CONDITION BASED MAINTENANCE PILOT PROJECTS AT PICKERING ND

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1.0 INTRODUCTION

Ontario Hydro's nuclear power plants (20 Candu units) were designed, built and commissioned without effective formal maintenance programs being developed beyond the 'vendor recommended practices and call-ups'. Each station has been obliged to develop its own procedures. High maintenance costs and audits by the nuclear regulator (Atomic Energy Control Board) have underlined the need for positive actions on an integrated overall plant maintenance strategy.

Ontario Hydro has recognizedrecognized that the approaches to maintenance have undergone significant changes in the past decades. The traditional break-down maintenance approach has been replaced by preventative maintenance and, more recently, by condition-based maintenance. The nuclear plants of Ontario Hydro have evaluated on a number of alternative programs to improve their maintenance effectiveness and to reduce costs, including Reliability Centred Maintenance (RCM), call-up review, component-based PM programs, analysis of failure history etc...

Pickering ND (Nuclear Division) and (Ontario Hydro - NTS (Nuclear Technologyies Services Division) NTS have embarked on a Condition Based Maintenance (CBM) pilot project to address the above issues as a 'breakthrough' solution for 'smarter maintenance'. The Condition Based Maintenance (CBM) pilot project will demonstrate an end-to-end 'process' utilizing a Reliability Centred Maintenance (RCM) structured approach to re-engineer and redefine the existing maintenance programs. The project emphasizes on-condition maintenance where justified, and utilizes an information management tool to provide the required records keeping and analysis infrastructure.

This paper briefly describes the planned maintenance model at Pickering ND used to guide the CBM pilot, and an overview of the methodology used to develop on-condition equipment indicators as part of a re-engineered maintenance plan.

2.0 PICKERING ND MAINTENANCE MODEL

Various technologies and methodologies have recently emerged which provide both a framework and the associated tools for redefining maintenance. The framework, in general, concentrates on the replacement of a 'fix-it-when-it-fails' approach to a planned approach which emphasizes on-condition maintenance. The Pilot model of planned maintenance process used for this project is shown in Figure 1.1, decomposes the process intoand has the following 7 major steps.

2.1 Identify Production Resources

This consists of the identification of the equipment assets (things to be maintained) and but can also encompass the identification of the resources (equipment and personnel skill sets or 'crafts') available and necessary to conduct maintenance.

2.2 Define Maintenance Requirements

This is a critical step in which is decided what forms of maintenance will be conducted for each equipment asset and its components. The optimum mixture of corrective ('after the fact'), preventive (scheduled and failure finding), and on-condition maintenance to be applied can be rationally established by giving consideration to:

- the operating context and consequences of failure of the equipment;
- the known or likely equipment failure modes, failure effects, and reliability characteristics (based on generic data for the equipment type, manufacturer's data for the equipment mode, and/or any actuarial data available); and
- technologies that are available and feasible to address various failures.

One methodology for guiding this rationalization process is known as Reliability Centred Maintenance (RCM). The RCM methodology provides the procedures and decision logic for guiding the identification

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of maintenance requirements. A computerized approach to RCM iwas used during this project to enable convenient maintenance of RCM data, to facilitate the accessibility of RCM records, to directly 'feed' a computerized equipment maintenance plan, and to support continuous improvement.

2.3 Plan Maintenance Tasks

It is at this step that one transcribes the maintenance requirements identified in Step 2 into a 'template' maintenance plan for each different subject equipment type. Included in the template are the suggested maintenance activities, the frequency of their execution (e.g. every month orf every 2000 hours of operation), the skill sets or crafts of the personnel required to carry out the tasks, the data to be gathered when maintenance is executed (in order to provide the feedback to the system), etc. The current station 'call-ups' are examples of maintenance plan templates.

2.4 Schedule Maintenance Tasks

This step involves the creation of an 'instance' of the maintenance plan for which is identifieds the actual personnel that will carry out the work and the actual time frame (e.g. July 5-6, 1995) in which the maintenance is scheduled to take place. The determination of the required time frame in which to carry out the maintenance is governed by the intervals identified in the maintenance plan as well as the availability of personnel and access to the subject equipment.

This step is typically executed from within the organization's work scheduling system.

2.5 Execute Maintenance Tasks

This step involves the actual execution of the maintenance tasks as well as the recording, in the field, of the prescribed equipment maintenance/performance feedback data.

2.6 Process Maintenance Data

This step involves:

- the entry of maintenance/equipment performance feedback data into the maintenance tracking system;
- the calculation of predefined equipment condition indicating parameters ('condition indicators') from the raw gathered data;
- the comparison of condition indicator values to expected baselines in order to assess current equipment condition; and
- the execution of diagnostic procedures to relate abnormal condition indicators to the affected equipment subsystems and or corrective maintenance tasks.

2.7 Analyze Maintenance Effective

This step involves the regular review of the mainte-

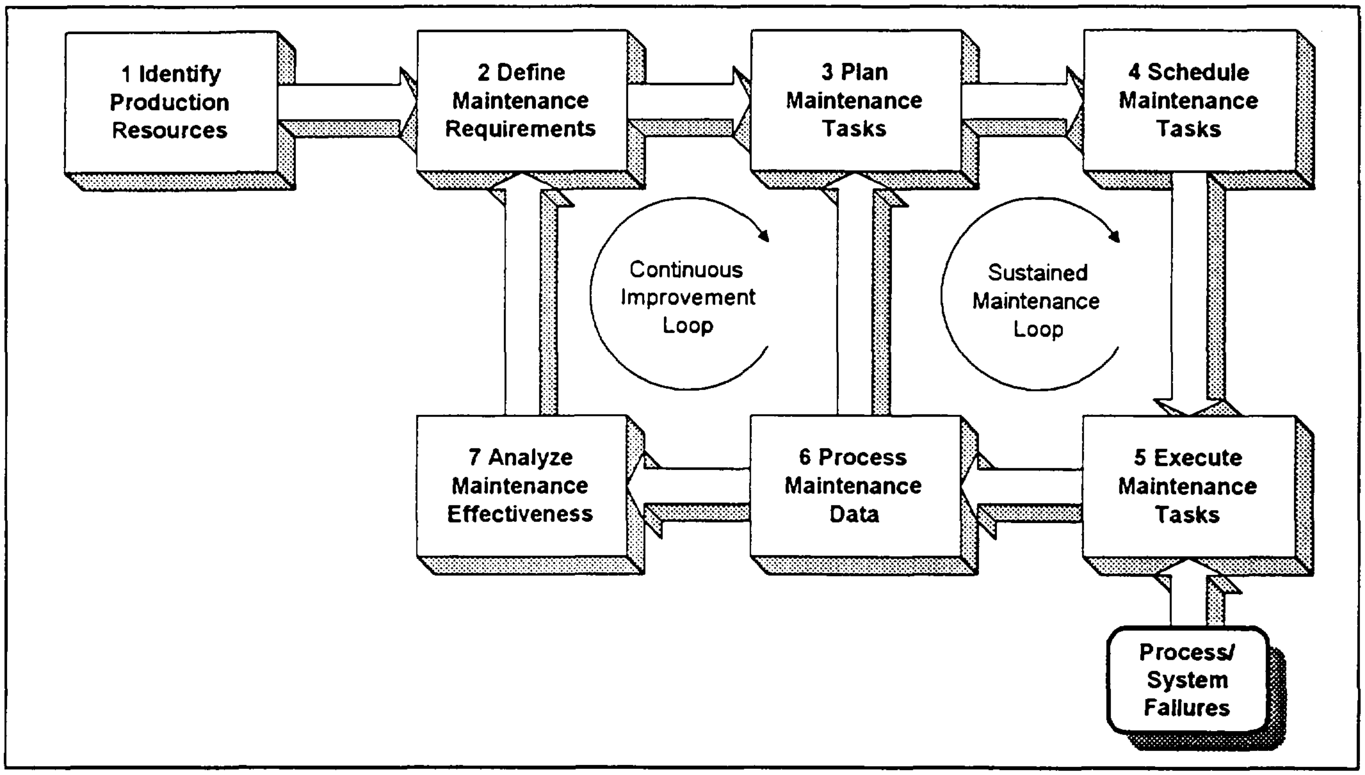


Figure 1: **Planned Maintenance Model**

nance programme as part of a continuous improvement feedback loop. IncludedCovered in the review would beis an the examination of the effectiveness of the current condition indicators, maintenance and data gathering intervals, as well as thean analysis of any equipment failures for the purpose of refining the maintenance plan to alleviate future failures.

3.0 PILOT PROJECT

Ontario Hydro's ultimate objective is to improve maintenance of its nuclear plants. A proposed component of the improvement strategy is a structured approach to the reassessment/redefinition of what maintenance activities should be performed against plant equipment, and a desire to emphasize an on-condition maintenance approach where justified.

In order to confirm the applicability and benefits of the proposed maintenance "re-engineering", Ontario Hydro has undertaken a pilot project which is confined to a single station (PND) and to two selected plant systems (Instrument Air Compression (IAC), and Low Pressure Service Water (LPSW)). Please see Figure 2 for the schematic of the air compressor.

This pilot approach is considered to be optimal for these reasons:

- the entire planned maintenance process can be piloted, verified and assessed
- the project can be completed with low risk and in a compressed time frame
- as a contributing component to the planned maintenance process the CBM Information Management tool (MAINSTAY) can be piloted and assessed. Mainstay is a software product provided by our consultant GasTOPS.

3.1 Methodology And Approach

3.1.1 Overview

A key step in the maintenance reassessment is the process of "taking a step back" to identify the in-house maintenance requirements for the targeted equipment considering its operation context, failure modes, and the effects of failures. The pilot project,

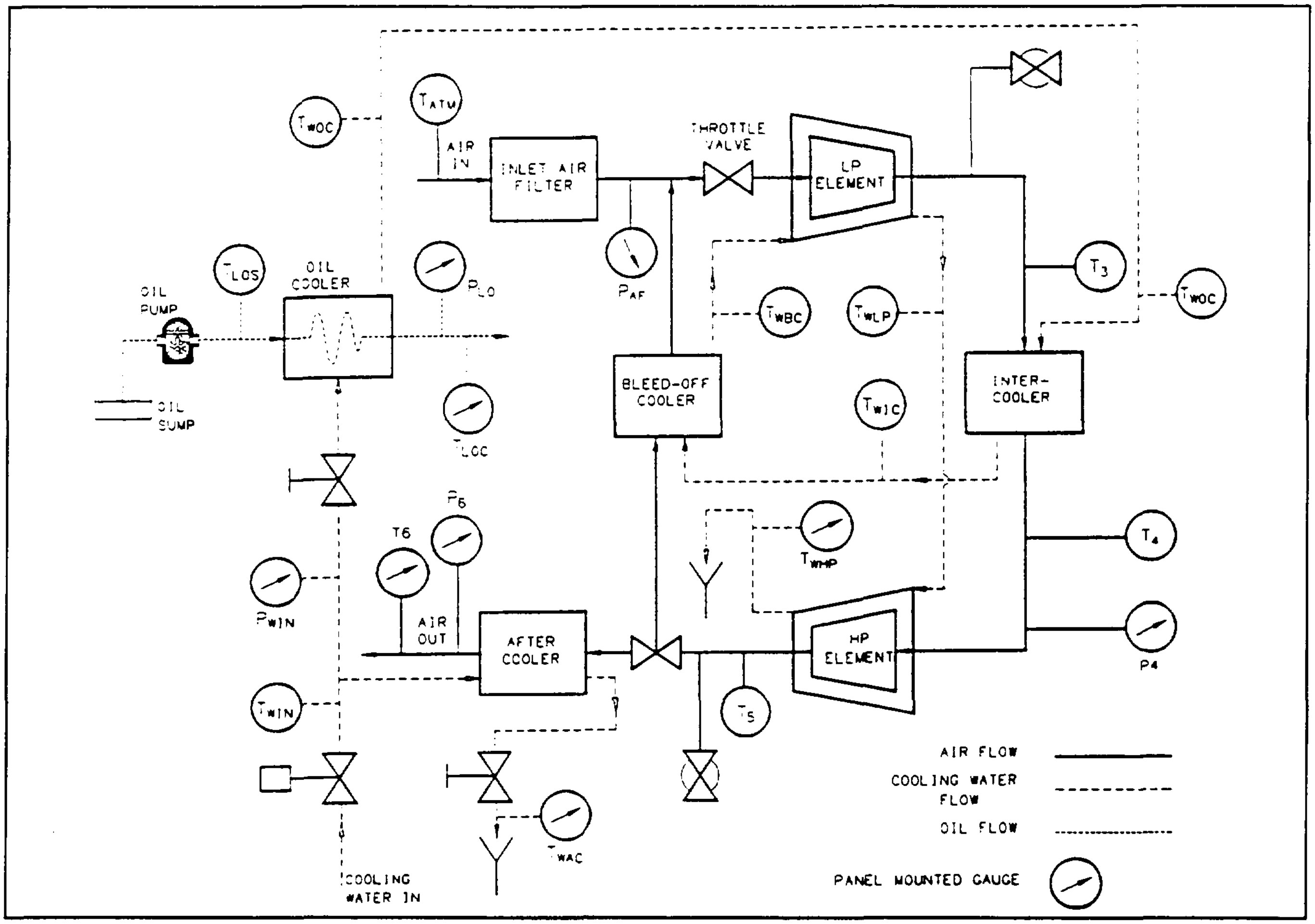


Figure 2: **Air Compressor Schematic**

adapted Reliability Centred Maintenance (RCM) methodology to facilitate the above.

Subsequently, the project took advantage of advancements in the maintenance field as well as in-house experience to emphasize the application of condition based maintenance techniques to address the predominant equipment failures.

3.1.2 Information Management

There is a considerable amount of data collection and tracking required to ensure that assessments of machinery condition and maintenance requirements are meaningful and will result in an improved approach to maintenance. The significant volume and importance of the data gathered lends itself to the use of a computerized information management system to support a CBM programme. GasTOPS' MAINSTAY product is a software tool designed to manage general maintenance and CBM information and is utilized throughout this CBM pilot project. See Figure 3 for an overview of the CBM information "architecture".

3.1.3 Equipment Engineering Analysis

The engineering analysis results in the definition of new maintenance tasks, including on-condition tasks. As such it is a key activity of the project. A thorough understanding of the design, operation and maintenance was developed from the following sources.

- reviewing the detailed technical documentation, including:
  - design manuals
  - operating and maintenance manuals
  - manufacturer documentation
  - process flowsheets
- conducting "interviews" or discussions with the equipment maintainers, Engineering and suppliers

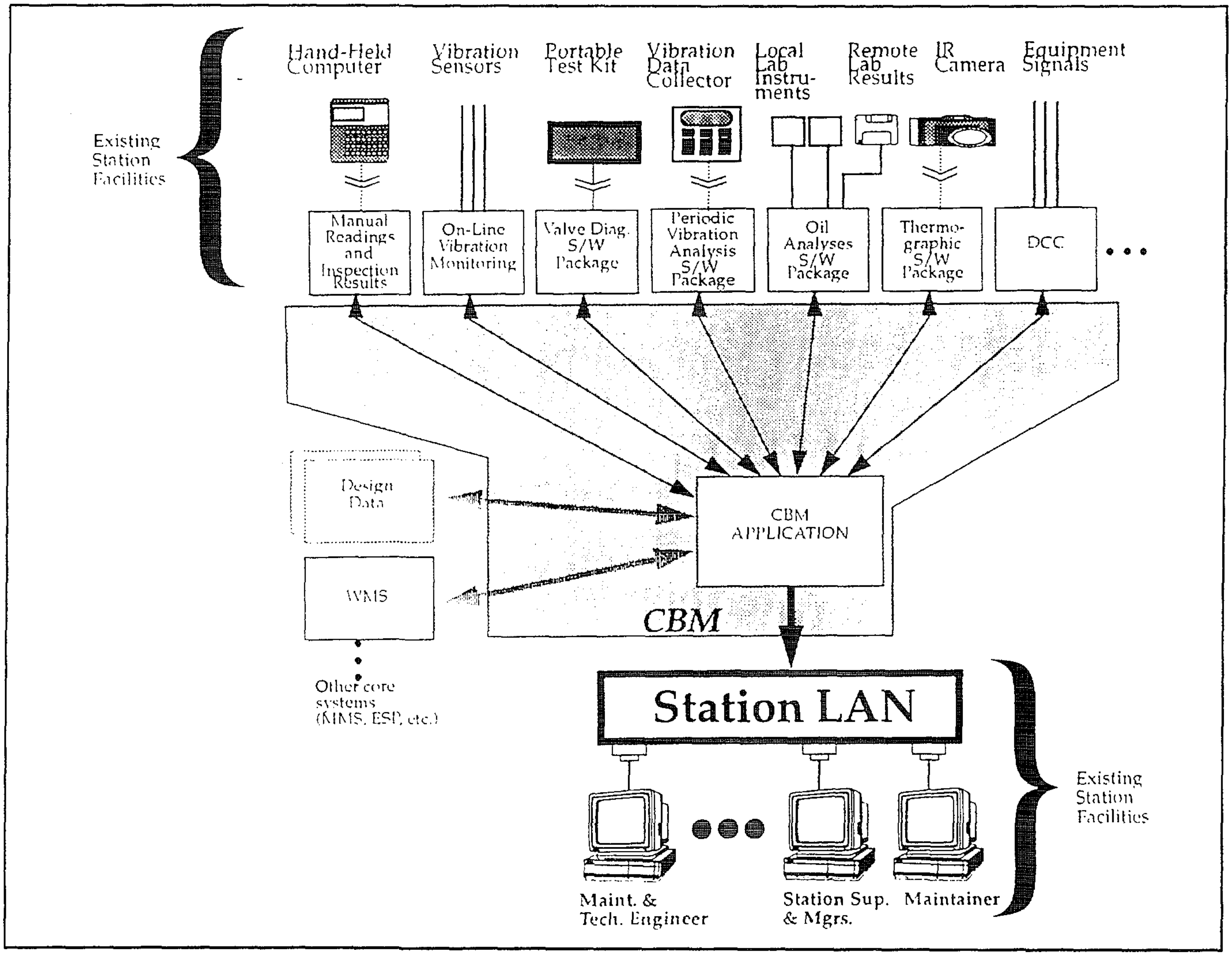


Figure 3: **CBM Information Architecture**

- reviewing maintenance, reliability and failure data including the following sources:
  - WMS data (Work Management System)
  - CORDS data (Component Reliability Data System)
  - SRE interviews/logs (System Responsible Engineer)
  - maintainer interviews/logs
  - other studies or reports as available

3.1.4 Reliability And Failure Analysis

Based on the above data, a reliability and failure analysis was conducted for each system using the techniques of RCM that resulted in:

- a description of functions fulfilled by the system/ equipment
- for each function, a description of functional failures
- for each functional failure, a description of failure modes
- for each failure mode, a description of the failure effect
- for each failure mode a proposed maintenance task that best addresses it

The software selected for the project includes an integrated RCM module that allows the project to document equipment failure modes and effects using RCM techniques and to drive the selection/definition of appropriate maintenance activities. This integration also allows maintenance rationalization to be a living process since the RCM analysis which lead to the selection of an activity is readily visible and able to be fine-tuned.

3.1.5 Maintenance Design Analysis

The consequences of each failure mode wasere weighed and possible maintenance activities were identified. The decision analysis of RCM asks the necessary question in an order which gives priority to on-condition and restoration tasks over scheduled discard or failure finding activities.

The required weighting of the worthiness of proposed maintenance activities, generally derived from a comparison of the cost of performing maintenance versus the consequences and cost of a failure was based on engineering judgement. Table 1 summarizes the breakdown of recommended maintenance strategies for the 166 failure modes identified during the RCM analysis. Figure 4 shows part of the activity list summary screen for maintenance.

3.2 Development Of Condition Maintenance Indicators

On-condition maintenance is based on the fact that a great many failures do not occur instantaneously, but actually develop over a period of time. If evidence can be found early in its development that a particular failure process is underway, it may be possible to take action to avoid the failure completely (e.g. through :on-condition" maintenance) or reduce the magnitude of the failure effect, i.e. the amount and severity of the collateral damage. The point in the failure process at which it is possible to detect that a failure is occurring or is about to occur is known as a potential failure. On-condition tasks entail checking equipment for potential failures.

In order to determine if a piece of equipment is "healthy"; that is, it has no potential failures, one must develop one or more indicators of equipment health. In order to be effective a condition indicator must be responsive to changes in the health of the machine, and at the same time be insensitive to changes in the operating environment. In the case of an air compressor environmental changes include variations in inlet air temperature, delivery air pressure, etc..

Condition indicators are usually calculated based on a number of measured parameters, and are tracked over time. Limits are developed which envelope the indicator values during normal "healthy" operation. tThe space or dead band between the limits accounts for variations in the health indicator values due to machine operating condition and measurement variability. tThe selection of suitable health indicators is a key element in establishing a successful on-condition maintenance program and will depend on machinery type and operating context. See Figure 5 for an example of a display of a trended health indicator.

The condition indicators and on-condition tasks ("tests") identified for the instrument air compressors were:

- Performance Test
- Lubrication Oil Test
- Vibration Test

Examples are shown for the development of compressor performance condition indicators. Lubrication oil and vibration indicators were developed similarly.

Examples of Air compressor Failure modes for which performance testing and hence monitoring is effective are shown in Table 2.

The goal of the Rotary Screw Air Compressor Performance Test is to:

i. determine the health of the compressor elements;
ii. track the condition of the inlet air filter;
iii. monitor the proper adjustment of the cooling system flow regulating cocks;

	CP1	CNT	COOL	LUB	UNL	ELEC. MOT	REC	DR Y	TOT
Total # Failure Modes	45	18	33	22	18	8	4	18	166
PM	4		7	3	1			9	24
VA	4					1			5
OA	4			1					5
IT	1	9							10
ULD	4				2				6
SD				4	3			1	8
SR	5		7	3	7		3		25
FF	12	9	9	7	2		1	4	44
MP			1	2					3
NSM	15		10	3	3	4		4	39
MCR						2			2
MG						1			1

Legend

VA - Vibration Signature Analysis
PM - Performance Monitoring
IT - Infrared Thermography
SR - Scheduled Restoration
ULD - Ultrasonic Leak Detection
MG - "Megger Tests"
OA - Oil Analysis
FF - Failure-finding Inspection
NSM - No Scheduled Maintenance
MP - Maintenance Practice
MCR - Motor current readings

CP1 - Compressor
CNT - Compressor Control System
COOL - Compressor Cooling System
LUB - Compressor Lubrication System
UNL - Compressor Unloading System
DRY - Air Dryer
REC - Air Receiver
ELEC - Electric Motor

Table 1: **Summary of CBM Practices for Instrument Air System**

iv. determine the presence of a build up of silt or other foreign material in the cooling system components, in particular the heat exchangers;

v. detect a deterioration of the electric motor windings due to overheating; and

vi. monitor the condition of the oil pump and oil bypass valve.

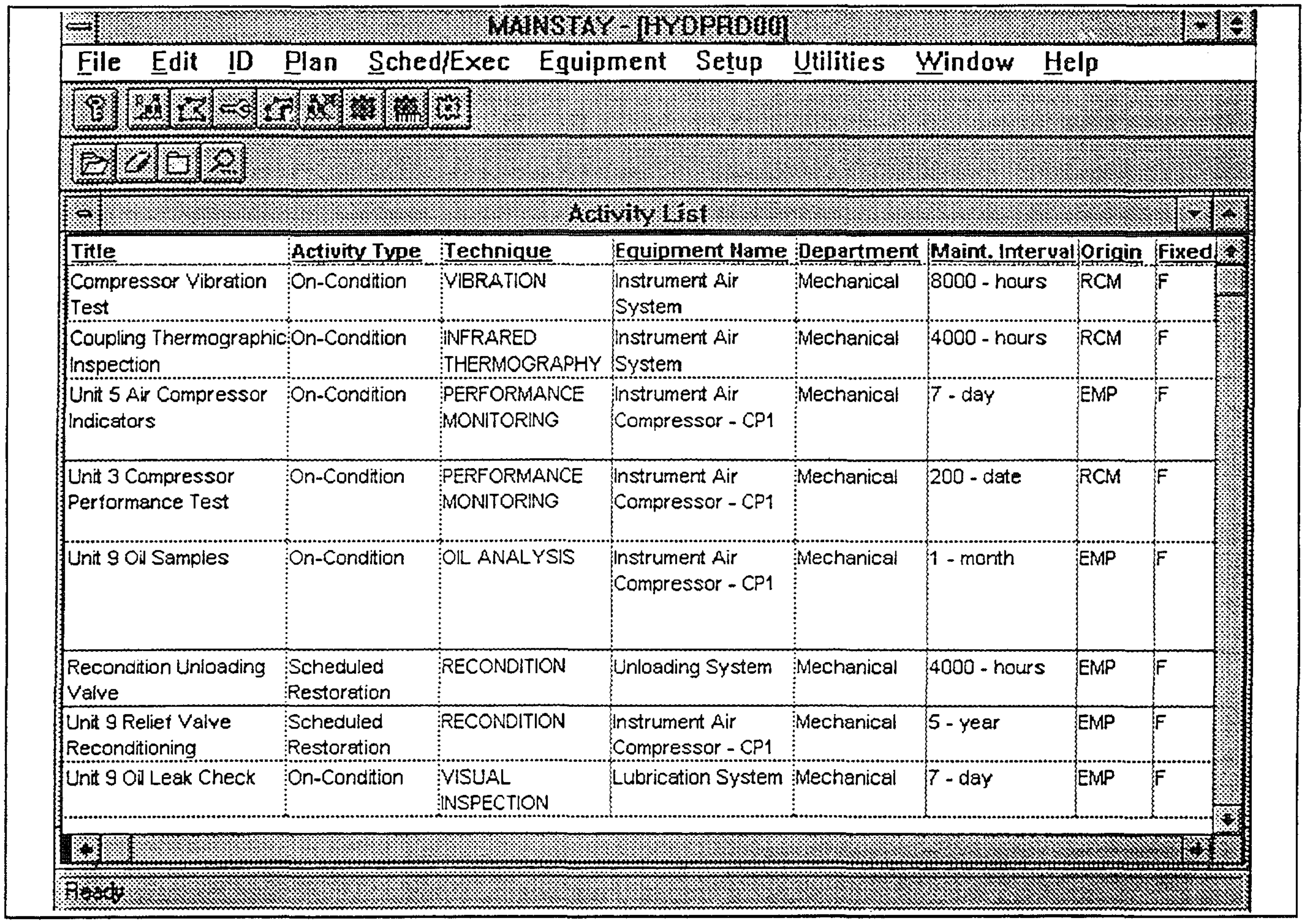
An example of some of the data which is collected to support the performance indicators is shown in Table 3. Initial baselines and limits are developed and programmed into the system which automatically alarm when exceeded.

3.3 Reconciliation With Current Maintenance Practices

Before implementing the "Condition-Based" maintenance program (which includes corrective and scheduled), a reconciliation of the current maintenance program is made to ensure that nothing has been overlooked.

In the case of this pilot project the CBM Program, replaced a number of previously scheduled maintenance tasks with on-condition maintenance. Each task involves the collection of the information necessary to make condition-based maintenance decisions. Based on the information collected corrective actions are scheduled to replace, repair or overhaul system components. These activities have been hitherto performed on a scheduled basis. The following Table 4 shows examples of such tasks.

Not all components or failure modes lend themselves to condition based maintenance. For some components, in particular rubber diaphragms and O-rings, the time and effort spent in determining the condition would far exceed any benefit from extending the in-service life. For such components scheduled replacement or refurbishment is appropriate. The following Table 5 identifies some examples of activities which were previously done on a scheduled basis and will continue to be. The activities have been organized in a way which will allow flexibility and customization of the frequency.



Title	Activity Type	Technique	Equipment Name	Department	Maint. Interval	Origin	Fixed
Compressor Vibration Test	On-Condition	VIBRATION	Instrument Air System	Mechanical	8000 - hours	RCM	F
Coupling Thermographic Inspection	On-Condition	INFRARED THERMOGRAPHY	Instrument Air System	Mechanical	4000 - hours	RCM	F
Unit 5 Air Compressor Indicators	On-Condition	PERFORMANCE MONITORING	Instrument Air Compressor - CP1	Mechanical	7 - day	EMP	F
Unit 3 Compressor Performance Test	On-Condition	PERFORMANCE MONITORING	Instrument Air Compressor - CP1	Mechanical	200 - date	RCM	F
Unit 9 Oil Samples	On-Condition	OIL ANALYSIS	Instrument Air Compressor - CP1	Mechanical	1 - month	EMP	F
Recondition Unloading Valve	Scheduled Restoration	RECONDITION	Unloading System	Mechanical	4000 - hours	EMP	F
Unit 9 Relief Valve Reconditioning	Scheduled Restoration	RECONDITION	Instrument Air Compressor - CP1	Mechanical	5 - year	EMP	F
Unit 9 Oil Leak Check	On-Condition	VISUAL INSPECTION	Lubrication System	Mechanical	7 - day	EMP	F

Figure 4: **Maintenance Activity List Screen**

4.0 CONCLUSION

The CBM project is a pilot program to demonstrate a "structured" approach to re-engineering the maintenance programs of two specific systems at the Pickering Nuclear Generating Station. The pilot approach was chosen to demonstrate the effectiveness of CBM in terms of equipment/system availability, and cost effectiveness and utilization of maintenance resources.

The maintenance program recommendations for these two systems (which include condition-based maintenance, scheduled maintenance and corrective maintenance) were derived from a thorough understanding of the design, operation and maintenance histories of the systems and components, and their failure modes and effects. Each maintenance "element" was uniquely designed and is traceable to specific failure modes and mechanisms, and performance requirements. The re-engineered maintenance system, including the supporting system software for data collection, trending and analysis has been installed. The trial period of CBM over the next eight months will conclude with a "performance evaluation" measured against several benchmarks which were developed prior to deployment.

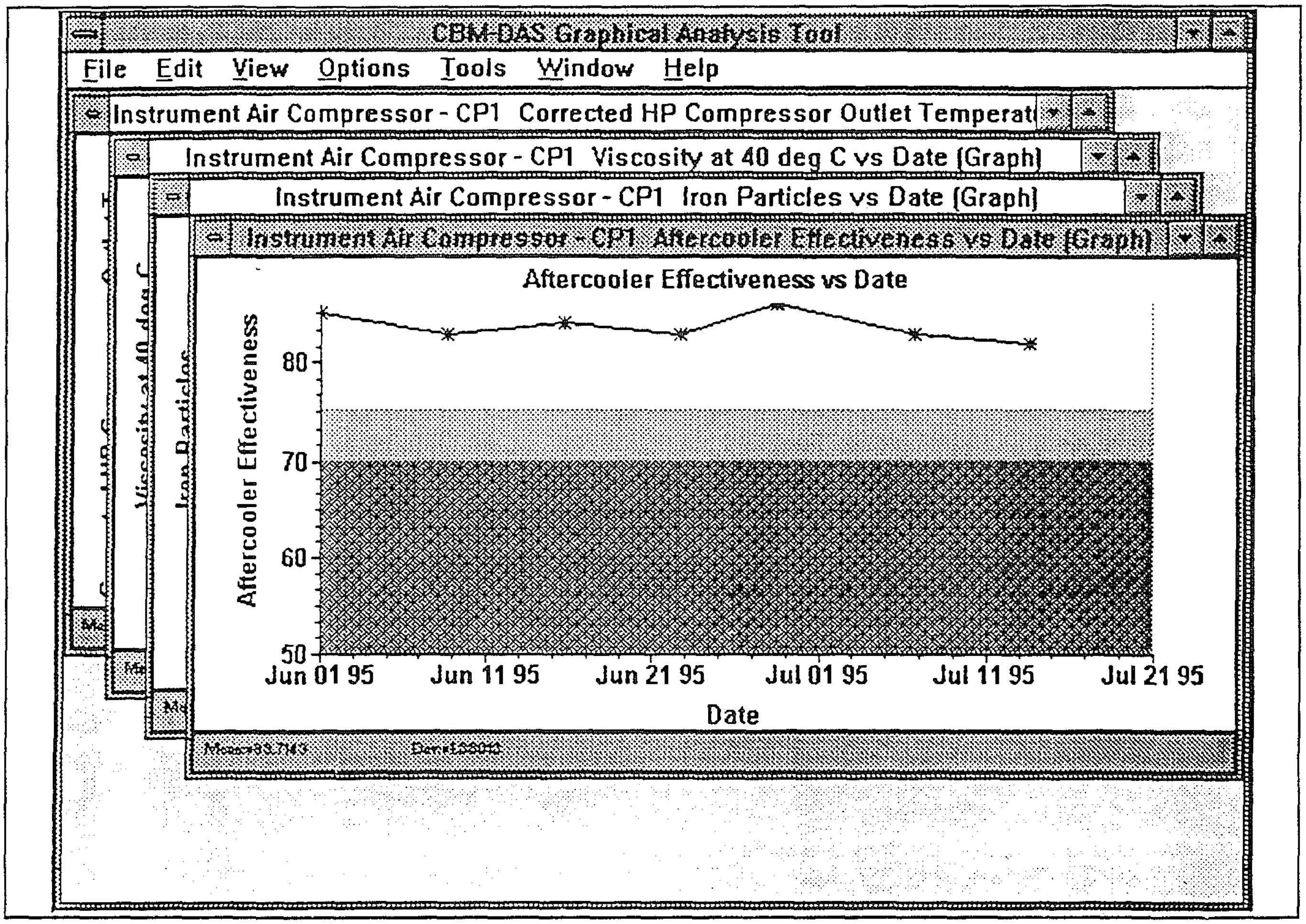


Figure 5: **Aftercooler Effectiveness Health Indicator Trend**

Table .2 - Rotary Screw Air Compressor Failure Modes for which Performance Monitoring is Relevant				
Component	**Function**	**Functional Failure**	**Failure Mode**	
Rotary Screw Air Compressor (RSAC)	1	B	4	Performance of the LP element has been reduced due to wear and erosion.
	1	B	5	Performance of the HP element has been reduced due to wear and erosion.
	1	B	11	The compressor intake air filter has become blocked by dirt and debris.
	1	E	1	The intake air filter sealing gasket has failed, i.e., it has become punctured.
RSAC Cooling System	1	A	2	Insufficient water flow through the aftercooler caused by improper adjustment of the aftercooler flow regulating cock.
	1	A	3	Insufficient water flow through the system due to the solenoid valve or other system components being plugged with debris eg scale, dirt, or shells.
	2	A	1	Insufficient water flow through the intercooler caused by improper adjustment of the intercooler flow regulating cock.
	2	A	3	Same as Cooling System 1A3.
	3	A	1	Same as Cooling System 2A1.
	3	A	3	Same as Cooling System 1A3.
	6	A	2	Same as Cooling System 2A1.

Table 2: **Air Compressor Failure Modes/Performance Testing**

Step	Description	Condition Indicators			Notes
		Description	Units	Initial Baselines / Limits	
1	Gather Compressor Data (Atmospheric)	Inlet Air Temperature	°C	0 - 50	Reasonability Limits
		Barometric Pressure	kPa(abs)	88 - 108	Reasonability Limits
2	Gather Compressor Data (Gauge Panel)	Inlet Water Pressure	kPag	321-400	Caution High
				227 - 321	Normal
				170 - 227	Caution Low
				< 170	Warning Low - (Annunciator Message below 145)
		Intercooler Air Pressure	kPag	270 - 290	Warning High
				258 - 270	Caution High
				226 - 258	Normal
				200 - 226	Caution Low
				194 - 200	Warning Low
		Air Filter Vacuum Pressure	kPa(vac)	4.5 - 6.0	Warning High
				0 - 4.5	Normal
		Discharge Air Pressure	kPag	874 - 930	Warning High
				822 - 874	Normal
				770 - 822	Caution Low
				550 - 770	Warning Low
		Oil Pressure	kPag	250 - 282	Caution High
				210 - 250	Normal
				173 - 210	Caution Low
				140 - 173	Warning Low - (Compressor will trip below 138 kPa)
		Oil Temperature	°C	> 75	Warning High - (Manufacturer's Limit = 75)
				65 - 75	Caution High
				55 - 65	Normal
				48 - 55	Caution Low
				< 42	Warning Low

Table 3: **Condition Indicator Data/Baselines/Limits**

Table 4: Examples of New On-Condition Tasks

Maintenance Requirement To Be Addressed	Previous Scheduled Maintenance Task	Revised Maintenance Programme	
		Condition Based Trigger	Condition-Driven Corrective Maintenance Action
LP Compressor Element Failure	Replace the LP element upon failure Frequency: Failure driven	Trends of element compression ratios and discharge air temperature, as per data analysis driven by suggested WO Template # 1, will show degradation of the elements. Maintenance action will be triggered and prioritized based on observed trends. This approach allows the relative health of all elements to be ascertained. Elements can then be replaced on an as required basis.	Replace the compressor element when observed performance is unsatisfactory, but prior to failure.
HP Compressor Element Failure	Replace the HP element upon failure Frequency: Failure driven		Replace the compressor element when observed performance is unsatisfactory, but prior to failure.

Table 5: **Examples of Modified Scheduled Tasks**

Maintenance Requirement To Be Addressed	Previous Scheduled Maintenance Task	Revised Maintenance Programme Scheduled Maintenance Task
The heatless air dryer outlet screens are plugged.	Inspect and clean the dryer upper and lower outlet screens as part of call-up # 7209 - Inspect Dryer, Change Filter Frequency: 104 weeks	Inspect and clean the dryer upper and lower outlet screens as part of suggested WO Template # 12 using the procedure described in call-up # 7209. Desiccant which escapes through the screens can foul the chamber purge valves and the after-filter. It is therefore recommended that these screens be cleaned and inspected on a more frequent basis. Frequency: 52 weeks
The heatless air dryer control panel instrument air filter is plugged with desiccant.	Inspect the pilot air filter and change if required as part of call-up # 7209 - Inspect Dryer, Change Filter Frequency: 104 weeks	Inspect the pilot air filter and change if required as part of suggested WO Template # 12 using the procedure described in call-up # 7209. In view of numerous dryer switching problems an increase in frequency is recommended. Frequency: 52 weeks
The heatless air dryer desiccant material no longer functions.	Change the dryer desiccant material as part of call-up # 14393 - Desiccant Change Frequency: 416 weeks	Change the dryer desiccant material as part of suggested WO Template # 14 using the procedure described in call-up # 14393. Frequency: 416 weeks