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FEASIBILITY OF LEAK
DETECTION INSTRUMENTATION
FOR DUPLEX-TUBE STEAM GENERATOR

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ABSTRACT

A literature search has been carried out to determine if current state-of-the-art for sodium vapor and water vapor detectors are feasible as leak detection instrumentation for the Westinghouse duplex tube steam generator. A commercially available probe-type water vapor detector has been identified and a thermal ionization type sodium vapor detector, currently being developed by Westinghouse, has been selected as the reference sodium vapor leak detector. Recommendations are made concerning the experimental studies required to adapt the selected instrumentation to steam generator plant applications. Proposed future instrumentation development programs are also identified.

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1. INTRODUCTION

Steam generators for sodium-cooled fast breeder reactors are susceptible to serious damage from sodium-water reactions initiated by a steam generator tube fault. Consequently, the Atomic Energy Commission is sponsoring the development of alternate designs for units that can avoid the effects of such reactions. The Westinghouse duplex tube steam generator concept utilizes pressurized helium to fill the space between the duplexed tubes and establish a buffer zone separating the sodium and water sides.⁽¹⁾ This helium provides a means for detecting the occurrence of an individual fault on either the inner or outer tube. As presently conceived, the inside surface of the outermost duplex tube contains four longitudinal grooves located at 90° intervals that run its entire length to facilitate the flow of helium. These grooves are 20 mils in diameter, while the gap spacing between the inner and outer tubes is much less than 1 mil. By rapidly detecting these faults when they occur, and then taking some remedial action, the occurrence of a sodium-water reaction can be prevented.

During FY 1974, the overall objective of the Westinghouse steam generator effort is to demonstrate the technical feasibility of the duplex tube concept, and an important aspect of this includes the capability to detect an individual tubing fault on either the water/steam-side or the sodium-side of the duplex tube using the helium system. This requires the identification of potential methods for making the detections as well as instrumentation which is available for use in a reference leak detection system.

An analysis of the duplex tube steam generator indicates that it is possible for many different kinds of faults to occur in an actual system from a myriad of locations but that the types of leaks may be

summarized as follows (see Figure 1): (a) water/steam-side leaks where high pressure water or steam can enter the helium system, (b) sodium-side leaks where either helium gas can enter the sodium stream or sodium vapor can enter the helium system, and (c) helium-to-air leaks where the pressurized helium system is leaking to the outside atmosphere. Since the free surface between the duplexed tubes will stop the propagation of faults across the interface region, a sodium-water reaction is possible only in the very unlikely event that both portions of an individual tube are simultaneously breached near each other, as would occur if a tube is sheared.

For the leak detection aspects which are peculiar to the duplex tube design (i.e., those related to the helium system), there are two important feasibility concerns which can be identified and which must be considered: (1) Can the occurrence of a water-side or sodium-side leak in a duplex tube be detected by some instrumental means involving the helium system? and (2) Can a satisfactory leak detection system be constructed from instrumentation that is either available or under development? The purpose of this topical report is to address these feasibility concerns by accomplishing the following tasks:

- (a) evaluating from the literature available leak detection methods and instruments for the detection of sodium-side leaks (sodium vapor in helium) or water-side leaks (water vapor in helium, pressure rise in helium),
- (b) assessing the applicability and adaptability of the methods and instruments for an operating steam generator,
- (c) selecting a reference leak detection instrument system for the duplex tube design, and
- (d) specifying necessary modifications and instrument developments that will be required for an operational plant.

For completeness, this report will also make brief mention of in-sodium leak detection instrumentation needed for the duplex tube steam generator, such as the gas sparger system which Westinghouse is developing under this contract for detecting helium-in-sodium, and the electrochemical oxygen meters and diffusion hydrogen meters which are used to detect sodium-water reactions.

2. CONCLUSIONS

1. Based on reviewing state-of-the-art developments and instrument availabilities, leak detection instrumentation for the Westinghouse duplex tube steam generator is feasible. However, further characterization and adaptation of the instruments for plant use will be required.

2. The leak detection system should contain the following instrumentation associated with the helium plenum: water vapor detectors, sodium vapor detectors and pressure transducers, and the following associated with the sodium: gas chromatograph with sparger. These instruments are specifically for the third fluid system. Electrochemical oxygen meters and diffusion-type hydrogen meters should also be included on the sodium side as additional instrumentation for detecting sodium-water reactions.

3. Commercially available water vapor detectors were reviewed for their applicability in view of the requirements and constraints set up by the third fluid leak detection system. A total of 59 commercially available humidity and moisture monitors were identified. Of these, eleven units appeared to be applicable to the duplex tube concept: one unit was selected as the reference instrument.

4. The Panametrics moisture monitor equipped with a high pressure probe has been selected as the reference water vapor detector. This device is small, relatively inexpensive, capable of remote positioning at multiple locations, and sensitive to water vapor concentrations below 1 ppm. The probe provides electrical readout and can withstand pressures to 1500 psig, although its temperature of operation is limited to 60°C. An outstanding feature to plant application is the fact that reliable results are obtained in either static or flowing gaseous systems.

5. Currently developed, commercial state-of-the-art sodium vapor detectors do not fulfill the requirements defined by the application. However, an instrument being developed by Westinghouse appears to satisfy requirements. The reference sodium vapor detector must not only be sensitive and reliable, it must also respond rapidly and show some specificity in detection.

6. A thermal ionization-type sodium vapor detector, currently being developed by Westinghouse, has been selected as the reference detector. In addition to having the capability of detecting sodium vapor in inert atmospheres, this device also functions in atmospheres containing 1 to 2% oxygen and water vapor. It has electrical readout and is small in size, with a sensitivity to sodium vapor below 1 ppm in inert atmospheres.

7. In addition to sodium and water vapor detectors, the third fluid leak detection system should contain pressure transducers associated with the helium plenum. These transducers can serve as an alternate and less sensitive means for detecting a steam-to-helium leak. A typical transducer that might be employed should be sensitive to pressure variations of ± 15 psi at base pressures of approximately 300 psi.

3. RECOMMENDATIONS

1. Additional engineering studies should be conducted to adapt commercially available instrumentation to the duplex tube steam generator application. This should include development work to study detector responses and to harden their design.

2. Feasibility of the Westinghouse thermal ionization gauge as a sodium vapor detector has been demonstrated. Further studies are necessary to characterize and adapt this device to plant applications.

3. A detailed engineering effort is necessary to explicitly define the instrumentation and control package that together with the detectors will finally make up the third fluid leak detection system. This package should be capable of signal assessment and logic functions to permit the detection of a leak occurrence with a high degree of confidence.

4. SODIUM VAPOR DETECTORS

In order to select the best available sodium vapor detection method for the duplex tube steam generator, a number of parameters must be considered. A properly selected detector should be able to respond quickly to extremely small leaks to lessen the possibility of component deterioration or other potentially serious situations. Additionally, because the purity of the gaseous helium within the steam generator may vary at a given location, leaking sodium may behave differently in various sections of the system. For instance, in a location where the helium is quite pure, the sodium will remain in metallic form and be present as sodium vapor. However, if the helium contains significant quantities of water vapor or oxygen, the sodium will either hydrolyze or oxidize and sodium aerosol, a mixture of sodium-containing compounds, will be formed. Consequently, a suitable sodium leak detector for the duplex tube steam generator should be responsive to both sodium vapor and sodium aerosols. It should also be small in size and adaptable to electrical readout.

4.1 PRESENT STATE-OF-THE-ART--MEASUREMENT AND DETECTION TECHNIQUES

A search of the available literature has shown that a number of sodium leak detector instruments have been proposed, some of which have been tested in prototypic environments.^(2, 3) These instruments can be broadly classified as to whether they sense leaking sodium by detection of: (a) liquid sodium, (b) sodium vapor, or (c) a reaction product formed by sodium. Only the last two types of instruments have application in the duplex tube steam generator. Unfortunately, the development of instruments in these categories is still in the early stages and no commercial instruments have been developed.

In addition to the work cited in the literature, Westinghouse is conducting in-house development studies on two different types of sodium vapor detectors. One type, a solid state device, employs the solid electrolyte, $\beta\text{-Al}_2\text{O}_3$, which in the presence of sodium vapor can be made to generate a current by the conduction of sodium ions. The second device, a thermal ionization detector, depends upon the thermal ionization of sodium or sodium-containing compounds and the subsequent measurement of an ion current.

4.1.1 IMEC Review⁽²⁾

One of the most recent reviews of liquid sodium-to-gas leak detectors is presented in a report by K. A. Davis.⁽²⁾ This section summarizes portions of that report which are relevant to the duplex tube steam generator. Basically, the detection of sodium-to-gas leakage may be divided into two methods: (1) leak detection by sensing sodium vapor and (2) leak detection by forming and sensing a reaction product.

4.1.1.1 Leak Detection by Sensing Sodium Vapor

All vapor detection methods reviewed in the report were dependent upon the quality of the sodium vapor formed, since it is a function of ambient pressure, sodium temperature, gas environment impurities, and chemical interaction with other substances or materials causing a possible loss of sodium vapor. Additional factors were also considered including: (1) impediments to sodium vapor formation, e.g., reaction with impurities in the gaseous environment and the presence of ambient pressure, (2) condensation of sodium vapor prior to reaching the detector, and (3) the diffusion of sodium vapor from the leak site to the detector system.

The types of sodium vapor detector methods include: chemical indicator or conductivity measurements, light

emission methods (flame excitation of vapor and sensing via a photoelectric cell configuration), light absorption (atomic) using photocell activation in conjunction with a CdS detector cell, and gamma radiation sensors for radioactive Na^{24} from the primary sodium loop (not applicable to the duplex tube design).⁽⁴⁻⁶⁾ While the light emission type is both sodium sensitive and commercially available, it is large, bulky and insensitive to sodium oxide or aerosol. Most of the vapor-sensing detectors rely upon an auxiliary piping system to bring vapor to the detector. This generally increases total system cost and makes multi-location sampling difficult. These methods would not be well suited for use in the duplex tube steam generator.

4.1.1.2 Leak Detection by Forming and Sensing a Reaction Product

Reaction product sensing methods that have been tested include: optical, radioactive source ionization, or water reaction (ionic conductivity) and smoke detection techniques. Various chemical approaches, such as hydrogen detection from the methyl alcohol-sodium vapor reaction, special chemically reacting paint for container surfaces (proposed -- not tested), special thermal insulations that yield readily detectable reaction products, or sodium sensitive materials that produce some reaction signal, were also discussed.⁽⁷⁻⁹⁾ Most of these methods have not been fully tested on large scale systems and very little actual operational data is available. Therefore, they cannot be appropriately considered for use.

4.1.2 Atomics International Report⁽¹⁰⁾

This report, in addition to reviewing current methods for detecting and locating sodium-to-gas leaks, classifies various techniques (electrical, thermal, and smoke detectors and sodium vapor detection by

corrosion) according to their applicability in various areas of the LMFBR demonstration plant. As indicated in the LMEC review,⁽²⁾ many sodium vapor detectors have been defined, but because of limitations set forth by the variety of environments in the LMFBR demonstration plant, no single detector may be employed throughout. Indications are that a number of detection techniques will be required for the complete monitoring of the plant. Additional sodium leak detection development and testing has also been indicated, pointing up the inadequacy of previously developed methods.

4.1.3 Westinghouse Current Studies

During the past few years, Westinghouse Electric Corporation has maintained a sodium vapor detection development program based on two techniques: (1) solid electrolytes employing sodium beta-alumina and (2) thermal ionization. An acceptable sodium vapor detector for reactor plant use should be able to operate remotely and unattended for long periods of time, often in inaccessible, high radiation field environments, and for a maximum usefulness, it should also be capable of indicating both the size and location of a leak. As indicated in the aforementioned review articles, most of the possible instruments are clearly too large, costly or insensitive to sodium oxide or aerosol. Consequently, there remains a need for a simple, reliable, low-cost device that is capable of sensitive, remote, in situ detection of a sodium leak. The above mentioned Westinghouse sodium vapor detectors appear to satisfy most of the necessary requirements.

4.1.3.1 Solid Electrolyte Sodium Vapor Detector

Sodium beta-alumina (hereafter β -alumina), which has the chemical formula $\text{Na}_2\text{O} \cdot 11\text{Al}_2\text{O}_3$, is an impervious ceramic solid electrolyte that has the ability to conduct sodium ions.⁽¹¹⁻¹³⁾ This unique conduction property provides an opportunity for the construction of a sodium vapor detector as well as a number of other electrochemical devices.⁽¹¹⁾ The ionic resistivity of this material in the polycrystalline form is 200

to 250 ohm-cm at 25°C and approximately 18 ohm-cm at 300°C.^(11,12)

Another sodium ion conductor, commonly called beta-double prime alumina (β'' alumina), can also form the basis of these devices. This material has the chemical formula $\text{Na}_2\text{O} \cdot 5\text{Al}_2\text{O}_3 \cdot \text{MgO}$ and has a higher sodium ion conductivity than β -alumina,⁽¹¹⁾ making it more attractive for certain applications. However, β'' alumina is not yet available as a commercial material.

This solid electrolyte device is composed of a small β -alumina pellet with attached metal electrodes. Under an applied bias voltage, this detector shows an instantaneous current response when in contact with an inert gaseous environment containing sodium vapor. When sodium vapor is absent from the gaseous environment, the device shows essentially zero response. Under moderate bias voltages, the detector yields readily measurable currents at temperatures from 300 to 500°C and for sodium vapor concentrations from 0.2 to 1700 parts per million. A typical detector response curve to a simulated leak experiment for a beta-alumina type sodium vapor detector is shown in Figure 2. The simplicity of the detector design lends itself readily to multiple location use and to remote operation in inaccessible locations. However, it does not appear to sense sodium-containing compounds in the vapor state.

4.1.3.2 Thermal Ionization Sodium Vapor Detector

This detector takes advantage of the low ionization potential of sodium ($\text{IP}_{\text{Na}} = 5.12\text{V}$) relative to helium.⁽¹⁴⁾ Sodium vapor is ionized and detected as a current that is proportional to the number of positive sodium ions. Sodium vapor concentrations have been measured in the range of 0.009 to 160 ppm. A typical response curve of the thermal ionization-type detector to a simulated sodium leak in argon is shown in Figure 3. Studies have shown that the presence of oxygen and water vapor in the inert gas affect the sensitivity and response of the detector by less than 10%.

The detector is operated in an inert gas atmosphere (nitrogen, helium, or argon), and a low initial background signal may be recorded prior to the arrival of sodium vapor at the detector system. This background signal may be useful in indicating proper functioning of the detector. A large sudden increase in signal is an indication of the presence of sodium vapor, and this rapid increase could be used to trigger an alarm, thus indicating a sodium leak.

If either Na_2O or NaOH reach the ionization detector, they will also be detected yielding a response similar to that of sodium. The compounds will first be dissociated ($\Delta H_{\text{DISS}} \text{Na}_2\text{O} = 99.4 \text{ kcal/mole}$; $\Delta H_{\text{DISS}} \text{NaOH} = 45.7 \text{ kcal/mole}$),⁽¹⁵⁾ and then the sodium will be ionized.

4.2 SELECTION OF REFERENCE SODIUM VAPOR DETECTOR

Previously developed sodium vapor detectors do not meet the requirements for monitoring the onset of possible sodium leaks in the Westinghouse duplex tube steam generator. The ideal reference sodium vapor detector must not only be sensitive and reliable, but it must respond rapidly and show some specificity of detection. In addition, the potential for plant operation and cost must be considered. The two devices currently being developed by Westinghouse better fit the criteria of the idealized sodium vapor detector. Feasibility experiments have confirmed that the solid electrolyte sodium β -aluminum detector has the ability to detect small concentrations of sodium vapor (0.2 to 1700 ppm) in inert gas environments operating at temperatures from 300 to 500°C. In addition, simulated leak experiments also have shown that it has a high sensitivity and fast response for the detection of sodium vapor. However, the thermal ionization-type sodium vapor detector shows the most promise as the best available sodium vapor detector. In addition to having the capability of detecting sodium vapor (0.009 to 160 ppm) in inert atmospheres, this device also functions in atmospheres

containing 1-2% oxygen and water vapor. The experimentally observed selectivity of the detector for sodium, as well as its speed of response and low cost, make it the most suitable candidate for consideration as a reference sodium vapor leak detector.

5. WATER VAPOR DETECTION

5.1 PRESENT STATE-OF-THE-ART MEASUREMENT TECHNIQUES

A comprehensive search of the technical literature, as well as technical brochures of commercially available instrumentation, indicates that a number of techniques are currently being employed to detect the presence of water vapor in gases. The selection of a specific technique, and thus a particular instrument, for the duplex tube steam generator depends on a number of factors, the two most important being (1) the sensitivity of the technique to water vapor in an inert atmosphere, and (2) the adaptability of the instrument for use in the intended application. This section will review presently available methods, as surveyed in an Instruments and Control Systems Review, with emphasis being placed on available commercial instrumentation.^(16,17)

5.1.1 Dew Point Method

The dew point of a gaseous system is defined as the temperature to which a gas must be cooled at constant pressure to be saturated with water. In general, dew points are normally expressed in degrees Fahrenheit or Centigrade. Thus, dew point monitors must include a refrigeration device which is capable of cooling a gas until condensation occurs (saturation). In general, cooling is achieved by refrigeration mixtures (dry ice / acetone/alcohol) and thermoelectric devices. Recent commercial instrumentation has automated this type of operation by employing optical detectors which sense water condensates on a cooled mirror; see Figure 4. Although this type of device can cover a wide range and provide highly accurate results, usually high cost and instrumentation complexity does not permit simple operation.

5.1.2 Hygroscopic Devices

At the present time, a number of commercially available instruments utilizing hygroscopic material are being employed to detect water vapor in gases. These include: (1) Impedance devices, (2) Capacitance sensors, and most recently, (3) Piezoelectric crystals. One of the chief restrictions offered by this type of device is that the hygroscopic material employed in the detector or probe absorbs and/or adsorbs water causing a historical or memory effect.

5.1.2.1 Impedance Devices

An impedance water vapor detector is based on the fact that hygroscopic materials change resistance as a function of moisture content. A number of hygroscopic materials have been employed with the most common device being the Dunmore element utilizing lithium chloride. Other hygroscopic materials currently being employed include: (1) aluminum oxide, (2) various ceramic materials, and a less common material, (3) polyvinyl chloride.

5.1.2.2 Capacitance Sensors

This device utilizes the concept that the dielectric constant of a given material changes in the presence of water vapor. A typical probe for monitoring water vapor in gases or liquids may consist of two concentric cylinders forming a capacitor. The circular gap is generally filled with a dessicant so that the absorption of water by the dessicant changes the capacitance between the plates. In general, measurement of water vapor concentration is made via bridge or frequency response techniques.

5.1.2.3 Piezoelectric Crystals

This device also depends upon the adsorption of water vapor by a hygroscopic film. A piezoelectric crystal in an electronic oscillator circuit is generally coated with a hygroscopic film which in the presence of water vapor adsorbs moisture. Since the adsorption increases the mass

of the crystal, the natural oscillation frequency of the crystal changes (decreases), thus indicating the presence and amount of water vapor. Because of the sensitivity of this type of device, commercially available instruments employ a dual oscillation system in which one crystal is exposed to a dry gas and serves as the reference material.

5.1.3 Electrolytic Hygrometers

The electrolytic hygrometer is a coulometric device for the measurement of water vapor. The mode of operation is that of a coulometric cell, i.e., the moisture or water vapor content in a given gaseous atmosphere can be determined by electrolyzing the water in a given sample volume into hydrogen and oxygen and observing the resultant current. If the mass flow rate or gaseous volume is held constant while flowing through the electrolysis cell, the monitored current is directly related to water concentration. In general, commercial instruments consist of an electrode system connected by a layer of dessicant material. Any absorbed moisture is electrolyzed by a voltage applied across the electrodes. A number of limitations exist for this type of device but the primary measurement error is due to the recombination effect of oxygen in hydrogen-rich atmospheres. In addition, this type of device is sensitive to element contamination and corrosion and the gradual elution of the dessicant. Another important consideration is that the gaseous density, flow rate, and pressure must be carefully controlled.

5.1.4 Heat of Adsorption Hygrometers

This is a rather simple technique, but it is not widely employed in commercial instrumentation. The adsorption and desorption of moisture are processes which release and absorb heat, respectively. The method generally employed in commercial instrumentation involves cycling a sample of dry reference gas and the gas to be analyzed alternately through a column of adsorbant material. The measured temperature differential is noted and is an indication of the amount of moisture present in the sample gas; see Figure 5.

5.1.5 Spectrometers

The technique of infrared spectroscopy may be employed as a technique for the measurement of water vapor in a gaseous medium. This method detects the moisture content by monitoring the energy absorbed by an infrared active water band. This device can yield extremely accurate results but tends to be complex. Moreover, it requires gas cells with long path lengths to detect low level moisture. Figure 6 illustrates this type of water vapor sensor. Another limitation is the masking of water vapor bands by impurities which may be present in the gaseous system being analyzed.

5.1.6 Microwave Devices

This type of device may also be considered as a spectroscopic technique. The absorption of microwave energy by water may also be employed as a means of determining the concentration of water in a given fluid. In general, microwave techniques are applicable to gases, liquids, and solids with a general restriction being that the material cannot be electrically conductive. In general, this technique is quite complex and does not lend itself well to on-line instrumentation.

5.1.7 Nuclear Moisture Monitors

This method commonly consists of a high energy neutron detector with a gamma ray source and detector to provide a necessary gas density measurement. In principle, the retarding effect of hydrogen atoms on the speed of neutrons can be used to detect moisture. Also required is the simultaneous density measurements to provide compensation for other effects. This method and the complexity of instrumentation required by this technique is far too sophisticated for routine on-line measurements of water vapor.

5.1.8 Resistance-type Moisture Monitors

This method is normally applied to the measurement of water in solid systems. The resistance of many solid materials decreases with

moisture content. Thus this property may be applied to the measurement of moisture in solids. In general, fixed electrodes are placed in contact with the sample and the measurements are made by making the contact electrodes part of an AC bridge circuit.

5.1.9 Other Methods--Non-Commercial

A retrospective literature search utilizing the facilities provided by the Aerospace Research Application Center (ARAC) at Indiana University, to assess present water vapor measurement techniques for gaseous systems was also employed. This computer search covered the following literature sources: (1) Defense Documentation Center File (Unclassified), 1964 to 1970 and (2) Government Report Announcements, 1968 to date. This survey has identified 36 references pertinent to water vapor detection in inert gases with five being directly related to helium/water vapor systems.⁽¹⁸⁻²²⁾ A critical review of these references has indicated that a number of spectroscopic techniques, e.g., neutron inelastic scattering, infrared and photoelectron methods are presently being employed but are far too sophisticated for this particular application.

5.2 CANDIDATE WATER VAPOR DETECTORS

As part of this study, 59 commercially available humidity and moisture monitors have been identified, and of these, 11 units appeared to have some potential use for this application and are listed below in Table I along with the mode of detection and operation.

TABLE I - Candidate Moisture Monitors

<u>Manufacturer</u>	<u>Detection Mode</u>	<u>Operation Mode</u>
1. Alnor Instrument Co. Chicago, IL	Dew point, cloud chamber	Manual
2. Anacon, Inc. Ashland, MA	Infrared	Continuous
3. Atlantic Instruments & Electronics, Inc. Watertown, MA	Resistance	Manual
4. Beckman Instruments, Inc. Fullerton, CA	Hygroscopic	Continuous
5. Dupont Co. Wilmington, DE	Electrolytic, Hygroscopic	Continuous
6. General Eastern Corp. Watertown, MA	Hygroscopic	Continuous
7. Mine Safety Appliance Co. Pittsburgh, PA	Heat of Adsorption	Continuous
8. Panametrics, Inc. Waltham, MA	Hygroscopic	Continuous
9. Process Analyzers, Inc. Houston, TX	Electrolytic	Continuous
10. Singer, Vap-Air Div. Chicago, IL	Dew point	Continuous
11. Yellow Springs Inst. Co. Yellow Springs, OH	Hygroscopic	Continuous

These instruments are discussed below in terms of their suitability for use in the duplex tube steam generator.

5.2.1 Alnor Dew Point Meter

The Alnor dew point meter is a commercially available moisture monitor which will provide batch measurements in the range of 8 to 10,000 ppm(v) water vapor.⁽²³⁾ This is a highly reliable device and is generally employed as a calibration instrument since its mode of measurement (cloud chamber) is fundamental by design. In general, the instrument operates at ambient temperature and pressure. From an economic and potential for plant application point of view, this device is moderately priced (\$430 to \$635 depending upon model selected) but because it is a non-recording batch measuring device, a continuous monitoring system is not feasible.

5.2.2 Anacon Infrared Analyzer

Anacon Incorporated manufactures a monitor which is capable of continuously monitoring the moisture content of gases. Only a limited amount of information has been obtained concerning this device, although its mode of operation is described as an infrared moisture monitor.⁽¹⁶⁾ As previously discussed in section 5.1.5 extremely accurate results may be obtained by this technique, but complex instrumentation utilizing long path gas cells are generally required. In addition, the masking of water vapor bands by impurities in the gas stream is possible, thus providing erroneous results.

5.2.3 Atlantic Instruments Resistance-Type Moisture Monitor

The detection mode employed by this instrument is the resistance type, i.e., hygriators (hygroscopic elements) whose resistance changes with ambient humidity. Although only a limited amount of information was available, operation appears to be by manual mode.⁽¹⁶⁾ Information available does indicate that the hygriators are especially designed for use in sealed systems, and since absorption is reversible the elements may be re-used.

5.2.4 Beckman Instruments Hygroscopic Moisture Monitors

Various models of hygroscopic moisture monitors are commercially available from this instrument manufacturer.⁽²⁴⁾ In general, these devices are described as rapid response instruments which provide highly reliable results in flowing gas streams. The moisture content of gaseous systems in the ranges 0 to 10 and 0 to 1,000 ppm(v) in four steps with an accuracy of $\pm 5\%$ full scale (FS) may be monitored. In addition, sensitivity is less than 1 ppm(v), but a bypass gas flow rate on the order of 2 CFH is required. The Beckman instruments have been utilized in plant applications for process gas analysis, Thus adaptation and potential for industrial use has been demonstrated.

5.2.5 Dupont Electrolytic, Hygroscopic Moisture Monitor

Dupont (previously CEC) moisture monitors provide continuous moisture measurement in gaseous systems.⁽²⁵⁾ The range of water vapor detection is between 1 to 1,000 ppm(v) with an accuracy of 10 ppm FS. A response time is quoted to be $6\frac{2}{3}\%$ FS in 30 seconds and operating conditions of 20 to 100 psig up to 125°F are described. A flowing gas stream of at least 100 cc/min is required, and alcohols and light hydrocarbons may interfere or produce false signals.

5.2.6 General Eastern Hygroscopic Moisture Monitor

The instrument manufactured by this corporation is one of the very few which offers a probe type sensor with operating capability in stagnant gas systems.⁽²⁶⁾ This device is a continuous water vapor monitor with a response of less than 30 seconds (less than 5 minutes in non-flowing gas systems) in flowing gas streams and an accuracy of $\pm 3\%$ between 10 and 95% relative humidity (RH). The device is capable of operation between -40 and 120°F and a pressure to 200 psig. The fact that the sensor probe is independent of the instrumentation gives this monitor potential for plant applications, although the rather low detection limit (10 to 95% RH) confines it.

5.2.7 Mine Safety Appliance (MSA) Heat of adsorption Moisture Monitor

MSA instrumentation is capable of continuously monitoring low concentrations of water vapor in flowing gas streams.⁽¹⁶⁾ Measurements may be made in two ranges: 0 to 10 ppm(v) and 0 to 5,000 ppm(v) with an accuracy of $\pm 2\%$ FS. The speed of response is described as 90% FS in 180 seconds. The mode of operation is by heat of adsorption, thus a dry reference gas is required for calibration purposes. The construction of this moisture monitor permits its use in plant operations where a continuous water vapor monitoring device is required for flowing gas streams.

5.2.8 Panametrics Hygroscopic Moisture Monitor

The instrument manufactured by this company employs a probe type detector which may be located remotely from the measurement instrumentation.⁽²⁷⁾ Technical literature has indicated that a 63% change is obtained over the entire dynamic range of the instrument (20,000 ppm(v) to about 0.001 ppm(v)) within a few seconds. In addition special probes are available which permit operation in gaseous environments at pressures of 1,500 psig; a temperature limit has been set at 60°C. An outstanding feature to plant application is the fact that reliable results are obtained in either static, or flowing gaseous systems. Additionally, sensor probes may be located remotely at distances up to 2,000 feet without introduction of error. Data shows that these sensors have been continuously operated for 5,000 hours with no apparent drift from original calibration values.

5.2.9 Process Analyzers Electrolytic Moisture Monitor

The Process Analyzers' instrument can measure the water content in flowing gas streams in the range of less than 1 ppm(v) to 1,000 ppm(v) with an accuracy of 5% FS. Construction of the instrument makes it applicable for plant operation, but because it is an electrolytic device, the density, flow rate and pressure of the gas stream must be accurately known. In

addition alcohol impurities, if present, will produce a false or erroneous signal.

5.2.10 Singer (Vap-Air Div.) Dew point Moisture Monitor

This device utilizes an automated dew point method of detection to monitor the moisture concentration of gases.⁽²⁸⁾ The range of operation is between -20°F and 140°F (425 ppm(v) to greater than 10,000 ppm(v)) with a speed of response of $5^{\circ}\text{F}/\text{sec}$. The device is operable at ambient temperature and an upper pressure limit of 1,000 psig. In addition, sampling pumps and chambers as well as transmitting dew point probes are available; calibration facilities have also been made available for routine calibration checks. However, the sensitivity of the instrument is low.

5.2.11 Yellow Springs Inst. Hygrometer

This instrument employs the hygroscopic mode of detection and a continuous mode of operation is standard, thus permitting on-stream or real time water vapor measurements. Technical literature indicates that the range of water vapor measurement is a dew point from -30°C to $+50^{\circ}\text{C}$ (375 ppm(v) to greater than 10,000 ppm(v)) with an instrument response of $3^{\circ}\text{C}/\text{sec}$.⁽²⁹⁾ In general the instrument is operable with gas streams at ambient temperature and a maximum pressure of 100 psig. Although the potential for plant application exists, a flowing gas stream is required.

5.3 SELECTION OF REFERENCE WATER VAPOR DETECTOR

A review of current state-of-the-art literature and commercially available water vapor detectors has shown that water vapor leak detection instrumentation for the duplex tube steam generator is feasible. Additional characterization is necessary to adapt this instrumentation for plant use since the constraints and requirements set up by this particular application are rather unique. In defining a reference water vapor detector, a number of parameters were considered which include: (1) detection limit, (2) speed of response, (3) accuracy, (4) reliability, (5) possible false signals, (6) potential for plant application, and (7) overall economics. Although each water vapor detector reviewed had one or more associated problems when considered for this application, the most desirable was the Panametrics device (see Appendix 10.1) equipped with a high pressure probe. This device is small, relatively inexpensive, capable of remote positioning at multiple locations, and is sensitive to water vapor concentrations below 1 ppm(v). In addition, the probe can withstand pressures to 1500 psig, but its operational temperature is limited to 60°C. A schematic of the probe is shown in Figure 7. A most important factor which makes the Panametrics device applicable is the ability to measure water vapor in a static environment--a condition which must be considered for the third fluid leak detection system.

6. ADDITIONAL INSTRUMENTATION

When considering the definition of a total leak detection package for a single duplex tube steam generator module, additional instrumentation beside sodium vapor and water vapor detectors must be defined. Monitoring devices must be considered for the sodium-side of the tube bundle in the duplex tube steam generator to detect helium-to-sodium leaks. In addition, on-line meters for monitoring the hydrogen and oxygen activity of the sodium side must be considered to detect the onset of sodium-water reactions in the very unlikely event that both tubes in the duplex tube assembly are breached. The helium system will also require some pressure monitoring device.

6.1 HELIUM SIDE (GAS PLENUM)

In addition to sodium vapor and water vapor detectors, the third fluid leak detection system should contain pressure transducers associated with the helium plenum. These transducers can serve as an alternate and less sensitive means for detecting a steam-to-helium leak than water vapor detectors. They are an alternate means because the high pressure steam entering the helium system will ultimately cause a pressure increase, but they are less sensitive because they are incapable of confidently signalling a leak from a small pressure change. Normal load variations in the steam generator will cause temperature and pressure fluctuations that can mask a small leak, whereas a chemical detection method for water vapor is a precise, sensitive technique.

A number of commercially available transducers may be adapted for this application. A transducer, Model No. 540, manufactured by Gilmore Industries, Inc., Cleveland, Ohio, is of the type which may be considered for this application. Although capable of operating pressures up to 10,000 psi, these transducers are temperature limited

to 250°F. Quartz transducers for operating at temperatures up to 650°F and pressures to 3500 psi are commercially available (Kristal Instrument Corporation, Grand Island, New York) and may also be considered for this application. A typical transducer that might be employed would be sensitive to pressure variations of ± 15 psi at base pressures of ~ 300 psi.

6.2 SODIUM SIDE

A gas chromatograph equipped with a gas sparger must be employed downstream on the sodium side to monitor the presence of dissolved gases such as helium in the sodium coolant. This apparatus is currently being defined by experimental work at the Westinghouse Advanced Reactors Division (ARD) and will be described in a separate document. The system will detect the onset of sodium-side tube faults.

Electrochemical oxygen meters and diffusion-type hydrogen meters should also be included on the sodium side to detect the onset of sodium-water reactions. These instruments have been well described in the literature,⁽³⁰⁻³²⁾ and since they are not unique to the duplex tube design will not be considered further.

Table II summarizes the proposed leak detection instrumentation package for a single duplex tube steam generator module. Further studies are necessary to adapt both the commercially available and laboratory experimental instrumentation to the final leak detection system. In the final analysis, this instrumentation must be capable of signal assessment and logic functions to permit the detection of a leak occurrence with a high degree of confidence.

Table II. LEAK DETECTION INSTRUMENTATION PER
STEAM GENERATOR MODULE

<u>Instrument</u>	<u>Function</u>	<u>Type</u>	<u>No. Required Per Module</u>
A. Helium Plenum			
1. Water Vapor Detector	Water in Helium	Panametrics Model 1000 with M21 Probe	2 Probes per Plenum (4 per Module)
2. Sodium Vapor Detector	Sodium in Helium	Westinghouse Thermal Ionization Type	2 Probes per Plenum (4 per Module)
3. Pressure Transducer	Helium Pressure	Gilmore Model 540 or Equiv.	2 Probes per Plenum (4 per Module)
B. Sodium Side			
1. Electrochemical Oxygen Meter	Oxygen in Sodium	Westinghouse Model LM-3	2 Outlet side*
2. Diffusion Type Meter	Hydrogen in Sodium	Westinghouse Model HM-1	1 Outlet side*
3. Gas Chromatograph with Sodium Sparger	Helium in sodium	Varian, Model No. 90-75 or Equivalent	1 per Module

*Assume secondary loop has meters for measuring inlet levels.

7. PROPOSED FUTURE INSTRUMENTATION DEVELOPMENT PROGRAM

While it is believed that sufficient experimental work has been done with the detector instruments to accept their basic technical feasibility and to permit their use in the FY-74 test program at their present stage of development, it is recognized that each type of sensor may require some modification, adaptation, or additional development in order to be used in an actual steam generator. Consequently, the development work to produce sensors, whose response characteristics, background, sensitivity, detection limits, and fault conditions are well known, must be defined.

7.1 CHARACTERIZATION OF THIRD FLUID LEAK DETECTION SYSTEM INSTRUMENTATION

Prime consideration must be given to establishing the response characteristics of leak detection instrumentation under prototypic plant conditions. Modification of reference instrumentation should be carried out to meet detailed plant design criteria. Correlations of instrument output with duplex tube geometry leak site and leak size must be determined.

7.2 DEMONSTRATION OF THIRD FLUID LEAK DETECTION SYSTEM IN STEAM GENERATOR MODEL TEST

Following third fluid leak detection instrument development and characterization, leak testing should be carried out on a steam generator model test. Methods should be considered for simulating leaks in the model, and the total system should be qualified as to its ability to detect leaks in the prototypic steam generator unit.

7.3 INSTRUMENTATION AND CONTROL SYSTEM FOR LMFBF STEAM GENERATOR OPERATION AND LEAK DETECTION SYSTEM

The instrumentation and control system to monitor both normal and abnormal operation of the duplex tube steam generator for LMFBF plant

application must be defined. A separate monitoring and control system for the leak detection instrumentation must be developed with the capabilities of signal assessment and logic functions. This system must be able to identify the onset of a leak with a high degree of confidence.

7.4 DEVELOPMENT AND DEMONSTRATION OF LEAK LOCATION PROCEDURE FOR SODIUM-SIDE LEAKS

An independent research effort should be established to develop instrumentation and methods for locating, from the plenum region, individual tubes subject to sodium-side leaks. A technique for plugging these tubes should be developed. In addition, a method for locating a leaking sodium-side tube-to-tube closure weld should be developed and demonstrated.

In summary, the proposed future instrumentation development program must be designed to define practical, well characterized leak detection instrumentation that will be directly applicable to LMFR plant design.

8. REFERENCES

1. Westinghouse Letter Contract AT(04-3)-962 under General Electric Contract AT(04-3)-893 Task 10 LMFBR Steam Generator Development Program.
2. Davis, K. A., "Sodium Leakage Detection, State-of-the-Art Study," Liquid Metal Engineering Center Memo 69-35, Canoga Park, Calif., February 1970.
3. Meeting of Specialists on "Sodium Combustion and its Extinguishment--Techniques and Technology," TID-26076, Hanford Engineering Development Laboratory, Richland, Washington, May 22-25, 1972.
4. Westervelt, D. R., "Sodium Leak Detector," NAA-SR-Memo-1163, November, 1954.
5. Duncombe, E., et al., "Some Analytical and Process Instruments for Measurements in Sodium," Symposium on Alkali Metal Coolants, Corrosion Studies and Operating Experience, Vienna, Austria, November 28, to December 2, 1966, Conf.-661110-20, Paper SM-85/16, pp. 13 and 24.
6. Shepard, R. C., "A Sodium Vapor Detector Based on the Principle of Atomic absorption," NAA-SR-TDR 10553, November, 1964.
7. Yevick, J. G., et al., Fast Reactor Technology: Plant Design, (The MIT Press, 1966) pp. 650-651.
8. Bell, A., "An Improved Leak Detection Unit," Patent No. 765,239 (U.K.), January, 1957.
9. Henley, H. L., "A Method of Detecting the Presence of NaK in an Inert Atmosphere Under Conditions of Ambient Pressure and Temperature," NAA-SR-TDR-11848, February, 1966.
10. Nelson, C., Investigation and Rating of Sodium-to-Gas Leak Detection Techniques," Atomics International LMFBR Technology Supporting Document No. TI-707-520-008, February 12, 1973.

11. Kummer, J. T., "The Sodium-Sulfur Secondary Battery," Materials Problems and Opportunities in Energy Storage Seminar, Philadelphia, 1971.
12. Kummer, J. T., and Weber, N., "A Sodium-Sulfur Secondary Battery," Intersociety Energy Conversion Engineering Conference, American Society of Mech. Engrs., New York, 1967.
13. Yao, Y. Y., and Kummer, J. T., "Ion exchange properties of and rates of ionic diffusion in Beta-alumina," J. Inorg. & Nucl. Chem., 29, 2453-74 (1967).
14. Barrow, Gordon M., Physical Chemistry, McGraw-Hill, Inc., 1970.
15. Wicks, C. E., and Block, F. E., Thermodynamic Properties of 65 Elements--Their Oxides, Halides, Carbides, and Nitrides, United States Dept. of Interior, U. S. Gov't Printing Office, Washington, D. C. 1963.
16. "Survey of Humidity and Moisture Instrumentation," Instruments and Control Systems, pp. 75-82, January, 1972.
17. Wexler, A. (editor), Humidity and Moisture, Vol. 1, Reinhold, 1965.
18. Zimmerman, O. T., and Ramsey, R. C., Psychrometric properties of helium water vapor mixtures: A study of the relationship between temperature, pressure and humidity, and wet and dry-bulb temperatures, Contract N00014-67-A-0158 Final Report, Report No. TR-106, August, 1968.
19. Doebbler, G. F., Molecular Interactions of Water in Biological Systems, Contract AF49(638)-1611 Final Report, Report No. AFOSR-66-2762, November, 1966.
20. Patch, R. W., Absolute Intensity Measurements for the 2.7 Micron Band of Water Vapor in a Stark Tube, Contract AFOSR-71-63 Final Report, Report No. AFSOR-65-2488.
21. Blake, A. J., and Carver, J. H., Determination of Partial Photoionization Cross Sections by Photoelectron Spectroscopy, Grant AF-AFOSR-1131-66, 1967.
22. Courtney, W. C., Kinetics of Condensation from the Vapor Phase, Contract Nonr 415400, Report No. RMD-5515, January, 1965.

23. Alnor Dewpointer Technical Bulletin No. 72-2051, Alnor Instrument Co.,
420 North La Salle St., Chicago, Ill. 660610, October, 1966.
24. Beckman Trace Moisture Analyzers, Bulletin 4101, Beckman Instruments,
Inc., Process Instrument Div., Fullerton, Calif. 92634.
25. Dupont Moisture Monitor Bulletin 26303X, Dupont Instruments, Instrument
Product Division, Monrovia, Calif. 91016.
26. General Eastern Corporation Technical Bulletin, Instrumentation for
Measuring Humidity and Moisture in Gases, General Eastern
Corporation, 36 Maple St., Watertown, Mass. 02172.
27. The Newest Moisture Minder, Bulletin H-2000, Panametrics, Inc., 221
Crescent St., Waltham, Mass. 02154.
28. The Vap-Air Moisture Analyst, Bulletin No. 6511, Singer Vap-Air Division,
6444 West Howard St., Chicago, Ill.
29. YSI Dew Point Hygrometer Bulletin TDPH92, Yellow Springs Instrument Co.,
Yellow Springs, Ohio 45387, Sept. 1969.
30. McKee, J. M., Vissers, D. R., Nelson, P. A., Grundy, B. R., Berkey, E.,
and Taylor, G. R., "Calibration Stability of Oxygen Meters for
LMFBR Sodium Systems," to be published in Nuclear Technology,
March, 1974.
31. Witkowski, R. E., Berkey, E., and Grundy, B. R., "An On-Line Meter for
the Measurement of Hydrogen in Liquid Sodium Systems," ANS
Transactions, 14, No. 1, p. 234, June 1972.
32. Witkowski, R. E., Reed, W. H., Bauerle, J. E., and Berkey, E., "On-
Line Analytical Instrumentation for Monitoring the Oxygen and
Hydrogen Levels in the Sodium Coolant of Liquid Metal Fast
Breeder Reactors," Westinghouse Research Labs Unrestricted
Scientific Paper 73-136-HYMET-P1, November 16, 1973.

Fig. 1—Various fault configurations which must be considered when defining leak detection instrumentation for the Westinghouse duplex tube steam generator

Fig. 2—A typical detector response curve to a simulated leak experiment for a beta-alumina type sodium vapor detector using a flowing argon gas system

Fig. 3—Typical response curve of the thermal ionization-type detector to a simulated sodium leak using a pure argon carrier gas for the sodium vapor

Fig. 4 — Continuous recording optical detection dew point meter

Fig. 5 – Heat of adsorption type water vapor detector

Fig. 6 — Typical single-beam spectroscopic technique for the measurement of water vapor (Infrared, microwave etc.)

Fig. 7 – Capacitive type hygroscopic water vapor detector (probe configuration)

10. APPENDIX

10.1 PANAMETRICS MOISTURE MONITOR

ALUMINUM OXIDE HYGROMETER/MODEL 1000

OUTSTANDING FEATURES

- A true probe with the widest dynamic range available, capable of measuring dew-points from $+20^{\circ}\text{C.}$ to -110°C. ($+70^{\circ}\text{F.}$ to -170°F.)
- Extremely fast response, reaching 63% of its final value within seconds on either the "wet up" or "dry down" cycle.
- Eliminates all requirements for piping systems, manifolds, gas flow and pressure regulators.
- A single readout that monitors up to five (5) remotely located probes, which can be hundreds of feet from each other and the readout.
- Automatic readout available, providing sequential readout of up to six (6) probes every minute.
- Excellent accuracy and precision over the entire dynamic range.
- Low cost per unit measurement.
- A probe unaffected by
 - Large concentrations of most gases
 - Ambient temperatures
 - Ambient pressures
- A probe operable under static or flow conditions.

Theory of Operation

The aluminum oxide humidity sensor has resulted from seven years of intensive research investigation. This sensor originally developed for meteorological purposes to meet the extreme conditions encountered during flights in the upper atmosphere and through space to other planets.

Among the difficult environmental conditions under which it has successfully performed are high temperature sterilization prior to extra-terrestrial flight and measurement of the extremely small water content encountered in the vacuum and sub-zero cold of the stratosphere.

The sensor consists of an aluminum strip which is anodized by a special process to provide a porous oxide layer. A very thin coating of gold is evaporated over this structure. The aluminum base and the gold layer form the two electrodes of what is essentially an aluminum oxide capacitor.

Water vapor is rapidly transported through the gold layer and equilibrates on the pore walls in a manner functionally related to the vapor pressure of water in the atmosphere surrounding the sensor.

The number of water molecules adsorbed on the oxide structure determines the conductivity of the pore wall. Each value of pore wall resistance provides a distinct value of electrical impedance which in turn is a direct measure of the water vapor pressure.

Sensor output is measured with high quality all solid state electronic circuitry designed to provide excellent accuracy and resolution, and maximum stability.

Range

The aluminum oxide element provides the highest sensitivity and greatest dynamic range of moisture measurement achieved by any known technique.

The standard sensor probe will measure water vapor from Dew/Frost Points of $+20^{\circ}\text{C}$ to -110°C . This range represents a change in moisture from 20,000 $\mu\text{g H}_2\text{O/liter}$ to about 0.001 $\mu\text{g H}_2\text{O/liter}$. The lower moisture level is equivalent to at least two orders of magnitude greater sensitivity than achieved by other hygrometers.

A special high humidity probe is also available which provides measurements of Dew Point from $+20^{\circ}\text{C}$ to $+90^{\circ}\text{C}$.*

Speed of Response

Extremely rapid response is available from the humidity element. A 63% change is obtained over the entire dynamic range in a few seconds. This response rate is unmatched by other hygrometers and is obtained on either the "dry down" or "wet up" cycle.

Temperature Range

The standard humidity probe is operable over a temperature range of $+60^{\circ}\text{C}$ to -110°C . No appreciable correction for ambient temperature is required since the element does not display a significant temperature coefficient over this very large temperature range.

In a similar fashion the high humidity probe is operable to temperatures of $+100^{\circ}\text{C}$.*

Pressure

The sensor indications are precisely related to the water vapor pressure

regardless of total ambient pressure without the need for a correction coefficient. Water vapor measurements can be made under vacuum or high pressure conditions from as little as a few microns to as high as 1500 psi total pressure.

Static or Dynamic Use

The sensor can be employed equally well under conditions of completely still air or where considerable gas flow occurs. Its small size makes it ideal for measuring moisture conditions within completely sealed containers or dry boxes.

It will also provide satisfactory use under gas flow conditions as high as 1000 cm/sec.

Accuracy

Excellent accuracy and precision are obtained with this moisture measurement system. In the high humidity regions values of $\pm 0.5^{\circ}\text{C}$ can be obtained over most of the range. As humidity decreases these errors will increase to values of $\pm 2.0^{\circ}\text{C}$ in the Frost Point region of -100°C (0.01 $\mu\text{g H}_2\text{O/liter}$). Every sensor is individually calibrated over its dynamic range by two completely independent methods assuring a high degree of absolute accuracy.

Unlike other hygrometers which assume good accuracy, each sensor is supplied with a calibration curve.

No calibration, particularly in the low humidity regions, can be completely divorced from the errors of the calibration apparatus. The element calibration curves indicate each value of humidity tested and include the combined error of both calibration methods which typically will approximate $\pm 1.0^{\circ}\text{C}$ throughout the entire dynamic range.

Long Term Storage & Operational Stability

The sensors are designed to provide long term stability in both use and storage. Sensors randomly selected over three year storage period show no change in characteristics. Other sensors continuously operated and cycled over wide humidity changes for 5000 hours show no drift from original calibration values. Sensors are not affected by continuous abrupt humidity changes or by exposure to saturation conditions.

Freedom from Interferences

Although designed for use with atmospheric gases, the sensor is completely unaffected by the presence of a wide variety of other gases. Large concentrations of petroleum gases, freons, chlorinated hydrocarbons, hydrogen sulfide, nitrogen dioxide, ozone, sulfur dioxide, carbon dioxide, carbon monoxide, hydrogen, alcohols and acetone have no effect on sensor water vapor indications.

True Probe Use

The aluminum oxide element is the only high sensitivity humidity sensor that can make "in situ" measurements. All other systems of this type require a flow of gas from the measurement area into an instrument. This element is designed for use directly within the region to be measured. All requirements for piping systems, manifolds, gas flow and pressure regulations are completely eliminated. This direct probe feature can be of extreme importance in the measurement of very low humidities or in cases where rapid moisture changes are occurring.

Any system which requires a flow of gas even if it has ideal characteristics with regard to accuracy and speed will

suffer from the dynamics of the gas flow and piping system. Response times and measurement values will be dependent on the degree of equilibrium reached by the piping system. Such factors as gas pressure and flow rate, materials of construction, length and diameter of pipe, etc. will to a large degree influence the moisture levels and response times measured by external sensors.

Under these conditions, specifications of accuracy or response time for external sensors are inappropriate. These are governed by the plumbing employed.

The most reliable analysis of water vapor calls for a sensitive, accurate, fast responding sensor capable of direct environmental measurements. These requirements are fully met by the aluminum oxide element.

The utmost in flexibility and ease of use are also accomplished by elimination of rigid geometry plumbing systems. The small size of the element permits its direct insertion into almost all systems. Sensor output is fed by cable to the electronic readout.

Multi-Probe Use

The electronic readout is equipped to monitor up to five sensors and has provisions for a recorder output. Sensor selection is accomplished at the front panel input selector switch permitting instantaneous readout of any sensor.

This multiprobe feature duplicates the work of five external type hygrometers. Five different portions of a process stream can be analyzed or five different process streams monitored by one instrument set up.

The multiple measurement feature permits a much lower unit cost of measure-

ment than available from other hygrometers.

Battery Operation

In addition to AC operation, the Model 1000 is also available with internal charger and batteries which will provide up to twelve hours of operation. This feature allows truly portable use for general plant utilization or field studies.

Automatic Unit

A special version of the Model 1000 features fully automatic sampling of the input sensors in addition to manual operation. This instrument can automatically monitor up to six sensors in a period of one minute. When used in conjunction with a recorder, it can provide a continuous and permanent record of the water vapor levels at each station.

Typical Applications

Aircraft & Missiles —

Moisture in propellant gases, missile loading, fuels, wind tunnels component manufacturing, weather stations.

Electronic —

Dry box monitoring, lamp manufacturing, encapsulation stations, crystal growing.

Refrigeration —

Monitor water content of refrigerants.

Metals —

Heat treating, carburizing, polishing, welding.

Chemical —

Monitor of gas used in chemical reactions, feed streams, freeze drying.

Petroleum —

Catalytic reforming, transportation of natural gas.

STANDARD PROBE MOUNT ASSEMBLIES

ELECTRICAL SPECIFICATIONS

Ranges:	High, (+20°C to +90°C), requires optional high humidity probe > +10°C; +10°C to -40°C; -40°C to -110°C. Approximate, depending on sensor calibration	
Accuracy:	± 1% full scale on all four ranges	
Sensitivity:	Better than 0.1% on all four ranges	
Ambient Temperature Range	-10°C to +55°C for electronic circuitry	
Warmup Time	Less than 5 minutes	
Calibration:	A calibration curve is supplied with each element	
Shock and Vibration:	Standard shipping specifications	
Inputs:	Five probe input jacks selected by front panel switch S1	
Recorder Output:	0 to 100 millivolts across a 200 ohm impedance	
Power Supply:		
AC —	AC — Line voltage 105-125 volts/210-250 volts	48 to 63 cps
Power —	Less than 6 watts	
DC —	Nickel-Cadmium battery pack	
	Note: Available with AC power only or both AC and battery operation (See list of Accessories)	

ACCESSORIES:

- Probes (specify type)
 - Probe adapter for wall mounting with "O" Ring Flange (Model P1)
 - Probe adapter with 3/4-14 NPT pipe bushing (Model P2)
 - High Pressure Adapter, using P2 fitting
- Internally mounted battery pack and recharger

MECHANICAL SPECIFICATIONS:

Size:	12 3/8" W x 10 1/8" D x 6 1/2" H
Weight:	11 1/2 pounds net
Construction:	Cast aluminum cabinet housing with formed metal rear cover plate. Unit is designed for bench or portable use
Finish:	Textured dark gray cabinet, trimmed with blue, light gray, and brushed aluminum satin finish.

Inquiries Are Invited for Custom Engineered Systems

PANAMETRICS Inc.

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