Challenges of Adolescent and Maturing Nuclear Plants:
a Chemistry Perspective on Maintenance & Outages

John G. ROBERTS

IN HIS ADDRESS TO THE CANADIAN NUCLEAR SOCIETY, BRUCE POWER'S SECTION MANAGER FOR CHEMISTRY DESIGN WILL RELATE HOW DESIGNERS AND SPECIFIERS FOR PLANT AND COMPONENTS HAVE HISTORICALLY LIMITED THEIR APPROACH TO THAT OF NEW PLANTS.

AS NUCLEAR PLANTS BECOME OPERATIONAL, JOHN G. ROBERTS WILL EXPLAIN HOW THE REQUIREMENTS TO PROTECT THE ASSETS CHANGE AS A RESULT OF CHANGED CAPABILITIES, ENVIRONMENTS AND REQUIREMENTS.

JOHN WILL OFFER EXAMPLES TO SHOW HOW CHALLENGES WERE MET DURING CONSTRUCTION AND COMMISSIONING. WHILE PLANT CHANGES ARE OFTEN NECESSARY FOLLOWING COMMISSIONING TO PREVENT SERIOUS OPERATIONAL PROBLEMS, JOHN WILL ALSO DISCUSS WAYS IN WHICH PLANNERS, SUPPLIERS AND MAINTENANCE STAFF CAN BROADEN THEIR VIEWS AND EMBRACE NEW WORK METHODS TO ENSURE THOSE CHANGES DON'T UNWITTINGLY CREATE NEW CHALLENGES.

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INTRODUCTION

Maintenance and outage activities can exert large impacts on plant materials and chemistry. Construction, initial or additional can exert similar effects. These impacts and effects have to be controlled such that expensive corrective/mitigating action is avoided in future years. I have been the Chemist overseeing construction and commissioning of five CANDU units, and subsequent operation of many of those units. Cleanliness, the friend of the chemist and plant, the bane of the constructor and maintainer, once a “foreign” concept to many has improved, but still requires constant vigilance. My perception, which is shared by others, is that many people have forgotten, or are unaware of the impact of nuclear reactors on materials.

UNIT CONSTRUCTION

The designers, by and large, did a good job specifying materials, material finish and installation guides. At Bruce B we benefited from the experience of many construction staff having previously been involved in construction of Bruce A. Taking cleanliness to the higher level required for Bruce B, through the Resident Engineer’s organization, was relatively easy but constant vigilance was required.

The designers had specified that all pipework for any system that would contain treated fluid was to go through the pickling plant. Stainless steel pipe was degreased, passing through the first two baths only, whereas carbon steel pipe was degreased and pickled. The pickling process removed mill scale and provided a coating which remained protective providing the pipe remained dry. The requirement also specified that following pickling, all piping had to be capped to exclude foreign material. This practice all too often had to be reinforced. Something the designers missed was the requirement to monitor the chemistry of the pickling plant phosphoric acid. If the iron concentration was not controlled, two things would happen – deposits would remain on the pipe and the carbon steel would suffer increased corrosion. This was easily remedied. In addition lengths of pipe were returned to for re-pickling. These deposits would have caused problems if they were to reach the steam generators or the reactor.

I have encountered coatings that were difficult, if not impractical to remove. At one plant, engineering had stipulated that zero rust was permitted on any internal surface of feed heaters during manufacture. The stipulation was unrealistic and was interpreted as "all carbon steel internals had to be covered with a protective layer to preclude rust formation". These feed heaters were assembled with this protective layer intact. This might have been a non-issue until it was learned that the paint was a mixture of polyvinylchloride and zinc. To exacerbate the issue, the zinc contained high lead contamination. Cutting open the feed heater to expose the tube bundle would have allowed only partial removal of the paint from divider plates, tubesheet and baffles. Total disassembly of the feed heater would have been required.

At Bruce B, hydrostatic tests of systems that would normally contain treated water were performed only after full system erection, with appropriately dosed water. These systems remained full to maximize protection and minimize corrosion. During commissioning, systems were flushed to remove foreign materials that might have found their way into the boilers or reactor. Whenever work necessitated a carbon steel system to be drained, my requirement was that as many tasks as possible were performed in parallel and work planned and executed to minimise the drain down period. This would minimize the amount of corrosion product generated.

Bruce Unit 5 secondary side received unusual treatment. It was drained immediately following the hydrostatic test, against my wishes, to allow for more rapid construction. Any schedule that might have been gained was later lost having to locate and reposition garter springs. 15 years later, we learned that the deposits on removed tubes from Unit 5 steam generators were heavier and more adherent than those of the other Bruce B Units. This extended drain down period of the secondary side represents the only significant difference between Unit 5 and Units 6, 7 & 8 over those 15 years. Whilst this may not be a consideration for nuclear power plant Architect/Engineering/Construction companies, it translated into a longterm liability for the utility operator/owner.

OPERATING REACTORS

Moving to a unit's operational phase, components – valves, vessels, pipes, etc – have to be maintained, repaired and sometimes replaced. These activities necessitate, in many cases, a partial or even full system draining. Many factors have to be considered, including material, heat sinks, foreign material exclusion, environmental emissions and corrosion.

Design specifications for pipework and valves at Bruce Power, until recently, had not changed significantly since Bruce B was constructed. Whereas this might appear to be inconsequential, the potential impact is quite the opposite. Pipework used to be purchased to a specification that assumed we still had a pickling plant – the plant was dismantled before the early 1990s. Since this time it meant that mill scale and/or protective coatings could not be removed from the pipework and would end up within the reactor or the steam generators – this was identified by an event on Bruce Unit 5 in 1999. This foreign material (mill scale, protective coating) could result in increased corrosion and/or radiation fields, both of which can be very costly to a Utility.

In addition to specifying requirements for material coatings and preservation, material storage specifications are equally important. Dust, dirt, salt, rain, critters and their detritus must be kept out. Recently, Bruce Power had to throw away spare feeder pipes due to corrosion. These materials had been improperly stored.

Moderator Systems

Moderator systems of CANDU reactors are usually flushed and the heavy water purified, prior to addition of the soluble gadolinium nitrate poison. Such flushing and purification is impossible when the unit is in the guaranteed shutdown state. At this time the moderator water is overpoisoned with gadolinium nitrate. Should maintenance work require the moderator to be drained, helium must be used to displace the water. The subsequent refill will use similarly overpoisoned water. Whilst this appears totally innocuous there are potential dangers. Should suppliers be allowed to use either phosphorous compounds or impure water to clean valves/pipework, destined for use in moderator systems, problems can result. Minute quantities of phosphorous compounds can cause gadolinium to precipitate and re-dissolution of gadolinium phosphate is extremely difficult. Sodium contamination can lead to gadolinium precipitation problems in the latter stages of the approach to criticality, as a result of gadolinium displacing sodium from the purification ion exchange resin. Such problems must be avoided and can be avoided by stipulating the correct specifications.

Whether or not a moderator system is drained, welding is sometimes required. Such welding usually employs inert gas to exclude oxygen from the weld. Care must be taken with the choice and use of the inert gas. If the cheaper argon is used, then care must be taken to prevent introduction of argon into the moderator water. Argon, like oxygen, is soluble in water, can easily capture a neutron and become activated to argon-41. Argon-41, an energetic gamma emitter, has a significant impact on doserates in normally accessible areas and airborne environmental emissions. This occurred in Bruce Unit 7. The impact of introducing argon into the liquid zone system would have similar consequences.

Purge Weld Dams

To overcome issues associated with leaving metal purge weld dams in Bruce A systems, a paper purge weld dam material was used for Bruce B. During commissioning several problems were encountered. One was the incorrect application of the paper. Paper was forced into tubing such that water could not penetrate and dissolve the soluble portion. The paper was described as being soluble, but in reality was only 50% soluble, the remaining 50% being comprised of cellulose fibres. For Unit 6 nitrogen from many cylinders was used to blow out plugged instrument lines. Some valves containing trims behaved unusually as a result of the trims plugging with cellulose fibres. The fibres dissolved easily in concentrated nitric acid, as did the trims!

Whenever stainless steel tubing has had to be replaced maintenance staff occasionally ran into problems. Sometimes, when working on blockages in tubing of the liquid injection shutdown system (LISS) maintenance staff had reported that crystals were present. Until recently no evidence had been retained to allow further investigation. An investigation conducted by Bruce B Operations Chemistry has shown that the purge weld dam paper used at Bruce B since construction did not dissolve in solutions containing 8000 ppm gadolinium, as nitrate, the solution in the LISS tanks. The paper was found to have a high sodium concentration which promoted the precipitation of gadolinium resulting in the paper not breaking up. It appears that the impact of the transition from construction/erection to operation had not been considered when this purge weld dam paper was originally introduced circa 1980.

Bruce Power has since approved, for use, an alternative purge weld dam material that dissolves in 8000 ppm gadolinium, as nitrate.

Steam Generators

Steam generators are, unfortunately, the garbage cans of pressurised water reactors. Any material that enters anywhere within the secondary side has a high probability of reaching the steam generators. Hence great care must be taken when working on steam generators, and the whole of the secondary side.

Contamination from condenser leaks is difficult to preclude, but requires excellent well rehearsed procedures that can be rapidly executed to identify and eliminate the leak(s). Contamination introduced during construction and maintenance is not usually as easily detected and remedied as that from a condenser leak.

Sulphur

Whilst the Bruce B turbines were stored, prior to commissioning, a preservation oil was used to protect the turbine blades and rotor. This material contained an organo-sulphur compound. Steam washed this water soluble oil off the turbine and the oil was carried to the steam generators. Once in the steam generators the organo-sulphur compound was hydrolysed to sulphate. This contamination lasted for a short period, but required much blowdown to maintain control of chemistry.

Condenser leaks allow raw cooling water to enter the secondary side and subsequently reach the steam generator. The water treatment plant, unless membrane technology is employed, will allow organo-sulphur compounds to pass through with the make-up water. Sulphur can also be introduced as a result of acid ingress from the water treatment plant. Bruce A and B steam generators have suffered from water treatment plant acid excursions, as have many other plants.

In 2001, pitting was observed on Bruce A steam generators' tubing. This pitting was the consequence of attack by "reduced" sulphur compounds. Organo-sulphur compounds, after entering the steam generator, are hydrolyzed to sulphate. This sulphate concentrates on power in deposits and crevices. This sulphate can also be reduced by hydrazine to sulphide and sulphur. The presence of sulphur compounds in steam generators is highly undesirable because, in the right circumstances, suphur compounds will cause tube damage. This can happen either at power or during cold shutdown via different mechanisms. At Bruce A, it is probable that both hot and cold degradation mechanisms were at play for several years. The cold degradation mechanism would have proceeded unchecked during periods when the steam generators were not preserved with hydrazine dosed water. At Bruce A draining steam generators for extended periods became common practice after the approval of Intermittent Boiling Induced Flow (IBIF) as the outage heat sink circa 1993.

The cleaner the steam generator, the lower is the probability that such attack will occur. However, examination of removed tube samples, from the much cleaner Bruce B steam generators, shows evidence of attack, whilst hot, by sulphur species. Hence draining the cleaner Bruce B steam generators for extended periods is highly undesirable. One week in the drained state is considered to be the acceptable maximum duration.

Maintenance of, and repair work on, steam generators is an essential activity for nuclear units. However suppliers, designers, outage planners and maintenance staff must remember that the onset of most steam generator tube degradation mechanisms is not immediately apparent, rather taking years to become detectable, by which time significant damage has been inflicted. Steam generator suppliers, designers, outage planners and maintenance staff must design, plan and execute work on, steam generators in such a manner as to minimize the duration for which they have to be drained, to prevent the severe damage which can result.

Steam generators must be drained occasionally for corrective maintenance/repair, so the facility must be provided to allow the tubing to be adequately protected. Currently this protection is not available.

For units having common systems linking steam generators in a unit, such as emergency water, reheat, blowdown and steam discharge lines, the ability to separately preserve one steam generator whilst safely allowing personnel access into an adjacent steam generator is required and must be provided.

It is ironic to think that in executing corrective maintenance work within steam generators, additional steam generator tubing damage may have been unintentionally initiated.

Condenser Air Ingress

The turbine low pressure cylinder halfshells allowed air in-leakage at the halfshell joints. At Bruce B steps were taken to seal these joints at my insistence. During maintenance outages when halfshells were separated, the mating surfaces were cleaned. Some years ago it was identified that the cleaning process for the removed halfshell was fine, but unfortunately not for the lower halfshell joint. Maintenance staff were allowing the sealant from the lower halfshell to fall into the condenser. The sealant contained a high concentration of chloride and therefore should not enter the steam generator. Some evidence of this sealant on a removed steam generator tube has been found. The maintenance procedure has since been modified. The search for an alternative sealant continues.

Turbine suppliers should provide good sealing faces that require no further assistance to exclude air-inleakage.

Lead
Unfortunately radiation fields can occur within the steam generator tubing. The consequence is that shielding is sometimes required to minimize the radiation exposure of persons having to work in the steam generator. Other than designing a method to easily install and remove such shielding, the shielding needs to be such that it will not result in steam generator failure. Lead is notorious for causing steam generator tubes to crack and fail. If lead must be the shielding material, then it must be provided in such a form at to prevent any lead from remaining in the steam generator. Lead contamination led to the demise of the Bruce Unit 2 steam generators and early shutdown that unit by Ontario Hydro only 18 years after commissioning.

Other Materials
Lead and sulphur are not the only materials that can cause damage to steam generator tubes, there are many others. Similarly if the wrong material enters the moderator and/or heat transport system, flux tilts and/or elevated radiation fields can result. Suppliers, Designers, Outage Planners and Maintenance staff must ensure adequate review by knowledgeable people is conducted to ensure that nasty, costly surprises are avoided. The recent decision to install valves containing more stellite in moderator and heat transport systems is especially troubling. I wonder if people have either forgotten about, or even were aware of, the troubling experiences at Douglas Point and Pickering A with cobalt 60. The trend of some CANDU units to increase the quantity of cobalt 59 in radioactive systems is in the opposite direction to that of the PWR and BWR community.

The nuclear industry has done an excellent job of increasing awareness of nuclear safety within utilities. I am concerned that a similar awareness of the impact of radiation fields on materials is lacking. The increased use of stellite and my observations, both inside of and outside of Bruce Power, lead me to believe that unless this awareness of the impact of radiation fields on materials, especially trace chemical elements, is reinforced, some utility owners will pay a significant price.

CONCLUSIONS

- Decisions to save schedule, like that to not store Unit 5 secondary side during construction, can lead to significant legacy issues.

- Design specifications of replacement materials for operating units are different than those for units under construction.
- Material specifications do not always define acceptable methods for storage.
- Steam generators were not designed and built to allow radiation shielding to be installed.
- Steam generators and interconnecting systems were not designed and installed to allow individual steam generators to be drained alone.
- Outage planning and maintenance activities are planned to suit resourcing rather than material impacts.
- Turbine manufacturers have designed seals that do not exclude air ingress.
- Lead shielding, if incorrectly applied such that contamination remains within a steam generator, will lead to steam generator tube damage.
- It appears the lessons of Douglas Point and Pickering A with respect to cobalt-60 are being ignored.
- The impact of radiation fields on materials appears to have been overlooked by many.

RECOMMENDATIONS

- Designers must ensure that material specifications are compatible with the needs of operating nuclear units.
- Material specifications for replacement materials for operating units must preclude introduction of unwanted contamination.
- Designers must ensure that material storage requirements specify means to preclude contamination and degradation during storage.
- Steam generator designers and suppliers must provide means to allow effective shielding whilst precluding loss of shielding material within the steam generator.
- The design of introduction, assembly, dis-assembly and removal of such steam generator shielding material must be such that it can be rapidly executed.
- Steam generator designers and suppliers must provide means to allow preservation of sensitive areas, such as the tubesheet, during periods when extended (greater than seven days) draining is required.
- Designers and suppliers must allow for effective isolation of steam generators permitting lay-up of all steam generators other than that for which maintenance is required.
- Maintenance of, modifications to, and construction of nuclear units must be executed in a manner that maximises material preservation and minimises material degradation.
- Designers, material specifiers and maintenance personnel must be aware of the impact of radiation on the chemical constituents, including trace elements, of materials that could be subject to radiation.