FEEDER REPLACEMENT TOOLING AND PROCESSES[1]

Robert Mallozzi
Ron Goslin

Atomic Energy of Canada Limited
Mississauga, Ontario

Dennis Pink
Ardi Askari

Babcock & Wilcox Canada Ltd.
Cambridge, Ontario

ABSTRACT

Primary heat transport system feeder integrity has become a concern at some CANDU nuclear plants as a result of thinning caused by flow accelerated corrosion (FAC). Feeder inspections are indicating that life-limiting wall thinning can occur in the region between the Grayloc hub weld and second elbow of some outlet feeders. In some cases it has become necessary to replace thinned sections of affected feeders to restore feeder integrity to planned end of life.

Atomic Energy of Canada Limited (AECL) and Babcock & Wilcox Canada Ltd. (B&W) have developed a new capability for replacement of single feeders at any location on the reactor face without impacting or interrupting operation of neighbouring feeders. This new capability consists of deploying trained crews with specialized tools and procedures for feeder replacements during planned outages. As may be expected, performing single feeder replacement in the congested working environment of an operational CANDU reactor face involves overcoming many challenges with respect to access to feeders, available clearances for tooling, and tooling operation and performance. This paper describes some of the challenges encountered during single feeder replacements and actions being taken by AECL and B&W to promote continuous improvement of feeder replacement tooling and processes and ensure well-executed outages.

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INTRODUCTION

The many issues experienced with feeder piping lead us to believe that feeder piping is gaining a reputation as the Achilles heel of the CANDU industry. Feeder piping supplies the fuel in CANDU reactors with a continuous supply of heavy water (D_2O) to cool the fuel and transfer heat to generate electricity. Operating experience demonstrates that CANDU feeders are not immune to cracking or thinning. Instead, they have been responsible for unplanned and planned outages due to cracks, thinning, and leaks. As a result, feeder systems have been at the centre of an enormous effort of inspection, surveillance, maintenance, and replacement.

Thus far, the CANDU industry has only one method to deal with a feeder pipe that has a life-limiting crack or thinning characteristic. The method involves removing the defective section of feeder and replacing the defective section with a replacement section. Defective sections of feeders have been removed in lengths varying from thirty-five centimetres to greater than two metres. Replacements are performed on-reactor, within a constrained space between the various neighbouring components. The very nature of removing and replacing a section of feeder pipe on-reactor, in a radioactive environment and within the extreme spatial constraints provided by the CANDU design is a significant undertaking of manpower and machinery.

Atomic Energy of Canada Limited (AECL) and Babcock and Wilcox Canada Ltd. (B&W) with their partners Ontario Power Generation (OPG) and Bruce Power, have refined the processes and tooling involved with removing and replacing defective feeders by introducing new advanced feeder tooling technology to virtually every procedure in the process. The execution of this new technology in the replacement of several feeder sections in Ontario has resulted in experience leading the AECL-B&W team to identify potential improvements. This paper discusses the experience thus far with advanced feeder replacement tooling and some of the advances that are being pursued.

TOOLING

The advanced feeder tooling developed by AECL, B&W, OPG and BP was first used to replace feeders on a CANDU reactor in 2006. Prior to this milestone, replacement of feeder piping in CANDU reactors can be considered a ‘conventional’ process. The conventional replacement process incorporated mainly off-the-shelf conventional equipment, modified to suit specific conditions and constraints. The main exception to the conventional available equipment was a low profile weld head designed by AECL to fit between the first and second feeder bends from the Grayloc connection at the end fitting.

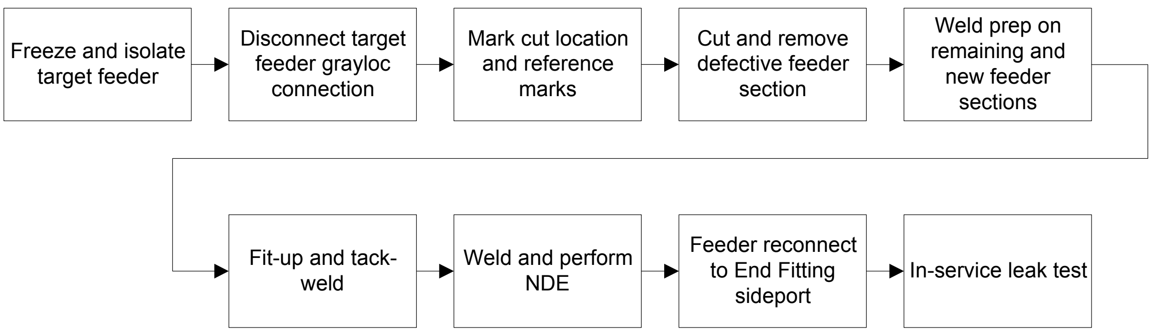

Figure 1 Feeder replacement flow chart

Figure 1 depicts the process that is used to replace a single feeder pipe in a CANDU reactor. At this level of detail, the process does not vary significantly between the conventional replacement and a replacement with the advanced feeder tooling. It was due to the constraints posed by the conventional process that advanced feeder tooling was being pursued.

Conventional tooling constrained all the feeder replacement processes to be within arm’s reach of operating personnel. All operations were performed on a platform, in front of the reactor face, by personnel, and completely manually. While some modifications were performed on tooling to reduce the required clearances and extend tooling capability, the cut and weld location had to be within arm’s reach in order for the operators to use the tooling. While this may not seem significant at first glance, the implication of the arm’s reach constraint has translated to removing feeders simply to gain access to a defective feeder, thus removing two or three feeders to replace one defective feeder. It also meant that operators were required to be maintained in the reactor vault during all operations. It is undesirable to face the prospect of replacing several feeders to access one defective feeder due to cost, duration, system isolation, and radiation dose.

The advanced feeder replacement tool set removes the condition that the cut and weld location must be within arm’s reach. Tooling has been designed to operate or be installed manually on a work platform located in front of the reactor face. From this work location, operators install tooling on target feeders within the tight clearances provided by neighbouring reactor components. Technical and human limitations resulting from the distance of the feeder operations from the end fitting face and the tight clearances have been overcome. Feeder pipes can be cut, removed, installed, welded, and inspected in an area where no human can reach and previous generations of tooling could not fit.

Operators located on the work platform perform installation and operation of tooling in most cases. Operators are still required to set-up tooling for welding and non-destructive examination (NDE) however tooling is technically operated by qualified operators in a command centre. This command centre is located outside the reactor building. Being able to perform welding and NDE operations without operators present on the reactor face benefits the process by reducing the amount of potential radiation dose to operators.

Tooling to identify and mark, perform cutting and weld preparation activities, fit-up old and new feeder sections, weld, and NDE have all been designed from the ground-up. Due to clearance limitations and the requirement to operate approximately two metres from the end fitting face, very little conventional technology could be carried over to the advanced feeder replacement tool set.

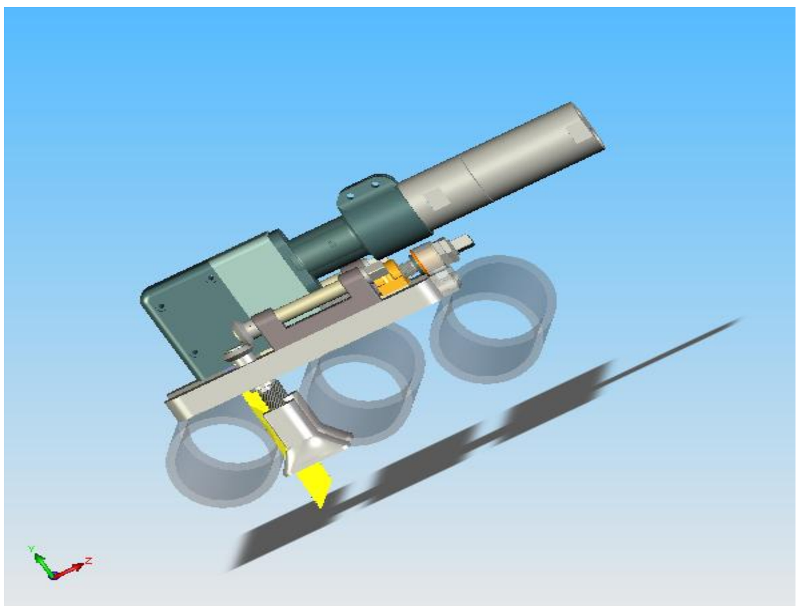

Figure 2 - Cutting tool

The cutting tool depicted in figure 2 is designed to be installed on the feeder via the use of delivery tooling. Above the clearance restrictions imposed on the tool design, the ability to properly align the tool to produce a cut normal to the feeder is a must. Should a cut be performed on an angle to normal, inefficiency due to durations and material loss would compound clearance issues. The cutting tool is clamped on to the feeder using remote extensions and is operated via an onboard air motor.

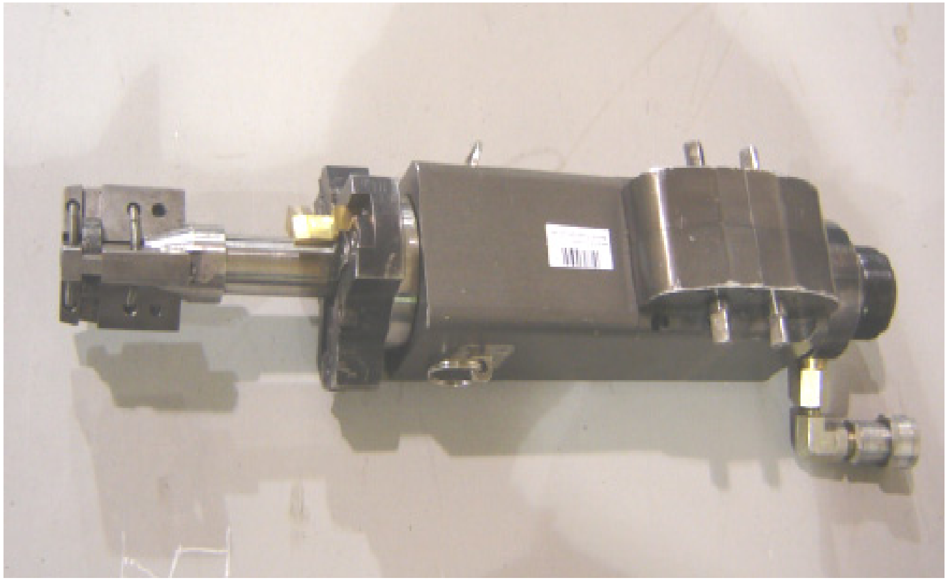

Figure 3 - Weld preparation tool

The weld preparation tool depicted in figure 3 is designed to clamp to the inside diameter of a feeder pipe, align itself with the feeder pipe and perform a ‘J’ weld prep. Both hydraulic and pneumatic systems are incorporated to provide clamping force and rotational forces. A mechanical system is used to advance cutting bits. The weld prep tool design minimizes the height/width profile and is in-line with the feeder pipe. This leads to minimal clearance interferences during operation on-reactor.

Figure 4 - Weld Tool

The low profile weld tool depicted in figure 4 is designed for installation and alignment by operators on a fit-up and tack welded feeder up to two metres from the end fitting face. Once installed, a weld can be performed within a one-inch clearance around the diameter of the feeder pipe by operators located remotely in a command centre.

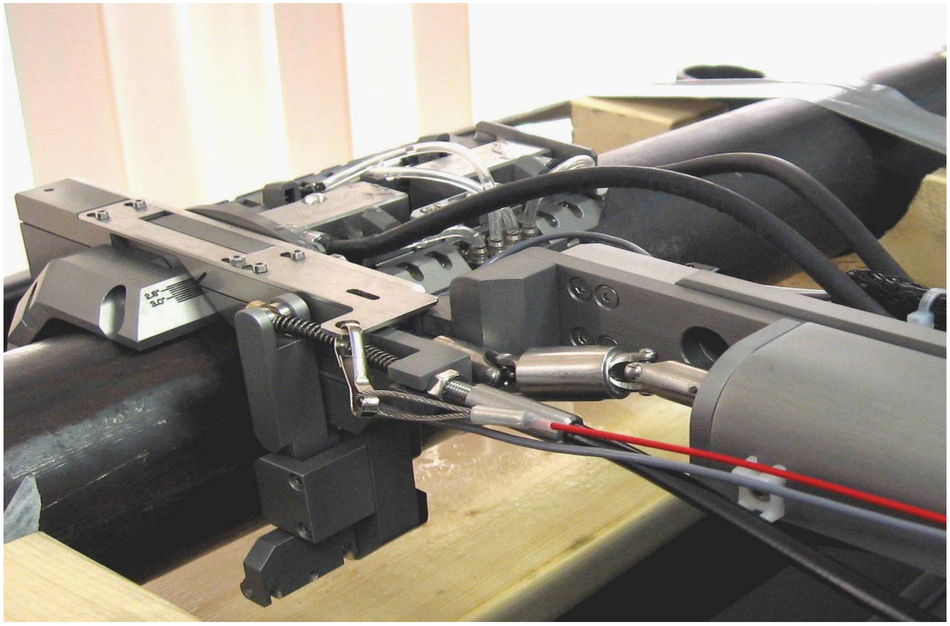

Figure 5 - Ultrasonic Phased Array Weld Inspection Scanner

In a similar manner to the weld tooling, the ultrasonic inspection tool in figure 5 is installed from the work platform in the reactor building and operated remotely from the command centre.

Advanced feeder tooling virtually eliminates the possibility of having to remove feeders to gain access to a defective feeder, thus making replacement durations more predictable and manageable. Further, being able to install a tool on the reactor and leave operation to qualified operators in a non-radioactive work location benefits the overall radiation dose for the work.

CHALLENGES TO DATE

Water Handling

Isolation from the heat transport system is a pre-requisite to the disconnection and eventual replacement of a section of feeder pipe. The isolation is provided by freezing heat transport fluid using liquid nitrogen to form ice plugs in the upper feeders. Once isolation is performed and verified, heat transport fluid is drained and work is allowed to proceed with feeder disconnection and cutting. This method of isolation is the only current mechanism available to provide a drained and dry area at the replacement or cut location.

While ice plugs have thus far been successful at isolating the heat transport system, there have been occasions where fluid has been present downstream of the ice plug, affecting the ability to execute feeder replacement. While several conditions can cause fluid to be present downstream of the ice plug, one primary cause is the inability to drain a non-vertical feeder run upstream of the cut location via gravity - draining. Any non-vertical section of feeder has the potential to trap fluid, until the feeder is pulled vertically by mechanical means, allowing fluid to travel downstream to the cut / weld location.

Figure 6 - Water Handling Tool

Instead of accepting the possibility that the cut / weld location may have moisture, action was taken to review the potential solutions to manage stagnant fluid in the feeder during a replacement. Tooling was developed to travel into the remaining feeder section up to the horizontal run and remove sufficient fluid to proceed with feeder replacement, eliminating the risk of moisture detrimentally affecting the replacement process. This tooling has been used on-reactor successfully on several occasions and is being improved further to improve vision and the vacuuming process.

Air Draft

The advanced feeder tooling welding system employs a Tungsten Inert Gas (TIG) welding process to perform the installation of new feeder sections to existing feeders. The TIG process employed requires that an Argon cover gas is present to protect the tungsten, arc, consumable, and base metal. Should the cover gas be interrupted, the welding process is sure to fail.

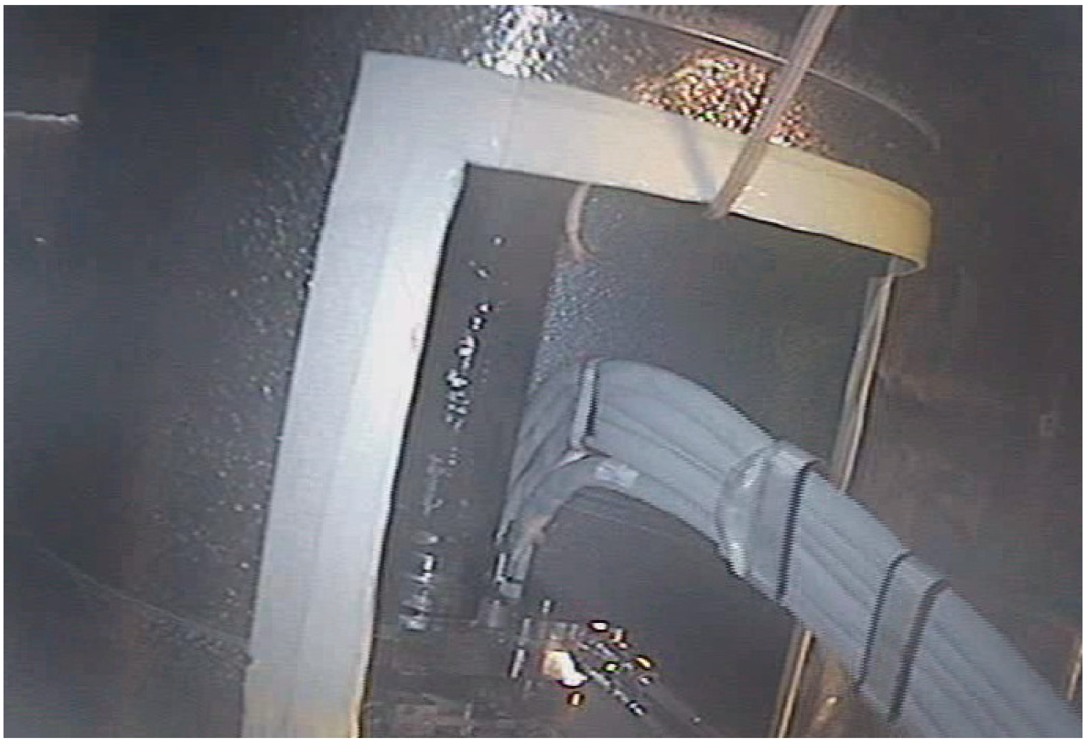

Figure 7 - Draft Reduction System, initial installation.

Normally a gas cup surrounds the Tungsten electrode, providing a cushion of cover gas and ensuring cover gas is forced around the electrode and into the weld as it is deposited. This full gas cup cannot exist with the advanced feeder tooling welding system due to clearance limitations and the low profile nature of the weld head. While all TIG welding systems are sensitive to air drafts, the advanced feeder tooling welding system is at a greater risk to drafts due to the lack of a traditional gas cup. As a result, welding procedures require smoke to be 'puffed' about the weld location to determine whether there is excessive draft or conditions are acceptable for welding.

Although all air movers are shut down in the reactor vault during welding, situations have been encountered where air drafts due to natural convection proved excessive and the cover gas required protection. Unfortunately, the solution could not be as simple as a fire blanket or similar barrier because the weld location is commonly out of arm's reach.

As is sometimes the case, situations force most unique solutions and the air draft protection solution precipitated from an on-reactor situation during critical path feeder replacement. The AECL-B&W team on shift quickly assembled and brainstormed solutions to deal with the show-stopping draft. The result was a draft protection cylinder (or 'keg') that was assembled immediately on-site and installed in two halves using delivery tooling. Within a few hours welding commenced and completed successfully.

Lessons learned from this situation caused AECL, B&W, OPG, and BP to embark on a program to design and deliver a draft protection system that would protect the weld at all locations on-reactor from naturally occurring drafts.

Weld Tooling

The advanced feeder tooling welding system has demonstrated a capability to perform as no previous welding system has performed prior to its existence. The system is installed on-reactor by reactor face operators at the weld location, alignment is verified by personnel in the command centre, and the reactor face operators back-out to allow welding to commence and be completed remotely by command centre personnel. It has demonstrated the ability to weld within a one-inch clearance at locations exceeding two metres from the end fitting face. While the capability has been demonstrated and impressive, execution has not been without incident.

Simply put, the advanced feeder tooling welding system is a torch containing a remote control and vision system delivered on a split C-frame style gear operating within a one-inch radial clearance. With the exception of the electrode – gas lens design, every aspect of the welding system was uniquely designed and manufactured to meet design requirements. Although the design has gone through several iterations and improvements, it can still be considered in its infancy.

The most significant improvements to the welding system thus far have been directed at the C-frame mechanism. The design, manufacture, and mechanical operation of the original C-frame design demonstrated susceptibility to wear, rotational stalling, mis-gearing or gear meshing problems, gear timing errors, and thermal distortion. Lessons learned collected from initial outage applications pointed to required improvements in the C-frame design and manufacture were this program to succeed.

Figure 8 – Weld Head (installed on-reactor)

Figure 9 – Weld Head C-Frame

AECL worked in collaboration with the tool supplier, Encompass Machines Inc. (EMI) to rectify the problems experienced with this new system. EMI was and remains open to suggestions and improvements, leading to two main improvements – a single worm gear drive package and using the EDM process to machine gears. A new C-frame design and manufacturing strategy was assembled and tests thus far on bench mock-ups demonstrate exceptional performance improvements compared to prior C-frame designs. The design is intended to be proven during subsequent feeder replacement outages where on-reactor behaviour will be closely monitored.

Shielding

The ultimate goal of the feeder replacement program is to replace feeders with minimum duration and minimum radiation exposure to operators. Unfortunately, the nature of the current replacement process does not lend itself to complete remote installation and operation of tooling. Instead the process relies mostly on reactor face operators to manually install tooling.

The main contribution to radiation exposure during maintenance outages at CANDU plants is gamma radiation. This type of radiation can be shielded with high-Z materials such as Lead and Tungsten. Traditionally, lead bags have been ‘hung’ from end fittings to provide shielding to workers. Lead bags weigh between 8 to 20 kilos, are difficult to handle, take a significant effort to install, rely on wire or rope rigging, and provide a debatable amount of radiation shielding unless employed on a large area of the reactor face. In the worst case, mishandling or un-wrapping of the rigging could result in dropping lead bags from the reactor face.

The feeder replacement team explored new shielding technologies to reduce radiation exposure both during the installation of the shielding and during maintenance activities on the reactor face. The result was a rubberized Tungsten product moulded to the profile of an end fitting. This designed product reduces installation effort as each shielding block weighs approximately 7 kilos and simply wraps about each end fitting, eliminating the drop potential. Further, initial assessments of the rubberized tungsten material indicate that the attenuation factor is three times greater than that of a lead bag.

Figure 10 – Shielding

This new rubberized Tungsten shielding has been used on-reactor and has proven to be effective when installed on a large enough area to protect the worker from direct gamma and the effects of Compton scattering. While the introduction of new shielding has a positive effect on minimizing radiation exposure, the CANDU industry would collectively agree that eliminating exposure to workers must be the ultimate target.

Weld Prep Verification

In order to perform a weld between the new feeder section and the existing feeder section, a weld prep (J-prep) must be executed on both sections. During conventional feeder replacements, a weld prep was performed on the remaining section of feeder by a hand-held bevelling tool. A Vernier calliper was used to verify the thickness of the J-prep and therefore it's compliance to the weld procedure specification.

When the cut / weld location is located out of arm's reach, verification of the J-prep is not possible using a hand-held measuring device. The initial intent was to perform a test sample and verification on a pipe section in a low-dose area with the bevelling tool, using the same tool to perform the weld prep on-reactor, and performing a final prep and physical verification on a subsequent section of pipe with the same bevelling tool. While this process excelled at determining whether the bevelling tool settings had changed from start to finish, there was no physical verification or check of the J-prep on-reactor.

The AECL-B&W team identified the need to perform a verification of the weld prep on the remaining feeder section. The results were a tool designed to perform a remote visual inspection of the weld prep with go-no go gauge established in the vision system. This system has yet to be commissioned on-reactor but promises to provide confidence that the condition of the remaining and new feeder are within specification and therefore suitable for the welding process.

Foreign Material Exclusion

The advanced feeder tooling system includes various Foreign Material Exclusion (FME) components to prevent foreign objects and tools from entering the open primary heat transport system as well as falling from the working area into the reactor face.

The portion of feeder tube typically replaced during a feeder replacement campaign includes the Grayloc hub and some length of pipe up to or including the second or third bend. Feeder replacement requires that the Grayloc hub be disconnected from the fuel channel end fitting and severed from the existing feeder tube, thus opening and exposing the primary heat transport system to the risk of foreign material entering the system.

Actions taken by the AECL-B&W feeder replacement team to mitigate the risk of foreign objects entering open systems include design of tooling with minimum loose parts potential, documenting tooling configuration for integrity review before and after use, establishment of FME control areas around open systems, logging of tooling in and out of the FME control area and open systems, providing protective covers over open systems to prevent ingress of foreign material, providing protective barriers under work areas to contain loose parts or falling objects, tethering tools to operators or fixed objects to prevent dropping or loose parts, and pre-outage training of the team on tooling and FME procedures.

Experience to date with prevention of foreign material from entering the open primary heat transport system has been very good, with preventive measures being effective. The reactor face appears to be the area of greatest risk, as it has been difficult to establish barriers under the work area that are 100% effective all of the time, particularly when working on vertical feeders. The AECL-B&W team are continuing to work with OPG and Bruce Power in the development of more effective barriers and processes for prevention of falling objects on future feeder replacement campaigns.

Detailed specific FME procedures in conjunction with training have enabled the AECL-B&W feeder replacement team to demonstrate good FME practice and continuously improve the process based on the lessons learned from previous outages.

CONTINUOUS IMPROVEMENT

The identification and communication of operating experience is a significant contributor to continued and improved future success of any project. The feeder replacement program and its contributors (AECL, B&W, OPG, and BP) maintain operating experience and lessons learned as the fundamental mechanism to improve.

Subsequent to the completion of each outage, meetings with all parties involved are held to document operating experience. The resulting experience is captured as 'lessons learned' and categorized into respective components such as tooling, resources, processes, interfaces. Should lessons learned be simply documented and filed, operating experience would never contribute to future successes and improvements.

The lessons learned on all previous feeder replacement campaigns are reviewed prior to the execution of specific replacements. Taking it one step further, the replacement team is embarking to put a program into place whereby all lessons learned from operating experience is documented and available in one central resource. This will allow actions and follow up to be tracked and is to serve as the mechanism to identify and communicate operating experience to the program. It was through the lessons learned process that the need for tooling and process improvements was identified. As more experience with tooling is gained, future design additions and changes are inevitable and necessary to improve the process.

In addition to documenting operating experience, AECL and B&W identified a feeder execution optimization team. The mandate of the optimization team was to review all aspects of the execution of feeder replacement from notification to closeout, identify potential areas requiring attention or improvement, and act to correct these areas. A general road map to execute a feeder replacement was the final result of the optimization team. More importantly, it unified the AECL B&W team by identifying potential conflicts, overlap, and efficiencies that could be gained in the partnership. Future executions were carried out with a clearer direction and path forward.

Resulting from the success of the internal AECL B&W optimization team, AECL and B&W are collaborating with their clients to establish a joint optimization team with the mandate to optimize the feeder replacement process. Similar to the AECL B&W optimization effort, this joint optimization team will dissect every aspect of feeder replacement and identify areas requiring optimization. With the understanding that the effort required to replace a feeder relies as heavily on the utility as it does on the contractor, the joint optimization team is optimistic that the effort will result in a model to replace feeders with greater success and efficiency in the future.

SUMMARY

Technical and operational shortcomings surrounding feeder piping have caused the CANDU industry to expend a significant effort to inspect, maintain, and replace components. Thus far, the only method to deal with a feeder pipe that has a life-limiting crack or thinning characteristic is to section the defective part of the feeder, remove it, and install a new section. Replacements are performed on-reactor, within a constrained space between the various neighbouring components.

Advanced feeder replacement tooling has demonstrated a capability to replace defective feeders within the space constraints of the CANDU reactor well beyond human reach. This tooling eliminates the need to remove perfectly good feeder sections in order to access defective sections. While this tooling has already demonstrated its capabilities, it is still in its infancy as far as design cycles go.

Improvements have been identified and completed to tooling design, and technology gaps have been filled based on operating experience. Continued diligence and focus on continuous improvement will ensure experience is communicated, and will inevitably reduce the burden of feeder replacements on utilities.