (b) uneven lifting incident

Several functional failures were encountered during the commissioning of the GEN4 transporters. There were frequent steer drive leaks which were caused by a minor fabrication issue. The laser

based safety system malfunctioned during poor weather conditions and the laser guides were hard to see in sunlight. The original solid rubber tires were too soft resulting in significant abrasion of the treads and displacement of the edge of the tire over the rim due to compression from vehicle weight. Stiffer rubber and rims with wider chamfered flanges (which retain the rubber more securely) were used for the tires. Uneven lowering of a DSC was experienced and resulted in DSC contact with the lift arms and damage to the trunnion cylinder. The frame was confirmed to have suffered no damage. Software logic to limit mis-alignment of the lift arms and the correct LED sensor logic were subsequently tested with success. Unfortunately, the misalignment caused damage in the trunnion mechanism which led to further troubleshooting and eventual replacement of the trunnion cylinder. Manufacturing deficiencies of bushings in the trunnion cylinder were also repaired in this evolution.

Successful completion of a sightline simulation, and success of the previous Liftking series without using the remote, resulted in no remote being ordered with the Gen4. It was discovered that maneuvering in close quarters was difficult without multiple spotters and steering was slow when unable to observe the multiple wheel positions from outside the machine. A remote was retrofitted after cyber security concerns were addressed by using an encrypted handshake and limited range.

Also, during commissioning, the on-board DSC made contact with another DSC during placement operations. An error in the step logic of the remote control was missed during commissioning because a hand wave was used to simulate the interruption of the laser beam sensor and simulate proximity to the stationary DSC. The resulting ‘remaking’ of the beam prevented an expected delay and did not allow the operator to react.

5. TOR DSC Transfer Vehicle

A DSC transfer vehicle capable of 20 km per hour was deployed at the Western Waste Site in 2005 for transporting DSC’s longer distances (4 km) than at the other two sites. The TOR (see Figure 4) is a truck-based vehicle to reduce unique design features and is not capable of DSC lift and place operations. Instead it relies on cranes in the IFB and the processing facility to load the DSC onto a flat bed. Most failures with the other transporters relate to the complex lift and place system requirements. The simpler TOR consequently has fewer functional failures than the other transporters. A Liftking is used at this site for lift and place operations in the storage buildings. The TOR also utilizes solid rubber tires and has had a number of teething problems involving tires debonding- almost off of the wheels. Current running hours average approximately 13-15 per month, totalling approximately 1100 lifetime running hours.



Figure 4 TOR transfer vehicle

6. DSC Transporter Maintenance

It is important to avoid catastrophic in-service failures of the DSC transporters because they carry used nuclear fuel, are used to fulfill contractual requirements in accepting used fuel from a separate nuclear utility (Bruce Power), and operate outside the protected area of the nuclear facility on occasion. A stranded transporter with a loaded DSC could have severe negative public relations impact to OPG and the whole nuclear power generation industry. Hence reliability is essential. In addition, disruption of production schedules could result in the IFB's becoming too full and impacting power plant operation.

Safety systems on the transporters such as the lifting system, onboard fire protection system, hydraulic systems require strict adherence to periodic maintenance. Components that require lubrications are maintained during planned preventive maintenance. These are all tracked using the preventative maintenance program and completed at Transport equipment facilities onsite. However major maintenance such as structural inspection (e.g. walking beam), major power train repair (e.g. cracked walking beam (see Figure 5) may require shipping the transporters off-site to the manufacturer or an alternate qualified shop to complete the work. Costs of annual maintenance for each transporter adds up to tens of thousands annually thus making periodic upgrades or new designs cost-effective when repetitive problems surface.



Figure 5 (a) walking beam cracked welds in cross members (b) damaged lift joint pin

7. Parts Obsolescence

Due to the unique application, proprietary design and long operational life of DSC transporters, parts obsolescence is a common occurrence in the life cycle. That is particularly true in electrical and electronic parts and components. Control system modules on the Liftking transporters became obsolete a few years ago. While remaining industry spares are searched for and purchased, eventually limited availability of spares necessitated the refurbishment of the control system on the Liftking transporters. Without the modules the transporters cannot be operated. The unique tire design also led to purchasing the remaining available stock for future use. Strict change control processes in the nuclear industry make the parts replacement process even more cumbersome. Managing spare parts is essential to keeping the fleet operating reliably.

8. Lessons Learned in Acquiring New Transporters and In-service Support

The followings are some of the valuable lessons learned in acquiring new transporters and in-service support:

1. Ensure the design is rugged and simple and ensure the Design Requirements are well thought out. Employ a healthy questioning attitude in design and operability reviews to ensure that conclusions for one design don't drive changes that may not apply to another design (e.g. assuming a remote control was unnecessary for the GEN4 even though removing the vehicle lift system in the design had already reduced the visibility for the GEN4).
2. Single or low volume vehicle designs require a thorough commissioning program that must include on-site shakedown trials as a complement to Factory Acceptance Tests to ensure real world conditions are tested (e.g. the visibility, LED logic tests on GEN4 and numerous items on the Hammant). With the GEN4, examples of deficiencies found at site are the need for a remote control for steering in tight quarters, the uneven lift arm issue, the DSC contact issue and for repositioning and also redesigning some of the LED sensors to make them more useful in controlling the vehicle.

3. Avoid proprietary components or designs in order to avoid obsolescence issues and retaining the ownership of the design and right-of-use must be included in the project contract.
4. Ensuring long term support from the OEM is critical for long term operation and maintenance of the transporters and, where not available, employing the services of a knowledgeable technical consultant to ensure support in case the vehicle supplier loses interest.
5. Thorough maintenance and life cycle management plans are essential and should be updated periodically.

9. DSC Transporter Life Cycle Management

The DSC transporters in the OPG fleet were designed for 20 to 25 years of service depending on the number of hours of operation. By comparison the duration of the OPG used Fuel Management program is 60-70 years. A Life Cycle Management schedule has been drafted to manage the maintenance, refurbishment, upgrade and replacement of the fleet. The objective of the plan is to ensure acceptable reliability and availability of the transporters and best return of investment.

Each new transporter design/build/refurbishment project is supported by a business case summary which analyses the costs and benefits of the proposed project. A typical new design and build project for a DSC transporter will require a substantial investment of 3-4 million dollars while refurbishment of the 3 newest Liftkings is less expensive at \$1.2 million, including some major maintenance work. Additional costs in commissioning, training (Operators and maintenance staff) and stocking spare parts will further increase the investment. A typical design/build/commissioning cycle for a new transporter will take about 2-3 years.

DSC transporters are usually designed for 20-30 years of normal operations. There are monthly, quarterly and semi-annual and annual preventive maintenance tasks (PM) performed on the transporters such as lubrication, fire suppression system inspection, hydraulic oil and filter replacement, lift system inspection etc. Every 5 to 10 years a major maintenance will be implemented such as tire change, hydraulic system refurbishment, structural inspection etc. This 5 yr maintenance is projected to cost in the range of \$45k to \$160k per machine depending on the extent of parts replacement with brand new parts rather than refurbished parts. The maintenance is based on a switch-and-refurbish model to allow reuse of parts that are no longer available. Near the end of design life of the transporters a detail condition assessment of the transporters is completed to identify the overall system health of the transporters to remain in service. This assessment is based on past system health reports, maintenance records, parts obsolescence, component condition assessments and system health team recommendation.

There are four possible outcomes from the assessment as follows:

- a. Decommissioning – Transporter is deemed to be not fit for service (Hammant)
- b. Refurbishment – Transporter is deemed to need component replacements which are due to either ageing or part obsolescence (3 newest Liftking transporters)
- c. Upgrade – some systems on the transporter need to be modified or replaced by new designs
- d. Run to end of life – Transporters are fit for service but no further investment will be made. The transporters will remain in service until the end of life. This is the path chosen for the oldest Liftking in order to balance refurbishment costs with reliability needs of the fleet. It will be run to failure and the critical spares harvested for use in the refurbished Liftkings.

Life Cycle Management (LCM) is critical for ensuring safe operation, meeting production goals, good value from investment, acceptable reliability and availability. LCM begins with targeted production, reliability and availability goals. Based on projected design life, past performance and part availability/obsolescence reviews, a LCM plan is formulated. It projects expected availability and reliability, part obsolescence, planned major maintenance, refurbishment and upgrade, fleet replacement and decommissioning. It is long term planning to achieve stable predictable performance with well defined margins or redundancy.

DSC TRANSPORTER – LIFE CYCLE DIAGRAM

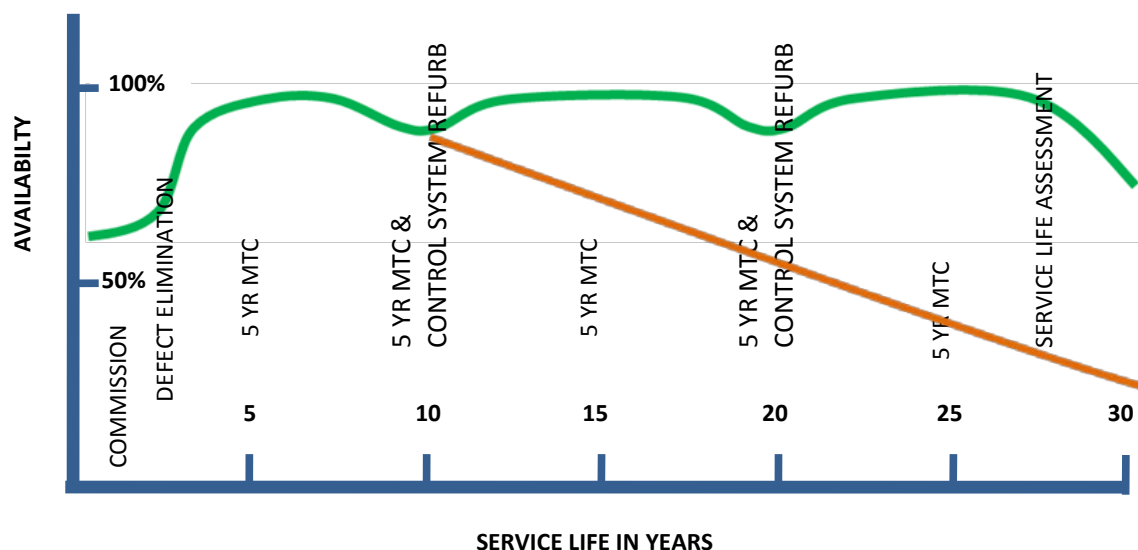


Figure 6

Currently, the goal is to improve the reliability of the Liftking transporters and eliminate the defects in the GEN4 transporters. With up to 6 transporters in service after the completion of Liftking refurbishment (excluding the TOR), each site will have two transporters that will increase the availability of the transporters. Previously, with only one spare Liftking, a serious failure of a transporter at one site could severely impact the production of that site because it takes time (up to a week) to prepare and ship the spare transporter to the site that needs it. Up to three spares will reduce the needs of shipping transporters from one site to another site. In addition, using two transporters at one site will cut down the running hours on the transporters to half. These changes will extend the useable life in the fleet and minimize future risks from transporter functional failures to dry fuel storage production. However, while the maintenance costs for keeping three spares will increase, fleet costs over the longer term will be reduced due to longer life of the existing transporters.

10. Decommissioning

The final stage in transporter operation is decommissioning and disposal. At some point limitations on transporter use and parts obsolescence/maintenance costs become too onerous and the machine

should be decommissioned. The greatest challenge is addressing the potential for contamination by radioactive materials. At OPG facilities contamination control in the last decade has moved to control at the source and potentially contaminated areas of the plant are much reduced. The DSC's are decontaminated when first removed from the IFB and dried in a 'rubber' area (an area of potential contamination). Typically the area is then decontaminated or the DSC is then moved by crane to a contamination-free area for pickup by the transporter. However, space limitations and limits of crane travel at the Pickering B station require the transporter to enter the 'rubber' area inside the fuel bay structure. Consequently the potential for contamination, although low, has to be addressed during decommissioning.



Figure 7 Body of Hammant with cab and lift structure removed ready for transport

The Hammant transporter was limited to use within the storage buildings and had numerous problems identified above and was decommissioned in 2015. All of the fluids were tested for contamination and removed for liquid disposal (no contamination found). The transporter cab and lift mechanism was removed since it was too tall for transport on a flatbed transport. It was decided that a conditional transfer permit to another licensed facility for final disassembly and decontamination would be less effort and cost than a full tear down and an unconditional transfer to an unlicensed facility. Prior to cab removal, control systems were emptied of fluids, the cab was removed by boom crane and the transporter driven onto the flatbed. After receipt at the disposal facility (Kinectrics) the machine was disassembled, decontaminated and the bulk of the materials free-released for recycling. Both a boom crane and the Hammant were successfully disposed of in this fashion and the only contamination found was on the basket of the boom crane. Total cost was less than \$200,000 of which one third arose from partial disassembly at site.

11. Transfer Routes

The route between the IFB and the processing and storage facilities is a significant part of fleet operation. The route is assessed for ground/roadbed capability, condition and the hazards en route are assessed against safety analysis prior to the route being approved and included in the Safety Report as part of the facility license. Issues that have hindered transporter use of the approved route include failure of buried services (firewater piping, yard drainage, bulk gas supply lines), snow removal equipment dislodging steel plate trench covers, maintenance of nearby equipment and the grade of

portions of the route were a problem for the Hammant transporter. Typically, 3-6 weeks of unavailability per year accrues from these impacts. A duplicate route is being considered at Pickering for redundancy due to aging and periodic failure of buried services. The hazard analysis and roadbed analysis are complete and remediation construction is being estimated at present.

The integrity of the roadway has to be inspected at least annually and maintained because of the weight of the transporter, its payload and the limited suspension travel of the transporter. Pre-operational checks include avoiding winter conditions too slippery for the solid rubber wheels, inspection for evidence of deteriorating catch basins and maintenance covers and symptoms of sinkholes from deteriorating buried services. At Pickering, several roadway closures annually have arisen as a result of failure of boiler blowdown lines, bulk gas lines and grey cast iron fire piping has regularly broken and resulted in a need to excavate the roadway for repairs. Major buried lines such as service water main line and steam blow down lines are located near the approved DSC transporter routes. Buried service installation for construction for nearby refurbishment project facilities has been a recent concern at Darlington after an unusual depression in the pavement was noticed. In 2014 a cursory ground penetrating radar (GPR) scan was performed at Pickering and a few anomalies were observed but no clear evidence of voids under the roadbed.



Figure 8 (a) catch basin sinkholes (b) buried service failure (c) yard drainage sinkhole uncovered

In 2015 a rusting and deteriorating yard drainage line, and lake level surges in the forebay tempering water tunnel into which it drained, result in a significant sinkhole (3m deep and 2.5 metres across) that was only evident because of a 20 cm hole in the covering asphalt. This sinkhole was not observed by the 2014 study of nearby roadway. It occurred directly in front of the approved entry to the processing and storage facility, enroute to the Pickering B fuel bay and halted production for 2 months. Subsequent review of the safety analysis confirmed that current design basis bounded the case of a transporter dropping with the pavement into a sinkhole of this size.

A review of ground inspection techniques has been concluded by the Engineering group and a more sensitive GPR array is being purchased to complete continuous scans of the route triannually. This technology will decrease the risk of slow-growing sinkholes. Fast-growing sinkholes from pipe rupture occur very rapidly and the probability of affecting a transfer has been estimated to be very low. Towing procedures are available and have been proven for vehicle recovery; however procedures will be updated for specific circumstances as needed. The road closures have also highlighted the need to get approval for an alternate transport route and entry point for the processing facility. Hazard and roadbed analysis for an alternate entry point to the processing facility, has been completed, approval obtained and is currently in service. It was successfully used

during excavation of a recent fire protection water line break that occurred beside the primary entry door. An alternate route is being considered for transport between the IFB and the processing shop. Hazard and roadbed analysis has been completed and a business case is being prepared for a project to complete costing and design of the alternate route. This will be needed to increase loading and transfer rates, empty the wet bays faster and reduce operating costs following the end of Pickering commercial operation. A second entry point to the processing facility has been assessed and is in the approval process currently. A project for assessment of the risk from buried services has been initiated at the other two nuclear sites in Ontario.

Current fleet practice is to maintain a divisional spare transporter in order to avoid shutting down production at one of the sites if the transporter fails to operate. Once there are significant break-in running hours on the new GEN 4 transporter remote control and reliability demonstrated, both will be placed at the western facility to take advantage of the higher roadspeed (4 km transfer distance), maintenance and operational familiarity with co-located GEN4 machines and reduce the opportunity for differences in transporter to cause human error. That will leave Liftking transporters to service Pickering and Darlington sites (one per site, one spare). The remaining Liftking will be run to failure and critical spares harvested where feasible.

12. Conclusion

OPG has successfully operated a transporter fleet for over 20 years to transfer used fuel containers from the used fuel bays to processing and storage facilities at three Ontario nuclear sites. Four generations of these custom built machines from three manufacturers have been commissioned, maintained, upgraded, and reliably operated transferring over 2,000 containers and keeping pace with used fuel production. Review and timely assessment of operational experience by supporting engineering groups has resulted in optimizing maintenance, identifying appropriate design changes to improve safety and reliability, and avoiding significant delays in production while balancing cost with reliability. Obsolescence and maintenance history suggests a nominal service life of a typical transporter to be 20-30 years. An aging management plan has been put in place to assure continued reliability of the fleet for the estimated remaining life of the temporary used fuel storage sites. Over the last 20 years, experience has also been obtained with program costs, route repairs and safety analysis on approved transfer routes to support a high level of confidence in safe and reliable operation of the fleet.