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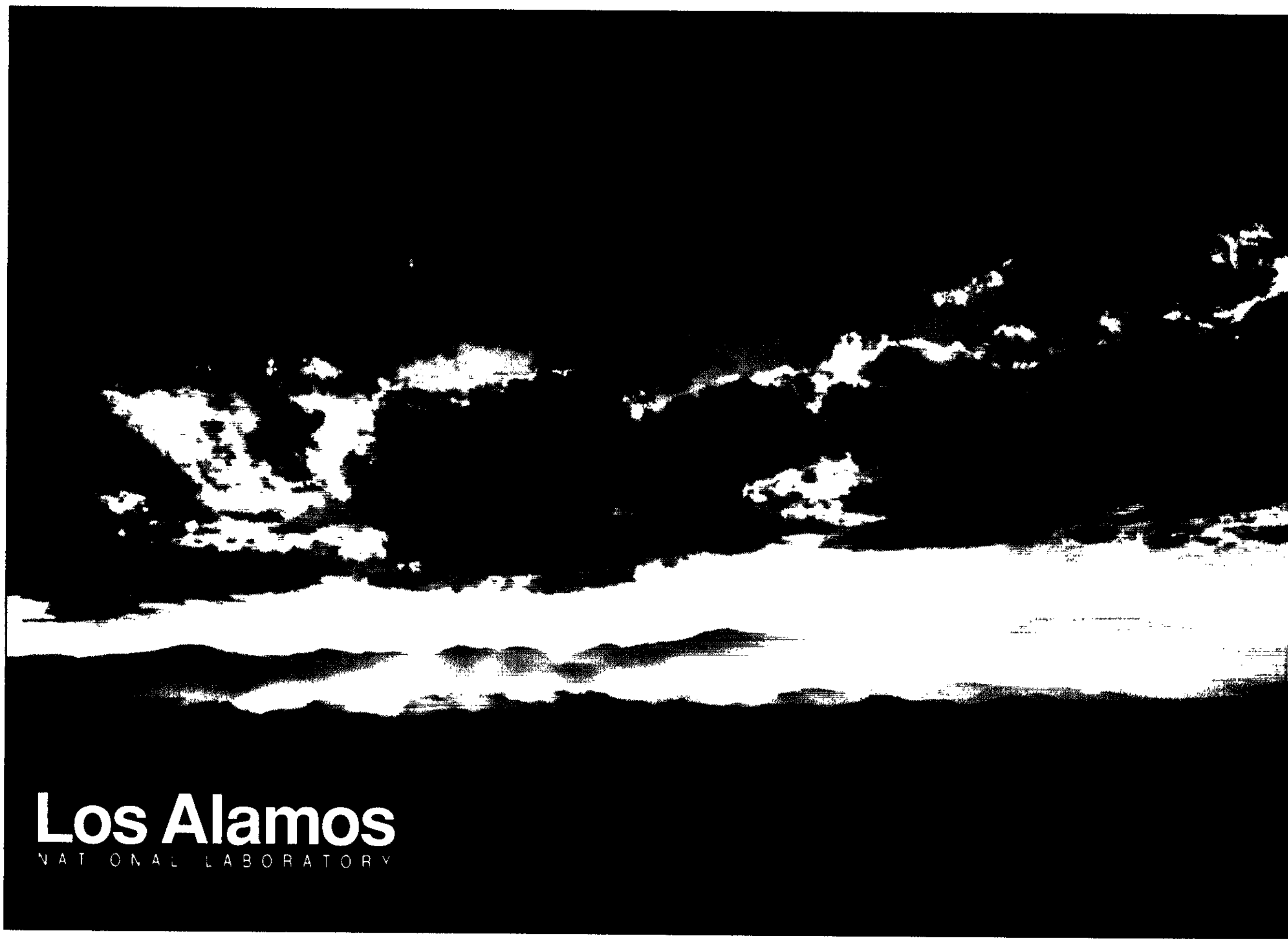

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ABSTRACT

A mound electrical calibration heater (MECH) has been used in several EG&G Mound developed calorimeters as a calibration tool. They are very useful over the wattage range of a few to 500 W. At the lower end of the range, a bias develops between the MECH probe and calibrated heat standards. A low-wattage electrical calibration heater (LWECH) probe is being developed by the Safeguards Science and Technology group (NIS-5) of Los Alamos National Laboratory based upon a concept proposed by EG&G Mound personnel. The probe combines electrical resistive heating and laser-light powered heating. The LWECH probe is being developed for use with power settings up to 2W. The electrical heater will be used at the high end of the range, and laser-light power will be used low end of the wattage range. The system consists of two components: the heater probe and a control unit. The probe is inserted into the measuring cavity through an opening in the insulating baffle, and a sleeve is required to adapt to the measuring chamber. The probe is powered and controlled using electronics modules located separately. This paper will report on the design of the LWECH probe, initial tests, and expected performance.

INTRODUCTION

Operation of a radio-isotopic heat-flow calorimeter as a nondestructive assay (NDA) instrument requires that it be calibrated. In addition to the calibration step required during the instruments' manufacture, the calorimeter must also be calibrated when it is installed in the user facility. The American National Standards Institue (ANSII) N15.22 standard specifies the calibration procedure. All calibration measurements must be performed using National Institute of Standards Technology (NIST) traceable standards. During its use as an NDA instrument, the calorimeter should be monitored with a measurement control (MC) or quality assurance program. The ^{238}Pu heat standard is NIST-traceable and a Department of Energy (DOE) approved primary "standard". Isotopic standards may be used as check sources and secondary standards. The Mound electrical calibration heater (MECH) is a NIST-traceable secondary standard.

Plutonium-238 heat standards are used routinely for calibration of calorimeters, but there are some disadvantages. Plutonium-238 heat standards are nuclear material and must be administratively controlled. They require security and accountability at all times, and documentation must be provided every time they are moved. Each heat standard is sealed and contains a fixed amount of material. Therefore the heat standard emits a fixed amount of heat. Multiple heat sources must be maintained to calibrate a calorimeter over its entire working range. Periodically heat sources need to be returned to the Heat Standards Laboratory located at Los Alamos National Laboratory (LANL) for recertification. Although this certification process is required only every three years, it may require several months to complete. During this time, the standard will not be available for routine use. The time period includes the certification time plus transportation of a highly regulated material. Another disadvantage is radiation exposure to the operator. The operator must handle the standard multiple times for each calibration or measurement control run.

Use of an electrical calibration heater has several advantages over the use of ^{238}Pu heat standards. A calibration heater does not contain any nuclear materials. Therefore the security and accountability requirements are reduced. The operator radiation exposure is reduced for calibration or MC measurements. The power output of the heater probe is adjustable over a broad range. A single heater probe is useful over the entire calorimeter operating range. This eliminates the need to have a range of heat standards available for routine use.

The electrical calibration heater does has some disadvantages. The electrical calibration heater requires additional equipment to provide and measure the electrical power using instruments with NIST-traceable calibration. These instruments must be calibrated more frequently, usually 6 months to one year; but numerous facilities are available for the calibration of the instruments, possibly including a calibration site at the user's facility. Expensive and time-consuming transportation and calibration procedures are eliminated. A more important disadvantage is that a bias is observable between the electrical calibration heater and the heat standards.[1] The bias is observed at the low power settings. The potential exists to remove a portion of the bias calibration curves, but the preference is to reduce the bias to a zero or nonsignificant effect.

To minimize the observed bias, EG&G Mound developed a low-wattage version of the MECH probe. The low-wattage version used reduced size components. This probe resulted in reduced bias between the electrical values and the heat standards. Additional techniques have been proposed for use as calibration probes. One technique is to use optical power from a laser diode, and the other is to use resistive heating with reduced conductor sizes. The paper will report on the development to date, including preliminary tests, and a recommendation for future direction.

MECH PROBE

The MECH probe is inserted into the sample cavity through a hole in the baffle. The baffle is fabricated using high-quality insulating material, typically Styrofoam. A hole is bored through the baffle. A hollow phenolic tube is inserted into the baffle, as a sheath, to protect the baffle material from damage. The tubing ranges from 12.5 to 25.4 mm inner diameter (ID) with a 1.5-mm wall thickness. The probe shaft is fabricated using a high-density hollow plastic tube, such as phenolic or fiberglass, with a 3.175-mm wall. Four or more conductors, of #22 American Wire Guage (AWG) or larger, are connected between the heating element and the connector on the opposite end of the shaft. The electrical conductors are spirally wrapped on the outside of the shaft to increase the path length and thus reduce the heat loss. All the materials used in the probe construction are of higher density than the Styrofoam used in the baffle construction and therefore have a higher heat conductivity. Heat leakage is directly proportional to the heat conductivity[2].

HARDWARE DESCRIPTION

For the optical power measurements, an evaluation calorimeter was used. The calorimeter contained a gradient-type thermal measuring element, thermel, with a small water bath. The thermel had a sample winding and a reference winding separated by a thermal resistance made of an epoxy material. The temperature difference across the thermal resistance was determined by independently measuring the resistance of each winding and computing the difference. Heat from an internal resistive heat element was used for calibration to obtain a differential-ohms-watts conversion factor. The data collection system consisted of multiple Hewlett-Packard[3] digital voltmeters connected to a data collection computer using an IEEE-488[4] instrumentation bus. A data collection program was written in LabView[5] to acquire and store the data values from the digital voltmeters. Data analysis was performed off-line using MathCad.[6]

An 810-nm continuous wave (CW) laser diode is used to provide optical power into the sample chamber. The output of the laser diode is controlled using a driver with output and temperature regulation. The optical power is coupled into the sample chamber using the fiber optic cable with a connector. A non-reflective beam stop is used to capture the optical power and couple the heat to the sizing adapter located in the sample chamber (see Fig. 1). The fiber optic cable is passed through an unsheathed hole in the insulating baffle. The volume around the cable was filled with insulating material.

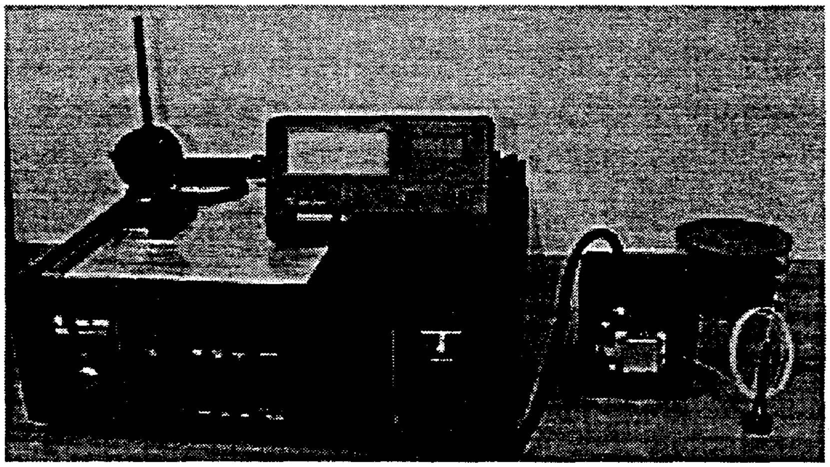

Fig. 1. Laser diode system with beam stop and chamber adapter.

The flexible circuit measurements were performed in a Serial Number 286, Mound model 151 calorimeter. It is a large water bath, full-twin 17.8-cm (7-in.) diameter configuration. The unit was operated in equilibration mode using the WinCal software package. A pair of ^{238}Pu heat standards were used as the heat source. The heat standards were placed in an adapter in the sample chamber. Flexible circuits were routed into the sample can near the adapter and out between the jacket and the baffle. Approximately half of the flex circuit length was outside of the sample chamber and exposed to the room environment.

Two flex circuit strips are evaluated. Both are 94 cm long and 3.8 cm wide of primarily Kapton® material. Each has two copper traces running the length of the circuit strip. The traces are 250-µm wide. One of the circuits is 64-µm thick with 2.2-µm thick traces. The other circuit is 127-µm thick with 36-µm thick traces.

DISCUSSION

A calorimeter calibration instrument requires precision monitoring of the power delivered to the sample chamber. For the optical power technique, three detector technologies were reviewed. The pyro-electric detector uses a material with a permanent electrical polarization, such as a crystal. As the material changes temperature, the polarization changes and produces a transient current. This detector is usable only with time-varying beams, non-CW. The quantum detector such as the silicon or germanium photo-diode use a semiconductor junction. The incident beam promotes electrons from the valence band to the conduction band, causing electron current to flow. The current flow is read by a meter to measure incident power. Use of a quantum detector required additional conductors into the sample chamber, and the sample beam is not available for heat production. A calorimetric detector uses a thermopile as a detector. The thermal pile is thermally coupled to the adapter in the sample chamber.

None of the optical power detection techniques were suitable for use as an *in-situ* power monitor. A calorimetric optical detector most nearly matches the measurement requirements for an *in-situ* monitor. The accurate calibration of the thermopile required components in the sample chamber and conductors into the sample chamber. Potentially, the need for additional conductors diminished the benefit of using fiberoptic cable to deliver the power to the sample chamber.

Precision monitoring of the power delivered to the sample chamber is performed using a 4-wire technique. In this technique, two of the conductors are used to provide power. An additional pair of conductors is used to sample the potential at the point of power production. The current is constant through the circuit and can be measured at any convenient location. The flexible circuit strip with the 36-µm thick traces is evaluated as a candidate for the sensing circuit. The circuit strip with the thicker traces is evaluated for use in the power supply circuit. During the design of the calorimeter baffle, the circuit trace widths are selected to balance the electrical power conduction loss with heat leakage.

The flexible circuits are an extension of existing technology. In the implementation, the flexible circuit would be imbedded in the insulating baffle and used with connectors for interconnection through the baffle. The external connector would connect to the power source and measuring equipment. Internally, a removable probe with a resistive heating element would mount to the bottom of the insulating baffle with a quick-disconnect connector. Use of a resistive heating element with a few 100 ohms of resistance would provide the few watts of power necessary with minimum current flow and nonhazardous potentials.

TEST RESULTS

The laser power measurements are made using an external power meter. The fiber optic cable was connected to the power meter. The power output measured is measured at several settings on the laser diode driver. The fiber optic cable is then connected to the nonreflective beam-stop in the sample chamber. The driver settings were repeated while the calorimeter was permitted to reach equilibration conditions. The differential resistance values for the electrical heater calibration and laser-powered operation are compared in (See Fig. 2). The power meter rated accuracy was 3%. A separate calorimeter measurement was made with the fiber optic cable inserted in the sample chamber but not connected to the beam-stop. No change in the operating conditions could be detected when the fiber optic cable was removed while the calorimeter was operating in equilibration condition.

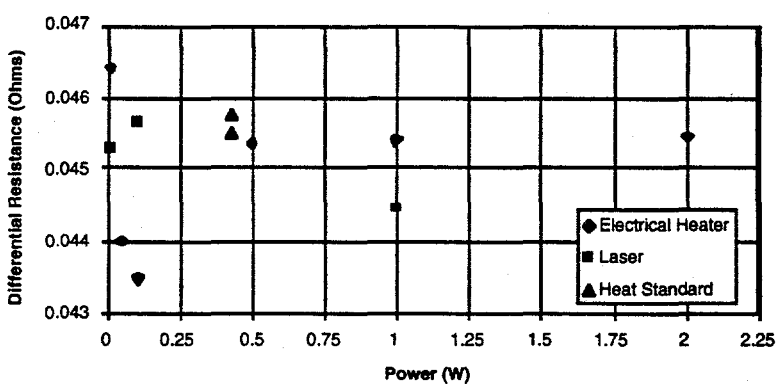

Fig. 2. Comparison of measurements with electrical calibration.

A different technique was use to examine the heat loss with flexible circuit strips. The adapter in the sample chamber was loaded with a 429- and a 2.005-mW heat standard. The thick and thin flexible circuit strips are placed in the top of the sample chamber, but not in contact with heat standards. The circuit strips were routed between the baffle and the jacket on the calorimeter. About half of the strip was exposed to the room environment, ~22°C. There was no direct metallic contact with the jacket, 25°C. The calorimeter was permitted to come to equilibration, and then one of the circuit strips was removed without disturbing the baffle. The observation continued until the calorimeter returned to equilibration and then the second strip was removed in the same fashion. After the unit reached equilibration, then the baffle was removed and the 2.005-mW heat standard was removed. The observation continued until the calorimeter again returned to equilibration. The heat loss of both thicknesses of flexible circuit are compared with a heat standard (See Fig. 3).

2.005 mW Heat Standard	Thin Flexible Circuit		Thick Flexible Circuit	
Signal (μV)	Signal (μV)	Power (mW)	Signal (μV)	Power (mW)
21.8	-3.0	0.41	-6.3	0.58
17.2	-3.5	0.41	-8.4	0.98

Fig. 3 Comparison of flexible circuit heat loss measurements with heat standard.

CONCLUSION

Using a fiber optic cable, optical power may be efficiently coupled into a calorimeter sample chamber with low heat leakage to the room environment. The incident beam striking a nonreflective beam stop may be used as a heat source in the chamber. For a precision long-term measurement, it is necessary to monitor the full beam power delivered to the sample chamber. To perform this measurement, a detector must be placed in the sample chamber. The detector and its *in-situ* calibration components would require additional metallic conductors to pass through the upper baffle. Heat loss or gain from using fiber optic cable was below the threshold for measurement. Adding metallic conductors through the baffle would diminish the benefit of using the fiber optic cable as the power conduction medium. At this time, optical power monitors do not have the accuracy and precision measurement capability that is comparable to a precision heat-flow calorimeter. Therefore laser power is not a suitable tool to use for calibration or measurement control of a heat-flow calorimeter.

Copper is used to conduct both electric power and heat. Low heat transfer through the copper traces on a flexible circuit has been observed. Using a resistive load with an elevated value, power can be produced with reduced currents and nonhazardous potentials. The reduced currents can be carried by conductors with reduced cross-sectional area. The smaller area of the copper conductor results in increased thermal resistance or decreased heat flow. The cross-sectional area of copper conductors can be controlled by the etching of copper on a substrate. During the design of a calorimeter, the trace dimensions and heater resistance can be optimized to minimize heat loss while delivering the necessary power into the sample chamber. Flexible circuits with low heat loss can be embedded in the upper insulating baffle. Heat losses in the sub-mW range have been observed with a 3°C temperature differential using a flexible circuit of nearly 1 m in length.

The future direction of this effort should be to implement the probe with resistive heater and thin-conductor flexible interconnect circuit on a production calorimeter system operating in a low-wattage application environment. The same equipment used to power, control, and monitor the

MECH probe is also compatible with the LWECH. The existing computer programs are also compatible. The MC system on the production calorimeter may require modification to monitor performance of the LWECH probe.

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