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AEC RESEARCH AND DEVELOPMENT REPORT

A WATER-COOLED TWIN CALORIMETER FOR CURIUM SLUG ASSAY

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Savannah River Laboratory

Aiken, South Carolina

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Instruments
(TID-4500, UC-37)

A WATER-COOLED TWIN CALORIMETER FOR CURIUM SLUG ASSAY

by

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ABSTRACT

A water-cooled twin calorimeter of 20 watt capacity was developed to assay routinely the curium-244 content of aluminum-jacketed slugs. The instrument is operated with master-slave manipulators and requires approximately 45 minutes for a determination. Precision is within 2.5%.

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INTRODUCTION

The Target Fabrication Facility (TFF) of the Savannah River Laboratory produces cylindrical aluminum-jacketed slugs, each containing about seven grams of curium-244 and a smaller quantity of americium-243 blended with 140 grams of compacted aluminum powder. The slugs, 15/16-inch diameter by 6 inches long, will be irradiation targets in a reactor for conversion of some of the curium and americium to californium. Since both curium and americium are highly radioactive, the slugs are fabricated in a shielded enclosure using master-slave manipulators. The slugs dissipate radioactive energy as heat at a rate of approximately 20 watts (2.83 watts/gram of curium) and in free air have a surface temperature of about 100°C. A water-cooled twin calorimeter was developed to measure the heat generated by each slug and thereby to confirm the quantity of curium loaded.

PRINCIPLE OF OPERATION

The calorimeter consists of a pair of identical water-jacketed copper containers and a small dual heat exchanger encased in a stainless steel box. A constant cooling water flow is routed in series through the heat exchanger, through the jacket of one container, back through the heat exchanger, and finally through the jacket of the second container (Figure 1). A thermopile is mounted across the water connections to each container so that temperature changes in the cooling water, caused by contact with the container, may be measured. Each of the two containers is thermally insulated so that all of the heat liberated within a container, either from a curium-containing slug or from a built-in electric heater, is delivered to the cooling water flowing through the jacket.

A curium-containing slug is placed in one of the containers; the temperature rise of the cooling water is measured; then the other container is heated electrically, with the electrical power adjusted, so that the cooling water passing through the jackets of both containers has the same temperature rise. The electrical power is then measured using an ammeter and a voltmeter and is equal to the power in watts dissipated by the radioactive slug.

The power in watts divided by 2.83 watts/gram equals the grams of curium-244 in the slug. If the slug contains americium-243 as well as curium there will be a small contribution from this element to the total power; usually this contribution is negligible.

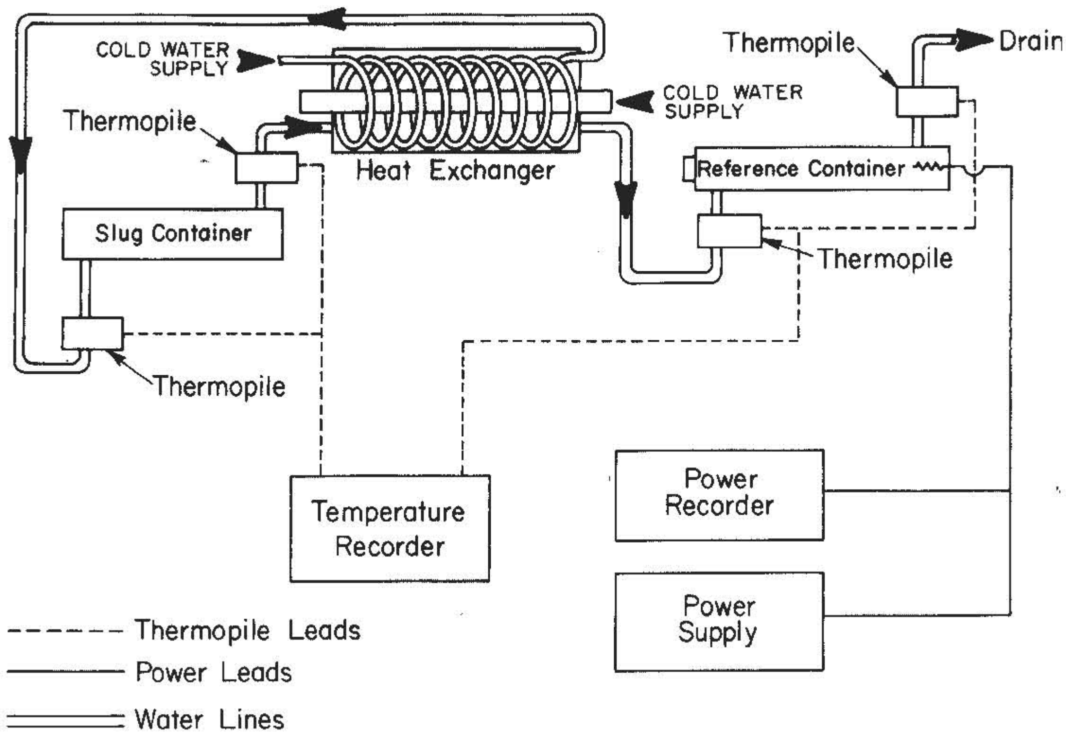

FIG. 1 INSTRUMENTATION SCHEMATIC FOR CALORIMETER

CONSTRUCTION

The twin calorimeter has two unusual features. First, it is designed for service in a production type remote facility with size limitations. The unit must be as rugged and maintenance-free as possible and arranged so that slugs are introduced or removed easily with master-slave manipulators. Figure 2 shows the internal arrangement of the containers and the heat exchanger. Slugs are introduced or removed through either of the tubes (labeled A and B) at the end of the box.

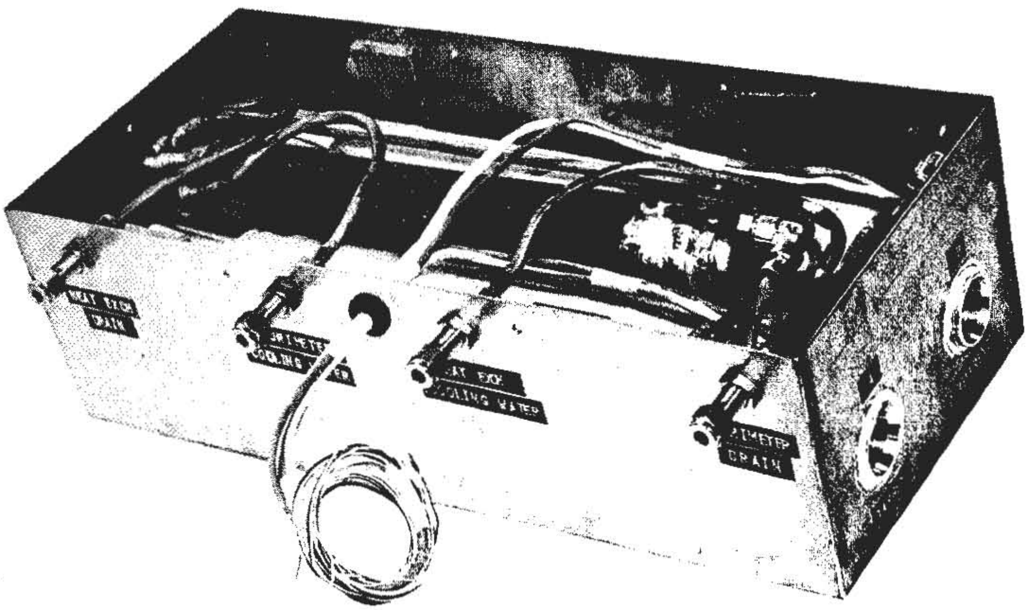

FIG. 2 INTERNAL ARRANGEMENT OF CALORIMETER

A second construction feature was that each container was dimensioned to fit within a vacuum flask to assure excellent thermal insulation in a minimum of space. After being positioned in in the flask, the container was encapsulated in polyurethane foam for firm support.

Figure 3 shows an individual container. The jacket is formed by silver soldering a larger copper tube, with water connections, over the primary container tube. A one-inch-ID aluminum tube lines the container so that the aluminum-jacketed slugs will not contact copper. The total length of the container is 10 inches. A disk inside the liner sections off a compartment 3 inches long in which a 500-ohm, 25-watt electrical resistor is sealed. The thermopile is iron-constantan with ten junctions cemented into each of the copper blocks, which are in turn soldered to the cooling-water fittings. An additional thermocouple, with individual leads, at each block is referenced against an external iron-constantan junction at 0°C to measure absolute temperature at the block as well as temperature difference between blocks.

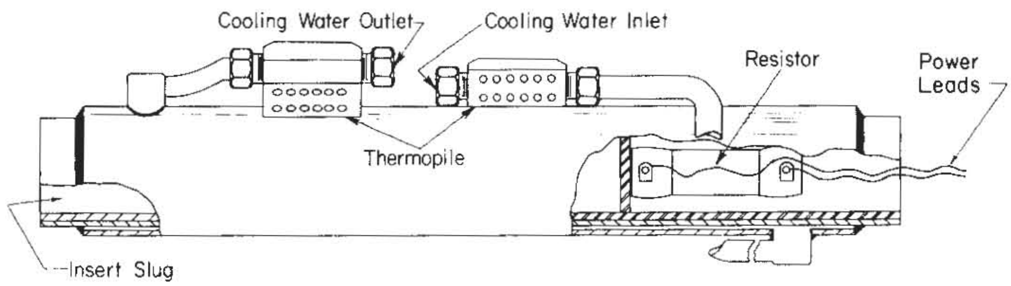

FIG. 3 CALORIMETER CONTAINER

The tubular opening through the encapsulating foam in the vacuum flask was painted with epoxy cement in order to form a smooth, rigid, thermally insulated liner, through which slugs are passed. The transfer tube from the vacuum flask to the exterior of the stainless steel box is an aluminum pipe.

The heat exchanger (Figure 4) is similar in construction to the containers. Three concentric copper tubes are soldered together to form two annulus-shaped passages through which water flows. The inner annular space has wound throughout its length a helix of 3/16-inch-OD copper tubing leading to external water connections thus providing a third water channel through the unit. The cooling water which flows through the calorimeter containers, at about 100 ml/min, flows first through the helix and, after passage through the first container, returns to the

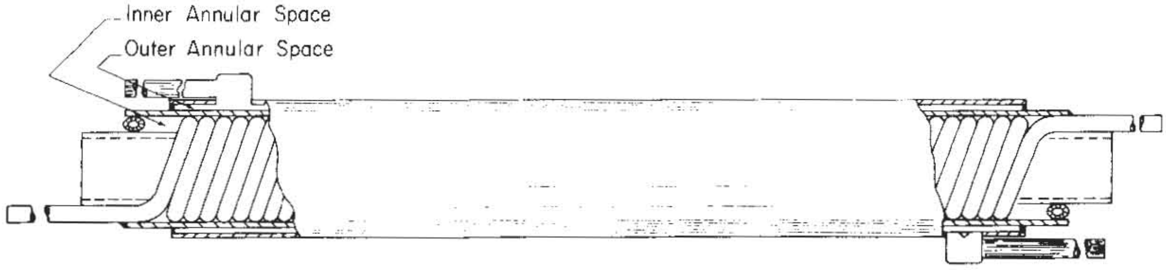

FIG. 4 CALORIMETER HEAT EXCHANGER

heat exchanger to flow through the outer annulus passage (Figure 1). A water flow of approximately 600 ml/min is passed countercurrently through the inner annulus space but through no other component of the calorimeter. Its function is to re-cool the calorimeter cooling water and to assure that the stream enters both containers at the same temperature.

Incidental components of the calorimeter are the flexible foam insulated plugs which stopper the openings in the containers. Rotameters are used for measuring water flow rate through the equipment. A small silicone rubber suction cup, connected by flexible tubing to a vacuum system, is inserted into a container to withdraw a slug after a measurement.

Both the thermocouple and the power leads are combined into a cable which connects the calorimeter to a rack-mounted control and instrument panel in the operating area. Two recorders and two regulated DC power supplies make up the control panel. The two power supplies furnish power to the 500-ohm resistors in the calorimeter containers. One of the recorders, a four point unit, records voltage and current being supplied to each of the two heater resistors (Figure 1). The second recorder, an eight point unit, is used to record temperatures indicated by the various thermocouples and thermopiles in the calorimeter. The two thermopile voltages are each printed out twice during a two minute recorder cycle. Three of the remaining points of the cycle are thermocouple outputs; the final point is voltage difference between the two thermopile outputs. At power balance this voltage difference should be zero even though both of the thermopile outputs might increase or decrease as a result of cooling water flow rate variations.

INSTRUMENT PERFORMANCE

Preliminary tests with no slugs in the calorimeter, using electrical power on both resistors, showed acceptable performance but indicated a small bias (about 1.6%) between the two containers. The first group of tests on production slugs confirmed satisfactory operation of the instrument. Ten tests were made on one slug in order to establish precision of the instrument. Four determinations of the power level were made with the slug in one container and four more determinations with the slug in the other container. These tests confirmed the bias detected in the preliminary electrical tests. Electrical resistors were inserted in the thermopile leads to introduce a compensating bias. Two more tests on the slug were made, confirming that the bias between containers had been corrected. The average power level for the ten determinations was 19.96 watts. After corrections were made for the electrical bias, the range of the ten power levels was 19.63 to 20.22 and the standard deviation was 0.166 watt. These data indicate that 99.7% of the determinations made by the instrument will have a precision of 2.5%.

A further purpose in measuring the power level of this slug so exhaustively was that, after its power level was established, it could be inserted as a reference power source into the calorimeter while balancing the heat output of any other slug. The only electrical power then needed was that added either to the test slug container or to the reference slug container, to achieve total power balance. The life expectancy of the resistors in the calorimeter should be increased by operating them in this fashion, with less than one watt dissipated, rather than 20 watts, which approaches their rated capacity in open air.

The time required for a determination was approximately 45 min. No difficulty in loading or unloading the instrument with manipulators was experienced.