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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 will be used by operations personnel to evaluate the potential for SG tube corrosion in the crevice region. 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 in the SG as a function of time, based on concentrations of corrosion product in the final feedwater and plant operating conditions. Operations personnel can use this information to predict where to inspect and when to clean. In a future development, SLUDGE will track deposit loading arising from start-up crud bursts and will be used in conjunction with the thermohydraulics code, THIRST, to predict the effect of fouling on degradation of thermal performance.

ChemAND is currently undergoing a field trial at the Gentilly-2 nuclear power plant, and a commercial version is planned to be available within a year.

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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 plant key 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, while a System Health Monitor (SHM) [1] for plant chemistry must include data acquisition and display, to help the plant operators assess the effect of operating chemistry on corrosion and fouling it must also provide easy access to diagnostic, analytical, and predictive models, to 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 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 is in a pre-commercial phase and is currently undergoing field trials at Gentilly-2. A commercial version will be available within a year.

ChemAND has several components. First, it provides enhanced 'situational awareness' to the plant chemist or SRE. ChemAND currently monitors and trends chemistry parameters from 4 key systems in the plant (see Figure 1):

- Steam Cycle (balance-of-plant, BOP)
- Heat Transport System (HTS),
- Annulus Gas, and
- Moderator–Cover Gas.

Monitoring of other plant systems can easily be added as the need arises. Recently, in response to feedback from the field trial users, we have added certain safety-related chemistry parameters from other sub-systems, such as the gadolinium storage tank and the emergency core-cooling system.

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, will be added in the future.

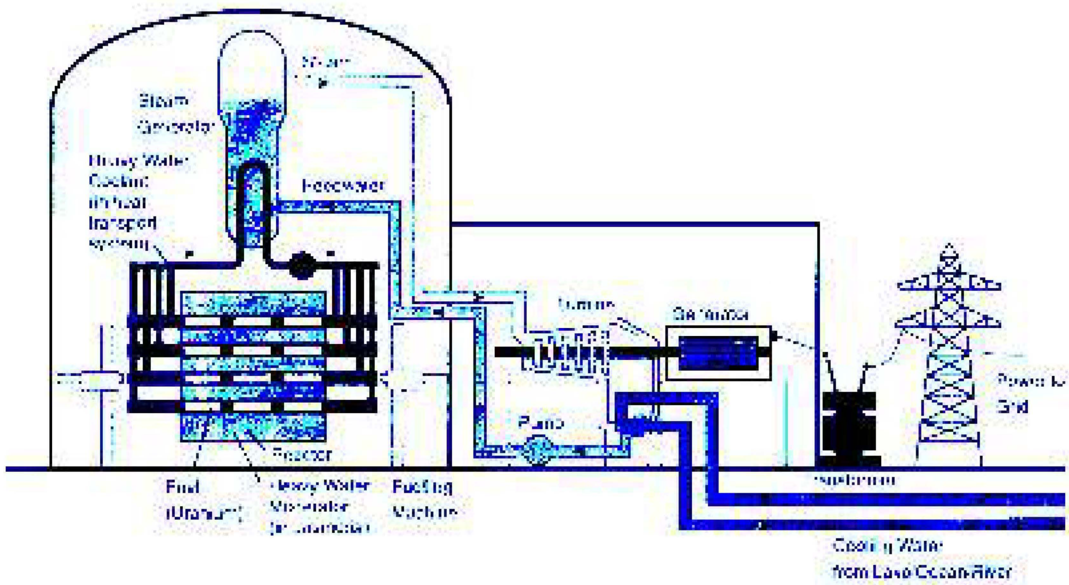

Figure 1: Major Systems in a CANDU Power Plant.

ChemAND also has an annunciation function. Alarm limits are established for each parameter, and an alarm 'bar', akin to the 'window tiles' used in control rooms, will change colour if a parameter from a given system (e.g., HTS) is out of specification.

The foregoing may be described as a 'present' and 'past' view of plant operation. The SRE must, however, also manage the future. Chemistry models resident in ChemAND are used to determine the effect of the current system chemistry on plant life. Two models are currently resident in ChemAND: SLUDGE/THIRST and CHEMSOLV.

The fouling model, SLUDGE/THIRST, tracks deposit buildup and distribution in the SG from corrosion-product transport data and calculates the effect on reactor inlet header temperature. To manage fouling, estimates of future increments to deposit buildup can be run as scenarios from

ChemAND, dependent on feedwater chemistry and plant operating conditions, e.g., blowdown rate[1].

A second model, CHEMSOLV, can be used to calculate the effect of a condenser leak or impurity ingress from the water treatment plant. The model predicts crevice chemistry in the SG, which is directly related to the likelihood of a subsequent corrosion failure of the SG tube. 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 can be installed at any nuclear power plant where an HDS exists, but the infrastructure must also exist for ChemAND to extract chemistry data from the plant's HDS.

The ChemAND system is currently under field trial at Gentilly-2. Personnel at Gentilly-2 developed an indigenous historical data server called STDE. Installation of ChemAND at Gentilly-2 for the field trial required some on-site work to set up the data extractions and make the appropriate changes to file formats. CANDU 6 and CANDU 9 reactors have standardized on the PI Historical Data Server, and ChemAND has been developed accordingly for a PI system. Ontario Power Generation and NB Power have also adopted PI as their data historian. Interfaces can be built for other plants that do not have PI historians.

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.

The latter capability was used for connecting to the STDE historian at Gentilly-2. The 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

[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.

into a Microsoft Access database, which is then read by ProcessBook and FIX. The scheme is shown in Figure 2.

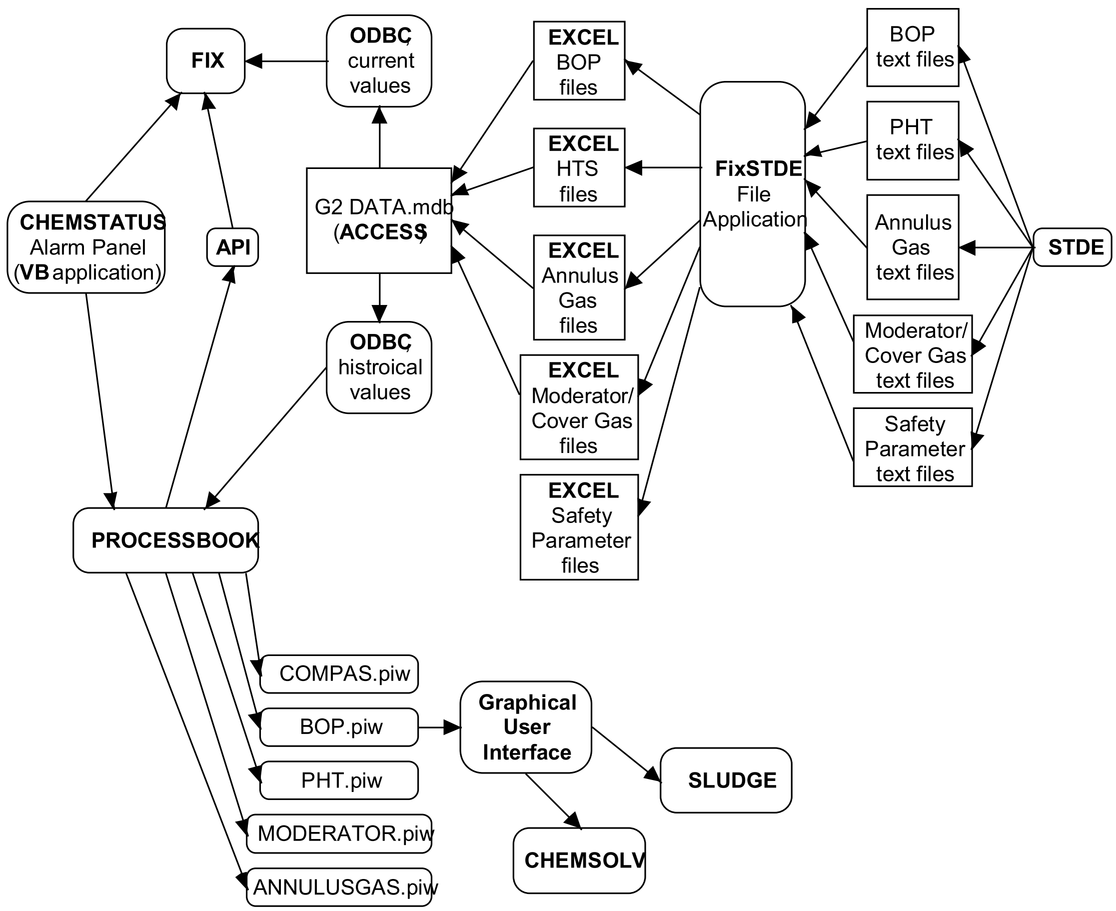

Figure 2 - Data Flow within ChemAND

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. The plant chemist 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.

<u>ChemAND USE</u>

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.

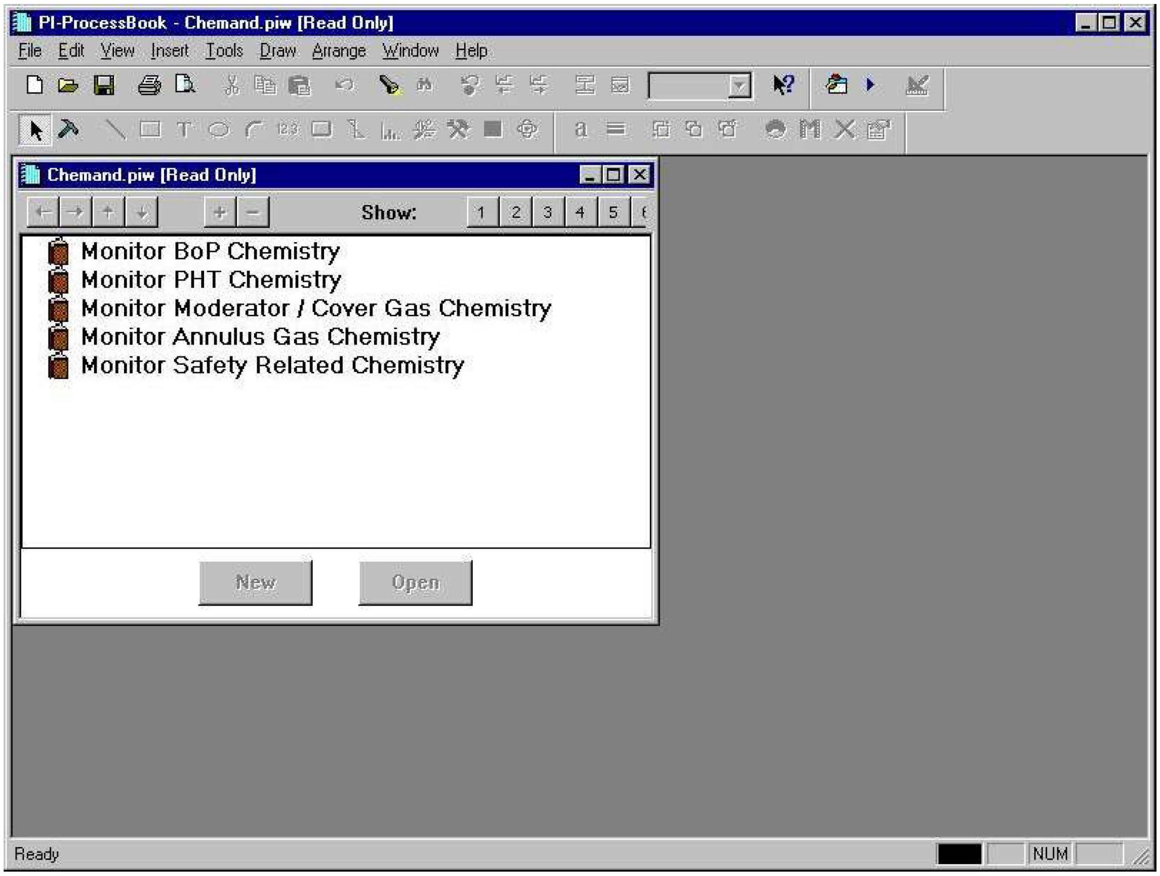

Figure 3 - ChemAND Main Dialog Screen

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.

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.

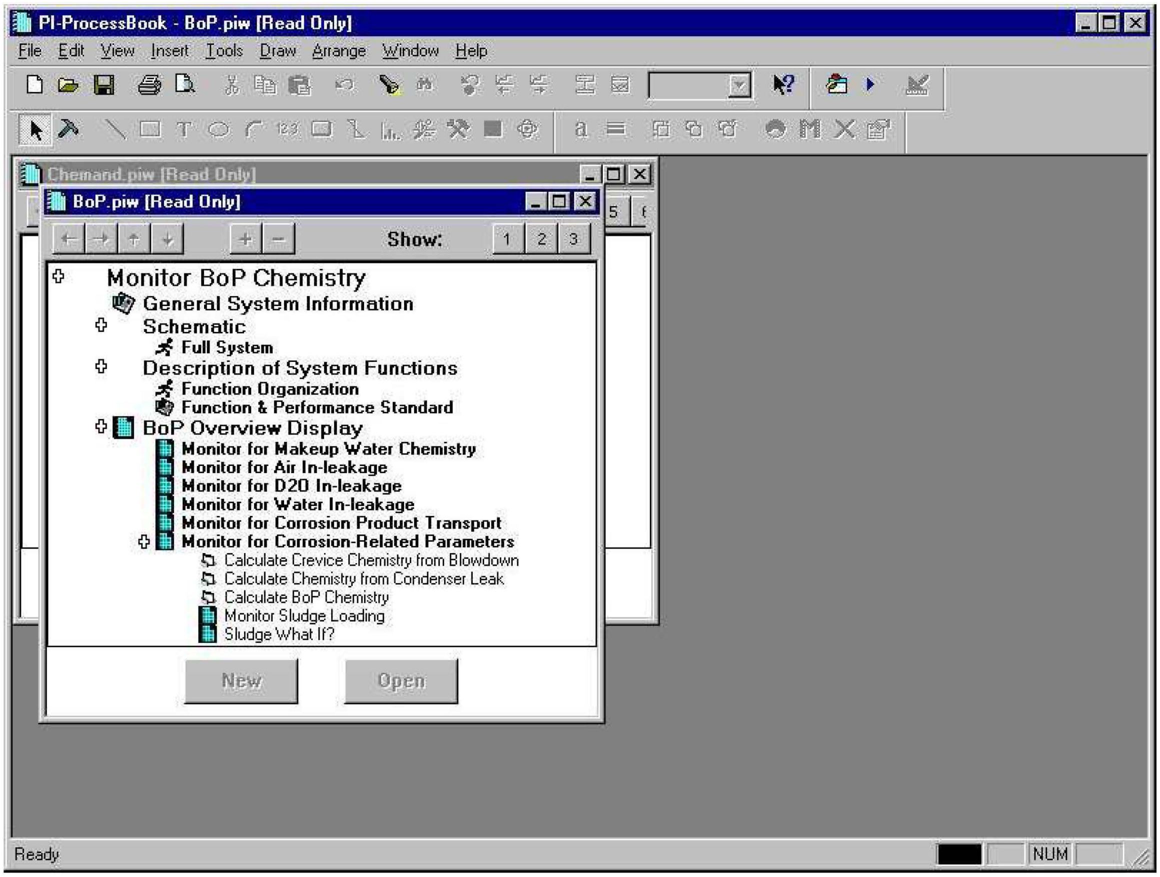

Figure 4 - Steam Cycle Workbook

ChemAND TRENDING 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".

The plant chemist needs 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.

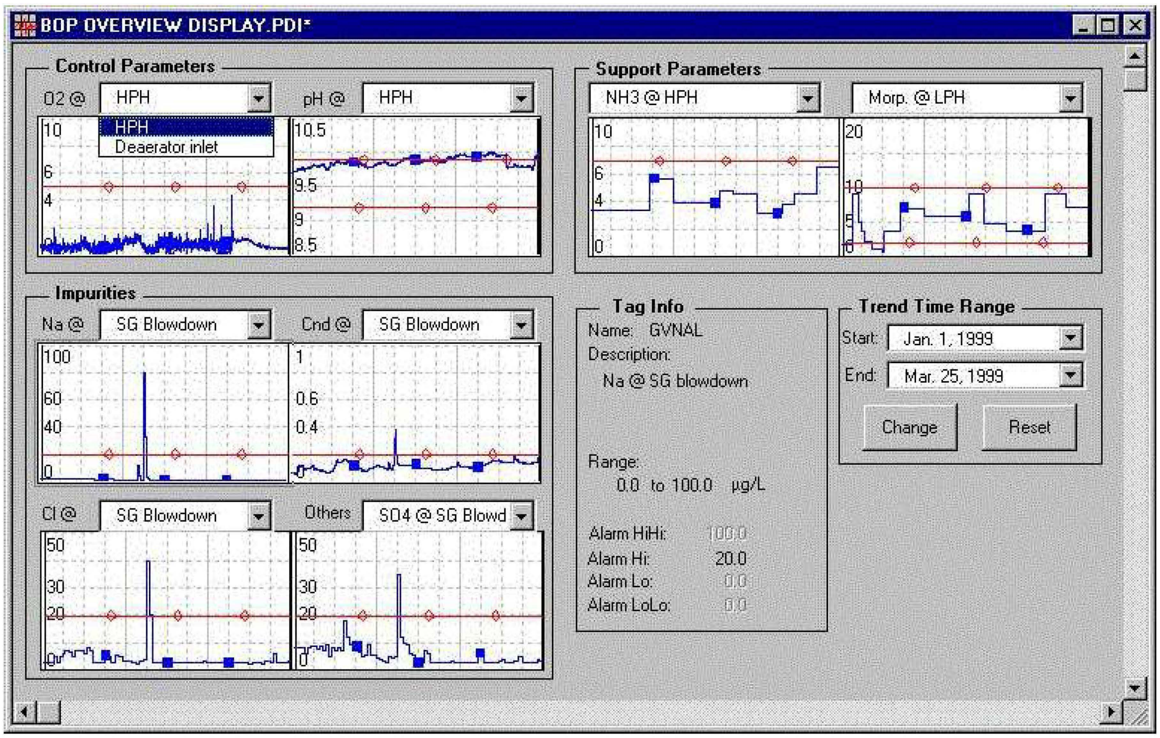

Figure 5 - Steam Cycle Overview Display

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, and by using the "arrow" feature the user can select both the support parameter of interest and the location monitored. The parameters to be controlled are pH and oxygen, and are labelled "control parameters" in Figure 5. Again, the user can display the concentration of "control" parameters at different locations using the "arrow" feature. Displays for the support and control parameters, together with graphs showing the concentrations of key impurities, 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.

ChemAND MODELS

In addition to displaying present and past conditions, ChemAND uses diagnostic and analytical models to assess the future, specifically 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 6 shows the output screen for a calculation of crevice chemistry by CHEMSOLV, based on a simulated 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 shows the output screen for a calculation of crevice chemistry by CHEMSOLV based on simulated blowdown chemistry. Although the blowdown impurity levels are within “acceptable” limits, the crevice pH is below the acidic end of the acceptable range and, therefore, potentially corrosive conditions exist. This somewhat unexpected result illustrates the value of using these models to assess and, on this basis, optimize the operating chemistry conditions.

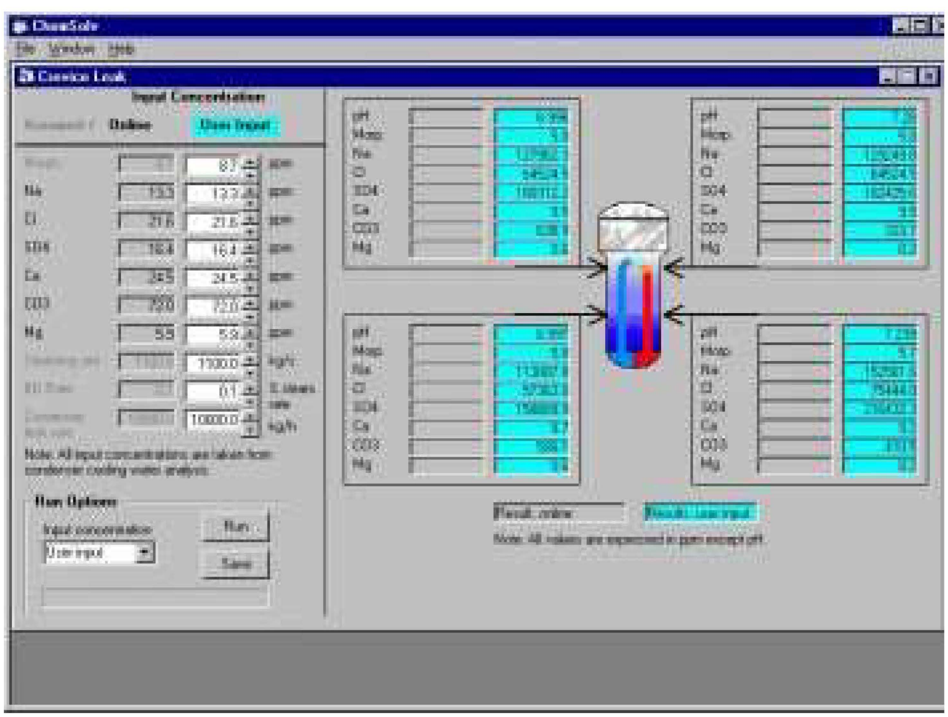

Figure 6 - Crevice Chemistry Calculated from a Simulated Condenser Leak

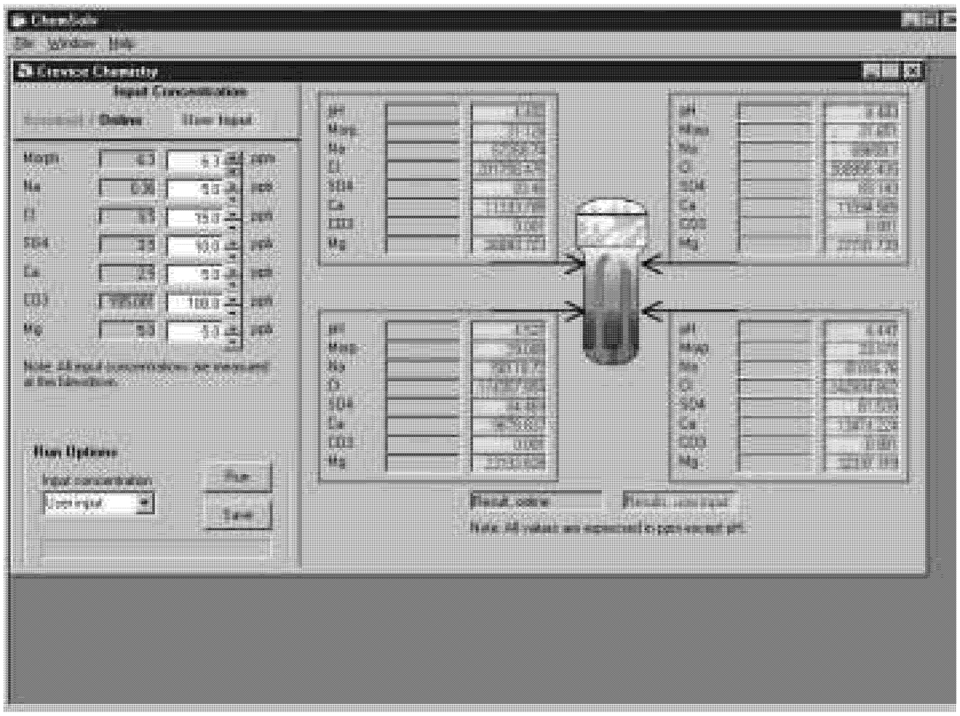

Figure 7 - Crevice Chemistry Calculated from Simulated Blowdown Chemistry Conditions

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. The fouling model SLUDGE/THIRST tracks sludge deposit loading and its effect on degradation of thermal performance. Future steam-cycle applications will include the addition of a corrosion model and the modelling of the effect of startup crud bursts on thermal performance.

SUMMARY

ChemAND is a software tool that provides plant chemists with on-the-spot access to current and past plant chemistry conditions, and offers models to asses 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

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