LEAK LOCATING IN BRUCE NGS-A STEAM GENERATORS USING GAS TRACER TECHNIQUES

J.H. Vandergeest, L.J. Recoskie, and J.A. Aikin

Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
CHALK RIVER, ONTARIO K0J 1J0

ABSTRACT

In 1981, Ontario Hydro requested development of a leak locating technique capable of locating a 0.5 $kg.h^{-1}$ heavy water leak within 72 h of access to the steam generator head. A gas tracer technique has been developed to the point where it can now be used in the station to locate such leaks. The technique consists of pressurizing the shell side to 450 kPa with a sulphur hexafluoride (SF_6) air mixture and sampling on the tube side.

To speed up the search, a multi-tube sampler is used to simultaneously sniff a number of tubes. The technique as proposed requires a man to enter the steam generator head, but can be adapted for use from outside the steam generator head. The development equipment and procedures required to complete a search are described.

INTRODUCTION

In 1981, Ontario Hydro asked AECL (Chalk River) to investigate techniques for locating small heavy water leaks of 0.5 $kg.h^{-1}$. At the time, leaks in the Bruce NGS-A steam generators of less than 10 kg D_2O h^{-1} had existed for some time, resulting in losses over 9 M$. The existing fluorescein leak locating technique* was too insensitive for this application. An extensive literature search revealed two possibilities for better leak locating (1, 2, 3). A feasibility study identified the gas tracer technique for further development (4, 5).

Development was divided into a number of phases:

i) correlation of water leak rate at operating conditions to tracer leak rate at test conditions,

ii) development of the tracer gas leak locating technique, and

iii) specification and supply of leak locating equipment.

Most of the program was supported by Ontario Hydro, Central Nuclear Services (the leak rate correlation work was funded by AECL).

* To locate a steam generator leak using fluorescein, the shell side is filled with fluorescein solution and pressurized. The tube ends inside the steam generator head are then monitored with a "black light" for fluorescence of the fluorescein dye (maximum sensitivity of 10 $kg.h^{-1}$).

GAS TRACER/WATER LEAK RATE CORRELATION TESTS

A number of theoretical relationships exist for calculating gas and water flow rates through small leak paths. However, because of basic assumptions, these relationships are difficult to verify and do not account for the phase change that occurs when water leaks from the primary heat transport system. Therefore, an experimental program was started to develop an empirical correlation between water leak rate at steam generator operating conditions and detectability at test conditions by various techniques, such as gas tracer, acoustic emission, and fluorescein (5, 6).

Artificial defects were created in steam generator tubing by different methods listed in Table 1. An annulus was then welded around each specimen as shown in Figure 1 to collect leakage.

For each specimen, the helium leak rate was measured before and after measuring the water leak rate. The helium leak rates were measured using the water displacement technique. Water leak rate was determined by collecting the leakage and measuring the volume or weight. The results of these tests are shown in Figure 2. For the target water leak rate of 0.5 $kg.h^{-1}$, the equivalent helium leak rate is 0.09 Pa m^3 s^{-1}.

Two tests were done to establish the leak test conditions required to clear the leak paths of water due to clogging by surface tension. At a pressure of 0.45 MPa all leaks that can be cleared, unclogged within a few hours. Therefore, a test pressure of 0.45 MPa should be suitable.

GAS TRACER SELECTION

A leak search is conducted by putting the tracer gas (such as helium) under pressure on one side of the leaking boundary and scanning the low pressure side with a detector. Because the tracer must easily pass through the boundary, monatomic gasses such as helium or argon are frequently used. They readily diffuse through small holes by molecular flow for leak rates less than 10^{-7} Pa m^3 s^{-1}. However, in the Bruce steam generator, the expected helium leak rate is 0.09 Pa m^3 s^{-1} (corresponding to a 0.5 kg h^{-1} heavy water leak). These helium leak rates are definitely not molecular; therefore, other tracer gasses, such as ammonia, argon, carbon dioxide and sulfur hexafluoride can be considered. To be suitable, a gas must be:

- non-corrosive,
- preferably heavier than air,
- detectable above atmospheric background,
- detectable with portable detectors, and
- non-toxic when used at low concentrations.

TABLE 1: SPECIMEN MANUFACTURING HISTORY

SPECIMEN NAME	TUBE DATA	MFT METHOD	COMMENTS
DH4, DH5 & DH7	304 SS 12.7x1.2 mm	Laser and twist drill	Twist drill #80, i.e, Drill Hole or Laser drilled holes approximately (0.08) mm.
P1 & P2	304 SS 12.7x1.2 mm	Welding	7 m Porous stainless steel filter 12.7 mm OD x 1.2 mm wall welded to tubing.
SCC3, SCC4, SCC6, SCC7 & Scc8	304 SS 12.7x1.2 mm	Stress Corrosion Cracking	Stainless steel tubing was rolled into a split blocked to produce high tensile residual stresses. The tubing was next placed in a 46% solution of boiling Ma Cl_2 for 17 h.
PC1, PC2, PC3 PC4, PC5 & PC8	I-600 13x1.3 mm	Pressure cycling	A stress riser was placed either on the outside or inside tube wall using EDM techniques. The tube was then Pressure Cycled (0-28 MPa). Average number of cycles to failure 40 000$\pm$40 000.
R3 & R4	I-600 13x1.3 mm	Rotary cycling	A circumferential stress riser was scratched on the tube. A load of 28 N.m was placed on the tube and then rotated at a frequency of 29 Hz.
F1	I-600 13x1.3 mm	Fretting fatigue welding	Attempts to produce a fretted crack ended up being a fatigue crack.

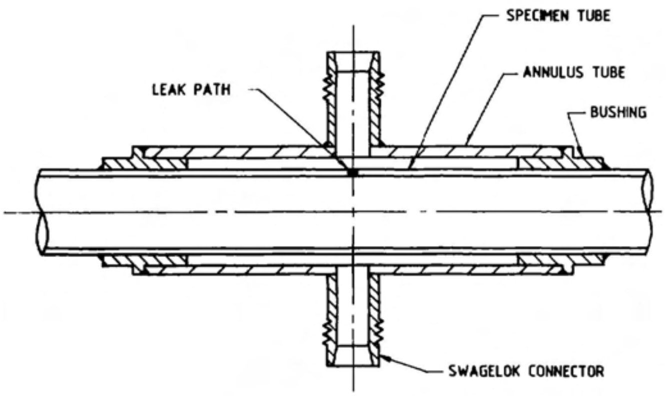

FIG. 1 TYPICAL LEAK SPECIMEN

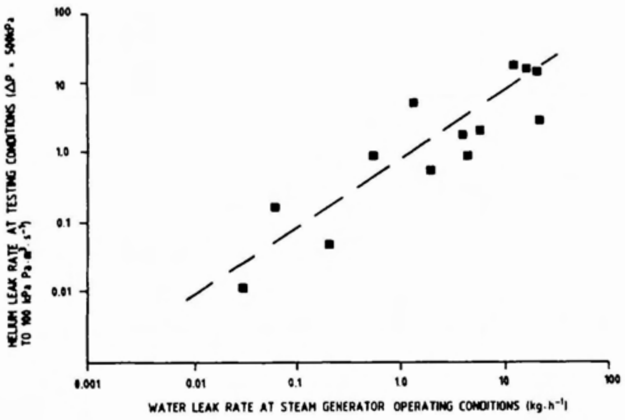

FIG. 2 HELIUM FLOW THROUGH ARTIFICIAL DEFECTS IN STEAM GENERATOR TUBES AS A FUNCTION OF WATER LEAK RATES AT CANDU STEAM GENERATOR OPERATING CONDITIONS

Argon was eliminated because of the high background of argon in air. Carbon dioxide and ammonia were eliminated because of their corrosiveness to carbon steel and copper alloys. Helium will quickly diffuse through the secondary side, requiring a large amount of helium or installation of a diaphragm above the tube bundle. This leaves sulphur hexafluoride (SF_6) as the most promising tracer gas.

Sulfur hexafluoride is heavier than air and is easily detected at very small concentrations. The major drawback is its chemical composition, sulfur and fluorine. Fortunately, the SF_6 molecule is very stable making it acceptable for use as a tracer (7, 8). A simple test with two stainless steel canisters containing simulated sludge and SF_6 was carried out to verify this conclusion (8).

In Bruce A four steam generators share a common steam drum. Consequently, it is important that the tracer gas remain in the steam generator without diffusing into the remainder of the shell side. Various candidate tracer gasses were compared by stratification tests in a test rig that modeled a Bruce-A steam generator and steam drum assembly (Figure 3). The results confirmed the suitability of SF_6 and demonstrated a method for mixing SF_6 with compressed air while injecting the mixture into the steam generator.

The gas/water correlation was developed using pure helium. Because the leak rate of gas varies inversely with viscosity and air has a similar viscosity to helium, the leak rate of 5% SF_6 in air mixture should be close to that of pure helium. This was verified using a metering valve to simulate a leak. Therefore, the tracer flow rate of 0.09 Pa m^3 s^{-1} can be used.

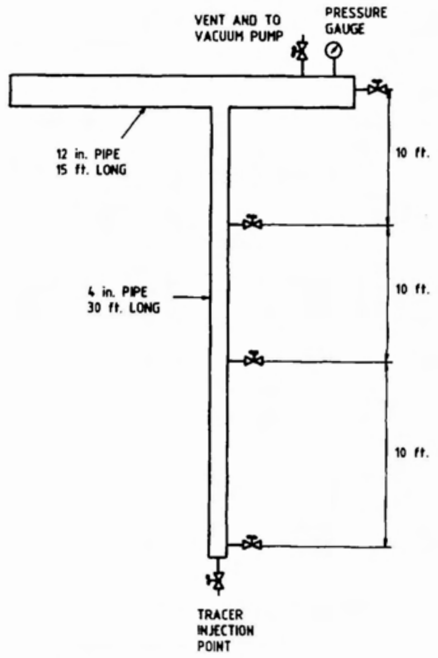

FIG. 3 GAS STRATIFICATION TEST RIG

LEAK SEARCH TECHNIQUE AND RECOMMENDED TEST CONDITIONS

A leak search is conducted by placing the gas tracer at a higher pressure on one side of the leaking boundary and scanning the lower pressure side with a detector. This applies equally to a steam generator, even though it is much larger than a conventional heat exchanger (a steam generator has 4200 tubes). Because of the cost of "down-time", the leak search must be quick and reliable.

Shell Side Conditions

It is preferable to pressurize the tube side as this is the normal operating condition, but scanning the tubes would be impossible. This problem was avoided by developing the gas water leak rate correlation for shell side pressurization. The shell side should be pressurized to 0.45 MPa with the tracer mixture to ensure the leaks are cleared of water.

Testing and analysis (7) have indicated that a 5% SF_6 concentration in air will give sufficient sensitivity to locate a 0.5 $kg.h^{-1}$ leak; therefore, this concentration of tracer is recommended. Because of the low diffusivity of SF_6 in air, it is necessary to mix the tracer and air while injecting the tracer. This can be accomplished using two flow meters.

Purge of Primary Side

As the shell side is charged with the tracer gas/air mixture, the mixture begins to pass through the leak(s). A slow steady purge will:

i) minimize cross-contamination with non-leaking tubes, and

ii) provide driving pressure for multi-tube sampling.

Compressed air is the most effective means of providing the air purge as a fan will recirculate leaked tracer back through the tube bundle.

A simulated leak can be located when sampling 108 tubes at purge rates of 2.3 to 4.3 Pa m^3 s^{-1}. The use of a purge rate of about 4.3 Pa m^3 s^{-1} per tube is recommended. This requires a pressure of 40 Pa (0.16" H_2O) on the inlet side and a compressed air flow of approximately 94 to 118 dm^3 s^{-1} (200 to 250 scfm). The flow schematic of the system supplied to Ontario Hydro is shown in Figure 4.

The carrier gas flow rate affects the upper leak rate for which this technique can be used. If the gas leak rate becomes large compared to the carrier gas flow rate in each tube, the tracer can flow in both directions out of the tube and enter the neighboring tubes. For the recommended carrier gas flow rate, the maximum water leak rate at which this could occur is about 8 kg h^{-1}. Higher leak rates could be located using this technique, by lowering the shell side pressure or raising the purge rate.

Sampling Technique

To speed up the leak search, a number of tube ends can be checked simultaneously by use of a "multi-tube sampler" (Figure 5). To match the tube layout and fit through the manway, the multi-tube samplier is hexagonal and smaller than 40.6 cm (16 in.) across the corners. The sampler provided to Ontario Hydro covers 169 tubes. It is placed against the tubesheet so that the top edge is between the tubes. As the carrier gas moves through the sampler to the leak detector, it is thoroughly mixed ensuring that tracer gas from any sampled tube is detected.

For a complete inspection, all tubes must be sampled at least once. The bulk can be checked with the multi-tube sampler but some tubes must be checked individually. There should be some overlap to permit inspection of tubes near the divider plate and head and to minimize time spent sniffing individual tubes.

The sampler should be held against the tubesheet for approximately 8 to 10 seconds per "sniff" because the total response time for the SF_6 leak detector and transit time through the sampler is approximately 6 seconds. The sampler can be cleared of tracer by holding it up to an area of the tubesheet that does not have any leaks. Assuming that each tube is checked twice, total sampling time is at least 10 minutes.

A detailed leak search procedure is given in Reference 7.

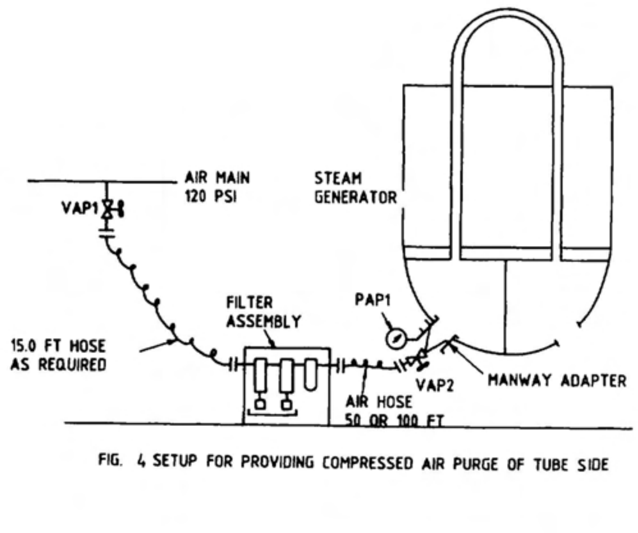

FIG. 4 SETUP FOR PROVIDING COMPRESSED AIR PURGE OF TUBE SIDE

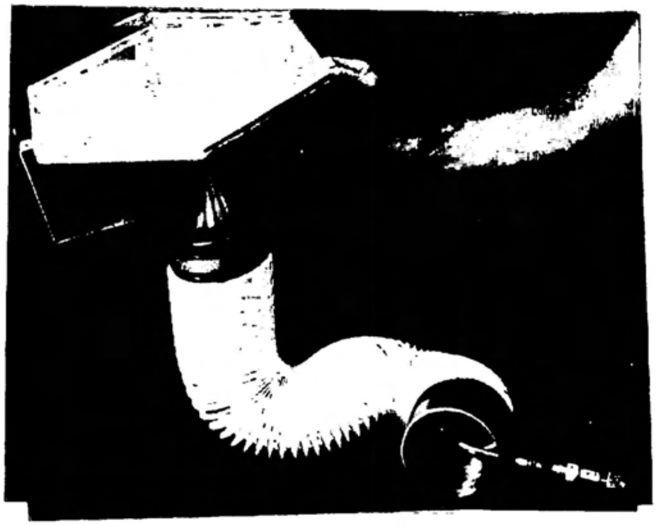

FIGURE 5: MULTI-TUBE SAMPLER

Laboratory Experiments

To verify the effect of carrier gas flowrates and multi-tube sampling, an existing Douglas Point steam generator (located at CRNL) was adapted as shown in Figure 6. Tracer gas was injected into a tube to simulate a leak at various rates, and purge gas passed through the tube bundle at a "high" and "low" rate. The tracer concentration in the discharge of various sized multi-tube samplers was measured. Results of the tests with a 5% SF_6/air mixture are summarized in Table 2. The measured results compared favorably with the predicted values.

CONCLUSIONS

A gas tracer technique has been developed to the point where it can be used in a nuclear steam generator to locate small leaks ranging in size from 0.5 to approximately 10 kg D_2O h^{-1}. To conduct a leak search, the shell side is pressurized with an air/tracer mixture, a carrier purge started through the tube bundle, and the tube ends "sniffed" with a multi-tube sampler. Once the shell side has been pressurized to 0.45 MPa, the leak search can be completed within 12 h.

The recommended tracer is sulfur hexafluoride (SF_6) and for the leak search, a 5% mixture should be injected into the steam generator through the blow-down system. Tests have shown that the mixture will remain uniform for over 72 h, sufficiently long to be able to complete the leak search.

To quickly locate the leak, a multi-tube sampler has been developed. This funnel-like device permits simultaneous sampling of a large number of tubes to determine if one of them is leaking. If so, the detector is disconnected from the sampler, and each of the tubes in the group is checked individually.

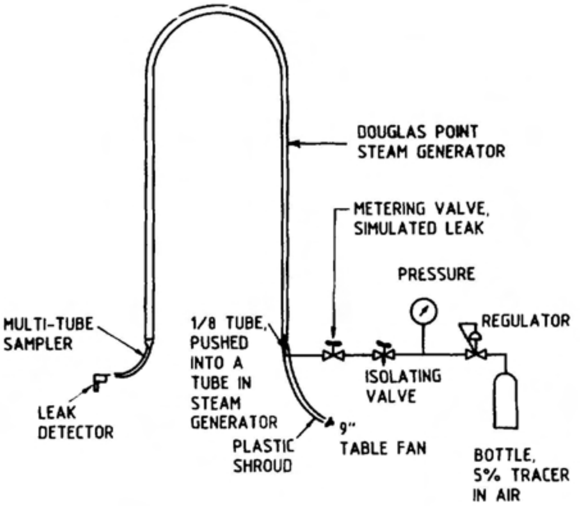

FIG. 6 SET UP FOR VARIFYING SUITABILITY OF USING MULTI-TUBE SAMPLER FOR LOCATING LEAKING TUBES

TABLE 2: MULTI-TUBE SAMPLING LEAK TEST RESULTS USING SF_6 TRACER AND LEAK DETECTOR

TUBE SAMPLE SIZE	5% SF_6/AIR FLOW, $Pa.m^3.s^{-1}$	AIR PURGE FAN SPEED	READING METER	SCALE FACTOR	TRACER CONCENT. ppm
196	0.025	high	20	100	2	1.4
		low	30	100	3	2.7
	0.10	high	30	300	9	5.9
		low	30	300	9	11
	1.0	high	off	scale	<30	59
		low	off	scale	<30	110
108	0.025	high	90	30	3	2.7
		low	40	100	4	4.5
	0.10	high	40	300	12	11
		low	50	300	15	18
	1.0	high	off	scale	<30	110
		low	off	scale	<30	180
53	0.025	high	40	100	4	5.6
		low	90	100	9	9.1
	0.10	high	60	300	18	22
		low	90	300	27	36
	1.0	high	off	scale	<30	220
		low	off	scale	<30	360
1	0.025	high	off	scale	<30	290
		low	off	scale	<30	480
	0.10	high	off	scale	<30	1 200
		low	off	scale	<30	1 900
	1.0	high	off	scale	<30	12 000
		low	off	scale	<30	19 000

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