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Document Number: NK38-REP-39000-10019	
Sheet Number: N/A	Revision: R00

Title: **KINECTRICS' DTRF/HWM 2005 AGING REPORT**

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Kinectrics' DTRF/HWM 2005 Aging Report

NK38-REP-39000-10019-R00

Sheet Number: N/A

2005-09-19

Order Number: N/A
Other Reference Number: N/A

Internal Use Only

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KINECTRICS

Darlington Tritium Removal Facility (TRF), and Heavy Water Management (HWM) Systems Aging Report

Kinectrics Report: 11146-001-RA-0002-R1

June 2005

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Kinectrics Inc has prepared this report in accordance with and subject to the Master Services Agreement (MSA) between Kinectrics Inc and Ontario Power Generation Inc dated January 1, 2002

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REVISION HISTORY

Revision Number	Date	Comments	Approved
A	Feb 4, 2005	Draft Released for review.	JRR
0	Mar 30, 2005	Issued	JRR
1	June 10, 2005	Comments from OPG incorporated	JRR

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KINECTRICS

TO: Nalini Valliere

Engineering Services Division
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1 EXECUTIVE SUMMARY

There are two main components of Heavy Water Management (HWM) at OPG:

- Tritium control via D_2O detritiation
- D_2O isotopic control via D_2O recovery, cleanup and upgrading

An essential contributor to efficient management of these two components is having adequate D_2O Storage and handling capability. Systems for cleanup, upgrading and detritiation of heavy water form a critical part of the heavy water management cycle at OPG. The recent low reliability of the Darlington Tritium Removal Facility (TRF) has focused attention on the fact that the TRF is a key facility for heavy water management at OPG. It is an essential facility for all stakeholders as it is the only source of reactor grade, low Curie make up water for the PHT system and is essential to ensuring that the Stations meet their OP&P limits. The decreased reliability of this aging facility has a large impact on management of heavy water including its storage, segregation, and diversion.

The operation of the Upgrader and the TRF is also integral to heavy water management at Darlington. The Upgrader product is generally only acceptable as moderator make-up, since recoveries are not segregated at Darlington during normal operation. Thus the tritium concentration of Upgrader product is normally too high for PHT make-up. In addition, the TRF is required to maintain moderator and PHT tritium concentrations below their OP&P limits (Darlington Moderator OP&P limit is 15 Ci/kg, the limit for the PHT is 1.2 Ci/kg).

This report provides an assessment of the aging of both the TRF and the Heavy Water Management Systems at the Darlington Nuclear Generating Station. The assessment is based on consideration of the factors that have caused aging of the systems in the past and that are expected to contribute to significant deterioration of system condition in the future. At this time, the study team has undertaken no in-plant investigations of the aging of components.

The report was prepared using OPG documentation such as previous reports, summaries prepared by OPG staff, or information such as SCRs contained within various databases. Detailed interviews with a cross section of staff were used to provide additional information. Operating experience in other industries has been investigated, if possible.

Operating experience over the past 15 years has shown that some areas of the TRF have been susceptible to aging by corrosion.

In the VPCE, stainless steel components have experienced stress corrosion cracking via the action of chlorides. These chlorides have originated from the Pt/carbon catalyst used in the VPCE which was found to have unacceptably high levels of chlorides.

Another source of corrosion is possible in the Recombiner system, where the low pH is obtained in the recombiner product due to the formation of nitric acid from the trace amounts of air in the oxygen feed to the Recombiner. This is formed by the energy release from the hydrogen burning in the Recombiner.

In the Deuterium Make-Up System some corrosion in the vent piping has been observed due to carry-over of KOD due to level control upsets. Some carbon steel vent lines from the Recombiner outlet and the Analyzer Room, which are connected to the Ventilation Exhaust, have experienced severe corrosion. Some vent lines will need replacement after a few more years of service in the corrosive environment. In the Deuterium Make-Up System some corrosion in the vent piping has been observed due to carry-over of KOD due to level upsets.

The TRF Chilled Water, Steam and Low Pressure Service Water (LPSW) supply systems show some signs of wear and corrosion. The LPSW system has biological growth (microbial induced corrosion, MIC) and some zebra mussels. WANO (World Association of Nuclear Operators) will be recommending that MIC damage be addressed. MIC damage is a concealed form of corrosion, which could lead to high cost for repairs. With a strategy for controlling MIC in place no foreseeable problems are anticipated for continuing service at present although refurbishment of corroding pipes may be required in the future. Replacement of the carbon steel bolts in the system is recommended.

The TRF and HWM Building has experienced some roof leaks and blow-out panel damage. However, no foreseeable problems are anticipated for continuing service.

The performance of the TRF and HWM Building Ventilation System has generally been satisfactory. No foreseeable problems are anticipated for continuing service.

The TRF/SUP Computer System components are relatively new (acquired by ABB in late 1996 and installed at Darlington in November 1998). However, different components have displayed different reliability since commissioning. Since Q2, 2001 the System has been monitored as per formal Performance Monitoring Procedure SPMP 69791 and Health Reports filed. The performance of the system has generally been satisfactory.

Aging of electrical components due to heat may result in failures such as the capacitors in power circuits. This type of failure will result in a cascading failure of other components.

Hard wired shut down relay failures were recently repaired because the springs on the relays had failed. The majority of these shutdown relays have been replaced now, and some more will be replaced in the next TRF outages.

In the Dryer Unit erosion of the molecular sieve pellets has resulted in gradual breakdown of the pellets. In addition, the binder used in the fabrication of the pellets is expected to deteriorate with age. The aging mechanism is hydrothermal stability of the binders [9].

The cryogenic adsorbers have shown signs of aging and blockage, which is discussed at length in the PCA report. Replacement of the cryogenic adsorbers is planned as a project to be executed during an outage in the next few years.

The equipment of greatest concern within the DTRF for long-term aging issues are:

- Dryers – molecular sieve aging
- High temperature components in the VPCE
- Recombiner high temperature areas
- All cooling water systems due to MIC
- Electrical and I&C equipment – general long term deterioration

2 INTRODUCTION

This report provides an assessment of the aging of both the TRF and the Heavy Water Management Systems at the Darlington Nuclear Generating Station. The assessment is based on consideration of the factors that have caused aging of the systems in the past and that are expected to contribute to significant deterioration of system condition in the future. At this time, the study team has undertaken no in-plant investigations of the aging of components.

Since 2001 the TRF has gradually moved from white to yellow to red in the plant health reporting system mainly due to the poor capacity factor, lack of spare parts and the large number of functional failures. The System Health rating for the TRF has been red for the past two years. The HWM is in the Yellow category.

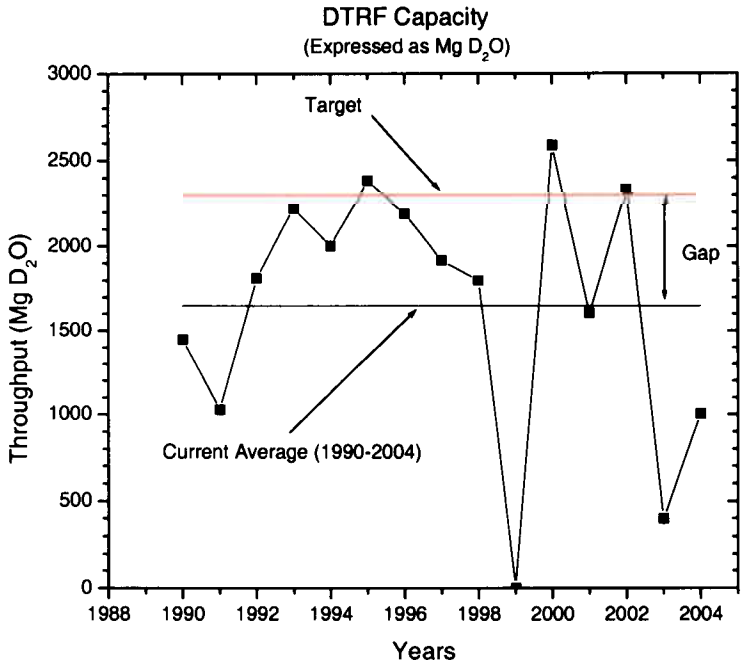

Figure 1 shows that the performance of the TRF has been quite erratic over the last 5 years and forced outages have been unexpected and unpredictable. Since the commissioning of the TRF, 15 years ago, it has experienced a number of significant forced/planned outages. These outages are listed in approximate chronological order as follows:

- Repair of seized VPCE Liquid Ring Compressor
- Replacement of the Charcoal Catalyst in CAT 1601(equilibrator in CD4) with Pt/Alumina. Changes to the piping configuration in the HTCB (this involved cutting and welding of tritium-contaminated equipment)
- Replacement of the tube bundles in all 8 VPCE evaporators and 1 feed evaporator due to stress corrosion cracking of the original bundles. Stainless steel tubes were replaced with Inconel-625 tubes.
- Replacement of the filter FR-3116 in the CRS with a filter having a more coarse mesh size
- DU molecular sieve flooding from LRC (Liquid Ring Compressor) seal tank water carryover
- Replacement of leaking superheater tube bundles
- Replacement of about 96 Fisher valves in the VPCE/DU due to failure of the bellows in these bellows-sealed valves.
- Replacement of the obsolete and trouble-prone control computer system in 1999 with a Fischer and Porter System 6 computer system.

- Flushing of the CRS system piping to remove oil which had carried over. The piping was flushed with a solvent to remove oil.
- Repair and inspection of the cracks in VPCE superheater nozzles (suspected to be caused by stress corrosion)
- The present unplanned outage, which is caused by plugging in the CRS (by oil carryover). During this outage cutting of the CRS tubing has been done. The root cause of this has not yet been determined.

Each of these outages has lasted for significant time periods ranging from a few months to up to 18 months.

Development of a TRF & HWM life cycle management plan (LCM), aimed at improving the reliability of this facility, is therefore of high importance to OPG. The focus of this report is the assessment of aging mechanism, which is expected to impact the reliability and lifetime of TRF systems.

3 AGING MECHANISMS AT THE TRF

An aging mechanism is a specific process that gradually changes the characteristics of a system, structure or component with time and use. Aging of a component may be experienced because of environmental factors, e.g. temperature, humidity or service conditions, e.g. vibration, mechanical stress, etc. A significant aging mechanism is one, which, if in the normal and abnormal service environment, causes degradation during the installed life of the equipment that progressively and appreciably renders the equipment vulnerable to failure [1]. There has been a shift in industry philosophy from attempting to identify and address all possible aging mechanisms to evaluating and mitigating known, significant aging effects [1].

Typical aging mechanisms are, corrosion, mechanical wear, erosion and fatigue. In addition, the effects of cryogenic temperatures, the presence of tritium and hydrogen in the process and refrigeration systems needs to be considered. In general the materials of construction in the TRF have been selected to be compatible with the process fluids and temperature and pressure conditions. For example 316L and 304L austenitic stainless steel and aluminum was selected for fabrication of components in the cryogenic parts of the TRF. In general, 316L stainless steel was used as the preferred material due to its slightly superior tritium compatibility and proven ductility at cryogenic temperatures. Further qualification of the material was done during testing of weld samples at 20K at the University of Vienna and Teledyne during the design of the system [10]. Cryogenic heat exchangers, condensers and reboilers were of the plate-fin type, fabricated from aluminum.

3.1 Corrosion

The TRF is generally free of corrosive chemicals, which are typically known to cause aging by corrosion. However, operating experience over the past 15 years has shown that some areas of the TRF have been susceptible to aging by corrosion.

In the VPCE, stainless steel components have experienced stress corrosion cracking via the action of chlorides. These chlorides have originated from the Pt/carbon catalyst used in the VPCE, which was found to have unacceptably high levels of chlorides.

Another source of corrosion is found in the Recombiner system where a low pH is obtained in the recombiner product due to the formation of nitric acid from the trace amounts of air in the oxygen feed to the Recombiner. This nitric acid is formed in the combustion process.

In the Deuterium Make-Up System some corrosion in the vent piping has been observed due to carry-over of KOD from level control upsets in the electrolysis systems.

3.1.1 DMS Electrolysis Cell Membrane

There have been a number of module failures for which the root cause is not determined (SCR D-2001-06617). Membrane failure in the electrolysis cells has been a problem contributed to by the high temperature, current density and high concentration electrolyte. There have been repeated failures with resultant downtime. A failure of the electrolysis membrane module occurred in 2001, and a new unit replaced the defective membrane module in early 2002. The unit is maintained charged with high concentration electrolyte during standby. This can lead to problems with membrane degradation, which is common in electrolysis units and KOD crystallization out of electrolyte solution. The electrolyzer manufacturer has recommended that the electrolyte should be drained when the DMS is not operating for an extended period of time (up to 30 days is acceptable).

3.1.2 Low Pressure Service Water (LPSW)

Corrosion and biofouling have been experienced in the LPSW system. Corrosion is in the form of rusting of the carbon steel piping and biofouling is the result of zebra mussel infestation. External corrosion is evident beneath pipe lagging. This may be caused by high humidity in the room. Carbon steel bolts in the plant are to be replaced. As a means of addressing the aging of the LPSW system, refurbishment of corroding pipes may be required in the future.

The VPCE condensers are susceptible to scale formation ($CaCO_3$) on the LPSW side due to the high process temperatures and the variation in lake water temperature.

The CRS also has corrosion in the recirculating cooling water system. Flow indicators on the system are stuck in a fixed position due to dirt.

Internal corrosion, microbially induced, is a serious form of degradation of system materials in the nuclear industry, particularly systems like the LPSW. Screening the COG OPEX database for just the year 2003 produced 65 hits. With a strategy for controlling MIC in place, no foreseeable problems are anticipated for continuing service at the TRF.

3.1.3 Chilled Water System

The chilled Water System is a closed loop system. The system has provisions for chemical treatment to mitigate corrosion. The piping is low carbon steel class B. As a result there are no major corrosion concerns.

3.1.4 LTC Expansion Tank Room and Air Cleanup System Dampers

Inlet louvers are provided in the south walls of the LTC Expansion Tank Room. These louvers are provided with dampers and when the dampers are opened, the LTC Expansion Tank is effectively exposed to the outdoor condition. However, these dampers for some reason cannot be closed completely. These dampers may need replacement due to aging and should be inspected.

Some dampers in the ventilation system are not leak-tight. There has been no in-service inspection of the dampers to date. There is a potential for degradation and malfunction due to aging.

3.1.5 Vent Lines

Some carbon steel vent lines from the Recombiner outlet and the Analyzer Room, which are connected to the Ventilation Exhaust, have experienced severe corrosion. Some vent lines will need replacement after a few more years of service in the corrosive environment e.g., the Recombiner vent lines normally see strong nitric acid, which is formed due to the combustion of nitrogen with oxygen in the Recombiner. In general the ventilation system is contaminated and corroding.

Rust scale formation in the vent lines can generate flow blockage and result in an overpressure protection issue, since some of these vent lines are equipped with relief valves. An inspection program has been carried out to routinely monitor the wall thickness of these vent lines and also signs of corrosion deposits in the vent lines.

3.1.6 Exhaust Stacks

There are three major exhaust stacks in the Heavy Water Management & TRF Buildings. No inspection has been done on these exhaust stacks to date. There is a potential for degradation due to aging.

3.2 Mechanical Wear, Fatigue

In the TRF, aging due to mechanical wear and other mechanical mechanisms such as fatigue and erosion is expected for components with moving parts, such as pumps, compressors, turbines, valves and components subject to large fluid shear forces such as the liquid ring compressors. Therefore, these components are generally subjected to regular inspections and maintenance, as opposed to most of the components, for example, in the cryogenic systems. At present it is not clear whether the repeated failure of the bellows in the DPS pumps is as a result of fatigue, weld defects or excessive vibration under operating conditions. Further investigation is recommended in order to determine the root cause of the failures.

3.2.1 Valves

Pneumatic (Fisher) valves are used in the TRF front-end systems. Bellows failures were detected on several Fisher valves in early 1999 (SCR N-1999-00736). All Fisher valves were refurbished, and a re-designed bellows installed, by the end of 1999[1]. Based on the previous valve bellows failure incident, it is anticipated that some of the Fisher pneumatic valves (~30 valves), particularly the ones that are operated frequently in the FTS/DU, may require another refurbishment, possibly after another 10 years of service as result of bellows fatigue.

3.2.2 VPCE Superheater Steam Side Gaskets

There have been 3 incidents is the past of steam leaks from the superheater gaskets on the steam side. This is a symptom of aging under the high temperature service conditions.

3.2.3 TIS

In the TIS system, equipment such as metal bellows pumps, Nupro PVs and Jordan PSVs have not received detailed preventative maintenance. Despite the lack of PM, the Nupro PVs have operated reliably and no major valve problems have been identified to date. It is apparent that the aging mechanisms that affect these valves are sufficiently slow and thus significant failure of these valves is not anticipated. However, a valve inspection program is recommended. Several of the oil-lubricated rotary vane pumps have experienced bearing failures, which may be due to heavy load conditions or lack of preventative maintenance during oil changes. Argon leakage from ganged solenoid valves into the gloveboxes has been believed to be a problem since start-up of the system. The elastomeric seals on the gloveboxes have not had any PM and as a result many are noticeably cracked.

3.2.4 Electrical and Control Systems

Aging of electrical components is primarily due to service conditions such as heat or length of service of the component. The electrical and instrumentation systems are considered a potential problem area due to the age of the systems. On the circuit boards of the analyzers, there is concern about the capacitors because if these fail, then the IC chips will lose their functionality and are not replaceable due to obsolescence.

It has not been possible, within the scope of this project, to check the status of electrical cabling in the TRF via inspection to determine if signs of aging are present in the cables. However, based on experience at other aging facilities (e.g. Pickering A) it is recommended that an inspection of the cabling should be performed to ensure that they are in good condition. Similarly, it is accepted that motor windings will deteriorate with age, particularly under conditions of high ambient temperature or humidity. As a result megger tests of key motors should be performed in the future.

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[1] This was a design issue rather than an aging of the bellows.

Electrical panels associated with the tritium monitors as well as other instruments are failing due to aging, requiring repair of individual boards by Control Maintenance since the instruments are, in most cases, obsolete.

Hard wired shut down relay failures were recently repaired because the springs on the relays had failed. They had been closed for 15 years and were checked periodically to ensure that the relay opened but only checked to ensure that the contact was lifting. The relays were never checked to determine that the contact actually went to the fully open position with the spring. Springs on the relays in the Hard-wired shutdown system may be aging – a potential safety concern. The majority of these shutdown relays have been replaced now, and some more will be replaced in the next TRF outages.

In the TIS, there have been problems experienced with failing capacitors on ion gauge controllers, pressure transmitters, turbo pump controllers and the mass spectrometers. The mass spectrometer used to analyze the quality of the tritium gas has experienced several computer component related failures (e.g. W.O. #D-83174 and D-1153486). Although still functional, the mass spectrometer is obsolete and replacement parts are difficult to obtain. The mass spectrometer CRT is now difficult to read. Instrument cables and elastomer instrument seals exposed to the dry glovebox atmosphere have not been inspected or replaced. Potential degradation of all pump motors is anticipated due to motor winding aging or overload.

Control room mimic panel annunciators and lights are failing due to aging.

3.2.5 TRF/ HWMB Building Roofs

The roof of the Heavy Water Management Building (El. 115 m) is adjacent to the roof of the TRF Building (El. 112 m). During/following heavy rainfall, water collected on the roof of the Heavy Water Management Building could also drain onto the roof of the TRF Building. This would result in a heavier precipitation and rain loads to the TRF roof. As a result of aging, roof leaks have been observed – one in the CRS Compressor Room (near the gravity ventilators), one in the HWMB room containing the Stack Monitors, and the other in the Exhaust Fan (F3 & F4) Room in the HWMB.

3.2.6 Blow-out Panels

A number of the blowout panels' perimeter seals have become separated at the corners, some of the caulking had deteriorated with age, and is a possible source of water migration into the building. A building inspection in 2002 has also uncovered damage to the single panel on the north side of room TR-203. The damage does not affect the panel's ability to perform its design function, but it will also require repair.

3.3 Erosion, Blockage

3.3.1 Dryers ADS 1301, 1302

Decrepitation of the molecular sieve in the Dryer Unit has already been experienced in the TRF. This is likely caused by erosion of the molecular sieve pellets by shear forces resulting in friction between adjacent pellets and gradual breakdown of the pellets. The binder used in the fabrication of the pellets is expected to deteriorate with age. This aging mechanism in molecular sieve is called caking. Caking is mostly observed in the middle of the adsorber. Without sampling of the molecular sieve this aging mechanism is not readily observed. Caking is the result of hydrothermal instability of the clay binder. Caking has an effect on the mass transfer behavior of the molecular sieve. Experiments have shown that deactivation by caking leads to a loss of water adsorption capacity due to increased residual water content upon regeneration rather than a loss of maximum water capacity [9].

In the petrochemical industry, manufacturers recommend replacement of the molecular sieve in adsorbers/dryers every 3-5 years. However, the TRF dryers operate in a very clean environment and as a result already have lasted for about 15 years.

There has not been a change in the pressure drop across the dryer despite the possible aging. Pressure drops across the beds have stayed consistent over the years. The bottom of the dryer bed has been inspected and deposits and caking is seen. Fine powder is produced and has been found in valve seats and there is evidence of blockage of drain valves in the DU by molecular sieve powder. As a result, replacement of the molecular sieve should be considered.

The performance of ADS1301 and ADS1302 has been acceptable, with the dew point of the outlet D_2 gas maintained at -80 °C (or lower). However, the dryers are not achieving the same dew point that they were able to achieve in the past, due to a variety of reasons including molecular sieve aging (SCR D-2003-08562). The dryer unit used to achieve, "off scale low" on the dew-point meter, but now it can have a problem to get to –80°C dewpoint. The observed trend in the dewpoint has been from values of –90 to –95°C to where it has reduced to –78 to –82°C. Although this dew point is currently in the acceptable range, further deterioration will eventually lead to a major load on the cryoadsorber.

3.3.2 Cryogenic Adsorbers ADS1401, 1402

The adsorbers have shown signs of aging and blockage, which is discussed at length in the PCA report. Replacement of the adsorbers is planned as a project to be executed during an outage, in the next few years. However, it is believed that the blockage that has been experienced is unlikely to be due to normal aging of silica gel. It is suspected that the blockage resulted from break down of the silica gel which may have occurred during an incident in the past where water may have been carried over into the adsorbers.

3.3.3 Liquid Ring Compressors

The performance of liquid ring compressors has been good. However, the inlet and outlet ports in these compressors experience high shear forces and possible gradual erosion. This should evidence itself with gradually increasing vibration levels over time. Recent detailed discussions with liquid ring compressor manufacturers[2] have indicated that it may become necessary to rebuild low clearance areas of these types of compressors after ten to fifteen years of operation. This type of aging will have to be addressed when the TRF observes a drop off in the generation of a head pressure by the compressors.

With proper maintenance (e.g., routine changes of the compressor seals) and an inspection program, it is anticipated that the liquid ring compressors will last until after the end of TRF life.

3.3.4 Charcoal Beds

The charcoal adsorber ADS1101 and 1102 in the FTS have high pressure drop, believed to be most likely due to break down of the charcoal particles by erosion. The pressure drop across these beds should be monitored in the future for possible signs of blockage.

3.3.5 Chiller Water System

The piping distribution is designed for 10 ft/sec velocity and thus there is no concern for erosion. The life expectancy of 40 years is comfortably achieved with the design features provided.

The manual and control valves are made of cast iron body with brass internals. The valve design is very robust and durable. However, the valve elastomers do breakdown with aging or when the valve is in a closed position for very long time. With periodic inspection and replacement of the elastomers 40 years life expectancy of these valves is achievable.

TCVs are subject to cavitation erosion because of their flow throttling function, which involves significant pressure drops. Therefore, it is expected that the TCVs including a short length of piping downstream will sustain erosion damage resulting in reduced life expectancy.

3.3.6 Steam and Condensate System

The major concern in this system is the frequent failure of steam traps. When the trap failure occurs, it results in water hammer and or severe piping vibration. Control valves and the piping immediately downstream will suffer degradation due to erosion effects.

3.3.7 D_2O Upgrader Distillation Towers

Distributor plugging can occur in D_2O Upgrader Distillation Towers due to corrosion of the phosphor-bronze packing by weak acidic attack and subsequent deposition in the fine

[2] Both GARO, a supplier of this equipment for the WTRF and NSB Gas Processing, supplier of the original equipment at the DTRF, have mentioned this problem as an aging issue.

distributor holes. During a recent SUP Tower Visual check, it has been observed that many distributor nozzles are plugged significantly to the point where the downcomers are overflowing on Sections 5 & 6 of Tower 1 and Sections 19, 21 and 24 of Tower 3. Tower 3 is scheduled to be opened during the next outage. Darlington has been very successful at controlling the Upgrader feed chemistry resulting in the long operation of the Upgrader (in service 1988) without distributor plugging but plugging has begun and cleaning of the distributors needs to be addressed.

3.4 Tritium Aging

Exposure of elastomeric materials to tritium is expected to result in effects such as hardening and degradation of the material. Hardening of elastomers will affect the effectiveness of the seals. Degradation can produce by-products that can further affect the associated systems. The TRF has been designed to avoid the use of elastomers where possible and to avoid the use of materials that are incompatible with tritium service (such as Teflon which degrades and produces HF). Thus this is not expected to be a significant aging mechanism.

Tritium exposure of oils and lubricants in general will result in a level of degradation. These effects are well understood within the TRF and are handled by either regular changing of the oil[3] or the replacement of equipment (for example the oil-filled vacuum pumps in the TIS)[4].

Hydrogen-induced cracking can occur more easily in steel exposed to tritium for extended periods of time because of the creation of helium-3 within the metal from tritium diffusion into the steel and its radioactive decay. The effects of helium-3 at ambient temperatures make fracture easier by impeding plastic flow. Helium precipitates as nanometer sized bubbles that pin dislocations and act as a barrier to dislocation motion.

These effects have generally been studied in metals exposed to tritium at elevated temperatures and pressures (423K and 4500 psi) [3] or by ion implantation studies from accelerators [4]. The results have shown that tritium and decay helium reduced the cracking threshold for certain stainless steels. They also indicate that subcritical cracking can occur in tritium-exposed stainless steel at velocities much lower than hydrogen-exposed steels because of decay helium effects.

This mechanism of aging in the TRF is not considered a concern. In general, permeation of hydrogen and tritium in metals follows the Arrhenius equation and is highly dependent on the driving pressure and temperature. At the sub-atmospheric pressure and ambient temperature conditions in the TIS, where pure tritium is handled, it is expected that tritium aging effects will not be a factor over the life of the TRF [8].

The ITC containers were the subject of some research into the effects of the tritium contained within them during their design in the early 1980's. A series of reports were

[3] Frequency of these oil changes exceeds the manufacturers recommended interval
[4] Pumps are only replaced on failure

commissioned to examine the potential problems of tritium in austenitic stainless steel and the effects of helium on the steel. It is understood that no problems have been observed in these devices due to tritium issues.

3.5 Cryogenic Aging Mechanisms

The cryogenic equipment within the TRF is exposed to stress associated with thermal cycling of the equipment through large temperature ranges. These effects were taken into account in the mechanical design and operational procedures of the plant. Well defined heat up and cool down rates has been established in the operating procedures. The choice of materials was made initially in the design of the TRF to withstand these stresses and be compatible with the temperatures found within the plant. Typical materials that are used in cryogenic systems, and were used in the TRF, are austenitic 304L and 316L stainless steel, and aluminum alloys. These materials were selected due to their suitability for cryogenic conditions.

Based on operating experience in the cryogenic industry, there have not been any specific aging mechanisms identified that can be associated exclusively with the cryogenic temperatures. Fatigue associated with the repeated application of stress is not expected to be a problem at the TRF. At cryogenic temperatures the selected materials retain their ductility and their fatigue strength generally improves.

Reflective insulation (such as aluminized Mylar) is typically used within the TRF cryogenic equipment. This type of insulation has the benefit of its ability to maintain its functionality for indefinite periods in adverse environments without causing or contributing to damage to the insulated component [4]. Within the vacuum cold box the insulation is not subjected to any form of harsh environment. The exception to this is around the electrical heaters where it is subjected to some heat effects and melting has been observed within the CRS system.

3.6 Hydrogen Embrittlement

The TRF handles significant volumes of hydrogen in a large number of systems both as a refrigerant and as a process gas. Hydrogen can cause a significant deterioration in the mechanical properties of metals. This effect is referred to as hydrogen embrittlement and is a significant design issue for cases where hydrogen is handled at high pressures. Hydrogen embrittlement involves a large number of variables such as temperature and pressure of the environment; the purity, concentration and exposure time of the hydrogen; and the stress state, physical and mechanical properties, microstructure, surface conditions and nature of the crack front of the material [5].

The types of hydrogen embrittlement are:

1. Environmental hydrogen embrittlement that has been observed in metals and alloys plastically deformed in a gaseous hydrogen environment (usually at high pressure). Deformations under such conditions lead to increased surface cracks, loss of ductility and decrease in fracture stress

2. Internal hydrogen embrittlement caused by adsorbed hydrogen. Small amounts of hydrogen may cause premature failures in some metals; the failures may occur with little or no warning. Cracks start internally.
3. Hydrogen reaction embrittlement that occurs when the adsorbed hydrogen chemically combines with one or more constituents of the metal to form a brittle hydride. This reaction more readily occurs at elevated temperatures.

The mechanical properties of metals are reduced in the presence of hydrogen:

1. The susceptibility of an alloy to adverse hydrogen effects increases as the strength of the alloy increases
2. Hydrogen embrittlement has been observed over a wide range of temperatures but for many metals and alloys the effect of internal and environmental hydrogen embrittlement is at a maximum in the temperature range of 200 to 300 K. In contrast, hydrogen reaction embrittlement is associated with temperatures above room temperature. Most data on embrittlement is at pressures in excess of 800 kPa.
3. The susceptibility of steel to hydrogen embrittlement increases as the hydrogen purity increases (a significant factor in the TRF).
4. Susceptibility to embrittlement generally increases as the tensile stress level increases.

Materials that exhibit negligible embrittlement are 316 stainless steel and aluminum alloys [5,6]. These have been used in the TRF in the cryogenic areas.

Welds are susceptible to hydrogen embrittlement in all hydrogen environments. The heat affected weld zone frequently produces hard spots, residual stresses and microstructure. In 1999 studies were done on material properties in liquid hydrogen environments [8] using SS 304, SS 316 and aluminum alloys. It was found that the base metal survived well in liquid hydrogen environments. However, weld metal showed high embrittlement susceptibility with respect to low temperature hydrogen embrittlement in liquid hydrogen. In low temperature hydrogen gas environments, SS 304L showed high embrittlement susceptibility.

Sulzer has used carbon steel (S.A. 516 Gr. 55, SA-266 class 1, SA106 Gr. B SA234 Gr. WPB) in non-cryogenic service areas in the hydrogen coolant side. Carbon steel can be classified as either severely or extremely embrittled in hydrogen service at high pressure. The key issue is the pressure. The maximum pressure that these carbon steel components should be exposed to is approximately 1045 kPa within the DTRF. This is a "low pressure" for hydrogen embrittlement problems. Typically problems of measurable failure are typically at pressures of 70,000 kPa.

Generally the materials chosen for construction of the TRF are negligibly susceptible to hydrogen embrittlement [5,6]. Information on the susceptibility of weld materials in liquid hydrogen environments is very limited. It is not considered necessary to inspect the TRF for hydrogen embrittlement problems.

4 AGING MATRIX

The attached aging matrix summarizes the aging mechanisms anticipated to affect the critical components within the DTRF.

A column in the matrix is given on Equipment Condition. The assessments in this column are based on the number of issues that were found with a given piece of equipment during the plant condition assessment. The ratings of "Good", "Fair" or "Poor" are a subjective assessment done by the team based on the plant condition assessment.

The equipment of greatest concern within the DTRF for long-term aging issues are:

- Dryers – molecular sieve aging
- High temperature components in the VPCE
- Recombiner high temperature areas
- All cooling water systems due to MIC
- Electrical and I&C equipment – general long term deterioration

5 REFERENCES

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6 APPENDIX A. DISPOSITION OF COMMENTS FROM OPG ON REVISION 0.

Disposition of Comments received on Revision 0 of the Aging Report

1. Edwardo Tam
    a. VPCE Condensers CD-1201 to CD1208 and the susceptibility for scale formation on the LPSW side due to high process temperature and lake water variations. Comment considered valid and added to potential aging mechanisms associated with the LPSW. $CaCO_3$ has an inverse solubility with temperature so increased temperature of lake water during the summer could increase the problem.
    b. CRS Hydrogen loop and hydrogen embrittlement in the H_2 compressors carbon steel discharge piping. Sulzer has used carbon steel (S.A 516 Gr. 55, SA-266 class 1, SA106 Gr. B SA234 Gr. WPB) in non-cryogenic service areas on the hydrogen coolant side. Carbon steel can be classified as either severely or extremely embrittled in hydrogen service at high pressure. The only question still outstanding is rate and pressure. It is difficult to know the rate of embrittlement a priori and the pressure at the discharge is approximately 1044 kPa (approx 140 psig). This is still a "low pressure" for hydrogen problems which are typically measured at 10,000 psig. However a note will be added to the report to cover the use of carbon steel in these areas and the higher potential for problems.

2. Harold Vogt
    a. Reference given for aging of Molecular sieve binder (Gas Purification). Aging mechanism is hydrothermal instability of the binders.
    b. Dates and durations of all of the past outages due to problems were not included as this list was only for information and not intended to be a specific chronology of the DTRF.
    c. Cutting and flushing of the CRS will be clarified
    d. The section on aging did not include all of the entries in the aging matrix. The report was only intended to highlight specific areas
    e. Agree with the comments on D_2O in the LTC Expansion tank and will modify the section.
    f. Will clarify ventilation and ACS systems
    g. A question was asked about the ITC containers and tritium aging. The team examined the references on the work done during the design phase of the ITC containers. A number of reports were done in the 1980's on the interaction of tritium and austenitic stainless steel (eg two reports were done at Chalk River on "Tritium in Austenitic Stainless Steel Vessels, The Integrity of the Vessel", C.E. Ells and "Helium in Austenitic Stainless Steel in Tritium Handling Facilities", C. E. Ells and S. A. Kushneriuk). It was concluded that the design of the containers had reviewed the potential problems with tritium in the containers. No evidence of problems is currently known to the team. The team was not able to identify a design life for the ITC containers. It is assumed that it is the same as the plant design life of 30 years. It is anticipated that there should not be problems

with the ITC containers but we are not aware of subsequent testing of any ITC container after use for a long period of time.

h. A note will be added to mention the problems of Mylar insulation near heaters and the melting that has been observed in the CRS system.
i. Hydrogen embrittlement is seen at a variety of pressures. Measurements on 304 stainless steel indicate that significant hydrogen adsorption into the steel does not occur below 800 kPa pressures. Most data that we have available for actual failure is at pressures in excess of 70,000 kPa. There is a lot of literature available on this subject but generally it is at pressures in excess of those seen at the TRF.

3. Kaly Kalyanam
   a. On your question about steam leaks causing SSC due to chlorides. This statement was based on a section in the PCA report discussing a tritium leak in March 2003 in superheater HX 1206. The leak in the weld at an outlet nozzle was inspected and the interpretation given to the failure was the possibility of a steam leak into HX 1206 being the primary source of chlorides (referenced a report on metallurgical analysis). This conclusion may have been based on the fact that the chloride source from the catalyst was long dealt with by 2003. Your details on the steam contents and the low chloride level indicate that the analysis done on the leak may not be the complete answer and this section will be rewritten.
   b. Aging of the DMS currently seems more to be related to operational issues and replacement of the unit with a modern system taking into account the way the DMS operates at the DTRF should not introduce new aging problems.
   c. The use of the term Charpy impact tests is not accurate and will be changed and the testing was at liquid hydrogen temperatures. Tests were undertaken by Sulzer on weld samples at 20K by the University of Vienna and Teledyne during their selection of material for cryogenic service (reference: Darlington Tritium Removal Facility Process Design Description, document no 4-04-DTRF-008-2, 1982, Sulzer Engineering)
   d. The bellows problems on the Fisher valves were a design issue not really an aging issue and this section will be rewritten to reflect that.
   e. The information on aging for the liquid ring compressors came from OEM information (the supplier of equipment for the WTRF – GARO and at a later date than revision 0 of the Aging Report, I also received information from the supplier of the DTRF compressors – NSB Gas Processing). We did not look at operating experience in this area.

Disposition of comments received on the Aging Matrix

1. Omar El Behairy
    a. Comments on the problems with the Alcatel pumps in the TIS will be taken into account and the aging condition changed

2. Kaly Kalyanam
    a. Use of notes on all of the tables will be cleaned up and references to removed notes eliminated
    b. Hydrogen embrittlement will be included (as a low probability event) for more equipment
    c. Thermal Embrittlement is used incorrectly in these tables and will be removed. The term specifically applies to embrittlement of autenitic stainless steel in the temperature range of 475°C and above where problems occur with the ferrite phase. The team had intended to use this phrase to cover loss of ductility in materials as they are cooled to cryogenic temperatures. This will be clarified in the tables.
    d. Notes will be added to cover the periodic replacement of UV lamps and IX resins
    e. Oxide coating degradation is still a potential mechanism for aging even with UV oxidation if the chemical control of the feed water to the distillation columns is not maintained. A note will be added to this effect.
    f. We agree that distributor plugging is more an aging mechanism of the packing and will be so noted.

3. Harold Vogt
    a. Questions on thermal embrittlement are correct in light of the incorrect use of this title.
    b. The inconsistencies on notes, similar equipment assessments and problems with equipment identification will be corrected
    c. It is a fair question as to how to assess the condition of cryogenic valves with no inspections of the valves. These will be listed as "Unknown".
    d. Electrical heaters can be exposed to fatigue due to thermal cycling (connections, mounting etc.) and it is felt that this is still a valid mechanism.
    e. Filters on the CRS will be re-examined and corrected
    f. Comments on the consistency between the PCA report and these matrices will be checked and corrected.

DARLINGTON TRITIUM REMOVAL FACILITY AGING MATRIX

Table A.1 Degradation Mechanism for Front End Systems

DTRF Front-End Systems: FTS (SCI 39310)/VPCE (SCI 39320)/DU (SCI 39320)/RS (SCI 39360)/DPS (SCI 39360)/DMS (SCI 39330)/LCS (SCI 39310)

Component	EQUIPMENT CONDITION	SCC	Fatigue	Thermal Embrittlement	Mechanical Wear	Erosion	Corrosion	Aging (see notes)	Blockage
Degassing Column COL1101	Good								
Feed Evaporator EV1101	Good						X	Note 1	
Feed Pumps P1101/P1102	Good				X				
VPCE Feed Pumps P1201/P1202	Good				X				
VPCE Product Pumps P1203/P1204	Good				X				
VPCE Evaporators EV1201 - EV1208	Good	X					X		
VPCE Catalyst Pots CAT1201 - CAT1208	Good	X						Note 2	
VPCE Superheaters HX1201 - HX1208	Fair Note 3	X		X			X		
VPCE Compressors CP1201/CP1202	Good				X	X			

Note 1: Deposits of radionuclides occur during abnormal conditions, continued deposit and difficulty of removal may present potential aging problem
Note 2: Potential catalyst degradation and loss of activity
Note 3: The superheaters will require on-going monitoring and inspection for leaks due to cracking

Table A.1(cont) Degradation Mechanism for Front End Systems

Component	EQUIPMENT CONDITION	*SCC*	*Fatigue*	*Thermal Embrittlement*	*Mechanical Wear*	*Erosion*	*Corrosion*	*Aging (see notes)*	*Blockage*
DU Compressors CP1301/CP1302	Good				X	X			
DU Dryers ADS1301/ADS1302	Acceptable trending to poor					X		Note 1	X
RS Recombiner TK1703	Good						X		
RS Recombiner Pump P1701	Good				X				
Hydrogen Generator HS125C note 3	Poor							Note 2	
Electrolyser Unit/Cell Module	Poor							Note 3	
DPS Vac. Pump Unit VACP2101/2102	Fair		X		X				
DPS Compressors CP2101/CP2102	Fair		X		X				
Liquid Collection Pump P2201	Good				X				
Valves (Manual/Pneumatic) Fisher, Velan & NUPRO, etc.	Good		X		X				

Note 1: Degradation of performance due to loss of adsorption capacity
Note 2: Electronic aging, relays and timers are weak points
Note 3: Expected life is 3 to 5 years; cell deltaP, temperature and torque control are critical; 3 or 6 month drain, open, inspect and deposit flush and electrolyte replacement recommended

DARLINGTON TRITIUM REMOVAL FACILITY AGING MATRIX

Table A.2 Degradation Mechanism for Cryogenic Distillation System

DTRF Cryogenic Distillation: AU (SCI: 39410)/LTD (SCI 39410)/HTD (SCI 39420)

Component	EQUIPMENT CONDITION	*SCC*	*Fatigue*	*Thermal Embrittlement*	***Mechanical Wear***	***Erosion***	***Corrosion***	***Creep***	***Aging (see notes)***	***Blockage***
Precoolers HX14011/HX1402 HX1411/HX1412/HX1403	Good		X				X			X Note 4
AU Adsorbers ADS1401/ADS1402	Poor note 1								Note 1	X
Heaters HX6003/HX6004	Good									
Adsorber Regeneration Vacuum Pump VACP6001	Good				X	X				
Low Tritium Column COL1501	Good									
Head Condenser CD1501	Good									
Reboiler EV1501	Good									
Vacuum Pump Adsorbers ADS1502/ADS1504	Good				X				Note 2	
Vacuum Pumps VACP1501/VACP1503	Fair									X Note 4
VACP1502/VACP1504					X					
Heat Exchangers HX1501/HX1521/HX1522	Good		X							
High Tritium Columns COL1601/COL1602/COL1603	Good									
Reboilers EV1601/EV1602/EV1603	Good		X							
Catalyst CAT1601	Good									
Vacuum Pumps VACP1601 /VACP1602	Fair									X Note 4
Heat Exchangers HX1601/HX1602/HX1621	Good		X							X Note 4
Cryogenic Valves (Manual/Pneumatic) WEKA, NUPRO, etc.	Unknown Note 3		X		X					

Note 1: Degradation of the silica gel, loss of adsorption capacity, problems with flow
Note 2: Loss of adsorption capacity
Note 3; No inspeciton has been performed on the cryogenic valves, they are expected to be in "Fair" condition

DARLINGTON TRITIUM REMOVAL FACILITY AGING MATRIX

Table A.3 Degradation Mechanism for Refrigerator

System: Cryogenic Refrigeration System (SCI 39440)

Component	EQUIPMENT CONDITION	SCC	Fatigue	Thermal Embrittlement	Mechanical Wear	Erosion	Corrosion	Creep	Aging (see notes)	Blockage
Hydrogen Compressors CP3401/CP3501	Good		X		X					
H_2 Coolers CLR3411/CLR3412/ CLR3511/CLR3512	Good						X			
Oil Pumps CP3401 & CP3501	Fair				X					
Auxiliary Compressor CP3801	Good				X					
Heat Exchangers HX3101/HX3102/HX3103 HX3104/HX3105/HX3106	Good						X			X
Turbine TU3200	Good				X					
Vacuum Pump VACP3301	Fair				X					
Vacuum Pump VACP3302	Fair				X					
Heaters H3111/H3112	Good			X						
Seal Gas Pump P3201	Good		X		X					
Turbine Oil Pump P3202	Poor		X		X					
Turbine Oil Cooler CLR3201	Good						X			
Filters FR3100/FR3101/FR3115/ FR3202/FR3801/FR3116	Good									X
Heater HX3842	Good			X						
Valves (Manual/Pneumatic) Fisher, WEKA (Cryogenic) & NUPRO, etc.	Unknown Note 1		X		X					

Note 1; No inspeciton has been performed on the cryogenic valves, they are expected to be in "Fair" condition

DARLINGTON TRITIUM REMOVAL FACILITY AGING MATRIX

Table A.4 Degradation Mechanism for ACS, GBCS, CHW & TIS

DTRF Auxiliary Systems: ACS (SCI 39520)/GBCS (SCI 39530)/TIS (SCI 39720)/CHW (SCI 73870)

Component	EQUIPMENT CONDITION	SCC	Fatigue	Thermal Embrittlement	Mechanical Wear	Erosion	Corrosion	Creep	Aging (see Notes)	Blockage	Oxidation
ACS/GBCS Regen Blowers F2	Poor				X						
ACS/GBCS Regen Heaters HTE2	Good			X							
ACS/GBCS Heaters	Good			X							
ACS/GBCS Dryers	Good					X			X Note 2	X	
ACS/GBCS Recombiners	Good										
ACS/GBCS O2 & N2 Removal Beds	Good									X	
ACS/GBCS Valves	Fair				X						
GBCS Argon Distribution Blower F3	Good				X						
Water Chillers RFU1	Good				X (Compressors)		X		Note 1		
Water Chillers RFU2	Poor				X (Compressors)		X		Note 1		
Filters FR2701/FR2702/ FR2751	Good									X	

Note 1: Loss of refrigerant or refrigerant no longer in use
Note 2: Degradation of performance due to loss of adsorption capacity

Table A.4(cont) Degradation Mechanism for ACS, GBCS, CHW & TIS

Component	EQUIPMENT CONDITION	SCC	Fatigue	Thermal Embrittlement	Mechanical Wear	Erosion	Corrosion	Creep	Aging (see Notes)	Blockage	Oxidation
TIS (39720)											
Process Roughing Pump P141/P241	Poor				X						
GB Airlock Pumps P163/P263	Poor				X						
Process Gas Sampling Vacuum Pump P199	Poor				X						
Sample High Vacuum Pumps P139/P239	Poor				X						
Circulation/Transfer Pum P126/P226	Good Note 1				X						
Circulation/Transfer Pumps P129/P229	Good Note 1				X						
Glovebox Pumps P166/P266	Good				X						
Tritium monitor pumps P453/P503/P513/P603/ P613/P623	Good										
ITC AL Heat Exchangers HX120/HX220	Good						X				
Valves (Manual/Pneumatic) Fisher, Worchester & NUPRO, etc.	Good		X		X						
Solenoid valves	Fair				X						
Flow control valve FCV405	Fair				X						
Pump relief valves PSV137/PSV2237	Good Note 2				X						
Glovebox relief bubblers ARV178/ARV278	Good									X	

Note 1: Pumps never used
Note 2: Little or no maintenance

Table A.4(cont) Degradation Mechanism for ACS, GBCS, CHW & TIS

Component	EQUIPMENT CONDITION	SCC	Fatigue	Thermal Embrittlement	Mechanical Wear	Erosion	Corrosion	Creep	Aging (see Notes)	Blockage	Oxidation	IC failure
ITC AL pressure safety valves PSV152/PSV252 PSV192/PSV292	Good				X							
TSC AL pressure safety valve PSV352	Good				X							
Rupture discs RD407, RD421	Good		X									
U bed TK221	Good										X	
U bed heater HTR621	Good		X									
ITC airlock heaters HTR190-1/HTR290-1 HTR190-2/HTR290-2 HTR190-3/HTR290-3	Good		X									
Mass spectrometer AIS110/AIS210	Poor											X
GB Oxygen monitors AIS197/AIS297	Good											X
ITC & TSC AL Oxygen monitors AIS813/AIS913	Good											X
GB Moisture monitor AIS196/AIS296	Good											X
ITC AL moisture monitor AIS106/AIS206	Good											X
GB tritium monitor AIS503/AIS603	Good											X
ITC & TSC AL Tritium monitor AIS513/AIS613	Good											X
Valvebox and transfer line tritium monitor AIS453	Good											X
TIS exhaust tritium monitor AIS623	Good											X
Capacitance manometers PE107-1/PE207-1	Fair											X

DARLINGTON TRITIUM REMOVAL FACILITY AGING MATRIX

Table A.5 Degradation Mechanism for HWM & SUP

Heavy Water Management (HWM) & Upgrader (SUP), (SCI 38410/38430/34510/38110/38500)

Component	EQUIPMENT CONDITION	SCC	Fatigue	Thermal Embrittlement	Mechanical Wear	Erosion	Corrosion	Creep	Aging (see notes)	Distributor Plugging	Blockage
SUP Feed Evaporators EV1 & EV2	Good										
SUP Towers TWR1/TWR2/TWR3	Good										X
Column Packings	note 1								Note 3	X Note 6	
SUP Pumps P1 to P13	Fair note 2				X						
SUP Reboilers HX1 & HX2	Good										
SUP Condensers/Coolers CD1/CD2 CD3, CD5 & HX3	Good										
SUP Filters FR1 & FR2	Good										X
SUP IX Column IX1	Good										
Oil/Water Separator O/S-1	Unknown										
Pump P4	Note 7				X						
UV Oxidation Unit	Good				X				Note 4		
Pumps P202, P203											
D2O Cleanup Pumps P1 to P3, P201	Good				X						
D2O Cleanup IX Columns IX1 to IX3	Good								Note 5		
D2O Cleanup Filters FR1 & FR2	Good										
Spent Resin Handling Pump P3	Good				X						
Spent Charcoal Handling Pump P4	Good				X						
Valves (Manual/Pneumatic)	Good		X		X						
HT Transfer Pumps P1, P2	Good				X						
Moderator Transfer Pumps P3 & P4	Good				X						
Loading/Unloading Facility Flexhoses and fittings	Good				X						

Note 1. Monitoring required; known problem with other upgraders
Note 2. High maintenance effort required for oil seals; one to two pump failures every three to four months
Note 3: Oxide coating on the phosphor bronze packing can degrade due to water chemistry, currently under control with UV Oxidation system
Note 4: Degradation of UV light source (UV lamps are replaced as necessary)
Note 5: Degradation of IX resin (IX resins are periodically replaced)
Note 6: Distributor plugging is a result of the aging of the column packi
Note 7: Has not been in service

DARLINGTON TRITIUM REMOVAL FACILITY AGING MATRIX

Table A.6 Degradation Mechanism for DCS and Electronics

TRF/SUP (HWM) Computer System, (SCI 69791/69891)

Component	EQUIPMENT CONDITION	*Environmental Conditions (T, H & Dust)*	*Hardware Software Fault*	*Mechanical Wear*	*Electro magnetic Interference*	*Aging (electronic component aging)*	*Incorrect Network Nodes/ Improper Configuration/ Design Deficiency*
MMIF (Man-Machine Interface)							
DCT Logic Box Failure (EPROM),	Good					X	
DCT Logic Box recoverable Memory Corruption,	Good					X	
CRT failure, Keyboard failure,	Good					X	
Mouse failure, Connector and cable failure,	Good					X	
Power supply failure or noise	Good					X	
Universal File Servers AP6400							
CPU, interface controller failure (e.g. Mother Board),	Good					X	
Memory card errors (e.g. SIMM modules),	Good					X	
Hard Disk#1 failure (in CPU box),	Good					X	
DAT Tape Drive Failure (in Exp. Bx#1),	Good					X	
Power supply failure or noise.	Good					X	
Dual Ethernet Data Highway:							
Fan-out Box failure, Repeater failure, Power Supply failure	Good					X	
or noise, Transceiver Failure, ECCS Board Failure,	Good					X	
T connector failure, Thin-net Cable failure,	Good					X	
Thick-net Cable failure, Terminating Resistor failure,	Good					X	
Slip-out of Terminating Resistor Cap.	Good					X	
Distributed Control Units DCU3200							
DCP	Good	X			X	X	
Connectors, cables, back plane, Power supply noise,	Good			X			
Power on/off cycles,	Good			X			
External Lambda Power Supplies &		X				X	
Intrinsic Safety Relays/Barriers	Good						
Fans, chassis and wiring.	Good			X			
Printers complete with Printer Server							
Microplex Printer Server failure	Good					X	
Print-head, toner cartridge, transfer rolls, paper supply	Good			X		X	
Paper Feed failure, connector and cable failure.	Good			X		X	
Software							X
Software corruption	Good			X			
Instrumentation							
Instrument IC Components	Fair note 1	X				X	
Instrument Cables	Good					X	

Note 1. Significant effort to keep instrumentation IC and capacitors in service

DARLINGTON TRITIUM REMOVAL FACILITY AGING MATRIX

Table A.7 Degradation Mechanisms for TRF Building

DTRF Front-End Systems: FTS (SCI 39310)/VPCE (SCI 39320)/DU (SCI 39320)/RS (SCI 39360)/DPS (SCI 39360)/DMS (SCI 39330)/LCS (SCI 39310)

Component	EQUIPMENT CONDITION	*SCC*	*Fatigue*	*Thermal Embrittlement*	*Mechanical Wear*	*Erosion*	*Corrosion*	*Aging*	*Blockage*	*H2 Embrittlement*
Panels	Fair				X Note 1		X			
Lighting	Good							X Note 2		
Power Cables	Good									
Utilitiy Systems	Fair		X			X			X Note 3	

Note 1. Several panels have fallen off the building (original installation problems)
Note 2: Electrical aging due to service and heat
Note 3. Sediment in water pipes; steam condensate systems instability