

# CANDU MAINTENANCE CONFERENCE 1987

## LESSONS LEARNED IN PROVIDING LONG-TERM FIELD SUPPORT FOR SPECIAL PURPOSE INSTRUMENTATION:

### THE BARRINGER D<sub>2</sub>O ANALYZER EXPERIENCE

R. T. FAUGHT and C. CUMMING

Atomic Energy of Canada Limited (AECL) and Barringer Research Limited (BRL)

#### ABSTRACT

The CANDU nuclear reactor requires several special purpose instrumentation systems that are unique to CANDU and not widely applicable to any other industry. Many of these systems were developed in AECL laboratories or under contract in private industry, at a time when the projected expansion of the nuclear industry would provide a large enough market to financially justify transfer of the technology to private industry for manufacture and long-term support. Although the manufacturing capability was easily transferred, the capability to provide long-term support was less so. With the downsizing of CANDU business in the seventies, industry found it uneconomical to establish or maintain a long-term support capability, and over the following years, staff turnover resulted in the initial resource and knowledge investment being lost. At the same time, utility operators were faced with maintaining these systems for an operational life of thirty years.

An example of one such system is the Barringer D<sub>2</sub>O Analyzer. This paper will review the experience in supporting these instruments in field operation and discuss the lessons learned from the developer, manufacturer and operator perspectives. A strategy to protect industry investment in future cases will be outlined.

#### INTRODUCTION

The development of specialized instrumentation for application within the nuclear industry is very expensive. The initial labour and capital costs of research, development and manufacturing can only be justified if the potential market is very large, or if the equipment function is essential to protect plant safety or investment. Thus, many of the specialized applications for instrumentation within the CANDU program were not feasible as self-supporting industrial development projects. Consequently, these instruments were either designed and developed directly by AECL in their own facilities, or were supported in private industry by development contracts.

In the mid 60's, on-line monitoring of heavy water was recognized as a requirement to protect the multi-million dollar capital investment in heavy water in CANDU reactors. A CANDU reactor requires approximately one megagram of heavy water per megawatt of electricity generated. The present cost of heavy water is approximately \$300/kg; thus the heavy water inventory represents about 15% of the plant initial cost.

At the outset, two general reasons for on-line heavy water monitoring were identified:

#### -Leak detection For Inventory Protection:

Process systems have the potential for leaking heavy water to secondary fluid streams as a result of component failure. On-line instrumentation can provide timely detection of leak occurrence.

#### -Optimization of Process Performance:

Heavy water in reactor systems must be kept above a certain level of purity to maintain high fuel burnup. This purity is maintained using on-line upgrading facilities that remove any natural water that dilutes heavy water purity. Continuous monitoring instruments are recommended for efficient operation of upgrading facilities.

A summary of the system specific applications for heavy water monitoring in CANDU reactors is summarized in Table 1 (1). On-Line Analysis is feasible in six of the ten applications.

#### DEVELOPMENT BACKGROUND

At the onset of the development program, a review of the measurement techniques applicable to on-line heavy water monitoring was performed. Infrared spectroscopy was identified as the technique having the greatest potential for realization as an on-line instrument. This technique is based on the relative measurement of specific infrared absorption peaks that are a fundamental characteristic of the heavy water molecule. The infrared spectroscopy technique was selected over other options because:

- it was sufficiently precise,
- it was relatively immune to interference from chemical and particulate contamination, and
- successful operational experience with laboratory-based instruments had been achieved at Chalk River Nuclear Laboratories (CRNL) (2).

The initial instrument development by Atomic Energy of Canada Limited spanned the period from 1965 to 1974 (3). The instrument technology was transferred to Barringer Research Limited for manufacture, and by 1975, twenty-seven instruments had been manufactured for the nuclear industry. The final product was called the Barringer Series 400 Rotating Filter Heavy Water Analyzer. A picture of a typical leak monitor, installed, is shown in Figure 1.

The recommended complement of on-line heavy water monitors for a CANDU reactor is two monitors for leak detection per reactor and two monitors for

## CANDU MAINTENANCE CONFERENCE 1987

control of upgrader performance. The installation details for these instruments were left primarily to the system designers, with local installation being the responsibility of the customer's construction and operations personnel. Following initial system commissioning, operational staff encountered problems with these instruments; the measurement performance and instrument reliability were much poorer than expected. Many system upsets were noted and unidentified failures, compounded by maintainers' lack of training and fundamental understanding of instrument principles, resulted in a very negative reputation for these instruments, that continues in some areas to this day.

Manuals were rewritten from a development to a user focus. CRNL and BRL identified personnel to be available over the long term for consultation to assist utility operations personnel. As a result of these efforts, all stations that have chosen to use on-line heavy water monitors have been able to maintain the instruments in working order over the past ten-year period. The current operating locations and status of these instruments is summarized in Table 2.

TABLE 1: SYSTEM SPECIFIC APPLICATIONS FOR ON-LINE HEAVY WATER MONITORING

System Specific Application	Range (weight % D <sub>2</sub> O)	Accuracy (weight % D <sub>2</sub> O)	Frequency (per week)	Feasible for On-Line Monitoring	Present Monitoring Technique
Heat Transport	> 97.5	0.01	3-7	yes	Laboratory Infrared Spectroscopy
Moderator	> 99.5	0.01	3-7	yes	Laboratory Infrared Spectroscopy
D <sub>2</sub> O Supply	> 99.7	0.01	as required	no	Laboratory Infrared Spectroscopy
Upgrader Product	> 99.7	0.01	21	yes	On-Line Infrared Spectroscopy
D <sub>2</sub> O Recovery	1-95	0.5	24-100	no	Laboratory Refractometer
Service H <sub>2</sub> O	0.014	0.001	1-21 (1)	yes/no	On-Line Infrared Spectroscopy
Mainstream System	0.014	0.001	21	yes	On-Line Infrared Spectroscopy
Upgrader Tails	< 1	0.01	21	yes	On-Line Infrared Spectroscopy
Active Sumps	< 1	0.01	21	no	Laboratory Infrared Spectroscopy
Stack	< 1	0.001	7	yes	Laboratory Tritium Analysis

As a result of poor field performance, AECL undertook a review of the instrument status. A Working Party was created in 1975 to review operating experience and to resolve the identified difficulties that the users were encountering. The Working Party initiated an overall design review of the instrument as a cooperative effort between BRL, Chalk River Nuclear Laboratories (CRNL) and Ontario Hydro. The Working Party concluded that the instruments were still justified, and that the operational problems could be overcome via design changes and improved documentation.

A team, assembled at CRNL, obtained instruments from Ontario Hydro's Bruce Generating station "A" and modified them to correct the problems that had been identified. These instruments were installed and commissioned at Bruce by personnel from CRNL, and their performance monitored closely for one year. Hands-on training courses were offered to maintenance groups from the different CANDU stations to ensure trained field support personnel.

From this design review and subsequent testing, commissioning and training efforts, a number of lessons were learned.

### Lesson 1: Field Testing

Before an instrument is passed from designers, and placed in a manufacturing and production environment, field testing of the design in its final configuration should be performed. The results of field testing should be reviewed by instrument designers, manufacturers and potential users to identify any shortcomings prior to commercial manufacture. Users provide a more critical, unbiased review of instrument performance since they recognise the problems that they will face with the instrument once it becomes their responsibility.

If field testing of the Series 400 Analyzer had been performed, one cause of operational

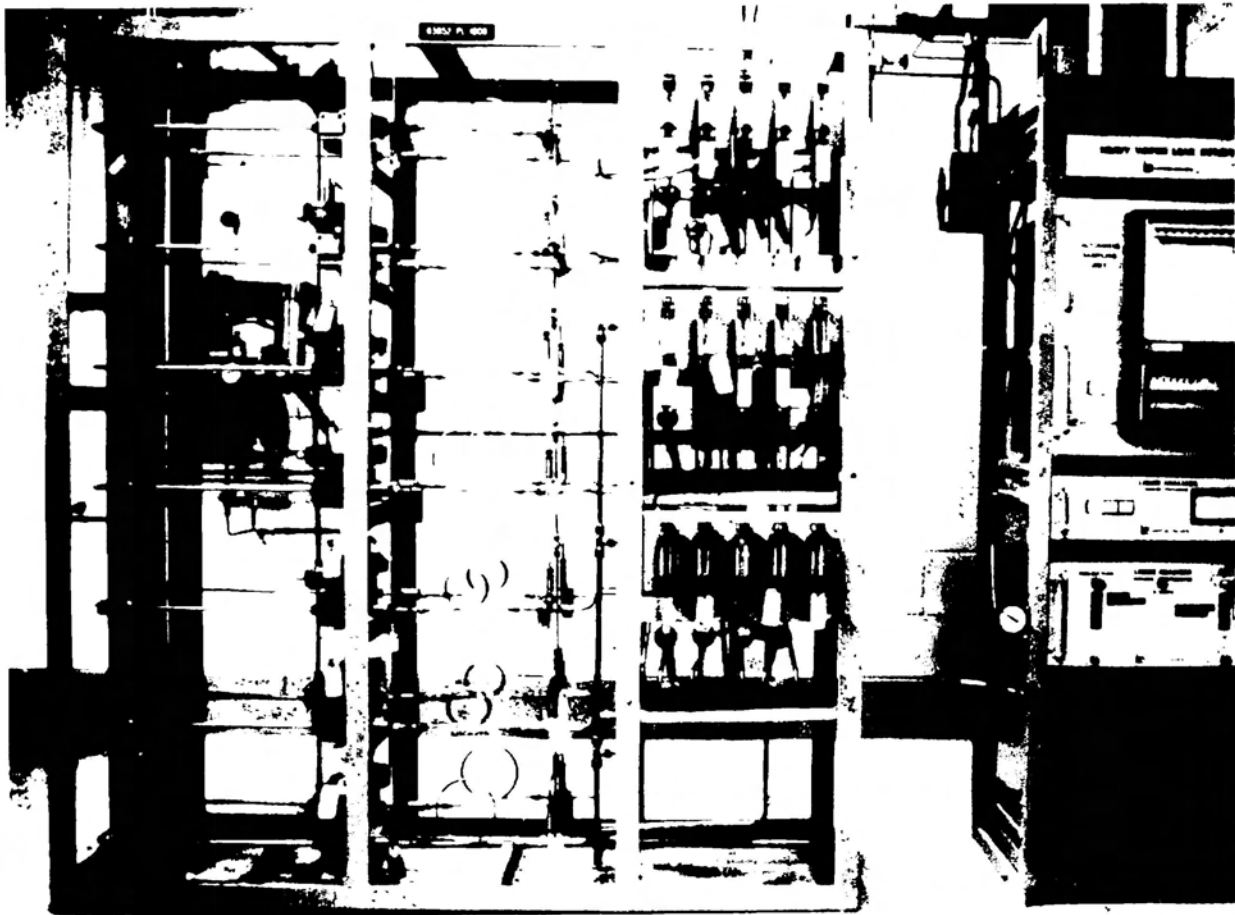


FIGURE 1: HEAVY WATER LEAK MONITOR INSTALLATION AT BRUCE NGS "A"

difficulties could have been avoided. A major cause of instrument failures in the original Series 400 analyzer was the sample cell orientation. The original CRNL designers recognized the likelihood of air being included in the liquid sample being sent to the instrument from the sample delivery system. If a bubble passes through the optical path in the infrared spectrometer, an incorrect concentration result is displayed by the instrument. To divert entrained bubbles from the optical path, a second sample path had been included in the original design. This was an operational aid which improved the measurement reliability, but did not enter into the actual optical design.

Following transfer of the design to BRL, the alternative sample path was not included in the manufactured design. Once the instruments were commissioned at site, unreliable performance resulted. This problem was identified during the design review and previously manufactured instruments were modified to include a sample bypass stream.

If field testing had been performed on the instrument in its final configuration, measurement unreliability would have led the design and manufacturing team to recognize this oversight since it was a part of their original concept. The

feedback path from field testing to the designers is an important development input.

#### Lesson 2: Field Support

No matter how well an instrument is designed, problems will occur with complex analytical instrumentation, and users must have a ready source of information and assistance if successful operation is to be achieved. The on-line heavy water instruments were not an overly complicated design, but the complexities of the sample delivery system and instrument responses to seemingly trivial upsets failed to create user confidence. Many of the operational problems with the instruments resulted from lack of understanding of their responses. Experience showed that performance was most successful when operational staff:

- had a knowledgeable contact person to address their questions and concerns
- received instruction on the maintenance and operation of the equipment, and
- performed a regular maintenance schedule which kept the instruments serviced and maintainers familiar with the monitors.

## CANDU MAINTENANCE CONFERENCE 1987

TABLE 2: THE CURRENT STATUS OF BARRINGER SERIES 400 ANALYZERS

Customer	Location	Application	Number of Monitors	Installation Date	Current Status
Ontario Hydro	Bruce Heavy Water Plant "A"	Product Isotopic	1	1972	Plant Shut Down
AECL	CRNL	NRU Isotopic	1	1976	Operating
AECL	CRNL	NRU Upgrader	1	1985	Operating
AECL	WNRE*, Pinawa	WRI Isotopic	1	1975	Plant Shut Down
AECL	Douglas Point	HTS Isotopic	1	1974	Plant Shut Down
AECL	Douglas Point	Stack Loss Monitor	1	1982	Plant Shut Down
AECL	Glace Bay Heavy Water Plant	Product Isotopic	1	1974	Plant Shut Down
CNEA**	Cordoba	Leak Monitors	2	1983	Operating
CNEA	Cordoba	Upgrader Monitors	2	1983	Operating
Hydro Quebec	Gentilly-2	Leak Monitors	2	1983	Operating
KECO***	Wolsung	Leak Monitors	2	1983	Operating
KECO	Wolsung	Upgrader Monitors	2	1983	Operating
Ontario Hydro	Pickering Nuclear Generating Station "A"	Leak Monitors	7	1972-74	Out of Service
Ontario Hydro	Pickering Nuclear Generating Station "A"	Upgrader Monitor	1	1972	Out of Service
Ontario Hydro	Bruce Nuclear Generating Station "A"	Leak Monitors Units	8	1976-79	Operating
Ontario Hydro	Bruce Nuclear Generating Station "A"	Upgrader Analyzers	4	1978	Operating
Ontario Hydro	Pickering Nuclear Generating Station "B"	Leak Monitors	8	1980-82	Operating
Ontario Hydro	Pickering Nuclear Generating Station "B"	Upgrader Analyzers	2	1982	Operating
Ontario Hydro	Bruce Nuclear Generating Station "B"	Leak Monitors	8	1985-87	Operating

\* WNRE = Whiteshell Nuclear Research Establishment

\*\* CNEA = Comision Nacional de Energia Atomica, Argentina

\*\*\* KECO = Korean Electric Company

This feedback from users to a development team contact person was often useful in identifying shortcomings in the instrument design and documentation, or misconceptions regarding instrument characteristics.

The availability of field support was valuable in instilling confidence in operations personnel that the instruments would operate successfully. As long as a resource person was available to assist and advise, operations personnel were not reluctant to tackle almost any problem. Each installation had its own installation idiosyncrocies. Some stations had water quality problems that affected the cooling water reliability. Line voltage stability and sample quality were a source of problems in other locations. Each situation required a user-developer dialogue to optimize performance, and development assistance could only be supplied by an experienced field support person who had adequate knowledge of all aspects of the design.

### Lesson 3: Training

Adequate training of maintenance personnel is an essential component in obtaining satisfactory field performance of any instrument at site. For the on-line heavy water monitor, the original development team had placed very little effort on user training and site support. The instruments were placed into operation following the manufacturer's instructions and the operating and

service manuals remained the only support that the users initially had. In most cases, the instrument warranty had expired long before the instruments were ready to be placed into service.

The design review produced a group of experts knowledgeable in the performance characteristics of the instrument. This group shared their experience with the operators and maintenance staff via specific training courses geared to operating and maintenance issues. These courses were attended by personnel from Hydro Quebec, G-2; New Brunswick Electric Power Commission, Pt. Lepreau; Ontario Hydro, Bruce NGS "A"; AECL; CRNL; CANDU Operations; Glace Bay Heavy Water Plant and BRL.

Subsequent field support contacts indicated that stations with trained maintainers had fewer problems in obtaining reliable operation from these instruments.

### Lesson 4: Installation Justification

For very complex and expensive instrumentation, the justification for deployment must be very clearly identified. Instrument locations should be individually justified based on the value of the analysis as compared to a reasonable alternative. The cost of operating this equipment should include an estimate of maintenance effort.

## CANDU MAINTENANCE CONFERENCE 1987

The applications that were originally envisioned for the on-line heavy water monitors were summarized in Table 1. In some cases the requirements as envisioned by the instrument developers were different from the practical requirements that the operations personnel identified after a few years of experience. There was a trade-off between the value of on-line analysis results and the cost of the maintenance effort required to keep the instruments in adequate operating condition. In some cases this assessment resulted in the conclusion that off-line laboratory analysis was sufficiently prompt and accurate to satisfy station requirements at lower operational cost. Two examples of the conflict between the justification identified by the developers and that of the operational staff follow.

First, one of the justifications for on-line heavy water monitors had been the inability of station laboratory analysis to provide the promptness and measurement accuracy that is required. The Barringer Series 400 Analyzers provided an on-line accuracy that was at least a factor of ten better than the comparable laboratory measurement techniques. However, in practice, the on-line instruments were perceived to be unreliable and inaccurate, so this original justification was viewed as no longer valid by some operational staff.

Second, the CANDU reactor system is relatively new in terms of operating experience. The Barringer Analyzer itself has been justified as a diagnostic tool serving the larger reactor process systems. As the number of operating years of experience on these reactor systems increases, better statistical information is compiled to identify the reliability of components such as heat exchangers and seals whose failure is the target of the heavy water leak monitor location abilities. The probability of leakage often decreases with initial operating experience, as the causes of recurring leaks are identified and design changes are incorporated to avoid the situation in the future. There is a continual evolution of component quality which results in an increase in reliability for the overall design provided standardized design components are used. Operator experience also enhances reliability as operators become more aware of system weaknesses. In the long term, increases in leakage are likely to occur as components approach the end of their service life. Thus, while on-line monitoring may be justified during early operation and near the end of station life, it may not be justified during a period of mature operation if performance indicates the chance of leakage is remote. Individual station experience and perceptions will determine the requirement for on-line heavy water monitoring throughout the various phases of station life.

### THE REMAINING PROBLEMS

A few years after the training courses were completed, it was apparent that the personnel who had taken the courses were no longer responsible for maintenance of the monitors, and problems were reported in some locations that resulted from lack of training or information regarding the system design, operation, or performance. A continuing effort is required to assist station operational staff in optimizing the instrument performance and

maintenance over the long term. If this effort is not expended, users can become disenchanted with the instrumentation and it falls into a state of disuse and disrepair.

A second difficulty became obvious as the development team was disbanded and relocated to other projects. The expertise that had been assembled to deal with the initial operational problems rapidly became inaccessible because new projects that the experts were assigned to, would not tolerate the upsets and interference that were generated in providing site support. If a clear responsibility for site support is not defined, then no one assumes it. As time goes on, the expertise is lost as the designers retire or move on to other jobs and locations. The key to adequate site support is the availability of a dialogue between a development support person and the user. The monologue provided as user documentation alone will not serve this purpose.

### APPROACHES FOR THE FUTURE

To deal with these problems, CRNL is exploring the applicability of a new approach to these general CANDU support problems. The intent of this approach is to preserve the dialogue capability between the developer and the user that successful field support depends on, without the investment required by full-time assignment of personnel for long term instrument support.

The approach takes advantage of low-cost personal computers and application tools based on Knowledge-Based Systems (Expert Systems). Expert Systems programs can record the knowledge and expertise of the original design team and instrument maintainers in a manner that is readily accessible. The instrument knowledge base embedded in an Expert System may be accessed as an interactive dialogue for training or trouble-shooting purposes.

This application software, as an extension of design documentation, offers many advantages. First, Expert Systems provide an audit trail of the reasoning processes used to find a response to a user request. This ability to explain how an answer is reached provides a valuable training role for operational staff in that it uncovers the reasoning behind a given solution. This explanatory feature is also an inexpensive method of allowing support personnel to accurately refresh their knowledge when they have been away from the support role for some time. Second, if the knowledge base is accumulated by the development team, it will very likely include the original concepts of the instrument design, and assist in covering questions that may otherwise be overlooked. Third, in answering the questions that the creation of this knowledge base presents, the developers are temporarily placed in the position of a potential user. Thus they gain insight by viewing their development from a user focus, leading to a better overall product.

To test the suitability of this approach to field maintenance, the Instrumentation and Control Branch staff at CRNL are developing an Expert System application to assist operational staff in the operation and repair of the Series 400 Barringer Analyzers. Information for the knowledge base has

## CANDU MAINTENANCE CONFERENCE 1987

been assembled from the original development team, user experience and instrument documentation. This application runs on an IBM PC and is implemented with a low-cost commercially available Expert System shell. The product will be offered for field evaluation by the end of 1987.

### SUMMARY

The lessons that were learned in the development of the Barringer Heavy Water Analyzers were costly. Future development projects will benefit from this experience. New technology now offers assistance in reducing the impact of these lessons as computer-aided information storage and retrieval systems are used by design teams to back-up their expertise and transfer it to their customers in a readily useable form.

### REFERENCES

- (1) LYNCH, G.F. and FAUGHT, R.T., "The Suitability of Density and Refractive Index Instruments to the On-line Measurement of Heavy Water Concentrations, AECL Report 8103.
- (2) BAYLY, J.G., KARTHA, V.B. and STEVENS, W.H., "The Absorption Spectra of Liquid Phase H<sub>2</sub>O from 0.7 um to 10 um", Infrared Physics, vol. 3, pp 211-223, Pergamon Press Ltd., Great Britain, 1963.
- (3) ALLEN, V.H. and BAYLY, J.G., "On-Line Heavy Water Monitors Based On The Absorption of Infrared Energy", IEEE Transactions on Nuclear Science, Vol.NS-23, No.1, February 1976.