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MODIFICATION OF THE CAMI ROTATING WHEEL FOR USE IN FULL-SCALE FIRE TESTS

by

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FORWARD

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INTRODUCTION

The Federal Aviation Administration (FAA) has initiated a program for evaluating the contribution of aircraft interior materials to the hazard of a postcrash fire. One aspect of the postcrash fire hazard is the potential toxic threat presented by the thermal decomposition products of the interior materials. Typical aircraft interior materials will be compared on the basis of both toxic gas concentrations and small-animal response data obtained during full-scale fire tests in a 13,000-cubic-foot fuselage (reference 1). These tests will be conducted at the FAA's National Aviation Facilities Experimental Center (NAFEC). One of the purposes of these tests is to characterize the fire environment and to provide a data bank upon which laboratory tests can be modeled.

Since animal response data are to be obtained, an animal test procedure is required which can function under the extreme conditions encountered in many full-scale fire tests. Such a procedure must satisfy several criteria. The reproducibility of the procedure must be high so that a reasonable number of animals can be used to obtain statistically valid data at multiple locations within the test article. In addition, simple procedures which employ untrained test animals and which do not require biological parameters to be monitored are more convenient for full-scale tests. A gross toxicological endpoint, such as incapacitation, is preferred. Such an endpoint is simple to obtain, provides a quantitative comparison of materials according to their relative potential toxicities, and specialized training is not required to evaluate the response. Finally, one must be able to electronically monitor the activities of the animals in order to determine the toxicological endpoint, since the animals are usually obscured from view during a full-scale fire test.

The FAA's Civil Aeromedical Institute (CAMI) has developed a small-animal test procedure which satisfies most of these criteria (references 2-6). This procedure provides both the times-to-incapacitation (t_i) and times-to-death (t_d) of male Sprague-Dawley rats as a basis for comparing the relative potential toxicities of thermal decomposition products released by nonmetallic materials (reference 6). Each rat is contained in an individual Plexiglas/polyolefin-mesh wheel which is rotated at a constant rate by an electric motor. This forces the rats to remain active during the period of exposure. Incapacitation is denoted by the rats' loss of voluntary movement in the rotating wheel, while death is reported when respiratory movements are no longer visible. Both t_i and t_d are determined by visual observation.

Visually monitoring the activity of the rats, besides being somewhat subjective, requires the observers to be in constant visual contact with the test animals. Although this can be accomplished during small-scale laboratory tests, it is often impossible during full-scale fire tests due to the presence of heavy smoke and/or the remote location of the animal exposure sites. Therefore, the CAMI rotating wheel has been modified so that the activity of the test animals can be monitored electronically. This is accomplished by installing a pressure transducer in a slotted wheel which generates a voltage whenever the test animal contacts the transducer. Visual observation of the test animals is not required with this modification, and the NAFEC-modified rotating wheel is suitable for use in full-scale fire tests.

The purpose of this report is to describe the modifications that have been made to the CAMI rotating wheel. In addition, representative analog recordings of animal activity are presented and analyzed.

EXPERIMENTAL

Test Animals

The test animals were male Sprague-Dawley rats obtained from Charles Rivers Laboratories. They were maintained and used according to specified procedures (reference 7). The animals were received by a local college, placed on Tetracycline, and quarantined for 2 weeks prior to use. They were delivered to NAFEC, as required, 24 hours prior to testing. The weight range of the test animals was 150-300 grams.

NAFEC Exposure Chamber

The animal response data were obtained in the NAFEC animal exposure chamber which is illustrated in figure 1. The chamber, which is constructed from 0.25-inch (0.635 cm) Plexiglas, is 8 ft. (2.45 m) long, 2.5 ft. (0.77 m) wide, and 2 ft. (0.62 m) high. The chamber contains a movable bulkhead so that the volume can be varied from a minimum of 15 ft.^{3} (0.42 m^3) to a maximum of 40 ft.^{3} (1.12 m^3) in increments of 5 ft.^{3} (0.14 m^3). The data contained in this report were obtained using a volume of 30 ft.^{3}.

A section of the chamber top 6 feet in length can be removed to provide access to the interior. The remaining 2-foot section is cement board which provides a thermally stable area for the radiant panel heater. In addition, the cement board contains a 3-inch (7.62 cm) diameter electrically operated valve which is used to evacuate the chamber following a test. The removable top contains a 9-inch (22.36 cm) diameter fan which can be varied from 0-1,000 rpm with a variable voltage transformer. The fan blade is made of polypropylene and the 3-inch shaft is covered with epoxy paint. The fan rapidly distributes the thermal decomposition products and prevents localized heating within the chamber. The chamber top is sealed with a foam rubber gasket, and it is held firmly in place with 10 trunk clasps.

The data in this report were obtained by thermally decomposing samples of materials with a Model F8-12 radiant panel supplied by Aten Limited. This is a 1,200-watt (115 VAC) heating element with dimensions of 12 inches (30.48 cm) by 8 inches (20.32 cm). The voltage is controlled with a variable transformer. The radiant panel is enclosed in a cement board housing which is described in figure 2. The sample material is supported vertically on a cement board backing with the front face of the material an inch (2.54 cm) from the surface of the radiant panel. The chamber is then sealed and the radiant panel is heated from room temperature to approximately 820°C (1500°F) in a period of 15 minutes. A water cooled radiometer, inserted through a hole in the center of the cement board backing, measures a maximum heat flux of 5 watts/cm^2 under these conditions. After 15 minutes both the radiant panel and the mixing fan are turned off.

Continuous gas analyzers are used to monitor oxygen, carbon monoxide, and carbon dioxide concentrations within the exposure chamber. The minimum oxygen concentration is generally greater than 18 percent. Smoke density is measured with a photometric detector (reference 8). Temperatures are recorded at three locations within the chamber. The surface temperature of the radiant panel is recorded along with the temperature at the surface of the sample material. The temperature at the rotating wheels is also recorded. The maximum temperature at the rotating wheels is generally 33-36°C (92-97°F).

The chamber contains three NAFEC-modified rotating wheels supported on a stainless steel shaft. The shaft rotates on stainless steel collars which are supported by machined Teflon bearings in the sides of the chamber. It is rotated at a rate of 4 rpm by a 0.125-hp electric motor supplied by Dayton Electric Co.

Rotating Wheel Assembly

The construction details of the rotating wheel are illustrated in figure 3. The wheels are constructed from 0.25-inch (0.635 cm) Plexiglas. Each wheel half consists of an end plate, 10 crossbars, a support rim, and a plastic mesh walking surface. The end plates are 12.5 inches (31.75 cm) in diameter, with each plate containing 128 ventilation holes. Eighty of the holes are 0.50 inch (1.27 cm) in diameter, while 48 are 0.375 inch (0.95 cm) in diameter. The outer edge of each end plate and the inner edge of each support rim contain 10 slots, each 0.25 inch (0.635 cm) square. The end plate and support rim are joined by cementing the 10 crossbars into these slots. The crossbars are each 0.25 inch (0.635 cm) square and 1.25 inches (3.18 cm) long.

The walking surface is constructed from polyethylene mesh, 6 by 7 strands per inch. The mesh is an inch (2.54 cm) wide and is tied to the inside surfaces of the crossbars with nylon string. This produces a smooth walking surface and is easily repaired. A wheel assembly consists of two wheel halves separated by a 0.375-inch (0.95 cm) gap and supported on a 0.635-inch (1.61 cm) square stainless steel shaft. This results in an internal width of 2.375 inches (6.03 cm) and a diameter of 12 inches (30.48 cm). The shaft is rotated at 4 rpm which causes the test animal to travel a distance of 12.56 linear feet per minute.

An insertion plate, which is supported just above the shaft, is employed in order to restrict the test animal to the lower half of the rotating wheel. It is 1.875 inches (4.76 cm) wide and 11.25 inches (28.58 cm) long. The insertion plate is tapered at the rear to prevent the animal's legs from becoming trapped following incapacitation. The insertion plates are supported in a stainless steel assembly that has been covered with epoxy paint.

The pressure transducer assembly, as described in figures 3 and 4, consists of a pressure transducer, Teflon housing, contact bar, power supply, and an external balancing circuit. The pressure transducer is a Tyco series AB with a range of 0-6 psi (0-420 g/cm^2). Its voltage output is 100 millivolts (mv) full scale with a 5 VDC excitation potential. The machined Teflon housing fits over the transducer and provides a guide for the aluminum support rod on the contact bar. The depth of the housing is sufficient to prevent the test animal from dislodging the contact bar with its tail.

The contact bar is 0.25 inch (0.635 cm) wide and 10 inches (25.4 cm) long. The surface is contoured to match the curvature of the rotating wheel. The contact bar is centered in the 0.375-inch (0.95 cm) slot between the wheel halves and protrudes approximately 0.125 inch (0.318 cm) into the wheel assembly. The external balancing circuit is used to offset the baseline and keep the signal within the range of the recorder.

RESULTS

The activity of a test animal in the NAFEC-modified rotating wheel is monitored by the pressure transducer. When the animal touches the contact bar, which is positioned in the slot between the wheel halves, the aluminum support rod exerts a force on the sensing element of the transducer. This generates a voltage which is proportional to the applied force. This voltage is monitored continuously with a millivolt recorder.

A typical baseline recording is illustrated in figure 5. This represents the first 7 minutes of a test involving a wool seat fabric at a sample loading of 36 mg/liter. The baseline consists of a series of voltage spikes (typical walking pattern) superimposed upon a voltage due to the weight of the contact bar on the pressure transducer. Smoke was first observed at approximately 2 minutes. The loss of voltage spikes at this time corresponds with the animal's attempts to escape from the rotating wheel. The animal was clinging to the side of the wheel and attempting to get past the insertion plate. This behavior lasted for approximately half a minute. It should be noted that some baseline activity is still visible. The test animal was also attempting to escape between 6 and 7 minutes, with the baseline being reestablished by 7 minutes.

Figure 6 is the latter part of the same test. The t_i of 13.6 minutes is clearly indicated by a complete loss of activity. This particular test was run with a wider and less tapered insertion plate than the one currently used. As a result, the test animal's leg became caught between the plate and the wheel at t_i. At approximately 15.4 minutes, the animal slipped free and began tumbling in the wheel. The tumbling action produces a very distinctive pattern, and efforts are being made to further modify the rotating wheel so that a tumbling action is consistently obtained following incapacitation. The rotation of the shaft is stopped once all three animals are incapacitated. The recorder is then switched from 100 mv to the 20 mv range; the signal is adjusted with the external balancing circuit; and the respiratory movements of the animals are monitored. As indicated by the flat response, this particular animal had died at some time prior to stopping the rotation at 17 minutes.

Figures 7 and 8 illustrate the response of a second animal which was exposed during the same test. The baseline, as indicated in figure 7, was lost at 13.6 minutes, which was t_i. Rotation of the shaft was stopped at 17 minutes, and the respiratory movements of the animal were recorded. Between 17 and 19 minutes, the animal was lying on its side gasping for breath. At 19.2 minutes, the animal convulsed and entered a protracted period of shallow and erratic breathing as illustrated in figure 8. The animal experienced a minor body tremor at 28.1 minutes followed by a complete loss of activity at 28.3 minutes, which was t_d.

Figures 9 and 10 illustrate the behavior of two animals exposed to the thermal decomposition products of a coated fabric (polyvinylchloride on cloth). The sample loading was approximately 67 mg/liter. Incapacitation, indicated by a loss of baseline in figure 9, occurred at 14.2 minutes. Rotation of the shaft was stopped at 15.5 minutes. Death occurred at 18.1 minutes after a period of shallow erratic breathing. The behavior of the animal represented in figure 10 was somewhat different. The baseline was lost (t_i) at 14.5 minutes, and rotation was stopped at 15.5 minutes. However, this animal exhibited a series of deep, widely-spaced gasps prior to a complete loss of activity (t_d) at 19.5 minutes.

Figures 5 through 10 illustrate typical responses obtained with the NAFEC-modified rotating wheel. At this time more than 40 tests have been run without any malfunctions. The only maintenance, other than cleaning, has been the occasional replacement of the nylon strings securing the polyethylene mesh to the crossbars.

The rotating wheel developed at CAMI provides a means of obtaining a reproducible, easily interpreted endpoint, such as t_i, which is relevant to escape potential. The NAFEC modifications provide a means of objectively and electronically determining this endpoint. With these modifications, the rotating wheel can be employed in the presence of heavy smoke and at remote exposure sites. This procedure is therefore suitable for use in obtaining animal response data under conditions commonly encountered during full-scale fire tests.

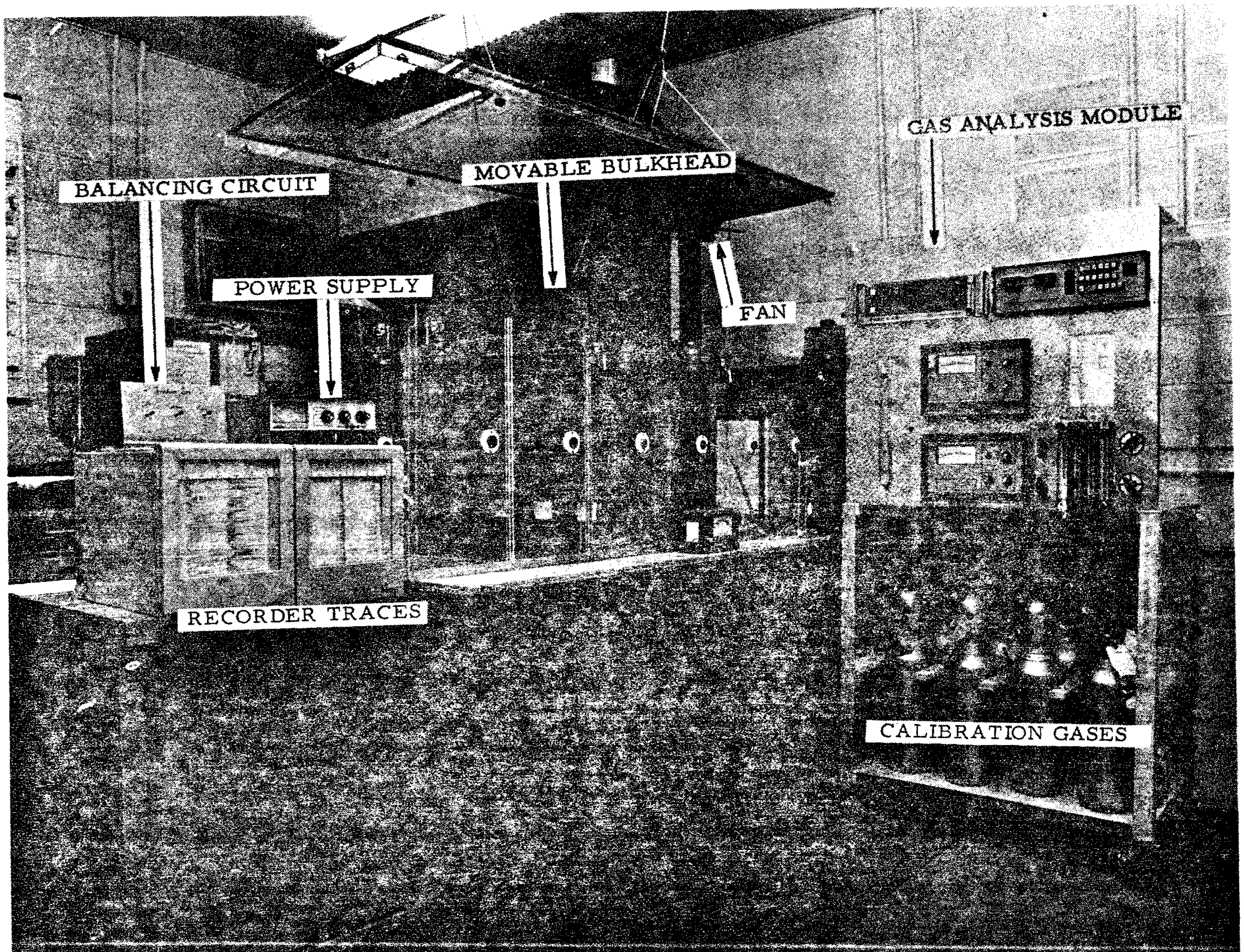

BALANCING CIRCUIT
POWER SUPPLY
MOVABLE BULKHEAD
FAN
GAS ANALYSIS MODULE
RECORDER TRACES
CALIBRATION GASES

FIGURE 1-A

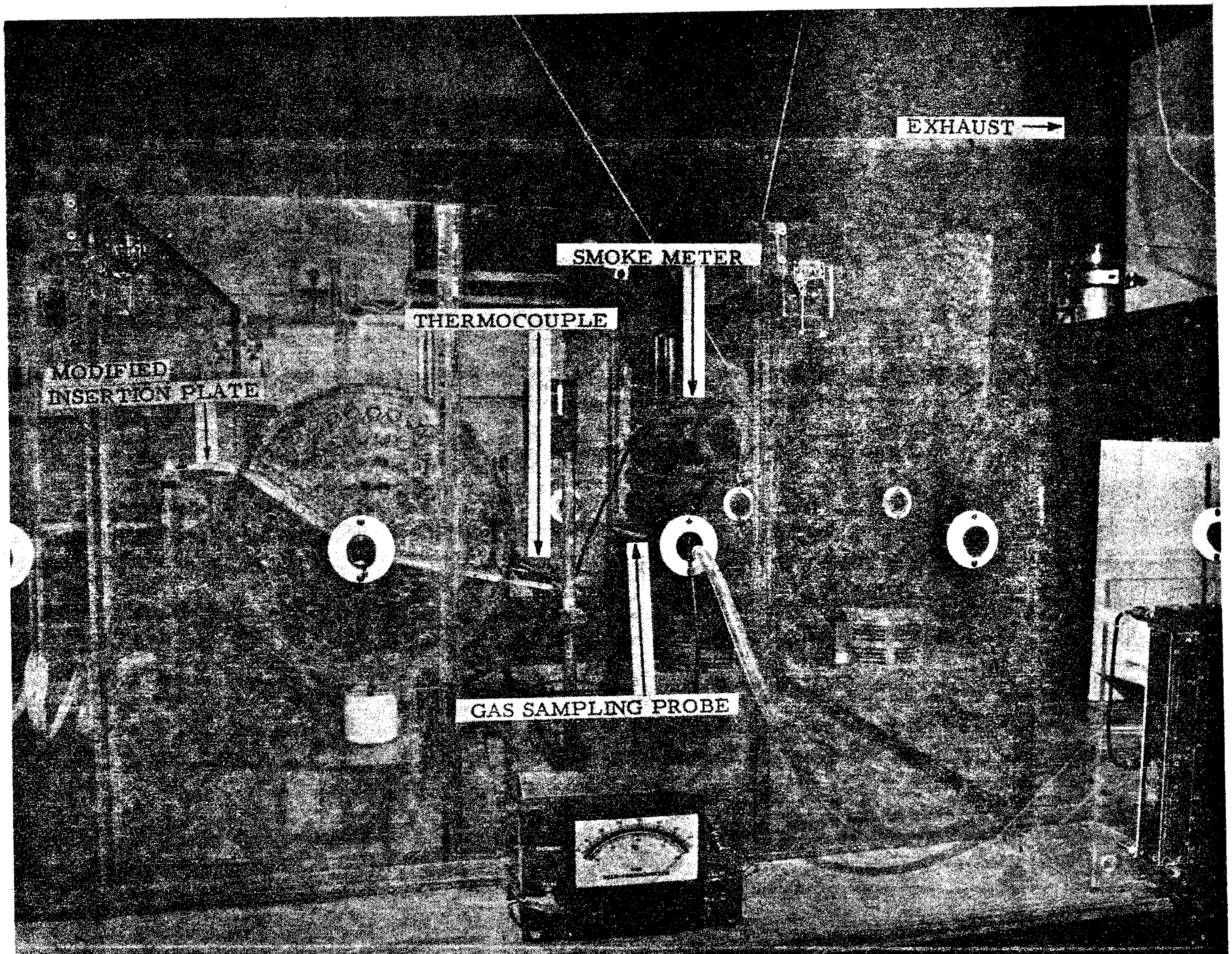

EXHAUST →
SMOKE METER
THERMOCOUPLE
MODIFIED
INSERTION PLATE
GAS SAMPLING PROBE

FIGURE 1-B

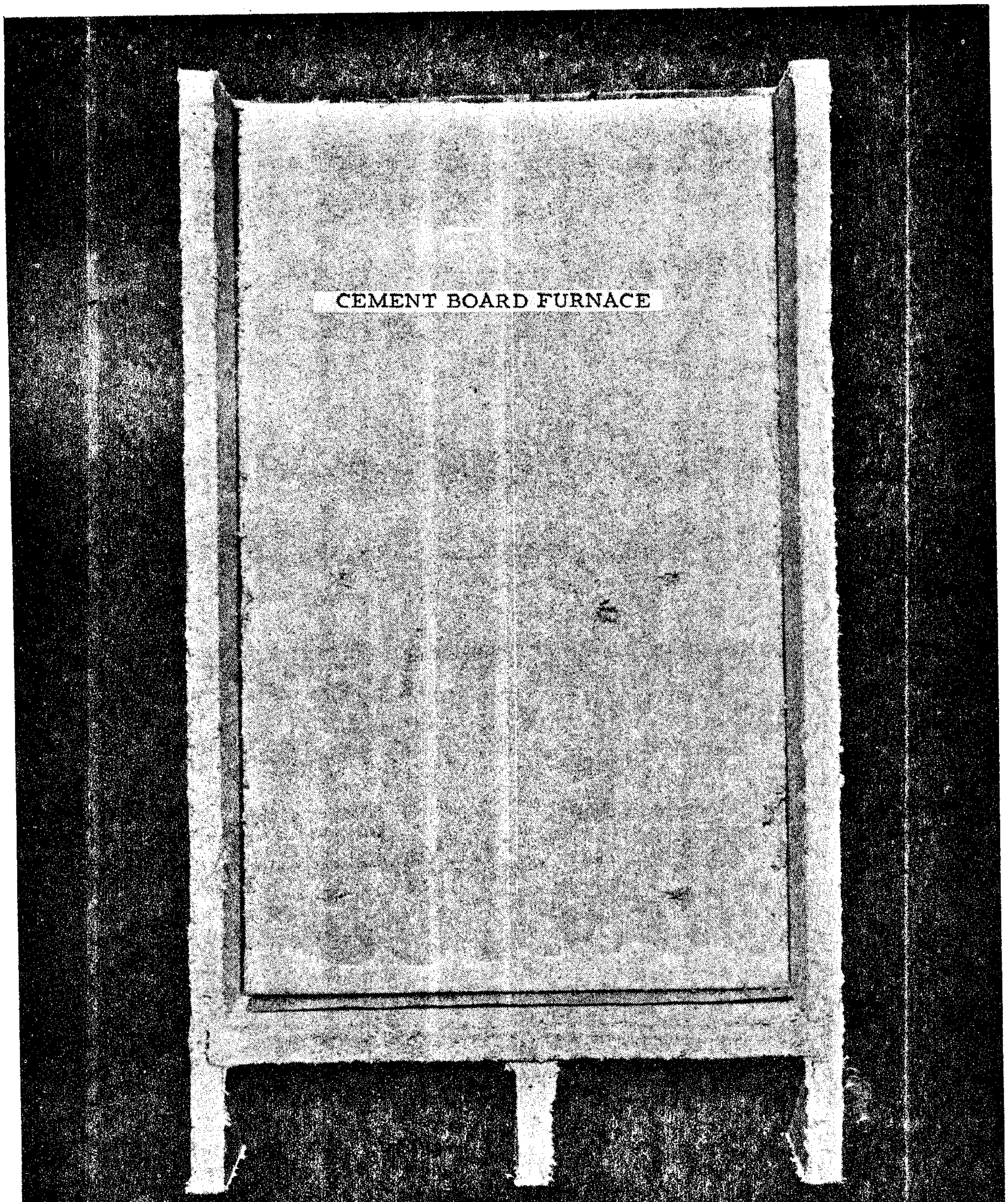
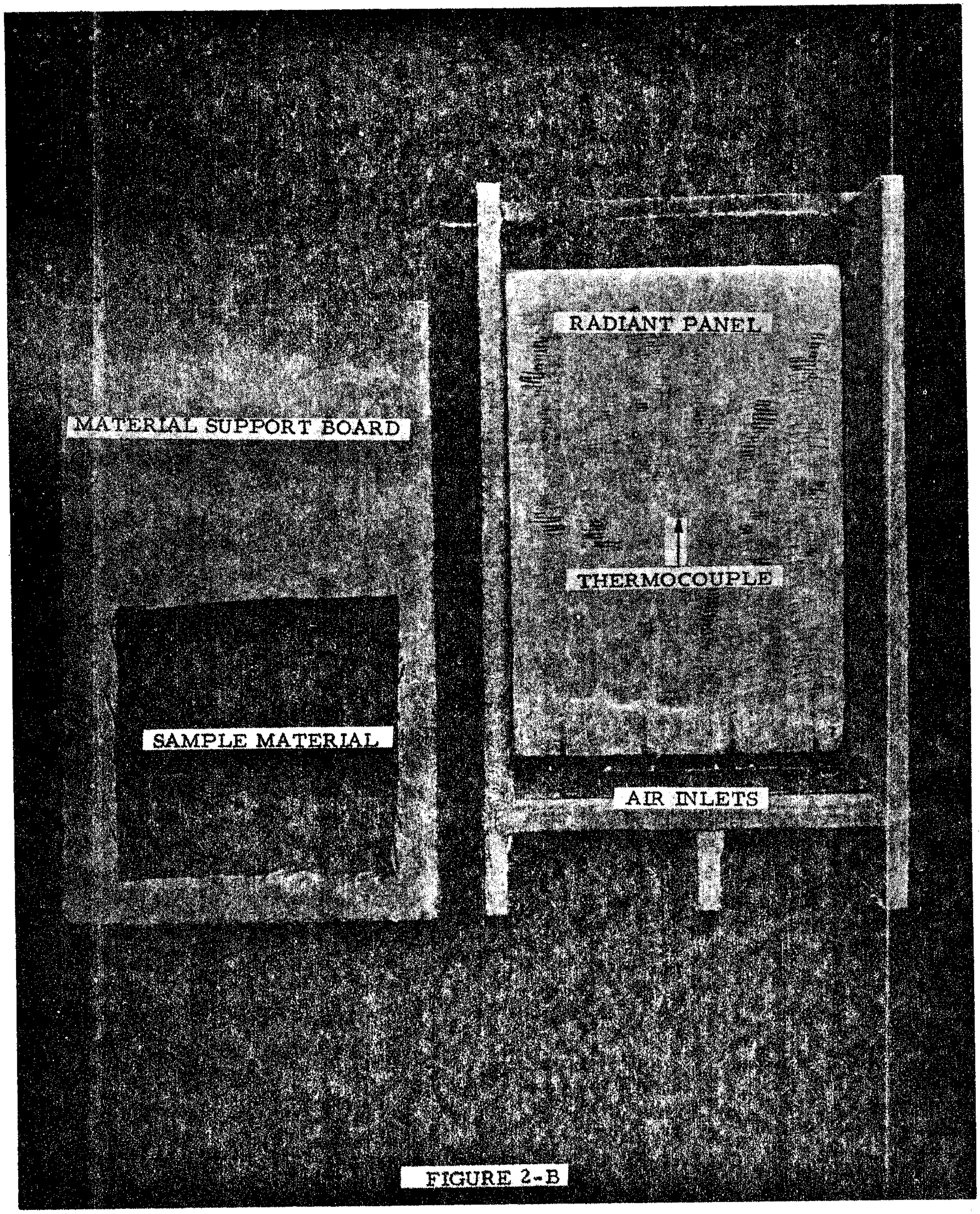


FIGURE 2-A


RADIANT PANEL
MATERIAL SUPPORT BOARD
THERMOCOUPLE
SAMPLE MATERIAL
AIR INLETS
FIGURE 2-B

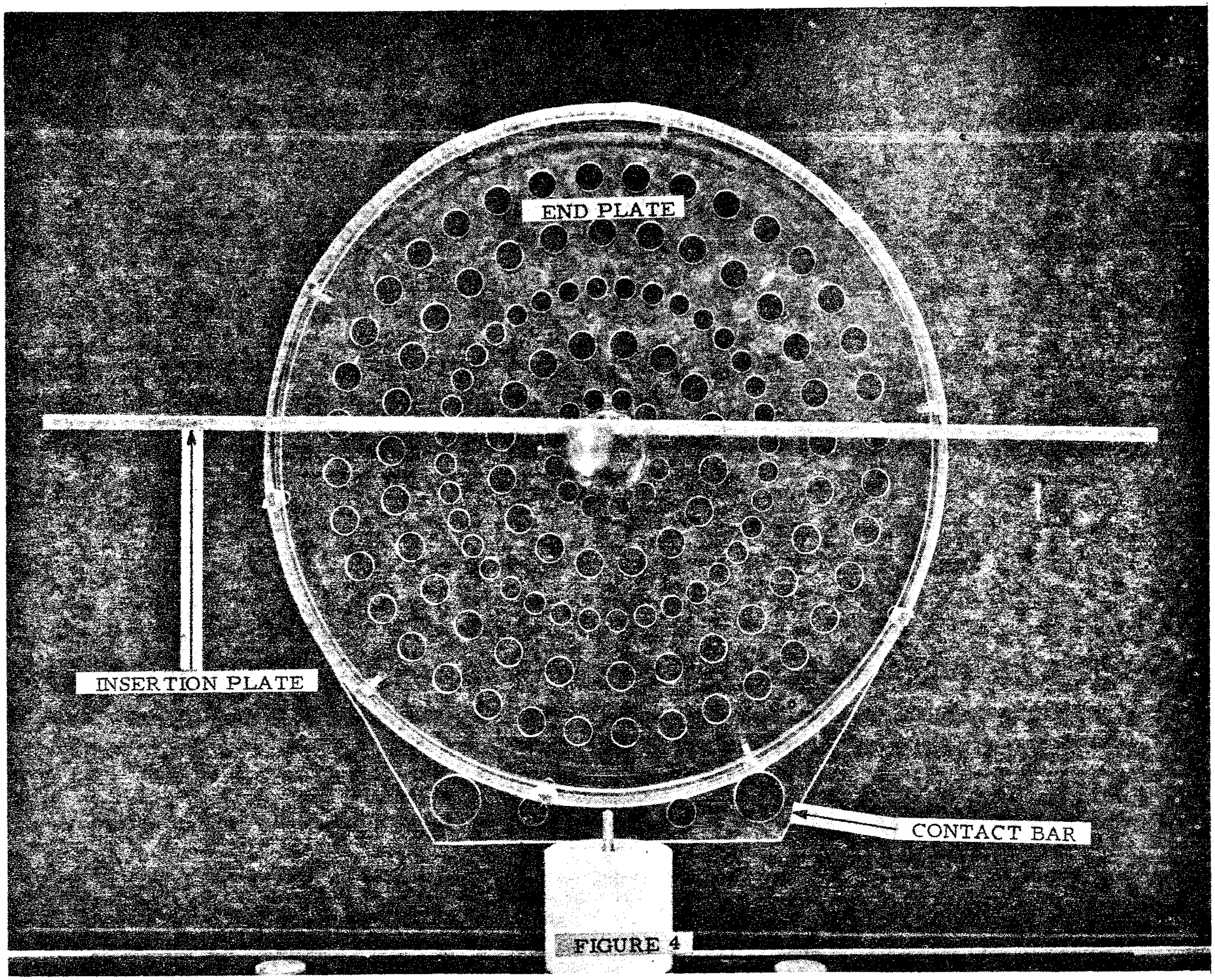


FIGURE 4

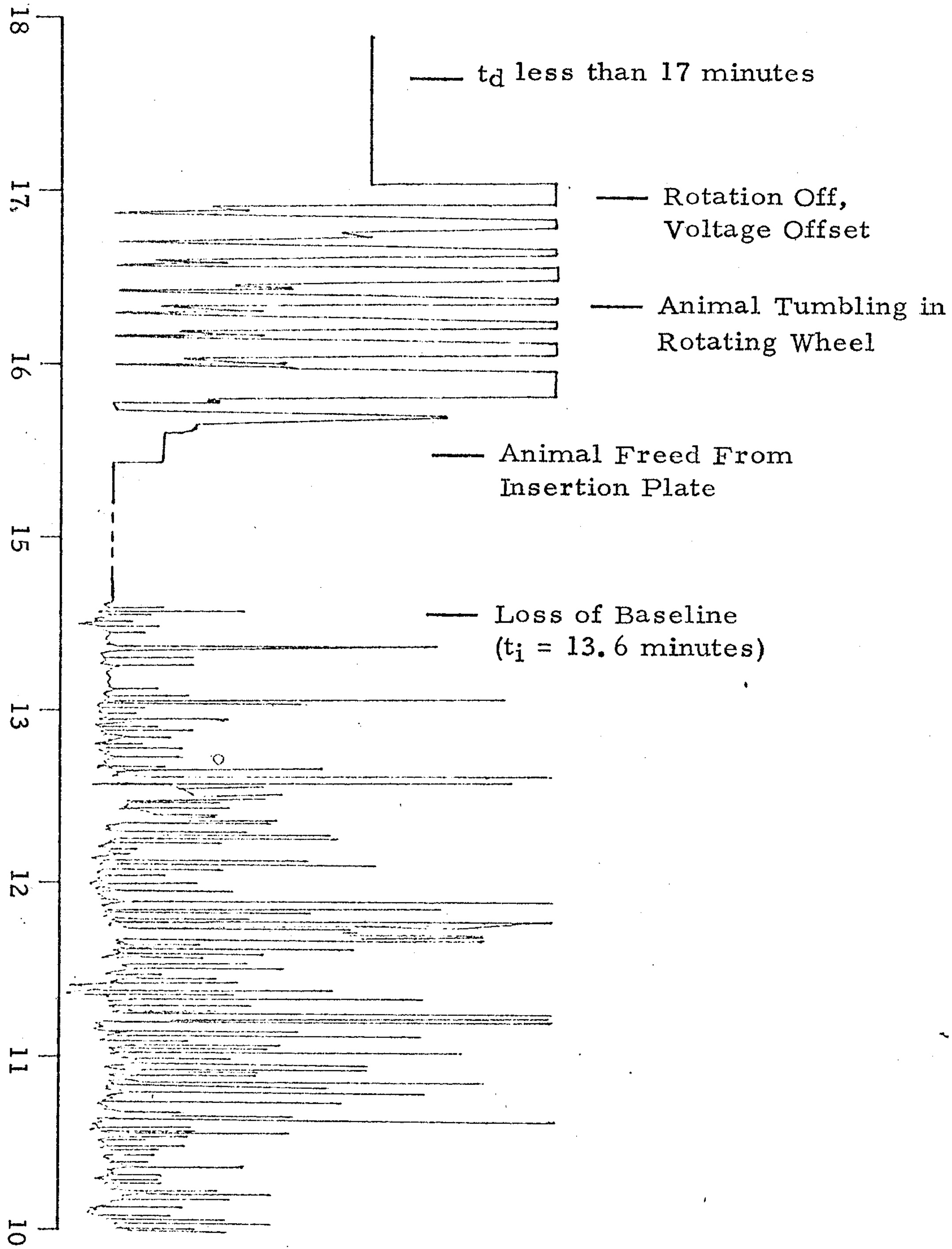


FIGURE 6. CONTINUATION OF THE BASELINE IN FIGURE 5; INCAPACITATION RESPONSE IN THE NAFEC-MODIFIED ROTATING WHEEL.