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# DEVICES FOR MONITORING THE THERMAL STATE OF THE OBJECT "ENCLOSURE"

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*The design of heat flow and temperature metering equipment used at the Chernobyl Atomic Power Station for heat and temperature diagnosis of the state of the damaged reactor is described.*

Beginning in 1961 heat flow metering devices have traditionally been used at the I. V. Kurchatov Institute of Atomic Energy, the Research and Design Institute of Power Engineering, the Institute of Nuclear Investigations of the Academy of Sciences of the Ukr. SSR, and a number of other institutions to diagnose the normal state of nuclear facilities. Naturally, when the first impact of the accident to the fourth reactor at the Chernobyl Atomic Power Station subsided, the need for heat flow meters arose to diagnose the energy state of an immense zone $10^5$ $m^3$ in volume and then to reveal and investigate the sites of accumulation of nuclear fuel.

It turned out that among various methods tested on the object "Enclosure" for detection of buildups of fuel-carrying masses (FCM) the heat flow metering method had the greatest effectiveness. It consists in the use of primary heat flux transducers (HFT) for determining anomalous heat sources, from whose character of spatial distribution it is possible to determine rapidly sites of accumulation of buildup of fuel-carrying masses and determine more precisely the amount of nuclear fuel remaining in the object.

Practical application of heat flux transducers in the zone of the accident at the Chernobyl Atomic Power Station began in June, 1986. Being glued at several sites on the walls of the bubbler, they gave the first objective information about the thermal state of the processes taking place. The urgency of obtaining this information can be judged on the example of the formulation of the erroneous hypothesis, advanced in the first weeks after the accident, that a plasma clot with a temperature of 15,000 K was formed in the central portion of the damaged reactor that could melt several one- and two-meter-thick floors and collapse into the ground under the reactor base. The main danger was thought to be the impossibility of stopping further unpredictable motion of it with an unpredictable power. To limit such a hazard, a water-cooled reinforced-concrete plate was built under the reactor, and only after completion of its construction was it realized that the plasma density at a temperature of 15,000 K is an order of magnitude smaller than that of air, and that the plasma clot, if it existed, would float up rather than sink.

The thermal measurements conducted made it possible to establish the true maximum values of heat flux and temperature, which turned out to be two orders of magnitude smaller than those assumed. Thus, figuratively speaking, the plasma clot created by the wild imagination of theoreticians was stopped not by a huge water-cooled reinforced concrete plate but by several heat flux transducers.

These heat flux transducers are of the type of thermoelectric temperature transducers made in the form of an auxiliary wall consisting of a battery of differential galvanic thermoelements connected in parallel with respect to the measured heat flux and in series as regards the generated electric signal [1, 2]. They are disks of diameter 120 mm and thickness 6 mm. At the expected values of the heat flux densities from $10^2$ to $10^4$ $W/m^2$ and in the

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** Deceased.

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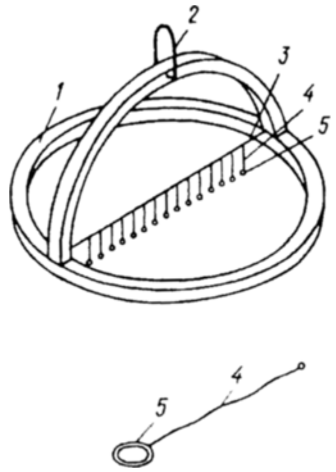


Fig. 1. A hot probe with fusible rings: 1) aluminum frame; 2) a lug for a helicopter cord; 3) fastening cable; 4) tow bars; 5) fusible rings.

presence of large thermal interferences it was desirable to obtain an HFT signal of several volts, i.e., the sensitivity should be from 1 to 10 $mV \cdot cm^2/W$, and this was achieved. The HFT signals entered the recording apparatuses via cables.

The practice of measurements of heat fluxes in the zone of the accident in 1986 showed great advantages in heat flow metering devices in obtaining diagnostic information and made it possible to specify requirements on the output parameters of heat flux transducers. More than 300 HFTs with different technical characteristics were required for monitoring. They were continually manufactured and installed on the objects.

Under the conditions of the affected zone of the damaged fourth block of the Chernobyl APS of more than $10^5$ $m^3$ in volume it turned out to be difficult to use directly the available heat flow metering equipment because of the great radiation hazard, since the dose of ionizing radiation exceeded several thousand roentgen per hour.

Special buoys were designed at the I. V. Kurchatov Institute of Atomic Energy for primary diagnosis of the state of the damaged block. They were equipped with different devices intended for obtaining information on twenty parameters. Such a buoy was brought to the object with the aid of a helicopter.

During transportation and also under the severe temperature and radiation conditions of the damaged reactor many of the various sensitive elements of the buoys were made inoperative even before connection to the cable joints. As a rule, the heat flux and temperature transducers were trouble-free. Some failures occurred because of breakdown of measuring circuits during installation (rarely) and operation under conditions of intense activity and uncoordinated crossing of the strong interests of the many different organizations that worked in the hazardous zone.

Each buoy had two heat flow metering transducers designed and manufactured at the Heat Flow Metering Department of the Institute of Technical Thermophysics of the Academy of Sciences of the Ukr. SSR (beginning from July 1, 1988 it is the Department of Heat Flow Metering and Heat Conservation of the Institute for Problems of Energy Conservation of the Academy of Sciences of the Ukr. SSR) that were suspended on a special mechanism that brought them into contact with the surface of the destruction after slackening of the cord on which the buoy was suspended to the helicopter. Without this mechanism the transducers would have been torn off.

To monitor the surface of the destruction, a special buoy-hot probe was designed at the Institute for Problems of Energy Conservation of the Academy of Sciences of the Ukr. SSR [2]. The thermometric phenomenon used was the dependence of the melting temperature of alloys on their qualitative and quantitative composition. The hot probe (Fig. 1) consisted of an aluminum frame to which a lug for a helicopter cord and a fastening wire with eighteen melting rings suspended on tow bars were fastened. The rings were made of alloys of different compositions, ensuring indication of temperature within the range of values from 30 to 330°C with a step from 6 to 24 K. The temperature in the zone probing is equal to a value lying between the melting temperatures of the last molten ring and the first preserved ring determined by inspection after retrieval of the hot probe from the monitored

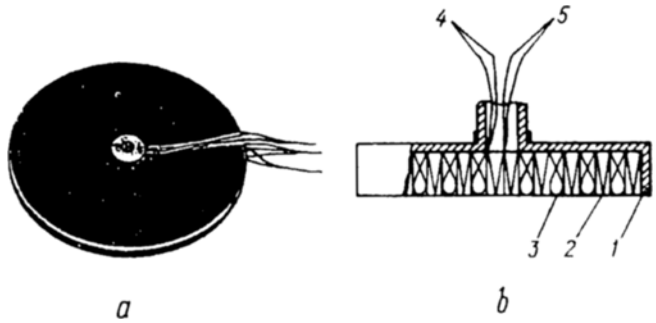

Fig. 2. Heat flow metering transducer of a device of an HFT model: a) external view; b) construction diagram; 1) casing; 2) HFT; 3) RT; 4, 5) leads of the electric connection of the RT and HFT with a V7-35 voltmeter.

zone. Unfortunately, after installation in the reactor crater and exposure for five minutes, the device, in being withdrawn, caught on a protruding pipe in the destruction and was destroyed. This unsuccessful experience was taken into account when the Institute of Atomic Energy developed the complex buoy described above.

The majority of the transducers that were applied to the object "Enclosure" were two-parameter and made it possible to measure not only the density of the heat flux through the surface of the object on which they were installed but also the temperature at the place of installation. For this purpose, the heat flux transducer additionally had a primary temperature transducer, namely, a copper resistance thermometer (RT) made using the technology for the heat-sensitive element of a heat flux transducer. The resistance thermometer was made in the form of an analogous plane spiral produced by winding copper wire onto a thin strip of electrically insulating film material. The height of the strip was equal to the height of the framework strip of the battery of thermoelements in the heat flux transducer. This simplifies the mounting of both transducers in a single casing. The casing can be made in the form of a Fiberglas laminate plane disk, one of whose faces has a groove of identical depth for placing the HFT battery of thermoelements and the RT spiral in it, or in the form of a metallic disk made of oxidized aluminum with a concentric circular groove into which the HFT thermosensitive element and the RT are glued, or in the form of a thin ring of oxidized aluminum inside of which the HFT with the RT are glued by an electroinsulating compound. And, finally, the heat flux transducer can be made without a casing, i.e., in the form of a monolithic disk formed by a filling compound with a battery of thermoelements and an RT molded in it [2-4].

In view of the fact that the placement of transducers over the damaged fourth block with the help of helicopters was extremely random, the demand arose for a portable device that would made it possible to measure simultaneously heat fluxes and temperatures in zones with radiation conditions that were relatively safe for operators. Such a device was intended for systematic operative monitoring of the thermal state of pile-ups and in preserved rooms of the object "Enclosure."

The first specimen of the device was an analog of the well-known HFT series [2] for measuring heat losses through protecting structures of buildings and insulation of technological devices and apparatuses. All of its indices such as the dimensions and sensitivity of the HFT, the sensitivity of the autonomous recorder, and the length of the HFT carrier were brought up to feasible extremal values. However, the specimen was used rather for demonstration, whereas for practical measurements a portable device of an HFT model was developed [2, 4] that included a primary heat flow and temperature transducer, a V7-35 universal digital voltmeter with an autonomous supply and a telescopic bar with a switcher of the kinds of operations and a potentiometer built into the handle of the bar.

The heat flow and temperature transducer, whose constructional diagram is presented in Fig. 2, consists of a battery of HFT thermoelements and an RT spiral mounted in a single casing, namely, a metallic disk 80 mm in diameter and 3 mm thick.

The HFT thermoelements were made of constantan wire galvanized discretely with a paired thermoelectrode material (copper). For a height of a thermoelement of 1.5 mm and an HFT diameter of 70 mm, the conversion factor was equal to 2.5 $W/(m^2 \cdot mV)$. To simplify the voltmeter readings to obtain values of the

TABLE 1. Composition (wt.%) of Alloys and Melting Temperature

| Temperature of complete melting, °C | Lead | Tin | Cadmium | Gallium | Bismuth | Indium | Antimony |
|---|---|---|---|---|---|---|---|
| 27 | – | – | – | 100 | – | – | – |
| 46 | 22.4 | 10.8 | 8.2 | – | 40.6 | 18 | – |
| 60 | 25 | 12.5 | 12.5 | – | 50 | – | – |
| 70 | 17.9 | 24.5 | 12.3 | – | 45.3 | – | – |
| 80 | 35.1 | 20.1 | 9.5 | – | 35.3 | – | – |
| 94 | 25 | 25 | – | – | 50 | – | – |
| 100 | 40 | 10 | – | – | 50 | – | – |
| 110 | 22 | 22 | – | – | 56 | – | – |
| 125 | 43.5 | – | – | – | 56.5 | – | – |
| 144 | 40 | – | – | – | 60 | – | – |
| 150 | 16 | 17 | – | – | 67 | – | – |
| 160 | 30 | 45 | – | – | – | 25 | – |
| 180 | 37.5 | 37.5 | – | – | – | 25 | – |
| 190 | 39.5 | 60 | – | – | – | – | 0.5 |
| 240 | 64.5 | 30.5 | – | – | – | 5 | – |
| 260 | 85 | 10 | 5 | – | – | – | – |
| 286 | 79.9 | 2.6 | 17.5 | – | – | – | – |
| 327 | 100 | – | – | – | – | – | – |

measured heat flux density under conditions of a strict time limit, a potentiometer was built into the handle of the bar, which made it possible, by decreasing somewhat the HFT sensitivity, to bring the conversion factor to the value 10 $W/(m^2 \cdot mV)$. Due to this the sought heat flux density is equal to ten times the reading of the voltmeter in the regime of heat flux measurements (the switcher of operations is set in position "$Q$").

Analogously the RT sensitivity was made equal to 1 $\Omega/K$, at which the temperature measured in Kelvins is equal to the readings of the universal voltmeter in the regime of measurement of resistance (the switcher of operations is set in position "$R$"). This is achieved by series connection, to the copper wire with the thermally dependent resistance $R$, of an additional portion of a constantan wire spiral with a thermally independent resistance $R$ wound on the framework strip similarly to the copper wire. The numerical values of both resistances are determined from the system of equations

$$R^0_{cop} + R_{con} = 273.15C_{RT}, \quad R^{100}_{cop} + R_{con} = 373.15C_{RT}, \quad R^{100}_{cop}/R^0_{cop} = 1.427 .$$

The solution of this problem gave the values $R_{con} = 38.96\ \Omega$, $R^0_{cop} = 234.2\ \Omega$, $R^{100}_{cop} = 334.2\ \Omega$.

For remote measurement the transducer was hinged at the end of a telescopic bar, for which a 4-m long glass-plastic three-section fishing rod was used. This made it possible for the operator to be at a relatively safe distance from the investigated object under conditions of strong ionizing radiation. The time constants of the heat flux and temperature transducers at a level of 25 and 40 sec, respectively, made it possible for the operator to decrease the stay at each point of measurement to 1.5–2 min. Four specimens of such devices were manufactured and handed over to the complex expedition "Enclosure," each containing further improvements.

After carrying out investigations on the surface, a program of internal diagnosis was begun that was fulfilled with the help of long horizontal or slightly inclined (up to +15°) holes whose length attained 30 m at a diameter from 93 to 103 mm.

To measure the density of heat fluxes passing through the filling, the pile-up, and the remaining structures of the damaged reactor, a borehole heat and temperature measuring probe (HTMP) was developed containing one standard resistance thermometer and two heat flux transducers manufactured at the Heat Flow Metering Department of the Institute for Problems of Energy Conservation of the Academy of Sciences of the Ukr. SSR. The two HFTs were located in one cross section, but on diametrically opposite sides of the probe. Before loading into the hole, the spring of the probe is compressed with the help of a steel cable stretched at the end face, thus decreasing the distance between the two heat flux transducers by 2–3 cm, and the probe enters the hole freely. In the measurement zone the cable is slackened and a clamp presses the two heat flux transducers to diametrically opposite sides of the hole. The probe can be rotated around its axis and moved along the length of the hole.

The heat flow and temperature metering equipment described made it possible to obtain, during the time of its service, a general thermal and temperature picture of the emergency zone (see Table 1).

Staff of the Department of Heat Flow Metering of the Pilot-Scale Production and Special Design-Technology Office of Precise Instrumentation at the Institute of Technical Thermophysics of the Academy of Sciences of the Ukr. SSR as well as staff members of the combined expedition "Enclosure" actively participated in the construction and operation of this combination of devices for primary and current diagnosis of the state of the emergency reactor.

## NOTATION

$R^0_{cop}$ and $R^{100}_{cop}$, resistance of the portion of the resistance thermometer made of copper wire at 0 and 100°C, respectively; $R$, resistance of the portion of the resistance thermometer made of constantan wire; $1.427 = R^{100}_{cop}/R^0_{cop}$, certificate value for copper wire.

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