Westinghouse
Savannah River Company

P.O. Box 616
Aiken, SC 29802

CC: L. W. Ice, 703-43A
File(WSRC-RP-89-679)
BSF-ISG-89-0236

August 1, 1989

Ms. W. F. Perrin, Technical Information Officer
U. S. Department of Energy
Savannah River Operations Office
Aiken, SC 29801

Dear Ms. Perrin:

REQUEST FOR APPROVAL TO RELEASE SCIENTIFIC/TECHNICAL INFORMATION

The attached document is submitted for approval for external release. Please complete Part II of this letter and return the letter to the undersigned by 08/15/89. Patent clearance is requested and received via direct communication between DOE Patent Counsel and Patent Reviewer. The document has been reviewed for classification by the WSRC Classification Officer and a designated WSRC Derivative Classifier and has been determined to be unclassified/~~UCN~~I.

J. A. Duschinski (by) WSRC Technical Information Manager
J. A. Duschinski

I. DETAILS OF REQUEST FOR RELEASE

WSRC-RP-89-679, "DESIGN AND TESTING OF A THERMAL LIQUID LEVEL SENSOR," By A. E. Levin, A. Schneider, J. D. Harris, and H. Pfeifer.

A report proposed for presentation and publication at the International Heat Transfer Conference in Jerusalem, Israel on August 19-24, 1990.

Technical questions pertaining to the contents of this document should be addressed to the author(s) or

H. F. Allen, Manager
Reactor Technology
Savannah River Site

Questions concerning processing of this document should be addressed to the WSRC Technical Information Manager, 5-3992 or 5-2646.

II. DOE-SR ACTION

DATE RECEIVED BY TIO August 1, 1989

X Approved as written.
___Remarks.

____Not approved as written;____revise and resubmit to DOE.
____ Approved upon completion of changes marked on document.

W. F. Perrin, Technical Information Officer, DOE-SR

Date 8-16-89

Westinghouse
Savannah River Company

P.O. Box 616
Aiken, SC 29802

BSF-ISG-89-0236

August 1, 1989

Mr. Warren Bergholz, Chief Counsel
U. S. Department of Energy
Aiken, South Carolina 29802

Dear Mr.Bergholz:

REQUEST FOR PATENT REVIEW

Please review for the patent matters:

WSRC-RP-89-679, "DESIGN AND TESTING OF A THERMAL LIQUID LEVEL SENSOR," By A. E. Levin, A. Schneider, J. D. Harris, and H. Pfeifer.

A report proposed for presentation and publication at the International Heat Transfer Conference in Jerusalem, Israel on August 19-24, 1990.

Please telephone your comments to the Records Management Office (ext. 5-2606) and notify me by signing and returning to C. J. Banick the original of this letter. A copy is provided for your file.

If you decide to pursue a patent on any development covered, I shall be happy to supply additional information required such as appropriate reference and the names of persons responsible for the development.

Very truly yours,

CJ Banick

C. J. Banick,
WSRC Patent Reviewer

The above item is approved for release.

Stephen D Hamel 11/7/89
Chief Counsel Date
DOE-SR

BSF-ISG-89-0236

August 1, 1989

TO: T. W. GREENE

FROM: C. J. BANICK CJB

DOCUMENT REVIEW

Document(s): WSRC-RP-89-679

Title(s): "DESIGN AND TESTING OF A THERMAL LIQUID LEVEL SENSOR"

Author: A. E. LEVIN, et al

Contractual Origin: DE-AC09-88SR18035

Present Classification: Unclassified Paper

References:

No items were noted that, in my opinion, should be called to the attention of the DOE for patent consideration.

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U.S. DEPARTMENT OF ENERGY

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5. Title

"DESIGN AND TESTING OF A THERMAL LIQUID LEVEL SENSOR, AE LEVIN, A SCHNEIDER, JD HARRIS, H PFEIFER

6. Type of Document ("x" one)

a. Scientific and technical report: ☐ monthly ☐ quarterly ☐ annual ☐ final ☐ topical ☐ other

b. Conference paper: Name of conference (no abbreviations)

INTERNATIONAL HEAT TRANSFER CONFERENCE

Location (city/st/ctry) JURUSALEM, ISRAEL

Date (mo/day/yr) AUG 19-24, 1989 Sponsor

Contents: ☐ proceedings ☐ viewgraphs ☐ paper ☐ poster sessions

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J. A. DUSCHINSKI, TECHNICAL INFORMATION MANAGER

Phone FTS 239-3992

(Organization) IRMD

Signature J. A. Duschinski

Date 11-10-89

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AUTHORS
A E Levin, A Schneider, J D Harris, and H Pfeifer

ORIGINATING DEPT. OR CORPORATE AUTHOR
Georgia Institute of Technology

TITLE
Design and Testing of a Thermal Liquid Level Sensor

ADDRESSEE

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Reactors
Anemometers
Microthermocouples
Nichrome heater
Fast scan data acquisition
Transient

Westinghouse
Savannah River Company

P.O. Box 616
Aiken, SC 29802

BSF-PUB-890241

October 17, 1989

Dr. A. E. Levin
Nuclear Engineering and Health Physics Programs
Engineering Science and Mechanics Building
Georgia Institute of Technology
Atlanta, GA 30332

Dear Dr. Levin:

This letter is a somewhat late confirmation of my telephone conversation with Dr. Schneider. Your paper **"Design and Testing of a Thermal Liquid Level Sensor"** (WSRC-RP-89-679) was released by Westinghouse and DOE as submitted. It can be used for a journal or for a presentation or both, whatever you decide.

Someone in the approval route made two minor suggestions for your consideration. The first is on the sixth line from the bottom of page 2 and it is to delete the "in" after the work compatibility. The second is to delete the comma after the word conductivity in the fifth line from the bottom of page 5.

If we can be of further assistance, please let me know.

Very truly yours,

L. W. Ice
Publications

LWI:jm

CC: Dr. Alfred Schneider

BCC: SRL file, 773-A (WSRC-RP-89-679)

WSRC-RP-89-679

DESIGN AND TESTING OF A THERMAL LIQUID LEVEL SENSOR (U)

by

A. E. Levin, A. Schneider, J. D. Harris, and H. Pfeifer
Georgia Institute of Technology
Atlanta, GA

W. D. Croft, Contract Administrator
Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

A paper proposed for presentation at the
International Heat Transfer Conference
Jerusalem, Israel
August 19-24, 1990

and for publication in the proceedings

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DESIGN AND TESTING OF A THERMAL LIQUID LEVEL SENSOR

FINAL REPORT

A. E. Levin, A. Schneider, B. Ip,
J. D. Harris, H. Pfeifer

Georgia Institute of Technology
Nuclear Engineering and Health Physics Programs
Atlanta, Georgia 30332-0225

May, 1989

INTRODUCTION

Liquid level detection is of extreme importance in nuclear reactor systems. In the event of a loss of coolant, plant operators should be able to ascertain quickly whether there is a danger of the core becoming uncovered.

In the Savannah River Plant (SRP) reactors, the configuration of the core is such that a tank of almost-stagnant liquid surrounds the fuel bundles, while core flow enters from an upper plenum, isolated from the tank. Level detection can therefore be accomplished in a number of ways. Current level detection devices in the SRP reactors include differential pressure and conductivity measurements. The first of these relates the liquid level to the static head of water in the tank, while the second measures the electrical conductance of the fluid around the instrument, thereby differentiating between water and gas. While these two methods of detection have functioned reasonably well, each of them is subject to uncertainties and drawbacks. The static pressure measurement technique can be affected by the fluid motion in the tank near the outlet of the fuel elements. In addition, the sensors for these measurements must penetrate through the bottom of the reactor vessel, which can provide a pathway for leakage from the vessel. The conductivity technique can be affected by variations in the ion content of the coolant. The electrical contacts used for detection can also become fouled or corroded by the reactor water, which can result in erroneous readings, should the level decrease.

Because of the drawbacks to each of the presently employed level detection methods, there has been a desire to develop a third, redundant and diverse level detection system. Various designs have been tried, for example, a "float" type of indicator, but the response or reliability of these systems were found to be unsuitable for in-reactor instrumentation. This project, therefore, was established to design, build, and test a new type of level detector, based on thermal behavior of the sensor.

BACKGROUND

The initial work preceding the establishment of this project was performed in the Georgia Tech Nuclear Engineering Senior Design course. At the suggestion of SRP personnel, a design project was organized to develop a conceptual design for a third level detection system in the SRP reactors. After considerable investigation, a concept based on differential heat transfer involving a heated thermocouple was chosen for further work, and a sensor design was developed. This design and analyses of its operation and reliability are discussed in Ref. 1.

Differential heating and cooling techniques for measuring thermal-hydraulic behavior are well-established in the nuclear field. Examples of these instruments include hot-wire and hot-film anemometers, microthermocouples embedded in materials for heat transfer measurements, and heat balance methods for determining flows. The use of a heated thermocouple to detect the presence of liquid is in fact presently employed in a commercially available instrument[2]; however, this instrument does not appear to be adaptable for use in the SRP reactors.

The use of heated and cooled thermocouples for liquid level detection in nuclear plants was explored shortly after the accident at Three Mile Island, as a result of the lack of adequate level detection and the severe consequences that followed at TMI. The design of the level sensor reported in Ref. 1 is a modification of a concept described in Ref. 3, for use in the SRP reactors. The sensor was modified further in the course of the present project, primarily for material compatibility. The sensor as modified for this project has been tested in conditions simulating those that would be experienced in-reactor, with good results. It is projected that this sensor can be employed as the "third" level sensor in the current generation of SRP reactors. In addition, the design should be appropriate for use in a new production reactor with a configuration similar to that of the current reactors.

OPERATIONAL PRINCIPLES

The probe operates on the principle of changing heat transfer coefficients at the outer surface when a liquid-vapor interface moves from above the heated TC to below the heated TC. The heater and heated thermocouple are placed at the elevation at which an alarm signal is desired. When the probe is fully immersed in liquid, the heat transfer from the surface to the fluid is relatively good, and the heated TC is therefore at a temperature moderately above that of the reference TC, with the magnitude of the temperature difference dependent on the heater power. If the liquid level falls below the heated thermocouple elevation, the probe is exposed to an environment in which the heat transfer at the surface is degraded substantially because of the difference between liquid and vapor heat transfer coefficients . This causes the heated TC temperature to rise to a much higher value relative to the reference TC. Such a change is registered as an increase in the differential voltage between the heated and reference TCs. The user selects the value of the differential voltage increase that is to be indicative of a real level drop, for use in an alarm system.

Sensor development consisted of two stages. First, a simple version of the instrument, shorter than what would be required in-reactor, was built for proof-of-principle tests. Once these tests were completed and proof of principle was assured, a prototype probe was constructed for more extensive testing in a geometry and under thermal conditions similar to those experienced in the SRP reactors.

SENSOR DESIGN

The design of the thermal level probe is shown "as built" in Fig. 1. The housing consists of an 11.11 mm (0.4735") OD aluminum tube with a 0.89 mm (0.350") wall thickness. The tube is filled with magnesia insulation. Heat is supplied to the probe by

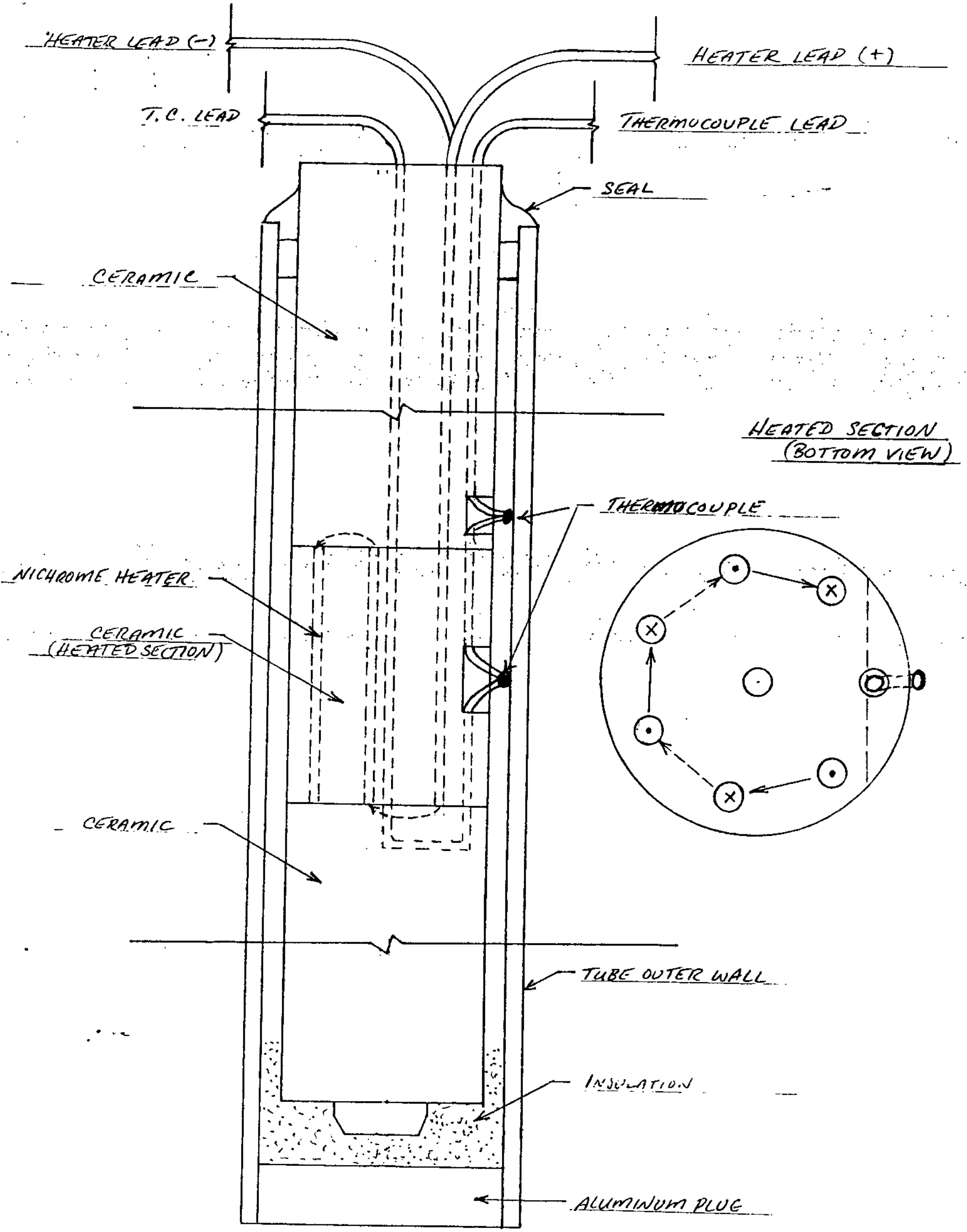


Fig. 1. Thermal level sensor, as built (not to scale)

electric resistance heating through a Nichrome wire, the leads for which pass through the ceramic insulation. The heater leads are copper, to minimize resistance heating away from the desired location. Thermocouple (TC) leads also pass through holes in the insulation. The TCs are chromel-alumel; one is placed at the same elevation as the heater and will be referred to as the "heated thermocouple." The second thermo-couple will be called the "reference thermocouple," and is placed approximately 150 mm (6") above the heated thermocouple. This spacing was chosen after considerable testing with other configurations. It allows the two thermocouples to be exposed to the same thermal environment on the exterior of the sensor; however, the two TCs are far enough apart so that the reference thermocouple is not influenced by the heater.

The materials of construction were chosen for their thermal properties and compatibility with the SRP reactor environment. The aluminum housing has an excellent thermal conductivity; in addition, it is similar to the material used for much of the SRP reactor internals. Chromel-alumel TCs were chosen because of their robust behavior in radiation fields. This type of thermocouple also has a relatively high voltage output per degree of temperature difference between the hot and cold junctions, allowing easier discrimination of the change in heat transfer behavior, the basis of the probe's operation, as well as a faster response. Nichrome heater wire is also capable of being used under irradiation, and has the proper resistivity characteristics to provide the necessary heater power without generating excessively high temperatures. Magnesia is employed for electrical insulation primarily because of its high thermal conductivity for a ceramic, and because of its benign behavior in a reactor's neutron field.

PROOF-OF-PRINCIPLE TESTS

The proof-of-principle sensor design was similar to the final probe design. The primary differences were: (1) the length was considerably shorter than that required for use in-reactor, and (2) the reference TC was placed near the bottom of the probe. The reasons for this placement will be discussed further in subsequent sections.

Testing was performed in water in two geometries. The first was a large-diameter Pyrex tank of water, while the second was a narrow-diameter (25 mm or 1") Pyrex cylinder. These two test geometries were chosen to examine whether the presence of a container wall near the outer wall of the probe would have a significant effect on the heat transfer at the probe's surface. The diameter of the cylinder was also similar to the test section planned for the prototype probe tests. Tests were performed with the water at room temperature. The probe was suspended from a small stand and immersed in the water (see Fig. 2). To simulate a level decrease, the probe was raised rapidly out of the water, so that the heated section was exposed to the air. The reference TC at the bottom of the probe remained in the water. Since the air and water were at the same temperature, errors due to temperature gradients were negligible. A shield was placed around the top of the tank or cylinder to protect the probe from excessive cooling due to drafts. Parameters varied in these tests were (1) heater power, and (2) heater axial length. Measurements were made using a digital voltmeter and a stopwatch.

Data from these tests are shown in Figs. 3 through 5. The proof of operational principle is clearly demonstrated by these plots: virtually as soon as the heated TC is exposed to air, the differential voltage begins to increase. The rate of increase is directly proportional to heater power. In addition, the shorter the length of the heated section, the better the response of the sensor. It can also be seen that there is very little difference between the probes's response in the two different geometries. Development of the longer-length prototype probe proceeded on the basis of these tests. Results of the testing of this sensor and subsequent modification of the design are covered in the following section.

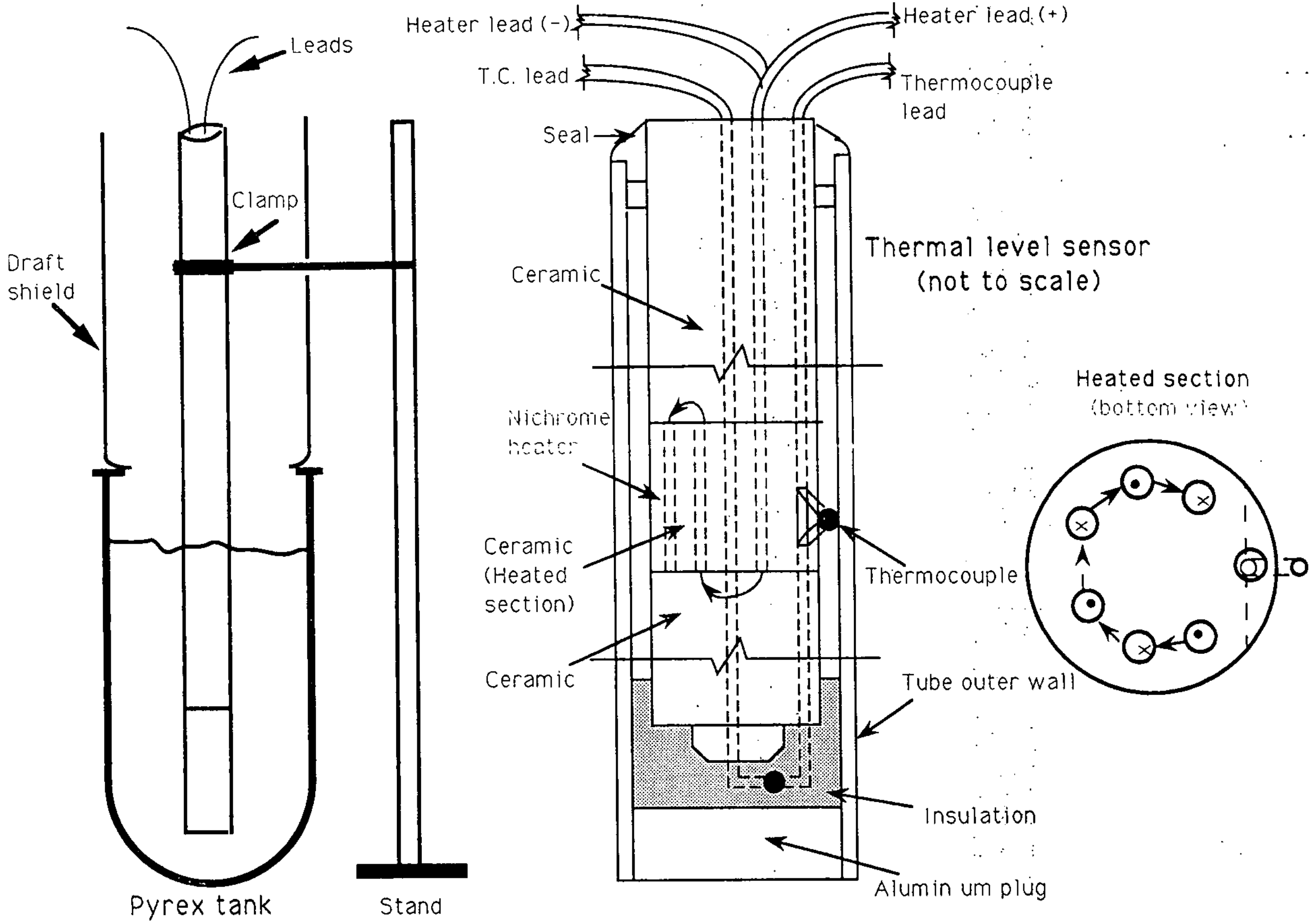
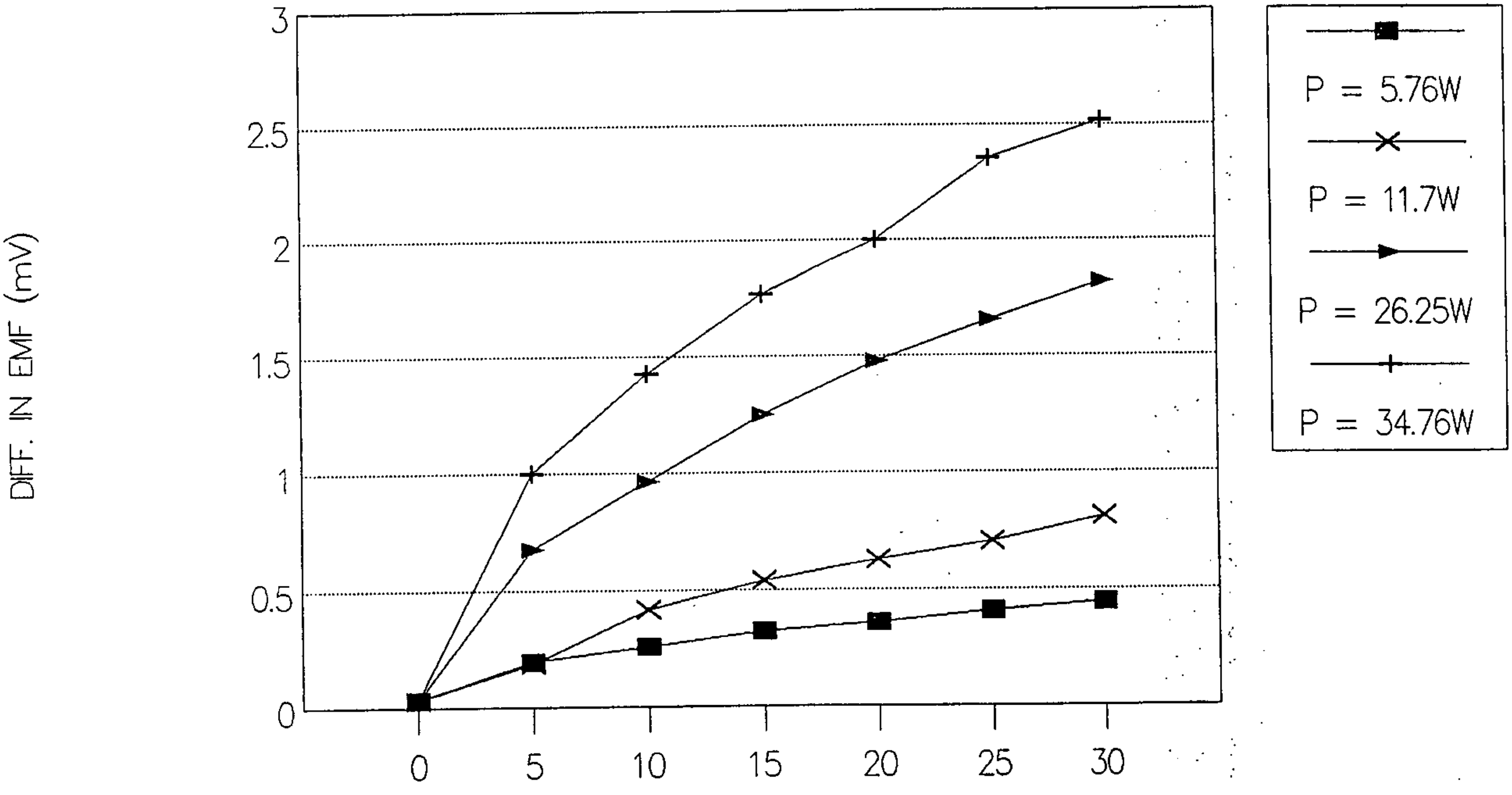


Fig. 2. Test stand and probe design used in proof-of-principle tests



1'' HEATED SECTION (TANK)

USING POWER AS PARAMETER

Fig. 3. Sensor response at four power levels, proof-of-principle tests

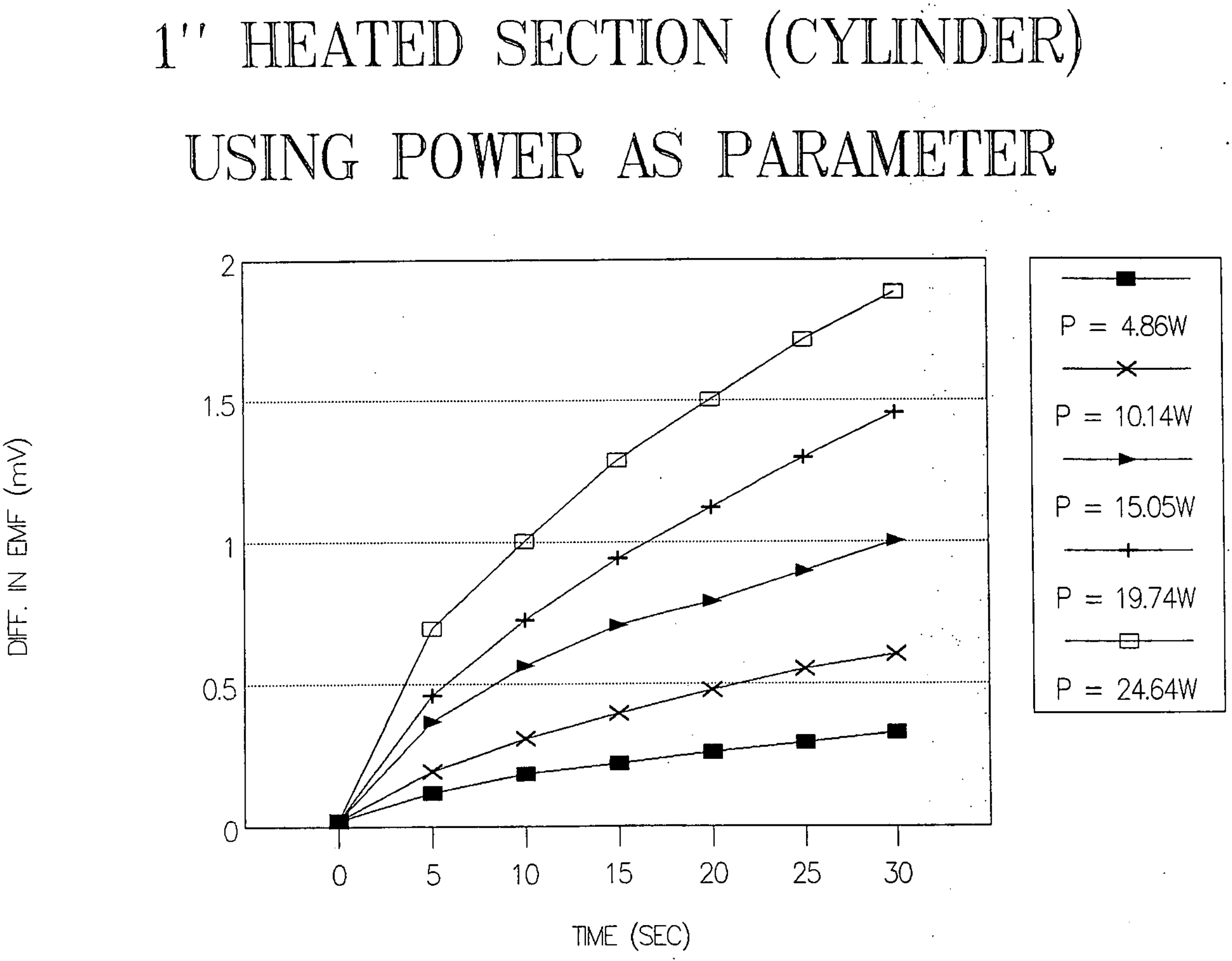


Fig. 4. Sensor response at five power levels, proof-of-principle tests

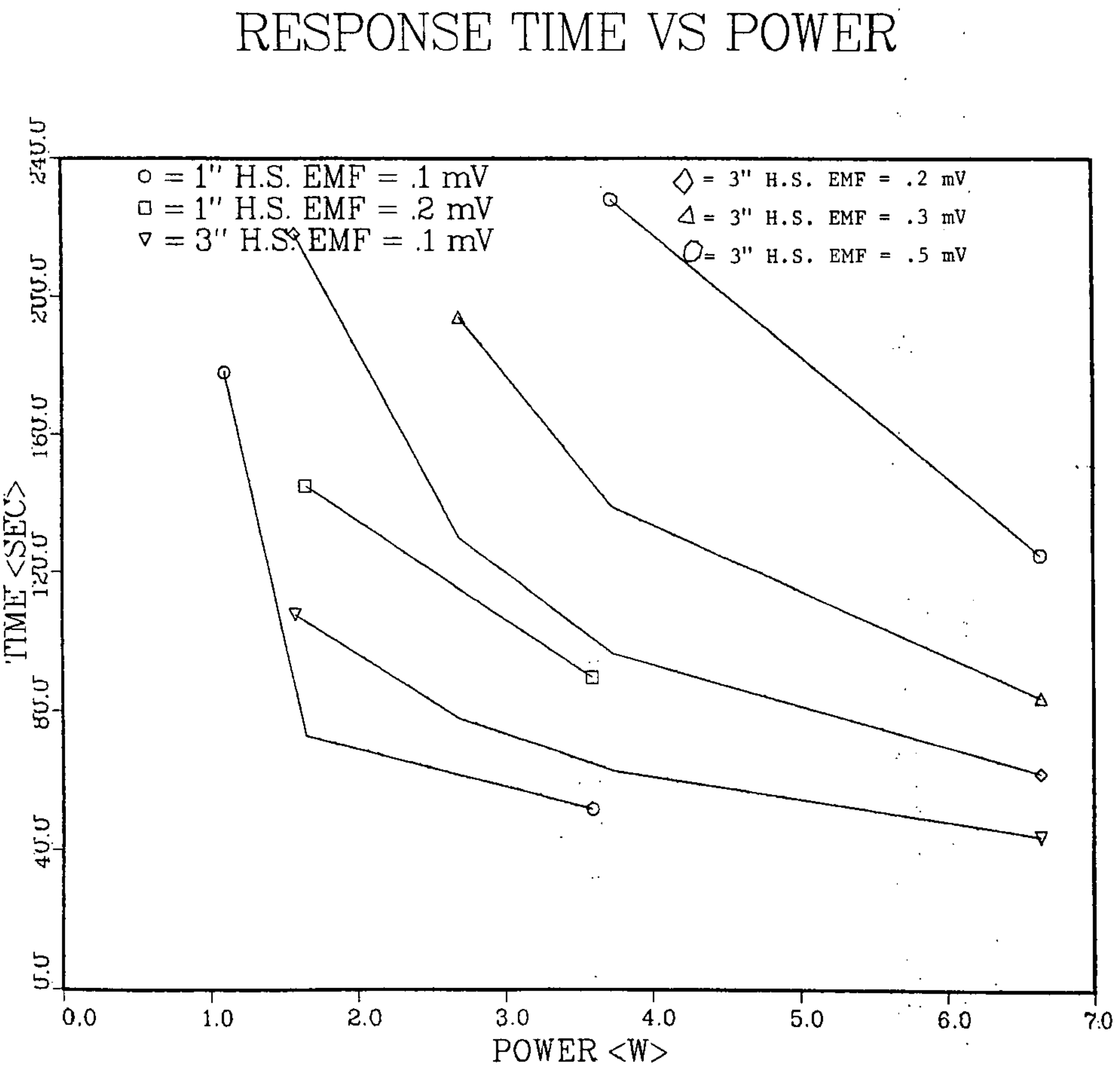


Fig. 5. Time required for given differential voltage change as a function of power and length of heated section, proof-of-principle tests

PROTOTYPE PROBE TESTING

The proof-of-principle tests demonstrated that the basic design of the level probe was sound, and a longer-length prototype instrument was designed and constructed based on the result of the first set of tests. This probe had the reference TC near the bottom of the housing tube, similar to the design used in the proof-of-principle tests. This configuration was chosen to isolate completely the reference TC from any effects of the heater. A 25-mm-(1"-)long heated section was chosen for this probe; while a shorter heater would have provided somewhat better response, it would also have been significantly more difficult to construct.

An experimental loop simulating a channel in the SRP reactor was constructed for the purpose of testing the response of the prototype probe. The loop is shown in Fig. 6. The test section consists of a Pyrex tube, approximately 25mm (1") ID and 38 mm (1.5") OD, and 2 m (6.5') in length. Pyrex was used for the test section primarily to permit direct visual observation of the level decrease during testing. The test section is erected in a wooden stand; the preheater and test section outlet are tied to the building water supply using flexible tubing. The helium cover gas supply is also connected to the test section by flexible tubing. Helium pressure is controlled by a pressure regulating valve. Water is run from the building supply into the preheater, and then into the test section. A heater ribbon is wound around the Pyrex test section to minimize heat losses and maintain the water at constant temperature. Helium is used as the cover gas to simulate reactor conditions, and additional pressure control is maintained by use of a bubbler system for the helium and a barometric pressure regulator for the water. The helium pressure is maintained at approximately 35 kPa (5 psi) gage, similar to the cover gas in the SRP reactors. In order to simulate flow conditions inside the reactor, in

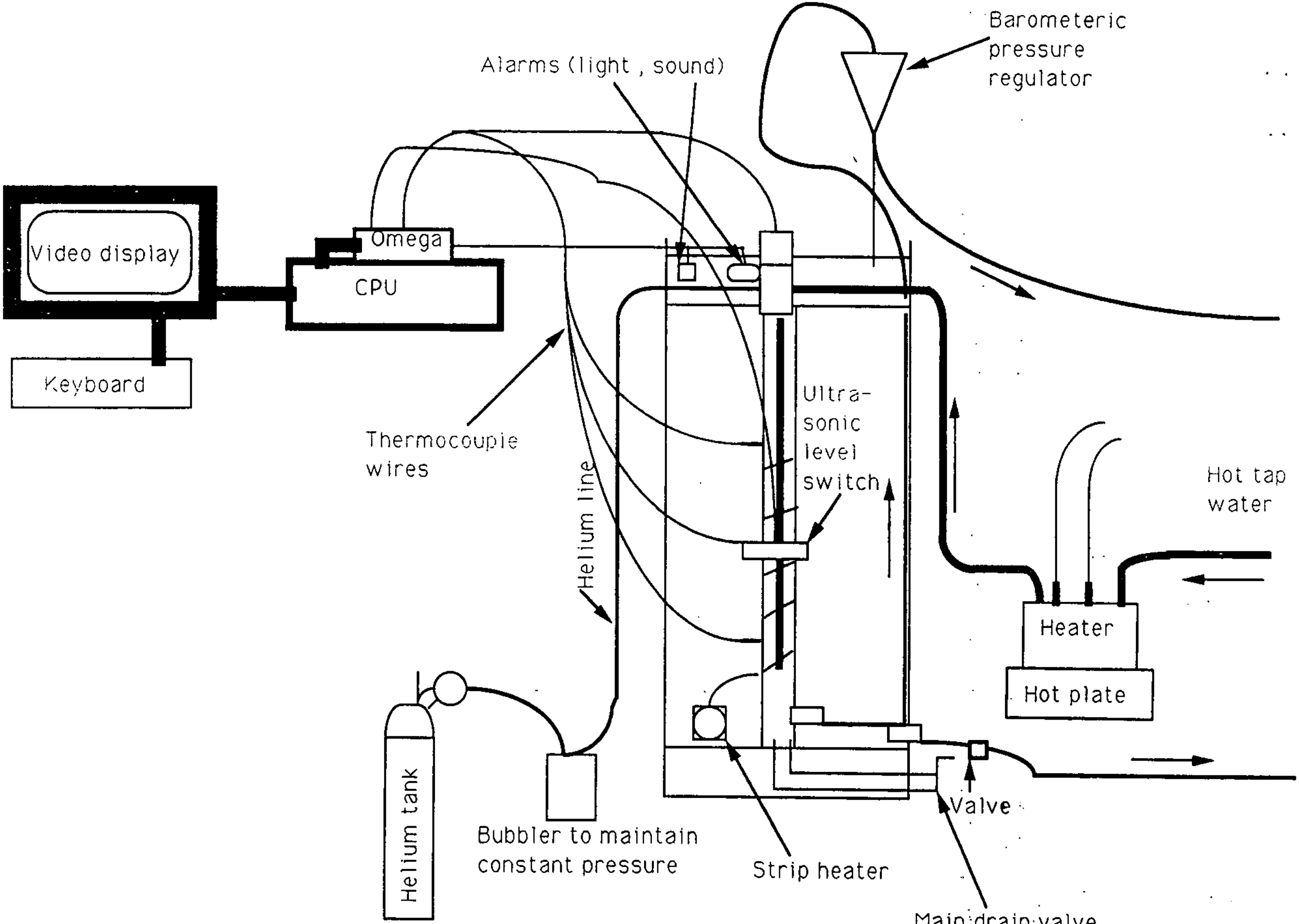


Fig. 6. Test loop for prototype probe tests

which a very small through-flow can pass down the tube housing the probe, heated water is metered into the test section at a low flow rate, using a needle valve to control the flow. Data are acquired using an Omega data acquisition board and associated software, installed in an IBM-compatible personal computer. The time response of the probe is determined by using an ultrasonic level switch installed on the outside of the test section housing. This instrument's current output changes from high to low within 0.5 seconds of the fall of the liquid below the switch elevation, thus providing an almost instantaneous indication of this event. The switch is located at the same elevation as the heater and heated TC. Thermocouples are also placed at three elevations in the test section to measure fluid temperature, to enable better control of thermal conditions during testing. These TCs are in direct contact with the fluid, inserted through small-diameter ports into the test section. The ports are then sealed with silicone rubber.

Tests can be initiated in two ways. The valve in the flexible tubing outlet line can be opened; this allows a relatively slow decrease in the level in the test section, which can be tracked visually. As an alternative, the large 63 mm (2-1/2") valve at the bottom of the test loop can be opened. This allows the water to drain very rapidly. Regardless of the method used to drain the test section, the flow in the test section is cut off prior to test initiation. Such a flow would not be present in the reactor at the time the water level dropped below the alarm point.

Data acquisition begins approximately five seconds prior to initiation of a level decrease, with indication of the time the water level falls below the alarm point by the ultrasonic switch as described above. Fast scan data acquisition speed is about two samples per second per instrument.

In addition to the fast scan mode of data acquisition, the data collection unit can be set to monitor and display the instrument readings, with updating of the data about once per second. In this mode, the data acquisition system can be set to indicate an alarm if an instrument reading moves above or below user-established limits; the instrument causing the alarm flashes on the computer screen. The unit can also be set to output a signal to an external device upon an alarm condition. This capability is exploited during testing by hooking up a light and a siren to the data acquisition system. The light is activated when the ultrasonic switch indicates the liquid level has fallen below the alarm point, and the siren is activated when the differential voltage reading from the level probe exceeds a user-established value; this value is based on the value of the differential voltage while the probe is fully immersed in liquid, and represents an increment of approximately 0.5 to 1.0 mV above this initial reading. The time response of the probe can be determined directly in this manner, using a stopwatch to time the interval between the activation of the light and the siren.

During the initial tests with the reference TC at the bottom of the housing, it was found that significant temperature gradients could develop in the test section between the heater elevation and the bottom of the probe, several feet below. The difference in temperature had a tendency to confound time response data, particularly if the liquid level was lowered to a point between the heated and reference TCs. In order to eliminate this problem, the design of the probe was modified and the reference TC was moved to the position shown in Fig. 1, approximately 150 mm (6") above the heated TC. In this way, both TCs are exposed to the same thermal environment both before and after the level decrease. The quality of the data improved significantly after the modification was made.

Numerous tests were performed at various power levels and water temperatures to investigate the response of the prototype probe. Samples of the data are shown in Figs. 7 and 8, and in Table I. The time response of the probe can be clearly seen on the plots. In addition, the fast-scan data displayed in Table I clearly shows the point at which the liquid level falls below the ultrasonic switch, and the time thereafter when the

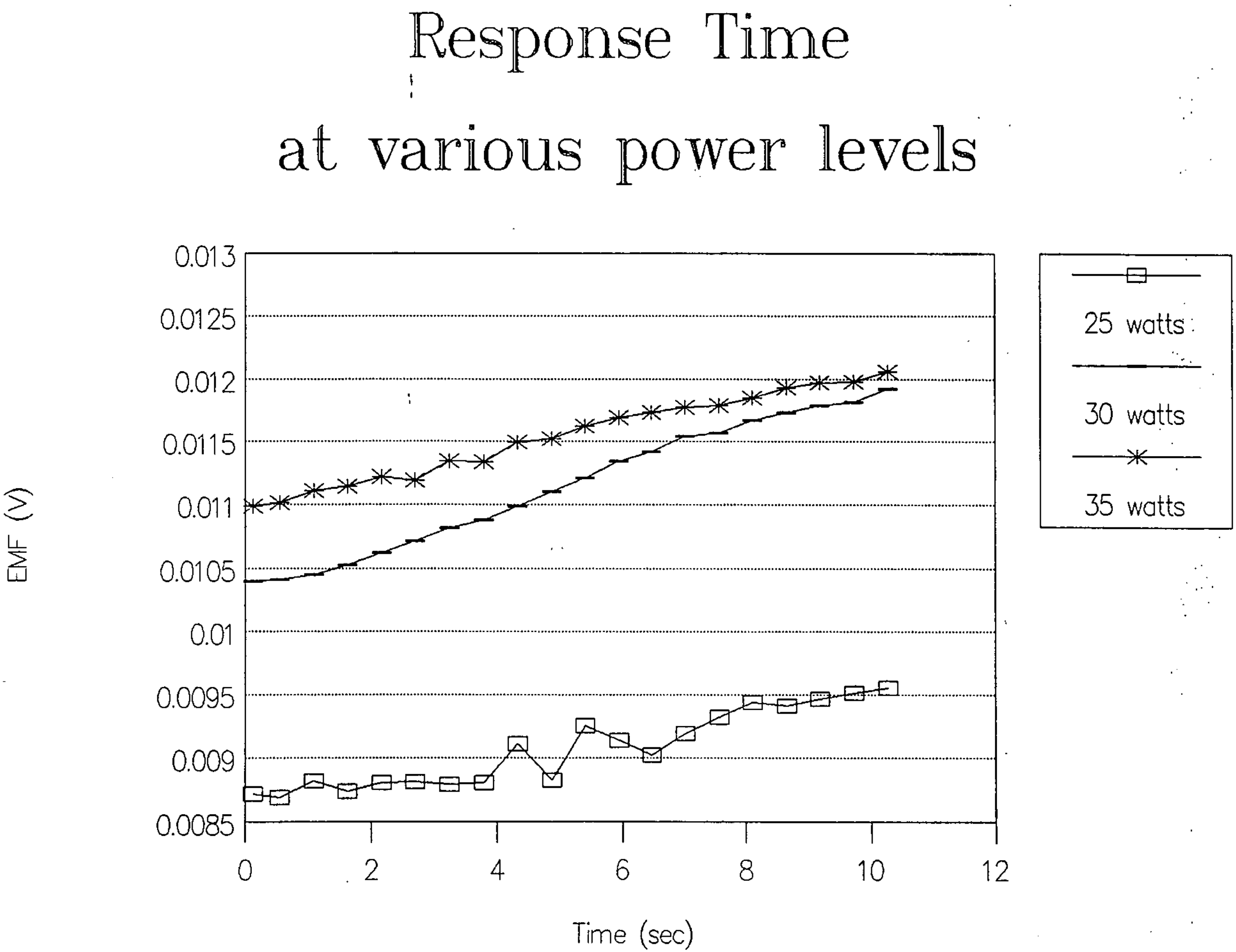


Fig. 7. Sensor response at three power levels, prototype tests

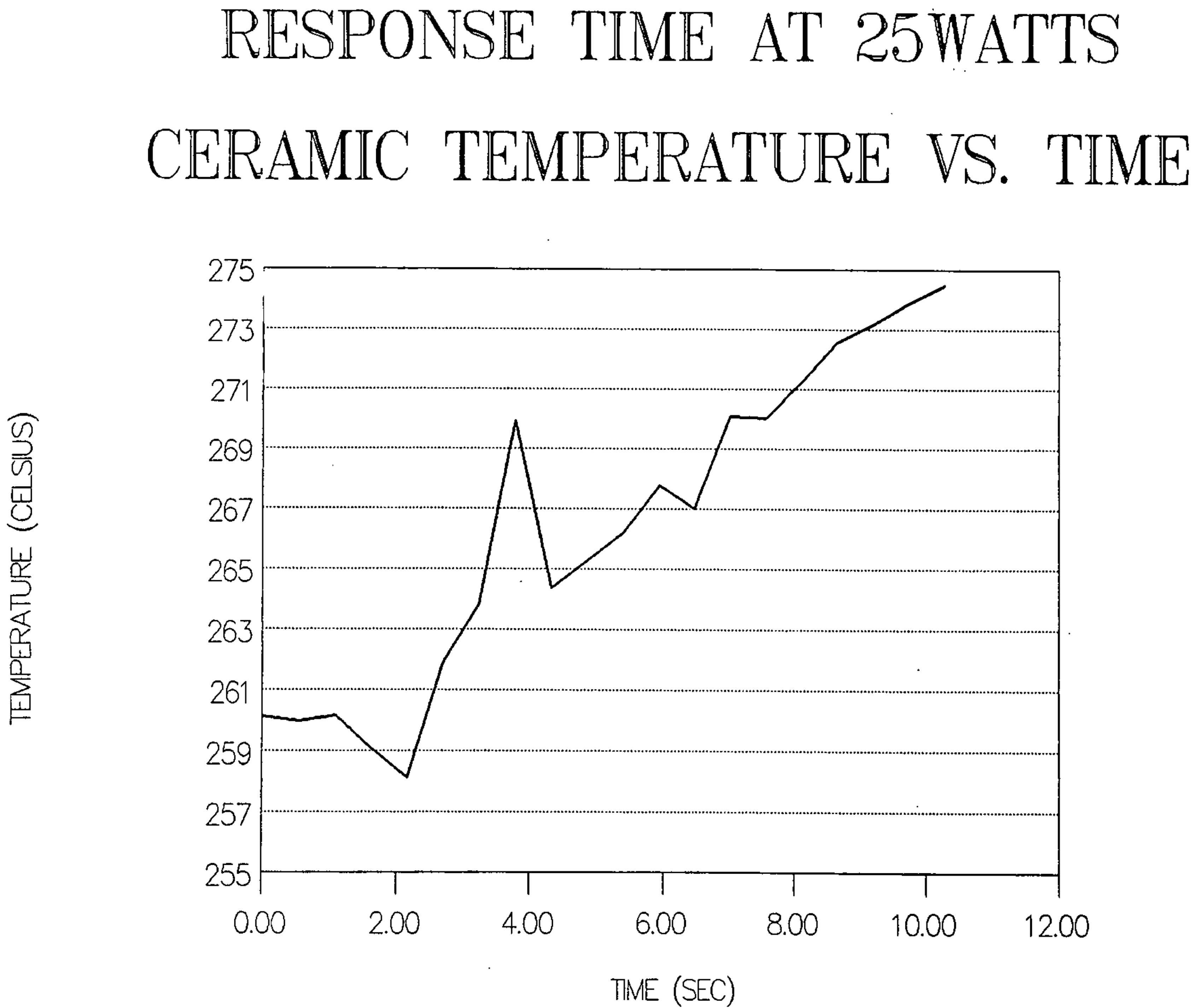


Fig. 8. Ceramic temperature during typical prototype probe test at 25 watts

```
"DATALOG"
"","",8 "channels",1
POWER WAS 25 WATTS
TIME INTERVALS WERE APPROXIMATELY .536 SECONDS
 T1        T2        T3       TCER.      TREF      DELATEMF        TIN      SENSOR
92.8100 ,91.2600 ,85.3200 ,252.360 ,90.1100 ,0.00830525 ,90.5900 ,18.0419
92.7500 ,91.0600 ,85.2800 ,252.150 ,90.0900 ,0.00829584 ,90.5900 ,18.0378
92.8600 ,91.0700 ,85.1300 ,251.930 ,90.0900 ,0.00828043 ,90.5700 ,18.0256
92.9200 ,91.1000 ,84.9900 ,251.590 ,90.0300 ,0.00826458 ,90.5300 ,18.0510
92.9000 ,90.8100 ,84.9000 ,251.280 ,90.0000 ,0.00824889 ,90.5100 ,18.0250
92.8700 ,91.0600 ,84.8200 ,251.100 ,90.0000 ,0.00824219 ,90.4800 ,18.0029
92.8900 ,92.0300 ,84.7100 ,251.780 ,89.9600 ,0.00827458 ,90.4600 ,4.96816
92.9300 ,94.0200 ,84.5000 ,251.170 ,89.9400 ,0.00824715 ,90.4500 ,4.96809
93.0400 ,92.4500 ,84.4400 ,251.360 ,89.9200 ,0.00826921 ,90.4400 ,4.96816
93.1900 ,92.6300 ,84.5200 ,252.050 ,89.9000 ,0.00831223 ,90.4200 ,4.96826
93.0300 ,92.8200 ,84.5600 ,252.960 ,89.8700 ,0.00836841 ,90.4000 ,4.96819
93.3000 ,91.7500 ,84.4500 ,254.060 ,89.8500 ,0.00843348 ,90.3800 ,4.96816
93.2800 ,90.9700 ,84.3700 ,256.850 ,89.7800 ,0.00859664 ,90.3300 ,4.96798
93.1500 ,90.7500 ,84.3200 ,258.370 ,89.7400 ,0.00868472 ,90.3000 ,4.96788
93.1000 ,90.5800 ,84.2400 ,259.950 ,89.7000 ,0.00877371 ,90.2900 ,4.96788
92.2600 ,90.4900 ,84.1800 ,261.360 ,89.6700 ,0.00885213 ,90.2700 ,4.96767
91.9400 ,90.4100 ,84.1300 ,262.550 ,89.6400 ,0.00891720 ,90.2300 ,4.96778
91.9200 ,90.3500 ,84.0500 ,263.580 ,89.6000 ,0.00897567 ,90.2200 ,4.96778
91.6800 ,90.2600 ,83.9400 ,264.520 ,89.5700 ,0.00902974 ,90.2100 ,4.96798
91.5800 ,90.1500 ,83.8700 ,265.400 ,89.5400 ,0.00908019 ,90.1900 ,4.96767
91.4200 ,90.0700 ,83.8100 ,266.200 ,89.5000 ,0.00912696 ,90.1500 ,4.96760
91.5000 ,90.0400 ,83.7300 ,267.000 ,89.4600 ,0.00917303 ,90.1600 ,4.96778
91.5800 ,89.9900 ,83.5900 ,267.770 ,89.4300 ,0.00921758 ,90.1100 ,4.96767
91.4700 ,89.9700 ,83.3700 ,268.510 ,89.3800 ,0.00926113 ,90.1000 ,4.96802
91.5800 ,89.9200 ,83.1800 ,269.220 ,89.3300 ,0.00930305 ,90.0900 ,4.96771
91.6000 ,89.8600 ,82.9900 ,269.960 ,89.3100 ,0.00934633 ,90.0700 ,4.96778
91.6300 ,89.8000 ,82.8900 ,270.680 ,89.2500 ,0.00938930 ,90.0500 ,4.96767
91.6500 ,89.7300 ,82.8200 ,271.410 ,89.2200 ,0.00943246 ,90.0300 ,4.96784
91.6800 ,89.6500 ,82.8000 ,272.090 ,89.1800 ,0.00947376 ,90.0000 ,4.96784
91.7100 ,89.5700 ,82.8100 ,272.800 ,89.1400 ,0.00951500 ,90.0100 ,4.96781
91.7100 ,89.4600 ,82.8000 ,273.490 ,89.1200 ,0.00955482 ,89.9700 ,4.96784
```

Water level
drops below
ultrasonic
switch

Table I. Sample of data acquisition record from prototype probe test

Legend: T1: Bottom TC in water in test section
T2: Center TC in water in test section
T3: Top TC in water in test section
TCER: Ceramic temperature (heated thermocouple)
TREF: Reference thermocouple (6" above heated TC)
DELTAEMF: Voltage difference between heated and reference TCs
TIN: Temperature of water entering test section
SENSOR: Output from ultrasonic level switch

differential voltage has risen by a given amount. At a heater power of 25 W, the change in differential voltage is seen to be approximately 0.5 - 0.7 mV in 5 seconds.

DISCUSSION OF TEST RESULTS

The objective of the initial proof-of-principle tests was simply to demonstrate that the concept and probe design were sound. During these tests, the power supplied to the heater and the heater length were varied to determine an optimal design and operating power for the prototype probe. In general, the best sensor performance was found at high power and short heater lengths. However, a compromise must be made on both of these parameters. Very short heater lengths become difficult to fabricate. The wire must be passed through small holes in the ceramic insulator, with several turns required to provide sufficient length. Since the total resistance sets the power level through the relation

$$P = I^2R, \qquad (1)$$

and the resistance is determined by the wire's resistivity (p), length (L), and cross-sectional area (A) by

$$R = \rho L/A, \qquad (2)$$

a short heated length requires several more turns of wire that must be compressed into a short axial space. This space is limited not only by the available room in the probe, but also be the stress placed on the wire as it is turned many times in a short run. This led to the choice of a 25 mm (1") heated length.

In addition, the temperature in the interior and on the surface of the probe must not be excessive. One of the major constraints on the design was the requirement that vapor generation at the surface of the probe be eliminated or, at most, negligible. Since natural convection heat transfer coefficients are very low even in water, high heater powers tended to drive the probe into subcooled boiling, as its surface temperature exceeded the saturation temperature. It was therefore determined that powers should be limited to less than about 35 W. These limits were employed in the design and testing of the prototype probe.

The prototype probe operated well throughout the test program. Once the reference TC was moved to the position shown in Fig. 1, the problems with regard to temperature gradients in the test section were no longer of concern. Since the differential reading is driven by the heat transfer coefficient at the heated section, as long as the reference TC is isolated sufficiently from the heater, it can be located anywhere in the probe. Its present position would appear to be optimal: when the water level is above both of the TCs, the differential voltage is low. When the water level is below both TCs, the differential voltage is high, and in the alarm state. If the level should fall to a position between the two TCs, the probe's output would depend on the temperature difference between the water and the cover gas. If the gas is at the same temperature as the water, the differential voltage should not change. If the gas temperature is different from that of the water, the magnitude of the differential voltage changes in inverse proportion to the direction of the difference: lower if T_{gas} exceeds T_{liq}, higher if T_{gas} is the less. The effect of evaporation would have a tendency to reduce the effective temperature of the vapor, so that it is likely that the probe's output would increase somewhat in this case.

The time response of the instrument was found to be most sensitive to the user-established alarm setting. The steady-state differential voltage was proportional to the operating power. Once this value was set and the system was at steady conditions, an alarm value was chosen. This value must be high enough to allow for small fluctuations in the probe's output that would be expected to occur, but low enough that it does not take an excessive time for the alarm setting to be reached in the event of a drop in liquid level. Through repeated testing, the optimal level is estimated to be within the range of 0.5 to 1.0 mV. Response times with this range were approximately 3 - 10 seconds. A response time under 5 seconds is highly desirable, and is clearly attainable with this instrument. Further reductions in response time may be possible with additional modifications to the instrument. This subject will be discussed further in a subsequent section.

Overall, the sensor proved to be reliable, and performed as expected in indicating insufficient water level. It is believed that it can serve effectively as the third level sensor in the current SRP reactors, and can also be employed in any new production reactor of similar design.

RELIABILITY AND FAILURE ANALYSIS

As part of the original work reported in Ref. 1, a failure analysis was performed to assess the ways in which the probe might cease to function properly. That work is summarized in this section.

There are basically five major modes of failure: the heater may fail; the heated TC may fail by breakage of the wire; the reference TC may fail in the same manner as the heated TC; the aluminum housing may fail; or the insulation material may fail inside the housing.

Should the heater fail, that failure would prove almost immediately obvious. The heater provides the means by which there is a difference in the temperature in the two TCs. A non-functioning heater would therefore result in a drop in the differential voltage to approximately zero, assuming that the fluid temperature at the heated and reference TCs is about the same. If either thermocouple breaks, the instrument's degraded condition should again become obvious, since the absence of two connected junctions will lead to zero differential voltage. A failure of the heater sheath might not immediately affect the output of the instrument. However, this event would likely lead to a degradation of the insulation and, eventually, to failure of the heater, should water enter the probe through the crack. In addition, insulation material could become entrained in the coolant. This is not projected to cause any problem in reactor operation; however, examination of water chemistry would indicate the presence of magnesium, which would indicate a problem with the sensor. Failure of the insulation may also not affect the instrument's operation immediately. If insulation failure were to lead to contact of the two thermocouple wires, this would in effect form a new junction inside the probe. This new junction could short circuit the reference junction; however, if it were far enough from the heated TC, there would be little or no noticeable change in the output of the instrument. On the other hand, if the new junction were formed much closer to the heater, there would be an immediate drop in the differential voltage output from the instrument, which would indicate some degradation in the probe's condition.

Of the failure modes discussed above, the most likely are considered to be heater failure and thermocouple breakage. In both of these cases, the output of the instrument would immediately decrease. Monitoring of the differential voltage, as well as the alarm point, would essentially make the probe self-diagnostic using the logic described above. The ability of the instrument to indicate clearly its own failure is a signifi- cant advantage of this type of approach.

Because of the instrument's simple design, it is anticipated that it should operate quite reliably in the reactor environment. Since the housing is a solid tube that would hung from the reactor head, it should prove to be easily integrable in the reactor design. In addition, it should be stable through virtually all reactor transient conditions, up to and including seismic events.

CONCLUSIONS AND POTENTIAL FUTURE DEVELOPMENTS

A thermal level sensor has been designed for use in the Savannah River Plant reactors. This instrument relies on the output of a differential thermocouple with heated and unheated junctions to indicate a reduction in liquid level below a selected alarm point. The concept depends on the change in heat transfer coefficient on the exterior of the probe to indicate that the liquid level has decreased below the elevation of the heated thermocouple junction. A prototype probe has been constructed an tested in conditions that simulate the reactor thermal-hydraulic environment with very good results. The response time of the instrument depends on the power of the heater and on a user-established difference between the steady-state output of the probe and an "action" value. At moderate powers of 25-35 W, the differential voltage of the probe rose by approximately 0.5-0.7 mV in 3-8 seconds after the water level fell below the heated thermocouple junction. The prototype instrument operated reliably through an extensive series of tests at varying heater powers and water temperatures, and should prove to be appropriate as a third redundant and diverse means for level measurement in the current SRP reactors as well as in any future reactors of similar design.

While the probe operated satisfactorily in these tests, it should be possible to improve the time response of the instrument even more by additional modifications to its design. The primary modifications would consist of making the instrument smaller in diameter, with a smaller wall thickness as well. This would reduce the ability of the probe to store energy, and would therefore reduce the time constant of the instrument. In addition, the thermocouples themselves have a finite thermal capacity due to the size of the beads. Reduction of the size of the TCs, or replacement of the TCs with resistance temperature detectors (RTDs) may also improve the response time. Since

RTDs also require a power supply to operate, it may be feasible to integrate the probe power supply with that of the RTDs, or in fact to have the RTDs supply the operating power to the probe.

The design could also be extended to measure several different levels by incorporating a series of differential thermocouples and heaters at various elevations within the instrument. A final modification would be the incorporation of an isotopic heat source, such as Pu^{238}, in place of the electric heater used in the prototype probe. This would make the instrument independent of any outside power source, and would therefore make it virtually self-contained. These modifications might permit the probe to be used as a generalized level sensor, appropriate not only for in-reactor use, but also for other applications where liquid level control is important.

Once a modified probe is constructed and tested, it must then undergo qualification for use in reactor systems. It is anticipated that such qualification could be accomplished for this probe because of its simple and robust design and simplicity of operation. This qualification would permit its use in a wide range of applications, where it will serve as a useful device for measuring liquid level.

REFERENCES

1. S. Eilertson, et al., Heated Thermocouple Liquid Level System, Senior Design Project Final Report, Georgia Institute of Technology, June 1987.

2. "Liquid Level & Interface Controllers," Fluid Components, Inc. brochure

3. J. V. Anderson and C. L. Jeffery, "Heated Thermocouple Liquid Level System," Proc. of the U.S. Nuclear Regulatory Commission Review Group Conference on Advanced Instrumentation Research for Reactor Safety, CONF-8090747--2\NUREG/CP-0015, July 1980

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