TOLERANCE OF MEN TO WORK IN HOT, SATURATED ENVIRONMENTS WITH REFERENCE TO MINES RESCUE OPERATIONS

BY

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A number of authors, for example, Fleisher, Stacey, Houghten, and Ferderber (1939), Robinson, Turrell, and Gerking (1945), Eichna, Ashe, Bean, and Shelley (1945), McArdle, Dunham, Holling, Ladell, Scott, Thomson, and Weiner (1947), and Ellis, Ferres, Lind, and Newling (1953), have provided information on upper tolerable limits of warmth for men. A recent review by Weiner and Lind (1954) showed that there is a fairly good measure of agreement between the results of these workers. Most of this experimentation was conducted on men resting or doing relatively light work for exposures of from two to eight hours, and often did not involve a large or rapid rise of body temperature.

In the mining industry, the part-time rescue personnel who undertake the various types of rescue operations are required to work in actual practice for periods of not more than two hours in adverse thermal conditions. Body temperatures in such circumstances would rise rapidly and it is during such a period of rapid physiological change that even trained men are very liable to experience severe distress and incapacitation, though there may be some improvement if body thermal equilibrium is attained (Eichna and others, 1945). For rescue purposes it is necessary to know the maximum period of endurance in hot environments which rescue teams can display without serious loss of efficiency. Present information derived from laboratory studies (such as those already mentioned) is almost entirely concerned with the environmental conditions in which a given task of fixed duration can be performed; moreover in these tasks (marching or step-climbing), which are not as exacting or complicated as the operations of rescue work, the criterion of tolerance usually adopted is the ability of the subject to re-establish thermal equilibrium. It is clear from Mackworth's (1950) and Pepler's (1954) findings that psychomotor disturbance will be in evidence at temperatures well below those at

which thermal equilibrium is physiologically still possible.

The valuable paper by Roantree (1951) on the relation between wet-bulb temperature and length of time worked by fire-fighting teams in the Kolar Gold Field in India relates to men who are highly acclimatized to heat and his results could therefore not be expected to provide the information which could be safely used in this country. The data provided by Craig, Garren, Frankel, and Blevins (reported while this paper was being prepared in 1954), though concerned with tolerance times, are likewise not immediately applicable, as the subjects were deliberately acclimatized to work in hot environments and were wearing protective clothing of various kinds.

The types of operation to which rescue personnel in the mining industry in this country are called may be classified roughly into four categories in their order of frequency :—

(1) **Fire** (a) "Open"—starts with free flames, as from a spark. (b) "Gob"—starts by spontaneous combustion—heating within a coal seam. Dry-bulb temperature is usually high. Wet-bulb temperature may be quite low but rises according to the amount of free water from strata and the water used in fire-fighting. Air movement is often maintained at quite a high rate.

(2) **Explosion** (a) with fire; (b) without fire: Dry-bulb temperature usually high. Wet-bulb temperature usually low but with fire rises as in preceding category. Air movement often poor or absent.

(3) **Life Saving from Areas of "Black Damp" or "Fire Damp"**. Dry-bulb temperature usually low or moderate. Wet-bulb temperature may be low or high. Air movement poor or absent.

(4) **Recovery of Sealed Areas**. Conditions are very variable. Dry-bulb temperature often moderate to high. Wet-bulb temperature often high. Air movement may or may not be present.

From the available data of past operations it appears that there is a considerable range in the thermal environments, both between and within

each of these categories. Conditions are often very severe. The most frequently recorded conditions fall into the range of dry-bulb temperature 30 to 45° C. (86 to 113° F.) and of wet-bulb temperature 24 to 35° C. (75 to 95° F.). The extremes of temperature in the records are dry-bulb temperature 23 to 71° C. (73 to 160° F.) and wet-bulb temperature 17 to 44° C. (63 to 111° F.). Air movement is variable, and often tends to make any given environment more severe; thus, when dry-bulb temperatures are high, as in a fire, air movement is frequently maintained in order to reduce fumes and the possibilities of explosion; where the dry-bulb temperature is low, air movement is often poor or absent. Men may have to work extremely hard in such conditions while wearing heavy rescue apparatus, and heat collapses have occurred.

Following a request from the National Coal Board, a series of experiments was undertaken, using 36 volunteers, each of whom was exposed three times to varying saturated temperatures.

The aims of these experiments were (a) to provide an estimate of "tolerance time" of men engaged on a stipulated routine in various hot, saturated environments; (b) to determine whether there is a demonstrable difference in the reactions to such conditions (i) in relation to age, and in particular whether the present upper age limit of 45 years for mines rescue personnel is acceptable or not, (ii) in relation to the different types of occupation in the mines rescue personnel, (iii) in relation to the two different types of self-contained breathing apparatus used in rescue work.

Experimental

Subjects.—The subjects were 36 mines rescue personnel chosen from a large group who volunteered for these tests. These men comprised 18 pairs, the members of each pair being of approximately similar physique as judged by height and weight; one member was drawn from a younger (19–31 years) and the other from an older age group (39–45 years). The 18 pairs came from six different rescue stations, three stations from a division using self-breathing rescue apparatus employing compressed oxygen (apparatus 1) and three from a division using a liquid air apparatus (apparatus 2). There were thus three pairs of men from each rescue station, and these represented three occupational categories: "severe" (S) comprising men who normally work at the coal face; "mixed" (M) comprising fitters, electricians, etc., many of whom spend only part of the time underground; and "deputies" (D) who supervise work underground. For the purpose of the experiment the 36 men were tested as three teams of 12 men, each team being of similar composition with regard to age, occupation, and type of apparatus. Members of the mines rescue service are medically examined twice a year as a normal routine; the 36 volunteers were all

re-examined and pronounced medically fit before being submitted to the present experimentation. Efforts are also made in the mines rescue service to maintain a good standard of physical training.

Clothing.—The subjects wore shorts, vest, socks, and boots, self-contained breathing apparatus, mining helmet, and safety lamp.

Work Routine.—The experimental task was designed to simulate a rescue operation, and comprised consecutively: (1) half an hour of walking at 2 m.p.h. wearing the self-breathing rescue apparatus (weight 40 lb.) and carrying a sandbag (weight 50 lb.) in cycles of four minutes followed by one minute rest on a stool; (2) a five-minute rest period sitting on a stool; (3) half an hour building a sandbag "stopping" using 24 sandbags of 50 lb each, carrying each bag singly for 15 ft. to build the stopping, in cycles of four minutes sandbagging, one minute rest. The energy cost of the three stages of this 65-minute routine was an average of (1) 170 kcal./m²/hr., (2) 55 kcal./m²/hr., (3) 250 kcal./m²/hr., and the mean energy cost for the complete 65-minute task was 200 kcal./m²/hr.

Thermal Environments.—Saturated environments were used in the present investigations since in mining rescue operations the moisture conditions are often near saturation as a result of natural water in the strata and that used in fire-fighting. Each team was exposed three times to various environments as follows (temperatures being shown in °C.). In order to minimize acclimatization effects, individuals made their successive visits at four-weekly intervals.

Exposure	Team I	Team II	Team III
1	29.4	30.8	29.4
2	29.4	30.8	33.6
3	32.2	35.0	37.8

Room temperatures were controlled to $\pm 0.5^\circ$ C. of the target temperatures. The air speed in the chamber in all these experiments was less than 20 ft./min.; but because of the rate of walking required for the task, the effective air speed was between 150 and 175 ft./min.

Measurements.—Measurements were made of rectal temperatures by means of an indwelling rectal thermocouple inserted 10 cm. (see appendix), pulse rates counted by palpation over 30 seconds, sweat losses by nude weight losses, blood pressures by sphygmomanometer and stethoscope, metabolic costs of work and rest using Douglas bags, and the inspired-air temperature within the breathing apparatus by means of a 30 s.w.g. thermocouple.

Experimental Timetable.—The subjects rested, sitting, for 60 minutes before entry to the hot chamber. Beginning 35 minutes before entry, rectal temperatures and pulse rates were recorded at five-minute intervals until 30 minutes after removal from the chamber. Blood pressure was taken before the entry into the hot chamber, during the five-minute rest, and immediately before leaving the chamber. Nude weights were recorded five minutes before entering and five minutes after leaving

the chamber. The breathing apparatus was put on immediately before entry to, and taken off immediately after removal from, the chamber. Inspired air temperatures were taken every five minutes throughout the experiment.

Experimental End-point.—The aim of the investigation made it undesirable for the subjects to reach a state of collapse. Unless they elected voluntarily to leave the chamber, the subjects were removed when their rectal temperatures reached 38.8°C . (101.8°F). The results of experiments by Ellis and others (1953) indicate that in saturated environments subjects with temperatures rising to this level are under obvious stress and may be approaching a point of incipient collapse, but would be able to leave the chamber in a reasonably fit condition, as is desirable in actual rescue operations. The validity of this criterion was well borne out in the tests as reported below.

In practice, especially at the higher environmental temperatures investigated, it was not always possible to achieve this end-point accurately since by the nature of the test the rectal temperatures rose quickly near the end of the exposure. In the less severe environments some men completed the 65-minute test without achieving a rectal temperature of 38.8°C . It has been necessary in some cases to make an interpolation or extrapolation of rectal temperatures to estimate the survival times. One man only of the 36 had a "low-threshold" rectal temperature of heat tolerance and in this case the

tolerance time was based on his lower threshold (about 38.5°C .) and on the observer's assessment.

The 36 volunteers showed great interest and consistent enthusiasm throughout the investigation and this spirit was encouraged by the observers as much as possible, since motivation is without doubt at a high level in actual rescue emergencies.

Results

Analysis of the results in relation to the factors of age, occupation, and types of apparatus falls into two parts: (1) analysis of the tolerance time, which may be considered as a gross measurement of ability to work in these hot environments; and (2) analysis of physiological responses.

(1) **Tolerance Times.**—Individual tolerance times for men in the various saturated environments are shown in Fig. 1. There was a distinct difference in the tolerance times due to the type of breathing apparatus worn by the subjects, and it was therefore necessary to construct separate graphs. Also shown in Fig. 1 are lines representing the calculated 90% confidence limits of tolerance for each apparatus. Only 10% of men would be expected to exhibit a tolerance time shorter than that indicated by the curves.

The observers considered that in most of the 108

FIG. 1.—Tolerance times of men performing a "mines rescue task" in various saturated environments. Only 10% of men would be expected to have tolerance times shorter than those indicated by the continuous lines.

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individual experiments the subjects left the chamber in a similar condition, as far as could be judged subjectively. The exceptions to this were, first, eight experiments at the two lowest temperatures where the men completed the 65-minute task without achieving the agreed end-point of 38.8° C. rectal temperature, and it was estimated that of the eight men five could have continued for a further five minutes, and three for a further 10 minutes; and secondly, one man in the 32.2° C., and a second in the 35° C., saturated environment were in a state of incipient collapse when they left the chamber, both displaying facial pallor and complaining of dizziness, slight nausea, and abdominal discomfort. It was considered that the remainder of the subjects would have been in a state of distress after about a further five minutes of the heavy work.

Table 1 shows the mean tolerance times for each age group, for each occupational category, and for the two types of breathing apparatus. Examination of the data reveals no significant difference due to age or occupation, but there is a significant difference (at the 1% level) due to the type of apparatus worn.

TABLE 1

MEAN TOLERANCE TIMES (MIN.) FOR TWO AGE GROUPS (18 MEN EACH), THREE OCCUPATION GROUPS (12 MEN EACH), AND TWO APPARATUS GROUPS (18 MEN EACH) AT VARIOUS SATURATED ENVIRONMENTS (°C)

Environment (°C)	29.4	30.8	32.2	33.6	35	37.8
<i>Age Group</i>						
Younger	63	65	57	50	45	36
Older	70	63	57	44	48	34
<i>Occupation Group</i>						
"Severe"	65	66	55	46	46	35
"Mixed"	64	59	58	46	46	36
"Deputies"	70	66	59	48	48	34
<i>Breathing Apparatus</i>						
Apparatus 1.. ..	62	62	53	44	48	34
Apparatus 2.. ..	71	66	62	50	46	36

In a separate test (to be reported elsewhere) all the subjects were exposed for four hours to conditions of dry-bulb 43.3° C. (110° F.) and wet-bulb 29.4° C. (85° F.), and carrying out intermittent work but without wearing breathing equipment. Analysis of these "uniformity" trials failed to show any difference in any of the physiological measurements between the two groups of men who wore the two different types of breathing apparatus in the present series of experiments. The significant difference in tolerance times between these groups is therefore not attributable to any peculiar difference between the men themselves but to the different types of apparatus worn.

(2) **Physiological Observations.**—Due to the severe environments and the nature of the work routine, most of the information common to all experiments

relates to the first 30 minutes of exposure, but it has been possible to make some comparisons over longer periods.

Age.—There was no detectable difference in tolerance times of men of the two age groups. Rectal temperature increments in all six environments over the first 30 minutes, shown in Table 2, were significantly greater at the 5% level in the men of the older group. This estimate includes the two most severe environments where little or no difference was observed. Increments in pulse rates over this period of 30 minutes did not, however, differ significantly between the two age groups.

TABLE 2
INCREMENTS IN RECTAL TEMPERATURES (°C.) AND IN PULSE RATES PER MIN. AFTER 30 MINUTES' EXPOSURE FOR TWO AGE GROUPS OF 18 MEN EACH

Environment (°C.)	29.4	30.8	32.2	33.6	35	37.8
<i>Rectal Temperature</i>						
Younger	0.37	0.37	0.34	0.46	0.80	1.17
Older	0.44	0.52	0.46	0.74	0.80	1.05
<i>Pulse Rate</i>						
Younger	61	47	62	48	76	69
Older	38	47	50	60	70	87

Over the first 30 minutes, systolic pressures rose, while diastolic pressures remained unchanged (so that pulse pressures increased) in both groups (Table 6) but there was no difference between the age groups.

Sweat losses were assumed to be the simple loss in nude weight from the start to the end of the experiments. For the purpose of comparison only those experiments where men have worked for the same length of time in the same environmental conditions can be used. The only temperatures at which a sufficient number of men exhibited the same tolerance times were at 29.4 and 30.8° C., where over half of the men exposed completed the 65-minute task. At 29.4° C. there were 13 results from the younger group and 14 from the older group, and four of these in each group represented repeated exposures. At 30.8° C. there were nine results from each group, of which four and three were repeated exposures in the younger and older groups respectively. The means are shown in Table 3. There appears to be a tendency for the younger men to sweat more than the men in the older group, but the difference is not significant.

TABLE 3
MEAN SWEAT-LOSS DATA (g./m²/hr.) IN TWO AGE GROUPS OVER COMPARABLE PERIODS OF EXPOSURE AT SEPARATE SATURATED ENVIRONMENTS

Temperature (°C.)	29.4	30.8
Younger	446	472
Older	375	405

The sweat losses on the first and second visits of the teams which were exposed on two occasions to the same environments were compared. The data are limited since only those results where men had exactly the same tolerance time on both occasions were comparable. The results are given in Table 4, and it can be seen that the sweat losses of all the younger men decreased on their second exposure (significant at 1% level), while the older group displayed no set pattern of behaviour, some increasing and some decreasing their sweat loss on the second exposure. These findings appear to show that the subjects did not acquire acclimatization to heat in the course of the investigation, for if acclimatization had occurred sweat losses would have increased. The younger men may have increased the efficiency of their work and this might account for the reduction of sweat losses on the second exposure.

TABLE 4

CHANGES IN AMOUNT OF SWEAT PRODUCED ON TWO OCCASIONS (g./m²/hr.) IN MEN EXPOSED TO SAME CONDITIONS FOR SAME TIME

Team 1 (29.4°C.)		Team 2 (30.8°C.)	
Younger	Older	Younger	Older
—	+24	—34	+81
—	+56	—98	—
—83	+59	—35	+58
—54	—40	—6	+1
—7	—38	—48	—4

Occupation.—There were no detectable differences in tolerance times due to the type of occupation normally pursued by the subjects.

Analysis of the mean rectal temperature increments over the first 30 minutes showed that the deputies, though they display no difference in tolerance times, have a significantly lower increment at the 5% level than either of the other two groups, which do not differ from each other (Table 5). The reason for this is not readily apparent.

TABLE 5

MEAN RECTAL TEMPERATURE INCREMENTS (°C.) DURING FIRST 30 MINUTES FOR EACH OCCUPATION GROUP OF 12 MEN

Environment °C.	..	29.4	30.8	32.2	33.6	35	37.8
"Severe"	..	0.45	0.54	0.47	0.60	0.88	1.10
"Mixed"	..	0.46	0.50	0.36	0.63	0.96	1.20
"Deputies"	..	0.31	0.50	0.38	0.57	0.55	1.03

No significant effects due to occupation were found in the data on pulse rates, blood pressures, or sweat losses.

Apparatus.—As already mentioned, there is a large difference in tolerance time due to the type of

apparatus worn (Fig. 1). Men wearing apparatus 2 are able to continue the rescue task for a longer time than those wearing apparatus 1. These differences are associated with differences in the inspired-air temperature. A detailed comparison of these two forms of rescue apparatus has been presented in another paper (Lind, 1955), and need not be considered any further here.

Environments.—The first 30 minutes of moderate work (170 kcal./m²/hr.) can be performed by all the men even in the most severe temperature conditions of this investigation, namely at 37.8°C. of the saturated air. As soon as the men change to the harder work, as is often required in rescue operations, the effect of the environmental conditions on their tolerance becomes very noticeable, as is shown in Fig. 1. From the maximum performance time of 65 minutes at 29.4°C. of saturated air there is an average fall of about 15 minutes for every 5°C. rise of wet-bulb temperature with apparatus 1 and 18 minutes with apparatus 2. The exact relationship between external temperature and tolerance time is probably a sigmoid curve, but these average values represent approximately a linear fall in tolerance time over the range of the environments in the present study.

Although the first 30 minutes of work are relatively easily tolerated, the body temperature even during this first period cannot be maintained at a steady level in saturated environments at temperatures above 32.2°C. (Fig. 2) and this is associated with a marked falling off in tolerance time (Fig. 1).

FIG. 2.—The relationship between saturated temperature (°C.) and rectal temperature increment (°C.) in the first 30 minutes of work at a mines rescue task.

A similar result appears when the pulse rates are considered. Fig. 3 shows the mean pulse rates for the complete exposure at each environment and here again there appears to be a progressive increase which becomes more marked when the temperature of the saturated air exceeds 32.2°C. It is interesting

FIG. 3.—Mean pulse rates of men working at a mines rescue task in various saturated environments ($^{\circ}\text{C}.$) throughout the 65-minute exposure to heat, and the 30-minute recovery period.

to note how extremely similar are the recovery curves for pulse rates irrespective of the duration of exposure or the environmental conditions during the exposure. This is added support for the belief that the men had attained a roughly similar end-point at the time of withdrawal from the heat.

Craig and others (1954) found a close correlation between the tolerance time and the time taken for the pulse rate to reach 160 beats/min. Such a correlation is not apparent in the present series, no doubt because the pulse frequently rose to the maximum countable rate soon after the beginning of the heavy-work period even at the lower environmental temperatures, and this "maximum" rate tended to be maintained until the end of the endurable exposure.

Blood pressures, taken over the first half-hour in the heat, show a definite tendency for systolic pressure to rise, although there was little change in diastolic pressure so that the pulse pressure also increases. The increment of pulse pressure (Table 6) tends to be enhanced after the environment has reached $32.2^{\circ}\text{C}.$ Individual variation is, however, very large.

TABLE 6

CHANGES IN MEAN SYSTOLIC AND DIASTOLIC PRESSURES AND PULSE PRESSURE AFTER 30 MINUTES' WORK IN VARIOUS SATURATED ENVIRONMENTS

Temperature ($^{\circ}\text{C}.$)	Blood Pressure (mm.Hg)			Pulse Pressure (mm.Hg)		
	Initial	After 30 min.	Change	Initial	After 30 min.	Change
29.4	123/84	138/87	15/3	39	51	12
30.8	121/83	137/88	16/5	38	49	11
32.2	121/83	141/87	20/4	38	54	16
33.6	122/82	153/92	31/10	40	61	21
35.0	122/83	140/82	18/-1	39	58	19
37.8	122/82	157/82	35/0	40	75	35

Discussion

The importance of giving captains of mines rescue teams guidance as to the (physiologically) permissible time available to them for carrying out rescue tasks needs no stressing. To do this it is necessary to think of the team as a whole and to allow a safety margin which will take account of the "weakest link". We have accordingly proposed for underground emergencies time limits shorter by 10 minutes than the 90% confidence lines shown in Fig. 1. These recommended limits should provide

for all but the most heat-intolerant individuals, though such men, it is hoped, will be eliminated in a heat test during the periodic training course.

The only information at all comparable with that reported here is that by Roantree derived from systematic observations of men fighting underground fires in the Kolar Gold Field. On the basis of such observations over a wide range of thermal conditions Roantree has prepared a "predicted" curve relating length of shift to wet-bulb temperature. Though the time limits he suggests are only some five minutes longer than our average observed values, they exceed our recommended limits by 15 minutes at 90° F. wet-bulb and 10 minutes at 100° F. wet-bulb temperature. These differences are quite reasonably attributable to the state of natural heat acclimatization of his subjects, and probably also to the elimination of heat-intolerant subjects in the course of their ordinary mining work in consequence of the high temperatures prevailing in the Mysore mines (Caplan, 1950). None of our 36 subjects could be said to have experienced even moderately high temperatures during their ordinary mining occupations over the last two years or more. This emphasizes the necessity of allowing a safety factor, for it must be accepted that rescue men in this country at the present time, while of very high morale and well trained, are in general quite unacclimatized to heat.

Other situations where tolerance times to heat have been determined are those investigated by Craig and others on men working in protective clothing, and by Blockley and Taylor (1950) and Blockley and Lyman (1950) whose subjects were exposed to high external radiant heat. These authors have summarized their findings in the form of a relationship between the rate of heating up of the body ("storage") and the tolerance time. The average tolerance of Blockley and Taylor's subjects for a given rate of "storage" was longer than that of Craig and others, but this is probably to some extent due to a difference in judging the termination of the exposure, for there is some overlap in individual values of the two series. In the experiments reported here it was not possible to follow the skin temperature so that "storage" could not be calculated, but from some recent experiments (to be reported elsewhere), in which we were able to record skin temperatures, it seems safe to conclude that the tolerance times of our subjects in relation to the rate of "heating-up" conform quite well to those of the American workers.

There is very little information in the literature on the effect of ageing on performance in the heat. The present investigation has not given any grounds

for making a distinction in our recommendations between trained rescue personnel of the two age groups investigated. To support this we may quote the recent paper by Lavenne and Belayew (1954) who report that prolonged exposure to heat *per se* does not increase the frequency of cardiac disorders in older mine workers. We have found, however, some small but detectable differences in physiological response between our two age groups. The older men in the first 30 minutes of exposure showed a somewhat greater rise in rectal temperature, and over a period of 65 minutes have a tendency to sweat less. This delay in heat-regulatory response on the part of the older men, slight though it is, was evident also in the "uniformity" trial referred to previously.

Mackinnon (1954) claims that the number of active sweat glands is markedly reduced with age. On the basis of her findings, we might expect a reduction of about 30% in the number of active glands from the younger to the older groups of subjects in our experiments. The observed reduction in sweat loss is, however, only about 15% (and this does not reach even the 10% level of significance). Mackinnon's sweat gland counts were confined to the palmar surface of the finger, where emotion influences sweating far more than does a thermal stimulus (Kuno, 1934; Weiner, 1945) and her results may therefore not be applicable to sweat glands in general. That men of 45 possess fewer active glands, each gland working at a higher average rate, remains a possibility, but this requires further investigation.

Summary

Thirty-six mines rescue personnel wearing self-contained breathing apparatus were exposed to a stipulated work routine in various saturated environments, and their "tolerance times" were determined.

There was no demonstrable difference in tolerance time of men in two age groups (19-31 and 39-45 years) although minor physiological differences were detected.

No difference was found in the ability of men in three occupational groups to work in saturated environments.

The use of the information on "tolerance times" as it affects the mines rescue service is discussed.

We wish to thank the National Coal Board, and in particular the Rescue Service of the National Coal Board, who provided administrative and experimental facilities. We are also indebted to the 36 subjects without whose whole-hearted cooperation these experiments would not have been possible.

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APPENDIX

Details of the Rectal Thermocouple Used in the Experiments

BY

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There appears to be no description in the literature of a reliable and comfortable rectal thermocouple which may be used on untrained subjects. No originality is claimed for the use of an indwelling thermocouple for taking rectal temperatures, but it was felt that details of its construction would be of interest.

Construction

The thermal junction was made of 30 s.w.g. copper-constantan covered with plastic to form a flat twin-flex. It was soldered within a thin-walled brass cap 5.6 mm. outside diameter and 5 mm. long. A 7 cm. length of 22 s.w.g. piano wire was taped to the plastic covering just behind the cap and the whole was placed in a specially made glass mould. After filling the mould with polyvinylchloride paste by oral suction and baking at 150° C. for 10 minutes, the finished rectal thermocouple was removed by carefully smashing the glass mould (Fig. 4).

The thermocouple was inserted into the rectum by means of a brass pusher, so that the bulb lay just beyond the anal sphincter. The pusher was then withdrawn along the lead.

Conduction Errors

Using a thermocouple 8 cm. in length and with 2 cm. of lead in the anal canal, the thermal junction itself was about 10 cm. from the exterior. If the air temperature was much different from the temperature in the rectum, then conduction along the lead could conceivably influence the thermocouple. In order to ascertain the

probable magnitude of this effect, a rectal thermometer was placed in a vacuum flask completely filled with water at about body temperature. Two cm. of lead passed through the cork (corresponding to the anal sphincter) and the next 40 cm. were formed into a tight coil. Placing the coil in crushed ice or water at 52° C. caused changes in the recorded temperature of less than 0.1° C. (Fig. 5). The conduction error caused by air at 0° C. or 52° C. would be less than this owing to the low specific heat of air.

Advantages

The thermocouple always remains a fixed distance within the rectum. It is comfortable to wear, even for untrained subjects for periods up to four hours at least, and no external fastening is necessary. Since only the flexible lead passes through the anal canal, the wearer may sit or perform vigorous exercise with no discomfort.

FIG. 5.—Effect of placing 40 cm. of the thermocouple lead in water at various temperatures on the temperatures recorded by the thermocouple.

FIG. 4.—Completed rectal thermocouple and brass pusher.