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HOW TO MINIMISE FUEL FAILURES, AND OTHER SURPRISES, FOLLOWING NEWBUILD/REFURBISHMENT

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ABSTRACT – Fuel failures (defects) present various immediate problems to Plant Executives, Managers, Fuel and Physics, chemistry and environmental monitoring staff. Longer term consequences are encountered if prompt action is not taken.

The construction of new, and the refurbishment of existing, units offer unique opportunities to prevent onset of fuel failures and their associated challenges.

Good planning, combined with strong quality control/quality assurance, of construction/refurbishment activities can significantly minimize fuel failures, and other surprises, following unit commissioning and subsequent operation.

Introduction

Construction of any, new or refurbishmentof a, facilityis usually conducted by field forces that will be accountable for neither operation nor maintenance of the finished product. This means, that no matter how good the training program of the construction (contractor) companies, the construction field forces feel little or no ownership of the completed project. Nuclear plants are no different in this regard. This paper suggests approaches that can be applied to reduce the number of surprises, including fuel failures, awaiting the owner/operator's staff. There is no question that these approaches all cost money and potentially can add to the schedule. However, the financial impact of not following such approaches can be exorbitant to the utility. These approaches are based on the author having overseen the construction and commissioning of five top-performing nuclear power plants.

1. Plant Construction - Good Planning

Good planning starts with excellent material specifications which includenot onlyhydrostatic test fluids and conditions but also component preservation means. Thesespecifications will prescribe all test and storage conditions from casting the "ingot" to the product being installed at the plant. The intent is to eliminate, as far as possible, corrosion products, undesirable contaminants and "foreign bodies", otherwise known as "foreign materials".

Project planning has to include appropriate storage of components during transportation and at the construction site. Should protective coatings have been employed then appropriate methods of removal must be prescribed. Following protective coating removal,further preservation of the component may be required to minimize corrosion, prevent entry of detritus, including dust, dirt and critters!Such precautions are required until such time that the component has been firmly installed in its final intended location - with pipework attached.

Hydrostatic testing of piping systems will be required following installation. Judicious application of the hydrostatic testing process can result in significant reduction of corrosion products - and project costs and schedules. The greatest advantage can be obtained with excellence in welding. During construction of Bruce "B"(Units 5-8) hydrostatic tests were conducted on total systems only [1] – no welds failed. The same approach was proposed for Cernavoda Unit 1; however theProject Management had little confidence in the welding capability of the contractors [2], however the use of wet lay-up solutions for hydrostatic tests did minimize corrosion product generation.

Hydrostatic testing is amandatory facet of plant construction and is performed to meet the necessary code and regulatory requirements. Historically, construction field forces were accountable for performing these hydrostatic tests. Even though specific fluid conditions may have been stipulated, field forces have a knack for finding methods which save them time and trouble; the saving of time and trouble are seen by field forces as an appropriate balance to avoiding the stipulated fluid conditions whilst meeting, or even advancing, schedule.

Performing hydrostatic tests on completed, as opposed to being partially built, systems has many advantages. These include reduction of the number of hydrostatic tests, quantities of fluid and chemicals to be used and reduced environmental emissions and/or disposal costs.The avoidance of sequential draining, air exposure and refilling of pipework results in reduced corrosion and corrosion product generation.

2. Plant Construction, Plant Refurbishment – Cleanliness or Build-Clean program

This facet of plant construction is crucial to the later performance of the plant. Plant performance isnegatively impacted by physical debris and chemical contaminants. Whereas the title of this paper refers to plant construction and refurbishment, the same principles extend to maintenance outages [3].

Examples abound worldwide of where theconsequences of physical and chemical contamination have resulted in huge losses to utilities, see Table 1. A few of the many examples of what happens when inadequate cleanliness, or foreign material exclusion, practices and oversight are allowed to exist include events at Bruce Unit 2, Point Lepreau, Latina, Hatch1, VogtleUnits 1 and 2, Cernavoda Unit 2 and Bruce Units 1 & 2. In each case there was significant cost to the utility - in some cases, the full impacts have yet to appear. In each case plant operators were distracted from their usual surveillance as a result of the introduction of foreign material.

Build-clean principles are common to all plant systems – the degree of vigilance will vary from system to system. For example the heat transport, moderator, boilerand related systems will have the highest degrees of cleanliness. Service water systems, whilst important for heat sink concerns, will receive great attention, but less rigorous than for the previously mentioned systems.

2.1 Cleanliness, or Build-clean, principles

There is no question that the principles of cleanliness or build-clean programs – similar to foreign material exclusion – are a logical extension to ensure that the plant avoids problems which foreign material would cause. The issue is with execution of the program; this depends totally on how much accountability the utility is willing to grant those in charge of oversight of the cleanliness program.

If such oversight has "teeth" and reports, for example, to the site President, vice-President, or utility board and has the power to stop field work until the program is back on track then it is probable that the utility will have a plant that performs well with few problems, and in the long-term. However, should accountability be given to the contractor organisation performing the work, or the Project Director/Construction Manager for whom the bonus depends on schedule compliance then the cleanliness program will suffer and, as a consequence the plant and the utility.It is essential that the utility retains oversight of cleanliness programs using knowledgeable, empowered, staff. These staff must be supported by the utility as undoubtedly relations with project/contractor management – having bonuses at risk – stand to become fraught!

2.2 Cleanliness program execution

For Bruce B the primary heat transport system cleanliness requirement was defined as "……..the system must have a clean interior surface and be free of rust, scale, lubricants and debris"….[4]. To ensure that this requirement was honoured Bruce Construction had not only trained its staff but had oversight via the on-site Nuclear Piping Engineering group and a separate Quality Assurance (QA) group with dedicated field inspection staff [5].State of the art (early 1980) tools available to the QA group included long fibrescopes with recording capability. In addition to the Bruce Construction groups overseeing execution were staff from Bruce B Operations led by the Station Chemist.

Unless being actively worked upon open pipework ends were not allowed, rather each pipe end was covered by a cap. Pipework that was transferred from outside Bruce B (large bore fabrication shop, pickling plant or storage area) had capped ends. Pipework that had been pickled had ends that were covered by plastic sheet secured by duct tape.The author recalls when pipework being transported to Bruce B would be rejected and returned for corrective action due to open pipe ends.

2.3 Primary Heat Transport System Specifics

Hydrostatic testing was conducted using heavy water dosed with lithium hydroxide and hydrazine- a wet lay-up solution. The system remained full until "hot conditioning" after which the system was drained to allow manual fuel loading. For hot conditioning each Bruce B fuel channel had a strainer placed in the inlet (position 13). Following examination of the Pickering Unit 1 G16 fuel channel, that failed in 1981, it was learned that the garter springs, or spacers, had been incorrectly positioned. Fuel channel spacer location checks at Bruce B identified that those of Unit 6 had moved – this was enabled by fluid flow vibration during hot conditioning. As a consequence an experiment was conducted in Unit 5 for which ten channels had their garter springs located in the correct position after which 12 of 13 fuel bundles were manually loaded into the channel [6]. A stainless steel shim was employed to avoid machining the fuel channels and the swarf generated in Unit 6 from both fuel loading and removal (to allow **S**pacer **L**ocation **A**nd **R**elocation) SLAR to be performed.

At least one SLAR head "blew up" necessitating the fuel channel to be changed. Interestingly a similar event requiring replacement of a fuel channel occurred at Bruce B Unit 6 during June of 2002 [7], [8].

Unit 5 underwent "hot conditioning" after which those ten channels containing fuel were manually defuelled. Unfortunately no shim was available to minimise swarf generation. Steps were taken to reduce the amount of swarf in both Units 6 and 5 but not all the swarf could be removed. For both units some swarf could well have fallen through the liner flow holes into the end fitting. Removal of all of this swarf would have been impossible; however, what could be removed was extracted from the system.Fuel failures were later experienced at Bruce B – as described in reference [8]. Unfortunately the swarf was generated after the strainers had been removed from the fuel channels.

As mentioned earlier for Bruce B, strainers were placed in fuel channels into position 13 (inlet). This was a good practice which was insisted upon by the regulator as a result of issues at Bruce A. The strainers collected debris and photographic evidence is available in commissioning reports. For reasons unknown to the author these strainers ended up being scrapped. Unfortunately the good practice of using fuel channel strainers was ignored for the restart of Units 1 and 2 resulting in more defect fuel than otherwise would have been the case.

Examination of the ten Unit 5 channels containing fuel during hot conditioning showed that only the centre two garter springs were "pinned" as a result of fuel channel sag induced by the mass of fuel. Consequently Unit 8 design was changed to have "tight" fitting, as opposed to "loose" fitting, garter springs. Both Units 7 & 8 were hot conditioned with fuel in core [9].

3. Operational Consequences – short term

Debris can, in the worst case, result in not just defect fuel but damage to the fuel channel requiring costly flaw evaluation and even fuel early channel replacement. Other related effects include difficulty replacing channel closure plugs. All debris will contribute to circulating material that will enter the core - some will become trapped in core, fuel is an excellent strainer. Not only can suchmaterial create mechanical mayhem but it can also result in elevated radiation fields outside the core.

Many alloys contain elements which will undergo neutron activation. Those of concern have half-lives in excess of a few days and have gamma decay energies >300 keV. Many elements are of concern, but from a radiation field perspective, that of greatest concern for occupational exposure is cobalt-59 which is used in many alloys in various concentrations. Cobalt-59 activates to Cobalt 60 which has a ~5.3 years halflife and emits 2.5 MeV per disintergration (1173 + 1332 keV gammas)!

During component manufacture suppliers have need to use lubricants and coatings to facilitate their manufacturing methods. Some of these coatings and/or lubricants can remain on the component when installed into the heat transport system. The impact of chlorine/chloride is well known and usually the specifications have requirements for low chlorine/chloride materials to be employed.

There are more innocuous materials which can lead to problems. One such example is zinc which has been used in lubricants during component processing. All four Bruce A units suffered from the effects of zinc-65; this radionuclide was responsible for most of the gamma radiation exposure of staff for the first three years of operation. Ontario Hydro pursued an investigation to eliminate the source of zinc-64. This exhaustive investigation revealed that there was not one source, rather many small sources which were difficultto eliminate.

As a result of the zinc-65 issue Bruce B took steps during commissioning to perform a low concentration decontamination, or chemical clean, to remove the zinc and other contaminants that may have been present. This process used dilithium (ethylene diamine tetraacetic acid) EDTA and was tied into the hot conditioning evolution. The process was successful [9].

NOTE: zinc addition has been credited with reducing the impact of cobalt-60 in US pressurised water and boiling water reactors. Zinc addition to CANDU® units will not be similarly effective due to both the huge mass of of magnetite (many tons) present and the continuous generation and transport of magnetite.

4. Operational Consequences – Long Term

Cobalt-60 can present problems over both the short and medium term and the effects are immediately felt by those tallying occupational exposure. However, the long term issues which are not always felt immediately are costly and have huge impacts on the utility. Such impacts are described in reference [10]. To summarise they include degradation of the sensitivity of on-line defect fuel detection and location systems, increasing concentrations of transmuted transuranic radionuclides leading to potential alpha exposure problems and increased environmental emisions. Such problems have been encountered at Point LePreau and Bruce Powerwhich also impacted on their refurbishments [10], [11].

5. Financial Consequences

Table 1

Plant	**Year**	**Event**	**Outage**	**Replacement Energy ~ M$**	**Other Costs**
Bruce 2	1990	Lead blanket	17 years	>600	
Latina	1970	Nitric acid rain	~6 months	~183	
Point Lepreau	1995	Plywood bungs	3 months	91	
Pickering 7	2008	Gadolinium oxalate	3 months	91	
Hatch 1	1982	Chlorinated solvent	5 weeks	35	
Vogtle	2002	Sodium hypochlorite	17 days	17	
Vogtle	2002	Sodium hypochlorite	7 days	7	
Bruce 5-8	1989	Sulphuric acid	3 weeks*	~21	
Peach Bottom	1981	Turbine lub oil	~1 week	~7	
Bruce 1-4	1986	Sulphuric acid	3 days	3	
Bruce 5	1995	Pitted boiler tube	No		Minor
Bruce 1	1979	Crushed fuel-P13	23	~23	Huge**
Point Lepreau	1982	Defect fuel - startup	No		Huge**

Cernavoda 2	2007	Defect fuel - startup	No		Huge**
Bruce 1	2013	Defect fuel - startup	No		Huge**
Bruce 2	2013	Defect fuel - startup	No		Huge**

*Estimated unit days production lost
** Huge cost associated with impact on normal operation, maintenance activities and refurbishment because of transuranic alpha emitting radionuclides.

More CANDU® specific events can be found in reference [12].

6. Conclusions

Plant operators are sufficiently challenged by normal day to day issues. The additional challenges resulting from debris/contaminants remaining from construction or refurbishment or even maintenance activities present unwanted distractions to plant operators.

Financial impact of debris and contaminants remaining following construction, refurbishment and/or maintenance can be exorbitant. This cost is far in excess of the cost of implementing and maintaining a comprehensive build-clean program.

A comprehensive build clean program is required as an integral part of any new plant construction, existing plant refurbishment and maintenance activity.

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