F.R. Note No.444.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

THERMAL CONDITIONS IN SHIPS' LIFEBOATS ENVELOPED IN FIRE

by

P. Nash and R. H. Bigmore

September, 1960.

Fire Research Station,
Boreham Wood,
Herts.

THERMAL CONDITIONS IN SHIPS' LIFEBOATS ENVELOPED IN FIRE

by

P. Nash and R. H. Bigmore

1. Introduction

The problem of escape from burning tankers was paramount during the Second World War and an examination of the problem by Rawlins(1) shows that in 17 typical instances, involving 918 crew members, 355 men lost their lives. Of these, some 55 per cent died of burns. In the ships carrying refined spirit about 60 per cent of the crews perished, 65 per cent of the deaths being due to burns. The deaths occurred not only aboard the ships but were also due to ships' lifeboats, or floating survivors, having the pass through seas covered with burning oil.

In March 1959 the Tanker Lifeboat Working Party of the Ministry of Transport decided to set up a Test Panel to investigate experimentally the problem of getting tanker crews in their lifeboats safely through the burning oil around a ship. The Working Party considered that, for lifeboats having a speed of 3 - 6 knots, a maximum period of 5 minutes complete envelopment in flame should be regarded as an operational standard to be achieved.

2. Preliminary assessment of problem

The two greatest difficulties in passing through the flames were to keep the crew members adequately cool and to provide them with an atmosphere not excessively contaminated with dangerous gases.

These problems could best be solved by enclosing the boat in a well-fitting canopy which was either adequately cooled by water, so that run-off water also cooled the hull, or by providing a hull and canopy which were themselves adequately heat-insulated and airtight.

An estimate of the water for surface cooling of a 25 foot boat and canopy subject to intense heat radiation (3 calories/cm^2/sec) showed that 20 gallons/min. was required. To counteract unevenness in water distribution and to provide a safety factor, it was considered about 100 gal/min. should be provided and distributed as evenly as possible.

As the canopy could not extend completely to the bow and stern of the lifeboat, additional water supplies would be required to cool the areas where run-off was not available. Details of the experimental arrangements adopted for the tests are given in Section 3C.

An estimate of the free air under the canopy, after allowing for the displacement of the occupants and equipment, suggested that there would need to be a replacement air supply available to compensate for wastage by breathing and through the induction of the engine. The loss of air by engine induction would also tend to induce burnt products from outside the boat, if no additional air were available.

It was considered that in the experiments, the atmospheres beneath the canopies of the boats would need to be sampled and analysed both with and without additional air available. The thermal conditions within the boats should also be measured.

3. Fire tests at Portsmouth

(a) Organizations engaged

The tests were made at the R. N. Atomic Defence and Damage Control School, H. M. S. Phoenix, Portsmouth, and the Staff of the school were responsible for providing the test fire arrangements and for all handling of boats and equipment.

A team from the Admiralty Chemical Laboratory of the Central Dockyard, Portsmouth, carried out the sampling and analysis of the atmospheres beneath the canopies.

A team from the Joint Fire Research Organization made the thermal measurements.

This report deals mainly with the thermal aspects and with the general behaviour of the boats and canopies under test.

(b) Test programme

The original complete test programme decided by the Committee is given as Table 1. This programme was rearranged and curtailed during the course of the tests, as circumstances required, but the original test programme numbers have been retained in the script for reference purposes. The programme actually carried out is given in Table II.

TABLE 1

Complete Test Programme

Test/Code No.	Hull	Canopy	Water spray	Engine	Air	Comments
1/A.1.	Steel	Asbestos	On	On	Off	
2/A.2.	Steel	G.R.P.	On	On	Off	
3/A.3.	Steel	Treated Canvas	On	On	Off	May be alternative
4/A.4.	Steel	Canvas	On	On	Off	
5/A.?	Steel	3 or 4	On	On	On	If gas analysis shows test to be necessary
6/A.1	Steel	Asbestos	Off	On	Off	
7/A.3.	Steel	Treated Canvas	Off	On	Off	
8/B.2.	GRP	GRP	On	Off	Off	
9/B.2.	GRP	GRP	Off	Off	Off	
10/C.5.	Alum$^{m.}$	Canvas	On	Off	Off	Could be done as (1) & (2) if required if asbestos canopy used
11/C.?	Alum$^{m.}$	Best of (6)(7)(9)	Off	Off	Off	
12/??	Best combination					
13/D.6.	Steel with bonded asbestos	Bonded asbestos	Off	Off	Off	
14/A.7.	Steel	Boat Cover Treated Canvas	Off	Off	Off	

TABLE II

Actual Test Programme

No.	M.O.T. ref.	Hull material	Canopy material	Wetted or dry	Additional air	Engine
1	1/A.1.	Steel	Asbestos	Wetted	No	Running
2	3/A.3.	Steel	Treated canvas	Wetted*	No	Running
3	5/A.3.	Steel	Treated canvas**	Wetted	Yes	Running
4	10/C/5	Aluminium	Canvas	Wetted	No	Not fitted
5	8/B.2.	Glass reinforced plastic	Glass reinforced plastic	Wetted	No	Not fitted
6	9/B.2.	Glass reinforced plastic	Glass reinforced plastic	Dry	No	Not fitted
7	13/D.6.	Steel with bonded asbestos skin	Bonded asbestos	Dry	No	Not fitted

*Water supply failed. See p.5.

**Canopy made from boat cover, adapted by use of asbestos cloth. See p.7.

(c) Description of lifeboats and protective equipment

The four lifeboat hulls tested were

(1) Steel, 26 ft long, fitted with Petter Type AVA/2 Aircooled Diesel engine. Fitted out by Messrs. Watercraft Ltd.

(2) Glass reinforced plastic (G.R.P.), 26 ft long, without engine, supplied by Messrs. Watercraft Ltd.

(3) Aluminium, 24 ft long, without engine, supplied by Viking Marine Ltd.

(4) Steel-hulled lifeboat 25 ft long with bonded asbestos protection, and a built-on canopy of timber with bonded-asbestos protection. No engine was fitted. This boat was supplied by Bristol Aircraft Ltd.

Canopies of treated canvas, untreated canvas and asbestos were available for use with the steel hull. An untreated canvas canopy was available for the aluminium hull, and a glass reinforced plastic sectional canopy was available for the G.R.P. hull.

The fabric canopies fitted to the steel and aluminium hulls were attached to the gunwhales and passed over a 2 in. diameter pipe which ran fore and aft above the centre line of the boat, and acted as a ridge pole. The canopies on the steel hull were supported at intervals by ribs fitted between the gunwhales and ridge poles; ribs were not used for the canopies on the aluminium hull.

The canopy for the glass-reinforced plastic hull consisted of a number of rigid sections made of glass-reinforced plastic. These sections could be clipped between the gunwhales and the ridge pole by ribs attached to the rigid sheets.

All these detachable canopies extended from about 2 ft aft of the bow to 2 ft forward of the stern. On the steel and glass reinforced plastic hulls, sheet metal decks were fitted between the ends of the canopies and the extremities of the hulls, whereas at each end of the aluminium hull a sheet metal turtle-back was fitted.

Provision was made for water-cooling the canopies and hulls from sprinkler heads which were mounted in an upright position at 18 in. intervals along the ridge pipe. Each head had a bore of $\frac{1}{4}$ in. diameter and delivered 6.3 gal/min. at 20 lb/in^2 nozzle pressure. Additional sprays were applied to the steel and glass reinforced plastic hulls at bow and stern, from sparge pipes fitted at gunwhale level. These were not fitted to the aluminium hull as it was assumed that the sheet-metal turtle-back would shed water from the sprinklers at the ends of the ridge pipe, onto the bow and stern of the hull.

The steel hull, insulated with bonded asbestos, had a permanent canopy of bonded asbestos moulded onto the hull. Access to the boat was through a small hatch at the top. This boat was not fitted for cooling with water.

(d) Conditions of fire test

It was agreed that the test fire would be of kerosine in a 47 ft x 32 ft static sea-water tank. Only one boat-canopy arrangement could be tested in each test and the boat would be moored centrally on the long axis of the tank.

Approximately 300 gallons of kerosine was poured on the surface of the tank in each test, and was primed with petrol for ignition. An additional supply of kerosine was fed to the surface from four 40-gallon drums during the course of each test in order to ensure that the whole surface was fully enveloped for the requisite 5 minutes. The timing of the tests was taken from the moment that the flames reached the boat.

Where water sprays were used, these were turned on, and the pressure was adjusted, immediately prior to lighting the fire. The water pressure was controlled throughout the tests to give a gauge reading of 20 lb/sq.in. at the sprinkler heads

(e) Instrumentation

Surface temperatures on the inside of the hull, and in one case, on the insulation inside the hull, were measured with chromel/alumel thermocouples brazed to copper discs which were screwed against the surfaces. Air temperatures at various positions in the boats were measured using chromel/alumel thermocouples suitably shielded from water leaking through the top of the canopies.

Radiation intensities were measured in the boats using a radiometer described elsewhere[2].

4. Results of fire tests

The results of the thermal measurements and general notes on the behaviour of the boats follow. The ambient temperatures in all tests were in the range 10-12°C.

Test No.1/A.1. p.m. Friday 25th March, 1960.

This test was made on the 26 ft steel lifeboat with asbestos canopy, water spray on, engine operating, no additional air being supplied. Thermal measurements were made as follows.

1. Air temperature on centreline of boat at thwart level.

2. Hull temperature amidships, 5 in. below gunwhale.

3. Radiometer amidships facing starboard, 20 degrees aft.

4. Microphone to listen to engine.

The boat was fully enveloped in fire for at least $4\frac{1}{2}$ minutes and was subject to severe conditions for the remaining $\frac{1}{2}$ minute. The engine continued to run throughout the test. The hull appeared to be relatively undamaged after the test although the paintwork was burnt off where the water sheet had been divided by the ribs supporting the canopy. The canopy showed a slight overall charring which was more pronounced where the supporting ribs tended to shed the water. At the corners, the canopy was severely charred and could be split easily. The water spray could not cover these areas due to the sharp angle between the side surfaces of the canopy and the end surfaces. The interior of the boat showed signs of sooting, but no charring anywhere.

The temperature records are given in Figure 1. The values recorded are lower than the actual temperatures in the boat because the leads were damaged by water seepage.

Test No.3/A.3. p.m. Monday 28th March, 1960.

This test was made with the 26 ft steel hull, treated canvas canopy, with water spray on*, engine running, no additional air being provided.

Thermal measurements were made as in Test 1/A.1. *In this test the water supply failed and in effect the test became 7/A.3.

Owing to the failure of the water supply, foam was applied to the fire which was brought under control 2 minutes after it had been lighted. This did not affect the conclusions to be drawn from the test, as the whole canopy was burnt away and the conditions in the boat were lethal. The engine continued to run throughout the test. The whole of the inside of the boat was severely charred. The temperature records are given in Figure 2.

Test No.10/C.5. p.m. Wednesday 30th March, 1960.

This test was made on the aluminium hull with untreated canvas canopy, water spray on, no engine fitted and no additional air supply. It had been noted before the test that the water coverage on the hull at bow and stern was inadequate. The rubbing strake was fitted forward, but not aft, of amidships on both sides of the hull to show whether this affected water distribution on the hull. Thermal measurements were made as follows.

1. Hull temperature, $3\frac{1}{2}$ ft forward of amidships on port side, 7 in. below gunwhale.

2. Hull temperature, $3\frac{1}{2}$ ft aft of amidships, port side, 7 in. below gunwhale.

3. Air temperature, $4\frac{1}{2}$ ft forward of amidships on C/L, thwart level.

4. Air temperature, 2 ft forward of amidships, 8 in. below spray pipe.

5. Radiometer, 1 ft above thwart on centreline, facing starboard, 30° aft.

The boat was fully enveloped in fire for a full 5 minutes, and the flames subsided so that the boat was in full view after $5\frac{1}{2}$ minutes. The canopy was remarkably free from damage and there were no appreciable signs of charring anywhere. The aluminium turtle-backs at the ends of the boat were undamaged, but a 2 ft square hole had been burnt in the stern of the boat on the port side, and $\frac{1}{2}$ sq.ft hole on the starboard side where the water run-off had not adequately wetted the hull. The bow showed similar overheating but no holes had developed. The timber inside the boat was slightly charred adjacent to the holes but was otherwise undamaged.

The temperature measurements are shown in Figure 3.

<u>Test No.8/B.2.</u> a.m. Friday 1st April, 1960.

This test was made on the 26 ft G.R.P. boat with G.R.P. sectional canopy, with water sprays on, engine not fitted, and additional air not supplied. Thermal measurements were made as follows.

1. Hull temperature amidships, port side, 8 in. below gunwhale.
2. Air temperature, 2 ft forward of amidships on C/L at thwart level.
3. Air temperature, amidships on C/L, 1 ft below spray pipe.
4. As (3), but 1 ft lower.
5. Radiometer, 1 ft above thwart at C/L, 2 ft forward of amidships, facing starboard, 30° aft.

The water sprays were found to give good water coverage on the canopy and the sides of the hull. The additional sparge pipes at bow and stern gave good coverage in these areas, although the pipes were fitted rather far from the hull and projected the water above the horizontal, rather than below it, as required. Additional drillings in the saddle-pipes which fed the sparge pipes were invaluable in protecting the vertical ends of the G.R.P. canopy, which would have been severely damaged otherwise.

The boat was completely enveloped in flame for a period of approximately 5 minutes, when the fire was subdued by the use of foam. On inspection, the boat and canopy were found to be in very good condition where the water coverage had been adequate. The sectional covers were scorched adjacent to the joints where the G.R.P. cover strips had tended to shed the water and disrupt the coverage. The hull was also scorched in lines vertically below the cover strips, and also where the rope fittings had split the water sheet.

The temperature records are shown in Fig.4.

<u>Test No.9/B.2.</u> p.m. Friday 1st April, 1960.

This test was made on the G.R.P. boat and canopy as before, but without the water spray. Thermal measurements were made in Test 8/B.2. except that No.5 was omitted.

The boat was completely enveloped in flames for approximately 5 minutes, when the fire was subdued with foam. The whole of the G.R.P. canopy was burnt off the boat, the conditions inside being lethal. The hull of the boat was charred and was left as a "spongy" mass of glass fibres with no plastic filler left unburnt. In its severely weakened condition it is very unlikely that it would have been seaworthy. It was easy to cut a hole through the hull with a penknife.

The temperature records are shown in Fig.5.

Test No.13/D.6. p.m. Tuesday 5th April, 1960.

This test was made on the steel boat with the bonded asbestos insulation and canopy, without the use of water sprays or additional air. Thermal measurements were made as follows.

1. Hull temperature amidships 6 in. below gunwhale.

2. Temperature of interior lining of bonded asbestos, 6 in. below gunwhale amidships.

3. Air temperature, $3\frac{1}{2}$ ft forward of amidships at thwart level.

4. Air temperature amidships, 6 in. below canopy.

5. Radiometer, amidships, 9 in. above thwart, facing starboard, 30 degrees aft.

The boat was fully enveloped in fire for approximately 5 minutes, when fire fighting commenced. It was seen that smoke and thick brown fumes were coming from within the canopy. The canopy and insulation were cracked in several places. On inspection, it could be seen that the timber inside the canopy was charred in some places.

The temperature records are given in Fig.6.

Test No.5/A.3. p.m. Wednesday 6th April, 1960.

This test was made as a repeat for the earlier test in which the water supply failed. It was also required to make a careful comparison of the air conditions with and without the additional air supply. The test was on the steel boat, with treated canvas canopy (made from a boat cover and adapted by use of asbestos sheet where necessary). The engine was run at cruising speed, the water sprays being on. An additional air supply averaging approximately 30 cu.ft/min. over the duration of the test was provided from 5 compressed air bottles discharging at regulated rates. Thermal measurements were made as follows.

1. Hull temperature amidships 5 in. below gunwhale.

2. Air temperature at thwart level forward of amidships.

3. Air temperature amidships 12 in. below ridge pipe.

4. Radiometer amidships 9 in. above thwart pointing at starboard side 30 degrees aft.

In the test the boat was completely enveloped in fire for approximately 5 minutes, when fire-fighting commenced. The engine ran continuously throughout the test, although it was heard to splutter and backfire at about $4\frac{1}{2}$ minutes. After the fire, the canopy was found to be burnt through at some of the supporting ribs, the steel hull being relatively undamaged. The woodwork inside the boat had been charred previously, and it was not possible to deduce the degree of entry of hot gases by this means.

The temperature records are given in Fig.7.

These readings only continued for $2\frac{1}{2}$ minutes as the subsequent readings were washed off the chart during fire-fighting operations.

Although it had been intended to repeat this test without the additional air supply, the damage to the canopy prevented this being done.

5. Discussion

An examination by Buettner of the tolerance limits of men exposed to hot air and radiant heat suggests that for 5 minutes exposure, an air temperature of 120°C could be tolerated and a radiant intensity of 0.03 cal/cm^2/s falling on the bare skin would not cause unbearable pain. (See Figs. 8 and 9).

There are three ways in which men might be burned while liefboats of the type described in this report are passing through flame:

1. by contact with the hot inner surface of the boat;

2. by being irradiated from the hot inner surfaces of the boat;

3. by being surrounded by a hot atmosphere.

In a lifeboat with canopy, as tested in this programme, it is assumed that direct burns from touching the hull or canopy of the boat could be avoided with care.

In general, the air temperature and radiant intensity inside the boat will increase with the time that the boat is enveloped in flame, and the final conditions after 5 minutes may only have to be tolerated for a fraction of the period. It will, however, be assumed in this report that an air temperature greater than 120°C, or a radiant intensity greater than 0.03 cal/cm^2/sec. would not be acceptable at any time. Consideration of the humidity of the atmospheres in the boats would only be relevant to a discussion of survival for a period longer than 5 minutes.

From the tests, it is apparent that the steel, aluminium or G.R.P. hulls, and the fabric or G.R.P. canopies could survive the fire satisfactorily if adequately cooled with water. The rate of application in the tests was generally adequate, but the detailed arrangements for distribution were not always good enough. Where this was so, partial failure of the canopy or hull (except the steel hull) occurred. Where no water was provided, only the steel hull was capable of surviving the fire, and none of the fabric or G.R.P. canopies could be deemed satisfactory. The steel hull with wooden canopy protected by bonded asbestos survived the fire without water spray, though with some damage to the canopy.

The thermal measurements, treating the hull and canopy as an enclosure for sustaining life, may now be considered. The test on the steel hull with asbestos canopy and water spray (Test 1/A.1.) gave unreliable readings due to water seepage, and results must be inferred indirectly by comparison with other tests. In Test 5/A.3. on the steel hull and treated canvas canopy with water spray, the air temperatures were well within the acceptance limits up to the time records were destroyed. On the aluminium hull with canvas canopy and water spray (Test 10/C.5.) hull and air temperatures were well within acceptance limits except immediately below the ridge pipe, where the higher temperatures may possibly have been due to convected hot gases entering at the hole in the stern. The G.R.P. hull and G.R.P. canopy with the water spray also gave satisfactory air temperatures within the boat. It is, therefore, thought likely that in all the combinations described, conditions would have been within the limits for the full period, if good water distribution had prevented hull or canopy damage. The radiation records show that in the tests with canopies cooled by water spray, the radiation level was generally less than the limit of 0.03 cal cm^{-2} sec^{-1}, and it is considered that since the occupants would normally be clothed, and could protect their exposed parts in various ways for a period of 5 minutes, no difficulty on this score would be likely to arise.

Where the canopy was not cooled by water there would have been no chance of human survival, except in the boat with bonded-asbestos protection, (Test 13/D.6.) Here the temperatures within the boat were satisfactory during the 5 minutes of test, but after the fire had been subdued, there was a general increase which was not satisfactory. In the case of the hull, this was probably due to "heat soakage" or to an exothermic reaction in the bonded material. The increase in air temperature near the canopy roof was very rapid and it is probable that the combustible canopy was on fire. This suggests that there is a possibility for the use of a boat with a heat-insulating construction, but that it should be constructed of non-combustible materials, and should have a readily-openable canopy so that the interior of the boat can be vented after the fire.

6. Conclusions

It is concluded from the above tests that there are two possible ways of obtaining satisfactory thermal conditions in a ship's lifeboat subjected for 5 minutes to the intense fire conditions described.

The first method is by providing a relatively airtight, uninsulated canopy which is adequately cooled by water, so that the run-off water will also cool the hull.

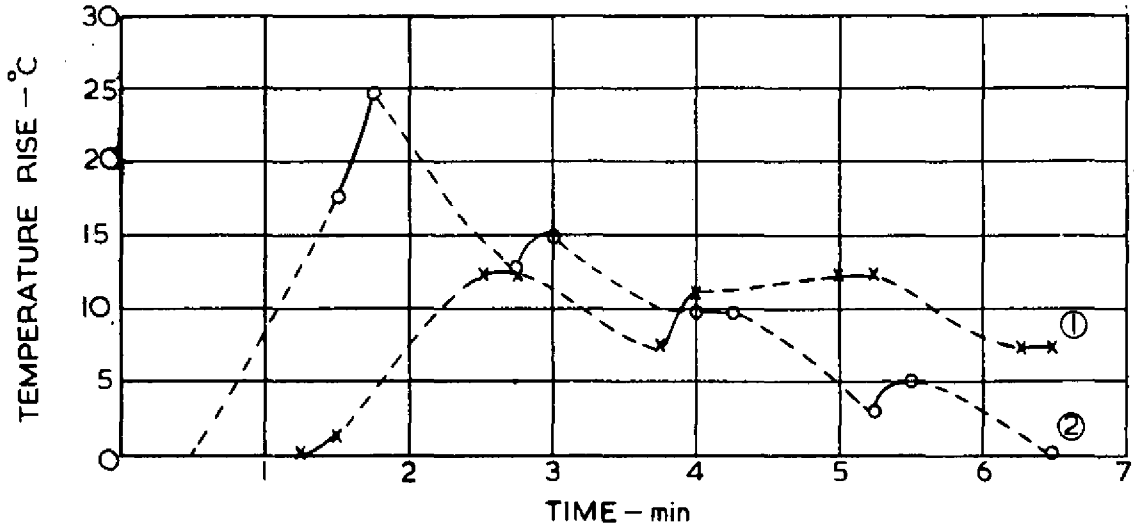
The second method is by providing a heat-insulating canopy made of incombustible materials. It would probably be necessary to make this canopy readily openable so that the boat could be vented after leaving the fire area.

References

1. RAWLINS, SURGEON LT/CDR. J.S.P. M.B.E., B.A., B.M., B.Ch. R. N. Admiralty reference N.L.S.C. 2/60. "Life-saving in oil-covered waters".

2. MCGUIRE, J. H. A radiometer for field use. F.R. Note No.394, 1959.

3. BUETTNER, K. Effects of conflagration heat. German aviation medicine in World War II, 2 Chap XIII. A. 1167-87. U.S. Department of the Air Force Washington, 1950.



Temperatures plotted are unreliable because the leads were damaged by water seepage

FIG.1. THERMAL RECORDS OF TEST No 1/A1

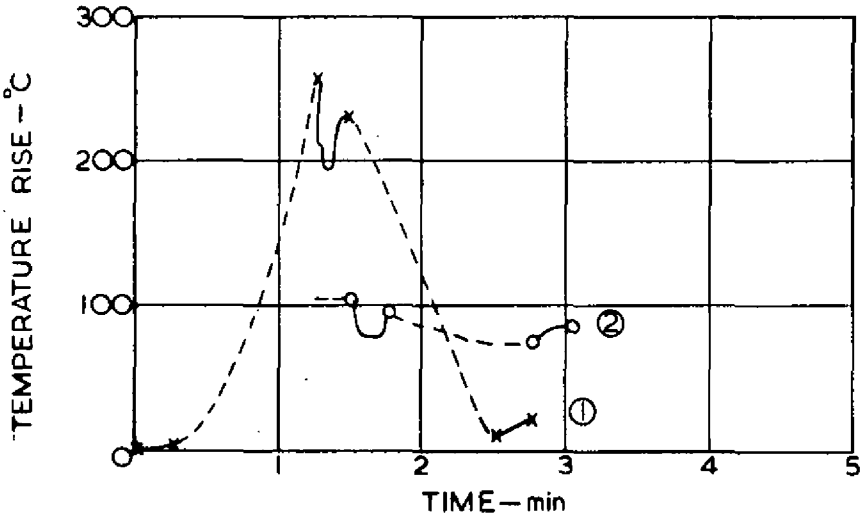


FIG.2. THERMAL RECORDS OF TEST No.3/A3

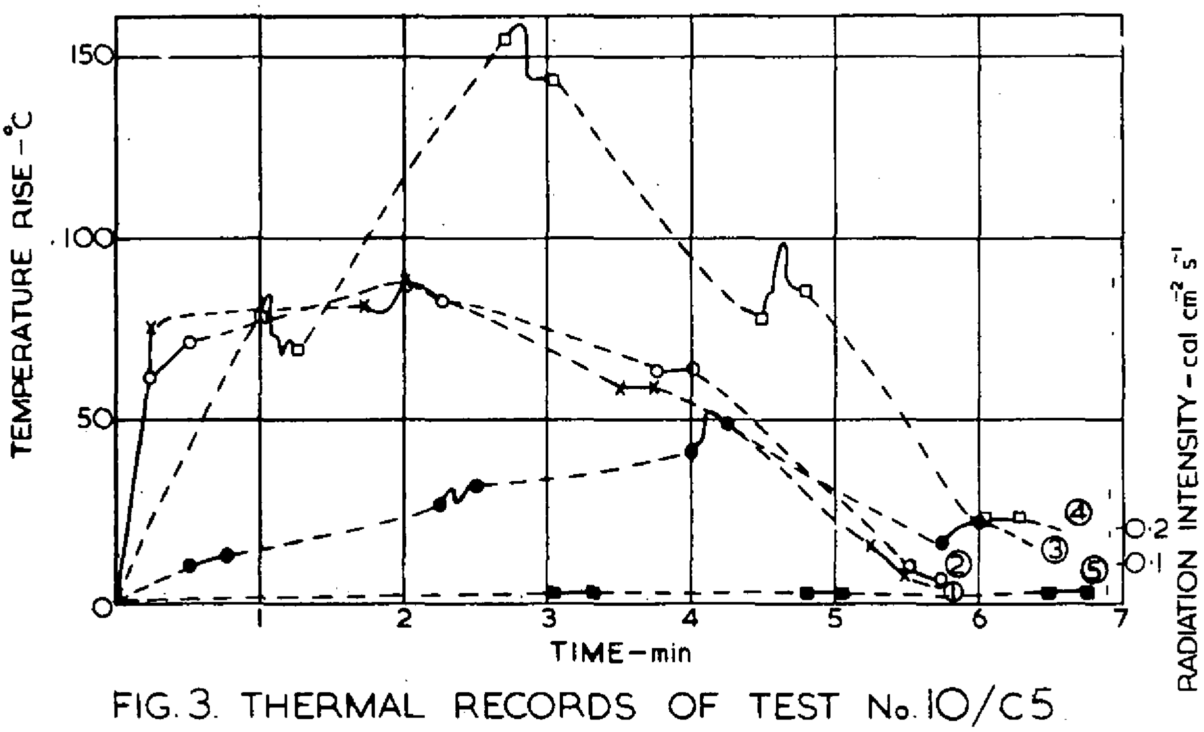


FIG. 3. THERMAL RECORDS OF TEST No.10/C5

FR 444

1/3876

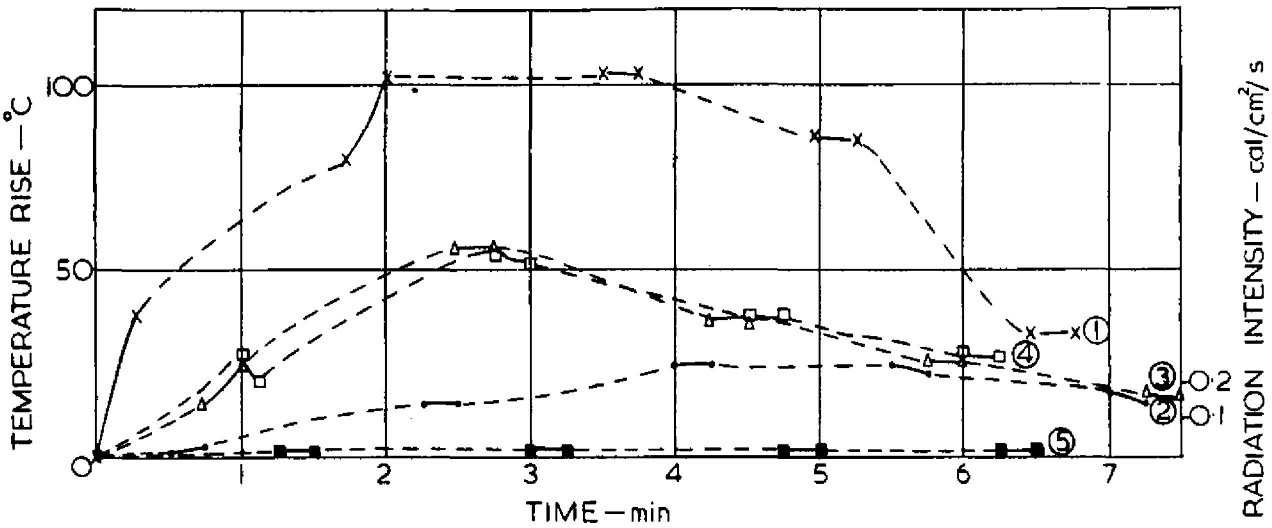


FIG. 4. THERMAL RECORDS FOR TEST No. 8/B2

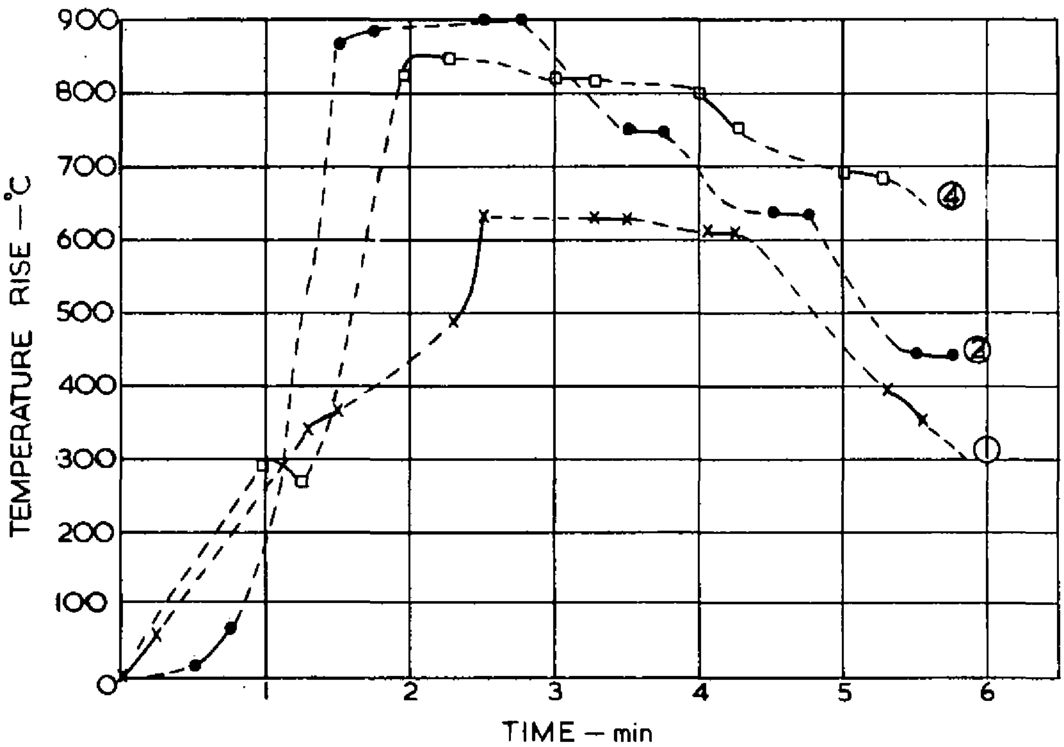


FIG. 5. THERMAL RECORDS FOR TEST No. 9/B2

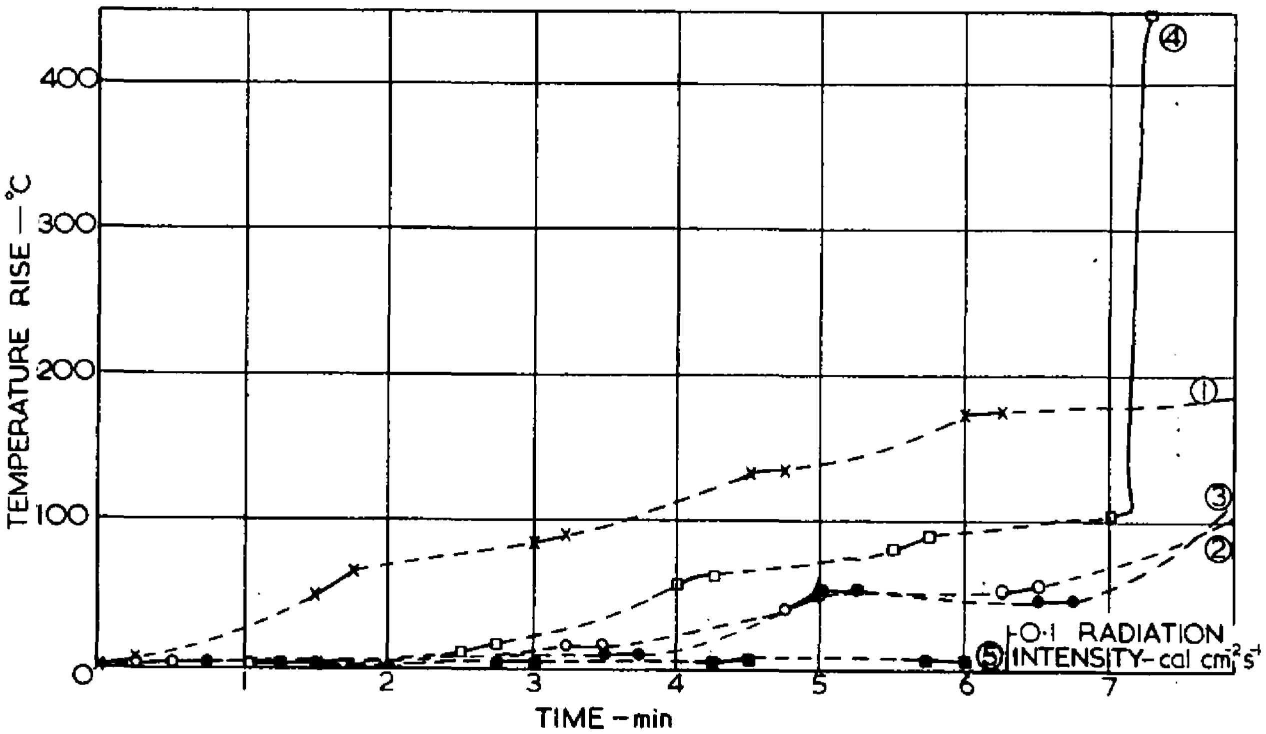


FIG. 6. THERMAL RECORDS FOR TEST No. 13/D6

FR 444

1/3877

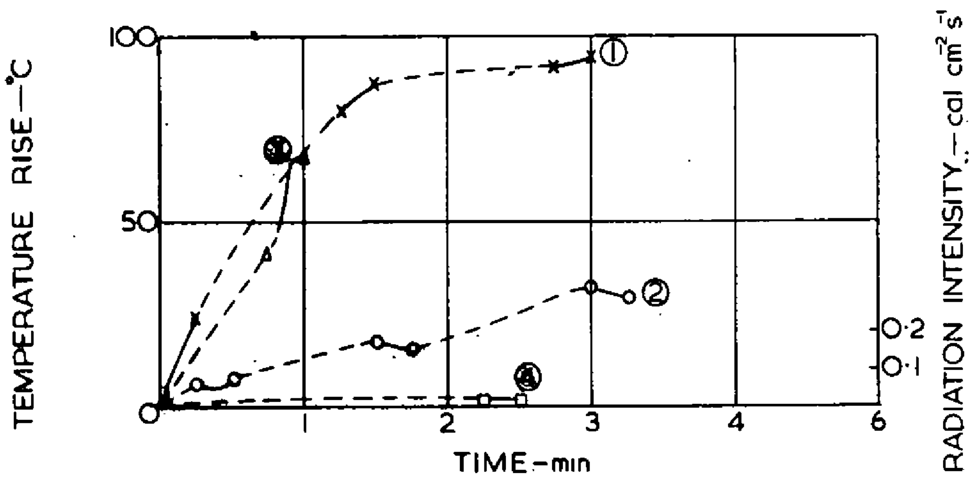


FIG.7 THERMAL RECORDS OF TEST No.5/A3

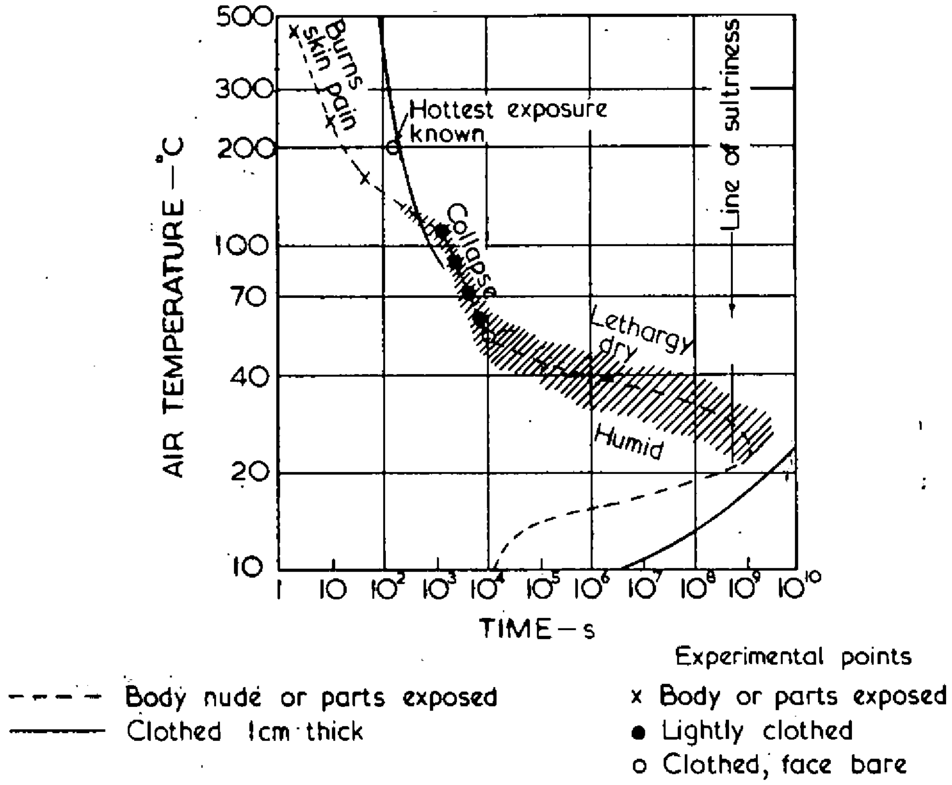


FIG. 8. TOLERANCE TIMES OF RESTING MEN

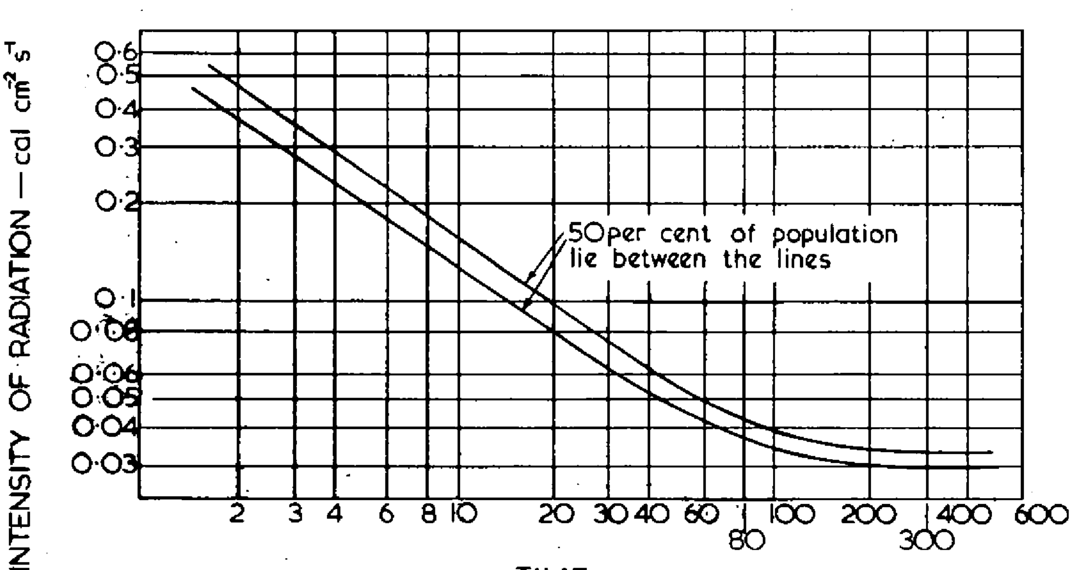


FIG. 9. TIME FOR UNBEARABLE PAIN

1/3878 FR 444