Hydro-Québec METAR Inspection Bracelet

Eric Lavoie[1], Gilles Rousseau[2] , Jean Lessard[1], Alain Drolet[2],

1- Institut de recherche d'Hydro-Québec
1740, boul. Lionel-Boulet, Varennes (Québec) Canada J3X 1S1
lavoie.eric@ireq.ca, lessard.jean@ireq.ca

2- Hydro-Québec, Centrale nucléaire Gentilly-2
4900, boul. Bécancour, Gentilly (Québec) Canada G0X 1G0
rousseau.gilles.a@hydro.qc.ca, drolet.alain@hydro.qc.ca

ABSTRACT

This paper will present the Gentilly-2 Inspection program targeting outlet feeder pipe thinning caused by FAC. The focus of the paper will be on the METAR inspection bracelet development and qualification process, as well as highlights of the 2000 outage inspection campaign.

In summary, the '99 inspection campaign allowed personnel to measure wall thickness of 66 outlet feeders totaling 106 elbows. Since the beginning of the inspection program in '97, about 80% of 2-inch outlets and 40% of 2.5-inch outlets have been measured at least once. Collecting high quality data is a challenge, mainly due to lack of space around the pipes -- especially for 2.5-inch pipes -- and the roughness of feeder pipes at Gentilly-2.

Hydro-Québec developed the MÉTAR Inspection bracelet to improve the quality of inspection data and increase efficiency. The MÉTAR bracelet is a mechanical device that can be attached directly onto the feeder to measure thickness in situ. It consists of 14 ultrasonic sensors, each mounted in its own shoe, attached together in an assembly called a collar. The collar permits each sensor some degree of movement while keeping the proper orientation, perpendicular to the feeder. The collar is held onto the feeder by the frame and kept in position by means of an elastic band. The frame is designed to ease movement and minimize friction. There is a different frame for each feeder size, but the same collar is used. In most cases, inspection can be carried out with only one hand and requires little adjustment by the operator. To date, the bracelet is not motorized and must be moved along the pipes manually.

A multi-channel acquisition unit was built for this project based on the R/D Tech μ Tomoscan ultrasonic system and Tomoview data analysis software. The system features real-time C-scan from all 14 channels and provides a thickness map of the scanned area for rapid evaluation of minimum wall thickness. The RF waveform is recorded and the sizing technique is based on the zero-crossing method for accurate off-line wall thickness measurement. Accuracy of wall thickness measurement is better than 0.001" for the 2.5 to 4.5 mm thickness range.

Finally, a summary of the results and highlights of the 2000 outage inspection campaign will be presented.

Introduction

This paper presents the METAR, a feeder pipe inspection bracelet developed at the Hydro-Québec research center (IREQ) in conjunction with the Gentilly-2 (G-2) power station. Because of a degradation mechanism called Flow Assisted Corrosion (FAC), excessive thinning occurs on the inside of the feeder pipes, especially on the outlet elbows close to the exit of the pressure tube (COG-JP-97-003).

Another inspection system, developed by Ontario Hydro's SIMD department, was used in Gentilly from 1997 to 1999. This provided information on the status of the feeder's first bends, more specifically the 2-inch ones. Because of the limited space around the feeders, data quality for the 2.5-inch feeders was poorer and fewer conclusions concerning thinning could be drawn. Furthermore, because of the lack of space and the intrinsic difficulties of using the SIMD bracelet, very little data was gathered on the second elbows of both the 2 and 2.5-inch feeders. However, analyses performed on PLGS and G-2 "spare elbows" show that the second elbow of a compound bend feeder is a critical area and will probably reach minimum acceptable thickness before the first bend on some feeders. (G2-RT-99-22)

IREQ began developing its own version of the bracelet (the MÉTAR) late in 1998 after a contract to develop a system to measure thickness was given to RD/Tech by G-2. Initial tests on the reactor were performed in April 1999 and an official inspection campaign took place in April 2000. IREQ's main objective in conceiving the bracelet was to design a system that would be very easy to use, reducing the strain on the operator, and also facilitating data collection on the second elbow, and this for all feeders of 2 or 2.5 inches. Space constraints, data quality, as well as robustness were also taken in consideration.

This article will mainly feature the sensor unit of the system, the bracelet, since it represents the primary innovation with regard to other systems. The data acquisition system will also be discussed, but as it does not form part of the developments made at IREQ for the feeder inspection system, emphasis will be on the mechanical aspects of the bracelet itself.

Extent of the feeder thinning problem on CANDU-6

Concerns about the feeders were prompted by the discovery of considerable amounts of magnetite precipitated in the cold leg of steam generators. Some corrosion was expected in the design of the Primary Heat Transport System (PHTS) but the amount of material removed from the steam generators surpassed predictions and excessive feeder thinning became a concern.

Considerable feeder thinning was observed for the first time at the Pointe-Lepreau reactor in 1995. Excessive wall loss was found in the outlet feeder bends closest to the end fittings. This prompted generating stations to implement an inspection program to assess the extent of the problem.

Feeder thinning measurement began at Gentilly-2 using a thickness gauge and the SIMD scanner. Results indicated that some 2-inch feeders would reach their minimum allowable thickness before the end of the life design. A precise date for repair was difficult to establish mainly due to uncertainty about the wall thickness of the original bends and the ultrasound measurement errors of +-0.007" obtained with the SIMD hand-scanner.

Predicting the remaining life of a feeder is hampered by the fact that the nominal installed wall thickness of elbows is unknown. Measurement was undertaken at Gentilly-2 using G-2 and Pointe-Lepreau replacement feeder elbows to measure the initial wall thickness (internal report G2-RTI-97-38). This study showed that the original wall thickness of the first and second 70-degree bends was thinner than expected and that the second elbow was even thinner than the first in some cases. Assuming an identical erosion rate for all bends (2" and 2.5" tubes), 2-inch feeders at positions 1, 4 and 5 (on a CANDU-6) were suspected to be the most critical elbows because their wall thickness margin was estimated to be the smallest.

The need to inspect the second bends of 2-inch feeders in positions 4 and 5 with a high degree of accuracy became obvious and was the starting point for the development of an inspection method that addresses this problem.

Technology

Ultrasound measurement

Measuring wall thickness can be done quite easily using ultrasound technology. Briefly, a transducer is used to send a high frequency wave into the test object and to listen to backwall reflections that occur as the wave bounces back and forth in the material. Measuring the travel time between two successive backwall echoes and converting this into metal path provides an estimate of the wall thickness. For reliable measurement, it is essential to know the material velocity, to ensure that the area under examination has two parallel surfaces and to keep the transducer perfectly perpendicular to the entry surface.

METAR Bracelet

If the general principle of ultra-sound is simple, getting the actual echoes with a good signal-to-noise ratio can be trickier. First, the transducer needs to be placed at a constant distance from the surface to be inspected and it must absolutely square to this surface. Also, to have an adequate reading, a couplant-filled space free of air bubbles or impurities, called the water column, must be kept between the surface and the sensor at all times. The height of the water column is a function of the thickness to be measured. Finally, all of this must be kept small enough to fit in the area to be inspected.

The transducer used in the METAR bracelet is the smallest readily available on the market, 0.16 inch in diameter and 0.25 inch long. Sensors are 10MHz focalized with high damping. There are 14 sensors per bracelet that cover an area from 140° to 170° depending on the size of the feeder.

Sensor holders and water column

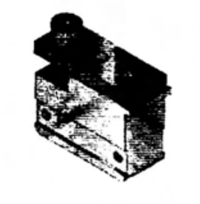

Figure 2 Probe holder

As mentioned above, the main difficulty in UT inspection is holding the transducers perpendicular to the surface to be inspected. The holders used for the feeder inspection with METAR are the key element of the development. Each holder is designed to perform many tasks, mostly to hold the sensor perpendicular to the surface and to maintain the water column while eliminating the air bubbles. A cover on the holder helps maintain the sensor in position.

Collar

Figure 3 Collar

Holders are then mounted to form a collar containing 14 transducers. The collar is very flexible, permitting all the holders to follow the shape to be inspected very closely. A small plastic-covered steel wire is used to attach the holders together. The space between the holders is kept constant by two spacers. At each end of the collar, a large loop of wire permits installation on the frame. The same collar with the same number of holders and sensors, is used for the inspection of both 2 and 2.5-inch pipes.

Figure 1 Frame

The frame

The frame is the rigid part of the bracelet. It maintains the collar in place and is attached to the feeder. Two different frames were used for the 2 and 2.5-inch feeders. Each frame has 8 rollers in order to move freely in the longitudinal direction of the feeder while limiting unwanted circumferential displa-cement. The frame holding the collar and the encoder is installed on the TAR via a ski boot type attachment that permits a very secure hold while maintaining a constant grip to the TAR.

The encoder

Again, the encoder used on the METAR is the smallest free-running encoder found on the market. As it is not waterproof, it has been covered with shrinkwrap and some silicon grease to prevent water from damaging the interior. Also, because of the way the encoder is attached to the frame and pushes on the feeder, some bending of the shaft occurs over time and then the encoder must be changed.

Ultrasonic Equipment

Ultrasonic system for METAR

Conventional ultrasonic flaw detection equipment which displays the waveform in an A-scan is commonly utilized for routine wall thickness measurement. Time-of-flight measurements made with instruments that rectify the signal are less accurate because phase information is lost. Accuracy can be improved by measuring several backwall echoes, but there are practical limitations due to the shallow water column (probe total height of less than 19 mm), beam spread and curved surface.

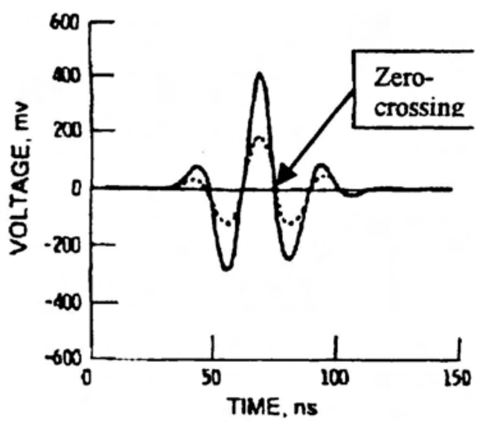

Figure 4 Zero crossing of flat botommed hole

Higher accuracy may be achieved with instruments that can digitize the unrectified waveform (RF signal). Using an unrectified signal, an accurate time-of-flight measurement technique can be implemented. A simple technique is the zero-crossing method that consists of measuring the zero-volt position from a negative to positive or positive to negative direction, immediately following the maximum peak amplitude (Figure 3). This measurement technique is extremely accurate with a modern digital instrument if there is no dispersion – which is the case for thin polycrystalline metal – and if the velocity is known to a high accuracy. Several experiments carried out on calibration block and feeder samples have shown that the greatest uncertainty comes from the material velocity. An uncertainty of +- 25 m/s yields an uncertainty of +-0.0005" for a 0.1080" thick sample. The velocity chosen is 5927 m/s. This number was provided by SIMD and found suitable with calibration samples made with replacement feeder pipes.

The desired features of the data acquisition system and analysis software are as follows:

- Multi-channel digital system with a minimum of 16 channels upgradable to 32;
- Single box system to minimize cabling;
- Single cable to connect the multi-transducer probe to the unit;
- Channel merging during acquisition – not off-line;
- Real-time display of the 16 channels in a single C-scan window for fast assessment of couplant quality;
- Multiple windows to display the thickness map, side view, end view and waveform;
- Once a datafile is loaded to memory, the analyst simply moves cursors to find and measure the minimum wall thickness.

An ultrasonic system with these features did not exist and R/D Tech was mandated to adapt its μTomoscan system to meet all the requirements. The ultrasonic unit assembled for this application has an internal 16-channel pulser-receiver board and the acquisition sub-system is the μTomoscan. The acquisition unit is controlled by a powerful data-analysis software called Tomoview. Version 2 of Tomoview was utilized for its real-time channels merging function. Tomoview version 2 was in the development stage at the time and a 2-month test program was performed in order to eliminate any bugs that could interfere with application.

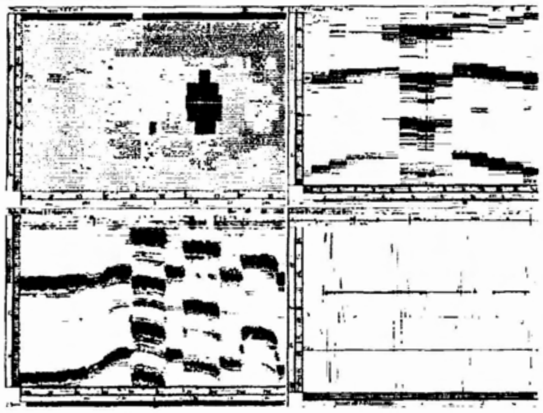

Figure 5 μTomoscan screen rendition showing 3 faults of different sizes on a calibration sample.

The data acquisition speed with 14 channels and a digitizing frequency of 100 MHz is 110 mm/s at a scanning resolution of 1mm in the axial direction. This speed was obtained after optimizing all the ultrasonic parameters, keeping only the information required to accurately size feeder wall thickness in the range between 0.080" up to 0.240" (thicker walls, up to 12 mm, are measured with lower accuracy).

Qualification

As with all the equipment used for measurement and inspection, the METAR had to pass qualification tests before being used in the reactor. This was necessary to evaluate the precision and reproducibility of the inspection system. Qualification was performed on the precisely machined feeders of 2 and 2.5-inch pipes. The document *R/D Tech D/4297-03* gives a good description of the qualification testing.

Figure 6 METAR on calibration sample

A total of 4 calibration samples were fabricated: two were made from replacement feeder elbows, one for each feeder outlet size, and two were straight feeder pipes, one for each diameter.

The feeder elbow samples have a 3-inch radius 70-degree bend. This represents the most difficult bend for 2 and 2.5-inch tube sizes. The elbows were cut in half and three 1-inch diameter flat-bottom holes were machined in the extrados. The flawed area was mapped with a thickness gauge (digital caliper hooked up to a computer). The mapping of the calibration flaws is extremely important because only a small part of a flaw was showing the minimum wall thickness. The accuracy of the wall thickness gauging is +-0.0005" and the mapping resolution is 5 degrees per 0.125 inch. The two elbow halves were then joined back together.

Equipment

The equipment used in the qualification was the same to be used later during the actual inspection in Gentilly 2, including the μTomoscan, a laptop, and the bracelet for both the 2 and 2.5-inch pipes.

Personnel Qualification

The personnel trained to use the METAR system were all technicians from the Periodical Inspection group (IP) from G2. They were all qualified CGSB ultrasound Level 2 operators. The report *R/D Tech D/4297-03* presents this work in detail.

All of these operators passed the training and were then in charge while the inspection was performed during the outage.

Equipment qualification

Equipment qualification is necessary to ensure data quality and repeatability. It is also used to specify the precision of the system and to define its operation as well as the method for achieving the best results. To ensure consistent result, specially machined pipes were used. The overall goal, apart from determining the accuracy of the measurement, is to show that the result is independent of a qualified operator and of the sequence of pipe measurement, whether an encoder is used or not...

For this qualification :

- Each operator scanned each calibration sample 5 times using 4 inspection sequences for a total of 40 scans.
- Each operator analysed and reported the 40 scans obtained by his collegues.

Operators were trained to locate and measure wall thickness with the zero-crossing method. No interpolation was used and the operator located the datum closest to the zero-crossing. Then, all the data from the 160 scans was compared to the minimum wall thickness found with the caliper mapping, and data was statistically analysed to evaluate the average UT sizing error and standard deviation. The results are reprinted in Table 1, along with qualification results obtained with the SIMD system (see *SIMD* report no N-01461-97551 September 1997). This table clearly shows the METAR system is more accurate and has up to four times less uncertainty.

	SIMD	MÉTAR
Error	+0.07 mm	+0.009 mm
Standard deviation	0.08 mm	0.015 mm
Uncertainty @ 95.5%	-0.09 à 0.23 mm	-0.022 à 0.039 mm

Inspection

As mentioned previously, the METAR system was used at Gentilly 2 during the Spring 2000 outage. Overall, a total of more than 120 feeders were inspected, including all type 4 and 5 bends for the 2.5 inch feeders of the reactors. The inspection was performed in two sessions of 3 days, one session for each face. On the average, when free from mechanical failure, the inspection of a feeder, including two elbows, took less than five minutes. The displacement between two feeders usually took more time than the actual inspection. Also, since the system was still in the prototype stage, some mechanical and technical failure occurred, slowing the process further. Nonetheless, compared to previous years, inspection time with the METAR system were estimed to be two times faster. However, with an improved bracelet, future inspection times are expected to be even faster.

Installation

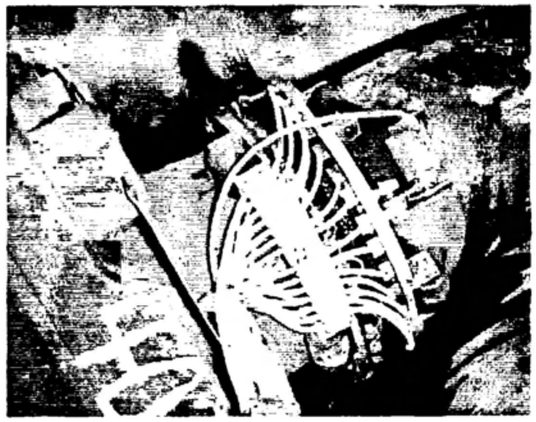

Figure 7 At the start of an acquisition

The METAR system was designed to be very compact and easy to install. Installation time is only a few minutes, thus minimizing radiation exposure. The entire system including the bracelet, the µtomoscan, the couplant-tank and the pump, is located inside the cabin; only the computer is installed in a remote location away from radiation area. An ethernet link-up up to 100 feet and a voice communication system connects the cabin and the computer.

Procedure

The inspection team was composed of 5 operators of whom 4 were technicians from the Periodical Inspection group and one was an engineer to provide support. During the actual inspection, 2 operators were in the cabin, one scanning the feeders with the bracelet, the other helping as needed and in charge of the displacement of the cabin. Two technicians and the engineer were in constant communication with the cabin, recording and pre-analyzing the data on the computer and preparing for possible mechanical failure. Operators were rotated frequently to minimize radiation intake.

Inspecting a feeder is fairly straightforward. First the cabin operator moves the cabin in front of the feeder to be inspected. When ready, the operator installs the bracelet on the feeder and starts the pump. Communicating with the operation desk, he moves (or shakes,

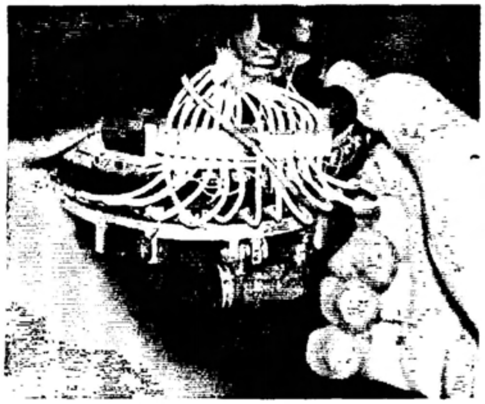

Figure 8 Displacement of the bracelet

to clear air bubbles) the bracelet until the UT signals become clear. The technician then starts the sequence on the computer and the operator moves the bracelet along the elbow. In most scans, the speed of inspection is irrelevant since it is triggered by the displacement of the encoder. In cases where the encoder is not functioning properly, the operator has a predefined time to move the bracelet over the area, usually 15 to 25 seconds. Depending on the quality of the data, the same bend may be scanned more than once. The operator then moves on to the next bend, rotating the bracelet according to the shape of the feeder. In general, 2 passes were made on each elbow, one going the other coming back. However, in some cases, because of poor surface quality, up to 4 or 5 passes were made. Once the data for all the feeders is gathered, technicians proceed to the analysis of all files, going over each one at least twice to find all the possible minima. A report is produced and erosion rate and remaining life are calculated using all available data.

Problems encountered

Most of the problems encountered during this first inspection came from the fact that this was the first real inspection using this device and that it is still essentially a prototype. One problem encountered was with the couplant tube that tends to disengage too easily. Though this did not occur very often during the actual inspection, it is very debilitating, impeding data acquisition from the sensor in the holder missing the tube. The short term solution of putting the tube back in place was simple and quick to implement. Another problem involved the encoder, which can lose its rubber tire while moving the bracelet. Tests have shown that a tireless wheel will produce sufficient contact on the feeder. Also, as mentioned above, the encoder is not designed to work in water, so it had to be changed every so often (5 times in total). A connector for this purpose was already installed, simplifying replacement.

The main inspection problem is achieving good signal quality throughout the bend. Gentilly-2 feeders are pretty much rusted as the result of a previous incident. The surface finish of the pipe is very rough, making it difficult to maintain contact even though the feeders were sanded prior to inspection. For this reason, when signal quality was poor, pipes were inspected three or more times, until sufficient data was gathered for analysis.

The most significant problem was encountered on vertical feeders, on the top part of the face. Because of the orientation of the exhaust hole in the holder, it was very difficult to build a good water column. However, by turning the entire bracelet around for these feeders, satisfying results were achieved. A lot of time was lost on this problem, but once resolved, vertical pipes were as easy to inspect as horizontal ones. The next version of the holders and the collar will address this problem.

Other problems occurred towards the end of the inspection. While the bracelet was aging, some holders eroded due to the friction with the feeder. For example, holders 1 and 14, at the extremities of the collar, became so worn that no data could be read from them. However, since these were located far from the area of interest, inspection continued. Also, probably due to aging or mis-manipulation, some sensors eventually stopped working. Again, when possible, these transducers were moved away from the area of interest and inspection was completed with fewer sensors on the bracelet. All important information from the pipe was taken nonetheless.

Outage 2000 Inspection Results

The purpose of METAR was to inspect critical bends that could not be reached with the SIMD scanner. All the critical feeders were finally inspected at least once between 1997 and 2000. Four feeders are expected to reach the minimum allowable wall thickness by 2010.

Two of these are being closely monitor: D05 and C06 on the South face. Based on measurement from 1997 to 1999, their disposal dates are respectively February 2002 and December 2002. These are the most pessimistic repair dates and take into account the uncertainty related to the measurement system. The new acquisition system using METAR has significantly reduced the uncertainty of measurements and moved the most pessimistic disposal dates to respectively December 2003 and February 2005. The accuracy of the measurement permits a delay of 20 months before repair is scheduled. Measurement at the next outage should provide a definite repair date unless the erosion rate has changed by then.

The next steps

Now that the first inspection has been completed, the METAR has proved itself under real working conditions, and some of the minor bugs have been identified, new features are planned to be extend METAR's capability.

The long-term goal is to inspect all bends at least once by the year 2004.

New features

To further extend the use of this system, some features or improvements may be added to the next version of the bracelet. Some of these features are in the development stage at this moment, so it is uncertain when they will be available for general use. Most of these improvements will reduce exposure to radiation and extend safe access to feeders. The first improvement will modify the holders to measure the inside portion of the bends. Other major improvements to the collar and the frame could allow to measure the entire circumference of the feeder (360°) in one pass. Also, motorization of the bracelet should permit access to feeders and bends too far in the reactor face to be reached by hand. Furthermore, while implementing these features, we will also try to lower the overall height of the bracelet, to be able to reach places where it currently does not fit.

Licensing

Following the success of this first inspection, a licensing contract was signed between Hydro-Québec and R/D Tech. This license gives R/D Tech the rights to reproduce and sell this product throughout the world. The products should include all necessary hardware and software to perform an inspection. All modifications to solve the problems documented during the trial period should be implemented before the product hits the market. Further development will be pursued by both Hydro-Québec and R/D Tech and the result could be commercially available at a later date. This product is also patent-pending.

Conclusion

This paper presents a system to measure the thickness of pipes at a nuclear power plant. The METAR device was designed at the Hydro-Québec Research Center (IREQ) for the Gentilly–2 nuclear power station. Confronting the weaknesses of other systems, this device is simple to use, can reach areas previously not accessible, and provides better data. On top of this, it is easier to use and can be more than twice as fast. The METAR has been used successfully at the G-2 reactor during the last outage. As shown above, a lot of consideration was brought to the design to minimize constraints while maximizing data quality. Before being used on the reactor, the system went through intensive testing and qualification in order to ensure the quality and repeatability of the results. Future developments will correct problems encountered during this first inspection and introduce features to enlarge the area on which inspection of pipe thickness could be performed. Overall, the G-2 Periodical Inspection team is very satisfied with the results obtained and plan to keep using this device. Finally, following a licensing contract with the company R/D Tech, this system is now commercially available.

References

Report IREQ-2000-145-C, *Bracelet MÉTAR 2000, Système de mesure d'épaisseur des* *tuyaux d'alimentation du réacteur Gentilly-2*, August 2000

Report R/D Tech D/4297-01, *Procédure de configuration du système μTomo employé pour l'inspection des tubes d'alimentation du réacteur*, March 2000.

Report R/D Tech D/4297-02, *Procédure d'inspection des tubes d'alimentation en eau du réacteur*, March 2000.

Report R/D Tech D/4297-03, *Qualification du bracelet MÉTAR et du système d'acquisition μTomoscan pour l'inspection des tubes d'alimentation en eau du réacteur*, June 2000.

Report IREQ-99-171-C, *Bracelet MÉTAR, Système de mesure d'épaisseur des tuyaux d'alimentation du réacteur Gentilly-2*, August 1999.

SIMD report no N-01461-97551, *Performance Assessment of SIMD Feeder Ultrasonic Inspection System – Phase*, September 1997

COG Report COG-JP-97-003, *Feeder Thinning Project – Final Report,* Dec 1997

Technical Report G2-RT-99-22 *Analyse des résultats d'inspection des tuyaux d'alimentation du réacteur* – Arrêt 1999, Sept. 1999