ChemAND™ —A System Health Monitor for Plant Chemistry

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ABSTRACT

Effective management of plant systems throughout their lifetime requires much more than data acquisition and display—it requires that the plant's system health be continually monitored and managed. AECL has developed a System Health Monitor called ChemAND for CANDU® plant chemistry. ChemAND, a **Chem**istry **AN**alysis and **D**iagnostic system, monitors key chemistry parameters in the heat transport system, moderator–cover gas, annulus gas, and the steam cycle during full-power operation and feeds these parameters to models that calculate the effect of current plant operating conditions on the present and future health of the system.

Chemistry data from each of the systems are extracted on a regular basis from the plant's Historical Data Server and are sorted according to function, e.g., indicators for condenser in-leakage, air in-leakage, heavy water leakage into the annulus gas, fuel failure, etc. Each parameter is conveniently displayed and is trended along with its alarm limits. ChemAND currently has two analytical models developed for the balance-of-plant. ChemSolv calculates crevice chemistry conditions in the steam generator (SG) from either the SG blowdown chemistry conditions or from a simulated condenser leak. This information can be used by plant staff to evaluate the susceptibility of the SG tubes to crevice corrosion. ChemSolv also calculates chemistry conditions throughout the steam-cycle system, as determined by the transport of volatile species such as ammonia, hydrazine, morpholine, and oxygen. A second model, SLUDGE, calculates the deposit loading and distribution in the SG as a function of time, based on concentrations of corrosion product in the final feedwater for both normal and startup conditions. Operations personnel can use this information to predict where to inspect and when to clean.

ChemAND has undergone extensive field trial at the Gentilly-2 nuclear power plant, and a commercial version is now available.

INTRODUCTION

Worldwide, nuclear power plant operators have shown considerable interest in improving the monitoring and the control of plant chemistry to improve capacity factors and extend plant life. WANO (World Association of Nuclear Operations) and INPO (Institute of Nuclear Plant Operators), for instance, provide comparative data to enable operators to evaluate their plant's performance against industry norms. Improved monitoring and diagnostics of plant chemistry will help the plant chemist to identify chemistry problems, evaluate them, and ultimately take appropriate action to remedy situations that could lead to degradation of key plant components.

This need for improvement is especially true in the steam cycle where all impurities introduced by condenser leaks, the water-treatment plants, air in-leakage, or poor chemistry control enter the Steam Generator (SG) where they can cause aggressive chemistry conditions to develop and ultimately cause corrosion failure of the SG tubes. Thus, a System

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Health Monitor (SHM) [1] for plant chemistry must provide both data acquisition and display and easy access to diagnostic, analytical, and predictive models to help the plant operators assess the effect of operating chemistry on corrosion and fouling and improve operational control of the systems.

HOW ChemAND WORKS

ChemAND (**Chem**istry **AN**alysis and **D**iagnostic system) is a chemistry SHM under development by AECL that provides additional capability to the plant chemist and system responsible engineer (SRE) in the areas of automated monitoring, alarming, diagnostics, prediction, and on-line execution of analysis codes. It is an integral part of the "smart" CANDU reactor that will be used with on-line, in-situ probes to optimize chemistry control for the entire plant. The product has been under field trial at Gentilly-2 since early 1999, and a commercial version is now available.

ChemAND has three main components:

- **Chemistry surveillance and reporting**
- **Alarming on chemistry out-of-spec, and**
- **Models for prediction and analysis.**

ChemAND provides enhanced 'situational awareness' to the plant chemist or SRE by **monitoring and trending chemistry parameters** from eight key systems:

- Steam Cycle (balance-of-plant, BOP)
- Heat Transport System (HTS),
- Annulus Gas
- Moderator–Cover Gas
- Endshield Cooler
- Liquid Zone System
- Emergency Core Cooling, and
- Gadolinium Storage Tanks.

Monitoring of chemistry from other plant systems can easily be added as the need arises.

The parameters from each system are acquired from the plant's Historical Data Server (HDS) [2], and are sorted and displayed according to their function, e.g., 'monitor for condenser leak', 'monitor for air in-leakage', or 'monitor for corrosion-product transport'. On-line chemistry parameters are integrated with laboratory analysis results ('grab samples') and are treated in a fashion transparent to the user and displayed with the same tools. Note that chemistry-related data can be easily correlated with other operational data stored in the HDS.

Using ChemAND, the SRE can trend current values, look at previous data, and compare values to design or commissioning data. ChemAND also provides a static library for information that the plant chemist needs to have readily available. Thus, for each parameter that is measured, there are links to tables showing the reason for monitoring that parameter, its control limits and its 'tag name' in the HDS. Additional information, such as links to the rationale for setting the control limit and the standards for sampling and analysis can be added in specific installations.

In each station, performance limits are established for each chemistry parameter. ChemAND supports two levels of high and low alarms, and **alarms when chemistry parameters drift out-of-spec**, flags the parameter(s) and provides the chemist with information to track down the source of the problem and rectify the situation by:

- displaying an alarm 'bar', akin to the 'window tiles' used in control rooms, that changes colour when a parameter is 'out-of-spec' and identifies the affected plant system,
- providing easy navigation from the alarm bar to trends of parameters in alarm for a given system, and,
- using 'function-based' displays to help the chemist diagnose the cause of the problem.

Chemistry parameters both in and out of spec are tracked continuously, facilitating the **calculation and reporting of both performance and safety-related indices** on an on-going basis. This feature greatly enhances the accountability of plant chemistry systems, and facilitates chemistry reporting to both management and regulatory authorities.

The foregoing may be described as a 'present' and 'past' view of plant operation. The plant chemist and SRE must, however, also manage the plant's future. ChemAND uses **models for the analysis and prediction** of the effect of current chemistry conditions on the degradation of plant systems and components. Two models are currently resident in ChemAND: SLUDGE and ChemSolv.

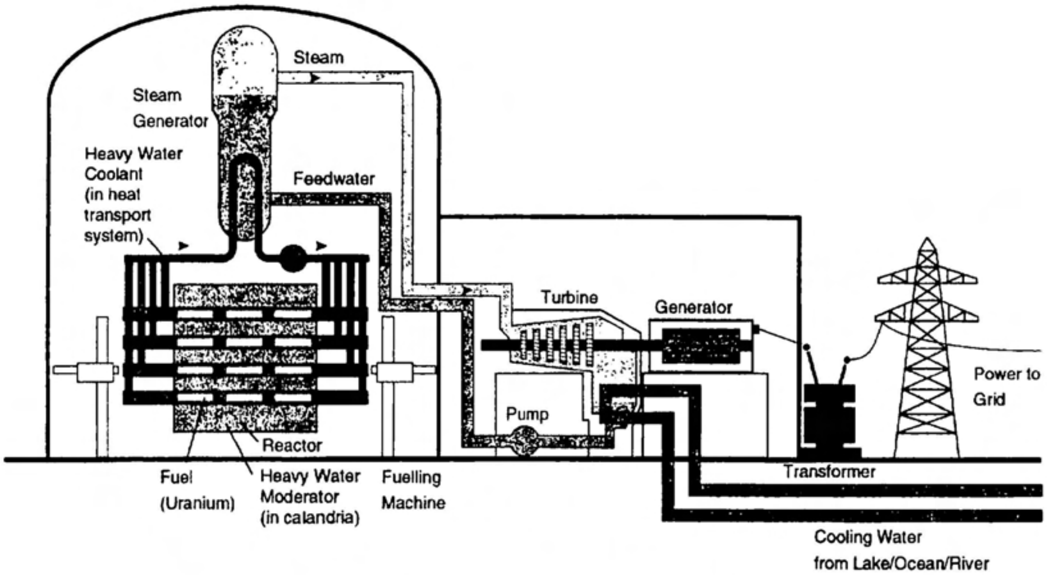


Figure 1: Major Systems in a CANDU Power Plant.

SLUDGE is a fouling model that tracks deposit buildup and distribution in the SG from corrosion-product transport data for both normal operation and start-up conditions, i.e., when a significant amount of corrosion product is transported to the SG in a 'crud burst'. Future increments to deposit buildup can be run as scenarios from ChemAND as a function of feedwater chemistry and plant operating conditions, e.g., blowdown rate[1].

A second model, ChemSolv, is a chemistry model that can be used to calculate the effect of a condenser leak or impurity ingress from the water treatment plant on SG crevice chemistry. Crevice chemistry is calculated at four strategic locations in the SG; two on the hot-leg and two on the cold-leg. ChemSolv also tracks the transport of volatile species—e.g., oxygen, amine, hydrazine, and volatile decomposition products—throughout the steam-cycle.

All models that have been incorporated into ChemAND can be run using either user-defined input parameters or parameters read from the station's HDS. This capability allows comparison between several scenarios, for example one where the future is a continuation of current conditions, another where a change has been made in additives or feedwater chemistry, and yet another under chemistry conditions, as observed some time in the past. The predictive models in ChemAND are also available as a 'stand-alone' module that can be run on a personal computer using user-defined input files. Model output files are saved and can be plotted as 'what-if' scenarios as a plant lifetime management tool.

ChemAND REQUIREMENTS AND LINKS TO OTHER SOFTWARE

ChemAND is a client–server application developed for the Windows NT/95 operating system. It uses two commercial off-the-shelf software packages: ProcessBook from OSI Software for displaying plant information stored in a data historian; and FIX from Intellution, which provides the automated monitoring, alarming and scheduling capabilities using its point database. Both software packages have a rich development environment for customization to suit the user's needs. FIX and ProcessBook have the ability to read data from PI servers as well as from ODBC-compliant databases. Thus ChemAND can receive plant data in a variety of electronic formats, e.g., ASCII text file, ACCESS database, and Excel or Quatropro spreadsheet.

If ChemAND has electronic access to historical plant data (on the plant's own HDS), much greater functionality can be achieved. For example, current chemistry behaviour can be compared to past events and new analysis results compared with previous analyses to validate grab sample data. If no data historian exists, AECL can build one under separate

[1] During operation, water is continuously removed from the SG at a small fraction of the steaming rate to limit the buildup of impurities. This is called blowdown.

contract and populate the database with the plant's historical data.

At Gentilly-2 plant personnel have developed an indigenous HDS called STDE. Installation of ChemAND at Gentilly-2 for the field trial required some on-site work to set up the data extractions from STDE and to make the appropriate changes to file formats. STDE generates text files containing rows of time-stamped data collected from on-line sensors and laboratory samples (grab samples). The data are converted into a suitable format for importing into a Microsoft Access database, which is then read by ProcessBook and FIX. The scheme is shown in Figure 2.

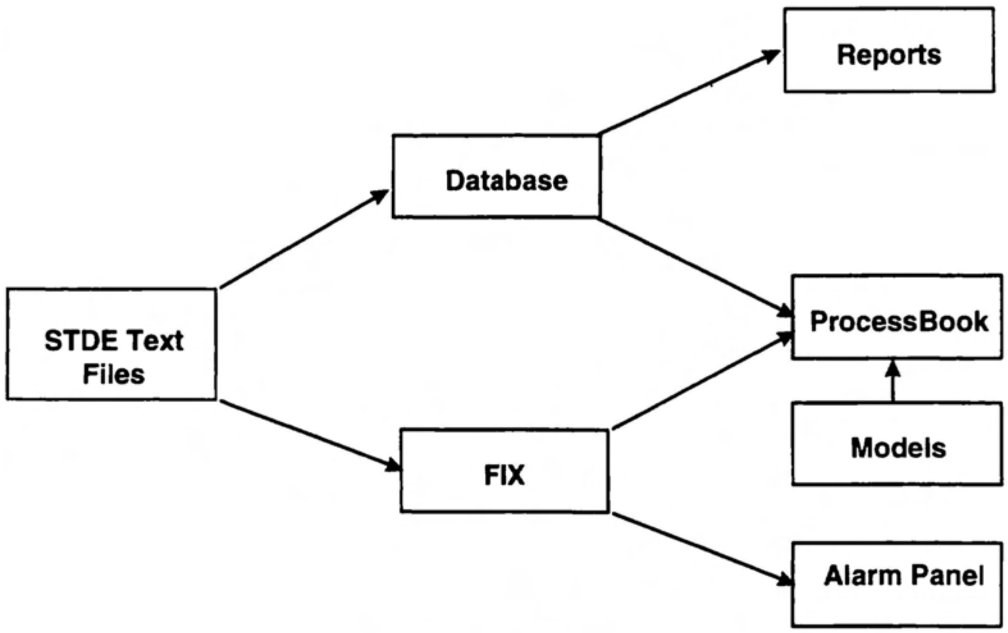


Figure 2 - Data Flow within ChemAND

Most of the user interface and display navigation takes place with ProcessBook. ProcessBook displays the historical trends and any additional display information—such as alarms, alarm limits, engineering units, and engineering range—is retrieved from the FIX point database. The point database, which defines sampled parameters, is custom-installed at each plant. Users can easily modify graph scales, alarm limits, and units.

ChemAND is fully compatible with Microsoft-Office products, such as Word, Excel and Power Point. This feature enables the user to easily cut and paste graphs and tables from ChemAND for reports and presentations. Operators can easily e-mail a snapshot of current plant conditions to other interested parties. Alternatively, ChemAND can be installed on a server with read-only access so that it is available to a number of plant users.

ChemAND USE

ChemAND is designed from the users' point of view, mindful of conditions and operating constraints in real plants. Our goal is to enhance accessibility to chemistry information, to facilitate the sharing of that information, and to promote its use in the timely response to events and in the management of equipment health and lifetime.

Upon opening ChemAND, the user sees the dialog screen shown in Figure 3.

Pi-Process Book defines ChemAND as several 'workbooks' (piw files) corresponding to the systems monitored. Opening a workbook, for example "Monitor Steam Cycle (BOP) Chemistry" in Figure 3, opens the Steam Cycle (BOP) page, shown in Figure 4, with navigation bars leading to the static, trending, and modelling portions of ChemAND.

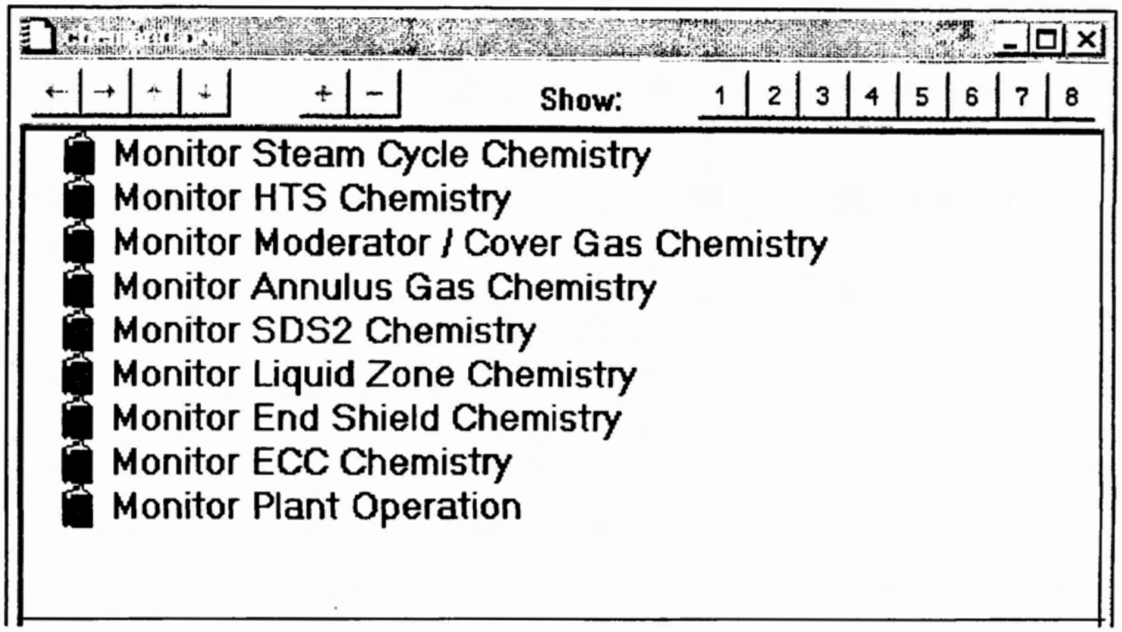


Figure 3 - ChemAND Main Dialog Screen

ChemAND STATIC FEATURES

Several 'static' features are illustrated in Figure 4. The upper lines in Figure 4 lead to a schematic of the system, and information on the functional decomposition of the steam cycle (BOP) [3].

Opening the 'Function and Performance Standards' sheet in Figure 4 opens an MS-Word document containing data on particular chemistry parameters, their 'tagnames' in the database, sampling frequency, sampling and analysis procedures, and operating limits. This information is a synopsis of the plant's chemistry operating manual. It must be recognized that, more often than not, problems will occur outside of normal working hours when plant chemists and other specialists may not be readily available. It was felt that the inclusion of this synopsis from the plant's chemistry operating manual could help operations personnel decide on the short-term response to a chemistry excursion; for example, whether a small condenser leak could be tolerated until morning or whether it should be isolated immediately by personnel called in for the occasion.

ChemAND TRENDING AND ALARM FEATURES

Displays of the chemistry parameters that are monitored in each system are organized on separate sheets of the workbook according to their function. For example, all of the chemistry parameters that are monitored to alert the operator to the onset of a condenser leak are organized on one sheet labelled "Monitor for Water In-leakage" in the Steam Cycle (BOP) workbook (see Figure 4). Similarly, chemistry parameters that measure the quality of water from the water treatment plant are organized onto a sheet labelled "Monitor for Makeup Water Chemistry". The chemistry parameters monitored in other systems are organized in the same way. Thus, the HTS workbook has a sheet labelled "Monitor for Corrosion Control", and the annulus gas workbook has a sheet labelled "Monitor for Air Ingress".

Plant operators need to monitor not only the concentrations of impurities that have leaked into the system, but also the concentrations of chemicals that are added to control the system chemistry. Displays for these parameters, together with the concentrations of key impurities that must be monitored very closely, have been collected together into an overview sheet. An example of the overview sheet created for the Steam Cycle (BOP) workbook is shown in Figure 5.

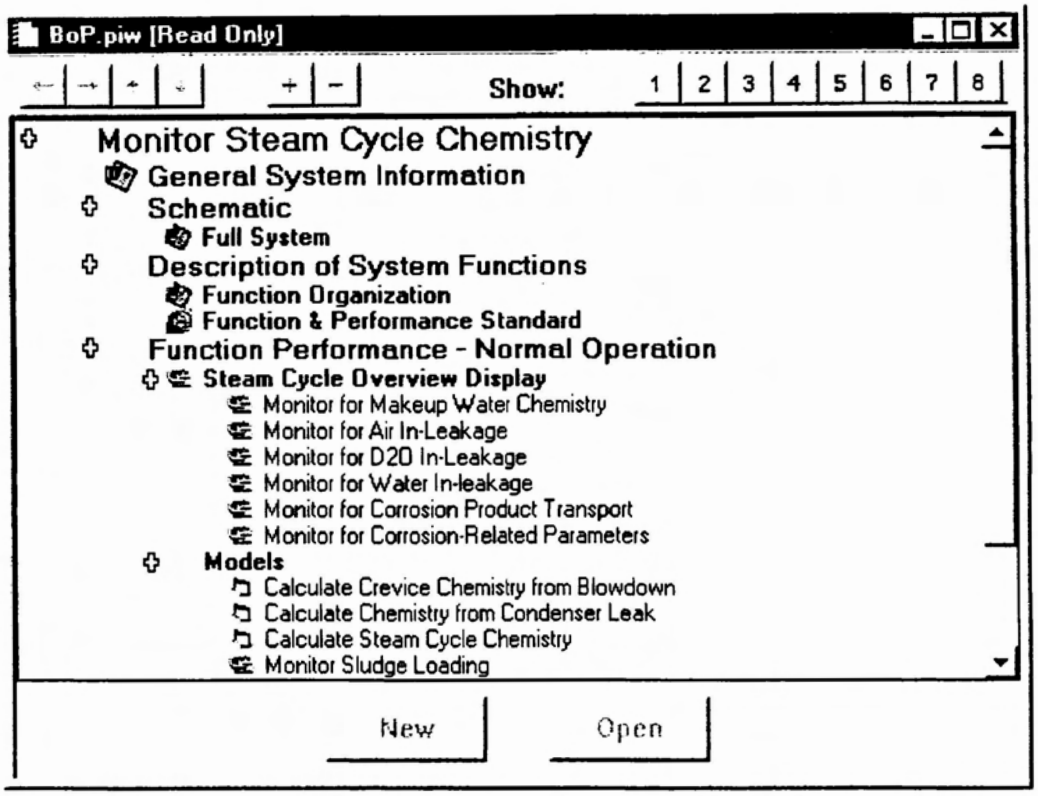


Figure 4 - Steam Cycle Workbook

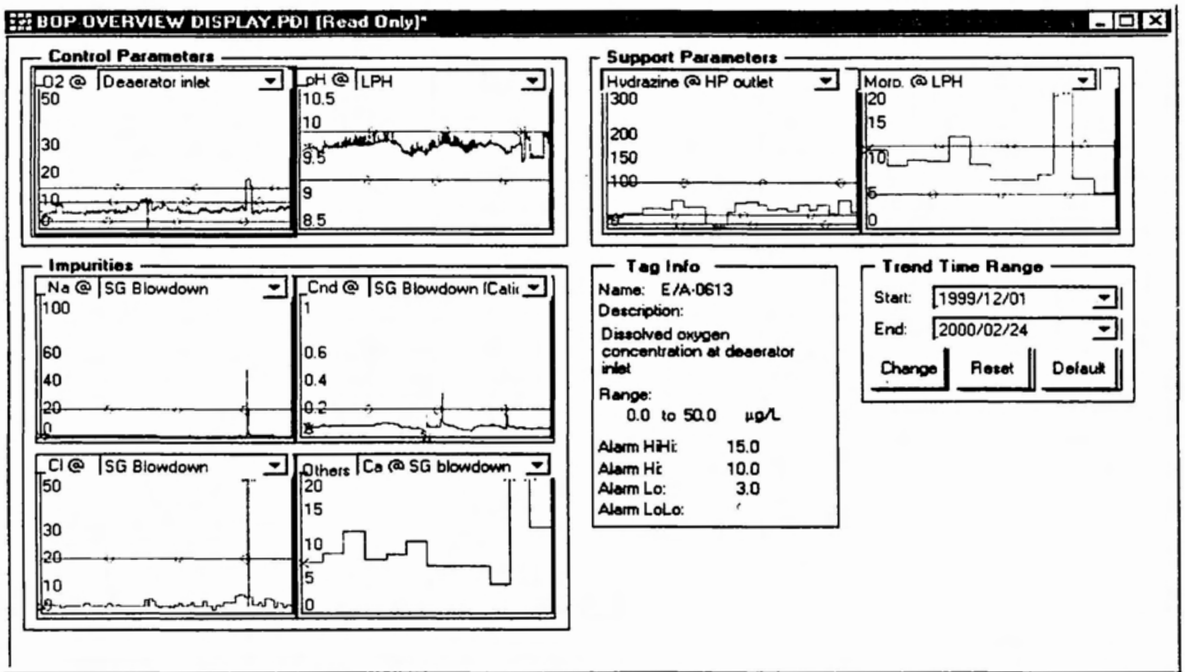
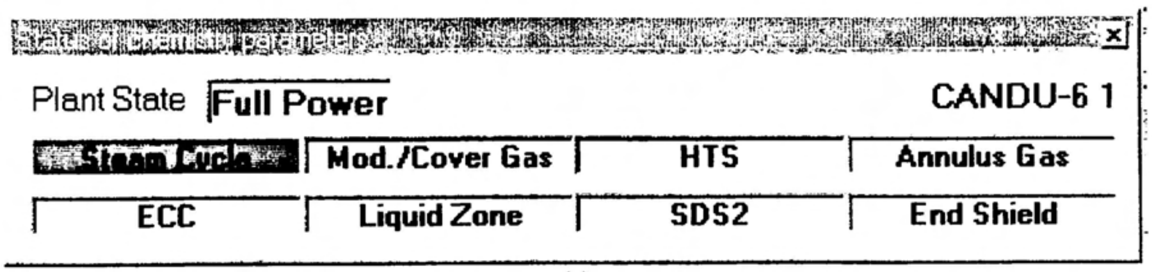


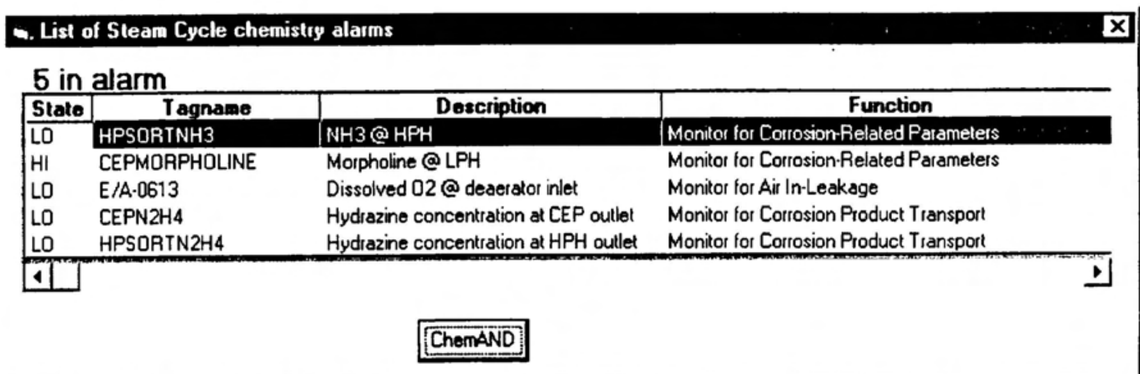
Figure 5 - Steam Cycle Overview Display

The support parameters are chemicals added to control system chemistry. In the steam cycle, an amine is added to adjust the pH, whereas hydrazine is normally added to scavenge oxygen. CANDU plants generally add morpholine to control pH in the steam cycle. Because ammonia (NH_3) is a decomposition product of both morpholine and hydrazine, it will be present in the steam cycle too. Two displays have been created for the support parameters. Figure 5 shows trends for the concentrations of hydrazine and morpholine at the high-pressure (HP) and low-pressure (LP) heater outlet, respectively. By using the drop-down menu, the user can select trends for other support parameters at locations of interest in the steam cycle. The parameters to be controlled are pH and oxygen, and are labeled 'control parameters' in Figure 5. The user can select trends for the concentrations of 'control parameters' at locations other than those shown in Figure 5 using the drop-down menu. Displays for the support and control parameters, together with graphs showing the concentrations of key impurities introduced to the steam cycle from either condenser leaks or from the water treatment plant, give the plant chemist a useful overview of the chemistry throughout the steam cycle. The "trend time range" feature allows the user to define the time range of interest for the displays. This feature is available on all the display sheets in ChemAND, and provides flexibility in reporting on important chemistry trends.

For chemistry performance monitoring the first line of surveillance is ChemAND's 'alarm panel', which is illustrated in Figure 6 (a). The 'alarm panel' interrogates the database for the latest values, flags parameters out-of-specification and points to appropriate displays to diagnose the problem. Specifically, when a parameter in one of the plant systems monitored by ChemAND strays out of specification the appropriate system field in the 'alarm panel' changes to red to indicate which system has a problem. Figure 6 (a) shows that at least one chemistry parameter in the steam-cycle (BoP) is out of specification. Clicking on the red field brings up a list of chemistry parameters that are out-of-specification in the steam cycle, as shown in Figure 6 (b). Clicking on the 'ChemAND' button below the list will bring up the 'function-based' display containing the parameter in alarm and related parameters symptomatic of a particular problem. For example, for the alarm on low oxygen at the deaerator inlet, the appropriate 'function-based' display is 'monitor for air inleakage'. By warning as soon as one parameter is out of specification and pointing to related parameters, ChemAND can provide early warning of impending problems and point the human expert to the cause.



(a)



(b)

Figure 6: Alarm panel showing an alarm in the steam cycle (a) together with the list of chemistry parameters that are out-of-spec and their location in the steam-cycle (b).

ChemAND MODELS

In addition to displaying present and past conditions, ChemAND uses analytical and predictive models to assess the effect of current operating chemistry conditions on the life expectancy of key plant components. This capability is especially important for transient conditions, e.g., start-ups, shutdowns, and condenser leaks, when systems are temporarily pushed outside of their recommended operating regimes. Good plant life management then depends on the ability of the operator to control these transient conditions and to estimate their effect on the degradation of thermal performance.

Figure 7 shows the output screen for a calculation of crevice chemistry by ChemSolv following a condenser leak. The concentrations are given as "user input" based on the chemistry of the condenser cooling water. The crevice regions of most interest are those at the tube/tube-support and tube/sludge-pile intersections in the SG. Boiling in these occluded regions concentrates the impurities, which leads potentially to the development of aggressive chemistry conditions. In this case, although high concentrations are predicted for soluble species, the crevice pH (at temperature) remains in the acceptable range of 5 to 9 at all 4 locations.

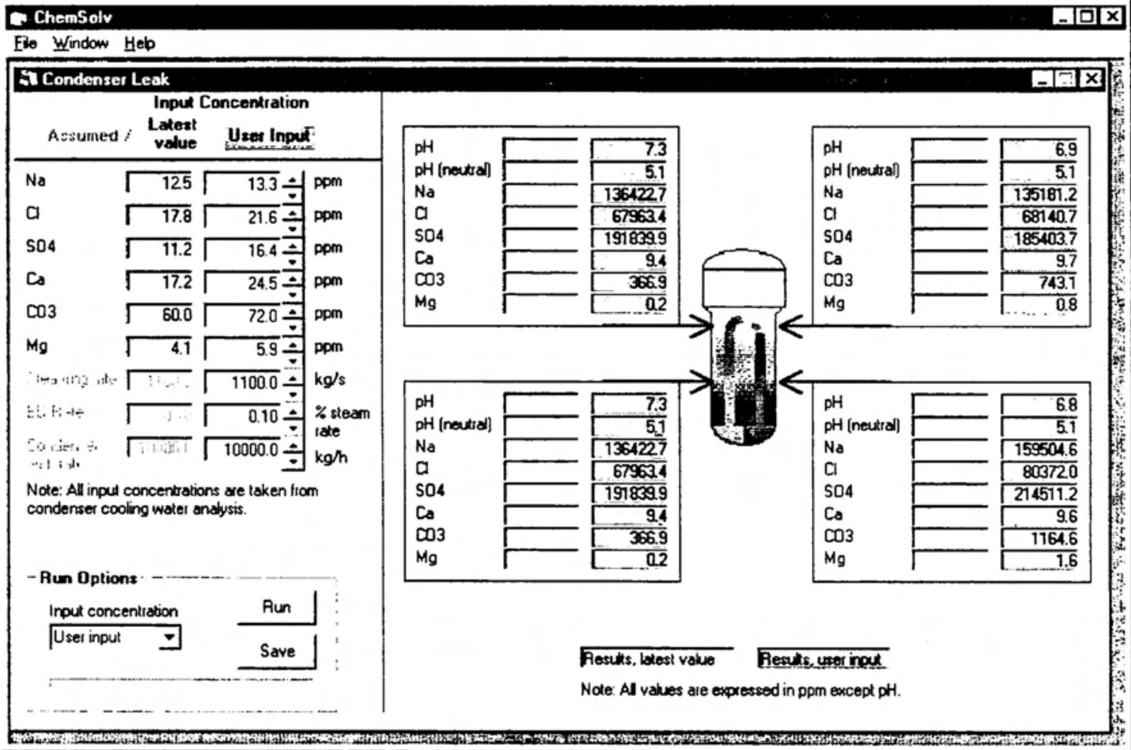


Figure 7 - Crevice Chemistry Calculated Following a Condenser Leak

Figure 8 shows a situation where chlorination in the water treatment plant (WTP) during the summer months has resulted in elevated chloride levels in the SG blowdown compared to operation during the winter when chlorination is not required. Although the blowdown chloride concentration is still within specification, the predicted crevice pH has dropped below the acidic end of the acceptable range. As a result, corrosive conditions may exist in the crevice regions. The plant can use this information to try to establish a chlorination program that will control microbial growth in the WTP while avoiding the development of aggressive chemistry conditions in the SG crevice regions. This example illustrates how a model like ChemSolv can be used to assess and optimize the plant operating chemistry conditions.

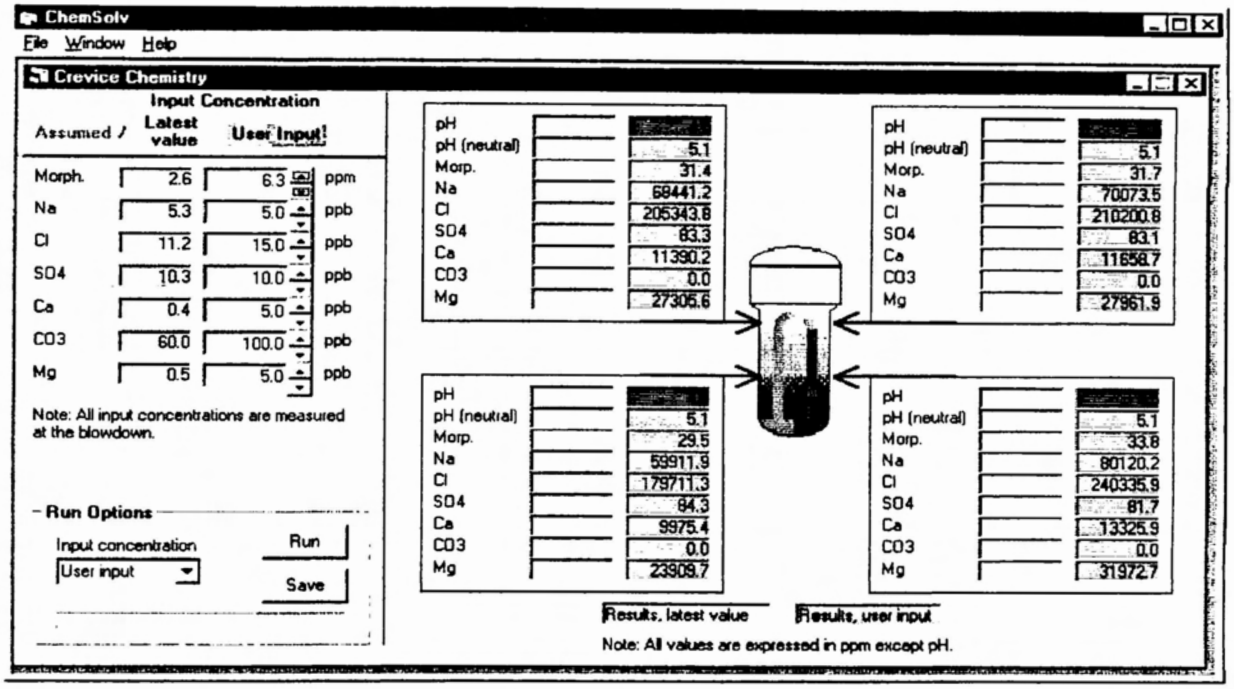


Figure 8 - Crevice Chemistry Calculated from Blowdown Chemistry Conditions

CHEMSOLV can also be used to calculate the distribution of volatile species and local chemistry conditions throughout the steam cycle as well as crevice chemistry in the SG during a plant shutdown.

SUMMARY

ChemAND is a software tool that provides plant operators with on-the-spot access to current and past plant chemistry conditions, and offers models to assess the effect of these conditions on plant life. It offers static information, such as chemistry specifications, trends and displays of live chemistry data, and links to a database of historical conditions. Most importantly, it offers predictive models to optimize plant operating conditions and manage the plant's lifetime.

REFERENCES

1. G. Tosello and M.T. DeVerno, *System Health Monitor Design Requirements*, AECL Report, SHM-66500-DR-001, Revision 0, 1997 September.
2. H. Pothier, and M.T. DeVerno, *Historical Data Systems: High Level System Requirements*, COG-96-150, Revision 0, AECL, Chalk River Laboratories, 1996 June.
3. G.R. Mitchel, E.C. Davey and M.P. Feher, *Example Plant Functional Basis*, COG 97-26, 1997 January.