DOE/SF/70030-T30

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Milestone X8.4
of SG027

Eng Syst

MASTER

November 18, 1980

XL-791-00168

Mr. S. G. Harbison, Director
Nuclear and Magnetic Fusion Division
U.S. Department of Energy
San Francisco Operations Office
1333 Broadway
Oakland, California 94612

SUBJECT: DOE Contract No. DE-AT03-76SF70030, Work Package No. Af 15 40 10.1, LMFBR Steam Generator Systems Development, WPT No. SG027, Subtask X8, Leak Protection for Post-CRBRP Steam Generators

Leak Injection/Detection Input for B&W Prototype Steam Generator Test Request

REFERENCE: Letter XL-791-0080, P. M. Magee (GE) to C. Kakalara (B&W) "Leak Injection/Detection Section for B&W Prototype Steam Generator Draft Test Request", dated July 15, 1980

Dear Mr. Harbison:

Attached is the required leak injection/detection input for the B&W Prototype Steam Generator Test Request, Report No. 73-01-PP-1. The input will become Appendix A of the Test Request when it is revised by B&W in early CY-1981. This transmittal satisfies Milestone X8.4 of WPT No. SG027.

A first draft of this material was submitted to B&W in July, 1980, by the referenced letter. The current input includes the following changes and additions:

1. Technical comments from Messers R. W. Hedin and S. P. Chakroborty of B&W have been incorporated.

2. Testing of the AI acoustic system has been added, with subsections prepared by Dr. A. Thiele of AI.

3. Subsections on the electromagnetic pinger, the in-pipe NaOH injection system and the cover gas hydrogen meter have been supplied by J. McKee of ANL.

Dr. P. M. Magee may be contacted regarding this transmittal.

Very truly yours,

W. V. Leeburn, Manager
Steam Generator Projects

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ATTACHMENT TO GE LETTER
XL-791-00168, NOV. 18, 1980

TEST REQUEST - LEAK INJECTION/DETECTION SECTION

AT03-76TO0030

1. INTRODUCTION

The goal of the leak injection/detection phase of the test program on the prototype steam generator is to obtain data that can be used to specify the leak protection system for the plant unit steam generators. Both chemical and two acoustic leak detection methods (by GE and Rockwell International) are to be considered. The chemical system has been selected as the reference based on its more developed state. The acoustic methods have potential both as small leak detection systems and as intermediate leak protection/automatic shutdown systems.

Simulated leak injections will be made at various locations within the steam generator to determine the performance of the chemical system as specifically applied to the B&W helical coil steam generator geometry. Acoustic tests will be made to characterize the various steam generator background noise sources and to record acoustic signals during simulated leak injections, in order to predict the performance of both systems.

2. TEST OBJECTIVES

The primary objective of testing for the chemical detection system is to determine the magnitude of time lag and the minimum leak rate detectable on a first-pass basis. These quantities are functions of leak location, sodium flowrate, temperature and the geometry of the B&W helical coil steam generator. The results obtained on the prototype test must be extrapolated to the plant units.

The reference leak detection system consists of an oxygen-hydrogen detection module on the sodium outlet line exiting the unit and two hydrogen detectors in the unit's cover gas space. An important consideration, therefore, is whether a detectable amount of the reaction products goes to the cover gas space.

The primary acoustic leak detection objective is to obtain acoustic signal data during simulated leak injections and background noise measurements. These data will be used to assess the ability of the two acoustic methods to provide leak detection for the steam generator. The GE method utilizes low frequency acoustic signals with accelerometers mounted to the shell, while the AI method utilizes high frequency with transducers mounted on the tubesheets.

The simulated leak sizes and the leak injection locations have been chosen to provide the information to evaluate these considerations as they pertain to leak protection system design for the plant unit steam generators. The leak sizes of interest extend from the smallest leak size whose reaction products can be expected to be detectable above background levels through a leak that is just below the size for which impingement wastage first occurs and, for the acoustic systems, to a relatively large leak for which rapid impingement wastage is expected.

3. SCHEDULE

[TBD]

4. TEST METHODS

4.1 Chemical Leak Detection

In order to obtain information for leak situations in which the steam generator geometry can be expected to affect the response magnitude and transport lag time of the reaction products, injections (simulating small leaks) will be made at the following five locations:

1) In the region of the steam tubesheet
2) In the sodium between the free surface level and the distributor
3) Between the distributor and the top of the tube bundle
4) In the upper portion of the tube bundle
5) In the region of the feedwater tubesheet

4.1.1 Steam Tubesheet

The steam tubesheets are somewhat isolated from the main cover gas space. Hydrogen injections will determine the time lag for the leak detection by the cover gas meter. The time delay is estimated to be longer for the tubesheet region than for other leak sites in the cover gas space. Consequently, no other injection locations in the cover gas space are deemed necessary. Injections are specified for three leak rates at each of two operating temperatures (normal and hot standby).

4.1.2 Between Sodium Free Surface and Distributor

Hydrogen bubbles are more likely to rise to the cover gas space from this relatively slow flowing region than from the lower sodium regions. Because of the high sensitivity of the cover gas meters, the leak rate for detection could be smaller than that for first-pass detection at the sodium outlet. Three hydrogen injections, covering both rate-of-rise and first-pass detection signals, will be used at steam generator full-load conditions. In addition, an attempt will be made to start each hydrogen injection at a low rate and step the rates up to the maximum specified. Detection will be attempted with both the cover gas and the in-sodium meters. Two water injections will be made in this region to determine if there is any significant difference in response of the cover gas meters to water and gas injections.

4.1.3 Between the Distributor and the Top of the Bundle

Sodium velocities in this region are significantly less than those in the bundle proper. Two gas injections will be made at different sodium flow rates with the primary objective of determining whether detectable amounts of hydrogen will reach the cover gas space. Response of the in-sodium meters will also be measured. As above, the gas injections will be started at a low rate and increased in steps up to the maximum rate.

4.1.4 High in Tube Bundle

Because of the high sodium velocities and induced turbulence, reaction products are more likely to move with the main sodium stream in this region than in others. However, at low loads, there is a possibility that hydrogen can rise to the cover gas space. Six LID's will be installed 1/4 of the way down from the top of the coiled tube bundle. Injections are planned at two rates: 1.05×10^{-5} lb/sec H_2 and 0.35×10^{-5} lb/sec H_2. The latter is less than that required for first-pass detection. Three sodium flows will be used: full load, lowest maneuvering load and hot standby. Therefore, a total of six injections is required. Concurrent with the cover gas meter measurements, response of the sodium outlet detectors will be monitored to verify that response magnitudes and time lags agree with calculations.

4.1.5 Feedwater Tubesheet

This region presents the possibility of reaction product hide-out because of the isolation of the tubesheet from the flowing sodium. Hydrogen bubbles, however, will rise out of this region and go into the flowing sodium. The potential hide-out may result in an increase in the leak size necessary to attain the threshold detection level for the sodium outlet meters. Testing will verify that the delay times are not excessive, that adequate sensitivity is achievable, and that design changes are not required to increase sodium circulation near the tubesheet. Hydrogen injections will be made at two leak rates for each of three sodium flow rates between full load and hot standby conditions. The injection rates will cover a range from rate-of-rise to first-pass detection.

At hot standby sodium flow, it is possible that hydrogen bubbles could rise through the tube bundle and reach the gas space. This possible cover gas hydrogen response will be tested during the low flow tests.

Also to be monitored are the two water injections discussed in the following Section 4.2.

NaOH injections will be made upstream of the steam generator using the NaOH in-pipe injector previously installed in the SCTI loop. These injections will be monitored by the chemical leak detections and will be used principally for system checkout and calibration.

4.2 Acoustic Measurements

4.2.1 G. E. System

Acoustic sensors (accelerometers) will be mounted on the steam generator wall to monitor acoustic signals transmitted through the sodium. The response of the sensors will first be calibrated by means of an electromagnetic pinger (provided by ANL) mounted inside the steam generator approximately 1/4 plane down in the test bundle. The acoustic characteristics of the various steam generator regions will then be measured over a wide range of test conditions to determine the contributions of various background noise sources (e.g., sodium flow, boiling, steam flow).

Gas injections will be acoustically monitored to demonstrate the detection/location capabilities of the acoustic systems. The hydrogen gas injections discussed in conjunction with the chemical leak detectors will be monitored. Of particular interest are the six LID's located high in the tube bundle as this region is expected to have the highest acoustic background noise and, therefore, the poorest performance for the acoustic systems. The leak rates used are quite small and will provide a severe test of the acoustic systems' sensitivity limits.

Four water injection LID's, with maximum leak rates of $\sim 5 \times 10^{-4}$ lb H_2O sec, will be installed specifically for acoustic leak detection monitoring. Two will be above the distributer (see Section 4.1.2), and two will be at the feedwater tubesheet. The water injections shall last for a minimum of 30 to 60 seconds and the amount of water introduced will be limited.

The water leak rates chosen correspond to the smallest leak size which could result in impingement wastage damage on an adjacent tube. No damage will actually occur as the LID's are designed to completely contain the sodium-water reaction zone.

An additional gas LID capable of injecting argon at a rate of $\sim$.005 lb/sec will be installed in the center region of the tube bundle. This injection will be used to determine the acoustic system's response to an intermediate size leak.

4.2.2 Rockwell International System

High frequency acoustic emission transducers will be mounted on the side of the steam generator tubesheets to monitor acoustic signals that are transmitted along the steam tubes. Attenuation measurements will be made during the fabrication process. The measurements will be conducted in the shop and consist of measuring signal strength vs distance for various regions of the steam generator. These attenuation measurements will be utilized during the testing to determine the contributions of various background noise sources as with the GE system.

The Rockwell system will be used to monitor the same schedule of gas and water injections that are conducted for the GE system. In addition, gas injections from the Rockwell designed Acoustic Leak Simulator(s) (ALS) will be monitored.

5. EXPECTED TEST RESULTS

The chemical leak detection tests to be conducted will determine the performance of the reference small leak system consisting of one in-sodium OH module on the sodium outlet line and two cover gas hydrogen meters for each steam generator. Particular emphasis is placed on detection issues specific to the helical coil steam generator geometry. These are:

1) Ability of cover gas meters to detect leaks at or near a steam tubesheet, in a side chamber off the main cover gas space.
2) Sensitivity of the cover gas meters to in-sodium leaks in various regions, at various sodium flowrates, and various axial temperature distributions associated with power operation.
3) Verification of leak transport times to the in-sodium detectors on the outlet line.
4) Sensitivity of module, on sodium outlet line, to leaks at or near the feedwater tubesheet. Determination of any hide-out problems in this region. Confirmation that design changes to increase sodium circulation near the tubesheets are not required.

The acoustic measurements will:

1) Determine the acoustic characteristics of the B&W helical coil steam generator. In particular, the sodium flow noise, boiling noise, and steam flow noise as functions of operating conditions and location within the unit. Permit comparison of these noise levels to those in the CRBRP hockey stick steam generator.
2) Demonstrate the ability of the acoustic leak detection systems to detect small leaks masked by typical plant background noise levels.
3) Permit predictions to be made of the acoustic leak detection systems' performance as applied to the B&W helical coil unit.

6. DESCRIPTION OF TESTS

6.1 Description of Leak Injection/Detection Apparatus

The injection of detectable impurities (gas and water) into various regions of the prototype steam generator shall be done by means of Leak Injection Devices (LID's) which have been permanently attached inside the steam generator. In addition, sodium hydroxide shall be injected by means of a NaOH injector through a penetration in the SCTI sodium loop upstream of the steam generator. Detection of the chemical impurities introduced shall be by means of a cover-gas hydrogen detector mounted on the steam generator upper enclosure which monitors the cover gas space and in-sodium hydrogen meters mounted off the main sodium outlet line of the steam generator. Acoustic noise detection shall be by means of sensors mounted externally on the steam generator.

6.1.1 In-Module Impurity Injection Equipment

The primary requirement for the in-module injection system is that no damage of the prototype steam generator vessel or steam tubes result from the test injections or any of the system's failure modes. Since the prototype tests at SCTI are primarily performance and endurance tests, the prototype unit will be drained infrequently. Therefore, the injection system and the LID's in particular shall be capable of withstanding extended times (>6 months) of exposure to hot sodium (100°F, 538°C) prior to their operation.

LID's of two basic designs are installed inside the steam generator: one for hydrogen (or hydrogen-argon mixture) gas injections and one for water injections. One basic design of ALS is used for argon injections.

Figure 1 shows the two LID designs. Each LID consists of 0.125 in. (.32 cm) OD stainless steel tubing (.049 in. (.124 cm) wall) connected to a diffuser by a fusion weld. The thick-walled tubing reduces the volume of the supply system and increases measurement accuracy. The nozzles of the LID's are attached inside the prototype unit. Each injection line exits the nozzle and is then wound into a heat exchanger coil.

A total of 26 LID's have been installed. Fourteen of these are strapped to the tubes or the tube support structure: 5 between the sodium level and the distributor, 2 between the distrubutor and the top of the bundle, and 7 in the bundle proper. Two of the LID's above the distributor are intended for water injections. Six additional LID's are ganged together near the steam tubesheet. Six are located near the feedwater tubesheet. Two of these are to be for water injections. The twelve tubesheet LID's are removable in that they are not attached to tubes but extend in through vessel penetrations.

Figure 2 shows the ALS design. Each ALS uses a supply line (pressure tube) of .094 OD X .020 WALL SMLS MIL-T-8504 TYPE 304 stainless steel tube. The ALS consists of a rupture disk that protects the leak orifice from sodium plugging. The additional port in the ALS is used to assure an open orifice exists after the rupture disk has been installed. Two Acoustic Leak Simulators are proposed at locations 1/4 and 1/3 of the way between the steam tubesheet and the feedwater tubesheet.

The flow rate during each injection shall be monitored. Each injection line has its own isolation valve. The valves are high temperature, high pressure

Figure 1. Leak Injection Devices

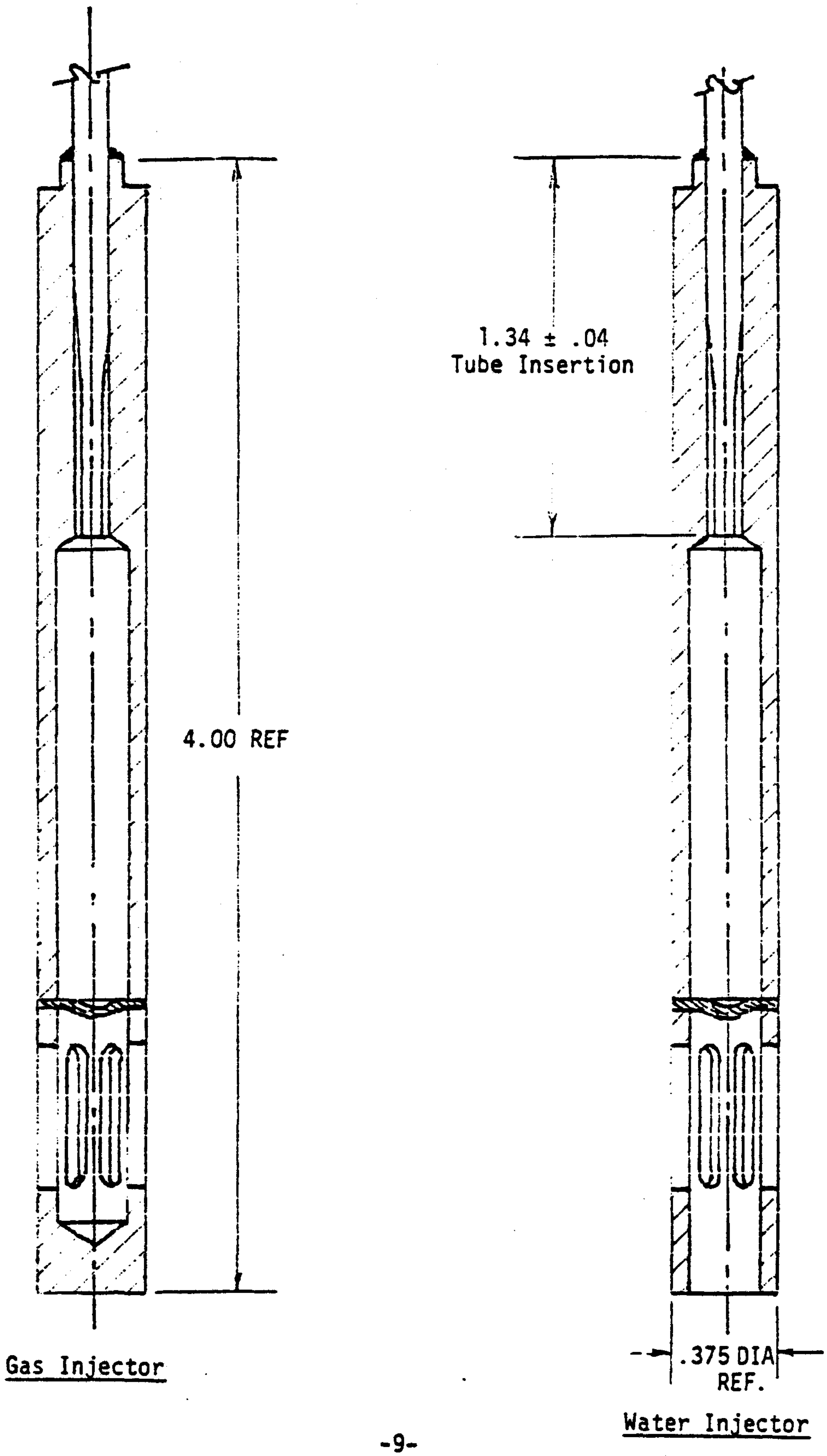

Figure 12. Acoustic Leak Simulator (ALS)

(To be supplied by AI)

ball valve designs with small orifices and low C_v factors. After each injection, the valve will be closed, and shall form the isolating boundary after the injection module is disconnected from it.

The SCTI impurity injection module is, with the exception of the gas supply bottles, designed to be portable and self-contained. The module is schematically illustrated in Figure 3. Specific operating procedures for the injection system, originally prepared for similar tests on the CRBRP prototype steam generator, are in place at SCTI.

6.1.2 Acoustic Measurement System

6.1.2.1 G.E. System

The G.E. acoustic measurement system consists of ∿150 accelerometers mounted onto the steam generator shell, and electromagnetic pinger for calibration mounted within the steam generator tube bundle, analog signal conditioning equipment mounted near the steam generator, and data processing equipment mounted in the control room. The basic setup is similar to that used on the CRBRP Prototype Steam Generator Test.

The accelerometers will be mounted onto the steam generator shell in a double helix pattern having a pitch of 75 inch and an accelerometer density of eight per pitch.

The major features of the accelerometer mounting on the vessel wall are shown in Figure 4. The mounting bolts are attached to the SCTI vessel wall by drill and tapping the vessel wall. A MACOR ceramic standoff is mounted on the vessel with a ceramic cement coupling to reduce the effect of local surface irregularities and improve high frequency response. A Belville washer spring is used to compensate for thermal expansion. A bowl-shaped opening in the vessel insulation provides natural circulation cooling. Excessive heat losses in the local region are prevented by the use of a small quantity of high efficiency insulation.

This mounting design, using a MACOR ceramic standoff, allows low-temperature (250°C), commercial accelerometers to perform satisfactorily with vessel

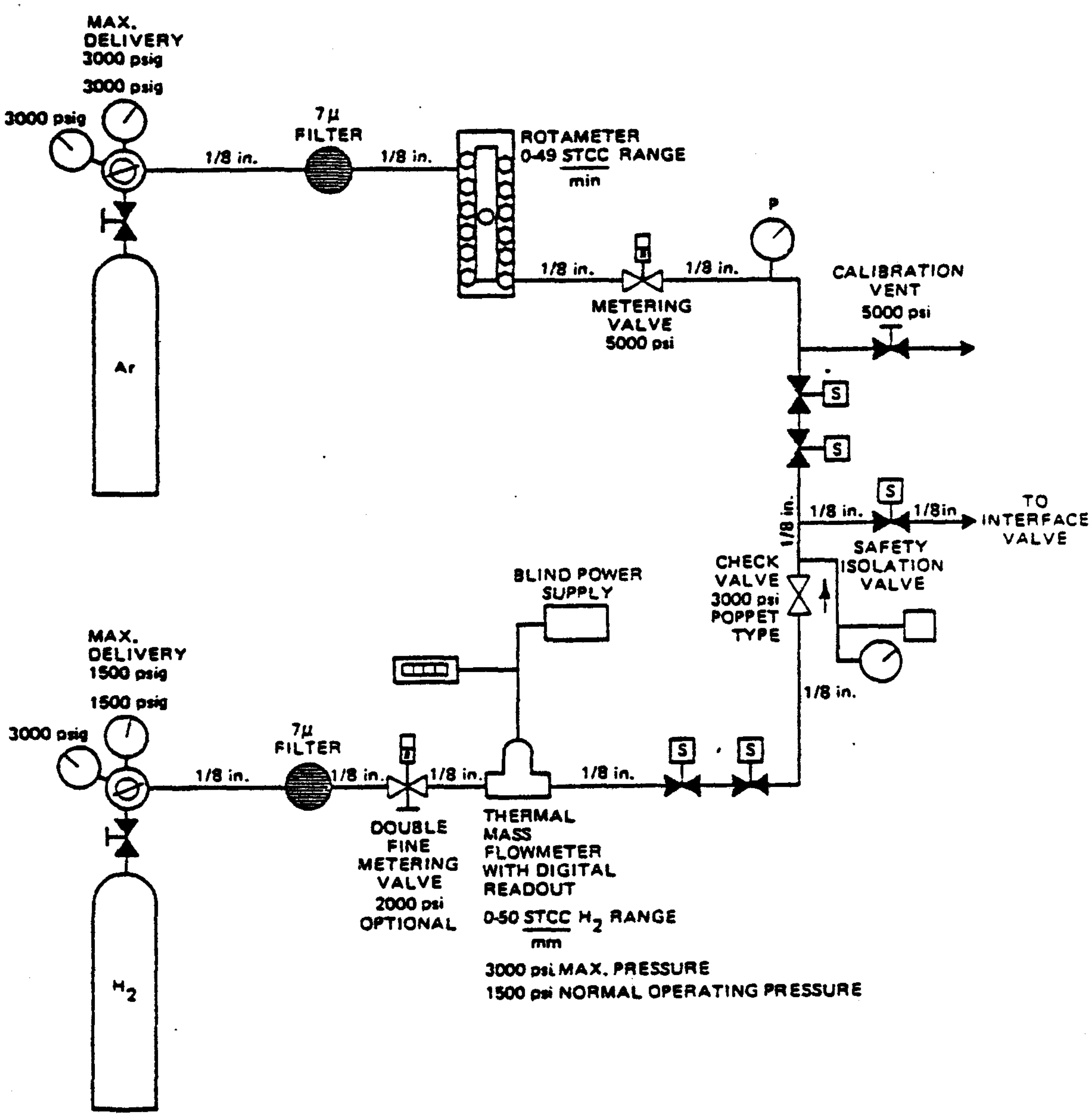

Figure 3. Hydrogen Injection Module

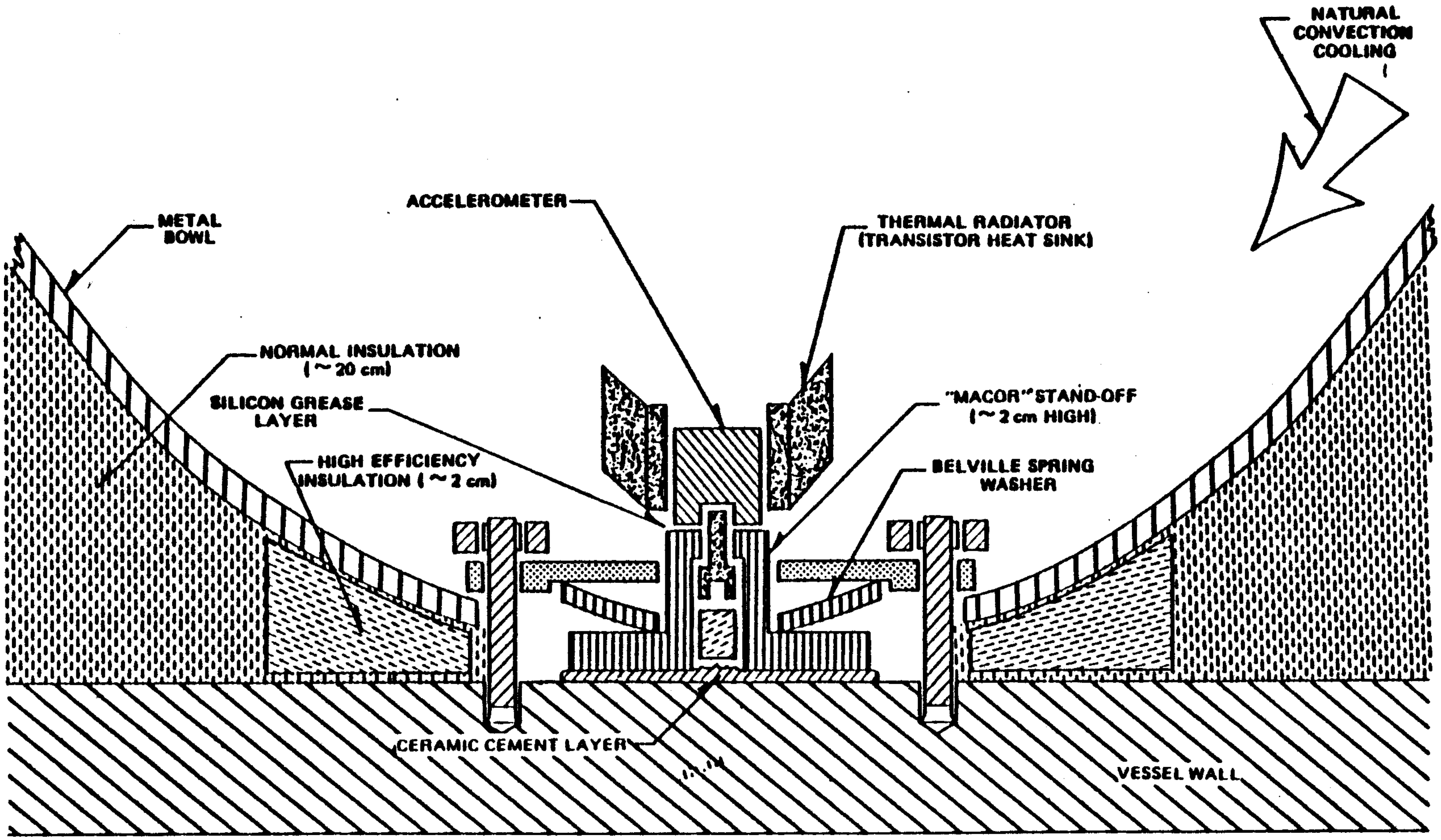

Figure 4. Acoustic Accelerometer Mounting

wall temperatures up to 950°F (510°C). The standoff also provides electrical isolation and eliminates equipment ground loop problems.

6.1.2.2. Rockwell Int. System

The Rockwell acoustic leak detection/location system consists of 3 transducers mounted to each tubesheet of the steam generator. The transducers are mounted in the same plane 120° apart. Each transducer housing includes its own preamplifier such that all data processing equipment can be located in the control room.

The transducers are mounted to the tubesheets using a steel rod waveguide or standoff. Each transducer housing is screwed into the end of the waveguide allowing easy removal. The waveguides can either be stud welded to the tubesheet or mounted using a drilled and tapped hole. Weld pads can be utilized if necessary to protect the tubesheet integrity.

6.1.2.3 Electromagnetic Pinger

The ANL high temperature sound source (PINGER) is a gravity operated impact noise generator designed for transducer checkout in hostile environments. It consists basically of a steel pellet permitted to drop through a fixed 15 mm (5/8 in) height on a stainless steel anvil. The pellet is picked up with a current pulse through a solenoid winding and held in place with a reduced holding current. The pickup coil is supplied with current from a mineral insulated cable welded onto a cylindrical housing.

In use, the Pinger is mounted vertically with the cable up. A large current pulse, used to lift the pellet, may be conveniently supplied by a capacitor discharge. To initiate the Pinger operation, the holding current is interrupted. The pellet begins to drop and hits the anvil about 55 ms later. The signal arrival at the transducer will be delayed an additional amount depending on the distance between Pinger and receiver and the sound velocity in the intervening medium. In water this travel time delay is 0.67 ms per meter. In hot sodium the delay is .4 - .45 ms/m depending on temperature.

The Pinger has been operated automatically once per second for over 20,000 times. The Pinger has been heated and cooled and operated intermittenly also. Thermal cycling between 20°C to 500°C (930°F) was undertaken 6 times with a total accumulated maintenance of the 500°C temperature of over 2000 hours. In addition, a 4-day cycle to 260°C (500°F) and one 8-day cycle to 350°C (600°F) was interspersed with the 500°C cycles.

During this period the coil resistance and inductance was checked about 30 times and the operation of the pinger was checked about 100 times. In addition, the Pinger output was rechecked in a water tank after the thermal cycling. No significant changes were observed.

6.2 Test Facility Interfaces with Leak Injection/Detection Apparatus

Requirements for the hydrogen cover gas meter are similar to those for the cover gas meter mounted on the expansion tank for the CRBRP Prototype tests. The meter requires a minimum overhead clearance of 5 ft. The equipment mounted outside the steam generator upper enclosure may be enclosed within an imaginary box that measures 15 in. by 12 in. by 24 in. 110 V, 700 W electrical power is required for the cover gas meter. DAS requirements consist of 4 analogue channels and 2 logic signals with alarm from annunciator.

The portable hydrogen and water impurity injection systems weight approximately 375 pounds each (minus gas supply bottles) and will require a working space of approximately 6 ft by 6 ft by 6 ft. The internals of the portable injection systems shall be enclosed in a standard 19 inch rack that stands about 5 ft high. The injection systems should be placed as close as possible to the leak injection device interface valves. Minimization of tubing length from injection system to LID is essential.

The NaOH injector will have been installed on the main sodium loop prior to the CRBRP Prototype Steam Generator tests. No changes in interface requirements are necessary.

Components of the acoustic measurement system shall be supplied as follows. Argonne National Laboratory will supply the electromagnetic pinger which will be mounted within the steam generator during its fabrication by B&W. GE will provide the accelerometers and all components of the accelerometer mounting including 10 m (32.8 ft) of high temperature cable. ETEC will be responsible for mounting the accelerometers onto the vessel to a specification to be provided by GE. ETEC will mount the high-temperature, low noise cable connecting each of the 150 accelerometers to a signal amplifier. Cable length is approximately 10 m in order to span the difference from the center of the vessel to the amplifier box at the base. GE will supply the analog signal conditioning equipment to be mounted by ETEC at the steam generator skirt and base. ETEC will provide power supplies for the two amplifier boxes. ETEC will provide nine cables to transfer the nine signal channels from the multiplexer to the control room equipment. Eighteen digital control cables are also required between the multiplexer and the control room. (This cable can be shielded 3M ribbon or coaxial type.) GE will provide ETEC with all of the hardware and software required for data manipulation. ETEC will provide space in the control room for the consoles and computer peripheral equipment. Similar responsibility breakdowns will be utilized for the Rockwell system.

6.3 Calibrations

Standard calibration procedures are available at SCTI for the in-sodium meters.

The cover gas hydrogen meter ETI gauge will have been calibrated at ANL prior to shipment by operation in known argon-hydrogen mixtures, in the absence of sodium. After the cover gas hydrogen meter is installed and sodium is present, dynamic mode calibration should be done at approximately one-month intervals until experience indicates that longer intervals can be used. The detailed procedure for calibration is given in Reference 1.

Calibration of the acoustic measurement system and its components shall be done by GE personnel, to procedures developed in the Small Leak Protection Base Program (SG027). Rockwell personnel shall calibrate their acoustic leak detection/location system.

6.4 Detailed Test Description

6.4.1. Leak Injections Within Steam Generator

Table 1 is a preliminary leak injection test matrix subject to revision.

The location of the LID injection is defined as above the distributor (AD), between the distributor and bundle (BDB), within the tube bundle (TB), at the steam tubesheet (STS), or at the feedwater tubesheet (FTS). The injections are specified as either gas or water. Each gas injection is to be started at a low value and ramped up, over a period of approximately one minute, to the maximum value specified.

Measurements will be made on the cover gas meter, the in-sodium meters and the acoustic instrumentation for all injections. Pertinent loop thermal-hydraulic conditions, such as temperature, flowrate, cover gas level, and cold trap temperature, will also be recorded.

Tests 1 through 3 are hydrogen gas injections in sodium above the distributor. They will indicate the sensitivity of the cover gas meter to under-sodium leaks in this region (by mechanism of gas bubble rise to the cover gas space). The transport time to the in-sodium meter on the outlet line and its reponse will also be determined. Tests 4 and 5 are similar for the region between the distributor and the top of the tube bundle. One run is made at full flow conditions and one at 40% flow. Tests 6 through 11 cover the tube bundle region.

Tests 12 and 13 are water injections above the distributor to determine if the cover gas meters respond differently to water and gas injections and, thus to verify the adequacy of the gas injections. These injections will also demonstrate the ability of the acoustic system to detect and locate a leak, sufficient in size to cause adjacent tube damage (if it were not contained within an LID), in the presence of typical, full-power background noises.

Hydrogen injections in the steam tubesheet region are listed in Tests 14 through 19. These are conducted at full-power and hot standby conditions. They are to determine the sensitivity of the cover gas meter to leaks in this region.

Tests 20 through 23 cover the feedwater tubesheet region and are run at full flow, 40% flow and hot standby conditions. The ability of the in-sodium meters to detect these leaks will be determined.

Test 24 and 25 are water injections near the feedwater tubesheet to demonstrate the acoustic system's performance in this region. Test 26 is an argon gas injection simulating an intermediate leak protection system.

Table 1 should not be interpreted to be an all inclusive matrix of injection tests. The matrix presents the minimum number of injections based on one injection per LID. If multiple injections can be made, the matrix may well be expanded. Responsibility for deletion or additions to the number of injections rests with the responsible test engineer.

Following each injection, cleanup shall be done to reduce the hydrogen impurity level to less than 100 ppb or to a higher level satisfactory to the responsible test engineer before another injection is made.

It should be noted that, in order to match the chemical leak detector response to a small leak in a plant steam generator within the smaller SCTI test unit the leak rates must be scaled to account for differences in system size and operating conditions. In order to derive the leak rates shown in Table 1, it has been assumed that the nominal hydrogen background concentration in the sodium is 100 ppb, the minimum first-pass detection can be taken as 10% of this, or 10 ppb H_2. Nine pounds of water are required to produce one pound of hydrogen (assuming 100% release).

The plant units at 100% power have a sodium flowrate of 16.29×10^6 lb/hr. Therefore, a leak rate of 4.07×10^{-4} lb/sec water will be the minimum first pass detection level. The test steam generator at 92.5% power (the maximum obtainable) has a sodium flowrate of 2.62×10^6 lb/hr and a minimum first pass detection level of 6.55×10^{-5} lb/sec water. With a nine-to-one conversion ratio, this corresponds to a hydrogen injection of 0.73×10^{-5} lb/sec.

The scaling laws are significantly different for acoustic leak detection. For the acoustic systems, the background noise is essentially the same

Table 1. Injection Test Matrix (Preliminary)

Test No.	Injection Location	Type of Injection	Rate, lb/sec	Max. Duration of Injection, sec.	ΔC PPB H_2	Na Flow Rate, 10^6 lb/hr
1	AD	Gas	0.35×10^{-5}	240	4.8	2.62
2	AD	Gas	0.7×10^{-5}	240	9.6	2.62
3	AD	Gas	1.2×10^{-5}	240	16.5	2.62
4	BDB	Gas	1.2×10^{-5}	240	16.5	2.62
5	BDB	Gas	1.2×10^{-5}	240	16.5	1.14
6	TB	Gas	1.1×10^{-5}	240	15.0	2.62
7	TB	Gas	0.35×10^{-5}	240	4.8	2.62
8	TB	Gas	1.1×10^{-5}	240	15.0	1.14
9	TB	Gas	0.35×10^{-5}	240	4.8	1.14
10	TB	Gas	1.1×10^{-5}	240	15.0	0.2*
11	TB	Gas	0.35×10^{-5}	240	4.8	0.2*
12	AD	Water	1.2×10^{-5}	60	16.5	2.62
13	AD	Water	1.2×10^{-5}	60	16.5	2.62
14	STS	Gas	0.08×10^{-5}	240	1.2	2.62
15	STS	Gas	0.35×10^{-5}	240	4.8	2.62
16	STS	Gas	1.2×10^{-5}	240	16.5	2.62
17	STS	Gas	0.08×10^{-5}	240	1.2	0.2*
18	STS	Gas	0.35×10^{-5}	240	4.8	0.2*
19	STS	Gas	1.2×10^{-5}	240	16.5	0.2*
20	FTS	Gas	0.7×10^{-5}	120	9.6	2.62
21	FTS	Gas	1.2×10^{-5}	60	16.5	2.62
22	FTS	Gas	1.2×10^{-5}	60	16.5	1.14
23	FTS	Gas	1.2×10^{-5}	60	16.5	0.2*
24	FTS	Water	TBD			2.62
25	FTS	Water	TBD			2.62
26	TB	Gas(Argon)	5×10^{-3}	60	--	2.62

*At hot standby flow and temperature conditions.

for the test and plant steam generators. Therefore, the full plant unit leak rates are to be used.

6.4.2 Acoustic Detection

A thorough noise characterization of the steam generator will be made by monitoring acoustic signals for a variety of operating conditions. These measurements will be made during other tests specified by the Test Request. The acoustic measurements will be made on an non-interference basis and will not extend test time.

The test plan requires the following operating conditions:

1. Calibration. Background (electronic) noise levels on all channels without sodium or steam flow through the unit. The electromagnetic pinger will also be used to calibrate as many accelerometers as possible. (As the pinger cannot be moved axially within the steam generator, it may not be possible to generate a sufficiently loud signal to calibrate all accelerometers.) Calibration data will be collected during the rig shakedown period.

2. Sodium Flow Only. Background noise levels will be measured on all channels at various sodium flows (e.g., 40%, 60%, 80%, 100% nominal SCTI flow) but without water/steam flow. These measurements will be taken during the shakedown period.

3. Power Operation. Background noise levels will be measured on all channels with various sodium and water/steam flows. The simulated Plant Operation Steady-State Tests will be monitored. Other thermal performance tests may be monitored, as judged necessary be the GE acoustic test engineer.

4. Simulated Leak Injections. Recordings of acoustic noise will be taken by the G.E. system during simulated leak testing with the LID's on the 8 to 12 accelerometers nearest the activated LID and other selected accelero-

meters, while the Rockwell system will record all transducers during simulated leak testing. The recordings will be used to demonstrate the leak detection/location capabilities of the acoustic system at signal-to-noise ratios typical of plant steam generator operation.

5. Endurance and Reliability Checks. At various times during the thermal tests, the performance of the mounted accelerometers will be checked for degradation and frequency shifts.

For each of the sodium flow and power operation tests, it will be necessary to hold steady operating conditions for up to 30 minutes to permit the acoustic data to be taken.

6.4.3 NaOH Injections Upstream of Steam Generator

Injections are to be made upstream of the steam generator using the injection system shown in Figure 5 for checkout and periodic calibration of the hydrogen and oxygen meters in the sodium. The injection procedure is described in section 9.2. The amount to be injected will be determined later but is expected to be sized to produce concentration increases in the range of 20 to 100 ppb hydrogen and 0.32 to 1.6 ppm oxygen in the SCTI secondary sodium inventory.

7. Data

Table 2 lists data requirements for the injection tests. Data files are to be produced for each test, and copies transmitted to B&W, G.E., and Rockwell within five working days following the test.

Data sheets for the operating and maintenance procedures need not be transmitted, but should be kept on file at ETEC for reference during the duration of the testing.

All data shall be identified and stored for a period of five years. In addition, a log book shall be kept in the control room and daily entries made concerning operation and maintenance of the cover gas hydrogen meter and the in-sodium meters.

Table 2. Injection Test Data Requirements

Time of Recordings

HMLD Readings

- Ion pump current μa*
- Hydrogen concentration in sodium, ppb
- Membrane temperature, °F
- Flow rate sensor, gpm
- Ion pump temperature, °F

Cover Gas Hydrogen Meter

- Hydrogen concentration in gas, ppb*

Injection Module

- Gas or water injected
- Flow rate, scfm*

Steam Generator System Parameters

- Temperatures, °F
  - Sodium inlet to steam generator
  - Sodium outlet from steam generator
  - Feedwater
  - Steam outlet
  - Cover gas
  - Cold trap
  - Plugging temperature indicator
- Cover gas pressure, psi
- Flow rates, gpm
  - Feedwater
  - Sodium
  - Cold trap
- Miscellaneous
  - Water pH
  - Dissolved oxygen content

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* Charts also included in data package with markings to indicate time and changes in S.G. system variables.

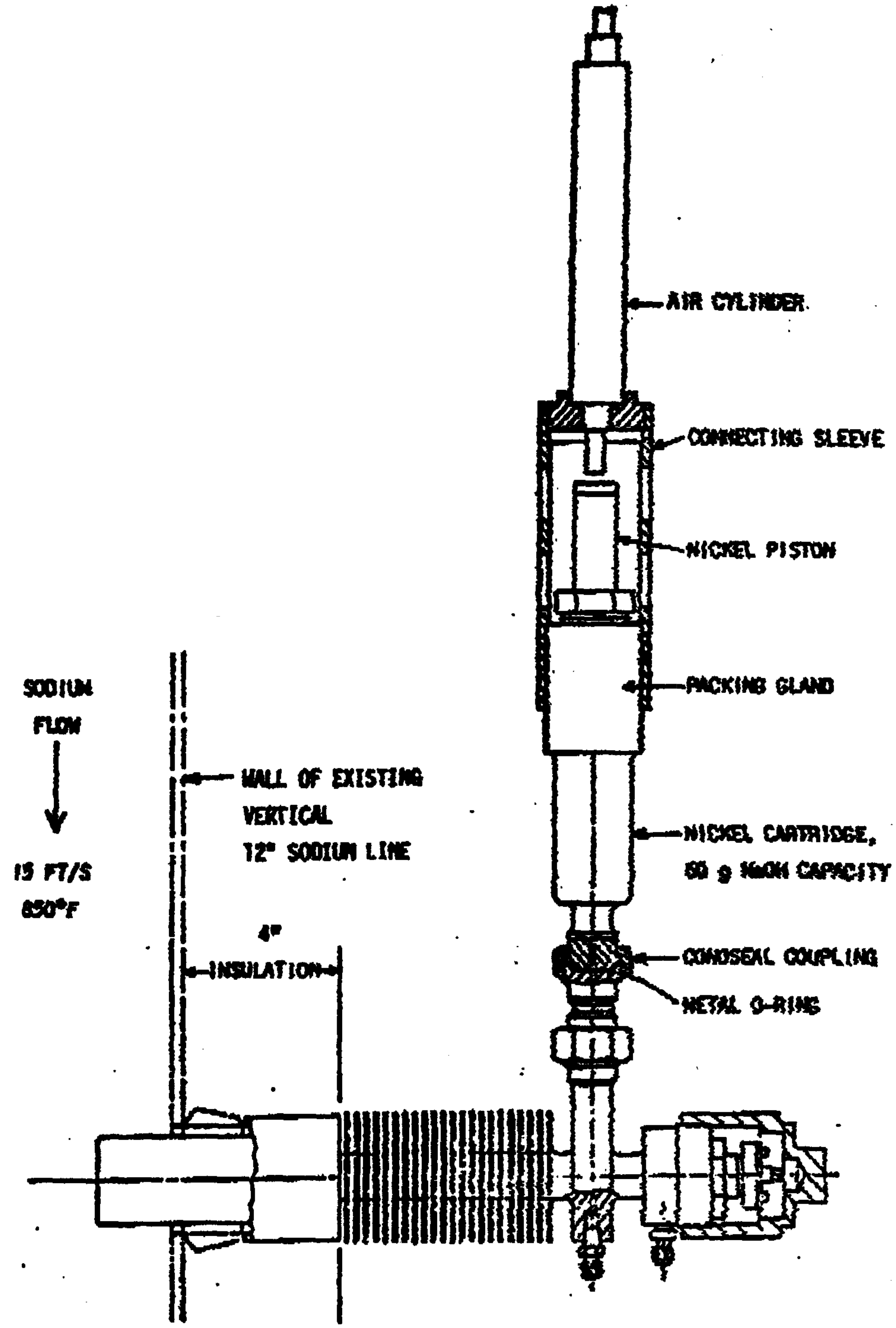

Fig. 5. In-Pipe NaOH Injection System

Acoustic measurements shall be the responsibility of GE who will maintain all data records. All data shall be identified and stored for a period of five years. In addition, a test log book shall be kept.

8. Interim Reporting

ETEC shall report to B&W, G.E. and Rockwell the test progress and significant accomplishments and occurrences on a timely basis. Reports are to be prepared upon the completion of each test phase. At the conclusion of the leak detection testing, GE shall prepare a final topical report that summarizes test results and analyzes leak detection system performance as used in conjunction with the B&W helical coil steam generator.

9. System Safety

9.1 LID Leak Injection Systems

The primary requirement for the LID injection systems is that no damage of the steam generator vessel, steam tubes or piping will result from the test injections or any of the system's failure modes. The injection systems (in particular, the leak injection devices) are required to withstand extended periods of exposure to hot sodium (1000°F) prior to their operation. When operated, the devices must not cause surrounding structures to exceed 1200°F and thereby structurally weaken them.

The LID leak injection systems are designed to meet these requirements. The LID's are designed to fully contain the sodium-water reaction "flame" and will not cause overheating of surrounding structures. On the three water LID's, the injector tube is swaged at its end to limit water flow to 5×10^{-4} lb/sec or less. Injections will be limited to 60 seconds or less to limit the total amount of reactor product gas generated.

9.2 In-Pipe NaOH Injection System

The primary safety concern in the design of the NaOH injection system is to assure that no sodium can leak out to air either during or between injections. Details of the injector valve design are shown in Figure 6. Between injections the primary sodium containment barrier is the closed valve. The valve seat is located outside the main pipe insulation and normally remains below 500°F, so the NaOH outside the seat is frozen, and above 350°F, so deposition of solids does not occur on the sodium side by diffusion cold trapping. If for any reason the valve should fail to seal completely when closed, the fins on the valve body hold the temperature at the outer end of the stem below 150°F by natural convection cooling. The freeze seal of NaOH or sodium, whichever is present, thus formed provides backup containment to the closed valve. A thermocouple in the well provided sounds an alarm if the temperature there should exceed 175°F while the valve is not in use.

To make an injection, a cartridge containing the desired amount of NaOH is attached at the Conoseal coupling on the valve body at room temperature. Electric heaters are clamped on, and the cartridge and valve body are heated to 650°F with the piston loaded to produce a pressure in the cartridge higher than the sodium pressure outside the valve. After the NaOH has melted, the backup containment to the closed valve becomes the carbon yarn packings around the valve stem and the cartridge piston plus the Conoseal coupling and the metal O-ring seal inside it. Leakage of either NaOH or sodium past the stem packing would short out the conductivity probe in the leak detector well provided and thus signal the operator. Leakage of NaOH at the piston packing or Conoseal coupling would be revealed by the piston travel recorder before opening the injector valve. Upon opening the valve the piston is driven in at a constant rate, completing the injection in approximately one minute. When piston travel is completed, the injector valve is closed with a torque wrench set at 20 in-lb, and the heaters are removed. The empty cartridge is removed at room temperature and replaced with a blind Conoseal flange. The reliability of the equipment and procedure is currently being tested at ANL-CT and will be further demonstrated at EBR-II before use on the SCTI.

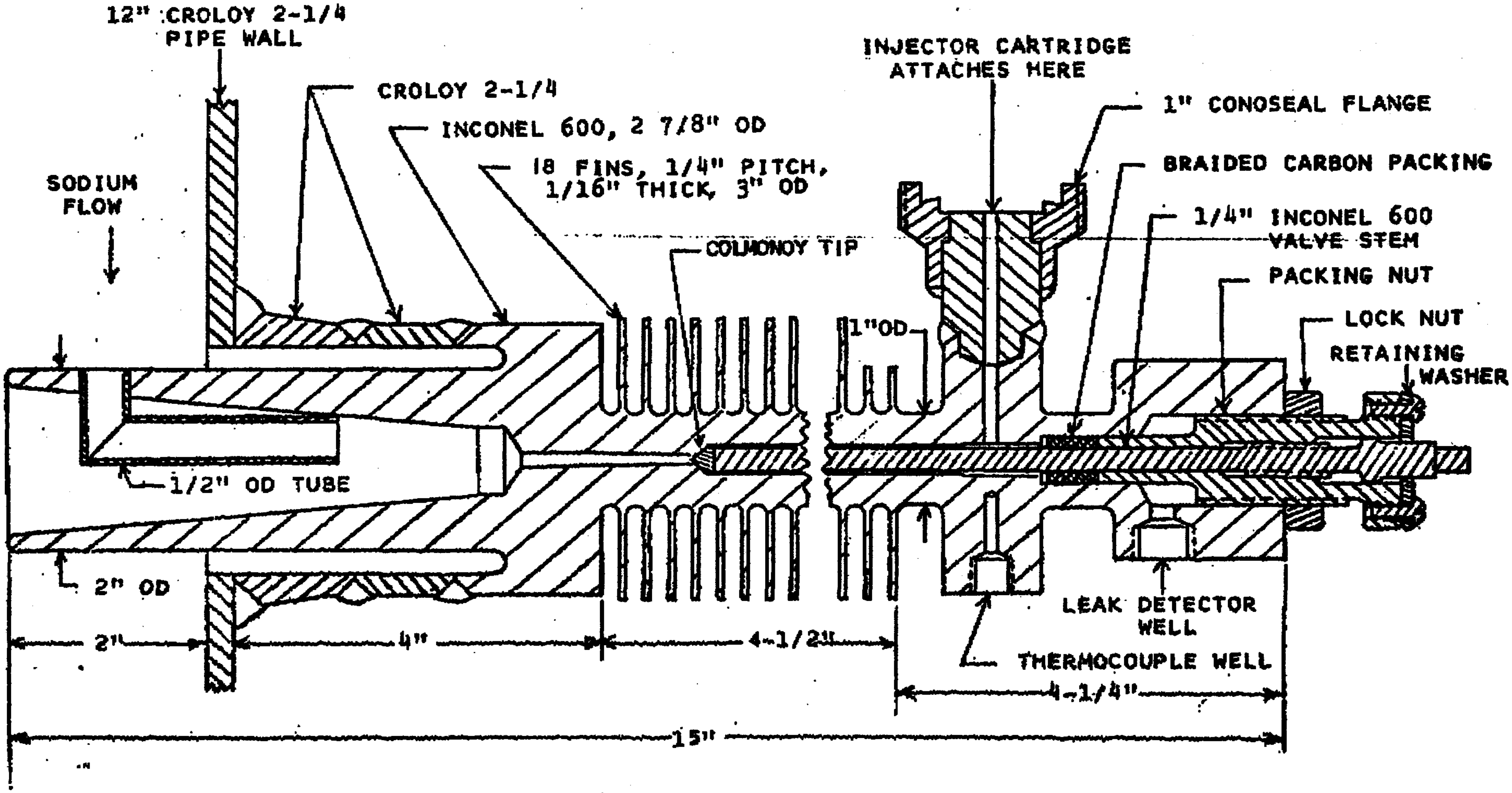

Fig. 6. SODIUM HYDROXIDE INJECTOR VALVE

During the injection the operator is protected from leaking NaOH by the heater outside the cartridge, Conoseal coupling and valve and by packing nuts, etc. outside the stem and piston packing. All handling of NaOH in preparing the cartridge for use is done in a separate laboratory. The cartridge and injector valve could easily withstand 10 times the maximum injection pressure without deforming. The materials used provide ample resistance to corrosive attack by NaOH during the brief periods when it is molten.

The amount of NaOH injected is sized to produce concentration increases useful in calibrating the hydrogen and oxygen meters in the chemical leak detection system but well below the level at which corrosive attack of the sodium containment would become significant. The flushing tube produces considerable dilution of the NaOH with sodium before it leaves the injection nozzle. Tests at ANL have shown that the injected NaOH dissociates into dissolved sodium oxide and hydride in less than a minute at temperatures near 900°F. The one-minute long "slug" of higher concentration produced by the injection will mix completely with the flowing sodium inventory in four passes around the secondary sodium loop. At EBR-II the injector valve is installed in a vertical stretch of pipe so that gravity does not attract the denser NaOH towards the pipe wall while it is dissolving. Tests at ANL have indicated that corrosive attack of the pipe wall would be negligible even without this precaution.

9.3 Cover-Gas Hydrogen Meter

The primmary safety concern with regard to the cover-gas hydrogen meter (CGHN) is to assure that it will not create an argon-to-air leak. The sensing element is a nickel tube, 1/4" I.D. x 0.010" wall x 2" long, evacuated on the inside and heated to 1040°F maximum by a heater coil surrounding the tube. Argon cover gas flows upward through the annulus around the membrane by thermal convection. Extrapolation from test results on larger diameter membranes at ANL indicates that this membrane would collapse quickly if the external pressure reached 1000 psi and should last indefinitely at 400 psi. In either case the membrane usually remains leak tight after collapse. If a leak does form, it is very small. In this case the pressure inside the vacuum system will gradually rise to that of the cover-gas. Tests on similar vacuum systems used on the EBR-II hydrogen meters[4] showed that the ion pump chamber starts deforming at ∿350 psi but does not leak until the internal pressure exceeds 800 psi. Thus the vacuum system provides adequate backup argon containment for the membrane. The CGHM probe is sealed to the top of a standpipe on the surge tank with a mechanical coupling to be selected by EBR-II. Any of several proven coupling designs are adequate for this service.

The CGHM probe also contains a small coil of 1/16" O.D. nickel tubing through which a tiny amount of hydrogen can be diffused into the up-flowing argon stream for on-line calibration of the meter. This coil can stand much higher external pressure without collapse than the 1/4" diameter membrane. If the coil were mechanically broken during service, the connecting tubing outside the probe would provide backup containment. The hydrogen source is a small cylinder of hydrogen gas or a hydrogen-argon mixture. The total quantity of hydrogen in the cylinder is too small to produce an explosive mixture in the surrounding room if it all escaped.

The ion pump lead carries 3000 V d-c and requires the normal precautions for high-voltage lines as described in the operating manual.

9.4 Acoustic Instrumentation

All attachments are to the outside of the steam generator vessel. Specifically, the General Electric accelerometers are held on by a ceramic standoff and mounting bolts attached to the vessel wall by drill and tapping. The Rockwell transducers are mounted to the O.D. of the tubesheet using drill and tapping or stud welding techniques. (See Par. 6.12)

10. References

1. S. H. Sheen and J. M. McKee, "operating Manual for EBR-II Cover Gas Hydrogen Meter, "ANL-CT-80-5, November 1979.

2. S. G. Stehling, et al., "Development Testing of Leak Injection Devices for Use on Testing Leak Detection Modules in LMFBR's," NEDM-14129, August 1976.

3. S. G. Stehling and P. M. Magee, "Interim Report - Leak Detection Test Activities on the General Electric Steam Generator Test Rig (SGTR)," GEFR-00400, September 1978.

4. ANL-7868, p. 19 (1971)