USING THE PAW/PEM MONITORING SYSTEMS TO SUPPORT OPERATIONS AT POINT LEPREAU

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INTRODUCTION

The plant data logger was brought on-line at the Point Lepreau Generating Station (PLGS) in 1992 in order to record information from instruments throughout the plant. Using the System Engineers Data Extraction (SEDE) utility, current plant data is at the fingertips of anyone with a network connection. System engineers can monitor the performance of their systems at any time and take pro-active measures to avoid problems with performance, as well as monitor behavior during tests and plant upsets. Nuclear Safety personnel gather data for use in simulation and analysis validation, as well as to ensure that plant parameters are kept within the safe operating envelope.

The Plant Data Logger and SEDE combine to make an indispensable analysis tool which is used in some form by most technical staff at PLGS. However, while this system has brought the potential benefit of widely available data, it has also brought the problem of potential information overload. There are over 3000 inputs to the data logger from the control computers, over 500 more from the Safety System Monitoring System (SSMS), and more still from other monitoring systems. Given that all of this data is logged at a six (6) second sample frequency, the amount of raw data available is exceedingly large.

Once the data is acquired with SEDE, it needs to be arranged and displayed in some logical form, and this has normally been done using commercial spreadsheet packages such as Quattro-Pro and Excel. However, this can be a time consuming and tedious undertaking for even simple operations like changing the scale of a graph. Also, spreadsheets are limited in the size of the data file they can accept, and even when a spreadsheet can accept a large data file, it may severely tax the capacity of the computer. This has forced users to be selective with the number of signals they review, as well as in the resolution of the data.

Faced with these problems, the PLGS operational safety group embarked on a project to develop a data management system. The project and the monitoring process has come to be known as the Plant Analysis Workbench (PAW). When the need for complex monitoring of safety system signals was identified, this led to a similar project called the Plant Expert Monitor (PEM).

In this paper we present an overview of the functionality of both PAW and PEM, outlining in particular the expert system architecture in PEM, and giving an example of its day-to-day use.

2 FUNCTIONAL REQUIREMENTS FOR THE PAW/PEM MONITORING SYSTEM

The development of the PAW/PEM monitoring tools was an iterative process. As the development team's understanding of the plant data improved, so did the tools to manage the data, and vice versa. As the tools and understanding evolved, so did the requirements and the scope of the project. The following is a short list of the basic requirements that have evolved for the plant monitoring routines.

2.1 Monitor Safety Systems and Core Parameters

There are strict limits placed on safety systems and process parameters upon which they act. These limits are monitored by operations personnel or by system engineers, but some of these limits are only checked occasionally, and only when the plant is in normal operation. The data logger gives us the ability to monitor these limits on a continuous basis.

2.2 Monitor Long Term Trends

Many plant parameters are subject to seasonal changes and the effects of plant aging. Plant parameters are monitored on a weekly basis, and statistics for each week are compiled and added to a long term trend database. These long term trends need to be reviewed on a regular basis to ensure that plant parameters are not in danger of drifting outside their tolerance in the near future.

2.3 Support Station Activities during Upsets and Off-Normal Operation

During plant upsets, station personnel will often require plant data in order to investigate the cause of the upset and/or to determine an appropriate course of action. Also, during off-normal operation such as shutdowns and start-ups, it may be required to have very specialized and stringent monitoring procedures in place.

2.4 Provide Input to Safety Analysis

Safety analysis personnel sometimes require a variety of plant data in order to ensure that assumptions used in the safety analysis reflect the as-built/as-operating plant. They also need data to validate the results of computer models against actual plant conditions.

3. PLANT ANALYSIS WORKBENCH (PAW)

Put very simply, the PAW is a tool for looking at and manipulating plant data. In summary, it works by taking a SEDE output file which is in ASCII text format and converting it into a binary database which the computer can read much faster. The PAW has a number of pre-arranged "maps-files" for the instrument signals which organize the data into logical system groupings.

For example, a certain map file may have a group called "Boilers", and within the Boiler group it will have a number of variables such as levels, pressures, temperatures, flows, etc. Within each variable the individual instrument signals are organized. By selecting the Boiler group, and then selecting the Boiler Pressure variable, the PAW will search the converted SEDE output file for those specific signal addresses, and then display the results on a pre-formatted graph with the appropriate scale, units and titles.

In the following few sections, we describe typical uses for the PAW.

3.1 Weekly PAW Report and Long-term Monitoring

The function of the weekly PAW report is to provide a regular review of the plant operation, with particular emphasis on the safety systems and safety related parameters. A second and equally important function of the report is to provide a weekly data summary for inclusion in the long term trend database.

A SEDE request is usually performed every Monday, with a start time of 00:00:00 on the previous Monday, an end time of 23:59:00 on the Sunday after, and the extraction is performed at a at 300 second sample frequency. Extraction time is typically 1/2 hour to 1 hour, and when complete the SEDE output file is opened in PAW and converted to database format.

The first step in the procedure is to review every parameter in the long-term safety map and try to visually detect any of the following:

1. anomalous or abnormal plant behavior;

2. significant changes in any safety system/safety related parameter (particularly in the unsafe direction);

3. signals which drift in such a way that remedial action may be required in the near future.

Unfortunately, the criteria for determining these conditions have not been formalized, so this process is very much dependent on judgment and experience. Another program of work underway at PLGS, the "Design, Operation, and Analysis (DOA) Program", will shortly feed the required information to PAW, in terms of various limiting values, or combinations of values, to help in making such judgements. However, for the Special Safety Systems this problem has been solved to a large extent by the development of the PEM program, which generates an alarm for any suspected safety system impairment.

If a perceived anomaly or safety concern can be readily explained and shown to be a normal part of plant operations and of no concern to safety, the item is considered dispositioned.

If an elementary explanation cannot be found for an anomaly or a safety concern, more information will be required. The item will be noted in the anomaly tracking list which is printed with a weekly PAW report, and it will be brought to the attention of the Operational Safety Supervisor who will give instructions on how to proceed. This may involve contacting system engineers or operations personnel, and it may involve performing calculations or numerical analysis to better understand the phenomenon. Depending on the judged significance of the item, a decision may be made not to pursue the issue.

As well as in the weekly review, the data for that week is used in the generation of a point on the long-term trend facility. The long-term trends are intended to reflect the normal full power operation of the plant, so other data, such as derating for fuelling, or flow verification, needs to be excluded. PAW incorporates a set of tools to do this.

In addition to the average behaviour of the signals for that week, PAW also saves a variety of statistics in the long-term trend: standard deviation, skewness, kurtosis. Review of these statisitcal measures over a long time-frame can help to identify deteriorating equipment.

Once this procedure is complete a report is prepared, identifying any anomalies, or interesting data features during the week.

3.2 Upsets, Transients and Abnormal Operating Conditions Data Gathering

During, and following plant upsets, transients and abnormal operating conditions, the availability of virtually unlimited amounts of plant data, and the capability of rapidly accessing it via PAW has proven very useful. It is not uncommon to present a full package of graphical material detailing, and giving a preliminary analysis of an over-night event to the daily planning meeting at 9:00 am.

There are thousands of instruments that input information to the digital control computers (Reference 2), and there are about 500 instruments which input to the safety system monitoring system (Reference 3). A series of data maps have been developed for PAW which arrange these instrument signals into a logical order, and a corresponding series of SEDE request files have been developed from the same source as the map files.

When an upset, transient or abnormal operation condition occurs, the monitoring and reporting requirement are usually made up "on the fly", since every event is different. The PAW operator is usually asked to perform a series of data extractions, and to keep updating them as new information becomes available. The pre-packaged sets of "requests" and "maps" have developed over time, as a result of the need to examine upsets etc., and so it is usually the case that one of the pre-packaged sets will meet most of the needs of the analyst interested in the anomaly.

Once the "dust has settled", a comprehensive set of data extractions will be made, describing the salient features of the anomaly, and a binder of graphs created to keep on hand for future reference.

3.3 Data Input for Safety Analysis

Often, safety analysts will need plant data for a variety of analysis applications. It may be needed as input for analysis, or perhaps to validate analysis. The scope of the work will be discussed between the safety analyst and the person assigned to retrieve the data.

In general, there will be a need to create data and associated statistics, and to document the resultant package.

3.4 Data Management and Archiving

The size and volume of data files that can be generated with SEDE and the PAW is staggering. SEDE output files can routinely take up 15 megabytes of space, and some operations on the PAW will produce another 100 megabytes of files.

Keeping an active archive of data available on the computer was not one of the original requirements of the PAW project, and, indeed, since all of the raw data is available in the formal plant archives, one might ask why any PAW data need be archived at all. However, keeping data from important events close at hand has proven to be extremely useful, and this data is regarded as a valuable resource. Getting data logger data restored to the servers by the computer group can be a long, drawn out process, and they are limited in the amount of time and disk space they can spend on data restorations. Having a good cross-section of normal operating data available in the long-term safety map archive, as well as data from many plant upsets and events means that people can get information quickly.

Fortunately, SEDE output data is very conducive to compression, and most compression utilities (PKZip, WinZip, etc...) can normally achieve up to a 5-to-1 compression ratio. With this kind of space saving, any data that is intended to be kept for long term use is usually compressed and archived shortly after it is extracted.

4. PLANT EXPERT MONITOR (PEM)

PEM is a system dedicated to the monitoring of the Special Safety System signals at PLGS. In this section we describe briefly how the expert system is designed, give some background to the PLGS impairments philosophy, then examine the use of PEM in daily impairments reporting, using recent plant data.

4.1 Expert System Design

In general, the diagnostic process of the expert system must address the following considerations:

- The problem domain of the expert system is very much customer-dependent.
- Detecting an anomalous signal needs knowledge about raw data, initial assumptions, a wide range of analysis modules and individual expert modules specialized in identifying a particular anomaly.
- Along with initial assumptions of physical processes, diagnostic assumptions are stored in a central place and used to reason their consequences.
- Success of detecting an anomaly often relies on results of identifying other anomalies.
- The reasoning process may vary from case to case.

The design architecture framework suitable for solving this problem is the so-called Blackboard framework.

<u>Blackboard Framework</u>

A blackboard framework consists of three elements, a blackboard, multiple knowledge sources, and a controller that coordinates among knowledge sources. A diagram showing the blackboard framework is given in Fig. 1.

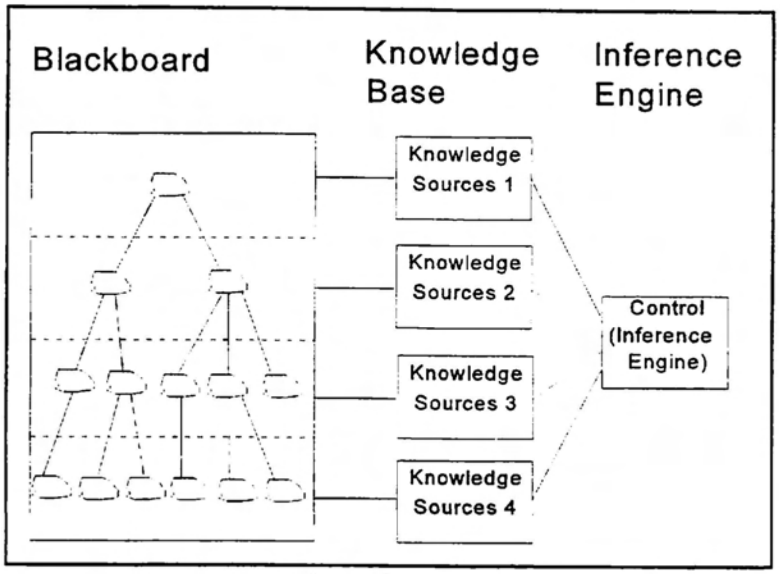

Figure 1

The blackboard object in Fig. 1 holds information for the solution space. During a diagnostic process, both intermediate messages and final solutions are displayed on the blackboard. Usually, the information shown on the blackboard should be organized in a hierarchical tree structure which parallels the different levels of abstraction inherent in the knowledge sources.

The knowledge source component of Fig. 1 is domain-specific. In general, knowledge sources are in parallel with the hierarchic structure of objects on the blackboard. Each knowledge source takes objects at one level as inputs and generates and/or modifies objects at another level as its output.

The Controller's task in Fig. 1 is to select and activate knowledge sources during the diagnostic process of the expert system. For example, at each stage of the diagnostic process, a particular knowledge source may find out that it can make a useful contribution to the problem, and therefore gives a hint to the controller. Given a set of hints generated by different knowledge sources, the controller selects the most promising one and gives the knowledge source the right to access the blackboard.

Using the blackboard architecture, the diagnostic process for detecting anomalous signals takes the form of an interactive process among PEM I/O modules, analysis modules and various expert diagnosis modules. An initial request for checking anomalous signals can be posted on the blackboard by initiating the expert system. In response to the request, all analysis modules and expert modules will actively participate in the diagnostic process by contributing their own knowledge on the blackboard when an individual module finds out that there is something the module can contribute to.

Classes designed for the expert system can be classified into four groups: foundation classes, knowledge sources, blackboard classes and controller. In total, there are 27 classes developed for the working version of the expert system. An example of a small set of classes is given in Fig. 2.

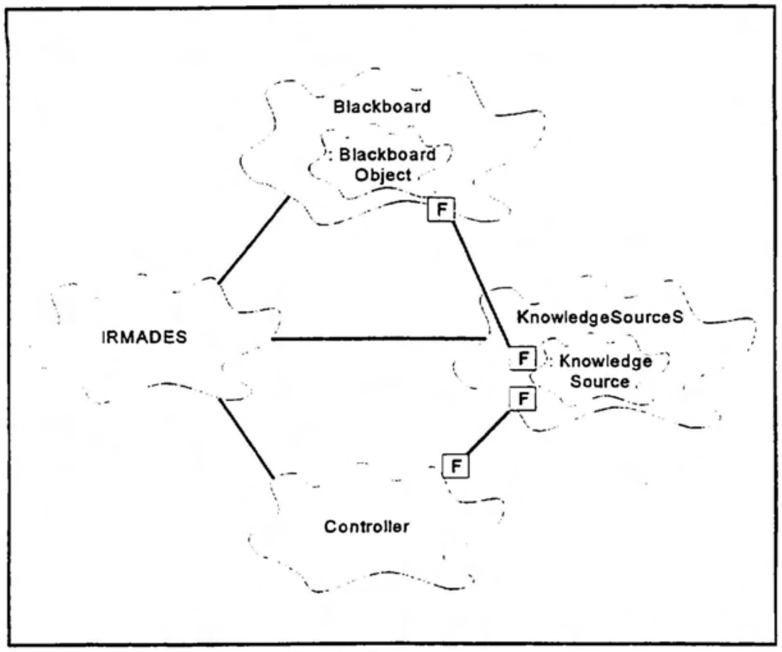

Figure 2

Fig.2 shows an object diagram of the PEM expert system. *IRMADES* object is associated with *Blackboard*, *KnowledgeSourceS* and *Controller* objects. The *BlackboardObject* is nested in object *Blackboard* and is associated with *KnowledgeSource* object by field, which is nested in object *KnowledgeSourceS*. Similar relation exists for objects *Controller* and *KnowledgeSource*.

4.2 Background to PLGS Impairments

Impairments of the special safety systems are classified according to their severity by assigning three levels of impairment. The levels differ in the time available to return the system to service, after which the reactor must be shutdown.

The three levels of impairments are described as follows:

- Level 1 - One of the special safety system is not poised and an orderly shutdown is required if repairs cannot be completed within a short period, usually 30 minutes if reactor is at full power. An example of a Level 1 Impairment would be when only 25 of the 28 SDS# 1 shutoff Rods were poised.
- Level 2 - The special safety system is poised but its predicted availability would be less than the availability target for normal operation. An orderly shutdown is required within 4 hours, if the repairs cannot be completed within eight hours of the discovery of the impairment. An example of a Level 2 impairment would be SDS#1 having only 26 of 28 shutoff rods poised. (26 is the number of rods required under the most conservative of estimates for a design basis accident)

- Level 3 - The special safety system is poised but there is a reduction in either the component redundancy or safety margin. In this case, the availability would be within safety targets for design basis analysis. An example would be 27 of the shutoff rods poised (enough to shut the reactor down, but the system is not at full capacity). An immediate reactor shutdown is not required for a Level 3. Nevertheless, repairs should be undertaken as soon as practicable, and the system returned to the safe state.

The function of the PEM is to compare the various rules and limits associated with these types of impairment to the SEDE output data and generate a list of possible violations of the impairment rules. The PEM uses the same SEDE output data conversion format as the PAW, and once the PEM is finished processing the SEDE data, the PAW can then use the same converted data file to review and investigate any alarms that were highlighted by the PEM.

4.3 Daily Impairments Reporting

The function of the daily PEM report is to provide a list of the possible safety system impairments, and a formal review of this list that will either disposition the non-concerns or bring attention to any real (or presumed real) impairments.

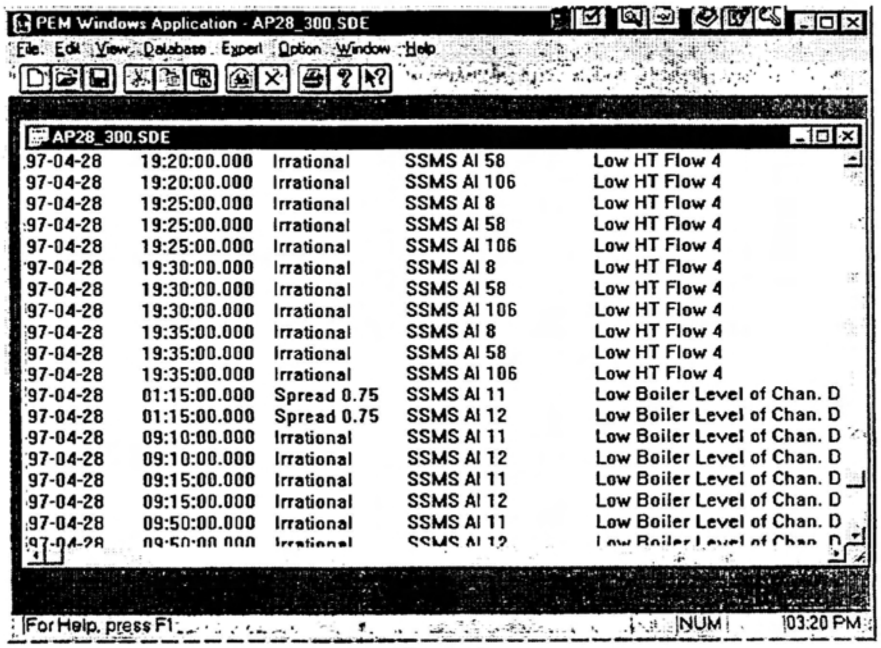

Figure 3

The SEDE request is usually performed every morning for the previous day, but after holidays and weekends a number of extractions may need to be performed. The data is extracted from 00:00:00 to 23:59:00 for the day in question, and the extraction is performed at a 300 second sample frequency. When the *expert monitor* function is invoked the computer will perform it's calculations and comparisons, and from this, generate an alarm list which can then be printed and reviewed. The printout will state the time of the alarm, the type of violation and what AI's were involved. A typical "violation list" is shown in Figure 3. It shows the date and time of the "violation", nature of violation (in the example shown, spread exceeded, or irrational value), the signal involved in the violation, and a description of the system element that is involved in the violation.

The first thing we learned in reviewing these "violations" is that there are many of them. However, the vast majority last only for a short period of time. Consider, for example, a potential violation, the "Low Boiler Level of Chan.D", with a "Spread 0.75" violation. Once identified, the PEM operator would review the data that produced this problem on PAW, with the result shown in Figure4.

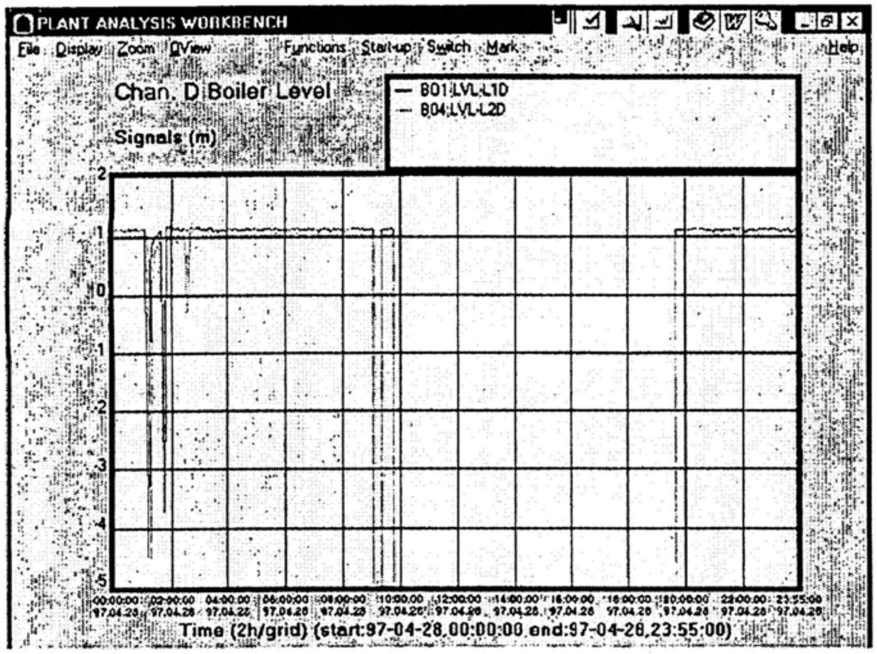

Figure 4

Clearly something was happening to the Channel D Boiler Level signals at about 01:00. In order to examine this in more detail, a new data request is made over this time period, at a sample frequency of 1 data point every 6 seconds. The results of this are shown in Figure 5, below.

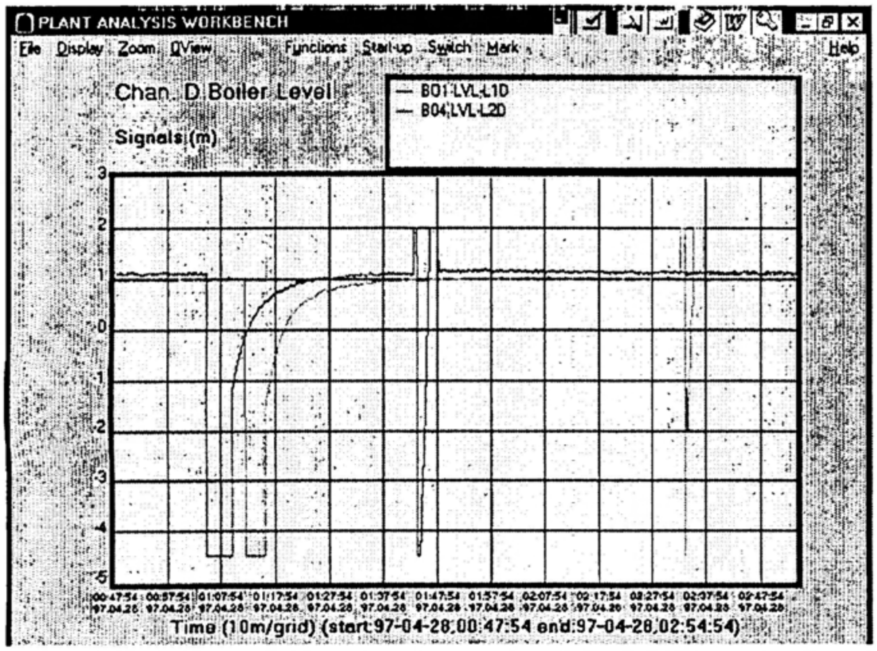

Figure 5

This "blow-up" shows that there were perturbations on each of the two

Channel D Safety System Indications of Boiler Level. A frequent user of PEM would probably guess that there was some routine maintenance going on. TO confirm this, the user would link to the electronic text of the Control Room Operators log at the appropriate time, the relevant extract of which is shown below, in Figure 6.

Point Lepreau GS - Control Room Operator's Log
APPROVED

Date: 97/04/28 *Crew: A Shift: 1*
Supervisor: ***Steve Brown***

Entry Event

04 ***SDS1 BLR LOW LEVEL TRIP*** ***68238***

20:33 - 0.0. issued to perform SOS 68200-1 during blowdowns of LTID and LT2D.

COMPLETED, NO ABNORMALITIES NOTED

22:20 - W.P. to blowdown HP Impulse lines for LTID and LT2D.

COMPLETED PRE & POST MTCE. TESTING SUCCESSFULLY COMPLETED.

0003 ***MODERATOR PURIFICATION*** ***32200***

-IX05 O/S AZL 46 %.

0225 ***SG LUBRICATION OIL INSTR*** ***65282***

-W.P. issued to perform calibration of PI26, PI30 and PI28 repair.

0225 ***SG STARTING AIR INSTR*** ***65225***

-W.P. issued to perform periodic calibration of PI86.
COMPLETED, RTS NO LEAKS.

Figure 6

Examination of the log shows that an Operating Order and a Work Permit were issued with regard to SDS1 Boiler Low Level Trip. The primary activity was blowing down the High Pressure impulse lines. The traces on Figure 5 show, first for Boiler 1 the blowdown process, lasting about 4 minutes, followed by a blowdown for Boiler 4. Then the Boiler 1 channel was tested, at about 01:40, followed by Boiler 4, at about 02:30.

The process of blowing down the impulse lines caused the signals to exceed their spread, and produce an indicated violation in PEM. As a general rule, a violation is not followed up unless it persists for a minimum of 10 minutes, or two 300 sec. time-steps. In most cases the violations have a valid explanation. When they don't, the Operational Safety group are informed. They then make a decision on the appropriate follow-up actions.

Once all the items on the alarm list have been dealt with (i.e. dispositioned or brought to the attention of operational safety), a standard report is prepared. This report does not restrict iitself to 10-minute impairments, but notes, for example, signals which had been well behaved, but have begun to misbehave on a regular basis for short periods of time.

4.4 Further Developments

In its current formulation, the expert system is analogous to a simple rule-based reasoning tool. However, the blackboard structure gives PEM the capability of performing more complex decision making. In future we plan to use the knowledge gained by the PEM operators, in terms of routine events that cause violations, to further develop the expert system.

For example, in the above case, a spread alarm was caused by an impulse line blowdown. The PEM operator characterizes this by noting the sequence of traces: first Boiler #1 blowdown, then, its partner on Safety System Channel D, Boiler #4, followed by the "blips" representing system testing following maintenance. This is confirmed by the Control Room Operators Log. The knowledge associated with this reasoning process can be saved, and used in PEM to identify the "violations" for what they are. Clearly, this type of system would need considerable commissioning time before being left to filter-out events.

However, experience to date suggests that such a system could be made to operate reliably. Once this level of sophistication was achieved, the nmany more signals could be included, process as well as safety.

5. CONCLUSION

Two tools have been developed at PLGS to assist the Operational Safety Group in plant monitoring. One of these, PAW, has been used for about 4 years to help in monitoring short and long term trends in plant data, to support station staff during upsets and off-nominal operation, and to provide input to safety analysis.

The other, PEM, incorporates expert system features, and has been used for approximately one year to assess Safety System data against the limits expressed in the station Impairments Manual.

Both tools have proved useful in both detecting problems, and also in learning more about plant operation and characteristics. It is expected that they will merge into one tool, with the expert system capabilities of the resultant application being enhanced over what is currently available in PEM.