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DETECTION OF PRESSURE TUBE LEAKS RELYING ON MOISTURE BEETLES ONLY

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ABSTRACT

A major decision was made for Pickering NGS A Annulus Gas System (AGS) that detection of a pressure tube (PT) leak should be achieved by using only moisture beetles and that dew point monitors would provide "early warning" without status to shut down the reactor. Experience with Unit 3 has shown that dew point monitoring of pressure tube leaks was particularly subject to gas leaks and surface adsorption effects. Unit 4 was the first one to be converted during the full scale pressure tube replacement programme. Because of the fundamental change in design philosophy, moisture injection tests were carried out during commissioning to demonstrate that performance matched design. In particular it was necessary to show that leak before break (LBB) would be achieved if a leak occurred in the limiting string.

Units 1 and 3 have since been converted. No decision has been taken to convert Pickering B units as gas leaks are small and no significant adsorption effects are anticipated. Hence dew point monitoring will not be impaired.

1.0 INTRODUCTION

The AGS is used for detecting and quantifying PT leaks in Ontario Hydro CANDU reactors. This was not its original role but extensive modifications have been carried out since the early 1980s to achieve the present high level of leak detection capability. The most recent extensive modification for Pickering NGS A Unit 4 is redesign of the moisture beetles to ensure that they are capable of deciding reactor shut down for a PT leak without reference to dew point monitors.

The AGS provides a dry thermal barrier between the Primary Heat Transport (PHT) System and the Moderator System. Its most important function is to provide adequate leak detection capability in the event of a PT leak. There are 196 parallel gas flow paths with two channels connected in series to provide each leak detection path. 6.4 mm (1/4 in.) diameter tubing connects the channels in series and connects the strings to the supply and return manifolds.Each length of tubing on the west reactor face is coiled and referred to as a "pigtail". The corresponding tubing on the east reactor face is shorter with bends and termed a "jumper". These tubing runs are the most restrictive part of the string flow path and most subject to some degree of blockage. They were originally designed to provide high resistance paths to minimize overpressurizing the remainder of the AGS.

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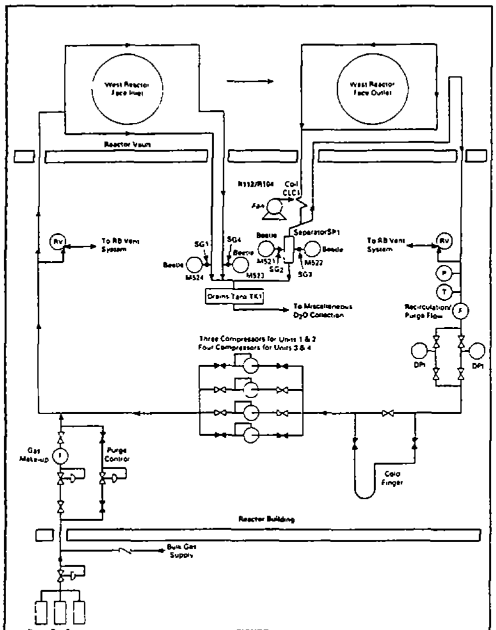

FIGURE 1
DIAGRAMATIC FLOWSHEET OF PICKERING NGS A AGS

The AGS is normally a recirculating system which can also be operated in purge mode. It is filled with dry CO_2 with pressure regulation. There is continuous moisture detection by means of both on-line dew point monitors and moisture beetles.The former monitor moisture leaks ranging from 5 g/h to 20 g/h but are sufficiently sensitive to detect moisture leaks as low as 1 g/h.

The reason for designing the moisture beetles as the primary leak detectors and the dew point monitors as the secondary leak detectors with reference to activating reactor shut down is as follows. During the extended outage for retubing. Unit 3, the pigtails of the AGS were tested for blockages. Those which were unacceptably blocked, in terms of PT leaks, were bypassed (reference 1). The ensuing connections increased the potential for gas leaks in channel strings which would invalidate dew point monitoring as a reliable means of leak detection. The suitability of dew point monitoring for Pickering NGS A was further reduced by moisture adsorption effects identified during the commissioning of Unit 3 AGS. Moisture was adsorbed on iron oxide and graphite dust particles accumulated over the years. Dew point monitoring was retained at the time by using a modified dew point criterion.

Moisture beetles alarm at much higher leak rates and are not so sensitive to gas leaks. They are also more robust and easier for the station to maintain in good working order. Dew point monitors require more careful calibration for accuracy and reliability.

When Unit 4 was shut down for retubing in 1991, it was decided that the AGS would be redesigned to ensure that moisture beetles only would provide adequate leak detection to meet Leak before Break (LBB) requirements. Previously, both dew point monitors and moisture beetles combined provided adequate leak detection capability. The modified design has to meet the following two main design conditions:

(1) The Unavailability target of 0.01 for a safety related system.

(2) The leak detection system will alarm for leaks which are large enough to locate but not large enough to allow the critical crack length for the leaking PT to be reached. This ensures that LBB will be met both economically and safely.

2.0 SYSTEM DESCRIPTION

There is a diagrammatic sketch of the AGS flowsheet given in Figure 1. The modifications for Unit 4 were carried out in November 1992 and Units 1 and 3 have recently been converted to an AGS with moisture beetles as the primary source of leak detection.

The 390 channel annuli which constitute the internal circuit of the AGS are connected in a series-parallel arrangement. The gas supply and return for the annuli are provided by two U-shaped 5.1 cm (2 in.) diameter headers across the west reactor face.The headers communicate with the annuli via 2.5 cm (1 in.) diameter manifolds. Figure 2 shows the arrangement of connections between headers, manifolds and annuli for Unit 3. It can be seen that there is a modified arrangement showing by-pass pigtails and supplementary headers and manifolds to connect into the pigtail by-passes. The arrangement for Unit 4 is identical except that there are no by-pass pigtails or supplementary headers and manifolds.

The modifications referred to in this paper are as follows:

Both the supply and return headers on the south side of the reactor have been capped and T- connections extend through the west reactor vault via Room 112 to Room 104. The return header from the calandria section on the north side of the reactor joins its counterpart from the south side prior to the vault penetration to Room 112. The south side supply header extension communicates with sight glass SG4 and moisture beetle M523. The north side supply header extension communicates with the beetle M524 via sight glass SG1. The return header provides moist gas to cooling coil CLC1 and the subsequent separator SP1 directs condensate to parallel beetles M521 and M522 via sight glasses SG2 and SG3 respectively. CLC1 is cooled by forced circulation from a fan with one on standby. A flow switch assures a minimum air velocity of 2 m/s across the coil. CLC1 is a serpentine cooler in five sections with external finning. Carrier gas is returned to the external circuit from the top of the separator.

3.0 SYSTEM ANALYSIS

In the original design the moisture beetles were located in a normally inaccessible area allowing testing every two years. The new design requires their siting in an accessible area to provide frequent testing. Also a moisture leak will be carried as vapour in the carrier gas initially rather than drain as liquid from the headers based on the ther-

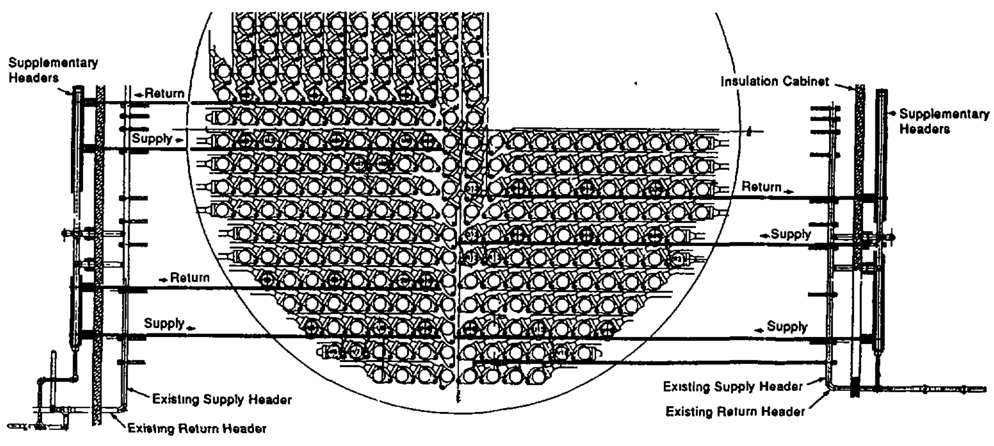

FIGURE 2
MODIFIED INTERNAL CIRCUIT OF UNIT 3 AGS

malhydraulics of the AGS. Consequently a cooling coil was designed to remove sufficient condensate early in the scenario to ensure the redundant moisture beetles M521 and M522 alarmed. It was also necessary to efficiently separate the condensate from the return gas flow using a separator.

The two moisture beetles connected to the supply header rely on direct liquid moisture flow. This is usually associated with larger leaks and are not credited in the analysis.

Liquid flow to the collection tank is monitored continuously at 30 s time intervals to alarm as soon as the instantaneous collection rate reaches 2 kg/h. This alarm target is based on previous experience which showed this collection rate could continue for an extended period of time without danger of the PT reaching the critical crack length (CCL) at zero power hot operation. The design analyses which have been carried out are as follows:

3.1 Hydraulic Analyses

An hydraulic network analysis programme entitled KYGAS is used to model the flow of carrier gas around the AGS and specifically through each string. Superimposed on this carrier gas flow is the moisture flow along the leaking string from the rolled joint location. A separate programme has been written to model moisture vapour flow both upstream and downstream from the rolled joint leak location. This is entitled MOIST-FLO. It is based on the limiting case of purge flow through the string and assumes that moisture condenses in each end fitting which is cooled to about 60oC.

The flow scenario is illustrated in Figure 3.

The programme considers the relative resistances of both upstream and downstream flow paths. All the resistances are in the pigtails including the level of pigtail blockage. All the pigtail blockages have been modelled as equivalent sharp edged orifices. An orifice diameter has been calculated to give the same pressure drop for a given flowrate. The percentage blockage is the closed area as a percentage of the total. Moisture is assumed to condense in each end fitting in sequence until full. As successive end fittings are filled the resistances of upstream pigtails are included until all the pigtails in the string are credited.

3.2 Condensation Efficiency

The flow stream to the cooling coil consists of the gas flow to the return header at 340 l/min (STP) (12 SCFM) and the downstream moisture flow from the leaking string. This is a prime input parameter to the cooling coil programme, PIPEHEAT. This programme calculates the condensation of moisture from the CO2 carrier gas along the cooling coil. The first section of the coil has unsaturated gas which then reaches saturation when condensation initiates. The analysis is standard treatment of condensation of a vapour from a noncondensable gas. This involves simultaneous heat and mass transfer in successive increments along the coil.

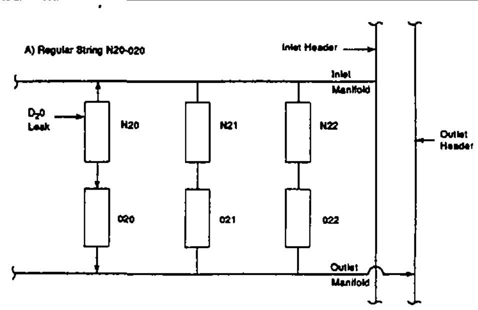

FIGURE 3
MOISTURE FLOW PATHS DURING A PT LEAK
FOR STRING N20-020

3.3 Dew Point Programme

A dew point programme entitled SAHARA models the early response of the dew point monitors prior to initial condensation of moisture in the end fittings. Information on this programme has been previously published (reference 3).

3.4 Sequence of Events Spreadsheet

The analyses described above provide input data to a sequence of events spreadsheet which lists the events following a PT leak whereby the reactor with operator intervention is successively shut down safely to the final cold depressurized state. The sequence of events for Pickering NGS A AGS beetle relocation design is shown in table 1.

The input data involves metallurgical crack velocities and critical crack velocities for PTs as well as process data relating leak rate to crack length. This is further supplemented by the beetle response time and target collection rate time to achieve 2 kg/h. This data is obtained from the design analyses above as follows:

3.4.1 Beetle Response Time

The beetle response time is calculated from the liquid collection rate and the hold up. The total liquid hold up includes the volumes of both beetle wells the connecting "balance" line and the hold up in the cooling coil and upstream piping. The beetle alarm is the signal for the station to shut down the unit from full power to zero power hot operation.

3.4.2 Collection Rate

Following the beetle alarm the collection tank will begin to fill with liquid. This is monitored by a level transmitter and a microprocessor is used to calculate the instantaneous collection rate updating every 30 seconds. It is alarmed if the rate reaches 2 kg/h which is the signal for the station to shut down the unit from zero power hot operation to the cold depressurized state.

3.5 Leak before Break (LBB)

The ultimate purpose of the redesign was to achieve LBB with improved operating reliability. This ensures that a PT leak will be detected and quantified so that the reactor can be shut down safely and expeditiously. It is also important that it is done economically so that the leak is large enough to locate prior to the cold shut down state.

3.6 Reliability

Another major design requirement is that the AGS meet an Unavailability target of 0.01. This ensures high reliability in monitoring PT leaks and achieving safe reactor shut down. An Unavailability analysis has been carried out for the beetles only design to show that it meets the above target.

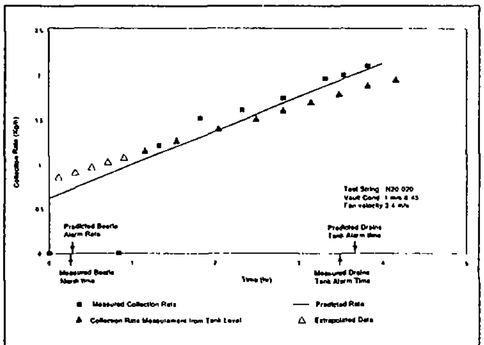

FIGURE 4
TEST NO 1 MEASURED AND PREDICTED COLLECTION RATE DATA VS TIME, PURGE MODE AT 12 SCFM

4.0 MOISTURE INJECTION TESTS

As the modified design makes a greater demand on the moisture beetles to detect pressure tube leaks it was decided to carry out moisture injection tests to simulate actual PT leaks to confirm that the response times were within design. These

Commissioning tests were carried out on Unit 4 AGS in January 1993 following full scale channel replacement.

Two channel strings were chosen, N20-O20 and V15-W15/V16-W15, both of which are limiting in terms of moisture response. The moisture flow path for the former is shown in Figure 3. It was not possible to inject moisture directly into a channel because of the subsequent liquid hold up which would require vacuum drying. Analyses were carried out to calculate the resulting moisture flow at the return header so that moisture injection could be carried out here. The system was operated in purge mode to ensure all the moisture was continuously removed from the AGS. The AGS was fully instrumented with data logging to ensure the performance of each of the main items of equipment could be measured and compared with theory.

A comparison of the measured and predicted results for string N20-O20 is given in Figure 4. This shows collection rate as a function of time. There was good agreement with the beetle alarm time within six per cent and the collection rate alarm time within five per cent. The only modification required following the tests prior to full power operation was the installation of a simple balance line between the two beetles to ensure that both beetles would receive liquid condensate within the predicted beetle response time. This meets the requirement of the Unavailability analysis that both beetles can be credited for leak detection.

5.0 CONCLUSIONS

Redesigning the Pickering NGS A AGS to rely on moisture beetles as the only means of leak detection initiating reactor shut down has been successful. It overcomes the problems of gas leaks and moisture adsorption which have significant effects on leak detection capability.

Moisture injection tests were carried out during Commissioning to show that the AGS performed according to design and confirmed the sequence of events which showed there was a suitable margin between the final crack length and critical crack length in the cold depressurized state. This demonstrated that LBB was achieved - an AGS prerequisite.

6.0 REFERENCES

(1) Kenchington, J.M., "Pickering NGS A Unit 3 Annulus Gas System Pigtail Blockage Programme", Annual CNS Conference, Saskatoon, Saskatchewan, June 1991.

(2) Kenchington, J.M. et al., "An Overview of the Development of Leak Detection Monitoring for Ontario Hydro Nuclear Stations", Annual CNS Conference, St. John, NB, June 1987.

Elapsed Time (h)	Description	Leak Rate (kg/h)	Tank Collection Rate (kg/h)	Beetle	Idealized Crack Size (mm)
0 00	Reactor at full power. Crack penetrates PT Leak starts Double ended crack velocity 3.01 mm/h	0.00	0 00	Clear	27.00
3.58	Beetle wells collected 0 31 kg of liquid D_2O Beetle alarm annunciates Wait for confirmation	6 6	0 68	Alarm	37.78
4.08	Half an hour elapsed. Beetle is confirmed Shutdown to ZPH.	7 5	0 84	Alarm	39 28
6.08	ZPH is reached. Start timer for leak search operation Crack velocity 1 46 mm/h	11.2	1 48	Alarm	45.30
9.47	Drains tank alarms Collection rate 2 0 kg/h Cool down and depressurize unit (assume 3 h)	14 3	2 00	Alarm	50.25
12 47	Reactor cold and depressurized.	17.0	2 46	Alarm	54 63

NOTE:

ZPH	= Zero Power Hot
Critical crack length	= 67 mm
Leak Search Time	= 3 4 h
Margin to Critical Crack Length	= 16 0 h
Category B Leak	Beetle Response
Limiting String	V15/V16/W15
Purge flow rate	340 L/min (12 cfm) (STP)

TABLE 1
SEQUENCE OF EVENTS FOLLOWING RJ CRACK PENETRATION