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VOLUME ONE
PHYSIOLOGICAL EVALUATION
OF
CLOTHING AND EQUIPMENT
FOR
USE IN HOSTILE WORKING ENVIRONMENTS

BY
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A Thesis

Submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy

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ABSTRACTPHYSIOLOGICAL EVALUATION OF CLOTHING AND EQUIPMENT
FOR USE IN HOSTILE WORKING ENVIRONMENTS

The thesis is associated with the evaluation and development of micro climates to enable satisfactory work tasks to be undertaken in environments hostile to man's normal physiological regulation. The areas of elevated temperature and high voltage electric fields, with particular reference to inspection and work tasks in pressure vessels associated with nuclear power reactors and 'live line' maintenance on electricity transmission lines, being the main objectives, based on the economic problems caused by the outage of modern electrical generating and transmission plant.

Parameters of typically hostile environments with particular reference to heat stress, energy expenditure, atmospheric contaminants, noise, nuclear radiation and contamination and electrical energy are reviewed together with a brief outline of the problems associated with man access under controlled conditions into pressure vessels of nuclear power reactor systems.

Development of a thermally comfortable pressure suit and associated equipment using the vortex cooling effect for use during access penetration into the Advanced Gas Cooled Nuclear Reactor System is described, together with methods of assessment of clothing materials and, in particular, the progressive developments of textile/metallic blended fabrics for use as conductive/ screening suits is covered in the context of specification and standards of performance presentation.

Complementary work is also reported on the development of a physiological data acquisition, analysis and presentation system for monitoring heart rates of ambulatory subjects working in abnormal or hostile environments.

The results of the investigations are viewed on the development basis of a system design of a Heat Balance Equation using the Ranque Hilsch cooling effect produced by a vortex tube used in conjunction with a ventile clothing assembly and the setting up of the system to achieve adequate protection for persons working in an abnormal environment up to 60°C.

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The preparation of the text was made much easier by the typing and assistance of Mrs Rosemary Morgan and for the figures and photographic work I am indebted to my colleagues in the Central Electricity Generating Board and to Mr Eddie Willcox in particular for skillful application of drafting techniques.

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QUOTATIONS

Claude Bernard (1878) in his concept of the 'milieu interior' stated "that all the vital mechanisms varied as they are contribute to the perservation of stability of internal bodily organisations; with an effective thermo-regulatory system to control his 'milieu interior' man is better equipped than the poikilotherm to live and work in a wide range of environmental conditions, a range which he has been able to extend by the invention and use of protective clothing or of air conditioning".

L & L Heat Stress Heat Disorders P.6

"The object of my invention is a method of automatically obtaining from a compressible fluid (gas or vapour) under pressure a current of hot fluid and a current of cold fluid that transformation of the initial fluid into two currents of different temperatures taking place without the help of any moveable mechanical organ merely through the work of the molecules of fluid upon one another".

George Joseph Ranque (1931)

French Patent No.646020

"While Ranques tube is finding a few isolated uses we have seen that it cannot serve in installations of size where power consumption is a consideration. For refrigeration in minute quantities or for very occasional use where stored compressed air is available, it is suitable. It remains one of the most remarkable inventions of the century".

C P Fulton (1950)

Journal of the ASRE

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CHAPTER 1
PHYSIOLOGICAL EFFECTS OF THE ABNORMAL ENVIRONMENT
AND BACKGROUND TO THE PROBLEM

1.1 Introduction. The ability of the human being to carry out physical work under abnormal conditions or in an environment hostile to his normal physiological functions has been the subject of much investigation. There cannot be much doubt that the ability to adapt enhances individual survival but there is usually a price to pay, the cost of adaption or prevention can be high, and accurate assessments are essential. Much is known about the immediate effects of exposure to hostile conditions, a fair amount about the subsequent physiological changes that develop more slowly. The long term effects in certain industrial processes resulting in asbestosis, pneumoconiosis and fatal carcinoma are currently the cause of great concern. New statutory legislation in the Health and Safety at Work etc Act 1974, require an even greater understanding and control of industrial processes.

When human beings are required to perform physical work in hostile environments there are a number of alternatives open to ameliorate the situation. Firstly, attempts may be made to reduce the risk to them by (a) acceptable engineering control methods, (b) reducing the work load, or (c) by achieving some compromise between these two possibilities. Secondly a work system may be devised whereby exposure durations are limited to those in which the risk is kept to a relative minimum. However, there will be circumstances in which for one reason or another these attempts will be uneconomical, impracticable or inadequate, or an emergency condition may arise due to a plant or process failure overriding the engineering control.

The necessity to work in these conditions is the origin of this research project on the study of protective clothing and devices based

on the Ranque Hilsch cooling effect to enable inspection and work tasks to be carried out in pressure vessels associated with nuclear power reactors and other conditions associated with the generation and transmission of electricity.

Ruffel Smith (1966) suggests the normal physical environmental conditions would approximate:-

Temperature 23°C Relative humidity of 45%
 Air at 1 bar uncontaminated and dust free
 Acceleration 1g steady
 Noise less than 80 dBA
 Daylight
 Circadian rhythm in phase with local time

The first three of these can be halved or doubled before man could not acclimate. Performance in terms of mental and physical skills will usually start to fall off when conditions are varied by much smaller amounts.

An example of an abnormal working environment can be shown by that to be expected under a controlled condition for planned human access into the pressure vessel of an Advanced Gas Cooled Nuclear Reactor (AGR) which is specified as follows:-

Temperature 60°C (metal contact temperature 70 - 80°C may be encountered).

Air - contaminated requiring respirable air to be supplied.

Noise - 132 dBA maximum.

Darkness for initial entry, limited artificial lighting to be installed for inspections to be carried out.

Difficult access and egress and cramped conditions generally.

It has been noted that a multiplicity of physiological parameters have been studied before, after, and more recently - due to technical innovation - during exposure to abnormal conditions when undertaking physical work. These parameters have been correlated with the work performance attained to demonstrate the quantitative relationship between

the performance (and one or more of the parameters) or to assess the limitations of human capability.

1.2 Physical Effects of the Abnormal Environment. Since the publication of the classical volumes, *The Physiology of Heat Regulation* and *The Science of Clothing*, Newburgh (1949); *Man in a Cold Environment* Burton and Edholm (1955); *Adaption to the Environment*, Dill (1964) and the *Physiology of Survival*, Edholm and Bacharach (1965), further investigations have added considerably to basic physiological knowledge of work and survival in hostile environments. The effects of abnormal physical conditions at work was the subject of an Ergonomics Research Society symposium, Davies C et al (1967), and the Physiological Society monograph No 29 Kerslake (1972) deals particularly with the stress of hot environments.

Whether hot or cold man's ability to survive and work depends not only on his physiological mechanism for temperature regulation but also on his behavioral response, to his ingenuity in controlling the micro-climate surrounding his body. The relative importance of these two factors in the maintenance of homoeothermy differs at the two climate extremes; ingenuity the major role in cold climates and ingenuity and physiology in hot climates. Physical laws determine this difference. Heat is continuously generated inside the human body; for homoeothermy there must always be a net flow of heat from the body to the environment in both hot and cold climates. In cold climates the rate of loss can be modulated easily by interposing more or less insulation to impede heat flow, whereas in hot climates the heat must be extracted against the natural gradient by some form of heat pumps; "It is easier both to design and to wear an overcoat than a refrigerator" Fox (1965).

When work tasks are performed under adverse environmental conditions physiological adjustments take place to counteract the effects of the environment. In work at elevated temperature for example, for a certain amount of energy requirement by physical work, an increased physiological effort is needed to maintain the body temperature as close

as possible to its normal level. Where this is not accomplished efficiently the physical work cannot be maintained for an appreciable length of time. Adverse conditions of the environment can transform an easy task into a hard one. Consequently it is essential to know the exact effects of the environment, physical and chemical, on the physiological functions of the man involved.

Temperature, humidity, air movement and atmospheric contaminants are the most common and important environmental factors which can influence the worker's physiological behaviour. The physiological response to changes in temperature depends on a number of factors; water and salt content of the body, individual characteristics, state of health and nutrition, degree of physical fitness and of heat acclimatisation and work load. Water balance is of primary importance, if withheld during work in heat, body temperature and pulse rate rise and rate of sweating declines. Physical fitness is usually correlated with tolerance to heat because of more efficient cardiovascular and vasomotor systems in the fit subjects.

Individual characteristics cause varying responses to heat exposure. The ability to adapt to heat lessens with age. Sometimes body size is crucial in determining a subject's ability to work under elevated temperature conditions. Brouha (1967) noted that it is commonly supposed that women are less heat tolerant than men and that it was a fact that generally under similar conditions they produce less sweat and may therefore be physiologically less efficient in their evaporative cooling mechanism. In fact very few studies have been made in which like exposures and activities prevailed for acclimatised and non acclimatised subjects of both sexes. However Hertig and Sargent (1963) have reported on the acclimatisation of women during work in hot environments being poorer than that of men.

Acclimatisation to heat can change the individual physiological reactions to high temperature. It was emphasised some two hundred years ago by Lind (1768) that habituation to hot climates reduced the danger to health. Liet head and Lind (1964) acknowledged that the process of acclimatisation to heat was one of the most dramatic examples of physiological adaption to a changed environment.

The heat balance of the body is regulated mainly by changes in heat loss. They are essentially accomplished by two methods, the physical and the physiological. The former includes conduction, convection, radiation and evaporation. During work in hot environments, particularly when the humidity is high, sweating and heat conduction may not be sufficient to dissipate the heat load produced by the work task required. Under these conditions the body temperature rises and the cardiovascular responses such as heart rate and cardiac output continue to increase even though the work rate level and oxygen consumption remain constant. The ability to reach a high level of oxygen intake and maintain satisfactory thermal equilibrium are the two essential requirements for working efficiently in a warm environment.

The heat exchanges between the body and its environment can be simply represented by the heat balance equation:-

$$M \pm C \pm R - E = \pm S$$

Where M is the heat of metabolism

C & R represent the heat gained or lost by the body, by Convection and Radiation respectively

E is the amount of heat lost from the body by the Evaporation of sweat

S is the amount of heat gained or lost by the tissues of the body

To this equation may be added - when necessary, values for heat exchanges for solid and liquid intake and loss - heat exchanges across the lung, and the heat gained or lost by conduction.

If these factors can be assessed quantitatively with reasonable accuracy simple addition or subtraction will show whether existing environmental conditions will allow heat balance to be maintained. If this is not the case, it is then usually possible to decide from the values of the components of the equation in what way the conditions can be most effectively modified to reduce the total heat load on the body, or to use some physical means to adjust these.

This method of assessing the amount of heat exchanged through the various channels of heat loss and heat gain is known as 'partitioned calorimetry' and was first examined on a systematic basis by Winslow et al (1936) subsequent experiments based on the same principle were carried out by Nelson et al (1947) and by Clifford et al (1959).

The amount of heat generated in the body as a result of metabolic activity may vary greatly. Passmore and Durnin (1955) suggested 70 - 80 watts (basal metabolic rate) up to the maximum rate of energy expenditure which could only be sustained for a few minutes of well over 1163 watts. In normal working situations neither of these extremes will be encountered and the range of energy expenditure will be from about 90 to 140 watts for sedentary work up to 580 - 700 watts for the heaviest tasks.

Table 1.1 from Passmore and Durnin (1955) show typical energy expenditures for a variety of industrial tasks.

It should be noted that merely moderate rates of energy expenditure involve the body in the continuous dissipation of large quantities of heat. Even at rest the body produces enough heat to raise the temperature of all its tissues by approximately 1°C/hr and if this heat were not dissipated an average energy expenditure of 350 watts would in the event of the failure of the body to dissipate any heat - raise body temperature by about 5°C/hr . Leithead and Lind (1964) gave this as an eloquent comment on the efficiency of man's thermoregulatory system.

DEFINITION OF DIFFERENT GRADES OF WORK (CHRISTENSEN 1953)			
Light work		174 to 349 watts	
Moderate work		349 to 523 "	
Heavy work		523 to 698 "	
Very heavy work		698 to 872 "	
Unduly heavy work		over 872 "	
Agriculture	Watts	Building	Watts
Setting up stocks	461	Mixing cement	328
Ploughing	440	Plastering Walls	287
Loading stocks on cart	391	Building wall	279
Mow with horse-drawn reaper	301	Shaping stones with hammer	265
Hoing	288	Carrying bricks or cement	251
Carpentry	Watts	Mining	Watts
Planing (hardwood)	635	Loading	516
Hand sawing (hardwood)	523	Hewing	495
Chiselling	398	Packing	475
Joining floorboards	307	Timbering	447
Measuring wood	167	Drilling	391
Machine sawing	167		

MISCELLANEOUS LIGHT INDUSTRIES

Occupation	Watts	Occupation	Watts
Loading chemicals into mixer (battery manufacture)	419	Pressing metal household utensils	265
Casting lead balls in mounds (battery manufacture)	335	Turning	258
Machine fitting	293	Joinery	254
Tool room workers	272	Moulding ebonite	251
Pressing (ironing)	272	Filing (large file)	244
		Tool setting	237
		Light machine work (engineering)	237

Table 1.1. Energy Expenditure in Different Occupations

(from Christensen (1953) and Passmore & Durnin (1955)) (Converted to watts conversion factor 1.163 Kcal/hr)

MISCELLANEOUS LIGHT INDUSTRIES - CONTD			
Occupation	Watts	Occupation	Watts
Plastic moulding	230	Radio mechanics	180
Machining (engineering)	216	Printing	154
Sheet metal working	209	Hand compositing	154
Shoe manufacturing	209	Electrical armature winding	154
Sewing machine work	195	Drilling	126
Shoe repairing	180	Light assembly work	126
Medium assembly work	180	Draughtsman	126
		Watch repairing	112
		Typing	98

STEEL AND IRON INDUSTRIES

Occupation	Watts	Occupation	Watts
Open hearth		Wire roll mill	
Slag removal	809	Wire bundling	712
Dolomite shovelling	761	Roughing	572
Tipping the moulds	419		
Heavy mill	Watts	14-inch merchant mill	Watts
Tending heating furnaces	712	Merchant mill rolling	656
Hand rolling	621	Forging	454
		Fettling	354

SUNDRY ACTIVITIES

Occupation	Watts	Occupation	Watts
Shovelling 8 kg load (1) distance 1m		(2) distance 2m	
(a) 1-2m lift 12 times/min	663	(a) 1-2m lift 12 times/min	733
(b) less than 1m lift 12 times/min	523	(b) less than 1m lift 12 times/min	593
Tree felling with saw	747	Digging trenches	593
Trimming felled trees	712	Pushing wheelbarrow (100 kg load)	349

The interrelationship of heat exchangers is complex and is apparently also influenced by the humidity and clothing worn and the rate of work. Adam et al (1955).

Clothing and various kinds of protective equipment can sometimes increase the stress of work to a considerable degree by hampering heat dissipation, as well as because of its weight and interference with freedom of movement. Any clothing assembly that interferes with the evaporation cooling process will put an additional load on the heart. Brouha (1967) showed that there was a close relationship between the effect of clothing, the work load, and the temperature of the environment.

Effects were also observed when wearing impervious clothing used for protection against chemicals. This design of garment interfered maximally with the dissipation of body heat. During work, the layer of air trapped inside the clothing assembly warmed up rapidly to body temperature and quickly became saturated with moisture. Under such conditions, no body cooling by evaporation took place and as a result the physiological load increased steadily toward a state of complete exhaustion with high heart rates and high body temperatures. Such reactions were present even when the temperature of the environment was favourable and the work load light.

Additional physiological loads of varying degree occur when respiratory protective devices are worn Davies J (1973) and these together with clothing assemblies must be taken into consideration in evaluating the physiological requirements of work in industrial operations.

Experiments of Fordyce reported by Blagden (1775a) and (1775b) were amongst the earliest deliberate hot room experiments for observing the effects of heat on man; there was at that time no wet bulb thermometer, no simple and accurate method of measuring air speed, and no measure of radiation. It was noted that when room temperatures were only 43° to 49°C,

but the air almost saturated, body temperature and pulse rate rose rapidly, there was profuse sweating and great increase in peripheral blood flow.

When the air was dry the subjects could withstand much higher temperatures of up to 127°C for appreciable periods; many of their contemporaries doubted whether this was possible, but later work, Blockley and Taylor (1949), fully confirmed the observation; there have also been reports, Fox (1965) of exposure to much higher air temperatures for shorter periods.

The controlling factor is the rise in skin temperature for at about 49°C it takes only a matter of seconds for the irreversible damage of a burn to develop. Blagden & Fordyce only partly appreciated the importance of the evaporation of sweat in temperature regulation.

During the early part of the nineteenth century much work on animal physiology contributed to the understanding of temperature regulation, but relatively little on human physiology. The experiments of Aaron (1911) and Shaklee (1917) proved that ill effects from insulation in the tropics was due to failure of temperature regulation. Progress during the twentieth century has rapidly gained momentum. The volume of new work published each year is now so large that it has been found extremely difficult for research workers to remain up to date in their knowledge of the whole field of temperature regulation and the acclimatisation to heat. In the following section an attempt is made to put the relevant indices of heat stress into the context of this thesis.

1.2.1 Indices of Heat Stress and Physiological Effects. The practical importance of finding some index or formula that would integrate all the factors contributing to the heat load into a single index expressing the heat stress, or the physiological effects of elevated temperature, was quickly appreciated. Unfortunately this has not proved easy, because of two fundamental difficulties (i) Inter comparison and (ii) in finding a

satisfactory yardstick for measuring the effects on the human being, and - as a result - many indices have been devised and promoted.

This is a source of considerable confusion in environmental physiology, because it is often difficult to compare the work of two groups who have expressed their results in terms of different indices. One of the difficulties arises from the need to make such an index suitable for the most diverse applications. A high degree of accuracy in prediction and universality of application is desirable; it is necessary to take account of as many as possible of the variables contributing to the situation. Such an index has appeared exceedingly complicated to formulate and cumbersome in use. Reducing the number of variables to the two that are usually the most important ie dry bulb and wet bulb temperatures, is not satisfactory where other variables such as radiation level, wind speed, and metabolic rate also become important, and may be the very factors desired to be evaluated.

The nature of these problems becomes apparent if one views the historical development of the indices. Attempts were made early to develop instruments which could, in some degree, simulate the effects of the environmental variables in the human body. Heberden (1826) produced a heated thermometer designed to give a combined measure of the effects of air temperature and velocity. The Katathermometer. Hill et al (1913), when the bulb of the instrument was covered with a wet silk finger stall was used for measuring the physiological effects of the environment, it also took some account of the cooling effect of the environment in hot conditions.

One of the most elaborate instruments developed was the eupatheoscope, Duftin (1929) (1932) (1936). This consisted of a black cylinder 55cm high 19cm diameter containing a heater and a thermostat set at 25.5°C. The surface of the cylinder therefore varied in temperature

depending on the environmental conditions of dry bulb temperature, radiation, and air velocity and simulated to some degree the effects of the heat loss from the clothed body. The amount of current consumed by the heater was used to express the reading on a scale of Equivalent Temperature. This ET index is used mainly by ventilating engineers and Bedford (1936) derived a nomogram based on the formula $ET = 0.522ta + 0.47tw + 0.0474v (100-ta)$

Where: ta = air temperature $^{\circ}C$
 tw = mean radiant temperature $^{\circ}C$
 v = air velocity ft/min were known

The thermal relationship between man and his environment appeared to be far too complicated to be reduced to a simple physical model. The alternative approach appears to have been to approach the problem using man as the measuring instrument and to construct formulae or nomograms relating to his physiological response to different combinations of variable environmental conditions.

In this empirical approach to formulating such an index it is necessary to undertake large numbers of experiments and to test different combinations of several climate variables. The problem of what physiological effect to measure also has to be decided. The easily measured effects that occur when man is subjected to elevated temperatures include, change in pulse rate, skin and deep body temperature, and in body weight through sweat loss, and subjective sensations of warmth and discomfort.

The Effective Temperature scale was the first of the empirical type. Houghton and Yaglou (1923) (1924) Yaglou and Miller (1925) who determined climates having widely differing combinations of air temperature, air speed, and humidity but having equivalent comfort as judged by the subjective impressions of groups of individuals. Two scales are used individuals (a) stripped to the waist (b) normally clad. No allowance was made in the earlier scales for radiation one of the reasons for this omission being the lack of a suitable measuring device in

common usage. Aitken (1887) had proposed the use of a hollow metal sphere blackened on the outside with a thermometer at its centre. Vernon (1930) (1932) reintroduced the blackened globe and Vernon and Warner (1934) demonstrated how to use it to measure mean radiant temperature. Bedford (1946) presented amended scales to include an allowance for radiation called Corrected Effective Temperature. Smith (1955) proposed a further modification to include an allowance for the level of energy expenditure, suggesting that the rate at which a man works can be taken into account in connection with effective temperature either by the use of a simple supplementary nomogram or of a series of graphs.

The Effective Temperature scales have great merit in the study of heating and ventilating.

The Wet-bulb Globe Temperature index. WBGT was derived from the Effective Temperature scales and represents a simplified form of them. It is favoured for its simplicity and as originally used by Yaglou and Minard (1957) combined the effects of dry-bulb ($t_a^{\circ}\text{F}$) wet bulb ($t_w^{\circ}\text{F}$) and globe thermometer temperatures ($t_g^{\circ}\text{F}$) in the simple formula.

$$\text{WBGT} = 0.7t_w + 0.1t_a + 0.2t_g$$

The Wet bulb - dry bulb index is similar to WBGT except that in calculating it no allowance is made for radiation and there is a small difference in the relative weightings of wet-bulb and dry-bulb temperatures. It was developed by Lind et al (1957) and Lind (1963 a) (1963 b) to relate tolerance times in saturated and non-saturated climates for mine rescue personnel.

The index is derived from the formula $\text{WD} = 0.15d + 0.85w$ where d and w represent dry and wet bulb temperatures in $^{\circ}\text{F}$ respectively.

In 1942 the Royal Naval Personnel Committee (RNPRC) was set up and the following reports have been published of their research. Benson et al (1945), Dunham et al (1946), McArdle et al (1947), Weiner (1948), Adam et al (1951) (1952) (1953) (1955), Ellis (1953) and Bell et al (1963) (1967).

The Predicted 4 hour sweat rate, P_4SR nomogram of McArdle et al (1947), is based on the assumption that the level of the environmental heat stress can be expressed as a function of the amount of sweat produced by the individual exposed. It was originally defined as the amount of sweat which would be produced in four hours in the environment in question by healthy acclimatised young men, dressed in the specified amount of clothing and performing the prescribed amount of work. It is then obviously limited to those circumstances in which sweating will occur. It was evolved for a specific purpose, as a result of the concern of the Admiralty for men in ships in tropical waters. The existing Effective Temperature scales were tested and found to be unsatisfactory in certain respects. A direct correspondence between P_4SR index and a group of individuals can be found when certain conditions are fulfilled (i) The individuals must be fully acclimatised to heat (ii) the exposure must last 4 hours (iii) the conditions must be such that a P_4SR above about 5.0 will not be indicated. Above this level the observed sweat rate falls below the predicted value because the maximum sweating capacity of the subjects has been exceeded. The index takes account of various factors contributing to the stress of a heat exposure, dry-bulb wet-bulb and globe thermometer temperatures, air speed, metabolic rate and two levels of clothing.

The P_4SR index was tested by Macpherson (1960) and the reliability of the index was in general fully confirmed.

The Operative temperature index was aimed to analyse the thermal exchanges between the human body and its environment and to base the assessment of the heat stress on the magnitude of heat flow. Winslow et al (1936) (1937) (1938) and Winslow (1941) used the technique of partitional calorimetry to analyse the magnitude of heat flow through each of the avenues of thermal exchange and to derive constants for the coefficients of convection, radiation and evaporation.

The index is somewhat similar to Equivalent Temperature and is derived from the formula

$$\text{Operative Temperature} = \frac{K_v(t_w) + K_c(t_a)}{K_v + K_c}$$

where t_w , t_a are the radiant wall and air temperatures $^{\circ}\text{C}$ respectively

K_v , K_c are constants for radiation and convection respectively

The index is applicable to lightly clothed or nude individuals.

At operative temperatures below $29^{\circ} - 31^{\circ}\text{C}$ body temperature can be controlled by vasomotor regulation but above 31°C evaporative cooling occurs.

Haines and Hatch (1952) further developed the basic concepts of Winslow et al (1937) by showing how the principle of thermal exchange could be applied to the evaluation and control of industrial heat exposures; this was later amplified by Belding and Hatch (1955) into the Belding and Hatch index (BHI) which expresses the thermal stress of a hot climate as the ratio of the amount of sweat that must be evaporated to maintain the body in thermal equilibrium to the maximum evaporative capacity of the climate. The index requires a number of assumptions and approximations, individuals are (i) of average build (ii) dressed in shorts (iii) have skin temperature 95°F and (iv) have body surface uniformly wetted with sweat it is further assumed that the thermal exchanges by conduction and respiration can be ignored.

The equation for basic heat balance for Evaporative capacity required becomes

$$E(\text{req}) = M + C + R$$

The maximum Evaporative capacity $E(\text{max})$ can be calculated

$$\text{and the BHI} = \frac{E(\text{req}) \times 100}{E(\text{max})}$$

E = Evaporation

M = Metabolic Heat

C = Convective Heat exchange

R = Radiant Heat exchange

The BHI has the virtues of simplicity and directness in that it expresses the heat stress quantitatively in terms of the stressing agent equated to simple physical measurements. The approximations and assumptions introduced for the sake of simplicity reduces its accuracy; in treating man as a physical model one is to some extent ignoring his physiology.

Fox (1965) states a more important criticism; that the index does not bear any simple relationship to physiological strain and that the equivalent levels on the index produced by different combinations of levels of the climate variables do not produce the same degree of physiological strain. This is easily demonstrated by choosing two climates with the same Heat Stress index, one a relatively cool but almost saturated climate the other a much hotter and drier.

The hotter drier climate is in fact much more stressful.

All the indices described have defects and weaknesses, but each also has its advantages for a particular application. Kerslake (1972) makes three classifications.

- 1 Indices based on Subjective Preference
 - (a) Effective Temperature ET
 - (b) Equivalences en Sejour (Missenard (1948)) ES.
- 2 Indices based on Analysis of Heat Exchange
 - (a) Heat Stress Index of Belding and Hatch HSI
 - (b) Index of Thermal Stress (Givoni (1963)) ITS.
- 3 Indices based on Physiological Observation
 - (a) Predicted 4 hour Sweat Rate P_4SR
 - (b) Wet Bulb Globe Temperature WBGT.

Of these, the three most important are the 'Effective Temperature ET', the 'Heat Stress Index HSI', and the ' P_4SR index.' Effective Temperature remains the best way of comparing and describing conditions at mild levels of heat stress and in the comfort zone. ES appears to be that preferred

for steady state. Heat stress index is valuable at higher levels of heat because it enables the situation to be analysed so that the most appropriate remedy can be chosen. P_4SR index affords the most accurate way of relating heat stress and physiological strain. It is comparable with ITS which is more flexible and sometimes preferred.

The simplicity of WBGT index also fills a useful place but whenever possible an index giving a more accurate and complete description should be used. There seems no good reason for attempting to introduce variants on the WBGT index for general use, eg the wet-bulb - dry-bulb index. Any benefits from increased accuracy seem likely to be more than offset by the confusion due to the multiplicity of indices.

The ideal index for assessing the heat load imposed on human beings in a hot situation and for predicting the resultant physiological strain still appears to be required.

In the field of Heat Acclimatisation the evolution of ideas began in the early years of this century. These ideas and hypotheses appear to depend largely on ill-documented or anecdotal material. The confusion between the effects of heat and tropical diseases were great barriers to clear thinking and to progress. Bazett (1927) discarded the confused state of knowledge - "The whole subject is unfortunately lamentably complicated and little understood; indeed we have advanced little beyond the views expressed by Bernard (1876)".

Acclimatisation to heat should facilitate homoeothermy but attempts to demonstrate such an effect were far from successful, so that

Sundstroom (1927) wrote "If it be true that the physiological response to a tropical climate is primarily due to the cooling power factor, the acclimatisation process to such a climate should in the first hand consist of means to adjust the heat regulating mechanism to the highest attainable degree of efficiency in order to preserve a normal body temperature. It is a curious fact that, in spite of the numerous attempts to assess this heat - regulating efficiency by body temperature measurements, this simple point should still remain one of the most contested in the whole field of tropical physiology".

Investigators had reported a rise in the resting body temperature when individuals went from temperate into tropical climates,

Davy (1850) and Neuhaus (1893) and that the increase was more marked during the first weeks in tropics, Rathay (1870) and Jousset (1884). It was further shown that the rise in body temperature after muscular work was frequently much greater also Young (1915) and Young et al (1919). However, there were also many reports of no demonstrable influence of tropical living on body temperature, Boileau (1878), Furnell (1878), Thornley (1878) and Wick (1910) and of little if any difference between the body temperatures of the indigenous race and white residents in the tropics, Jousset (1884).

In the 1920's it had become clear that further progress in the study of man's response to heat demanded a much closer control of the climate variables contributing to the heat stress than could be readily obtained by observations made in the field. An apparent solution was to simulate climates by climatic chambers where variables could be accurately controlled.

Investigations under these controlled conditions have usually followed a fairly well-defined pattern. Subjects are exposed to carefully controlled climatic conditions for a number of hours daily, during which they perform a known amount of physical work and their physiological responses are measured in terms of heart rate, body temperature and sweat loss. After this initial test the subjects continue to be exposed to hot conditions for a number of days at the end of which the physiological responses are again measured and compared with the first test. The difference in response between the first and final test shows the cumulative effect of acclimatisation induced by the intervening exposure. The choice of a criterion of safe exposure will be determined by many considerations outside the competence of ergonomists. Economic and social factors within particular industrial contexts may contribute to a decision at what level workers' exposure should take place.

Ellis et al (1953) were left with the firm conviction that none of the

methods available at that time for predicting probability of survival under extremely warm conditions were satisfactory.

Weiner (1971) in a discussion of the prevention of heat stroke suggested that in selecting subjects factors to take account, include of course the medical history so as to eliminate those with cardiovascular diseases, poor working capacity and obesity. More sophisticated selection requires a trial exposure of individuals to standardised heat tests for elimination of those that are heat intolerant.

The only way to determine with confidence how men will react is to expose them to the conditions expected and see what happens.

From the many studies and investigations made using climatic chambers, Bean & Eichna (1943), Taylor et al (1943 a) and (1943 b), Robinson et al (1943), Eichna (1945), Horvath & Shelly (1946), Eichna et al (1950), Ladell (1951), Bass et al (1955), Hellon et al (1956), Macpherson (1960) (1962) and Bell et al (1963) (1967) and (1971) the classical picture of acclimatisation has emerged. The main features are a less marked increase in heart rate while working, lower skin and deep body temperatures, a greater production of sweat and subjectively a lessened sense of discomfort.

Physiologically the brunt of work in the heat falls on the cardiovascular system, therefore those who have to live and work in the heat need a stout heart literally and figuratively, Macpherson (1973).

1.3 Energy Expenditure. Most of the factors involved in physiological adaption have been studied using laboratory techniques. Research on human beings in industrial situations is limited by the methods that can be used without impairing the subjects health and performance. This consideration restricts the number of direct measurements during work activities. To this must also be added the workers' co-operation to partipate in investigations and managements' sympathy that the investigation will prove useful to the performance and profitability of

the work. Numerous factors must be considered in achieving a complete evaluation, the most important being that the worker must be able to carry the basic work load.

The terms light, moderate, heavy and very heavy have been used by many investigators to describe the severity of muscular work. Considerable data has been published on the range of energy expenditure by workers in the field. BMA (1950) used additional or nett values, Christensen (1953) gross values and Passmore & Durnin (1955) gives a complete review of human energy expenditure in various activities and industrial occupations. Brown and Crowden (1956) and Wells et al (1957), attempted to substantiate the work of Christensen (1953) and classified physical work by work capacity tests: they also review the literature and summarise the data using the term "optimal work" as representing a high level of physical activity that is approximately 50% of the limitation in human work capacity. Work intensities have been classified according to oxygen consumption, energy expenditure and heart rate; Table 1.2 summarises some of the investigations made and the physiological parameters used.

Evaluating the work load by measuring oxygen consumption has proved reasonably accurate. The method does however present certain problems in practical industrial applications because of the size of the sampling equipment, the restrictions imposed on the subject's freedom of movement, and the use for instance of a sampling mouth piece, which may cause him to work in an unnatural way. The dependence of physical work capacity on maximal oxygen uptake is however supported by many researchers as one of the most significant functional characteristics and as an index of work capacity. Hill and Lupton (1923), Fursusawa et al (1924), Hill (1926), Dill et al (1930) (1932) (1933), Robinson (1938), Astrand P (1952), Christensen (1960), Astrand P and Saltin (1961), and Astrand P and Rhyming (1954) propose a simple method of estimating oxygen consumption from

INVESTIGATOR	ERGOMETRY			FIELD STUDY	HR	P	VO ₂	Temp	Lac	Ur
	1	2	3							
Dill et al (1930)		*			*		*			
Hickman (1948)				*	*		*			
Wahlund (1948)	*				*		*			
Muller (1951)	*		*		*		*			
Christensen (1953)				*		*	*	*		
Astrand et al (1954)	*	*	*			*	*			
Taylor (1955)		*					*			
Le Blanc (1957)		*			*		*			
Wyndham et al (1959)	*				*		*			
Balke (1960)										
Williams et al (1962)	*					*	*		*	
Malhotra et al (1963)	*			*		*				
+ Maxfield (1964)	*				*					
Sharkey et al (1966)		*				*	*			
Brouha (1967)	*			*	*		*	*		
Wilmore (1968)	*				*		*			
Astrand et al (1973)	*			*	*		*		*	*
Vogt et al (1973)	*				*			*		

1 Cycle

2 Treadmill

3 Step

+ all women subjects

Table 1.2 Some Physiological Parameters Used to Assess the Physical Work Capacity of Healthy Human's

heart rate at a single sub-maximal rate of work. Le Blanc (1957) presents data on human beings showing that pulse rate during exercise and recovery periods can be used as a measure of fatigue for measuring work performance based on the linear correlation between oxygen consumption and the pulse rate at the beginning of a work period. The linear relationship between heart rate increase and work load is in the opinion of many researchers a comparative one. Astrand P and Rhyning (1954), Wells et al (1959), Astrand I et al (1960), Rowell et al (1964), Astrand I et al (1964), Margaria et al (1965), Tabakin et al (1964), Cerretelli (1967), and Brouha (1967).

Astrand and Rhyning (1954) use it as the basis for estimating maximal values from submaximal data, eliminating the necessity to carry out maximal work capacity evaluations which may be detrimental, particularly with subjects not used to physiological investigations.

From the review of the literature available it has been shown repeatedly that heart rate changes, quite accurately reflect the physiological state of a human being during muscular activity. Heart rate however responds to many influences. Monod (1967) listed in addition to muscular exercise, digestion, posture, altitude, climate noise and psycho sensory activity. Two other elements, drugs and emotion should also be considered. In view that heart rate is the final common effector of such a diversity of responses all possible sources of its variation must be considered before assigning observed changes to spontaneous heart rate variability. Reciprocally, heart rate should be used as an index of a particular physiological factor only if the simultaneous influences of the other factors is properly taken into account.

In the industrial work situation the measurement of continuous heart rate, if made without too much inconvenience would be a useful adjunct to the analysis of the factors influencing fatigue and the measurement of work performance. Details on the development of a compact

ambulatory monitoring system for the acquisition of physiological data are given in Chapter 2.

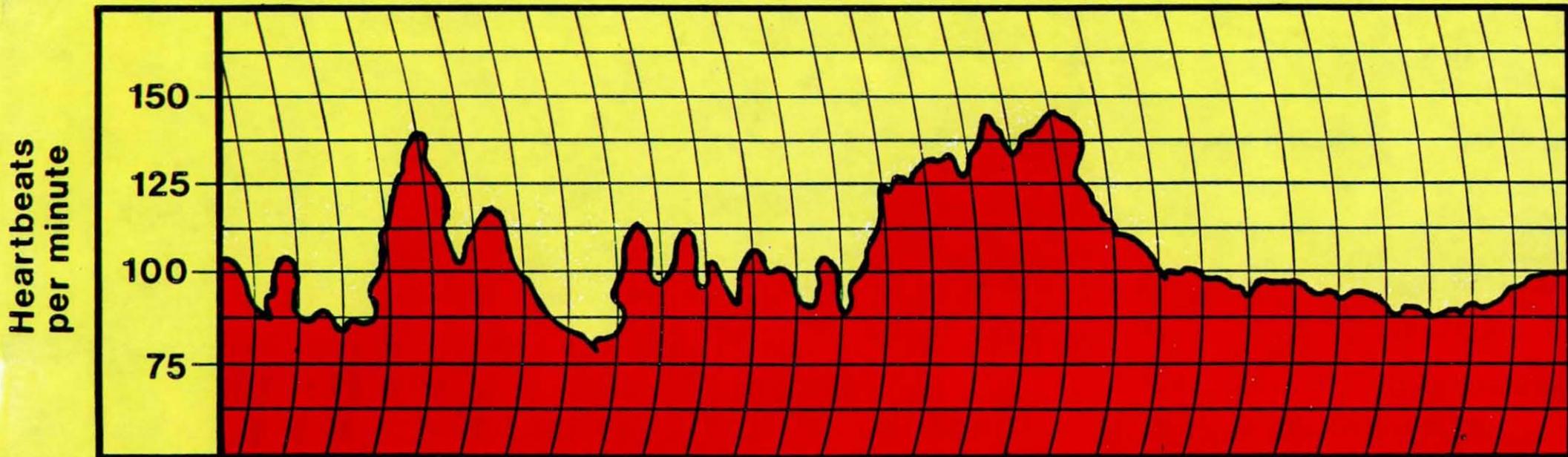
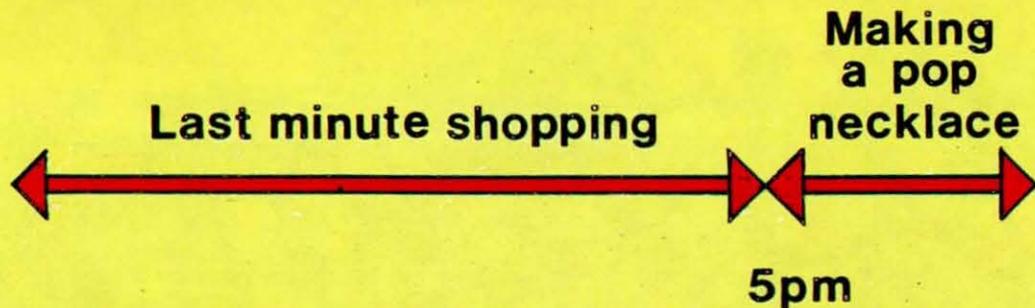
As stated previously heart rate can be affected by the emotional state of the subject, causing deviations from the expected response. Bowen (1903) noted that a rapid quickening or anticipatory response of the heart rate occurs at the onset of exercise, "the Bowen effect". Hickman (1948) reports that induced anxiety increased the cardiac output by measuring the heart rate. Beatty (1973) recorded heart beats of 177 and 180 per minute on two 14 year old girls at a pop concert, Figs 1.1, 1.2 and 1.3 attributed to the release of adrenalin due to excitement stimulation.

Various mathematical expressions have been proposed: a single exponential function of time, Davies C (1968) and Suggs (1968); an exponential function followed by a linear function of time, Mayer and Vogt (1970); a sum of two or more exponentials Schilpp (1951), Shephard (1970) and Wiggertz (1970); and a more complex function, Cardus & Zeigler (1968). Mathematical functions have also been proposed to describe the time course of heart rate after stoppage of work at a constant work load: a single exponential, Suggs (1968); a sum of two exponentials, Millahn and Helke (1968), Meyer and Vogt (1970) and Wiggertz (1970); and a more complex function Cardus and Zeigler (1968).

During muscular exercise a steady state level of heart rate is obtained only if the work rate is submaximal performed in the thermal comfort zone. For higher work rates the true steady state pattern is replaced by a slowly increasing heart rate, Christensen (1931), Le Blanc (1957). According to Karrasch and Muller (1951) the lack of a steady state occurs only when the work rate exceeds the "endurance limit" (Dauerleistungsgrenze) defined as the maximal energy expenditure covered exclusively by aerobic metabolic processes amounting to approximately 4 Kcal/min. This metabolic rate, much lower than maximal aerobic work capacity

HEART OF A TEENY BOPPER

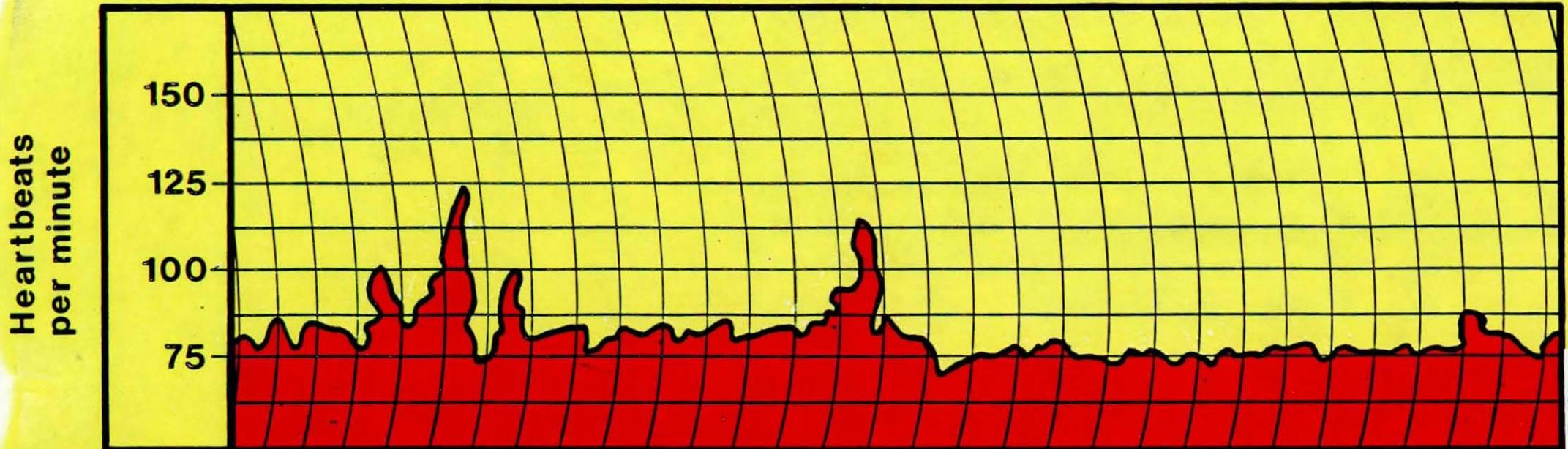
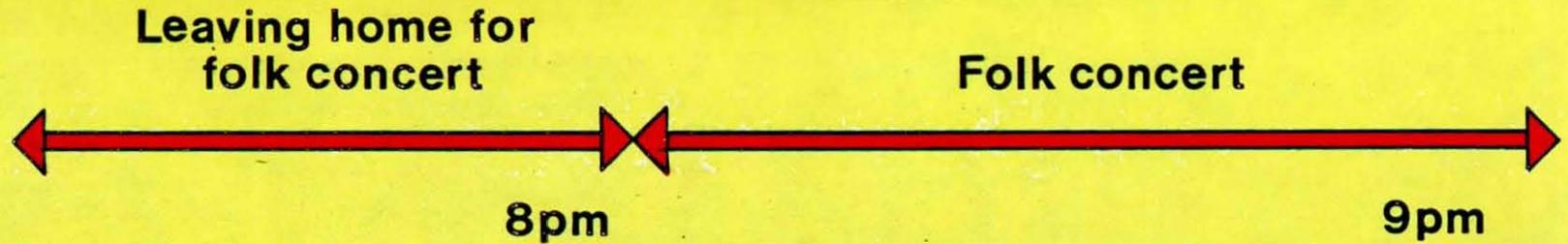
THE SUN, Friday,
November 16, 1973.



THE GRAPH that measured the mounting heartbeat of Ella. A heartbeat rate of 75 counts as normal

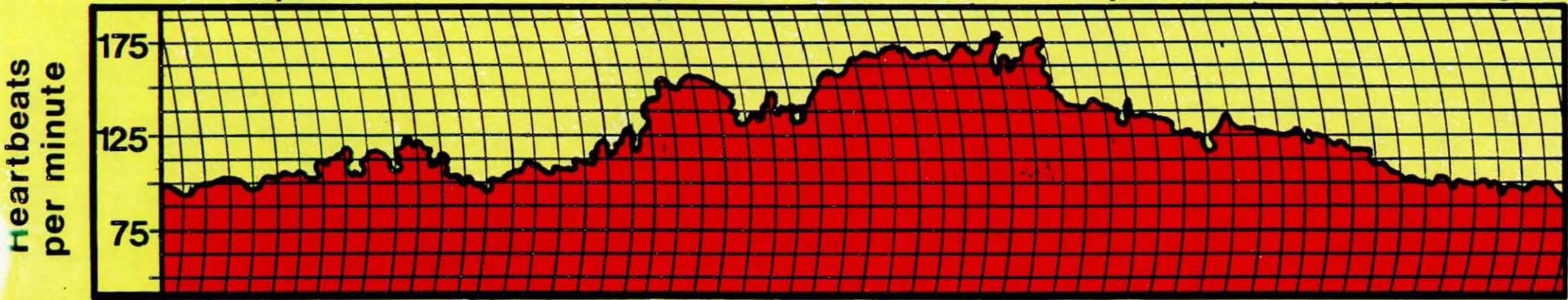
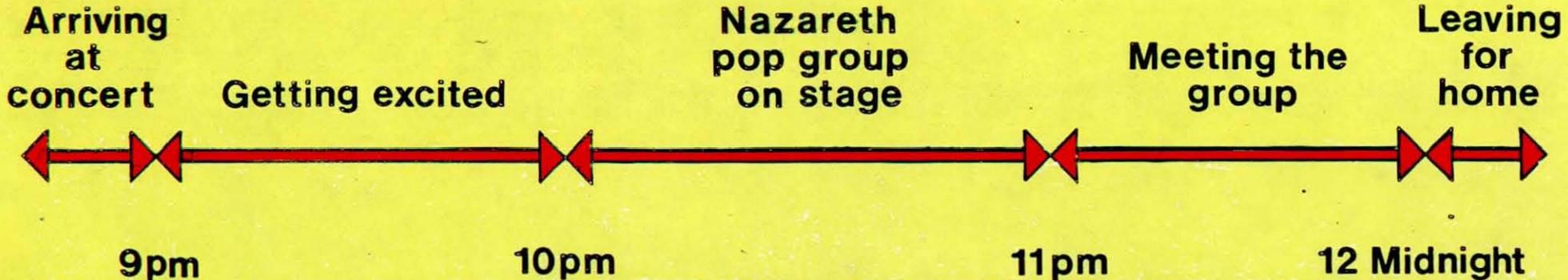
HEART OF A TEENY BOPPER

THE SUN, Friday,
November 16, 1973



THE GRAPH that measured the mounting heartbeat of Ella. A heartbeat rate of 75 counts as normal.

HEART OF A TEENY BOPPER



THE GRAPH that shows how 14-year-old Ella's heart reached an amazing 180 beats a minute while she listened to a rock and roll band.

corresponds to the rate of muscular exercise at which the level of anaerobic metabolites in the blood begin to increase significantly, Karpovich (1953).

A slowly increasing pattern is also obtained even from submaximal levels of work rate if performed in a hot environment, Le Blanc (1957), Brouha (1967). The rate of heart rate increase then depends upon the magnitude of the environmental heat stress, Vogt and Meyer (1968).

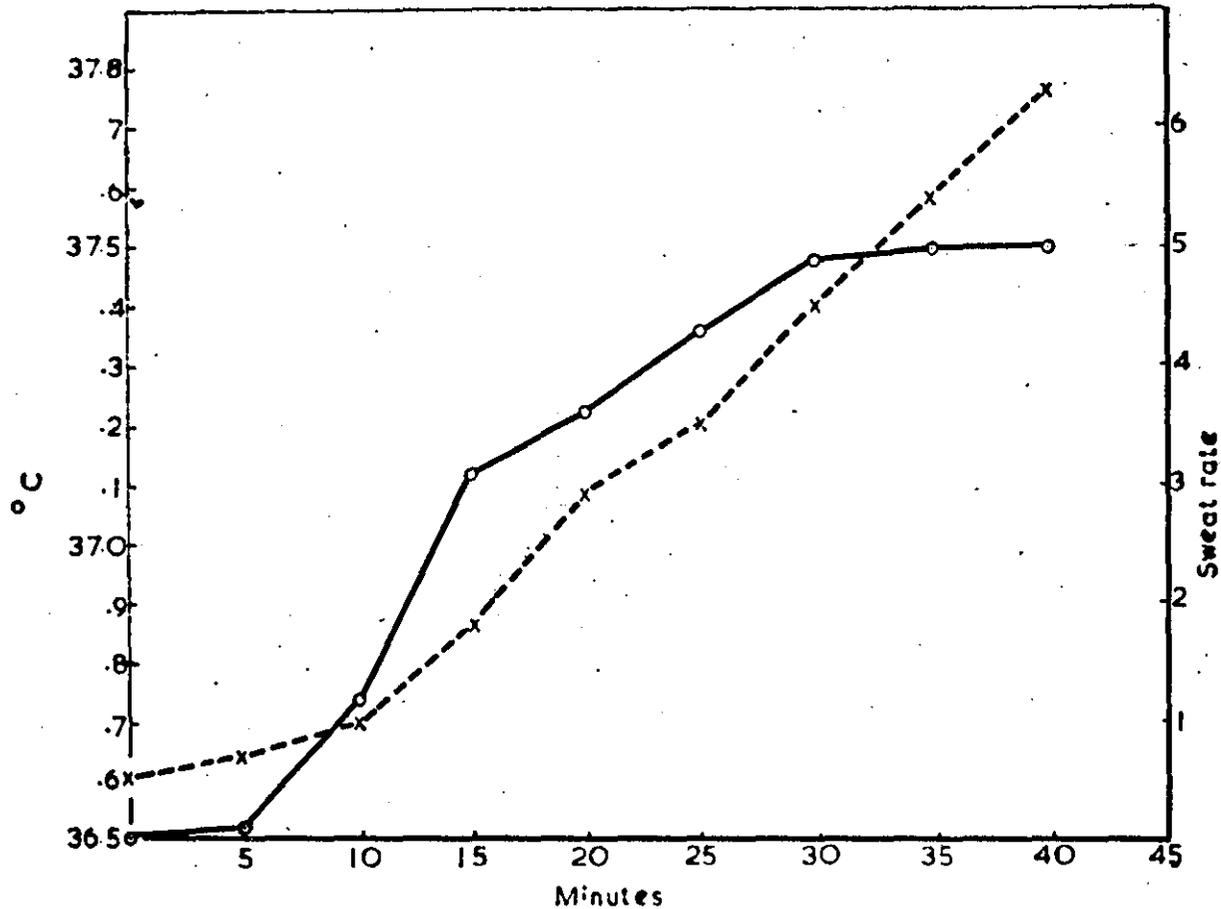
Baruch and Goldman (1973) present formulæ for the prediction of the heart rate response to work, environment and clothing. These formulae, derived from rectal temperature responses, predict the dynamic response pattern of heart rate with time of exposure, not only for a constant activity and environment but also with varying activity, environment and clothing during an exposure. Christensen (1953) reported increase in heart rate out of proportion to oxygen consumption changes when heat stress occurred in an industrial task and Falls and Weibers (1965) demonstrated a drop in exercise heart rate levels when work was preceded by cold shower immersion.

However because of its close relationship to oxygen consumption within the range of many industrial activities it is considered that the heart rate can be utilised to measure the stress imposed by muscular activity where continuous recording can take place to give the overall picture of the activity with the minimal interference in the subject's freedom of movement and performance ability. Use of a data acquisition system is reported by the European Coal and Steel Community (1973) to measure thermal stress and metabolic strain; in this particular instance the term "industrial situation" implies that

- i The measurement must be made without interfering with the worker or making him change his working habits
- ii The measurements must be taken under the exact conditions to which the worker is normally exposed

The whole measuring system is designed to give simultaneous transmission on a single carrier transmitted wave of the ECG, the rectal temperature and the respiratory frequency.

Other dependent variables are available to assess physiological responses, namely core temperature (usually represented by rectal or oral temperatures), skin temperature and sweat loss. Core temperature being usually measured in the mouth or in the rectum, oral temperatures are fully satisfactory only when the conditions are suitably controlled; there may be at times a disinclination on the part of some individuals to submit to rectal thermometry. Fox et al (1962) reported on a small transmitting device which subjects swallowed. Skin temperature is the most frequently favoured by subjects and the application of thermocouples or thermistors to selected areas of the skin is generally acceptable. Kerslake (1955) comments that the relation of sweat rate to skin and deep body temperature was difficult to reconcile with the hypothesis of controlled sweat rates depending on these two factors. On the basis of previous work, Kerslake and Cooper (1954), he put forward the hypothesis that the sweat rate depends on the temperature of receptors situated at some depth in the skin and that subjects exercising in a hot dry environment gave results consistent with the hypothesis whether or not the steady state was reached. The observed relationship was not affected by raising the humidity to a moderately high level. The same subjects at rest in a warm and very humid environment showed the same relationship between sweat rates and calculated deep skin temperature. Hatch (1963) commenced the use of sweat loss but this requires accurate measurements to allow calculation of sweat rates to the nearest 100 g/hr at least. Fig 1.4 shows the relationship between sweat rate and body temperature increases for one particular subject: no further increase in sweat rate occurred at a body temperature 37.4°C , the sweating mechanism reached its limit at about $37.4 - 37.5^{\circ}\text{C}$ and evaporation heat loss was not increased to compensate for



Graph showing the relationship between sweat rate (o) and body temperature (x). As the body temperature increases so the sweat rate increases, but note that above a body temperature of 37.4° C. in this subject no further increase in sweat rate occurs. In other words in this subject the sweating mechanism reaches its limit at about 37.4 – 37.5° C. and evaporative heat loss is not increased to compensate for further elevations of body temperature.

further elevation of body temperature. From the facts outlined in the preceding section it is suggested that by measuring heart rate and changes in body temperatures it is possible to evaluate the changes that take place due to work undertaken in abnormal or hostile environments.

1.4 Atmospheric Contaminants. The purpose of this section is to outline a classification of respiratory hazards and to highlight the toxic effect of two possible industrial gaseous hazards, namely, carbon dioxide and carbon monoxide.

Toxic materials can enter the body in three ways, through the gastro-intestinal tract; through the skin or through the lungs. Of these three modes of entry, the human respiratory system presents the quickest and most direct avenue of entry because of its intimate association with the circulatory system and the constant need to oxygenate tissue cells.

There are two basic respiratory hazards:-

- (i) Oxygen deficient air
- (ii) Air laden with contaminants

The normal constitution of air at sea level and normal barometric pressure of 760mm mercury is shown in Table 1.3.

Gas	%
Nitrogen	78.08
Oxygen	20.95
Argon	0.93
Carbon dioxide	0.035 (variable)
Neon	0.00182
Helium	0.00052
Krypton	0.00011
Hydrogen	0.0001
Nitrous oxide	0.00005
Xenon	0.000009
Ozone	0 - 0.000005

Table 1.3 Normal Constitution of Air at Sea Level

Oxygen concentrations below 16% will not support combustion and are considered unsafe for human exposure because of harmful effects on bodily functions, mental processes and co-ordination. At low oxygen conditions collapse can be immediate and death can ensue within minutes. While 16% oxygen at sea level is generally considered the lower limit for safe human exposure, the partial pressure of oxygen within the lungs is the important factor. Of the work which has been done on oxygen toxicity Paul Bert (1878) observed convulsive seizures in animals exposed to high oxygen pressure and reported that the higher the pressure the shorter was the time required to produce convulsions. The first report of man suffering an oxygen convulsion was made by Thompson (1935) who described the experience of two divers breathing pure oxygen at a pressure of 3040mm Hg (4 atmospheres). Haldane (1941) experienced a sudden and violent convulsion with little warning when breathing oxygen at 5320mm Hg (7 atmospheres) for 5 minutes.

Bean (1948) studied all the available reports, summed up the evidence both in man and animals and presented a full account of the problem. Donald (1947) as a result of a large series of experiments on man was able to give a clear picture of the clinical aspects of oxygen poisoning, the predisposing factors and the variability of reaction, this report also established limits of tolerance which are now generally accepted in diving practice.

Air contaminants include particulate matter in the form of discrete particles of solids or liquids, and aerosol material in the form of a true gas or vapour or a combination of both gaseous and particulate matter.

Particulate contaminants can be classified according to their physical and chemical characteristics and their biological effect on the body.

A useful classification of their physical characteristics is

as follows:-

Dust - mechanically generated solid particulate matter (found in the harmful size range of from 0.5 to 10 microns).

Mist and Fog - liquid mechanically produced particulate matter (with sizes generally in the visible or microscopic range).

Fumes - solid condensation particles of fine diameter commonly generated from molten metal as metal fumes, (size range from 0.1 to 1.0 microns).

Smoke - a system which includes the products of incomplete combustion of organic substances in the form of solid and liquid particles (size from 0.01 to 0.3) and gaseous products in air. It is usually of sufficient concentration to perceptibly obscure vision.

Living Organisms - airborne bacteria and viruses (usually found in the size range from 0.001 to 15 microns).

The particle size in microns is of utmost importance.

Particles below 10 microns have a greater opportunity to enter the respiratory system and particles below 5 microns are apt to be retained in alveolar spaces. In a healthy individual particles from 5 to 10 microns can generally be removed from the respiratory system by the cleansing action of the ciliated epithelium in the upper respiratory tract. The efficiency of the cleansing action is markedly reduced in diseased systems or it may be overwhelmed by excessive exposure.

The fate of particles which reach the deep lung or alveolar spaces depends upon their solubility, particle size, chemical characteristics, and metabolic consequences in the human body.

The biological effects can be classified as follows:-

Inert Aerosols - those which only produce minor irritation or discomfort although in sufficient quantity can overwhelm the protective mechanism of the upper respiratory tract.

Allergy Producers - those which cause severe sensitivity reactions with some individuals.

Chemical Irritants - those which damage the sensitive mucous membrane or lung tissue by chemical action.

Fibrosis Producers - those which cause the development of scar tissue in the lung such as silicosis from mine dust exposure and asbestosis from exposure to asbestos.

Carcinoma Producers - such as asbestos, chromates and radioactive particulates which produce cancer in some individuals after "latent" periods of 20 - 40 years.

Systemic Poisons - such as lead cadmium arsenic, which can damage certain critical organs and systems.

Febrile Reaction Producers - such as the fumes containing zinc and copper which produce chills followed by fever.

Gaseous contaminants or vapours from organic liquids can likewise be classified according to their chemical characteristics and biological effect on the body as follows:-

Inert Gases - such as nitrogen, helium, argon, and neon which do not metabolise in the body but as a dilutant may produce an oxygen deficiency by displacement of air.

Acidic Gases - such as carbon dioxide, sulphur dioxide, hydrogen sulphide, hydrogen chloride, which are acids or produce acids by reaction with water. They taste sour and many are corrosive to tissue.

Alkaline Gases - such as ammonia, phosphine arsine which are alkalis or produce alkalis by reaction with water. They taste bitter and many are corrosive to tissue.

Organic Compound - are compounds of carbon which can exist as true gases or vapours from organic liquids, for example saturated hydrocarbons (methane, ethane, butane) unsaturated hydrocarbons (ethylene and acetylene) alcohols, ketones, isocyanates, epoxy resins and aromatics.

Organometallic Compounds - comprising metals attached to organic groups such as tetraethyl lead and organic phosphates.

Gaseous contaminants can also be classified according to their biological effects as follows:-

Simple Asphyxiants - physiologically inert substances such as nitrogen, methane and argon which interfere with the uptake, transport or utilisation of oxygen in the body by creating an oxygen deficiency by air displacement.

Chemical Asphyxiants - such as carbon monoxide which in low concentrations interfere with the uptake and transport of oxygen by the haemoglobin of the red blood cells or hydrogen cyanide which oxidises the cell tissue.

Chemical Irritants - those acid or alkali gases which irritate the respiratory system and cause the development of pulmonary oedema or fluid in the lung.

Anaesthetics - cause loss of feeling and sensation with unconsciousness and possible death, for example nitrous oxide hydrocarbons and ethers. Some anaesthetics injure body organs, for example carbon tetrachloride (liver and kidneys), chloroform (liver and heart), benzene (bone marrow) and carbon disulphide (nervous system).

Systemic Poisons - those which can damage critical organs and systems of the body, such as metallic mercury vapour, hydrogen sulphide, and arsine.

The degree of effect of both gaseous and particulate contaminants depends largely upon the airborne concentration and the degree of exposure. The Department of Employment (DEP) publish annually a listing of Threshold Limit Values (TLVs) as a guide for exposure concentration which a healthy individual normally can tolerate for an 8 hour day 5 days a week without harmful effects. Airborne particulate concentrations are generally listed as milligrams per cubic metre of air (mg/m^3) and gaseous concentrations are listed as parts per million (ppm) by volume.

1.4.1 Carbon Dioxide. Normal atmospheric air contains 0.035% carbon dioxide. The concentration of carbon dioxide in alveolar air is approximately 5 - 7%. This increase in alveolar air as compared to that of normal atmosphere air is due to gaseous diffusion of carbon dioxide from the pulmonary capillary bed.

If the concentration of carbon dioxide in the inspired air increases, the ratio of alveolar to capillary carbon dioxide decreases and becomes progressively more unfavourable for normal diffusion of carbon dioxide from the blood. The body will compensate for this alteration in diffusion rate by an increase in respiratory depth and rate with an accompanying increase in cardiac output. If the carbon dioxide in the breathing atmosphere continues to increase, the increase in cardiac and respiratory ratio cannot effectively compensate, and carbon dioxide will accumulate in the blood and other body tissues.

The following Table 1.4 gives a guide to the relationship between percentage carbon dioxide in air, the depth and rate of ventilation and effect.

% CO ₂ in Air	Depth of Ventilation ml	Frequency/ min	Effect
0.04	673	14	
0.79	739	14	
2.02	864	15	Headache and dyspnea on mild exertion
3.07	1,216	15	Headache, severe diffused sweating, dyspnea at rest
5.14	1,771	19	Mental depression
6.02	2,104	27	Visual disturbances and tremors develop

Table 1.4 Effect of increase CO₂ concentration

Since the rate of production of carbon dioxide by man is approximately 88 to 90% of his rate of utilisation of oxygen, the air will attain a concentration of 3% carbon dioxide at about the same time that the level of oxygen has been reduced to 17%.

It is clear therefore that the carbon dioxide content of the inspired air should not be allowed to reach values that have a significant effect on the minute volume. A reasonable criterion based on such pertinent data as is available is that a concentration of carbon dioxide equivalent to 1% should be regarded as the maximum allowable, this concentration will increase the minute volume by 6% to 7% although the completely quiescent person - for instance a patient in hospital will best be served by a higher (5%) level.

In the industrial environment the maximum permissible concentration in the atmosphere to which persons may be exposed for a working day of 8 hours is set at a Threshold Limit Value (TLV) of 5,000 ppm DEP (1975) ie (0.5%).

1.4.2 Carbon monoxide. It is not normally present in the atmosphere but results generally from the incomplete combustion of carbonaceous materials. It is frequently found in the industrial environment produced from a wide variety of processes and conditions, and has been a toxic hazard to man throughout his history.

It is colourless and odourless and it is therefore most insidious in its action. Table 1.5 based on the work of Shulte (1964) gives a guide in summarised form to the symptoms following an exposure to various concentrations of carbon monoxide and also the correlation between % of carbon monoxide in air concentration and blood levels. It must be emphasised that these figures are approximate only and would not be reliable if the individuals were breathing a mixture with a reduced oxygen content or containing other contaminants. It also applies to sea

level atmosphere and not to atmospheres at reduced or increased pressure.

There is also some individual variation in susceptibility to carbon monoxide and therefore the statements in tables such as this cannot be precise, but must be used as a general guide.

CO in Air (ppm)	COHb (%)	Symptoms
100	10 - 20	Tightness across the forehead, possibly slight headache, dilation of the cutaneous blood vessels.
200	20 - 30	Headache and throbbing in the temples.
300	30 - 40	Severe headache, weakness, dizziness, dimness of vision, nausea, vomiting, and collapse.
500	40 - 50	Same as above, a greater possibility of collapse, syncope and increased pulse and respiratory rates.
750	50 - 60	Syncope, increased respiratory and pulse rates, coma, intermittent convulsions, and Cheyne-Stokes respiration.
1,000	60 - 70	Coma, intermittent convulsions, depressed heart action and respiratory rate and possible death.
1,500	70 - 80	Weak pulse, slow respirations, respiratory failure, and death within a few hours.
2,000	80 - 90	Death in less than an hour.
4,000	90 +	Death within a few minutes.

Table 1.5 CO in Air % CO Hb and resulting symptoms

Carbon monoxide has an affinity for the haemoglobin of the blood, Haldane (1895) attributed the harmful and often fatal effects of this gas to its greater affinity for haemoglobin compared to oxygen, forming the stable compound carboxyhaemoglobin in the red blood corpuscles. The % of this in the blood represents a direct measurement of the reduced oxygen carrying capacity. Douglas et al (1912) reported that the additional carboxyhaemoglobin altered the disassociation curve of the remaining oxyhaemoglobin impeding oxygen release to the tissue, this was the first indication that carbon monoxide was not an inert gas.

Due to a greater respiratory exchange of air contaminated with carbon monoxide the haemoglobin of an individual performing physical work attains its equilibrium concentration of carbon monoxide in a shorter time than that of a resting individual and symptoms appear faster. As exercises also involve an increased demand for oxygen by the active tissues any deprivation of oxygen carrying capacity is also felt more severely than when at rest.

The maximum permissible concentration in the atmosphere to which persons may be exposed for a working day of 8 hours is set at a Threshold Limit Value of 50 ppm DEP (1975).

1.4.3 Carbon monoxide/Carbon dioxide mixtures. Carbon dioxide at low concentration (1 - 2%) acts as a stimulant to both rate and depth of respiration. The effect of increasing the carbon dioxide concentration of the ambient air is to increase the alveolar concentration of carbon dioxide and the body reacts by attempting to wash out this excess carbon dioxide by increasing the depth and rate of respiration.

More carbon monoxide will therefore be absorbed in unit time if the air breathed contains a mixture of carbon monoxide and carbon dioxide than if air containing only carbon monoxide is inhaled because of the increased volume of air passing through the lungs. It would appear therefore that there is no justification in reducing the TLV for carbon monoxide in air in the presence of carbon dioxide. DEP Technical Data Note 2/75 states that special considerations should be given also to the application of the TLVs in assessing the health hazards which may be associated with exposures of two or more substances. A brief discussion is also included of basic considerations involved in developing TLVs for mixtures, and methods for their development is amplified by specific examples.

1.4.4 Summary of the Respiratory Hazards. Proper and adequate assessment of the hazard is the first important step to protection in assessing the overall hazard potential, consideration should be given to

possible emergency conditions which can arise in order to ensure that proper emergency control equipment and procedures are both available to and thoroughly understood by potentially affected personnel. Davies (1973).

The following Table 1.6 gives the number of cases of Carbon monoxide, and carbon dioxide poisoning reported by the Factory Inspectorate for the period 1961 - 75.

	GASES			
	carbon monoxide		carbon dioxide	
	Fatal	Total	Fatal	Total
1961	8	73	3	8
1962	12	102	0	2
1963	3	75	0	1
1964	5	76	0	4
1965	4	68	0	2
1966	1	72	0	4
1967	10	66	0	2
1968	3	77	1	4
1969	3	59	0	5
1970	6	63	*	*
1971	4	5	*	*
1972	4	48	*	*
1973	2	21	*	*
1974	6	27	*	*
1975	3	20	*	*

* Data not available.

Table 1.6 Gassing accidents analysed by nature of gas

1961 - 1975

1.5 Noise Industrial technology has created many environmental pollutants of which noise has been an identifiable example. Burns (1968) has written a concise summary of what noise does to man. Beranek (1960) gives a good description of sound and its measurement; other sources are Kinsler and Fey (1962) and there is an advanced comprehensive text on acoustics and vibration physics by Stephens and Bate (1966).

British Standard Institute (1969) in BS 661 defines sound in two ways, first as a - "mechanical disturbance propagated in an elastic medium of such character as to be capable of exciting the sensation of hearing". An alternative subjective definition is also given - "sound is the sensation of hearing excited by mechanical disturbances". The common subjective attributes of sound - its pitch, its loudness and its quality - must have their counterparts in the physical nature of the sounds.

Research in hearing conservation has concentrated on many aspects of the problem of noise over the years.

Researchers have for many years been interested in the effects of noise on work performance. Bartlett (1934) published a review of the position and discussed experiments in which various sounds such as speech, music or bells were used, the sounds were meaningful rather than loud continuous background noises. A classical early investigation of a real work situation was Weston and Adams (1932) (1935), in the textile industry; the work involved vigilance and attention to keep equipment working satisfactorily Burns et al (1964) and Taylor et al (1965) investigated the wearing of ear plugs. These were not liked and significantly the wearers did not believe that their use would improve their work. The results of the experiment showed a significant improvement in the efficiency of work by the criteria employed. Broadbent and Little (1960) studied the effects of noise level on the operators of film

perforating machines by treating rooms acoustically. A reduction in level of about 10 dB produced an increase rates of working. Comparative studies in an untreated room also at the time showed an increase in work rate - presumably due to the welfare interest being shown, but a highly significant fact does however emerge, - the rate of machine stoppage attributable to faults of the operators was five times as great in the untreated as in the treated rooms.

Effects on efficiency have also been demonstrated with broad band noises of more than 90 dB SPL overall by Broadbent (1957a). Sudden bursts of noise have been studied by Sanders (1961). Sudden alterations up or down in noise level produce momentary disturbances of work and the degree of disturbance is determined by the extent of the change in level, Teichner et al (1963).

A distinction must be made between the rate of working and the accuracy of work. In general noise appears not to reduce the speed of accomplishment but accuracy appears to diminish, Broadbent (1957 b). Where signals in a vigilance task are at lengthy intervals the deterioration is an increased delay in making the appropriate response, or in failure to see the signal at all, Broadbent (1954), Broadbent and Gregory (1963). Failures to notice unexpected events are another feature, Carpenter (1959).

When noise is associated with other factors, some interesting and confusing results have emerged. A curious effect has been shown by Corcoran (1962) and by Wilkinson (1963) when lack of sleep and exposure to noise occur together. In these circumstances a person who has not slept the previous night shows less ill effect from noise and in fact performance may even be better than in quiet surroundings. Carpenter (1959) speculates on the apparently opposite effects of these two factors, lack of sleep and noise, and invokes the concept of arousal, which if diminished by loss of sleep, might be elevated to near normal levels by noise, so restoring the performance.

Dean and McGlothlen (1965) reported on the effects of combined heat and noise to demonstrate that synergism may occur but the data from this study failed to reveal any evidence that noise alleviates the discomfort of heat. The data suggested that at 43.3°C the subjects were more comfortable under 100 dB noise than under 70 dB, but this could be attributed to chance because the noise temperature interaction on comfort was not statistically significant. Moreover no evidence was found to indicate that noise had any tendency to disrupt thermal equilibrium because rectal temperature remained essentially constant. ~~Wyon (1970) reported on studies of children under imposed noise and heat stress.~~

Noise impairing the perception of other sounds is an important and clear effect quite separate from annoyance and disturbance although it maybe associated with them. Wegel and Lane (1924), Fletcher (1940) and French and Steinberg (1947) studied the way in which the threshold of the masked sound is raised in the presence of a masking sound. The quantitative aspects of the masking of pure tones are complex, but certain fundamentals can be noted. Fletcher (1940) reported that when a tone is just audible against a noise background its intensity is the same as that in the critical band. Hawkins and Stevens (1950) state that this applies precisely for a wide range of intensities. To avoid masking of the tone, the intensity per critical band of the noise should be about 10 dB less than that of the tone. Some differences in the apparent widths of critical bands were found by Zwicker et al (1957) according to the method employed and it appears that for the summation of loudness the critical band may be some $2\frac{1}{2}$ times as wide as previously found.

The masking of speech by noise is a particularly important case whether speech is intelligible in a given noise may be discovered by a practical trial or by calculation, given certain facts about the acoustic properties of the speech and of the noise, and the degree of interference with

the perception of speech which it is possible to accept.

The significant factors are many, there is an extensive literature on communication by speech, see in particular, Morgan et al (1963). Fletcher (1953) gives a revision of historic earlier writings and Licklider (1951) surveys much material relevant to speech communication.

In assessing the effectiveness of speech communication in a given environment a direct practical test with a proper experimental plan and an adequate number of subjects is the most effective method. It is however, usual to calculate the effects of a given noise from direct measurement of the environmental condition and to classify the work accordingly.

The intelligibility of speech will also depend on the type of spoken material used; special speech procedures and vocabularies will assist in the attainment of satisfactory communication.

The entry of sound into the ear canal can be reduced by wearing some form of plug in the canal or external cups, usually referred to as ear muffs. Thiesson (1962) has studied extensively the theoretical basis of these devices. The performance of ear plugs has been analysed by von Gierke (1956) and fluid-seal ear muffs for high attenuation by Shaw and Thiesson (1958). An interesting observation on wearing hearing protectors is that as external sounds seem quieter while the wearer's voice seems to him different and louder they consequently have a tendency to talk more quietly, although the conversation should of course be louder. Kryter (1946) reported that in high noise environments wearing ear protection can improve intelligibility. The noise level at which it becomes beneficial to intelligibility to wear ear protection will vary with the degree of attenuation of the device used. The ear plugs used by Kryter (1946) improved intelligibility above a combined (noise plus speech) SPL of about 95 dB, the reason being that the ear muffs provided about 10 dB more

attenuation in the frequency region which is important for communication.

The acoustic attenuation of hearing protectors is usually expressed in decibels attenuation (dB) at various test frequencies Hertz (Hz) and is usually shown in graphical form or as Table 1.7 following.

Their prime function is to reduce the noise level at the wearer's ears to within safe limits and information on this aspect requires careful study when considering the most suitable type for a particular environmental noise.

Test Frequency Hz	125	250	500	1000	2000	4000	8000
Dry Cotton wool plugs:	2	3	4	8	12	12	9
SD:	(2)	(2)	(3)	(3)	(6)	(4)	(5)
Waxed cotton wool plugs:	6	10	12	16	27	32	26
SD:	(7)	(9)	(9)	(8)	(11)	(9)	(9)
Glass down plugs:	7	11	13	17	29	35	31
SD:	(4)	(5)	(4)	(7)	(6)	(7)	(8)
Personalised earmould plugs:	15	15	16	17	30	41	28
SD:	(7)	(8)	(5)	(5)	(5)	(5)	(7)
V-51R type plugs:	21	21	22	27	32	32	33
SD:	(7)	(9)	(9)	(7)	(5)	(8)	(9)
Foam-seal muffs:	8	14	24	34	36	43	31
SD:	(6)	(5)	(6)	(8)	(7)	(8)	(8)
Fluid-seal muffs:	13	20	33	35	38	47	41
SD:	(6)	(6)	(6)	(6)	(7)	(8)	(8)
Flying helmet:	14	17	29	32	48	59	54
SD:	(4)	(5)	(4)	(5)	(7)	(9)	(9)

Table 1.7 Typical Mean Attenuation Characteristics in dB of different types of hearing protection

SD Standard Deviation after Peisse (1957)

The Department of Employment (1972) published a 'Code of Practice for reducing the exposure of employed persons to noise; this is advisory in nature and follows previous publications 'Noise and the Worker' Ministry of Labour (1963), republished (1968) and revised (1971).

The Code applies to all persons employed in industry who are exposed to noise and sets limits of 8 hours at 90 dB(A) if exposure is continuous. If the non-continuous noise cannot be adequately measured and controlled, any exposure at a sound level of 90 dB(A) or more is considered as exceeding the acceptable limit and hearing protection must be used.

An unprotected ear should not be exposed to a sound pressure level measured with an instrument set to the 'fast' response exceeding 135 dB or in the case of impulse noise an instantaneous pressure exceeding 150 dB.

Other parts of the body should not be exposed to a sound pressure level measured with an instrument set to 'fast' response exceeding 150 dB, *due to capillary and nerve endplate damage.*

1.6 External nuclear radiation and contamination are also hazards that will be encountered in modern industrial processes. Their known effects on man are of a pathological nature and consequently it is considered that they do not belong in this physiological review of physical effects of the abnormal environment. The following notes have however been included to outline the association with that particular problem in this research topic.

Radioactive substances emit ionising radiations of three types namely alpha, beta and gamma rays. Alpha and beta rays are of a corpuscular type and have relatively low penetrating power whilst gamma rays are electromagnetic in nature and of considerable penetrating power.

Because of their adverse effects on biological cells, undue exposure to these radiations may be harmful to the individual (the 'somatic' effect) or to his offspring (the 'genetic' effect).

It may be noted here that the human has always been exposed to a small background level of radiation and radioactivity intake, for which 'natural' sources, ie cosmic radiation and radioactivity in the materials of the earth's crust are responsible. In addition, since atomic weapon tests began there is a man-made contribution to everyday radiation exposure and

radio-activity intake, by "fall-out" debris from such tests. Medical uses of radiation and radioactive materials also contribute to our long term radiation exposure.

For radiological protection purposes we distinguish between exposure to external radiation and to contamination respectively. External exposure results from any source of radiation (sealed or otherwise) outside the body. The existence of radioactive contamination however may also result in the intake of radioactivity to the body by the inhalation of contaminated air, the ingestion of food or water which contains radioactivity or by penetration through damaged skin.

Thus the handling of a sealed radioactive source would represent an exposure to external radiation only, whereas in the handling of uncontained radioactive material both radiation and contamination aspects must be considered.

Radiological Protection is achieved against radiation or contamination by one or more of the following means:-

- (a) Shielding, as in nuclear power stations where considerable thicknesses of concrete and steel are used to reduce the radiations from the reactors to acceptable levels.
- (b) Maintaining maximum distance between personnel and the source of radiation.
- (c) Limiting the time spent in the field of radiation.

Protection against contamination is achieved by:-

- (a) Good housekeeping, including the reduction of accessible contamination zones to a minimum, adequate ventilation rates and restrictions on eating or smoking in contamination zones.
- (b) Use of protective clothing, by changes of clothing, including shoes, on entering contamination areas. Where work is done in highly contaminated areas a protective plastic or PVC suit may be worn which

seals the worker from the environment entirely. In such cases air supply is by means of a portable bottle or a supply line from sources of respirable air.

(c) Limiting the time spent in the contaminated area.

The safety of any process involving radioactive materials is assessed by relating the levels of activity which are present to "Maximum Permissible Levels" (mpl's) and "Derived Working Limits" (dwl's). These mpl's and dwl's take account of the nature of the work being done and the type and form in which the radioactivity is present.

By comparing actual levels with the maximum permissible levels the extent of any precautions to be observed can then be recommended.

The recommendations of the International Commission on Radiological Protection (ICRP) provide a basis for radiological protection. The ICRP distinguishes between "persons occupationally exposed" to radiation and "members of the population at large". The former group includes certain persons employed in nuclear power stations. For individuals in this group, the ICRP have recommended Maximum Permissible Levels (mpl's) of radiation dose on both short term (quarterly) and long term (annual and working lifetime) bases.

For individual members of the public, including children, annual radiation Dose Limits are recommended. Broadly speaking these dose limits are equivalent in meaning to the mpl's for the first group, but the annual dose limits are one tenth of the mpl's for occupationally exposed people.

The ICRP has also recommended mpl's (for numerous individual radionuclides and groups of radionuclides) for the contamination of both air and water. These levels are such that if they exist throughout the working lifetime (assumed 50 years) of an individual, the radiation dose which he would receive as a result of his intake of radioactivity would not

exceed the recommended mpl's of radiation dose. Again, the contamination mpl's for individual members of the population at large are one tenth of those appropriate to occupationally exposed people.

The term "maximum permissible level" is used nowadays only for a level recommended by ICRP. However, direct reference to such levels is often not possible or appropriate when considering some aspects of a process. Thus in the safety assessment for oil disposal by combustion from the point of view of safety of the general public, the discharge of the combustion products to atmosphere is the most important consideration. In this case it is the extent to which milk may be contaminated due to deposition of activity on grass grazed by dairy cattle, rather than the contamination levels in air or water. Since the ICRP has not published mpl's which are directly applicable for either case, limits have been

arrived at by calculation and by reference to other sources. Such limits are known as "Derived Working Limits" (dwl's). They are usually appropriate only to the special circumstances for which they have been derived (in contrast with the general applicability of the ICRP recommendations) and usually incorporate considerable additional factors of safety, by virtue of pessimistic assumptions made in deriving them. For example, whilst the dwl's in the above instance take account of the effect of nearby buildings in reducing the effective stack height, no correction has been made for alleviating effects of the temperature and release velocity of gases.

Since dwl's can be calculated for almost any stage of a process they provide useful reference levels for comparison with monitoring results. In any process involving radioactive material it is necessary to ensure that radiation and contamination levels are acceptably low by reference to the appropriate Maximum Permissible Levels, and Derived Working Limits.

1.6.1 Electrical Energy Of particular physiological interest is the effect of exposure to fields which can by virtue of transfer of energy to the living organism potentially alter that system's future course.

Cosmic and artificially produced radiations have been extensively studied. The effects of magnetic fields are widely studied ~~in and extensively referenced~~ Federal Proceedings (1962). The influence of electrical fields and currents is not nearly as well represented in the literature, there appears to be scant work done on the exposure of man to strong electrical fields.

Man is very sensitive to electric energy because of his highly developed nervous system and an almost limitless number of thresholds of sensation could be defined depending upon the locations selected. Physiological perception, due to electrical stimulation depends to a very considerable extent upon the contacts whether they are firm and involve appreciable areas, or if they are point contacts. Currents almost too small to measure produce piercing pain when the flow is in or through an open cut or wound. The impedance of the human body is predominately resistive at low frequencies. However capacitive effects become important at the higher frequencies. Whitaker (1939) states that the resistance of thoroughly dry skin on the hands may have a range of 40,000 to 50,000 ohms per sq. cm. In contrast the skin may drop to as low as 1,000 ohms per sq cm when the hands are wet. In practice the surface moisture conditions of the hands may vary widely.

The threshold of perception currents was reported by Dalziel (1954) relative to home appliances, electrical operated hand tools and other portable devices and concluded that it was essential that the public be protected against perception currents by proper design, adequate materials and careful assembly. During the measurement on perception of electrical currents, Looms (1969) showed that at 50Hz, a current of 1 mA was perceptible between electrodes each of 25cm² area on the palms of his hands. When one electrode was replaced by a wire probe it was found that a current less than 0.1mA was perceived as a stinging sensation when the probe was placed on the skin over a vein in the side of the thumb. The potential difference to produce this current was 20V rms.

Similar values of resistance, about 10-30 kilohms, were measured between pairs of electrodes, each 25cm² in area, on the palms, forehead and foot, forehead and abdomen. These values are consistent with the known fact that the flesh and blood are relatively good electrical conductors and that most of the observed resistance resides in the skin and fat.

Body Resistance

Resistances were measured between 25 cm² electrodes of pure tin, applied to wet skin (DC measurements with Avometer).

<u>Current Path</u>	<u>Resistance, kilohms</u>
Forehead to sole of foot	20
Abdomen to sole of foot	34
Palm L to palm R	20
Palm R to back of hand R	24

(Results are clearly independent of path-length)

Perceptible Currents

Alternating (50Hz) currents were passed between electrodes applied wet as above.

Between 25 cm² electrodes on palms L and R current was just perceptible at 1mA (17V rms). Tingling in the hands was noticed at 2 mA (30V rms).

Between 6 cm² electrodes on palms L and R current was just perceptible at 0.8 mA (40V rms). Pain was experienced at 2 mA (30V rms).

Between a 25 cm² electrodes on R palm and a wire probe on the R thumb over a vein a sharp local sting was felt at 20V rms. The current was about 100 microamps.

It is worth note that currents as high as 10 mA are in general not dangerous but only painful.

One of the problems arising is the effect of the exposure of humans to the characteristics of AC intense electrical fields and the measurement of these fields, when associated with live line working is reported by Miller (1966) and body currents to be encountered by Kouwenhoven et al (1965). A detailed medical evaluation of man working in AC Electrical fields by Kouwenhoven et al (1966) developed the following facts:-

- 1 No X-Ray radiation is produced on a properly designed and constructed HV transmission line.
- 2 Electric currents are induced in a conducting body when in an AC electric field.
- 3 The currents that are induced in a lineman's body, when working barehanded, may reach high values if the lineman is not shielded.
- 4 The currents that are induced in a man's body when exposed to an AC electric field are essentially sinusoidal.
- 5 Rubber gloves and similar protective equipment offer no shielding from electric fields.

- 6 Properly designed metallic Faraday screens will protect a lineman working barehanded on an energised line and will reduce the induced current in his body to a negligible value.
- 7 Faraday screens can be constructed for aerial buckets, cages, etc. Proper conductive clothing will provide an effective Faraday shield.
- 8 At low field intensities the upper shielding may be omitted. However, in order to effectively shield the lineman from the waist down the bucket shielding (screening) should be complete.
- 9 Medical Findings: Considering the period of observation (2½ years) and the method of study, it can be reported that the health of the eleven observed linemen was unchanged by their exposure to high voltage lines. Also, no evidence of malignancy was found. There was a decrease in the sperm count of one of the eleven subjects at the last examination. However a recheck test was performed in November 1965 which showed a higher value, though still under what might be considered normal. The significance of this is not clear and warrants further study; but no correlation has been found between exposure to high voltage lines and any effect on the health of individuals in this investigation.

Among the eleven men tested, there were four who had had many hours of barehanded work during the period of this investigation. Not a single one of these men showed any change in their physical, mental or emotional characteristics. Their laboratory studies remained entirely normal. We found no evidence that an adequately shielded lineman is endangered in any way by working barehanded in a high voltage alternating current electric field, within the limits of our study.

The physiological effects of working in the vicinity of 400kV and 500kV-outdoor installations was reported by Sazanova (1967) as follows:-

Bearing in mind that fatigue of the organism is associated with the development of retardation in the higher parts of the central nervous system it can be concluded that prolonged action of electric field causes retardation in the cortex of the brain and promotes the development of fatigue.

The medical studies on the staff revealed certain directional changes in the central nervous system. These changes took the form of vegetative malfunctioning (increased variability of the pulse, and arterial blood pressure, primarily bradycardia and hypotension) and the neurasthenic syndrome. No symptoms of organic disturbances in the organism were observed as a result of the action of electric field when working in outdoor installations at 400 and 500kV.

The results of the physiological studies are in agreement with and supplement the results of the medical studies. The physiological studies revealed vagotonic changes in the cardiovascular system, weakening of temperature control processes, reduction in resistance to the action of electric current and functional mobility of the neuro-muscular apparatus a weakening of neurodynamic processes in the cortex of the brain. These functional changes in the organism occurred in maintenance staff (who worked in an electric field for at least 5 h during the shift) and they did not occur or were more weakly expressed in operational staff (who worked in an electric field for not more than 2 h per shift). Hence it can be concluded that the depth of functional changes in the organism is directly related to the working time under exposure to electric field, i.e. the changes caused by the field are cumulative. A similar relationship has been observed in tests on animals when studying the action of a 50 Hz electric field on the performance of the motor apparatus.

Bearing in mind that most of the staff did not have long service (5 years or less) on outdoor installations of 400 and 500kV the functional changes that were observed in the organism must be considered as the start of unfavourable effects of the field.

In this connection it is necessary firstly to take all possible measures to protect the staff of 400 - 500kV outdoor installations from prolonged exposure to electric fields and secondly to continue research to establish the limiting permissible electric field strength at power frequency.

In the vicinity of any energised power line there is an electrical field in the space surrounding each conductor. Whenever a lineman is working on an energised transmission line he is immersed in this electrical field. Faraday (1837) showed that there is no electrical field inside a cage made of conducting material regardless of the electrical charges that may exist on the exterior surfaces of the cage. While a man inside a total shield would be completely isolated from the electrical field such an arrangement is obviously impractical in the use of live line maintenance.

The nearest approach to complete shielding has been the use of conductive clothing by linemen to prevent displacement current from reaching him. The performance requirements associated with such clothing is further discussed in Section 1.9.4. The electrostatic discharge experienced by linemen during live line work do not constitute any hazard; at least not in a direct way. They are annoying, however, they decreased work efficiency and if they occur unexpectedly, they may lead to accidents of a secondary nature. Properly designed screening should reduce the induced current to a negligible value. Gingras et al (1976) gives measurements of the current induced in a lineman and his conductive clothing when installed on a 735kV transmission tower and the results of medical surveillance of a maintenance team is to be reported on by Ontario Hydro during 1977.

1.7 Nuclear Reactor Systems and Man Access. The first commercial nuclear power stations were commissioned in the United Kingdom in 1962.

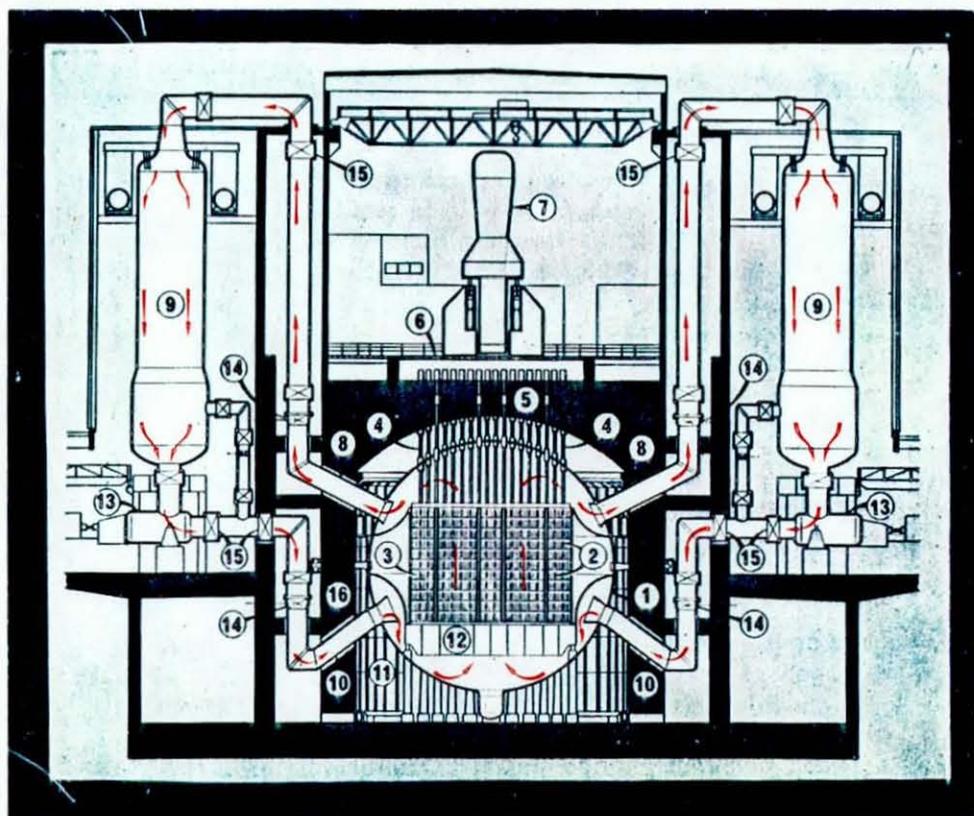
The designs were based on the United Kingdom Atomic Energy Authority (UKAEA) Calder Hall reactor commissioned in 1956. These reactors are of the Magnox type, the heat being produced by natural uranium fuel elements in magnox cans placed in a graphite moderated reactor core.

The heat generated is carried in a pressurised CO₂ atmosphere from the reactor vessel through gas ducts to heat exchangers, where it passes over a large number of boiler tubes. The steam generated in the pipes is passed at pressure to turbo alternators, see Fig 1.5.

In 1967 the first prestressed concrete pressure vessel was commissioned and in this case it was possible to enclose the heat exchangers in the pressure vessel thereby eliminating the separate gas ducting, isolating valves and heat exchanger shells.

In 1976 the first two Advanced Gas Cooled Reactors (AGR) were commissioned, Rippon (1976) and eight are under construction. This reactor system is based on the UKAEA Windscale prototype, Electrical Review (1961) and the pressure vessel is of the prestressed concrete type enclosing the heat exchangers. The reactor uses enriched uranium fuel with stainless steel cans; it operates at a much higher temperature than the magnox systems and the CO₂ gas coolant is at a higher pressure. Consequently it has a high neutron flux and a correspondingly high thermal capacity.

Carruthers (1965) showed that the location of heat exchangers relative to the reactor core is governed by a number of major considerations, such as the need for satisfactory gas distribution over the core, the need for adequate shielding between core and heat exchanger, capital economy, ease and time of construction, and a requirement to have a good natural circulation. The early designs were situated high up at some distance from the core, connected to the main steel pressure vessel by ducts weaving

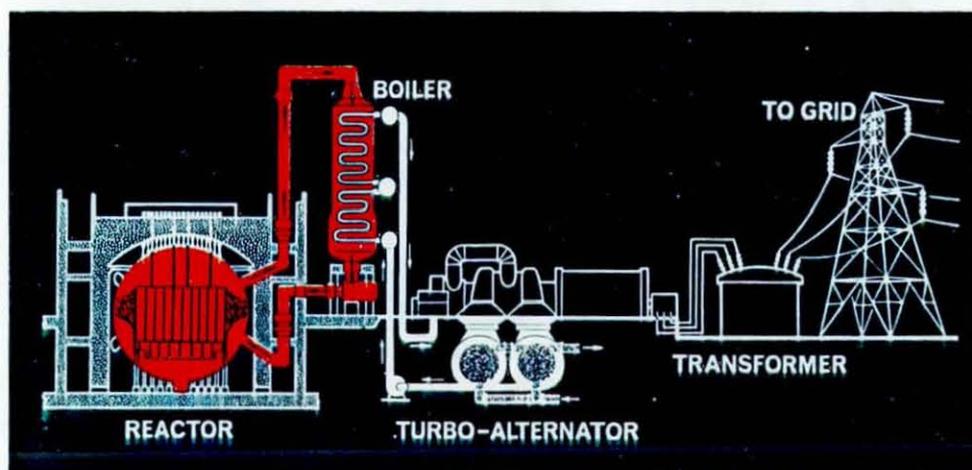


CROSS SECTION THROUGH A NUCLEAR REACTOR

ARROWS SHOW THE FLOW OF CARBON DIOXIDE THROUGH REACTOR AND BOILERS

KEY

- | | | |
|-----------------------------|----------------------------------|---------------------------------------|
| 1. Reactor pressure vessel. | 7. Charge/discharge machine. | 11. Thermal shield. |
| 2. Fuel elements. | 8. Hot gas outlets from reactor. | 12. Diagrid. |
| 3. Graphite—moderator. | 9. Boilers (six per reactor). | 13. Main circulators. |
| 4. Charge tubes. | 10. Cool gas inlets to reactor. | 14. Gas isolating valves. |
| 5. Control rod standpipes. | | 15. Hinged expansion bellows. |
| 6. Charge floor. | | 16. Can-failure detection standpipes. |



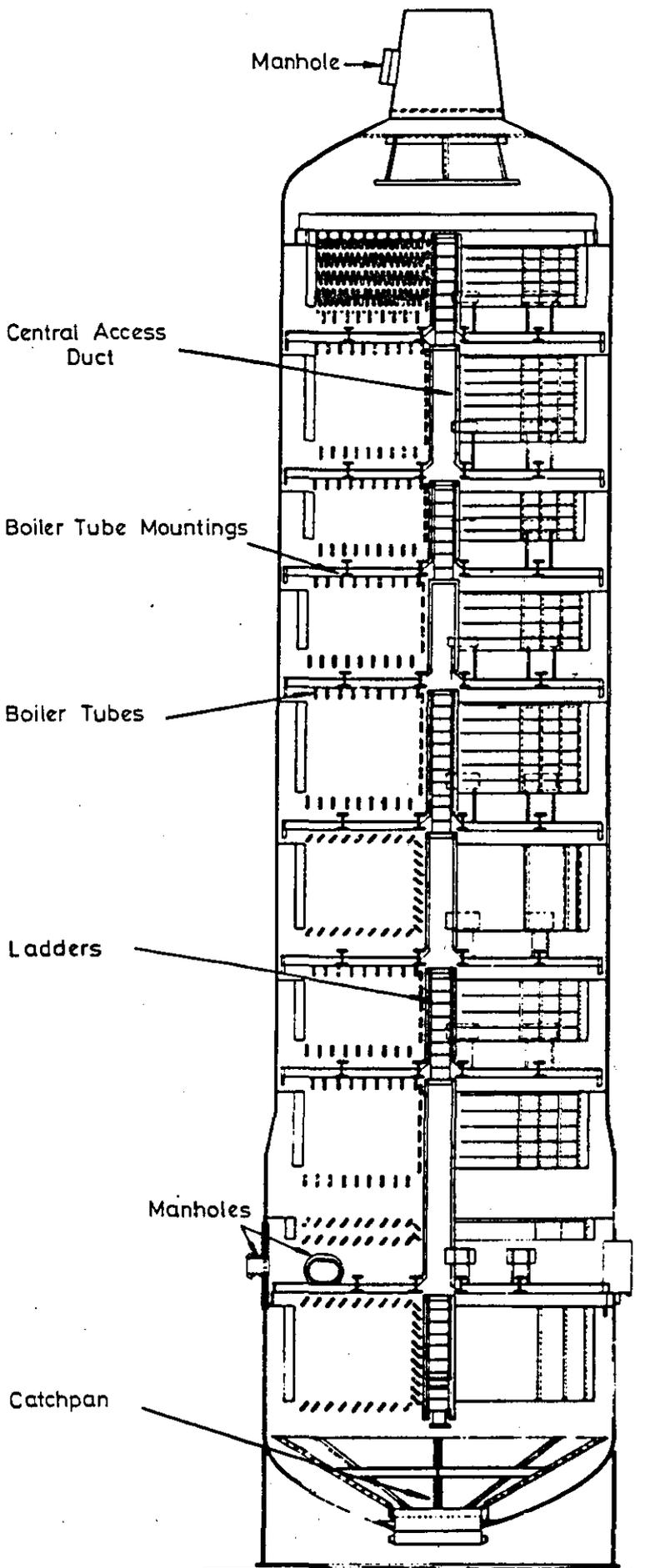
through the concrete shield. They range from 8 heat exchangers per reactor widely spaced almost evenly around the reactor perimeter to 6 per reactor with 3 placed either side as close as possible to one another to facilitate erection. In later designs the number was reduced to four per reactor.

With the adoption of prestressed concrete in place of the steel pressure vessel it was possible to enclose the heat exchangers in the pressure vessel and these vary from four to twelve per reactor.

As the heat exchangers are technically steam boilers they are subject to statutory inspection under the Factories Acts (1961) and it is a legal necessity to carry out regular inspection of the parts subject to pressure such as boiler tubes, welds and mountings etc. For this purpose access routes are part of the overall design. Human access to the heat exchangers of nuclear reactors have posed a number of challenging problems in attempting to protect people entering environments influenced by radioactive contamination fields, CO₂ contaminated atmospheres, heat and noise and where movements are confined, conditions are cramped and visibility is poor. A major feature of safe environmental control is based on "In House Safety Rules" and compliance with these ensure compliance with the Factories Act. A main requirement being to ensure that personnel entering an abnormal environment are adequately protected from any possible hazard.

Of course no entries are made to the heat exchangers or pressure vessel until the reactor is shut down, the areas purged with air and cooled to an agreed level to permit access. A disadvantage of the prestressed concrete pressure vessels of the AGR design is that it is a slow cooling process compared to the magnox systems with external steel heat exchangers which can be easily isolated for cooling purposes.

The design of a typical steel Heat Exchanger is shown in Fig 1.6. This is cylindrical, about 6.4m in diameter and 26m tall. The boiler tubes are welded together with 'U' bends to form nests and these nests are built



Typical Steel Heat Exchanger, Internals
(Boiler Tubes, Mountings, Access Ducts,
Catchpan and Ladders).

into boiler tube banks, and attached to the main header pipes. The heat exchanger contains a number of banks situated above each other and close together supported by the boiler tube mountings. A major factor of importance is the heat transfer from the circulating CO₂ to the steam necessitating a large number of close packed boiler tubes to achieve this. A catch pan grid at the base of the heat exchanger prevents any debris in the gas circuit falling into the gas circulator. With an economic incentive to keep the heat exchanger shell as small as possible provision of space for human access is inherently difficult.

Human access facilities are required both external to the gas circuit and internal to the heat exchanger. Man-holes situated around the gas circuit provide access to features within the gas circuit such as isolating valves, duct bellows and boiler tubes. External ladders, stairs and walkways are provided close to the man-holes in heat exchangers, although in many cases space on the access platforms is limited. Careful consideration has been given to access facilities within the heat exchangers, although by the very nature of the boiler tube banks and mountings, space is limited. Access is made through a series of installed vertical 450mm wide sectional ladders and horizontal 500mm square trap doors set into the floor of each cell.

During normal operation the CO₂ coolant flows round the gas circuit at a pressure of about 20 bar and a temperature approaching 350°C and can carry small particles of dust which become activated when exposed to the high neutron flux, some of these being deposited in the heat exchanger. The steam in the boiler is approximately 300°C. Prior to access the reactor is shut down, possible sources of hazard are isolated and an acceptable environment obtained based on ruling safety regulations.

The heat exchangers on steel vessels are positioned outside the biological shield and the duct runs are so arranged that heat exchangers are

not in the path of any direct or scattered radiation flux. Thus no activation is induced in the steelwork and no direct radiation levels result. No criteria can be set for radioactive contamination levels but all possible efforts are made to ensure the cleanliness of the reactor during construction, whilst during operation 'filtration' equipment is run to remove the free circuit particle activity - the filters having a high efficiency down to 5 microns. In addition great care is taken in the choice of materials in the design and erection of the reactor to limit corrosion products and to prevent the release of fission products into the circuits. When the reactor core remains under a CO₂ atmosphere the heat exchanger is physically isolated.

Wright (1966) suggested the following for limits for entry to CO₂ atmospheres:-

- (a) CO₂ levels should not generally exceed 0.1% if entry is required without air supplied breathing apparatus.
- (b) CO₂ concentrations shall be reduced to 3% CO₂ in air before short time entry is permissible without breathing apparatus.
- (c) It is appreciated that isolated pockets within the heat exchangers could contain CO₂ levels in excess of 3% CO₂ in air.
- (d) Entry into CO₂ levels in excess of 3% is acceptable with suitable breathing apparatus, so long as the wearer is not far from the access point.

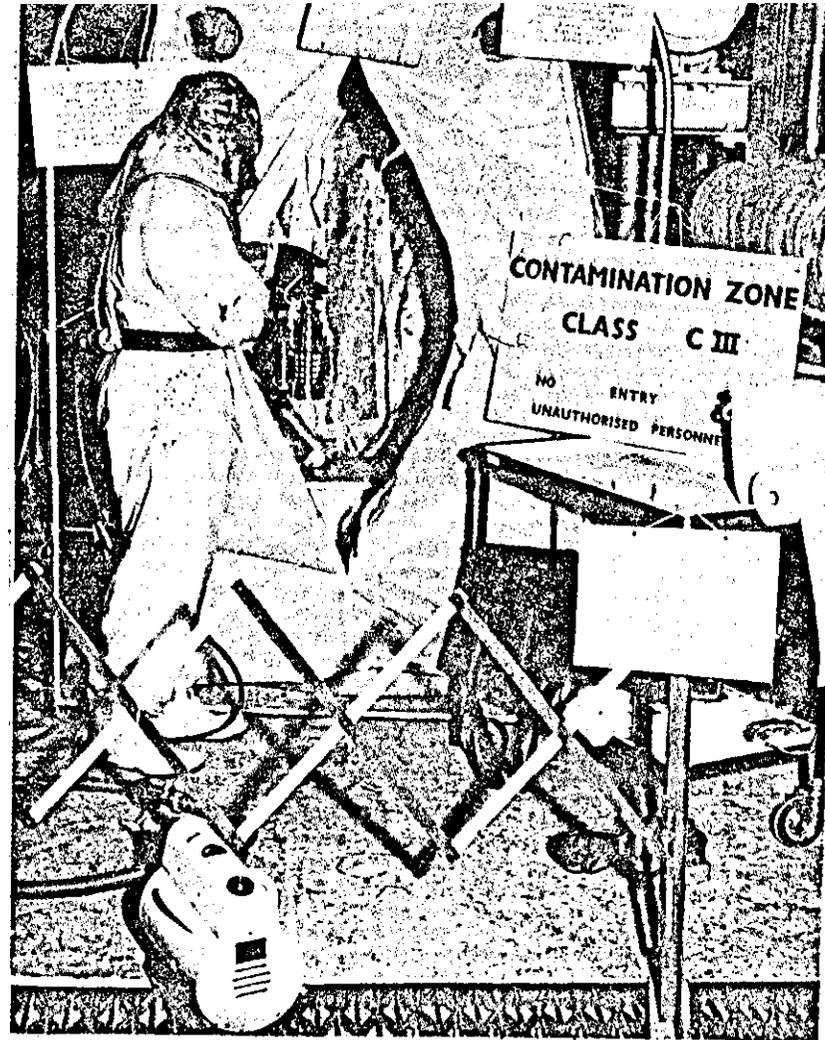
The method of heat exchanger isolation, cooling and purging differs slightly from reactor to reactor, but the following procedure is typical.

With the reactor shut-down, and the circulators running slowly, cold water is passed through the boiler tubes, for perhaps 2 days, during which time the graphite and fuel-can temperatures fall to acceptable levels and the reactor gas is blown down to a pressure slightly above

atmospheric pressure. The gas circulator is shut-down on the selected circuit and the gas inlet and outlet duct valves are shut. Evacuation pumps are connected to the top duct and a partial suction is created in the circuit, then air is admitted to purge the circuit and reduce the CO₂ concentration. This is repeated a number of times, perhaps as many as eight, until the general CO₂ level in the heat exchanger is less than 3%. At this point a manhole is opened at the bottom of the heat exchanger and air is sucked in and discharged via the vacuum system to the main stack. Cold water continues to pass through the boiler tubes and this continues until the internal temperature levels are acceptable. The whole process may take 3 days from reactor shut-down.

Once an acceptable environment has been established a sub-change room is erected around the point of access, and every precaution is taken to prevent the spread of contamination from the man-hole - this can be assisted by keeping a slight suction on the heat exchanger, or by erecting a portable tent which acts as an air and clean entry lock. A health physics survey can then proceed. Fig 1.7.

Anyone working inside the heat exchanger does not just require protection from radiation or contamination or CO₂ or heat, but needs protection from them all at once in varying degrees. Protection supplied for one hazard may not be suitable for another and where there are conflicting interests some compromise has been necessary in order to provide the worker with the most comfortable and safe environment. The general scale of protection consists of an impervious hooded coverall, rubber gloves, rubber boots and full face canister respirator, augmented in some cases by air cooled vests or hoods or full face air fed respirators to replace the canister respirator. The development of this type of protective assembly has been described in detail by CEGB (1964), UKAEA (1965), Rowlands (1962) (1966a) (1966b), Stevens & Ritchie (1966), Suter (1967) and Gregory (1970).



CONTAMINATION CLOTHING ASSEMBLY
AND
AIR LOCK ARRANGEMENTS FOR STEEL HEAT EXCHANGER ENTRY

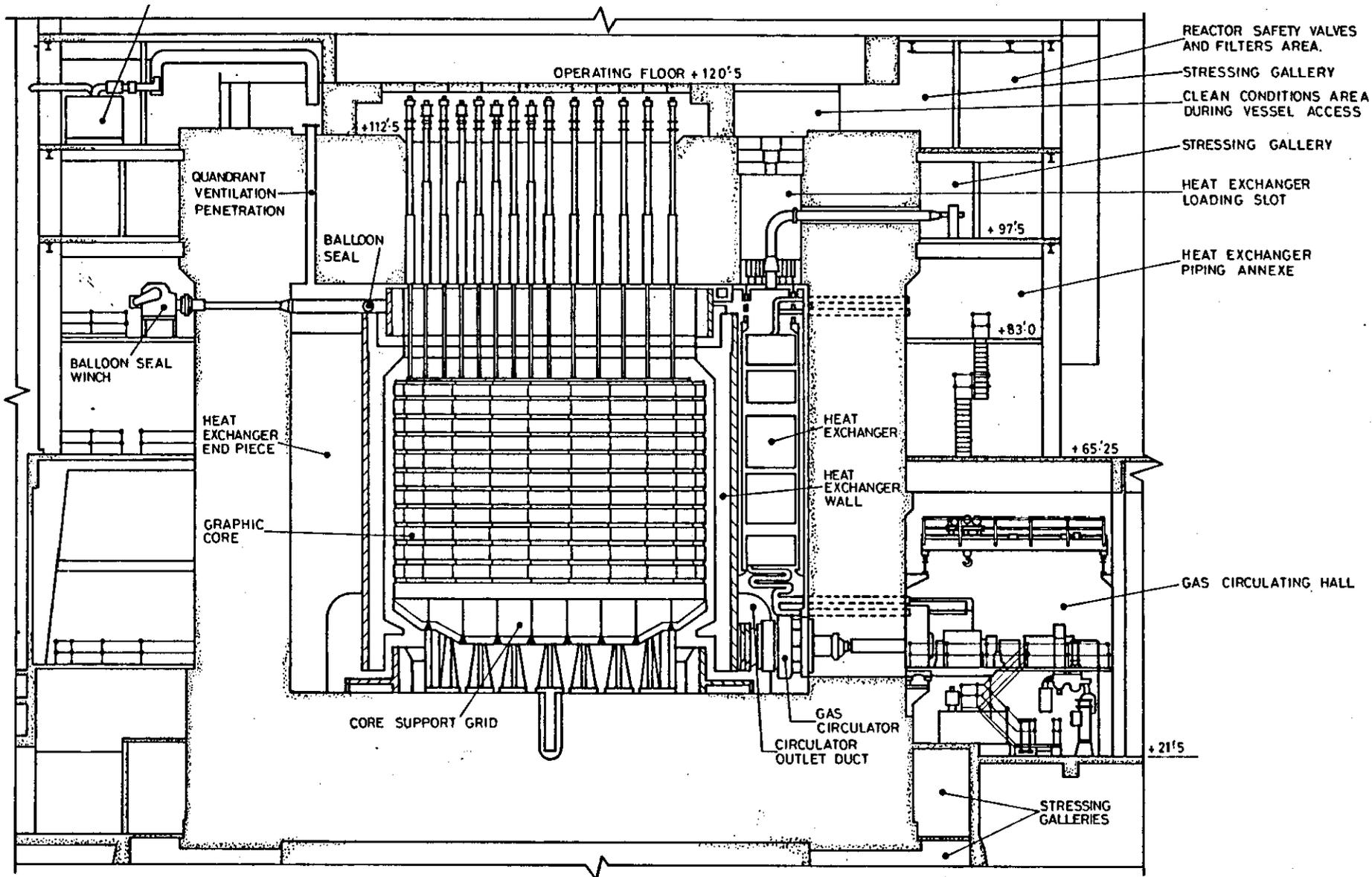
FIG. 17

1.7.1 Design of the Magnox Prestressed Concrete pressure vessel. The design of this reactor system is based on the 'integral' concept where the reactor core and the boilers are contained within a single pressure vessel. Reactor elevations in Fig 1.8 and 1.9 show the general arrangement. The pressure vessel is constructed of prestressed concrete lined with a thin steel gas-tight membrane. Four boilers are symmetrically disposed in an annulus around the core but separated from it by a boiler shield wall. It is to this annulus that human access is required under reactor shut down conditions, in order to inspect and carry out maintenance work on the heat exchangers and gas circulators.

The potential hazards are the external radiation, toxic nature of the environment, temperature and contamination of the atmosphere and material surfaces.

The provision of human access facilities to Magnox concrete pressure vessels was expensive for a number of reasons. Chiefly, since the heat exchangers are inside the concrete pressure vessel, close to the core, a special 'boiler shield wall' is provided to prevent activation of the steelwork - this ensures that radiation levels are acceptable for access. For reasons of design strength and economics, pressure vessel penetrations are small and limited in number and it may be necessary to gain access to all heat exchangers from one access point. This point may be some distance from the heat exchanger to be examined and entries are more problematic, although the provisions of control of the access facility outside the pressure vessel is simplified.

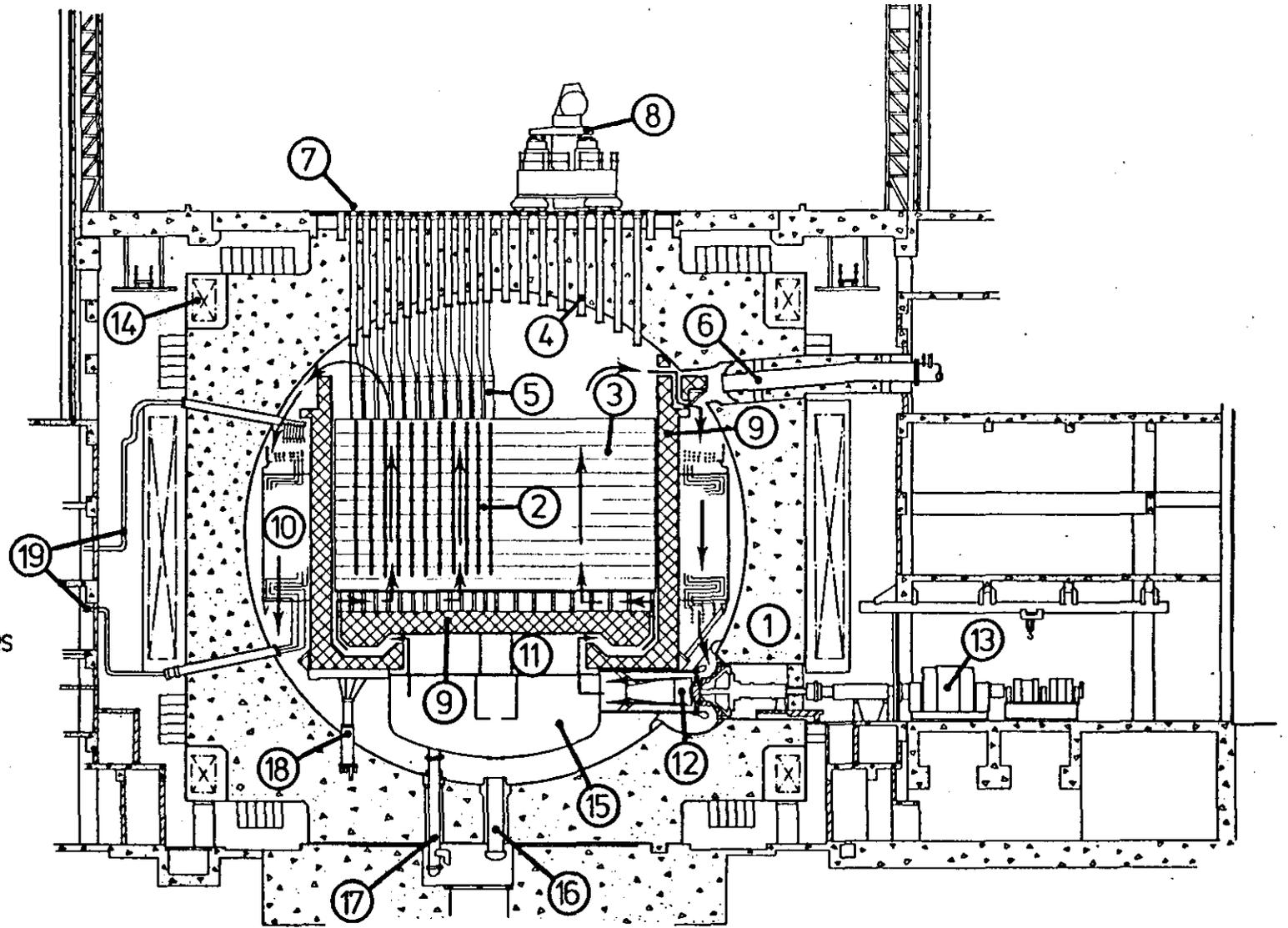
Two magnox reactors with prestressed concrete pressure vessels are in operation. Certain design features are common to both reactors - such as ladders and gangways being, where possible, 700mm but at least 450mm wide - manholes being at least 450mm square and trap doors being provided for access on to the boiler tube banks. The heat exchangers form 4 quadrants of a narrow cylindrical toroid around the core. On one reactor design, one



CROSS SECTION OF A MAGNOX PRESTRESSED CONCRETE REACTOR "A"

FIG. 1-8

1. Reactor pressure vessel
2. Fuel elements
3. Graphite moderator
4. Charge standpipes
5. Guide tube assemblies
6. Safety relief valve penetration
7. Pile cap
8. Charge machine on transporter
9. Neutron shield
10. Heat exchanger
11. Radial grid
12. Gas circulator
13. Gas circulator drive motors
14. Pressure vessel pre-stressing cables
15. Core gas inlet plenum
16. Vessel access
17. CO₂ penetration
18. Structural support columns
19. Boiler steam & feed pipework

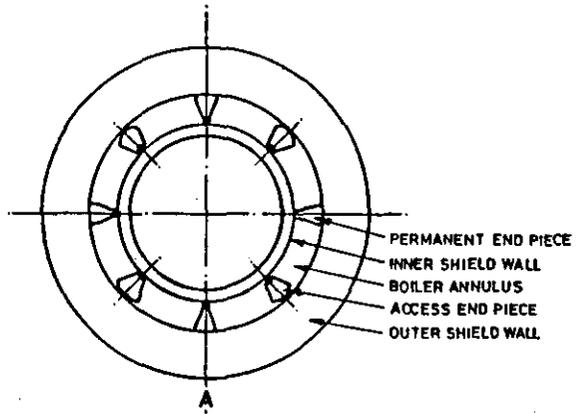
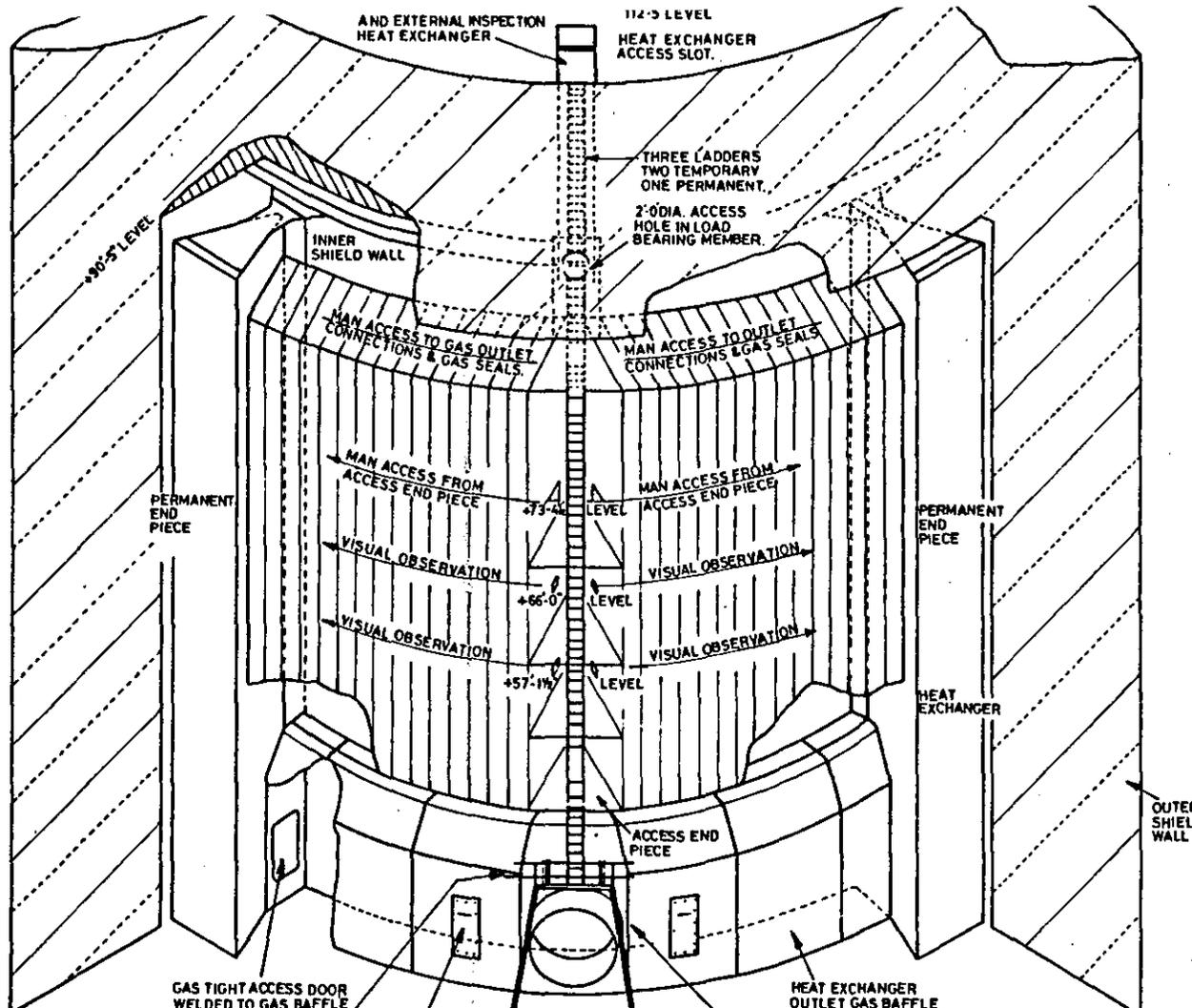


CROSS SECTION OF A MAGNOX PRESTRESSED CONCRETE REACTOR 'B'

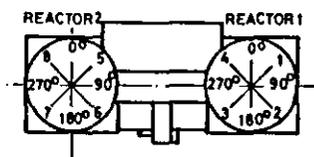
eries of banks is omitted and this space is used as an access duct - see Fig 1.10. Access in this system is made with the heat exchanger isolated and the pressure vessel full of CO₂, sealing being effected by long 'balloons' and cover plates in the sealing ducts.

During construction the boiler nests were lowered into the vessel through a boiler slot in the centre of the concrete above each heat exchanger. Human access is made by removing a smaller plug from this boiler slot plug, to act as an access port. See Fig 1.11. There is then a particularly difficult operation in a confined space to remove the gas relief pipe - to make accessible the heat exchanger slot penetration. A vertical ladder then extends to the base of the heat exchanger, passing in sections through the cells in the access casing. Access is made to the tops of the boilers banks through vertical doors 600 x 750mm in the access casing. A ventilation duct system is built into the access casing and connects to a quadrant ventilation duct at the base of each quadrant. These quadrants are separated vertically by permanent end pieces, therefore access points are provided for each heat exchanger. Sub-change room facilities are erected at these points when access is made.

In the other reactor design Fig 1.12 only one access point is provided. At the base of the reactor core a stairway leads from the bottom dome along the vessel circumference to a platform at the base of the heat exchanger, which connects by a vertical ladder in the centre of the heat exchanger to the top. Circular galleries run around the exterior casing of the heat exchanger at three points and it is possible, though difficult due to the layout, to walk around these galleries and gain access to other heat exchangers. A ventilation system is connected to the base of the vessel for purging the air and the air lock access point was designed as a permanent sub-change room and is fitted with all main service including a respirable air supply system. Radiation levels are reduced by a carbon



BLOCK PLAN ON REACTOR



KEY PLAN

AND EXTERNAL INSPECTION HEAT EXCHANGER

112'-0" LEVEL
HEAT EXCHANGER ACCESS SLOT.

THREE LADDERS
TWO TEMPORARY
ONE PERMANENT.

2'-0" DIA. ACCESS HOLE IN LOAD BEARING MEMBER.

INNER SHIELD WALL

MAN ACCESS TO GAS OUTLET CONNECTIONS & GAS SEALS.

MAN ACCESS TO OUTLET CONNECTIONS & GAS SEALS.

MAN ACCESS FROM ACCESS END PIECE

MAN ACCESS FROM ACCESS END PIECE

VISUAL OBSERVATION

VISUAL OBSERVATION

VISUAL OBSERVATION

PERMANENT END PIECE

PERMANENT END PIECE

HEAT EXCHANGER

OUTER SHIELD WALL

HEAT EXCHANGER OUTLET GAS BAFFLE

ACCESS END PIECE

GAS TIGHT ACCESS DOOR WELDED TO GAS BAFFLE DIVISION PLATE AFTER COMMISSIONING.

PLATFORM GIVING ACCESS TO UNDERSIDE OF HEAT EXCHANGERS, INLET TAIL PIPES AND HEAT EXCHANGER GAS SEAL.

PRESSURE SEAL GAS TIGHT DOOR OPENS FROM OUTSIDE ONLY FOR ACCESS INTO GAS BAFFLE.

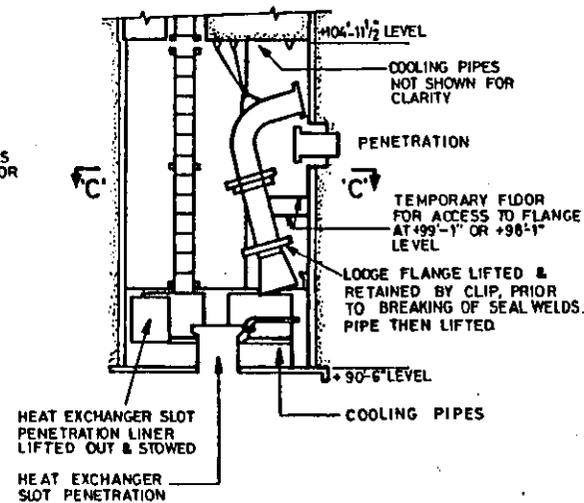
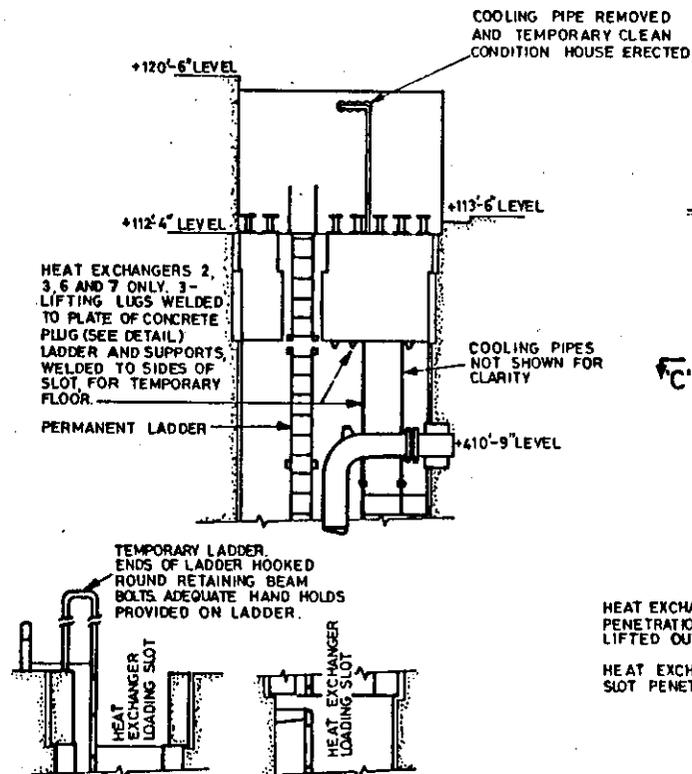
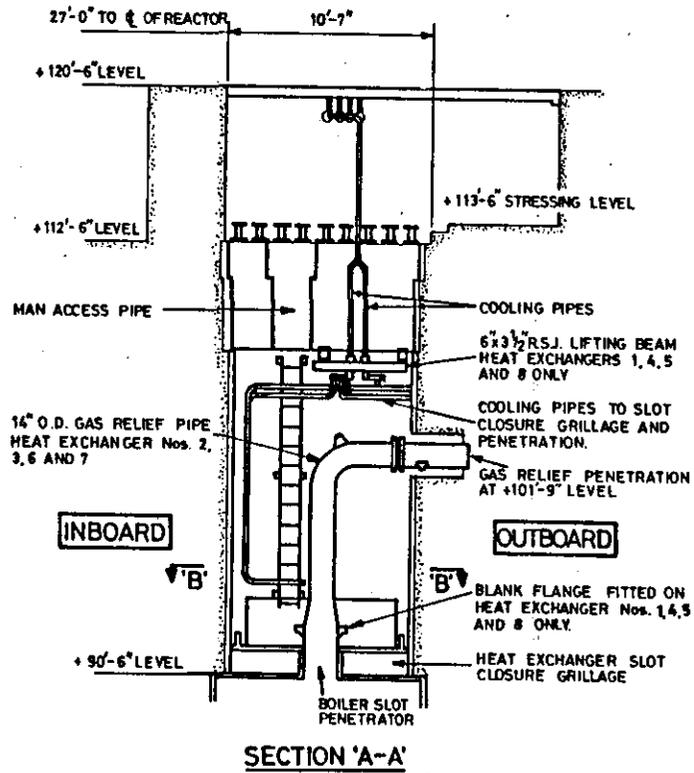
LADDER GIVING ACCESS FROM END PIECE DOWN TO ANNULUS FLOOR, BLOWER & OUTLET GAS BAFFLE.

NOTE:-
SEALING PLATES TO BE PASSED THROUGH 2'-0" ACCESS HOLE TO TOP SEAL PATH ANNULUS WHEN REQUIRED FOR MAINTENANCE PURPOSES.

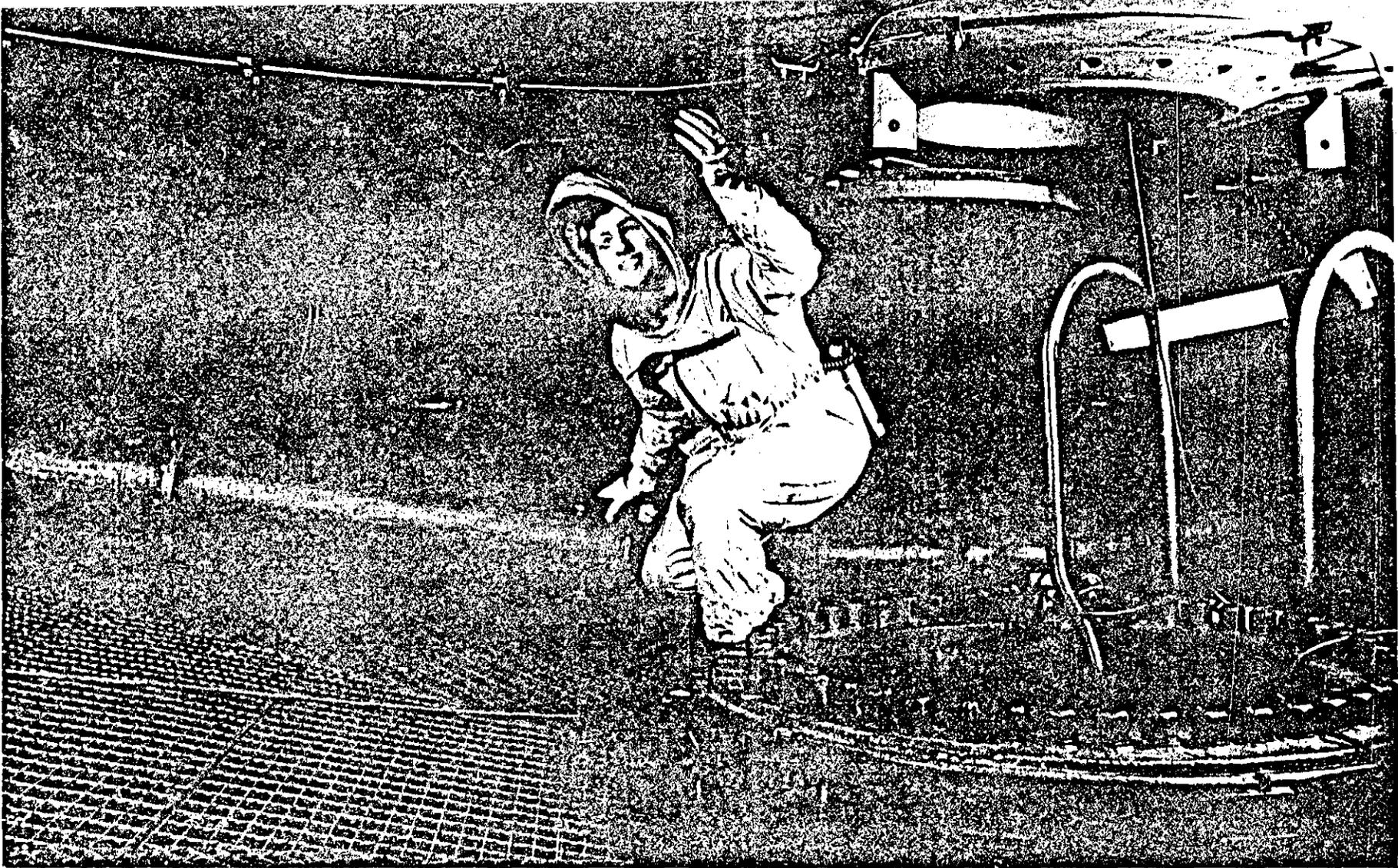
VIEW ON QUADRANT IN DIRECTION OF ARROW A (SEE BLOCK PLAN)
(OUTER SHIELD WALL REMOVED FOR CLARITY)
ACCESS ROUTES WITHIN CONCRETE PRESSURE VESSEL 'A'

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FIG. 1-10



PROCEDURE FOR ACCESS PORT REMOVAL



ACCESS INTO MAGNOX CONCRETE PRESSURE VESSEL 'B'
PERSONELL PROTECTIVE ASSEMBLY

FIG. 1-13

and steel bottom shield and the vertical cylindrical boiler shield wall comprising layers of carbon and steel totalling 230mm thickness of steel and 50 to 200mm thickness of carbon.

Control of the Environment requirements are similar to those in magnox reactors, with the exception that access into concrete pressure vessels is made at air temperatures of 60°C and maximum metal temperatures of 65°C.

In the case of the Reactor Design shown in Fig 1.8 there is a means of heat exchanger isolation and the cooling process is similar to magnox reactors.

Once the reactor is blown down and the CO₂ temperature has dropped to 120°C the gas circulator of one circuit is stopped and a balloon seal is pulled onto the top duct using an external mechanical winch and pulley system. A similar balloon is fitted into the lower duct and the balloons are pressurised to .75 bar. The access plugs are removed and a ventilation fan is connected to the quadrant ventilation system in the access duct purging the air at a rate of 2,360.1/sec to below 3% CO₂ in air and 60°C. The CO₂ pressure in the core is reduced to 980 mbar and access is made to the top duct by persons wearing protective clothing to fit planking plates over the balloon seals. During access the quadrant cooling is continued at a reduced ventilation rate of 1,420. 1/sec.

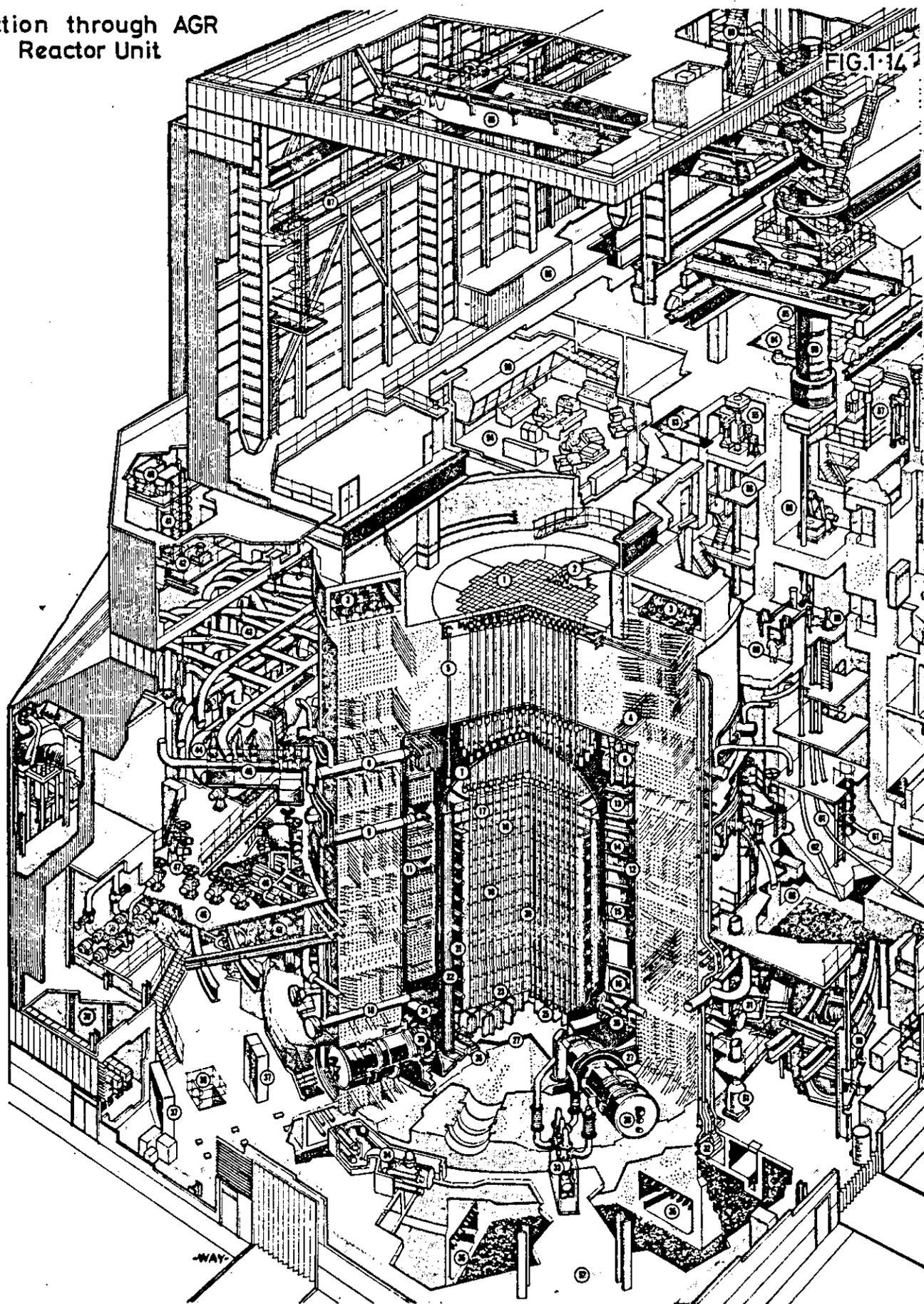
In the case of reactor design Fig 1.9 - following studies by Blake & Phennah (1964) of the effects on radiolytic oxygen in air at temperatures below 200°C on the air reactivity of the graphite - it was concluded that no detectable reactivity increase would occur even in the presence of 100% air during a short period, and it was decided that air could be admitted to the pressure vessel during the reactor shut-down. This policy was introduced on this design which has no gas duct isolation.

To obtain a suitable environment for access the reactor is shut-down and the vessel is cooled for 3 days by running the gas circulators and passing cold water through the boiler tubes. The reactor pressure is then blowdown and a ventilation system is operated in the bottom human access tunnel. An engineer wearing a pressure suit and positioned on a 'beanstalk', breaks the dome seal and installs hydraulically operated jacks under the dome. He then leaves the area and the dome is raised remotely by the hydraulic jacks. Air is drawn in via this access point until the circuit is purged to 0.5% CO₂ in air and the temperature is below 60°C. The dome is slid to the side to allow human access, and the air purging continued with the circulators running at slow speeds, the air passing up through the core, then down the heat exchangers, 10% being discharged, filtered, to the main stack.

Control of access and personnel protection is basically similar in nature to that described in Section 1.7. In this case however initial entries would be at 60°C air temperature. The development of the personnel protective assembly used (see Fig 1.13) forms part of the work described in Chapter 2. Youell and Tresise (1966) have reported on the access to the Boiler Annulus of the Magnox A design, Fig 1.8 under Reactor shut-down conditions.

1.7.2 The AGR Man Access Problem. The advent of the Advanced Gas Cooled Reactor design shown in Fig 1.14 presented a new set of environmental conditions the fuel-can temperature of the system being 825°C compared with 430°C for a magnox system. Due to fission product heating it is necessary to cool the reactor as long as it is fuelled so that the gas circulator noise is a particular problem during access. Extensive consideration has been given to the design of the access routes but the temperature, noise and airborne contamination of gas borne dust will require the use of personnel micro-climate assemblies for all personnel entering the pressure vessel. To ensure safe access extensive training programmes will

Section through AGR Reactor Unit



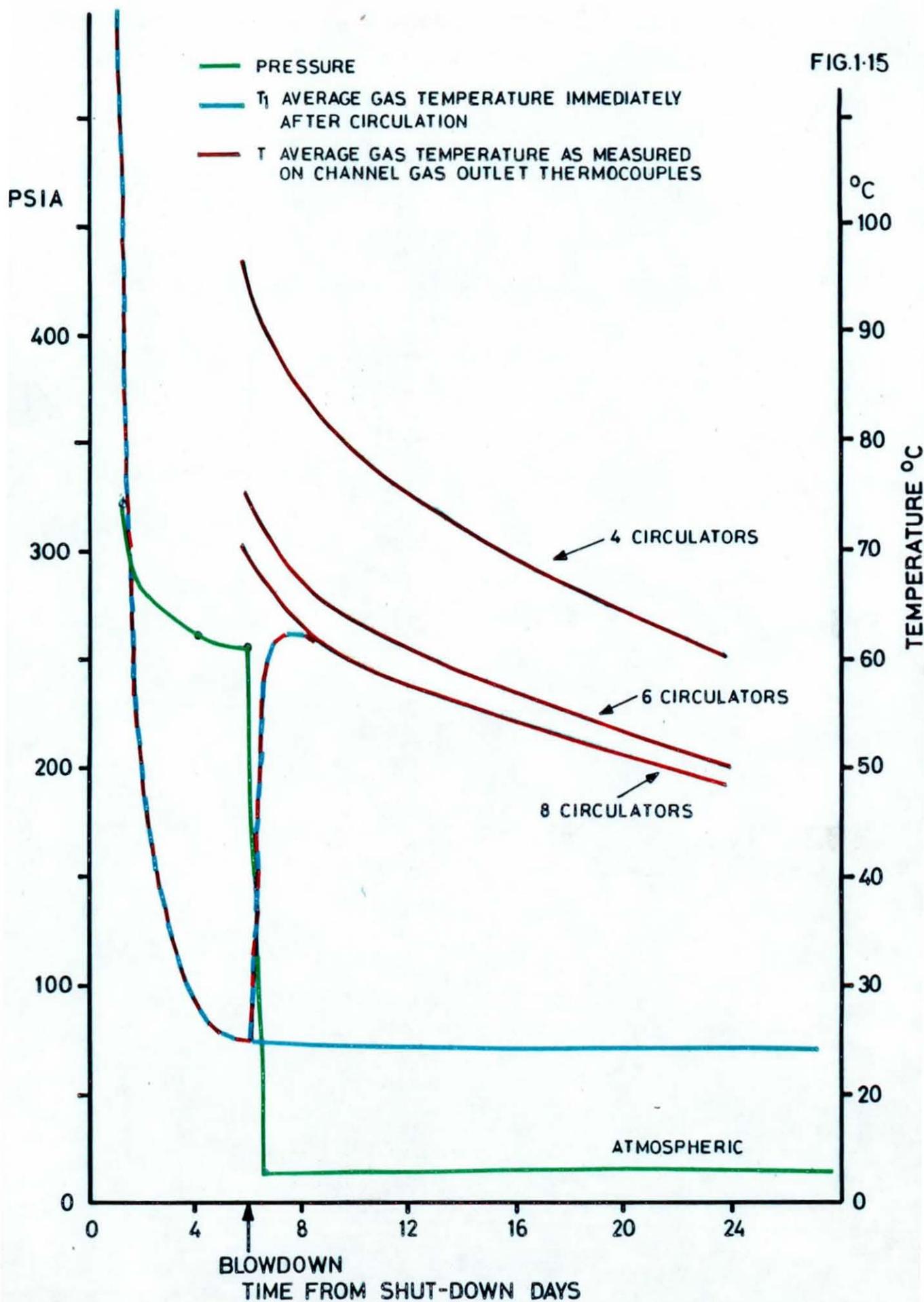
1) Reheat penetration. (2) Permanent access penetration. (3) Upper stressing gallery. (4) Helical stressing cables. (5) Flux measuring penetration. (6) Reheater slings. (7) Gas (8) Reheat penetration. (9) Main steam penetration. (10) Feed penetration. (11) Boiler 16. (12) Boiler 15. (13) Reheater. (14) Superheater. (15) Evaporator. (16) inner. (17) Neutron shield. (18) Top reflector. (19) Graphite core. (20) 308 fuel channels (8 elements per channel). (21) Restraint rods. (22) Boiler shield wall. (23) Bottom r. (24) Circulator outlet gas duct. (25) Reactor diagrid. (26) Reactor roller supports. (27) Thermal insulation. (28) Boiler support beam. (29) Circulators (8 per reactor). reactor closure dome. (31) Decay heat penetration. (32) Pressure vessel cooling water mains. (33) Gas relief valves and filters. (34) Oil tanks and coolers. (35) Lower g gallery. (36) Access to lower stressing gallery. (37) Circulator gauge boards. (38) Battery room. (39) De-gasser extraction pumps. (40) De-gasser pressure setting 41) De-gasser. (42) De-gasser vacuum pumps. (43) Steam pipe well. (44) Start-up vessel. (45) L.T. relief valves and access platform. (46) 66 ft level platform. (47) valves (pedestal control). (48) Pressure vessel treated water coolers. (49) Auxiliaries system treated water pumps. (50) Circulator house crane grab. (51) Boiler emptying (52) Ground floor. (53) Control room viewing gallery. (54) Control room. (55) New fuel cell. (56) Lower new fuel cell. (57) Upper maintenance room. (58) Irradiated mounting cell. (59) Bottling machine. (60) Manipulators. (61) Fuel disposal tubes. (62) Tie rod disposal tubes. (63) Debris vault. (63) Hoist well cover. (64) Test facility 85) Charge machine maintenance well cover. (86) Charge hall viewing gallery. (87) Charge hall crane access walk way. (88) Charge hall crane. (89) Charge machine staircase. (90) Charge machine.

have to be developed and a medical examination of all personnel before entry (see Appendix A), will be required until the temperature of the pressure vessel environment will be below 35°C . The following outlines in further detail the conditions that are to be anticipated.

For men entering a purged and depressurised reactor an upper temperature limit of 60°C has been set after consideration of the medical and economic factors. This temperature would be the maximum gas temperature in the circuit in the hot box above the gas baffle dome after about 10 days from shutdown. Under the core the temperature will be about 30°C . As the fission product is further reduced gas temperatures will gradually drop, dependent on the number of gas circulators running. When the reactor is off load, cooling at full pressure and at an agreed rate is commenced to remove fission product heat stored within the reactor. When the gas temperature has dropped to about 40°C the reactor is depressurised and purged with air and a maximum of 3% CO_2 by weight in air atmosphere established. The maximum air temperature should then be about 60°C above the hot box dome in 10 days from shutdown as shown in Fig 1.15.

The intensity of noise levels within reactor systems have been the subject of special studies - Nairne and Burt (1974)⁶, Fahy (1973) and Rivenais (1972). The noise is produced by the operation of the gas circulators for reactor cooling and early predictions indicated that the range would be from 90 112 dBA - subsequent measurements demonstrated that levels up to 130 dBA would exist in certain reactor locations, the COGD (Circulator Outlet Gas Duct) for example. The following Table 1.7 shows some typical noise levels. Extensive noise survey of the access areas are still to be carried out with a variety of circulator running conditions.

FIG.1-15



REACTOR GAS OUTLET TEMP & PRESSURE V TIME FROM SHUTDOWN

LOCATION	NOISE LEVEL dBA	
	Predicted	Tentative
Above gas baffle dome	90	83
Above the boilers	92	90
Below the boilers	92	100
In the circulator inlet plenum	112	110
In the COGD	116	130

Table 1.8. Noise levels predicted and tentative
in various reactor locations

The criterion contained in HMSO (1972) Department of Employment Code of Practice" (1972) for reducing the exposure of employed persons to noise states that the unprotected ear should not be subjected to greater than an equivalent noise level of 90 dBA for 8 hours per day. Since noise exposure is a function of noise level and time, these parameters can be interchanged on an energy basis as shown:-

- 90 dBA for 8 hrs
- 93 dBA for 4 hrs
- 96 dBA for 2 hrs
- 99 dBA for 1 hour
- 102 dBA for $\frac{1}{2}$ hr

The Code of Practice sets an overriding limit for unprotected ears at 135 dBA (measured on fast response) and indicates that other parts of the body should not be exposed to more than 150 dBA (fast).

The results of predicted and tentative noise levels will, from a statutory point of view, require all entrants into the pressure vessel to wear hearing conservation devices, presenting another unavoidable demand on the physical attributes of personnel making entries.

Communication aspects are also affected by this and the development of a 'voice processor' system to improve communications between

ne team inside the vessel and the outside controller has been reported on y Nairne and Burt (1974).

Shielding has been provided around the reactor core to reduce adiation levels within the reactor pressure vessels to values which will ermit human access. Two design criteria were used to determine shielding equirements.

category (1) 25 m rem/h in areas to which access is required for extended eriods for maintenance or inspection purposes, at intervals not greater han two years, giving a permissible access time of 120 hours (3 rem/qtr aximum dose).

category (2) 200 m rem/h in areas where access would only be required as result of a foreseeable but unlikely fault giving a permissible access ime of 15 hours (3 rem/qtr maximum dose).

These of course assume no other radiation exposure within the relevant quarter.

Areas included in (1) are the heat exchangers when physically ccessible, and positions from whence gas circulators are removed. Category 2) applies to areas above the hot box dome.

Radiation levels from contamination have been estimated for a umber of reactors, Walton (1973a), (1973b) and 1972) and are additive to hose shown above. It is considered that contamination would be deposited n the heat exchangers, which virtually act as filters, although most articulate matter will be arrested in the central inertial collectors at he top of a proportion of the fuel channels. However deposition in other arts of the gas circuit should be low since the particles are small and he gas velocities are high.

In order to reduce the quantity of as borne particles within the gas circuit of one reactor design central nertial collectors will be fitted to 75% of fuel channels at initial fuel oading - this figure to be reduced to 50% at equilibrium.

Table 1.9. shows radiation dose rates and permissible access times in the various areas using the best radiation data available at present.

The spalled oxide contributions have been calculated assuming design operating conditions. It is anticipated however that due to 9% Cr constraints, the fuel cladding temperatures will in the first few years - and possibly longer - be very much less than the design values. This will have the effect of reducing the amount of spalled oxide by a factor of up to about six. The predictions for early years of operation although certainly pessimistic require full body protection and a respirable air supply.

The initial entry has to be made in total darkness and lighting and monitoring equipment will have to be taken into the vessel. Although access routes Figs 1.16 & 1.17 are designed to ensure the safe passage of personnel, some parts are unavoidably restricted; notably the access manhole in the hot box dome, and the passage through the heat exchanger supports below Landing 4, Fig 1.18. The lack of space under the dome will also make access difficult. Air line control will also be a problem, especially on the deep vessel penetrations to the reactor floor and through air locks. Air flow above the hot box dome will be a particular hazard, although isolation of relevant heat exchangers may give local reductions. Since there is a pressure drop of about .15 bar over the dome it will be necessary to provide an inreactor air lock, or the use of a special duct will be made as shown in Fig 1.16 to prevent unacceptable gas velocities through the access in the dome.

It is recognised that proper training of personnel will be the key to success and this is a feature dealt with in depth also in Chapter 2.

LOCATION			PERIOD OF FULL POWER OPERATION YEARS						
			1	2	5	10	20	30	*
BELOW BOILERS	Dose rate m rem/h	Act Ox	4 65	7 88	15 144	22 183	28 215	30 222	30 222
	Access time hours	a b	46 9	34 7	21 4	16 3	14 3	14 3	14 3
BETWEEN BOILERS MID CORE	Dose rate m rem/h	Act Ox	3 65	5 88	8 144	10 183	11 215	12 222	13 222
	Access time hours	a b	44 9	32 6	20 4	15 3	13 3	13 3	13 3
BETWEEN REHEATER AND SUPERHEATER	Dose rate m rem/h	Act Ox	6 130	12 175	24 287	37 366	47 430	49 443	50 443
	Access time hours	a b	22 4	16 3	10 2	7 1	6 1	6 1	6 1
ABOVE REHEATER	Dose rate m rem/h	Act Ox	6 65	12 88	24 144	37 183	47 215	49 222	50 222
	Access time hours	a b	42 8	30 6	18 4	14 3	11 2	11 2	11 2
WALKWAY	Dose rate m rem/h	Act Ox	12 33	24 44	48 72	74 92	94 108	98 111	100 111
	Access time hours	a b	67 13	44 9	25 5	18 4	15 3	14 3	14 3
HOT BOX (CENTRE) BELOW DOME	Dose rate m rem/h	Act Ox	240 -	480 -	960 -	1480 -	1880 -	1960 -	2000 -
	Access time hours	a b	12 2.4	6 1.2	3 0.6	2 0.4	1 0.3	1 0.3	1 0.3
HOT BOX (CENTRE) ABOVE DOME	Dose rate m rem/h	Act Ox	24 -	48 -	96 -	148 -	188 -	196 -	200 -
	Access time hours	a b	126 25	62 12	31 6	20 4	16 3	15 3	15 3

* Saturation

a Access time for a maximum dose rate of 3 rem/qtr.

b " " " " " " " " 600 m rem/qtr.

The Act (activation) and Ox (oxide) dose rates shown are not strictly additive, as they occur at different positions (activation just above bottom liner, oxide just beneath boiler). The oxide dose rate only is therefore used to calculate access time.

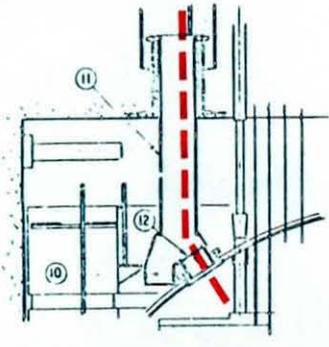
NB: CIC (Central inertial collectors) are assumed to be fitted in 50% of the channels.

Table 1.9 Radiation Dose Rates and Permissible Access

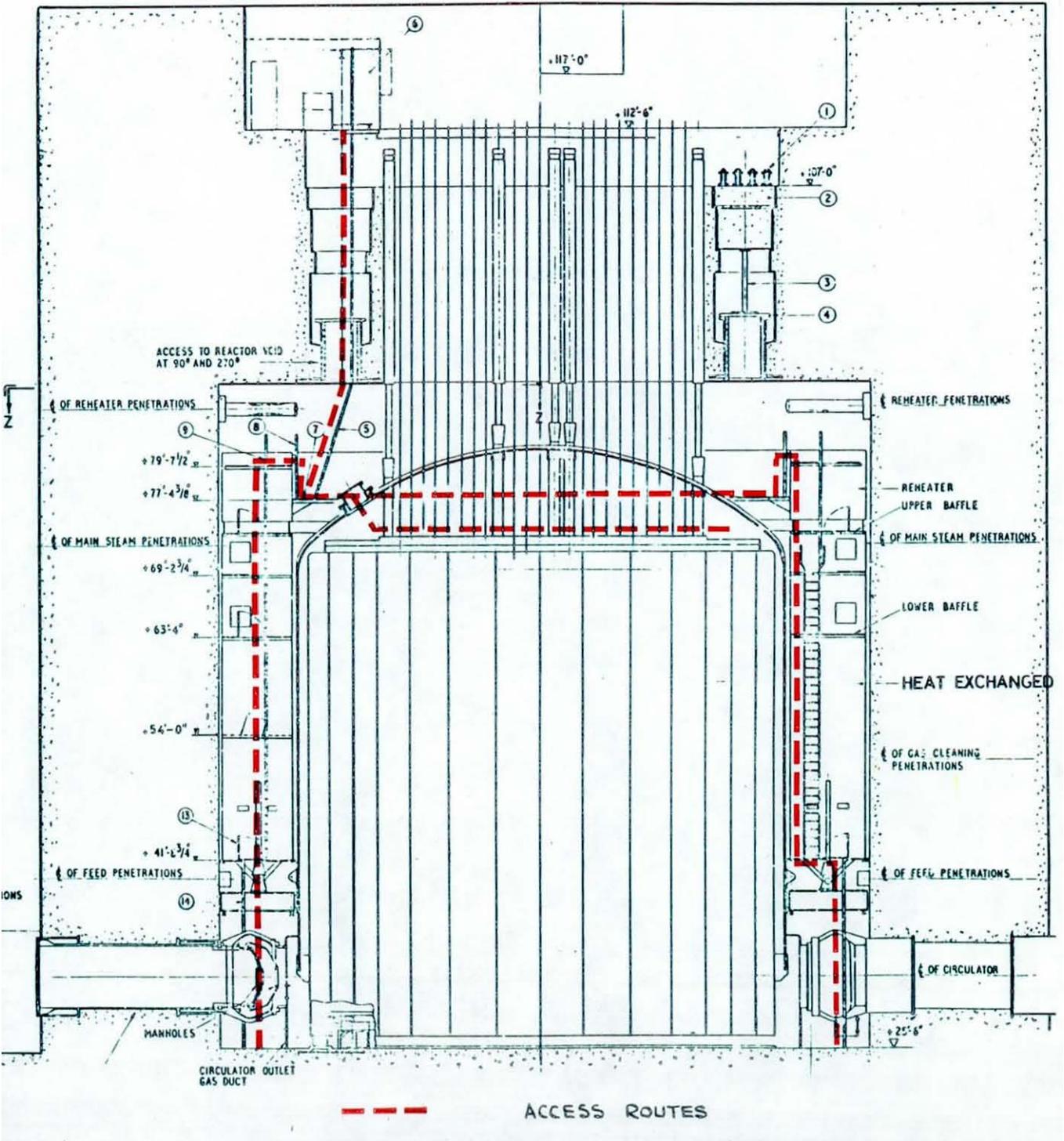
Times in the Various Reactor Locations
(using the best radiation data available)
Walton (1973)

FIG. 1-16

REF	DESCRIPTION
1	SHIELD PLUG HOLDING DOWN BOLTS & BEAMS
2	OUTER SHIELD PLUG
3	IMPACT SLEEVE
4	ACCESS MANHOLE COVER
5	ACCESS LADDER
6	CLEAN CONDITIONS TENT
7	ANNULAR PLATFORM
8	ACCESS LADDER
9	ACCESS LADDER
10	ACCESS CHAMBER
11	ACCESS DUCT
12	SECONDARY MANHOLE COVER
13	HINGED ACCESS BOOR IN BOILER SEALING PLATE
14	ACCESS LADDER



PART SECTIONAL ELEVATION SHOWING ACCESS TO AREA WITHIN GAS BAFFLE DOME



ACCESS ROUTES TO, AND WITHIN, AGR PRESSURE CIRCUIT

MAIN ACCESS PENETRATIONS
AT 90° AND 270°

FIG. 1-18

REHEATER PENETRATIONS

PERIPHERAL
WALKWAY

+79' 7 1/2" ▽

RE-
HEATER

TUNDISH

SCOUR
PLATES

+77' 4 3/8" ▽

DOME

GUIDE
TUBE

UPPER BAFFLE & HATCH COVER

ACCESS

MAIN STEAM PENETRATIONS

NEUTRON
SHIELD

LANDING 1 + 69' 2 3/4" ▽

INSPECTION DOORS

LANDING 2 + 63' 4" ▽

PART SECTION
PRESSURE VESSEL

LANDING 3 + 54' 0" ▽

..... MAN ACCESS ROUTES

ACCESS DOOR
IN BOILER
SLIDING PLATE

LANDING 4 + 41' 8 3/4" ▽

FEED PENETRATIONS

CLASING

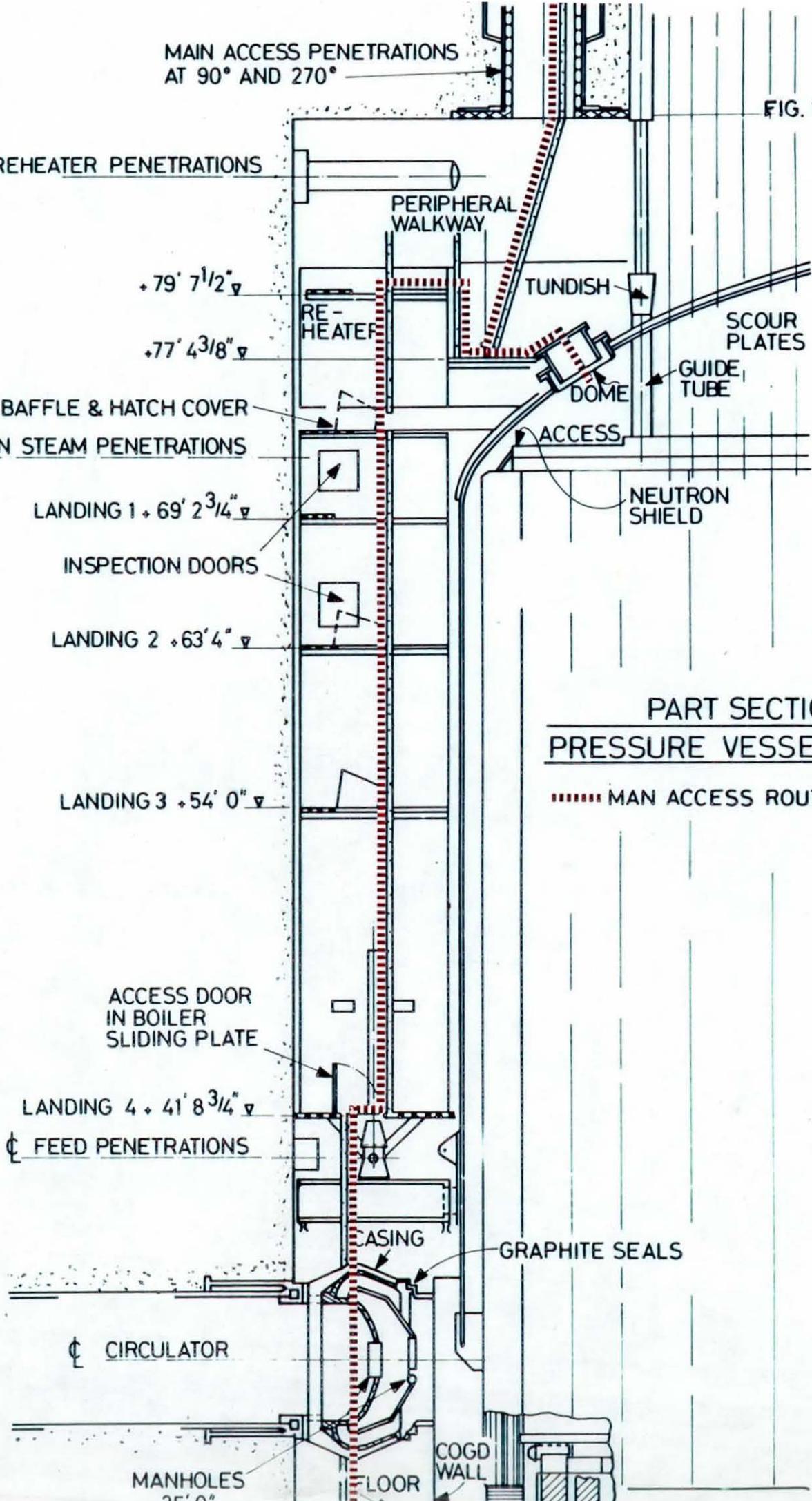
GRAPHITE SEALS

CIRCULATOR

MANHOLES
25' 0"

FLOOR

COGD
WALL



Units: t, are they 'tons' or 'tonnes'?

perhaps put in metric. 1000kg. mult

These are other abbreviations here (and elsewhere) that could be checked for clarity. e.g. 'ip'.

he physiological reactions of personnel will need to be closely observed.

After reactor shutdown adequate margins of gas flow and boiler feed will be in reserve to provide immediate extra cooling if any item of plant fails while personnel are in the reactor. It is envisaged that probably four or six men will be in a reactor at one time, working in pairs and if an emergency arose that might necessitate individuals being disconnected from the air supply and wired communication system, to reach the exit of the reactor, an emergency self contained breathing system will have to be used. Certainly breathing contaminated reactor air is not advisable and great care has to be taken to prevent such a situation.

The comparison of the Magnox and Advanced Gas Cooled (AGR) reactor design system is shown in Table 1.10.

		Magnox	AGR
Output main turbine	MW	6 x '93.5	2 x 660
Power sent out	MW	500	1,250
Area - Main station	ha	16.2	8.1
Fuel per reactor	tonnes	355	122
Fuel	Uranium	Natural	Dioxide*
Fuel can material		Magnox	Stainless St
Fuel surface temperature	approx °C	430	825
CO ₂ coolant pressure	bar g	12.7	41.4
CO ₂ channel outlet temperature	°C	387	665
No of channels per reactor		4500	308
Total wt graphite moderator/core	tonnes	1891	1199
Steam conditions: Turbine stop valve	hp °C	363	538
" " " " "	hp bar g	45.5	160
" " " " "	ip °C	354	538 +
" " " " "	ip bar g	12.7	38.9 +

* Slightly enriched in ceramic form

+ Reheat - no ip stage

Table 1.10 Comparison between a Magnox and AGR

Nuclear Power Station

The economics of operating the system in respect of increased revenue is shown in Table 1.11 based on the relationship of cooling times of the heat exchanger to pressure vessel in terms of days relative to the

cost of plant replacement, i.e. using alternative lower merit generating plant on the system. For this comparative purpose only a figure of £180/MW day has been used, this shows a relationship of nearly 5:1.

Reactor System	Reactor Design Performance MW		Cooling Days Before Entry		Plant Replacement Cost + £
	Thermal	Electrical	35°C	60°C	
Magnox A	588	138	3		24.840
" B	548	290	3		52.200
" C	892	300	3		54.000
" D	1.875	590	3		106.200
AGR	1.500	625	60*	10*	112.500

* C & D are prestressed concrete pressure vessels

* Plant replacement cost based on £180/MW day

* 6 gas circulators running

Table 1.11 Relationship of Cooling Days/Plant

Replacement Costs

1.8 Electricity Transmission. Generating plant is scheduled and loaded from economic orders of merit to meet the estimated area demands having regard to local security, the requirements of spinning reserves and programmed inter-area or inter-group transfer. The grid enables transmission to be run on a fully national basis, reducing the amount of standby generating capacity needed and allowing power stations which generate most cheaply, i.e. nuclear, to be used to the maximum, the operation of the older and less economic stations being restricted to peak periods. At the end of March 1975 the national grid system comprised 14,000 circuit Km of overload lines and underground cables including 8,000 operating at 400kV and 4,400 at 275kV.

The original grid, established in the early 1930's was designed to work at 132kV. It was strengthened by the 275kV system which began operating in 1953 and which permitted a measure of bulk transfer of

lectricity from large new power stations built near the coal fields to areas lacking in fuel resources. Almost all the 132kV lines and associated sub-stations and transformers were transferred to the Area Electricity Boards on 1 April 1969, and now represent their primary distribution systems.

In 1960, in order to increase its power carrying capacity, the generating Board decided to raise the voltage of the 275kV system to 400kV, and to adopt 400kV for major new lines. This also had the effect of keeping to a minimum the number of new lines required, thus contributing to the preservation of visual amenity. But 275kV is being retained in some industrialised areas of high-load density where it is suited to local high-voltage distribution.

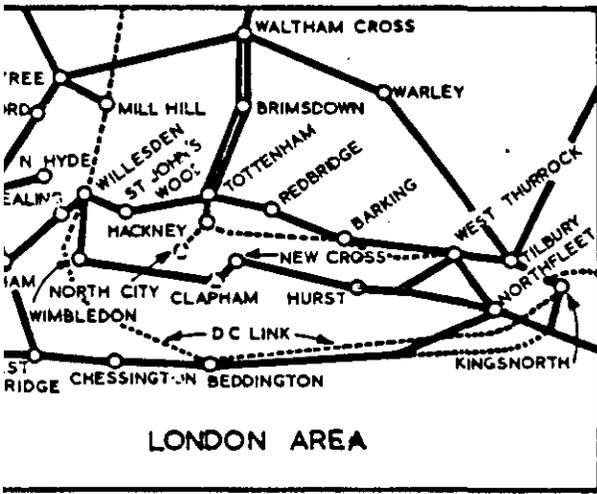
The first design of the heavy duty 400kV line, commissioned in 1965, had three times the power-carrying capacity of the heavy duty 275kV line and eighteen times the capacity of the original 132kV line. Within the past few years, as the result of transmission research, it has been possible to up-rate the heavy duty 400kV overhead line from 1,800 MVA to 2,800 MVA per circuit in normal weather. The 275/400kV network is now completed.

Fig 1.19.

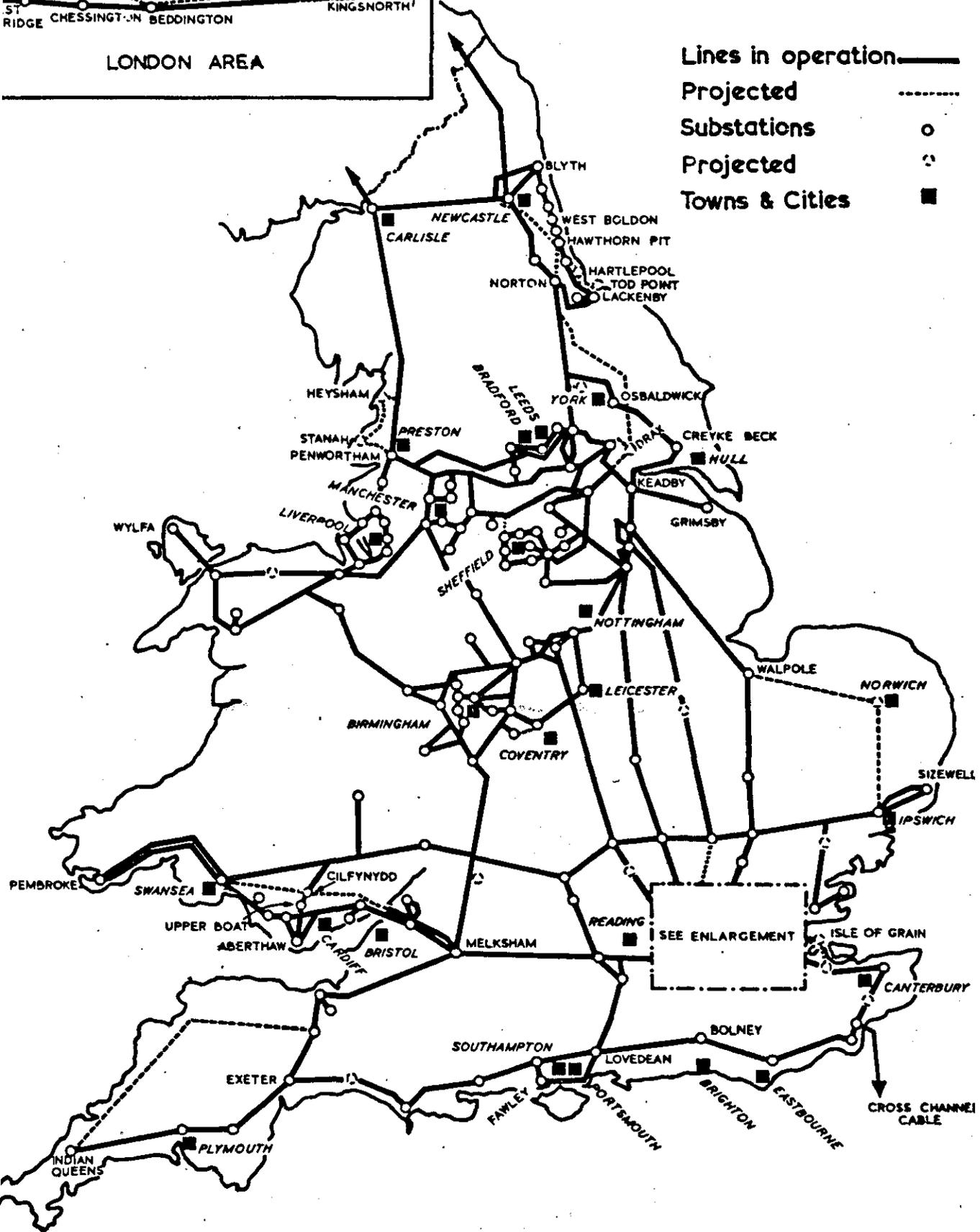
Subsequent development of the 400kV system will mainly be in the connection of new power stations and the establishment of new bulk supply points to give increased supplies to the local lower voltage networks. The 275/400kV network will, in principle, remain adequate for system loads of at least 110,000 MW, that is, up to the 1990's. Beyond that time there will be a need for a major expansion possibly involving higher voltages, or much more extensive underground transmission employing dc or superconductivity.

The introduction of the new grid system required consideration to be given to repairing and maintaining transmission lines while they are still energised. This technique known as "live line maintenance" was developed in North America and has been described by Elek and Simpson (1961) and AIEEE (1967).

Supergrid System



- Lines in operation —————
- Projected —————
- Substations ○
- Projected Substations ○
- Projected Towns & Cities ■



Live line working falls into two categories, 'tool work' and 'bare hand work'. With the former the linesman operates from the ground from a convenient vantage point on the transmission tower or pole using tools fitted with long insulated handles. In bare hand work, the linesman is in physical contact with the energised conductor and must wear a special suit to ensure that his body is at the same potential as the line itself so he can safely use uninsulated tools as he would if the line were dead. The advantage of live line maintenance is that it avoids line outage for such routine work as the inspection of insulators and conductor hardware and on rural distribution circuits, pole mounted switches and transformers. Indeed all these items can be repaired on site or replaced without interrupting the supply.

9 Personnel Protection. Much progress has already been made in the last few decades in protecting the human in industry against a large variety of hazards. The expanding atomic energy programme has highlighted potential hazards in the temperature, toxic nature and contamination of the atmosphere and the temperature of material surfaces that will be encountered during human access to circuits in certain reactor systems. Conditions may require both work in protective impermeable PVC clothing or work in special liquid or air conditioned micro climate suits. The work required may be in confined areas with difficult access and the bulky nature of clothing can add to the difficulties. Heat stress can develop within a suit of impermeable clothing at quite low workplace temperatures due to metabolic heat production, Rowlands (1966). No special precautions are usually necessary for work in temperatures up to 27°C providing there is no radioactive contamination, but above this figure conditions of heat stress may occur and it becomes necessary to control the working conditions and

ensure that the worker is adequately protected. At temperatures above 27°C the specific requirements and protection necessary will be determined by the prevailing temperature and humidity, and the duration and energy demands of the job.

For the purpose of this research project abnormal conditions are defined as the conditions existing when the dry bulb or globe thermometer temperatures of the working environment are between 27°C min and 80°C max and the environmental atmosphere is irrespirable.

Stress results when the heat balance of the body cannot be maintained and there is an accumulation of heat within the body. The heat balance of the body is a balance between the body's metabolic heat and the heat exchanges occurring between the body surface and its environment. The human body loses heat by three paths, radiation, convection and evaporation, and the rate of heat loss will depend on the temperature of the air, its humidity and rate of movement, and on the radiation from the surroundings, as well as on the physiological mechanisms which serve to control the body temperature. If the temperature and/or humidity of the immediate environment are such that adequate heat exchange cannot take place, the body temperature rises and heat stress will result. The two principal systems of the body concerned are the cardiovascular system and the sweating mechanism. The cardiovascular system transports heat to the skin for the heat exchange between body surface and environment to occur. The sweating mechanism controls the amount of sweat produced on the skin, where its loss by evaporation assists in maintaining the heat balance. In conditions of extreme heat and/or humidity, insufficient evaporation from the skin may result, or insufficient sweat may be produced for evaporation and cooling of the body. If it is impossible or impracticable to reduce the conditions of heat to an acceptable level for the work required then two alternatives are possible. The duration of exposure can be limited according to the

working conditions, or special, ventilated, protective clothing can be provided. In some extreme cases both may have to be applied.

1.9.1 Protective Clothing and Equipment. The basic problem with protective clothing is to maintain a microclimate round the human in which all physiological processes can occur without undue stress. The state of protective clothing technology from review of the literature is that this can be accomplished for many industrial situations although in terms of general comfort and interference with mobility, sight and hearing, designs still leave something to be desired. The feature which is common to all protective clothing is its influence on the thermal balance of the body so that it is important in designing or selecting clothing to determine this effect.

One can use heat balance equations as reviewed in Section 1.2.1 and determine quantitatively the thermal balance and then determine the quantity and temperature of the media to remove the excess heat, or alternatively tolerance times can be estimated, Leithead and Lind (1964) although it appears that the procedures available are not very accurate when applied to many industrial situations.

An outline of a suggested procedure for determining what form of protection is required in hot working areas is given by Ordianz (1970). Thick clothing, heavy clothing, aluminised clothing, air ventilated helmets and jackets, water conditioned suits and dynamic insulated suits are described. In the area of cooling equipment, evaporative and turbine coolers, conventional refrigeration units, heat sinks and vortex coolers are reviewed. But for the purposes of this research only garments based on the Liquid Conditioned System (LCS) and the Dynamically Insulated system, together with their associated equipment are considered.

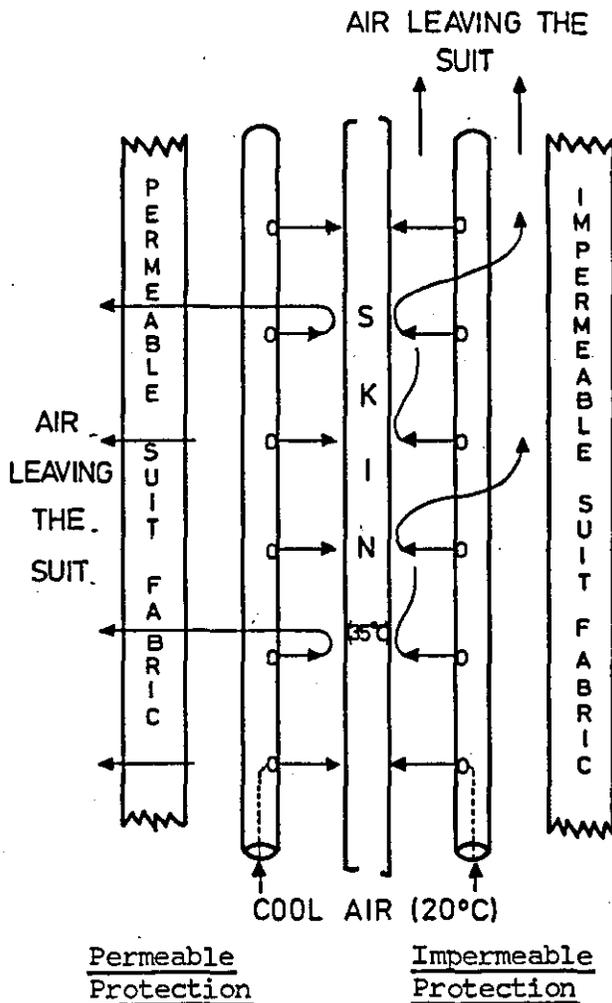
9.2 Liquid Conditioning Systems. A protective clothing system was designed by Burton and Collier (1965) and data on its performance in an industrial situation when worn under an aluminised asbestos suit has been reported by Hill J (1967). Webb and Annis (1969) reported on its use to suppress sweat during work as an aid to the design of protective clothing. London (1969) reviewed the work in the United Kingdom on water cooled suits. Lunneley et al (1971) reported a particular application of the principle to head cooling using a water cooled cap. Allan et al (1972) reports on the comparison of three methods, a water cooled system, a convective air system, and a reverse flow system, the subjects also being evaluated with no personal conditioning. This report concluded that under the conditions simulated (the thermal time course of an operational flying sortie) the water cooled suit appeared more effective than a conventional air ventilated suit at maintaining thermal comfort. The differences were small however and both systems produce acceptable control of thermal stress. Beeny and Short (1973) report the initial development of a liquid conditioning assembly for use in extremely hot and wet environments (70°C dry bulb - 65°C wet bulb) and embodied in the cooling circuit a breathing air heat exchanger. Conclusions from this investigation were that the liquid conditioning assembly gave adequate protection to a subject performing simple tasks under the specified environment for 30 minutes.

The system has also been adopted for the American space programme as the best means of removing the heat production of an active astronaut, Johnson et al (1966).

For the wearer to retain full mobility, self contained portable cooling units using water ice or solid carbon dioxide are necessary. These weigh when charged up to 9Kg and a maximum duration of 80 minutes was reported by London (1969). They must however, be carried by the wearer by hand or on the body. This could prove a major disadvantage in areas of limited access

Also the system cannot remove moisture and the clothing under some conditions will become moist from sweat and/or condensation and this is considered to be some significant physiological disadvantage. When used in contaminated atmospheres where ambient air must be kept outside protective clothing, auxiliary respirable air would also have to be supplied.

9.3 Dynamic Insulation Systems. Air ventilated protective clothing can be classified in two distinctive systems. In one the cool air flows parallel to the body surfaces and escapes at specific points such as the ankles, wrists or neck or if impermeable materials are used, at filter points designed into the garment: this system is called axial ventilation. Where the air passes through a fabric in the opposite direction to the flow of body heat the system is defined as dynamic insulation. The following diagrammatic cross section of an impermeable fabric (right) and a permeable (left) shows the route taken by air which is circulating in a clothing assembly.



y passing out through the fabric the ventilating air can pick up and carry away from the wearer four to five times as much heat as it could do by being directed to specified ventile positions - Crockford (1962b). This system also has an advantage in so far that the ventilating air is also used to dissipate heat flowing in from the elevated ambient environment as well as cooling the body.

Air permeable materials facilitate the entry of air and convective heat exchanges can take place. This alternative approach to insulation can be used to set up a heat counter-flow system in the fabric e.g. as heat is conducted along the fibres, through the air and radiation is absorbed by the fibres and converted into heat, that air itself is ventilated out through the material against the flow of heat. This sets up a dynamic situation in which heat is picked up by the air and removed to the environment. The thermal resistance to heat flow through such an assembly is not only dependent on the thickness of the material but also on the rate at which air is flowing through it. By using this approach it should be possible to prevent all heat penetrating the fabric and achieve infinite thermal resistance provided the air flow through the fabric is fast enough.

The function of a clothing fabric is to stabilise a layer of air between the environment and the wearer. The processes which are responsible for the transfer of sensible heat across a material are convection currents in the trapped air, conduction through the air and along the fibres, and radiation either directly through the fabric or by secondary radiation. There is no well defined outer boundary to a woven or knitted material, the density of the fabric increases towards the central portion and for that reason, the effective thickness must be measured between two flat surfaces under a stated pressure.

Air trapped in materials themselves and a boundary layer of still air on either side can be responsible for thermal insulation. When air movement is increased the boundary layer is eroded and the thermal resistance of the system falls, eventually moving air may even penetrate the fabric so facilitating convective heat transfer within it. A tightly woven material will prevent this from happening. Radiant heat can also be effectively absorbed by densely woven materials. With static insulation the maximum insulation is determined by the maximum thickness that can be worn, the value of dynamic insulation is determined by air flow and this thickness barrier can be reduced. The dynamic insulation of an air ventilated heat protective assembly can be tested by applying a standard heat load and measuring heat flow through, and the temperature gradient across the material with different air flow rates. This method of evaluation is discussed in Chapter 2.

The effectiveness of ventilated suit assemblies suitable for specific purposes has been examined by Webb (1956), Billingham and Phizackerley (1957) Phizackerley (1958) and Crockford and Hellon (1963a) (1963b). Theoretical studies by Spells (1956) (1960) and (1961) and Spells and Blunt (1962) and (1965) have all contributed to the application of the dynamic insulation effect.

Air hoses are also vital to the success of any ventilated clothing assembly which is going to be used for deep penetration into a hot working environment. A rise in air temperature in the hose can defeat the correct functioning of the cooling system and most air hoses do not provide a great deal of protection, rises of 3°C per m run occurring in very hot environments at flow rates of 14 to 24 l/sec, even in thick walled hoses. In order to maintain mobility the air hose must be capable of being handled easily.

The solution to this is to cool the air just prior to entry to the ventilated suit. For this purpose a compact device is essential.

avies J (1976) has reported on such a device using the principle of the Danque Hilsch cooling effect, together with an associated air hose assembly and this report forms Appendix B to this thesis.

9.4 Electrical Conducting/Screening Protective Clothing. In some areas of the world maintenance work is carried out on very high voltage equipment, particularly on overhead transmission lines with the lines still live. To protect the worker a suit of conductive material is worn which forms a Faraday cage. The Suit is manufactured with conductors woven into the material to form a mesh screen. In order to give protection a Faraday cage must form a complete conducting surface surrounding the wearer and with only small openings. The suit may conveniently be made in one piece or two, in the latter case the two parts must be electrically connected together by the use of press studs or by having on the two parts of the garment conductive tie ribbons. For the feet conductive footwear should be worn and it is preferable to have conductive socks inside the footwear. Such socks may be formed of a material which may be similar to that used for the suit, which can be electrically connected to the material of the suit by press studs or similar fastening. Similarly, conductive gloves are required and would be electrically connected to the cuffs of the suit. To cover the head a hood should be formed integrally with the suit, this being arranged as far as possible to cover the front of the face whilst leaving a suitable small opening for the wearer to see through.

The material used for the suit should also have a flame retarding property and should be of lightweight material to enable it to be worn underneath ordinary protective clothing, thereby minimising any possibility of accidental tearing of the screening suit.

When a screening suit is used, the wearer, on first approaching the live line must make an electrical contact and a very heavy charging current may flow for a short time through the terminal on the suit through which

contact is made. It is therefore important to note that any differences of potential between parts of the suit would cause currents to flow through the wearer. Looms (1969) states that there appears to be confusion in the literature between the properties as shields of Faraday cages, conducting suits and ideal closed conductors. All real Faraday cages and conducting suits should have finite resistances and inductances. Their surfaces are therefore not equipotential when they carry currents arising from capacitance, corona charging at contact or flash over. It follows that the degree of protection afforded by a screening suit decreases as the ohmic resistance and inductive reactance of the suit increases. Again since the current carrying ability of the flexible wearable material cannot be expected to approach that of a solid wire or bar cage, it is necessary for the possibility of large volt drops between the extremities of the suit to be minimised by the use of a single point connection to the screen. It is therefore suggested that the resistance between extremities and connection terminal of a screening suit should not exceed 25 ohms and that a suit should be able to carry 1A for one minute to accommodate emergency situations. It is possible that future system voltages may be of megavolt order; uncomfortably large electrical fields arise at ground level in substations operating at 735kV and the standardisation of protective conducting clothing may be considered a desirable prerequisite in the future.

The progressive development of a protective clothing assembly for personnel working in contact with high voltage conductors and against electric currents caused by conductor corona leakage, charging and discharging is described in Chapter 2.

1.10 Conclusion. It can be argued that plant should be designed and operated in such a way that personnel are never called upon to work under abnormal or hostile conditions. However not only could the

conomics of this approach be unfavourable compared with the cost of personal protection for the operatives, but also the redesign of plant and the design of machines to do particular jobs takes time and is expensive. It therefore, has to be accepted, that as far as working in unfavourable environments is concerned, the human is always going to be at risk and there will always be a continued demand for the protective equipment which is required to sustain humans in these environments. Once ideal personnel protection is available and accepted plant may be designed and operated if necessary within the limits of the protective equipment and not within the more exacting limits imposed by the human physiology.

CHAPTER 2

EXPERIMENTAL WORK AND RESULTS

2.1 Introduction and Summary of Previous Work. The originator of this thesis was a member of a study group set up in 1965 by CEEB to consider the requirements for protective clothing to enable work to be carried out in hot environments. In a report published in December 1967 it was concluded that clothing giving protection for prolonged periods in environments at temperatures up to 60°C was desirable. As no suitable equipment was available commercially a suit was developed in conjunction with Frankenstein Ltd. The assembly was to use a vortex tube for both cooling and breathing air. The suit was evaluated up to 80°C in the climatic cell at the Institute of Aviation Medicine, Farnborough, Fig 2.1. Field trials of manoeuvrability were carried out in the Magnox prestressed concrete pressure vessel, Fig 1.8. described in Chapter 1. The report of the study group, in view of its limited published circulation, is included in its entirety as Appendix C to this thesis.

The management responsible for the operation of the magnox prestressed concrete nuclear reactors imposed a further limitation on human access to 50°C and with the improvement of reactor cooling techniques the proposals of the working party were unable to be fully evaluated. With the advent of the Advanced Gas Cooled Nuclear Reactor System and the demise of the involved commercial manufacturing companies for the personnel protection system, a reappraisal of the earlier work became necessary. A personal accountability was placed upon the originator of this thesis to produce acceptable standards of design and performance for a hot environmental work suit and associated equipment to meet the new environmental access conditions anticipated in the AGR systems.



PROTOTYPE H-E SUIT UNDER EVALUATION

The following sections of this chapter describe some of the background work to these investigations together with parallel work in the development of protective clothing for use in working areas of high electrical field intensity. The principle of dynamic insulation of an air ventilated suit assembly for use in environments up to 60°C is reported on the basis of material insulation characteristics relative to air flow and thermal conductance by application of a standard intensity of radiant heat, together with a series of laboratory bench tests associated with the development of two designs of vortex tube for use with the clothing assembly. The use of thermography is also demonstrated as a means of establishing heat flow characteristics. Complementary work on the development of an ambulatory event physiological data acquisition/monitoring system is also given.

The chapter concludes with the results of field investigations on the use of the resultant designs of protective clothing and ambulatory monitoring systems when used on the training programmes for human access to Advanced Gas Cooled Nuclear Reactors (AGRs).

2. Protective Microclimates have been used in industry for many years to protect workers against various hostile conditions. This section describes a series of investigations; development and experimental work conducted to establish the design of an air ventilated clothing assembly for use in heated work environments up to 60°C for a particular application, the entry into the pressure vessel of Advanced Gas Cooled Nuclear Reactors, together with the progressive development of materials for conductive/insulating clothing for use in work areas of high electrical field intensity.

2.1 Hot Environmental Work Suit. The clothing assembly is shown in Figs 2.2 and 2.3 and consists of three pieces. (a) A one piece outer garment constructed from close cotton woven fabric, physical properties as shown in Table 2.1. The garment has a front entry closed with a slide fastener, the sleeve and trouser ends are elasticated ^{internally} to prevent escape



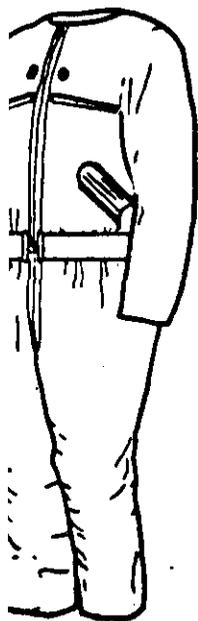
H.E. SUIT
ASSEMBLY
FRONT VIEW



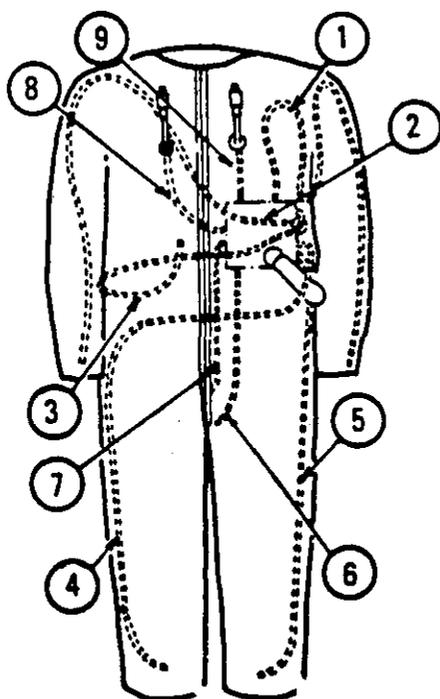
**H-E SUIT
ASSEMBLY
REAR VIEW**

air at the points, The surface area of the garment is approximately 2.12m^2 and designed to fit over, without constricting or crushing, (b) An inner garment manufactured from open cell nitrogen blown polyurethane foam, density 3.8 to 5Kg/m^3 covered on both sides with lightweight nylon fabric. Inside this garment is fitted a removable air distribution cooling system as shown in Fig 2.4. Seven outlets from the distribution manifold lead to supply to the body, arms and legs through 6.5mm bore plastic tubing, the air passing into the suit through small vent holes pitched from the sealed ends of the tube. Two supply plastic tubes of 10mm bore lead air from the manifold to the air distribution system in the helmet for cooling and breathing. At an air flow of 0.012 Kg/s the cool air distribution in the suit is designed to give 50% (0.006 Kg/s) to the arms, legs, body, back and groin (cooling tubes 1 to 6) 10% (0.0012 Kg/s) to body front (cooling tube 7) and 40% (0.0049 Kg/s) to the helmet assembly (cooling tubes 8 to 12.) The surface area of this inner garment is approximately 1.83m^2 . The helmet assembly fastened to the outer suit by three slide fastener closures is (c) a helmet assembly. This has a moulded perspex visor with a liner of the same material as the inner suit and an outer covering of the same material as the suit giving a permeable surface area of 0.214m^2 . The total permeable area of the complete assembly is approximately 2.33m^2 its function being both mechanical protection and thermal insulation. Air is fed to the suit for two primary purposes, namely breathing and cooling, and as a common supply is used the quality of the air must meet the requirements of breathing air as detailed in British Standard 4275. The basis of the system design is to ensure that the air brought into contact with the body facilitates heat removal from the body by the increase in sensible heat of the air and by the evaporation of sweat swept away by the air. The metabolic heat generated depends upon a wearer's activity level, and there may also be transmitted through the suit radiant heat from the environment.

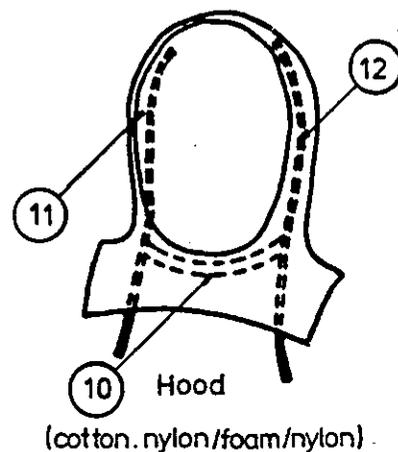
FIG. 2.4



Outer suit
(cotton)



Inner suit
(nylon/foam/nylon)



Hood
(cotton, nylon/foam/nylon)

TOTAL SURFACE AREA

•	•	•	Inner suit	2.33m ²
•	•	•	Outer suit	1.83m ²
•	•	•	Outer suit	2.12m ²

* Air distribution in suit

Inlet air pressure to vortex	4 bar
Inlet mass air flow	0.025Kg/s
Inlet air temperature	50°C
Cool air flow to suit	0.012Kg/s
Cool air temperature	15°C

Cooling tube details

Tube reference		Length mm	No. of holes	Pitch mm	Air * distribution Kg/s
No	Position				
1	Left arm	1350	10	114	0.0059
2	Right arm	1575	10	117	
3	Back body	1125	10	100	
4	Right leg	1550	14	117	
5	Left leg	960	18	61	0.0012
6	Grain	495	8	100	
7	Front body	300	10	38	
8	Hood connection	266	0	—	
9	Hood connection	170	0	—	0.0049
10	Hood front	300	5	50	
11	Hood right	350	5	50	
12	Hood left	350	5	50	

AIR DISTRIBUTION SYSTEM
FOR PROTOTYPE HOT ENVIRONMENTAL WORK SUIT

Based on some of the following experimental investigations,

the heat balance for the wearer and the suit is discussed in full in Chapter 3.

Physical Properties	Fabric Type		
	Cotton L28*	Nylon No 556**	PU Foam
WEAVE	OXFORD	PLAIN	-
Weight g/m^2	340	60	2.5
Breaking Strength Kp			
warp	80	20	-
weft	70	20	-
Threads/cm			
warp	64	16	-
weft	25	16	-
Air Permeability			
$\text{cm}^3/\text{cm}^2/\text{SC}$	0.2	52.0	20.0

Specification UK/AID/926

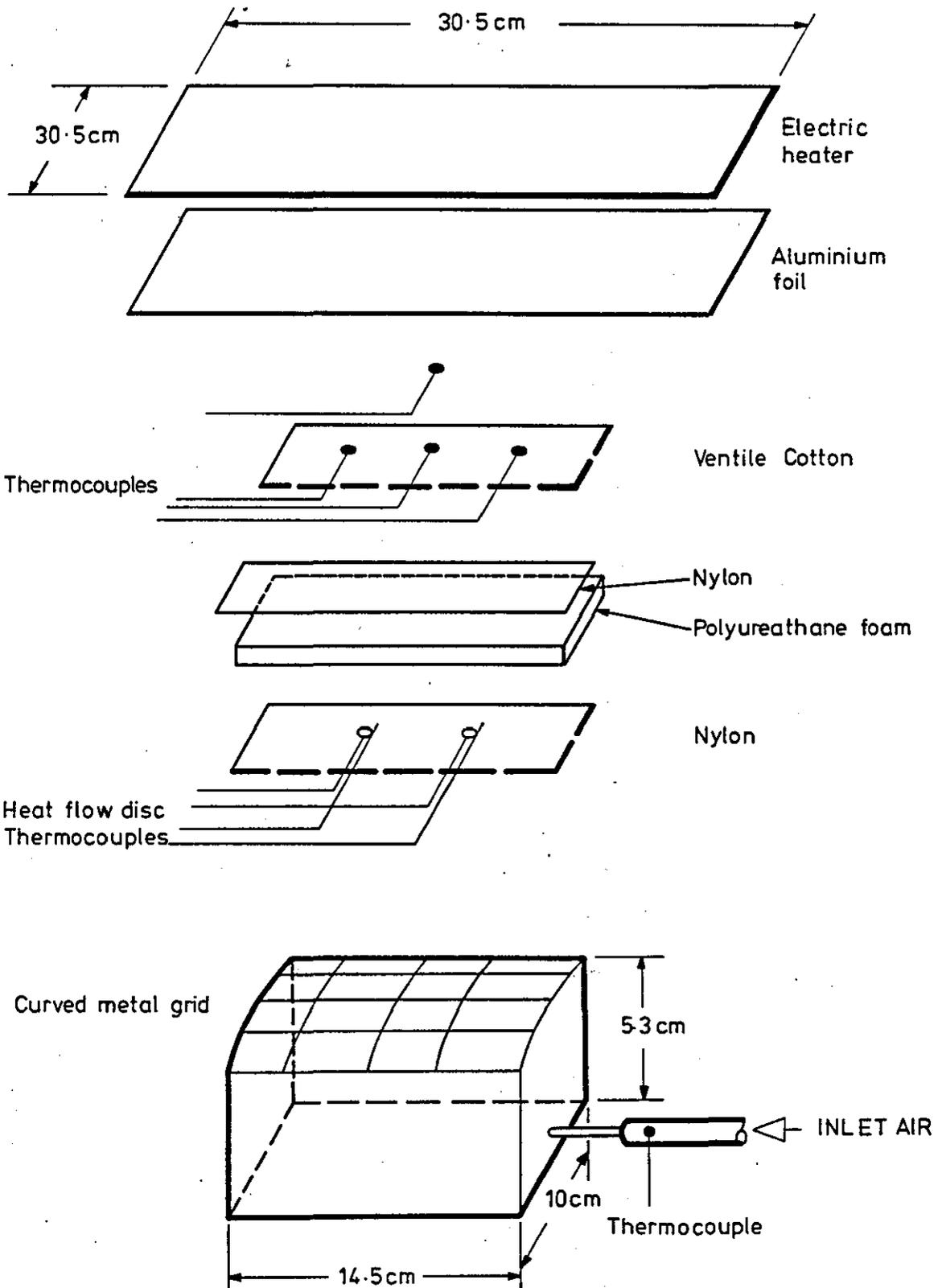
Specification BS F118

Table 2.1 Physical Properties of Fabric HE Suit

One of the functions, indeed probably the principal function of clothing materials, is to provide thermal insulation for the body of the wearer. A textile fabric is a heterogeneous system consisting of a mixture of textile fibres and entrapped air. The bulk density of the fabric, the state of aggregation of the fibres and the mode and magnitude of the yarn spacings are of far greater importance than the nature of its constituent fibres in determining the degree of insulation provided by the fabric. A variety of units are used to express the thermal insulation of clothing materials. These are of two types, namely (a) the transmission or conductance units which express the quantity of heat which flows through a given area of material in unit time under specified temperature difference and (b) the resistance units which are the reciprocal of the

transmission units. In dealing with clothing problems the resistance values of material to heat flow are considered more useful than their heat transmission values since the resistance to heat flow of the various layers in a clothing assembly can be added together to give the total thermal insulation value of the whole system. There are two specially named units of thermal resistance in current use in the field of clothing biophysics and physiology. These are the Tog: Rees (1946) Newburgh (1949), Gardener (1951), Kaswell (1953) and the Clo: Gagge et al (1941), Newburgh (1949), Gardener (1951), Kaswell (1953) and Burton and Edholm (1955). The Tog is a physical unit of thermal resistance defined in terms of measurable physical quantities, the Clo is based upon human physiological factors though Rees (1971) states that the Clo unit can be expressed in terms of measurable physical quantities so that $1 \text{ Clo} = 1.55 \text{ Togs}$.

For this investigation the dynamic insulation characteristics of the materials used for the clothing assembly apparatus shown in Fig 2.5 are used. In this arrangement air can be fed through material assemblies placed in a metal grid of known surface area. The heater placed above the assembly acts as a radiant heat source and temperature changes can be measured with thermocouples and heat flow by heat flow discs, Heatfield and Wilkins (1950). The results of a series of tests using this apparatus are shown in Table 2.2. The heater voltage was set at a value which brought the outer surface of the material assembly to 60°C and 112°C . Air was supplied at 20°C , temperatures were measured by 40 swg copper/constantan thermocouples threaded into the inner and outer surfaces, two on each surface, and heat flow by two 5mm diameter heat flow discs fastened to the outer surface of the inner fabric layer of the assembly. Measurements were taken at a number of air flow rates as the flow was increased from zero and as it was returned to zero from the maximum. Readings obtained at



EXPLODED VIEW OF APPARATUS USED FOR DETERMINATION OF THERMAL CONDUCTANCE OF MULTI-LAYER FABRICS

each flow rate were averaged. It was noted that heat flow discs had some effects on the air flow through the fabric lying above them, the thickness of the assembly used in this study, 6.5mm, is however such that they do not appear to influence the results seriously. If however, the air stream quickly reformed behind the disc and any elevation of temperature above the disc was reduced by conduction to cooler surrounding material, the heat sink in this apparatus, the box itself, is small, thus enabling the system to respond quickly to changes of air flow.

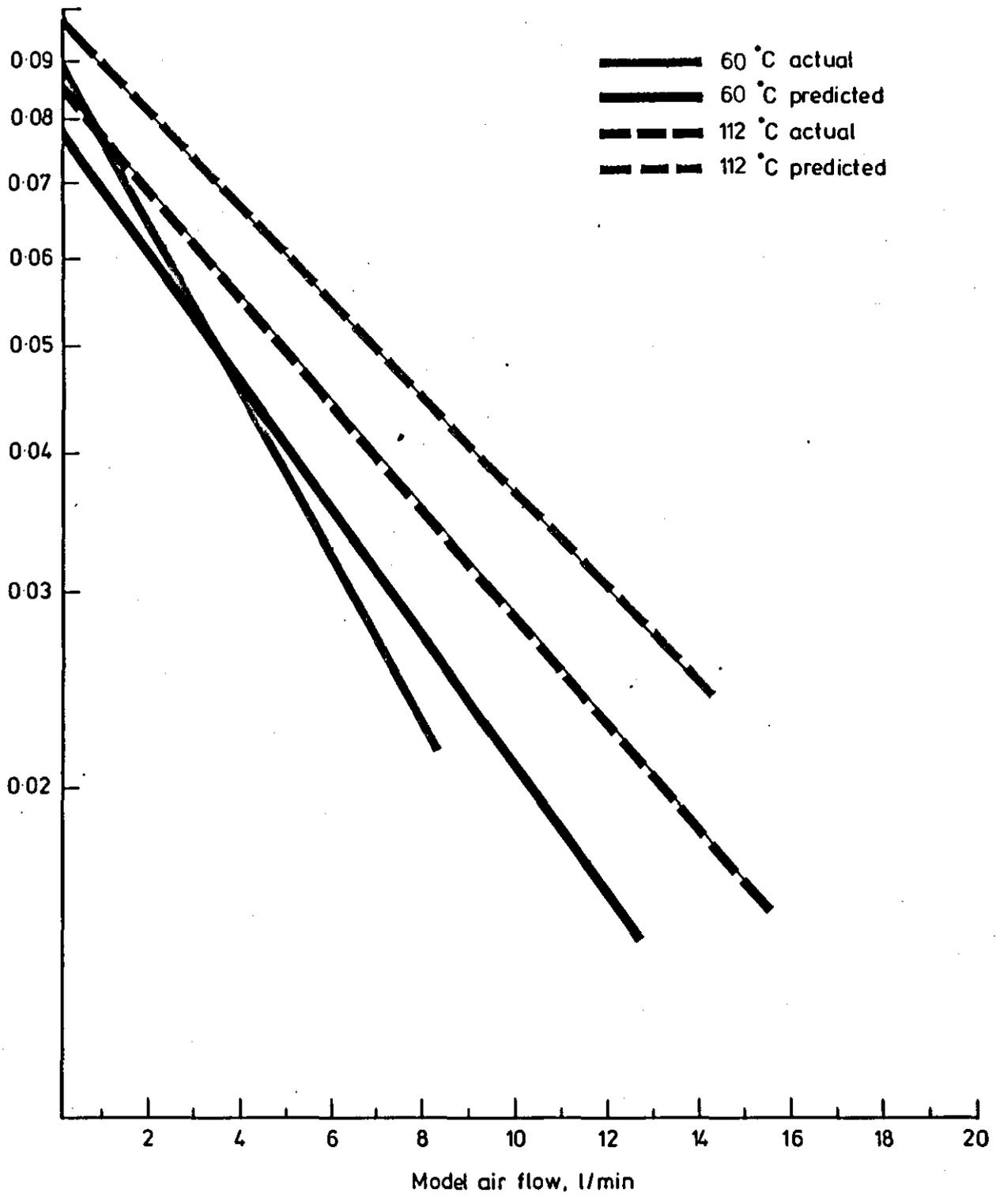
Air flow (l/min) (m/min)		Inner temp (°C)	Outer temp (°C)	Δt (°C)	Heat Flow w/m ²	Conductance (kcal/m ² min °C)
0	0	40.5	62.5	22.0	116.5	0.077
2	0.175	36.5	62.0	25.5	105.5	0.060
5	0.416	31.0	57.5	26.6	74	0.0406
10	0.833	27.5	48.5	21.0	30	0.0209
15	1.249	26.0	42.0	16.0	16	0.0144
20	1.666	25.0	38.5	13.5	9.6	0.0108
0	0	64.5	112.0	47.5	278	0.0850
2	0.175	57.0	110.0	53.0	253	0.0695
5	0.416	47.0	106.0	59.0	203	0.0502
10	0.833	37.5	86.5	49.0	94	0.0280
15	1.249	33.0	76.0	43.0	51	0.0171
20	1.666	31.5	66.0	34.5	33	0.0141

Table 2.2 Conductance of Garment Materials at 60 and 112°C

Initial Outer Surface Temperatures.

The conductance of the assembly increases as expected with the increase in the radiant load, but at both heat loads there is an unexpected change in the conductance curve at high rates of air flow. The increase of 8.6% in the static thermal conductance between 60 and 112°C is suggested to be due to the increase in thermal conductivity of air which would account for about 8.6%, and to increased radiant heat transfer as the temperature gradient across the assembly is increased from 22°C to 48°C. A predicted dynamic insulation curve for the material assembly is shown in Fig 2.6 for comparison, calculated from the following given by Crockford and Judge (1970).

Conductance kcal/m² min °C



RELATIONSHIP BETWEEN CONDUCTANCE OF MATERIAL ASSEMBLY AND PREDICTED VALUES AT 60°C AND 112°C

$$y = \frac{(\log t + 0.2785)}{1.0755} - (0.0453 + 0.0719t)x$$

where y = the conductance in $\text{Kcal m}^{-2} \text{ m}^{-1} \text{ }^\circ\text{C}^{-1}$

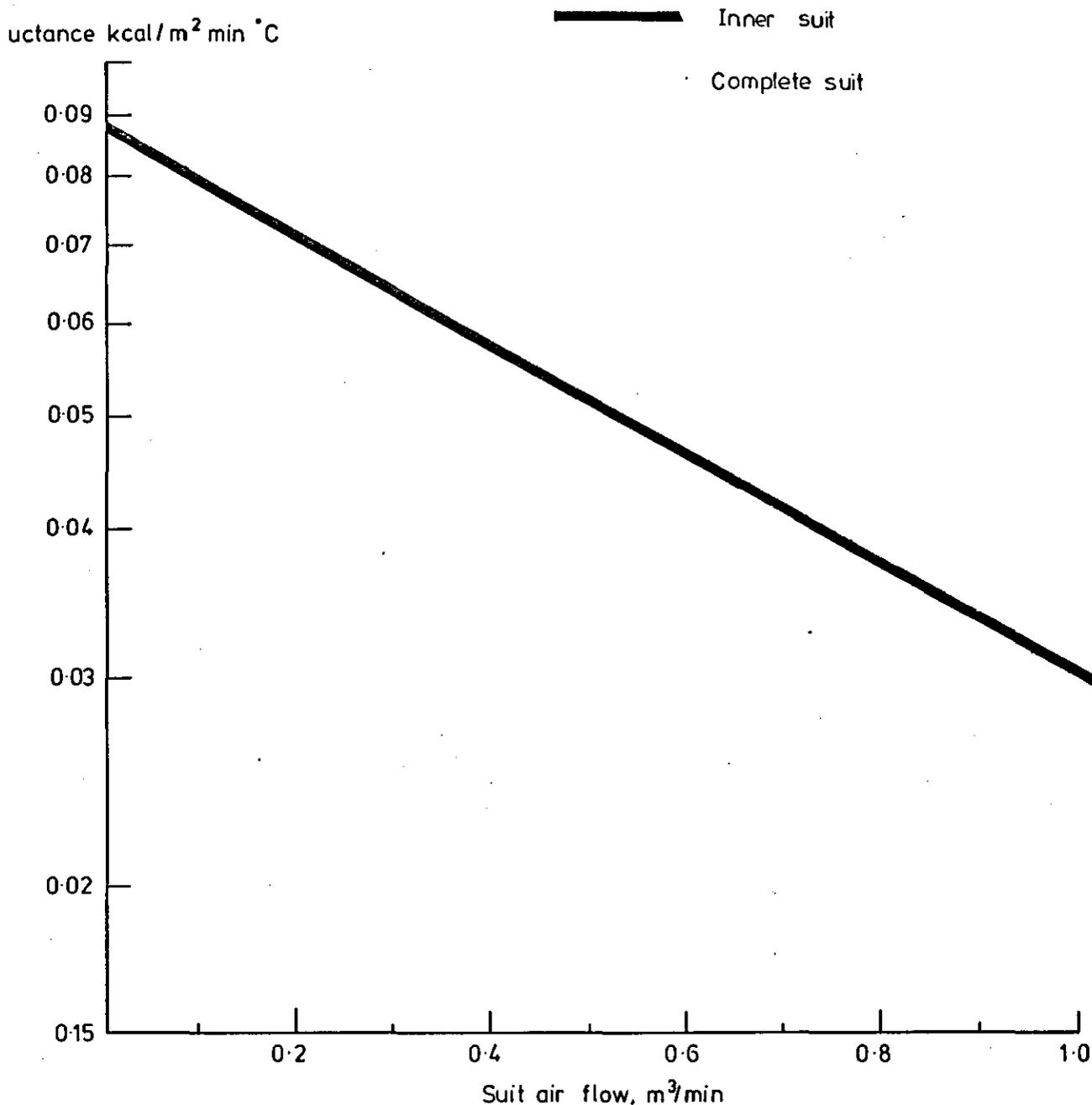
t = the thickness of material assembly mm

x = the air flow in m min^{-1}

The thermal conductance of the complete assembly was determined by applying a standard intensity of radiant heat to the outside of the suit by a manikin in a hot room and measuring the temperature on the inside and outside of the suit with thermocouples and the heat flow through materials by heat flow discs. Four thermocouples were placed in close proximity to the heat flow discs on the inside of the inner garment. The inner surface temperature was measured at the chest, abdomen, right and left lumbar region and back. The assembly was tested at 5 air flows in the order 0.13, 0.26, 0.40, 0.54 and $0.70 \text{ m}^3/\text{min}$ for 10 min each flow sequence being repeated five times and the values given in Table 2.3 are the mean of the thermocouple readings at each site. The curves are plotted in Fig 2.7 showing the conductance values for the assembly.

	Air Flow		Air Temp ($^\circ\text{C}$)	Outer Surface Temp ($^\circ\text{C}$)	Inner Surface Temp ($^\circ\text{C}$)	Δt ($^\circ\text{C}$)	Heat flow Wm^2	Conductance ($\text{kcal/m}^2 \text{ min } ^\circ\text{C}$)
	(m^3/min)	(m/min)						
Complete Suit Assembly	0.130	0.065	41.50	57.25	43.50	13.75	50	0.0525
	0.263	0.131	37.50	56.75	41.50	15.25	54	0.0514
	0.409	0.204	36.50	57.00	39.00	18.00	53	0.0448
	0.542	0.271	30.50	56.00	36.50	19.50	54	0.0402
	0.700	0.350	30.00	54.00	34.25	20.25	49	0.0351
Inner Suit Only	0.130	0.065	36.00	57.25	45.50	11.75	63	0.0782
	0.263	0.131	29.00	56.25	41.25	15.00	69	0.0668
	0.409	0.204	26.50	56.75	39.25	17.50	67	0.0560
	0.542	0.271	24.50	56.50	38.00	18.50	62	0.0479
	0.700	0.350	23.00	54.00	35.00	19.00	57	0.0440

Table 2.3 Averaged Results of 5 tests for Conductance of the Complete Suit Assembly and Inner Suit Only at a Radiant Temperature 60°C



THE RELATION BETWEEN THE AIR FLOW/ THERMAL CONDUCTANCE FOR COMPLETE SUIT ASSEMBLY AND INNER SUIT ONLY

The inner garment was then tested alone. The averaged results obtained are shown in Table 2.3 and Fig 2.7. With the outer garment removed because of the very low permeability of the inner suit the thermal conductance of the assembly increased substantially due to the loss of the insulating layer of air. At the higher rates of air flow it is noted that the conductivity of the inner suit approaches that of the complete assembly presumably through its higher initial conductance and the increase in the efficiency with which the ventilating air is used in dynamic insulation (see Fig 2.7).

The object of these investigations was to test for the establishment of dynamic insulation in a clothing assembly by determining its thermal conductance at a number of different air flows. The air flow/conductance curve Fig 2.6 indicates that dynamically insulation was established. This observation however indicates that dynamic insulated suits may only be effective at reducing heat flows through the suit outer fabric if they are used beyond the air flows at which dynamic insulation is counter balanced by an increase in temperature gradient across the garment. The air flow required to achieve this depends on the garment but with the assembly tested no significant drop in heat entry occurred up to the maximum air flow used. This situation however could alter if the material of the outer garment was changed. The differences between the performance of the material assembly as predicted by the equation and the actual performance could be due to the radiant heat load influencing its conductance and with surface temperature 112°C and zero air flow a direct comparison with the formula was shown.

The lower static and dynamic conductance values compared with those predicted indicates that the material assembly used for the inner garment are more suited for dynamic insulation than those used in the experiments from which the formula was derived. Textile assemblies for dynamic insulation will therefore vary.

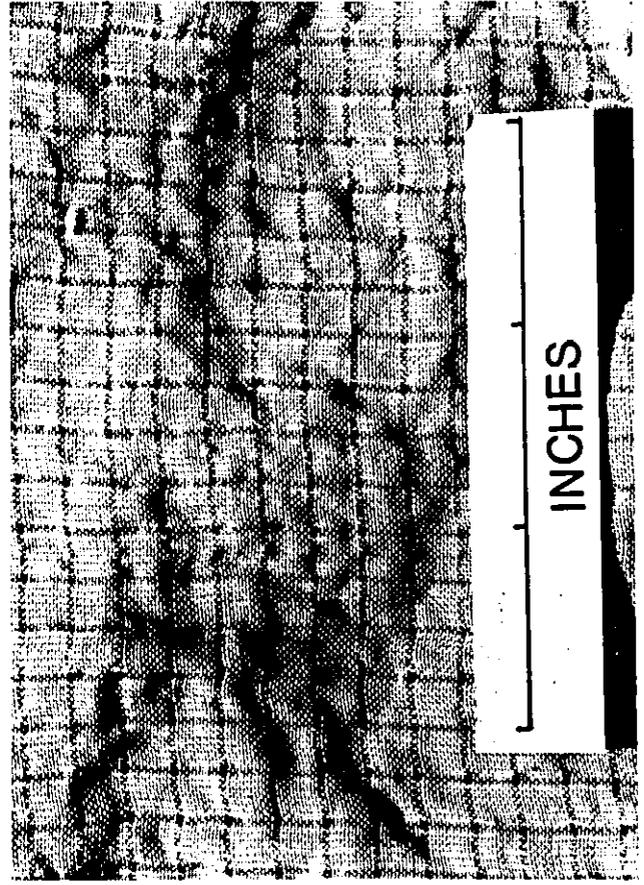
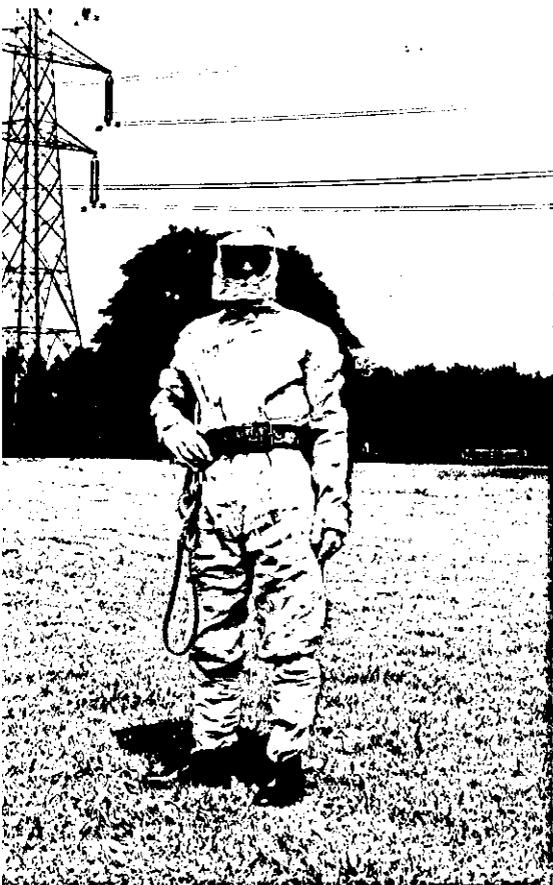
Following the completion of this series of investigations it as possible to draft a manufacturing standard CEGB (1977a) for a hot environmental work suit assembly for use with or without a vortex cooling tube. This is included as Appendix 'D'.

2.2 Conductive/Screening Protective Clothing. (Faraday Cage).

The initial investigation centered around the requirements for a protective clothing assembly to combat the pick up from the electrostatic field in the immediate vicinity of 400kV overhead line transmission towers or any environment where an inductance build up of electrical energy could occur to work people and when a subsequent earthing could result in a discharge above the threshold of feeling.

A number of enquiries were made to the textile, woollen and elastic industries to establish the availability of any fabric or material already being manufactured. Fashion fabrics were found which contained aluminium foil but in every case the foil had been coated with lacquer to prevent loss of its decorative aspect and its electrical conductivity was poor. Woollen/metallic materials examined gave spasmodic continuity figures which were due to the metallic fibre being in short staple form and pattern of conductivity could not be guaranteed. Conducting plastic compounds in tough flexible film form were also evaluated and although suitable from a conductive aspect garments produced from these materials could not be considered comfortable.

A material used for radar targets containing twin stainless steel solid wires each of 0.09mm diameter, woven into cotton in a 6.5mm mesh appeared to offer good electrical properties, and a suit was designed and manufactured from this material, Fig 2.8 suit A. and was used successfully on the first 'bare hand' maintenance operation in Europe on a live 400kV electrical conductor Jeffs (1969). The clothing assembly was however very uncomfortable to wear it was heavy and had to be lined to limit skin irritation.



Solid steel conductor
X 100

SUIT 'A' ASSEMBLY

articulation at the elbow, and knee positions were very restrictive. A difficulty in manufacture was the need to sew conductive material into all seams to maintain continuity of the conducting screen.

From these initial investigations it became evident that in order to guarantee the conductivity and to meet wearer acceptability it would be necessary for a textile/metallic material to be woven specifically for this purpose. Experimental weaving was put in hand for seven fabrics using on a 10mm square and 30 x 40mm rectangular lattice pattern a 12 denier/90 filament continuous stainless steel thread of the following specification:-

Number of filaments in thread	90
Filament diameter	12 micron
Thread diameter	0.1mm
Tensile strength	1.6 Kg to break
Electric resistance	0.8634 ohm/cm
Passing current in free air	1.5 amps

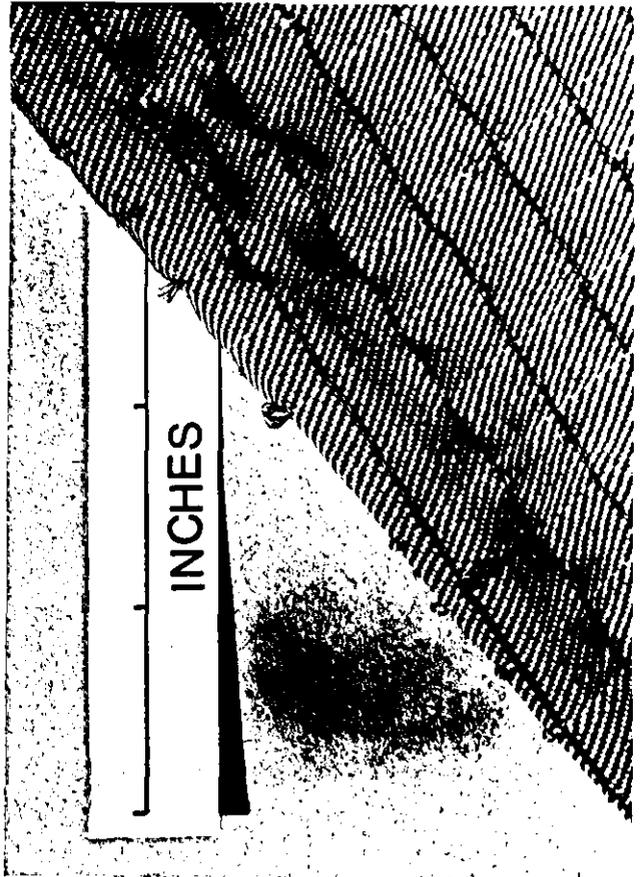
The base fabrics for these weaves included denim, nylon, rayon/nylon blend and polynosic rayon and the evaluation of these fabrics is shown in Table 2.4.

Production weaving of the cotton denim/stainless steel and polynosic rayon/stainless steel were commenced but the latter had to be abandoned because of weaving problems. In order to maintain continuity along the seams of any resultant garment a 12mm tape consisting of a stainless steel warp yarn with nylon weft was also manufactured.

The major problem arising from the weaving of the cloth was the dissimilar nature of the tensioning of the cotton yarn and steel thread producing a 'cockle' as shown in Fig 2.9. An alternative to the stainless steel therefore was desirable and a thread in the form of a 1% silver plated copper strip wound round a 75 denier textured filament nylon support, Fig 2.10, was used in experimental and production weaving.

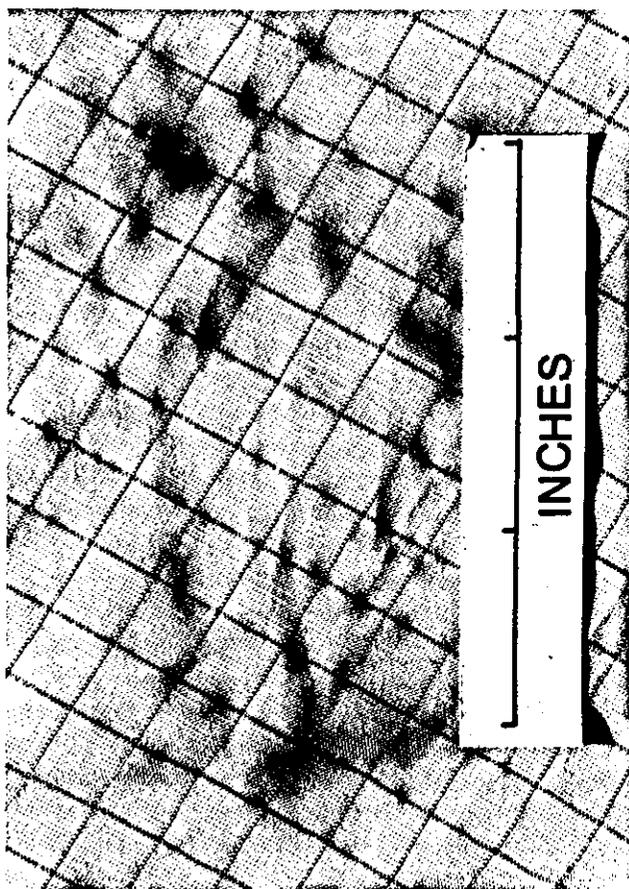
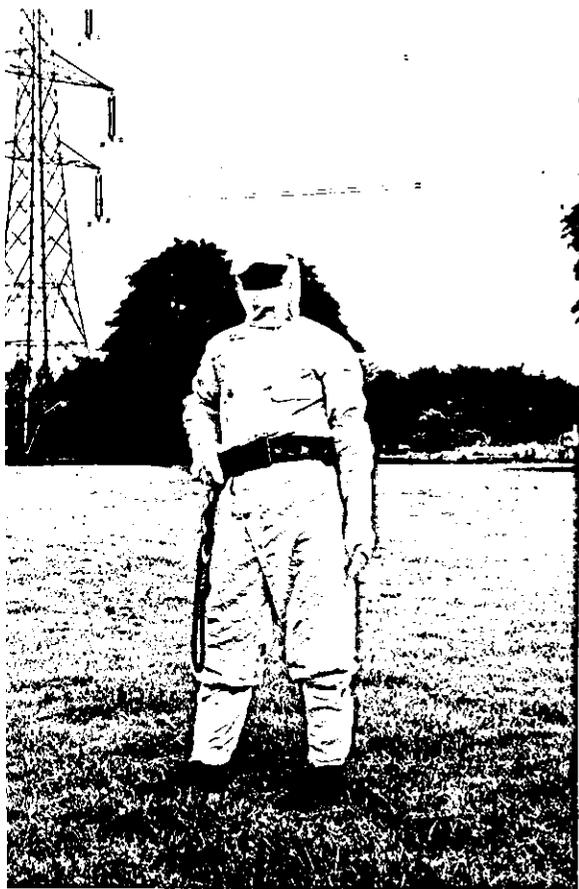
Position	Sample Number	Type of Material	Dimensions of Metallic Grid	Size of Cloth	Type of Weave	Resistivity ohm/sq metre	Stainless-Steel thread used to produce metallic grid	
1	D 58056/1	Denim	1 cm squares	20 cms	2 pick Weft Single Warp	5.36	Number of Strands in thread	90
2	D 58046/3	Polynosic rayon	1 cm squares	14 cms	2 pick Weft Single Warp	5.72	Strand Diameter	12 micron
3	D 58046/3	Nylon Rayon Blend	1 cm squares	16 cms	2 pick Weft Single Warp	7.10	Thread Diameter	0.1mm
4	D 58046/1	Nylon	1 cm squares	32 cms	2 pick Weft Single Warp	7.31	Tensile Strength	1.6 Kg to break
5	D 58056/2	Denim	1 cm squares	20 cms	Single Pick Weft. Single Warp.	9.51	Electrical Resistance	0.8634 ohm/cm
6	D 58056/4	Nylon	3 x 4 cm rectangles	30 cms	2 pick Weft Single Warp	19.8	Fusing Current in free air	1.5 Amperes
7	D 58056/5	Nylon	3 x 4 cm rectangles	30 cms	Single Pick Weft. Single Warp	44.7		

Table 2.4 Comparison of Conductive Cloth with Interwire Metallic Thread and the Properties of the 12/90 Stainless Steel Thread



Flexible steel conductor
X 100

SUIT 'B' ASSEMBLY



Textile supported
silver plated copper conductor
X100

SUIT 'C' ASSEMBLY

with denim and nylon base fabrics and proved very successful from electrical conductivity and cost basis. The cost of the silver plated copper conductor being 25% that of the stainless steel.

Garments were manufactured using the denim stainless steel blend Fig 2.9 suit B, and nylon/silver plated copper, Fig 2.10 suit C, and found general acceptance from the wearers. The problem of the use of tape in the conducting seam caused 'hot spots' when electrical current was applied to the suit. (See Section 2.4.)

Where there is a low propensity for static electricity build up, it has been the practise for sometime now to blend with natural and man-made fibres an electrical conductor in the form of a staple fibre. New metallic fibre technology makes available yarns spun from staple stainless steel fibre 75 - 150mm long, 12 micron diameter fibre giving all the characteristics associated with spun natural or man-made fibre yarns. These yarns are highly flexible and give good abrasion resistance and could be blended as slivers with any type of yarn using the sandwich blending technique in spinning.

Investigations revealed however that commercially available fabrics did not contain sufficient metallic content to meet the required electrical properties for conducting suits and it was necessary to blend higher ratio yarns, thus a 75/25% and 82/18% wool/steel blend were successfully spun and a cloth woven. Because of the conductive media in these materials it was possible to manufacture the suit shown in Fig 2.11. without taping the seams.

The following section summarises the evaluation of the materials for physical and electrical properties and the effectiveness of screening against electric fields.



SUIT 'D' ASSEMBLY

9.
 - a. INDIVIDUAL THREAD, 2/2 TWILL AS RECEIVED, 18% STEEL. MAG. X20.
 - b. DITTO, AFTER REMOVAL OF WOOL.
 - c. INDIVIDUAL THREAD, 2/2 TWILL AS RECEIVED, 25% STEEL. MAG. X20.
 - d. DITTO, AFTER REMOVAL OF WOOL.

Physical Properties were evaluated for the materials used for suits B, C and D using standard test methods. The results are shown in Table 2.5 and compare favourably with the performance requirements expected from standard commercial workwear materials used for protective clothing in more conventional work areas.

The distribution and measurement of the metallic staple fibre in suits D and D1 material was evaluated using a chemical washing technique, use being made of the fact that wool dissolves in solutions of sodium hydroxide. A known weight of cloth was heated in aqueous sodium hydroxide until all traces of wool were removed. The skeletal remains of the cloth consisting of the stainless steel fibres was washed, dried and weighed. From these weights the percentage steel content of the cloth was calculated. The two samples tested using this method were found to contain 23.5% and 17.8% respectively.

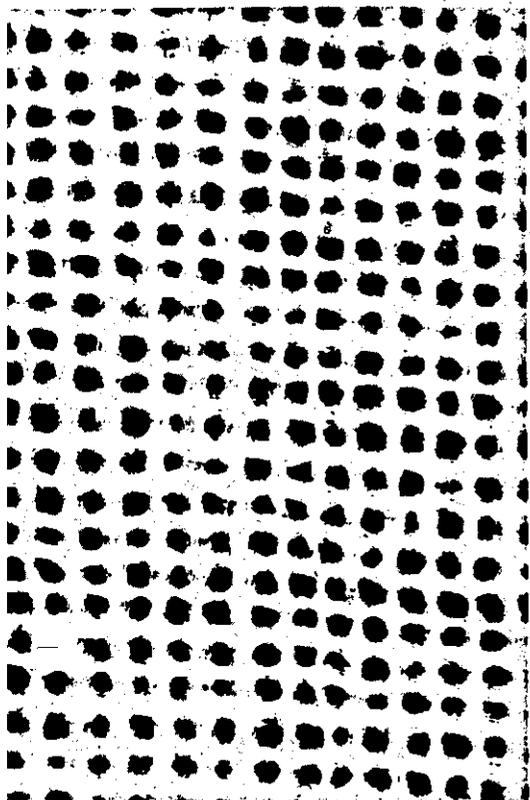
The visual examination of the woven steel mesh, after removal of the wool, is also helpful in assessing the uniformity of distribution of the metal fibres in the weave. A convenient way of conducting such an examination is to place the steel mesh between two glass plates in a photographic enlarger, the projected image being viewed under magnification and used to produce a photographic print.

The steel mesh that remains after removal of the wool had a tendency to roll up into a tight bundle that was difficult to mount between glass plates. This was overcome by securing the edges of the cloth specimen in a 5mm thick bead of cold-setting resin cement which, when set, has sufficient rigidity to act as a frame supporting the steel mesh and keeping it flat enough to be mounted. Two glass plates were then selected small enough to fit inside the resin frame.

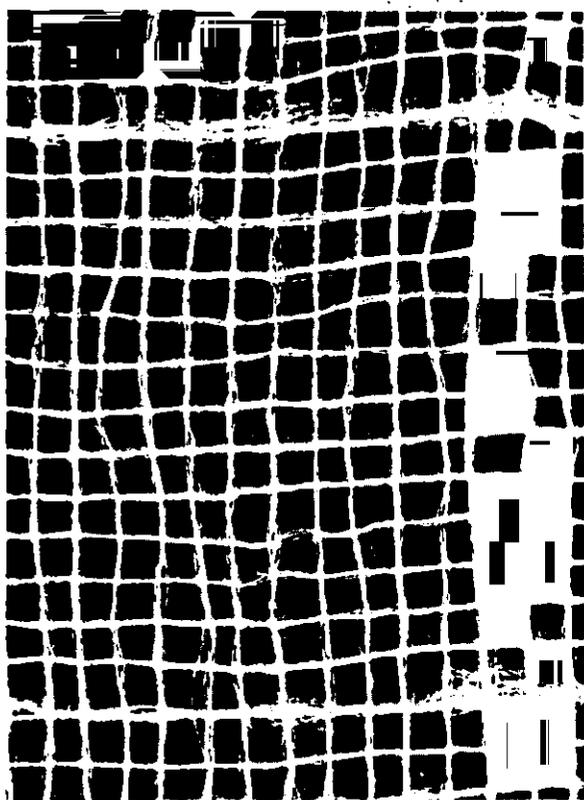
Some examples of the results that were obtained using these techniques are shown Fig 2.12.

PROPERTY	PERFORMANCE AND SUIT REFERENCE					TEST METHOD
	A	B	C	D	D1	
Base Fabric	Cotton	Cotton	Nylon	Wool	Wool	
Conductor	Solid	Flexible	Textile supported	Staple	Staple	
Blend	10mm mesh	10mm mesh	10mm mesh	75/25	82/12	BS 4407
Weave	Plain	denim	plain	2/2 twill	2/2 twill	-
Thread count						
warp	-	72	97	220	220	BS 2864
weft	-	49	91	193	193	
Weight g/m ²	281	255	128	215	215	BS 2471
Breaking Load N						
warp	-	1080	268	300	315	BS 2862
weft	-	680	220	290	280	
Abrasion resistance	-	25,000	50,500	23,000	23,500	BS Handbook No 11

Table 2.5 Physical Properties of Materials Used for Conducting/Screening Suits

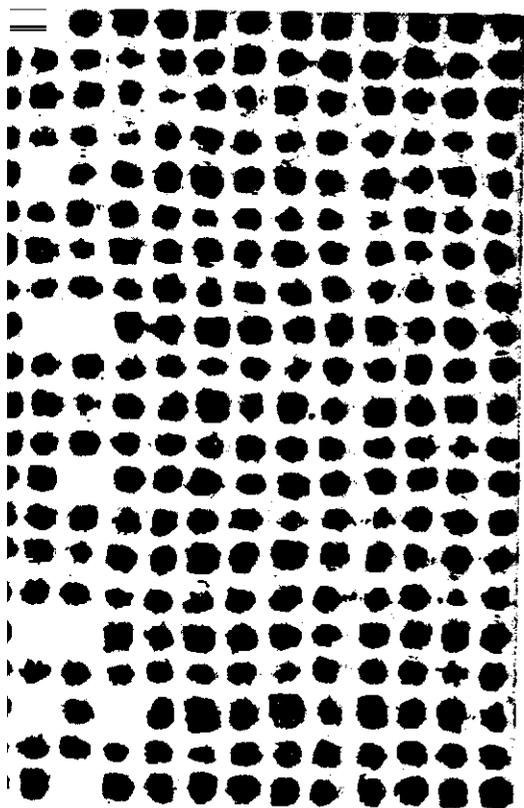


PLAIN WEAVE CLOTH AS
RECEIVED, 18% STEEL. MAG. X8

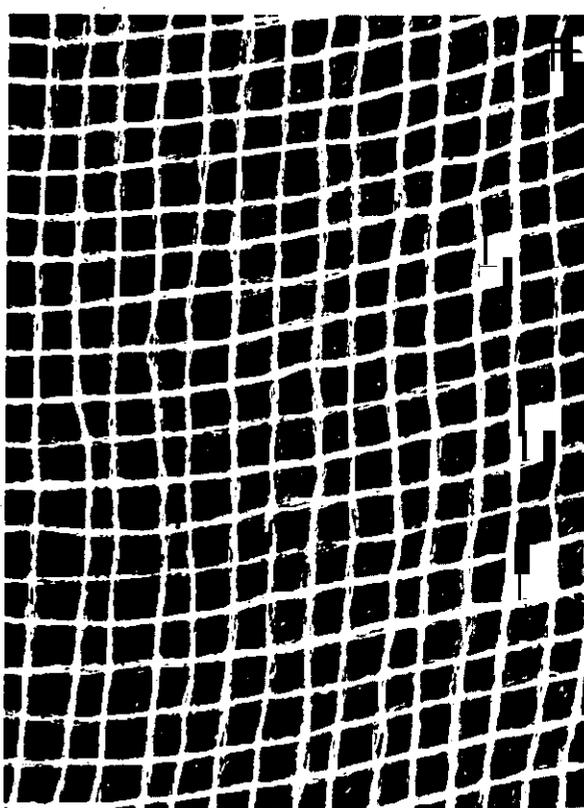


2. DITTO, AFTER REMOVAL
OF WOOL.

Fig 2-12



PLAIN WEAVE CLOTH AS
RECEIVED, 25% STEEL. MAG. X8



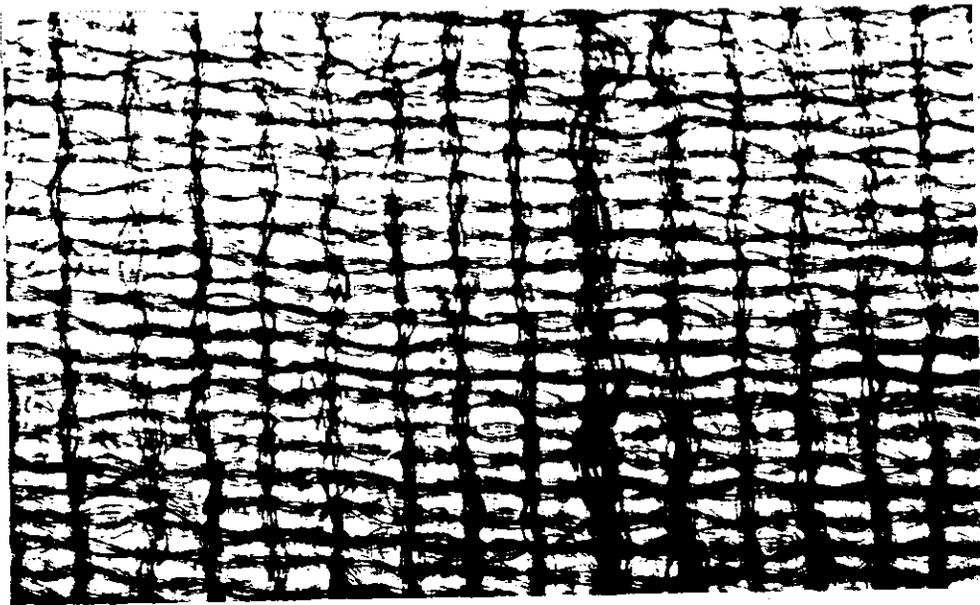
4. DITTO, AFTER REMOVAL
OF WOOL.

Where the base fabric is an Aramid fibre and cannot easily be removed without damaging the metallic fibres radiographs can be taken by modifying a back reflection Laue camera. The samples are attached to the front of the film holder which is placed some 175mm from the X-ray tube and exposed to the beam of X-rays for 4 seconds. The resulting film is printed under a magnification, X9. Fig 2.13 which shows the steel distribution of three textile/metallic blended materials.

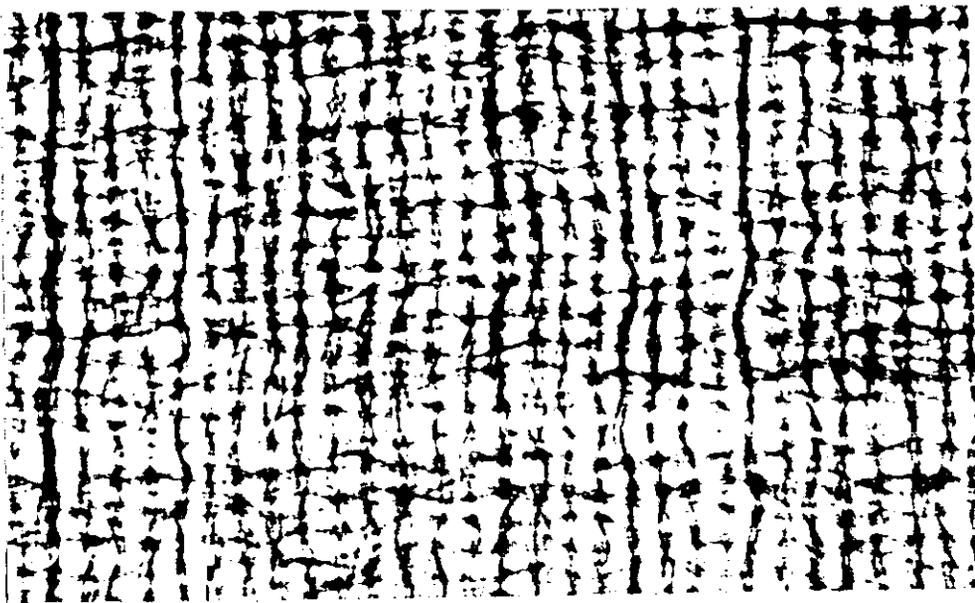
Electrical resistance of the conducting paths in the suits were measured using the ohms ranges of a Hewlett Packard type 3490A multimeter which provided a constant dc current of 1 milliampere, connections to the extremities being made using steel needles inserted at the measuring positions indicated in Fig 2.14. Initial measurements attempted with the suits stretched flat on a table and with a cardboard divider inserted in the suit showed that considerable variations in the resistance values rendered the results meaningless and that it was necessary to carry out the measurements while the suits were worn. The results of the test are given in Fig 2.14.

These preliminary measurements produced variations which indicated that the suit material required to be extended in order to obtain reasonably stable results. However when the suit was worn movement of the arms and legs produced variable values for resistance hence the results given are with the wearer of the suit remaining still. From these investigations a specified measurement of 25 ohms maximum could be stated as obtainable for each measured path for the materials of suits C, D and D2.

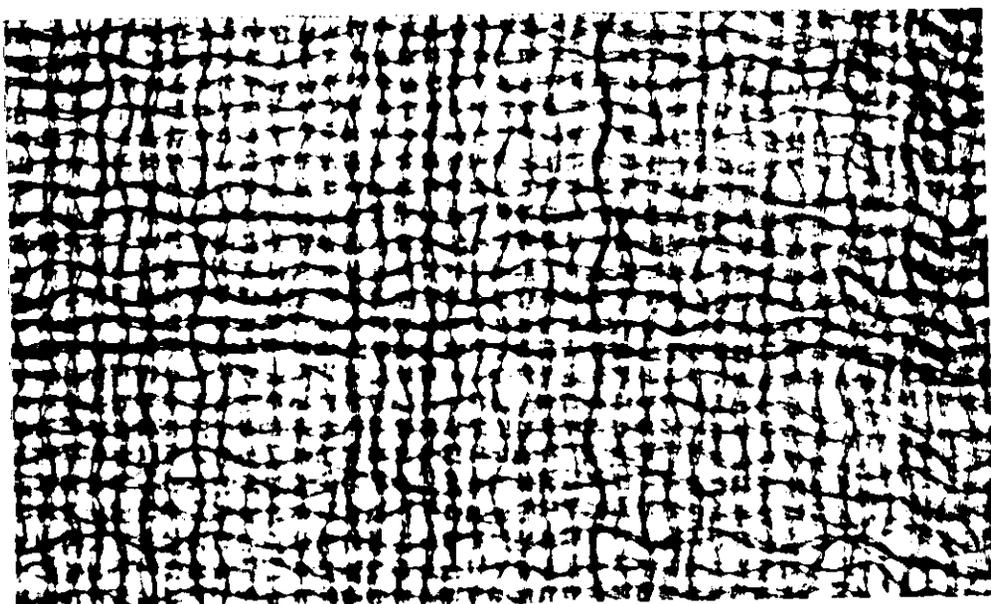
The effectiveness of the electrical screening of the materials used in the manufacture of suits A, C, D1 and D2 was found using the circuit arrangements shown in Fig 2.15; the separation between the plates being approximately 30mm. Readings were taken with no material present; with the materials earthed and laid on the melinex sheet above the guarding and detector plate; and with a sheet of aluminium foil in place of material.



18% STAINLESS STEEL/82% WOOL RADIOGRAPH (9X)



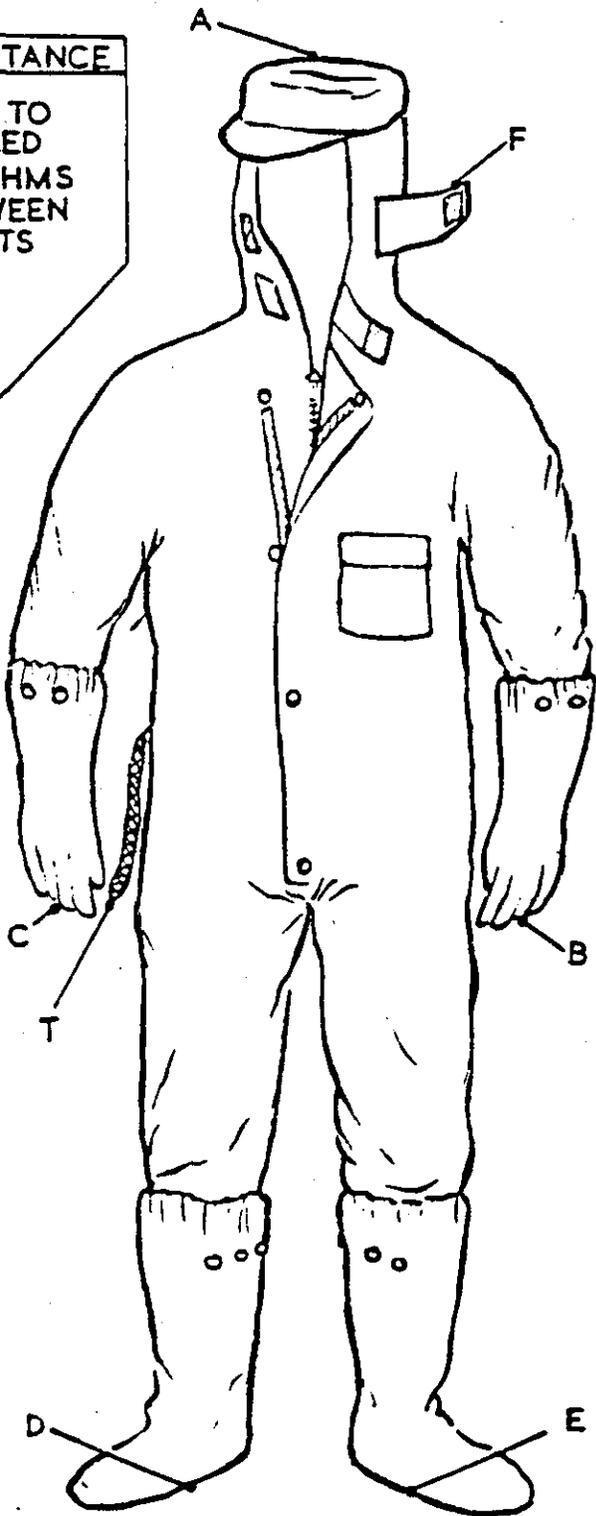
25% STAINLESS STEEL/75% WOOL RADIOGRAPH (9X)



25% "BRUNSMET"/75% "NOMEX" RADIOGRAPH (9X)

Fig 2:14

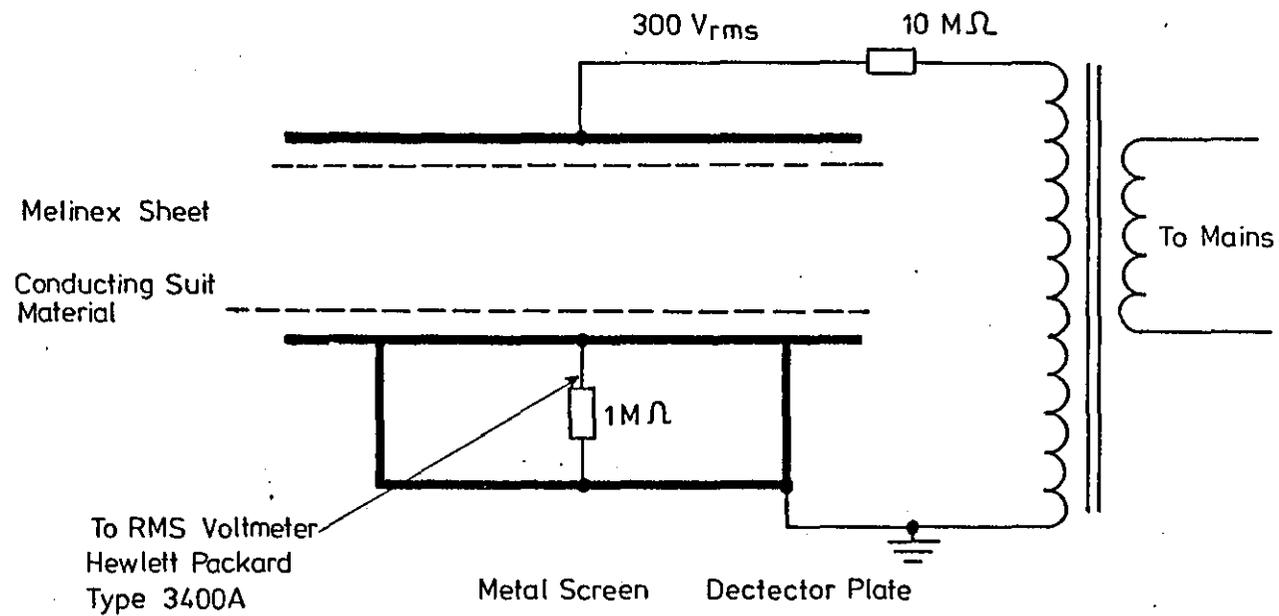
TEST POINTS	RESISTANCE
A - T	NOT TO EXCEED 25 OHMS BETWEEN POINTS
B - T	
C - T	
D - T	
E - T	
F - T	
B - C	
B - E	
C - D	



SUIT	TEST POINTS								
	A-T	B-T	C-T	D-T	E-T	F-T	B-C	B-E	C-D
A	300	95	100	100	160		240	55	150
B	11	98	200	38	8	511	200	130	145
C	8	17	25	7	16	11	27	34	14
D	12	12	9	12	15	21	18	13	14
D ₁	9	10	10	6	8	21	23	22	15

Values in ohms

RESULTS OF RESISTANCE MEASUREMENTS ON 5 CONDUCTING SUITS



CIRCUIT FOR SCREENING TEST ON CONDUCTING
SUIT MATERIALS.

The results are summarised in Table 2.6. Using the separation of 30mm, an effective field of 10 kV/m is established which approximates a typical electrical field encountered in the course of live line maintenance.

MATERIAL	CURRENT FLOW micro amps per square meter
NOTHING	30.5
Suit A	7.1
" B	7.4
" C	0.077
" D1	0.006
" D2	0.016
Aluminium Foil	0.002

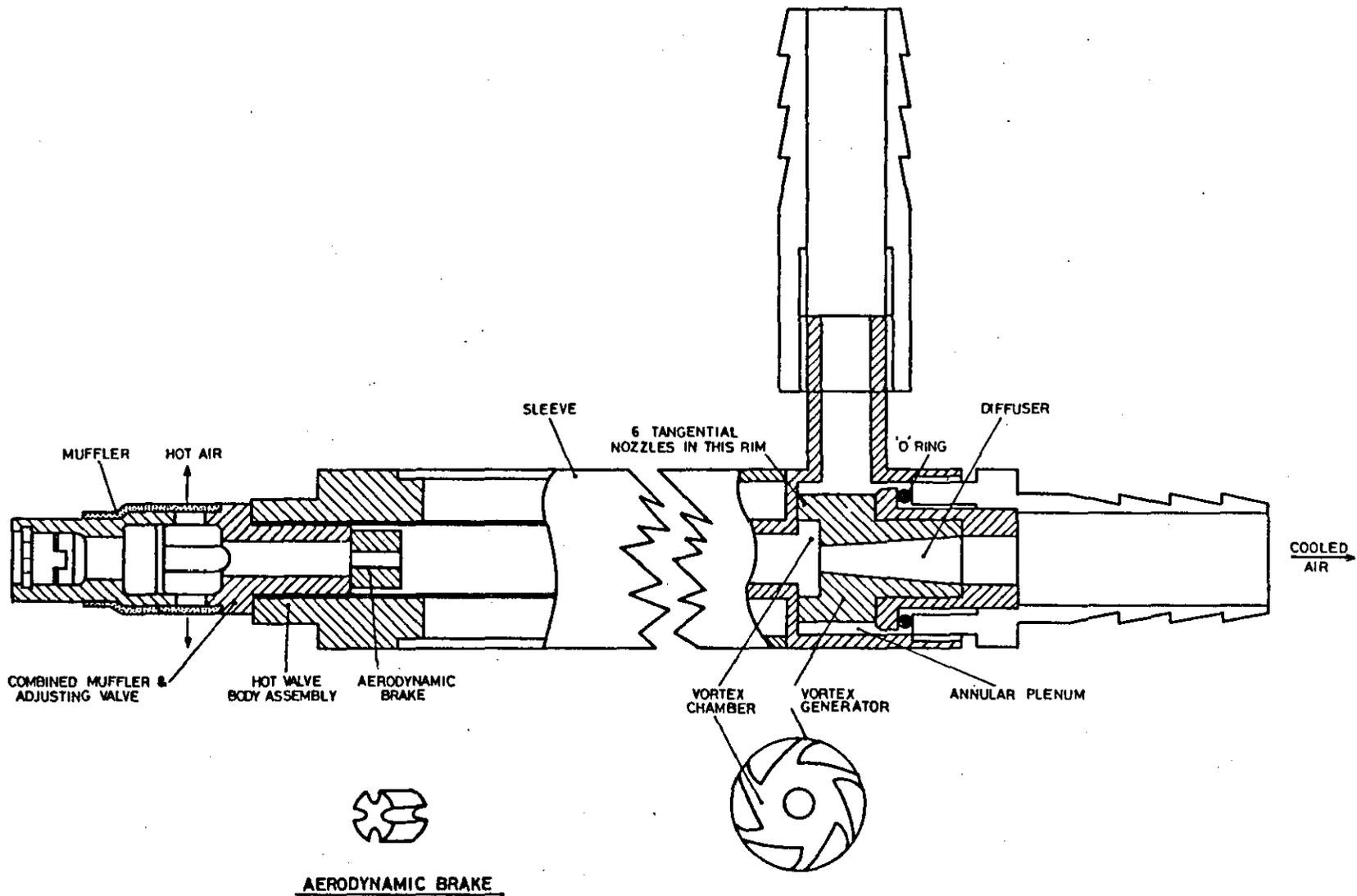
Table 2.6 Screening Properties of Material Fabrics
Current Flow micro amps/square meter

As a result of the foregoing investigation it was possible to produce a Specification for clothing designed for the protection of personnel making contact with live metal in the course of 'bare hand' live line maintenance work on overhead transmission lines operated at voltages up to and including 400kV CEGB (1977b) and this Standard is included as Appendix 'E'.

2.3 Vortex Tube. As stated in Chapter 1, using the Ranque Hilsch cooling effect appears to offer many benefits to the major development in the ventilation and cooling of protective clothing assemblies. The use of a compact efficient vortex tube which could form part of assembly would also assist the cooling of air prior to entry to a ventilated suit where the air supply hose is placed in the heated environment.

This section outlines the design investigations of performance characteristics for vortex tubes of single and duplex generator arrangement.

Fig 2.16 shows a cross section of a vortex tube with single generator arrangement. Compressed air applied to the tube enters an annular



CROSS SECTION DIAGRAM OF SINGLE GENERATOR VORTEX TUBE

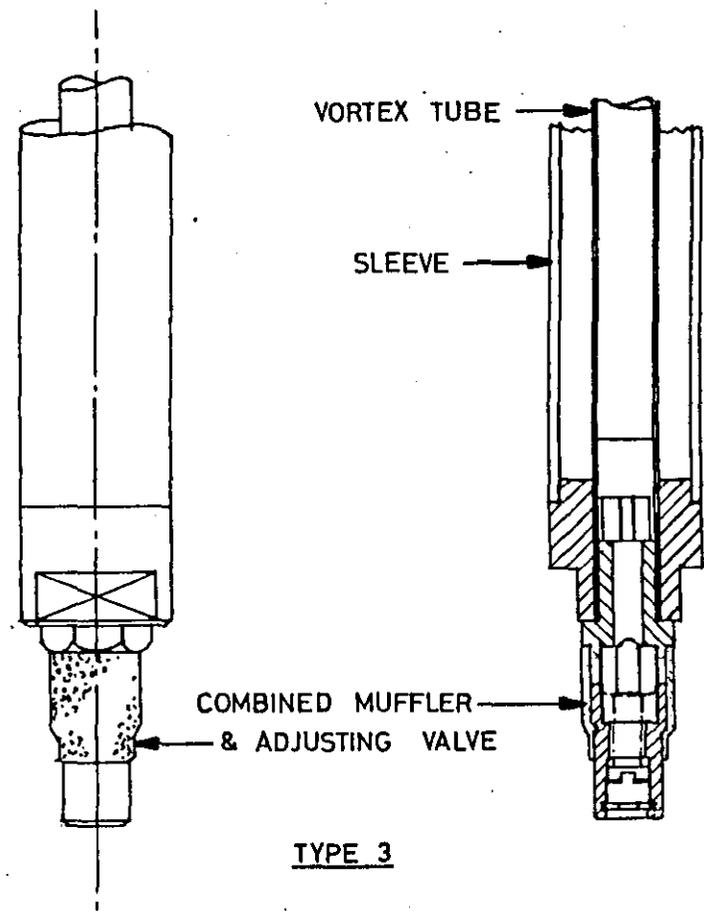
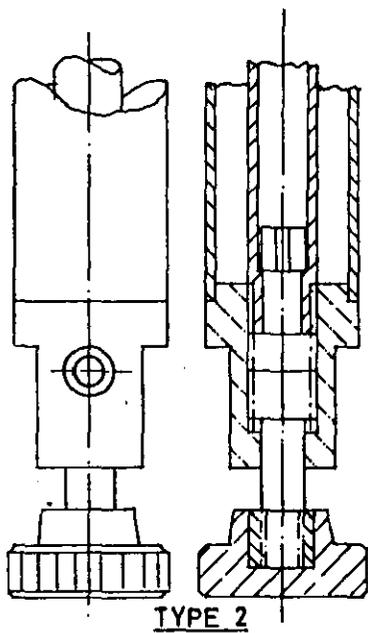
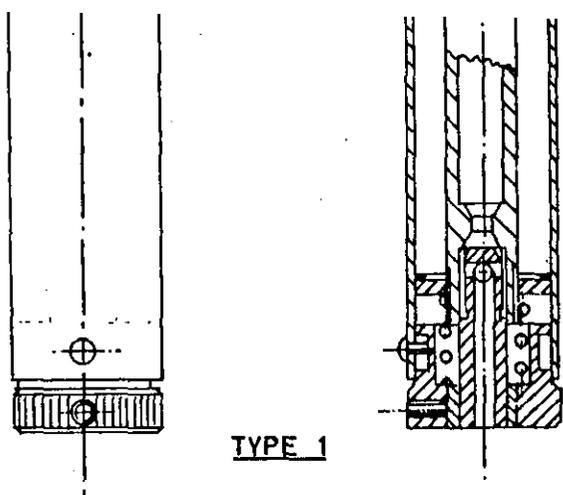
FIG. 2-16

lenum chamber holding the vortex generator. As a result of passing through tangentially arranged slots in the rim of the vortex generator an intense vortex is induced at the centre of the chamber. This forced vortex tends to develop a continuous exchange of heat energy from the inner to the outer layers of the vortex: thus, the centre of the vortex becomes cooled and the outer periphery heated. The geometry of the tube is such that the incoming air displaces cooled air from the eye of the vortex through the diffuser section to the cold outlet while the heated air appearing at the periphery of the vortex is constrained to flow down the hot outlet tube. The ratio of cold to hot air, the cold fraction delivered from the outlets, can be controlled by an adjusting valve located at the downstream end of the hot outlet tube. A vane type air brake (a set of stationary blades) is fitted just up stream of the hot valve assembly to reduce swirl in the hot outlet tube and assists in the production of optimum conditions of the vortex. The hot valve assembly is of paramount importance to the control of the performance characteristics and 3 designs are shown in Fig 2.17.

Type 1. This vortex tube is provided with a flush knurled adjusting screw with a fine thread form and the valve seating is conical in shape. The hot air is exhausted to atmosphere through circular apertures in the adjusting screw in line with the tube.

Type 2. In this vortex tube hot air is exhausted at 90° to the air flow. The flow control valve is coarse threaded and sealed on the end of the hot tube; complete sealing is not possible with this design.

Type 3. Is fitted with a combined noise muffler and flow control valve with fine threaded adjusting screw integral in the muffler seating on a semi circular machined sealing. An 'O' ring is fitted to the valve stem to prevent air leakage past the adjusting screw. The hot air, exhausted through a brass sintered muffler, gives a better air distribution than Type 1 or 2.



HOT VALVE ASSEMBLIES FOR VORTEX TUBES

FIG. 2-17

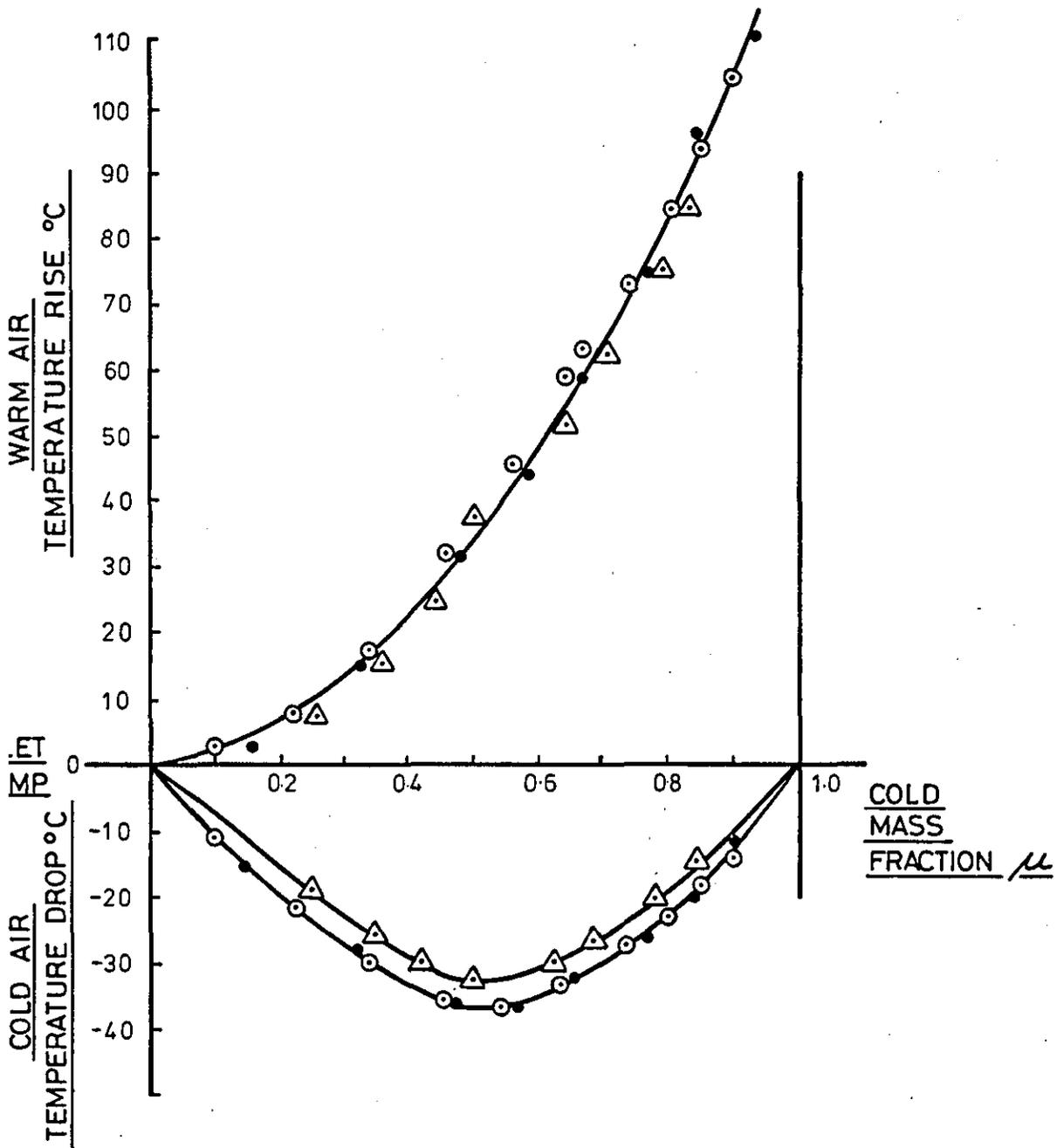
Performance data of a vortex tube based on the patent of Alton (1965) is shown in Table 2.7 and a set of curves relating to air temperatures obtained using de-humidified compressed air at 6.2, 5.17 and .4 bar at 20°C is shown in Fig 2.18.

To establish the validity of this data a test rig Fig 2.19, as constructed. It consisted of an air compressor with associated air filters and water jacketed air cooler supplying air to a bench mounted assembly. An air pre-heater was used for the performance tests which heated the inlet air temperature to 50° centigrade. (This simulated approximately the estimated heat pick-up of the air flowing in the line to the proposed micro-climate suit assembly). The air then passed through a low meter pressure reducing valve and pressure gauge before entering the vortex tube. To measure the relative humidity of the incoming air a slow bleed of air was passed through a chamber containing a wet and dry thermocouple arrangement and a thermocouple also measured the temperature of the main inlet air.

As the vortex tube was to be subjected to the elevated environmental temperature, to represent this condition the tubes under test conditions were mounted in a 60°C temperature-maintained chamber. A flow meter measured the total air output, and thermocouples monitored the hot and cold air temperatures. To simulate the restriction imposed by the cooling system the cold outlet air was connected to a ventile suit assembly worn by a manikin model.

3.1 Experimental Work and Results. This section outlines a series of bench tests that were carried out on single and duplex vortex tubes fitted with the three types of hot valve assemblies shown in Fig 2.17, to establish comparison data over a wide range of air pressure and air flow with varying settings of the hot outlet valves and to enable final design characteristics to be presented and a sealed design established.

- 6.2 bar : .014 kg/sec.
- ⊙ 5.17 bar : .012 kg/sec.
- △ 3.4 bar : .008 kg/sec.



INLET TEMP 20°C

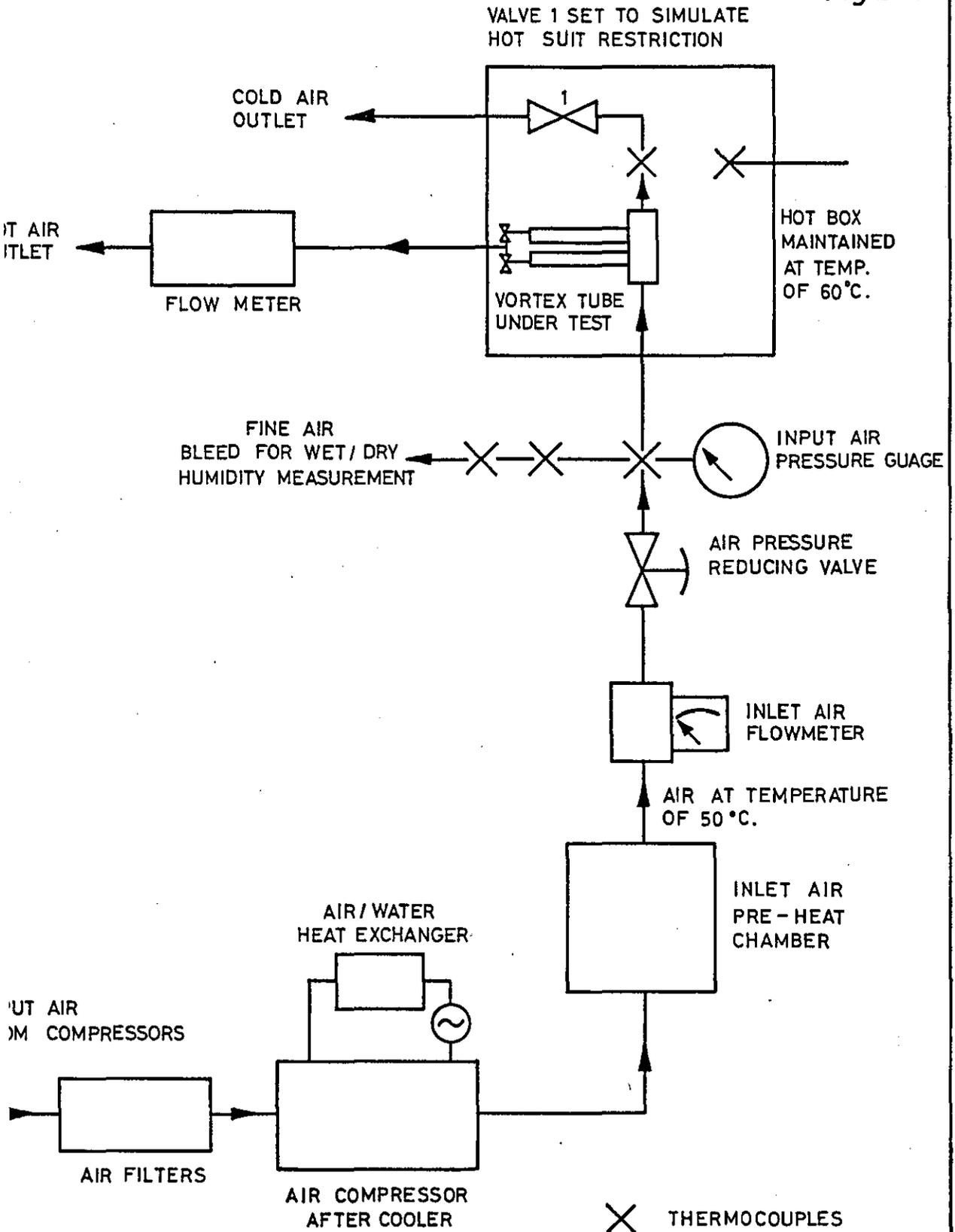
TEMPERATURE CHARACTERISTIC
COLD MASS FRACTION FOR VARIOUS PRESSURE FLOWS
(FULTON CRYOGENIC DATA)

INLET PRESSURE BAR	COLD FRACTION μ										
	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.00
1.4	17.2 (-17.2)	16.7 (-13.9)	16.1 (- 9.4)	15.0 (- 3.9)	12.8 (2.2)	10.0 (9.4)	6.1 (17.8)	2.2 (27.8)	- 2.2 (41.7)	- 8.3 (64.4)	- 77.2 (103.3)
2.75	33.3 (-18.3)	32.8 (-12.8)	31.1 (- 6.1)	29.4 (1.7)	26.7 (10.6)	22.8 (21.7)	16.7 (32.8)	10.6 (47.2)	3.3 (63.9)	- 3.3 (104.4)	- 17.2 (160)
3.4	42.2 (-18.9)	41.7 (-12.2)	40 (- 4.4)	37.8 (4.4)	33.9 (14.4)	28.9 (26.7)	22.8 (40)	15.0 (55.6)	6.7 (75.6)	- 1.7 (113.3)	- 16.7 (174.4)
5.5	48.9 (-19.4)	48.3 (-12.2)	46.1 (- 3.9)	43.3 (6.1)	38.9 (17.2)	33.3 (30)	26.7 (45)	18.3 (61.7)	9.4 (82.8)	- 0.6 (120.6)	- 16.1 (182.2)
6.8	53.3 (-20)	52.8 (-12.2)	50.6 (- 3.3)	47.8 (7.2)	43.3 (18.9)	37.2 (32.8)	30.0 (48.3)	21.1 (66.1)	11.7 (88.9)	0.6 (125)	- 15.6 (185.6)
8.2	56.7 (-20.6)	56.1 (-12.8)	53.9 (- 3.3)	51.1 (7.8)	46.7 (20.6)	40.0 (34.4)	32.2 (50.6)	23.3 (68.9)	12.8 (90.6)	1.1 (124.4)	- 15 (184.4)
9.6	60.0 (-21.7)	59.4 (-13.8)	57.2 (- 3.9)	53.9 (7.8)	49.4 (21.1)	42.8 (35.6)	33.4 (51.1)	24.4 (68.9)	13.3 (89.4)	1.7 (121.1)	- 13.9 (178.9)

TABLE 2.7 Temperature drop in °C with related cold fraction.
for Vortex tube (based on data from Fulton Cryogenics)

Figures in brackets give temperature rise of hot air °C

Fig 2-19



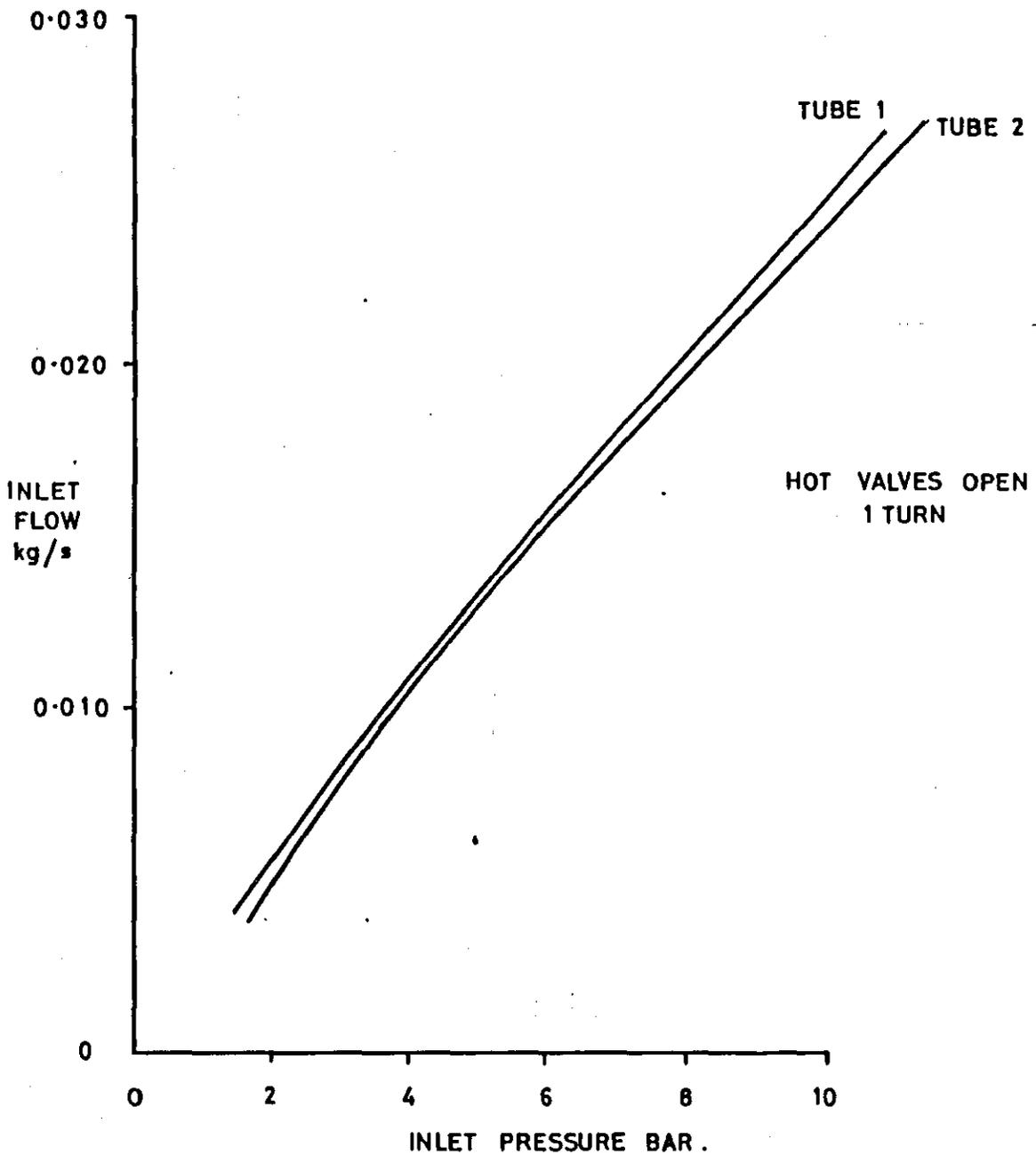
TEST RIG FOR VORTEX TUBE PERFORMANCE COMPARISON

Single Vortex Tube. Two tubes fitted with (a) Type 1 hot valve

Tube 1) and (b) hot valve Type 3 (Tube 2) were selected. The tubes were submitted to an air pressure test with the hot outlet valve closed and the old air outlet blanked off. The test pressure of 10.34 bars was maintained for 2 minutes. For the determination of the performance characteristics the tube was held at a temperature of 60°C and the inlet air was heated to a temperature of 50°C. As a preliminary to the operational tests the pressure/flow relationships for two positions of the hot air valve, with and without the non-return valve, were obtained over a range of increasing air pressures for a number of settings of the hot outlet valves. Inlet mass air flow, inlet pressure and outlet mass cold air flow were monitored together with the relative humidity of the inlet air and the temperatures of the inlet and cold outlet air. The cold outlet air was supplied through a short length of hose to a ventilator assembly worn by a manikin model to simulate approximately the back pressure conditions. The relative humidity of the input air varied between 17% and 60% and the atmospheric pressure was between 1019 and 1024 millibars for the tests. The measurements are subject to the following levels of uncertainty:-

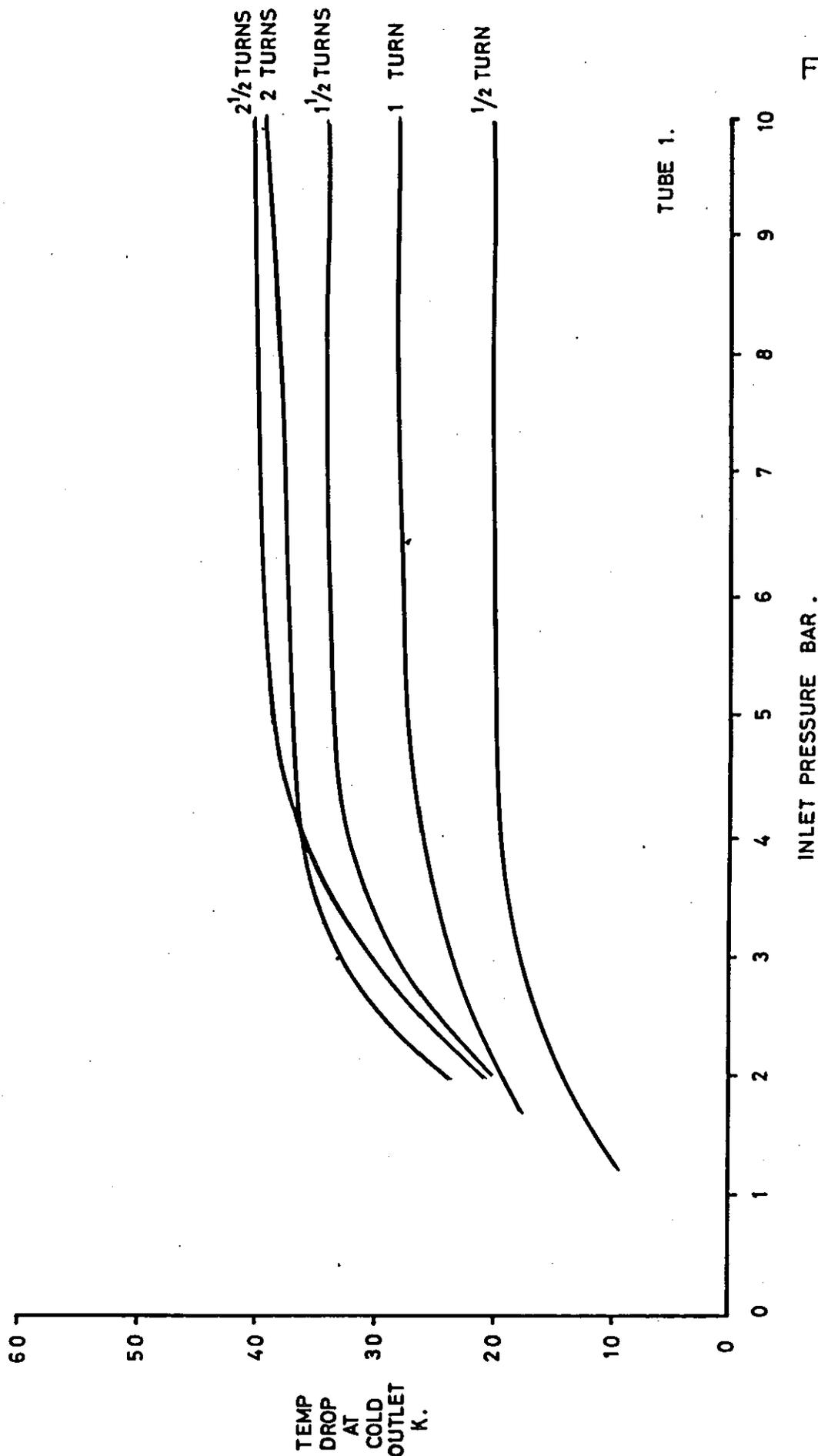
air flow data	+ 4%
air pressure data	+ 3%
old mass fraction data	+ 5%
inlet/cold outlet temp drop	+ 2°C
relative humidity	+ 5%

The characteristics obtained from the two series of tests are presented in Fig 2.20 to 2.24. The performance of the Type 3 valve, which includes finer adjustment, results in better control of the hot outlet air and of the amount of cooled air being supplied to the ventilator assembly. The inlet pressure to inlet flow relationship Fig 2.20 is similar for both, but with the maximum valve opening the temperature interval at the cold outlet of the Type 3 valve is increased by approximately 20% between 5 and 10 bar inlet pressure.



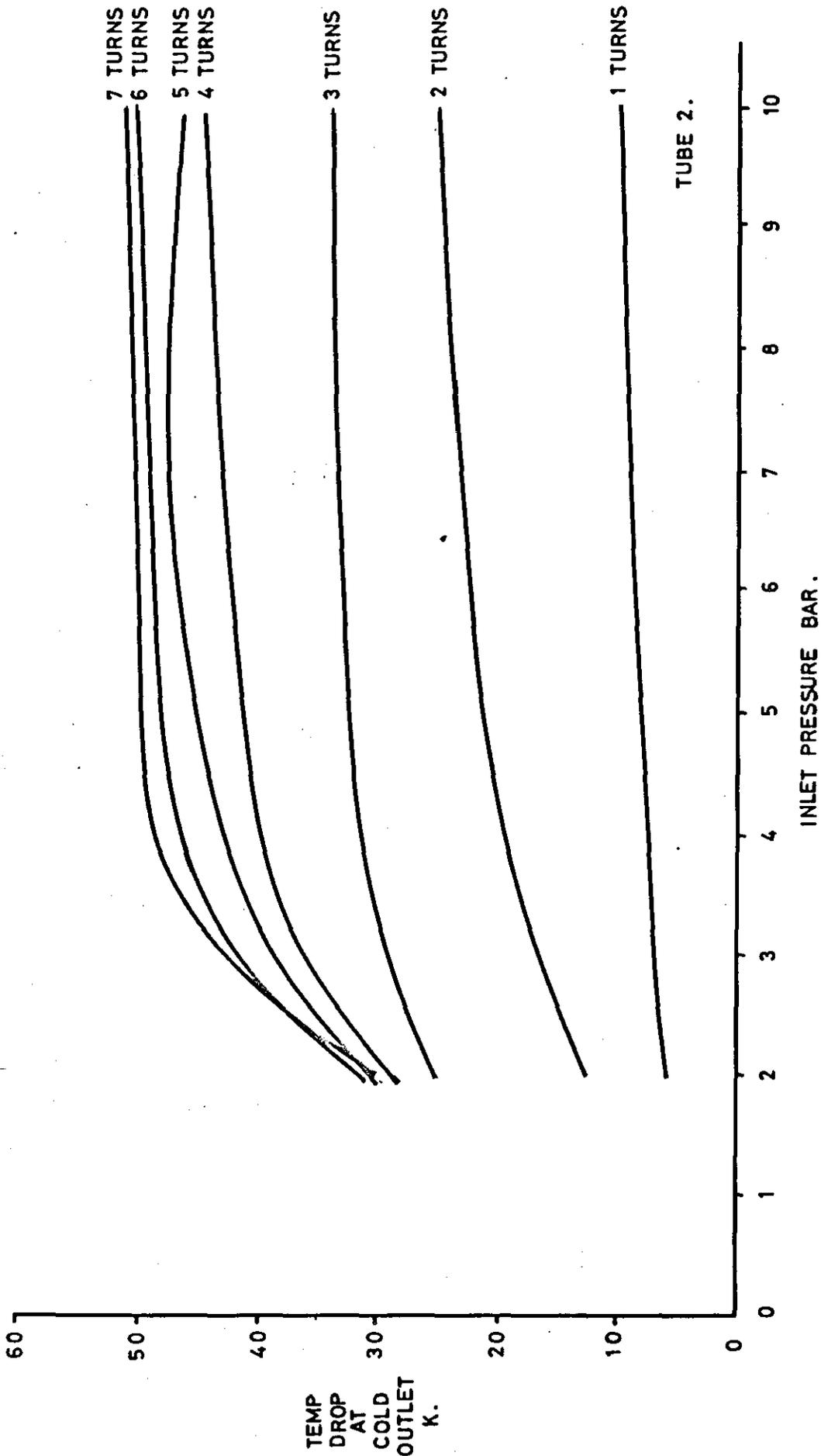
EVALUATION OF THE PERFORMANCE OF SINGLE BARREL VORTEX TUBES.
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND INLET AIR FLOW.
INLET AIR TEMPERATURE, AT 50 °C. VORTEX TUBES AT 60 °C.

Fig 2-21

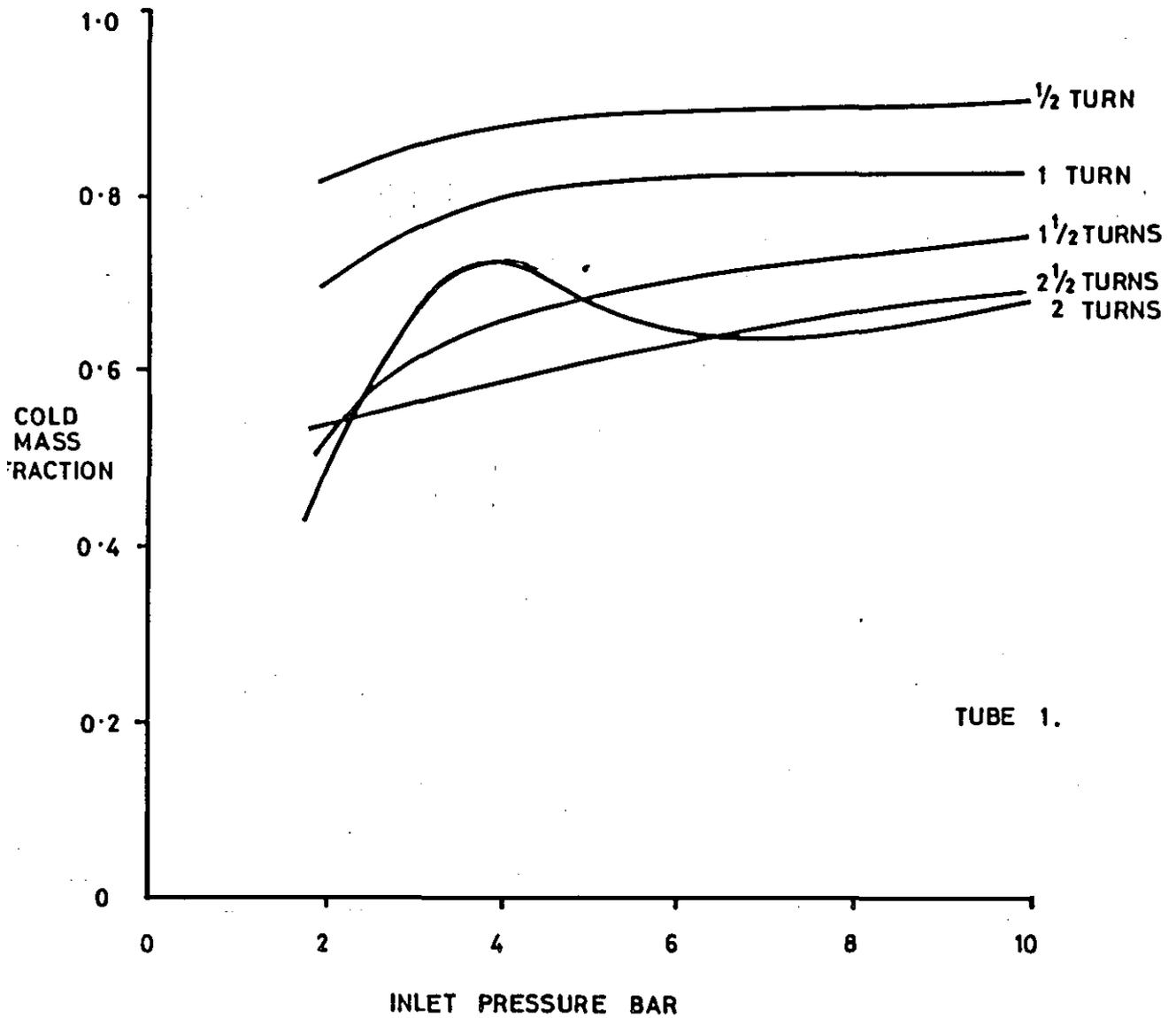


EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBES. RELATIONSHIP BETWEEN TEMPERATURE DROP AND INLET AIR PRESSURE WITH INCREASING OPENING OF HOT AIR VALVE. INLET AIR TEMPERATURE 50 °C. VORTEX TUBES AT 60 °C.

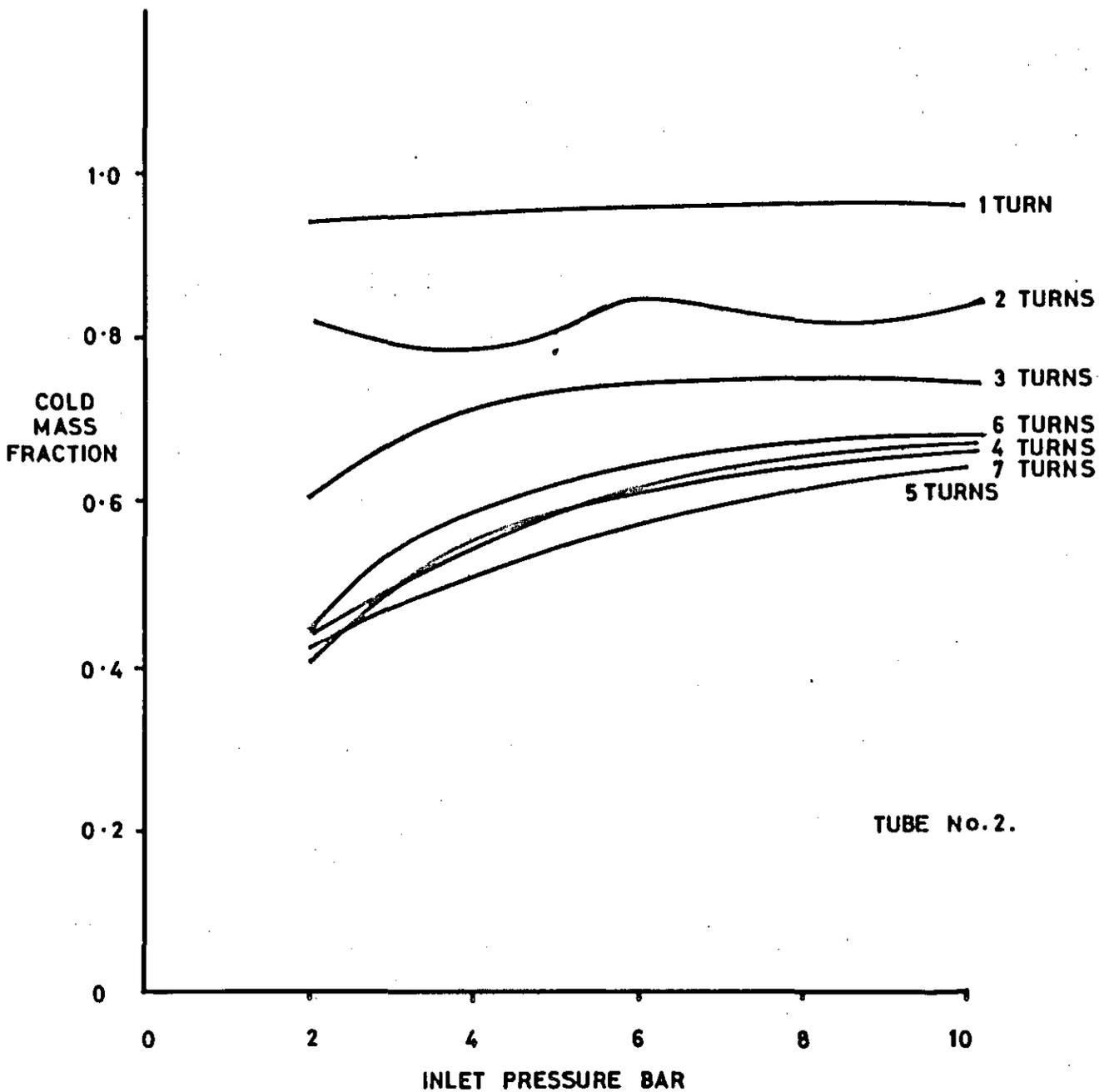
Fig 2-22



EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBES. RELATIONSHIP BETWEEN TEMPERATURE DROP AND INLET AIR PRESSURE WITH INCREASING OPENING OF HOT AIR VALVE. INLET AIR TEMPERATURE 50°C. VORTEX TUBES AT 60°C.



EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBES.
RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET AIR PRESSURE WITH
INCREASING OPENING OF HOT AIR VALVE. INLET AIR TEMPERATURE 50°C.
VORTEX TUBES AT 60°C.



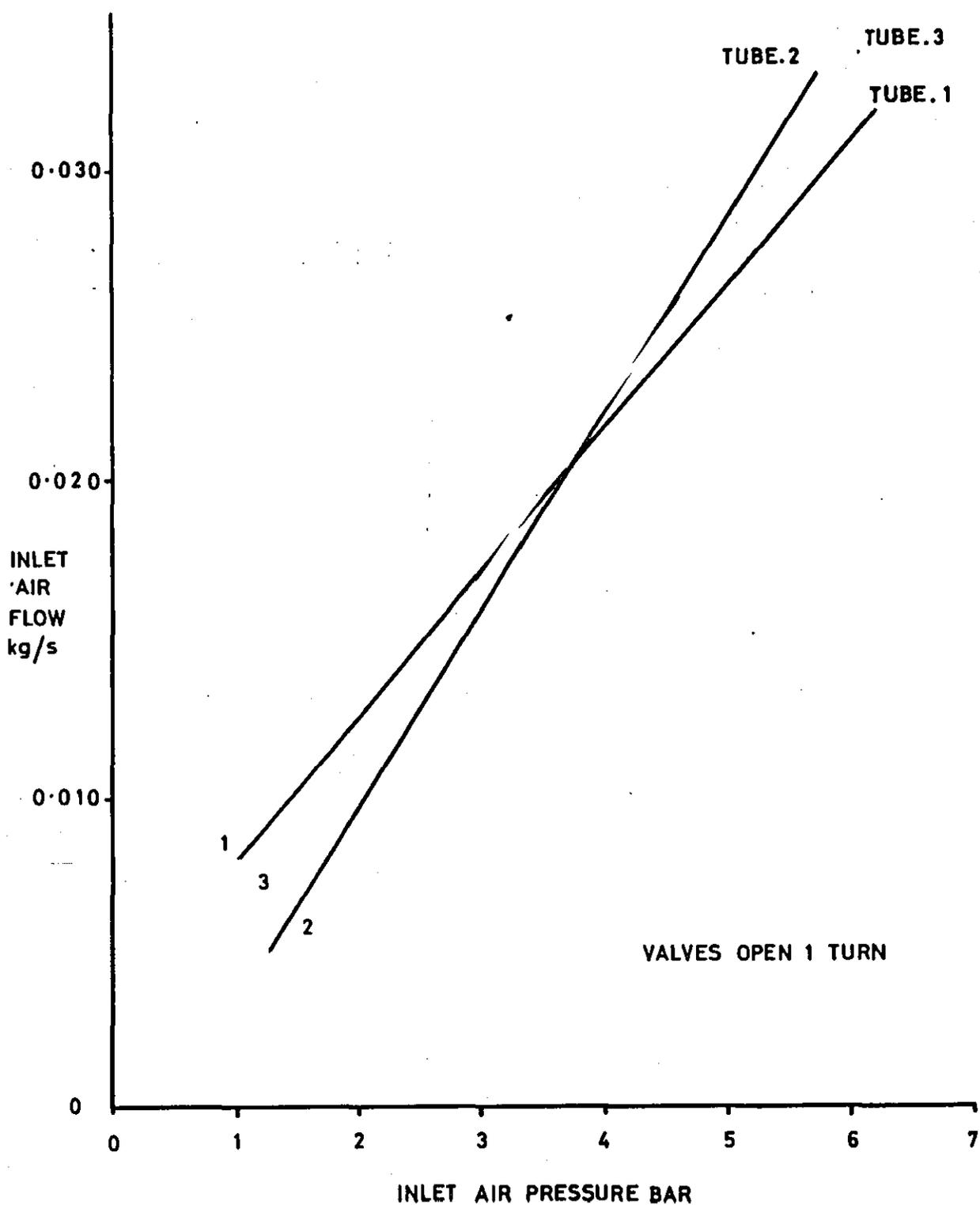
EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBES.
RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET AIR PRESSURE
WITH INCREASING OPENING OF HOT AIR VALVE . INLET AIR TEMPERATURE 5°C.
VORTEX TUBES AT 60°C.

Twin (or duplex) Vortex tube. To establish a ~~specified~~ design

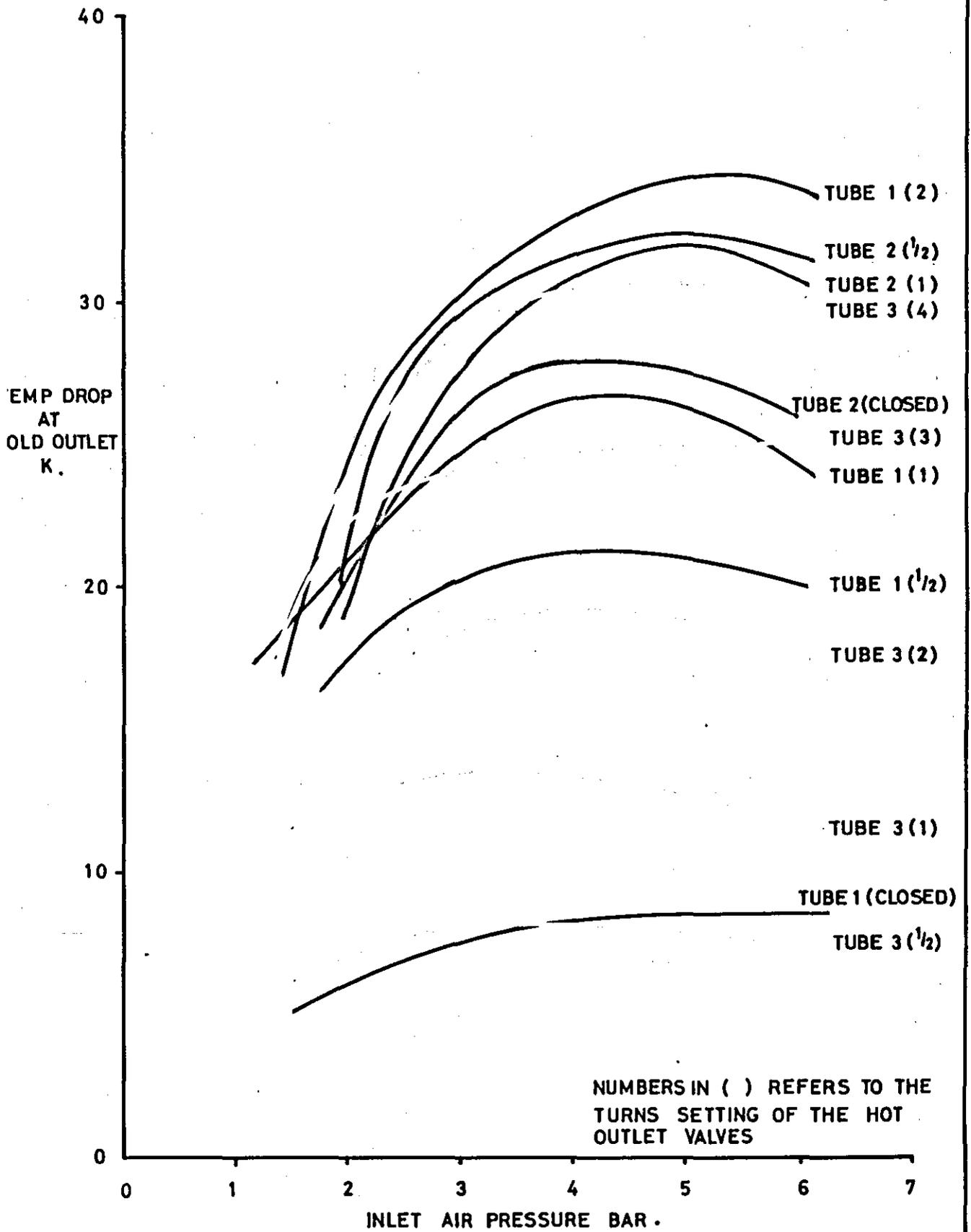
requirement an inlet flow of 0.03 Kgs at a pressure of 10.34 bar, the performance of the single vortex tube fell short and the performance characteristic of a duplex arrangement of the vortex generators was investigated using the same test rig.

Three tubes assemblies each fitted with Type 1, 2 and 3 hot valve assemblies were evaluated. The test procedure was the same as for the single vortex tube. The tubes were numbered 3, 4 and 5 were fitted respectively with Types 1, 2 and 3 hot valve assemblies the results of these tests are shown in Figs 2.25, 2.26 and 2.27. The preliminary test to determine the pressure/flow characteristics (Fig 2.25) confirmed that a linear relationship could be obtained for each of the assemblies and that an air flow of 0.03 Kg/s could be achieved with an inlet pressure of 5.7 bar. Characteristics relating the temperature drop at the cold outlet to inlet pressure (Fig 2.26) and the cold mass-fraction to inlet pressure (Fig 2.27) showed that a greater degree of control was available with Type 3 hot valve assembly, confirming also the findings of the single vortex tube investigation. The cold mass fraction ranged from 0.5 to 0.93 over 5 turns of the valves but the coarseness of the Type 2 valve made control and balance of the air flow extremely difficult to achieve.

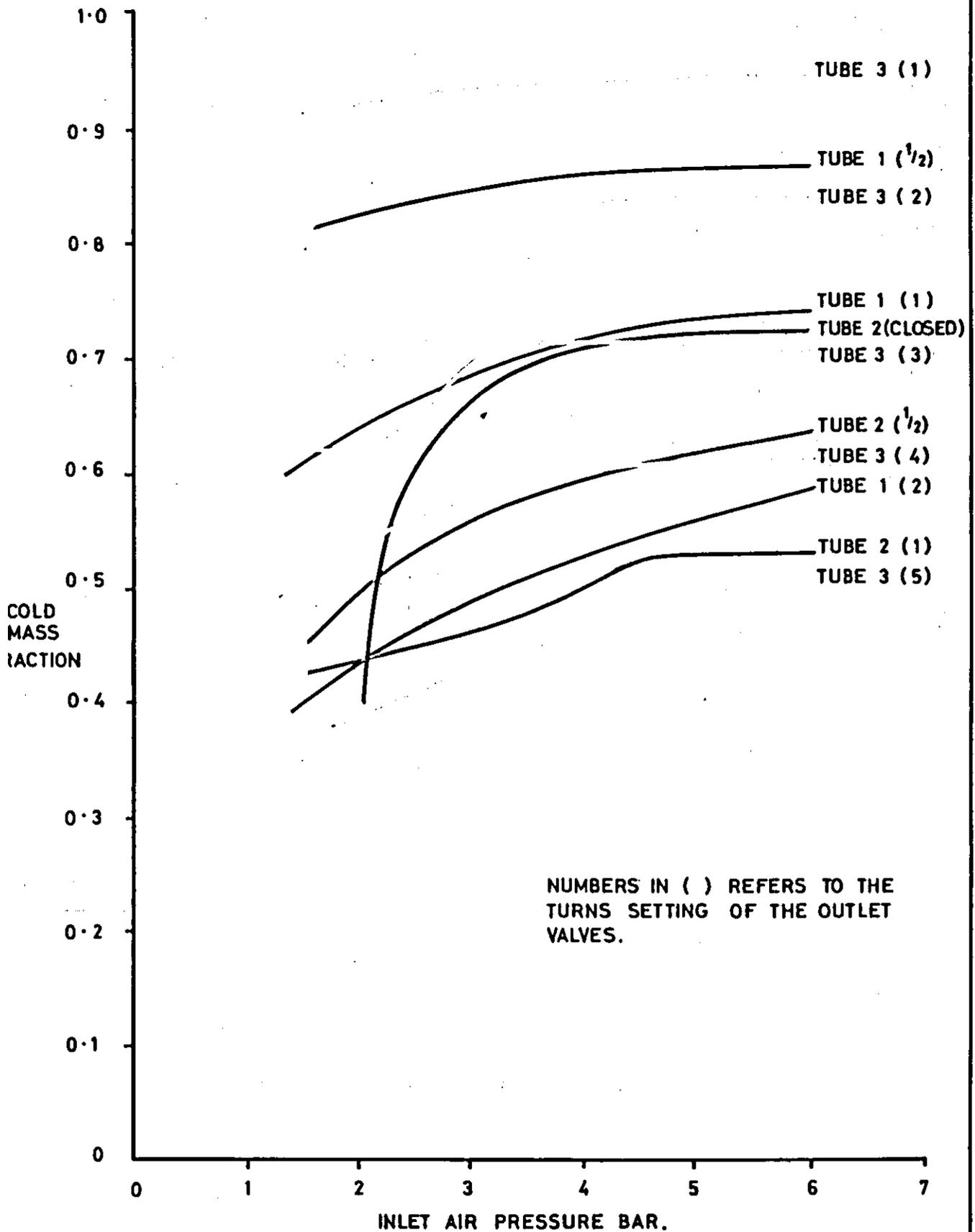
To establish reproducible performance a series of tests were carried out in a similar manner using 4 vortex tubes fitted with the Type 3 hot outlet valve. Tube No 5 was used again and the additional tubes were given identification numbers 6, 7 and 8. The results of these tests are shown in Figs 2.28 to 2.34. The cold outlet temperature drop plotted against inlet pressure and flow characteristics as shown on Figs 2.28, 2.29 and 2.30 tended to be more scattered than was expected. The cold mass fraction plotted against inlet pressure showed similar wide variations except that in the condition of maximum temperature drop there was much more agreement and uniformity in the curves (Figs 2.23 and 2.34).



COMPARISON TESTS ON THREE TWIN VORTEX TUBES WITH DIFFERENT VALVE DESIGNS. RELATIONSHIP BETWEEN INLET AIR PRESSURE AND INLET AIRFLOW. INLET AIR AND VORTEX TUBES AT 20°C.

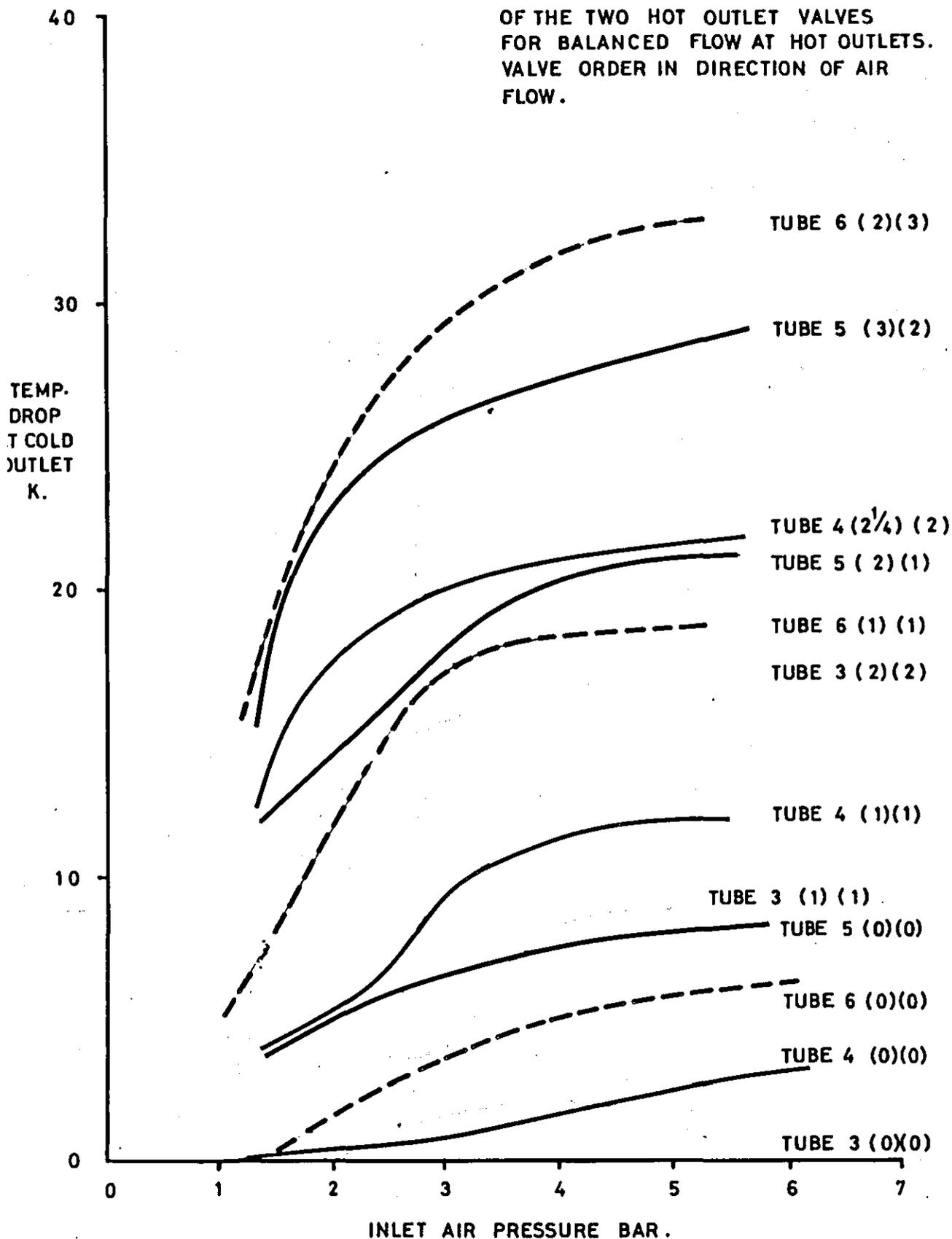


COMPARISON TESTS ON THREE TWIN VORTEX TUBES WITH DIFFERENT VALVE DESIGNS. RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES. INLET AIR AND VORTEX TUBES AT 20°C.

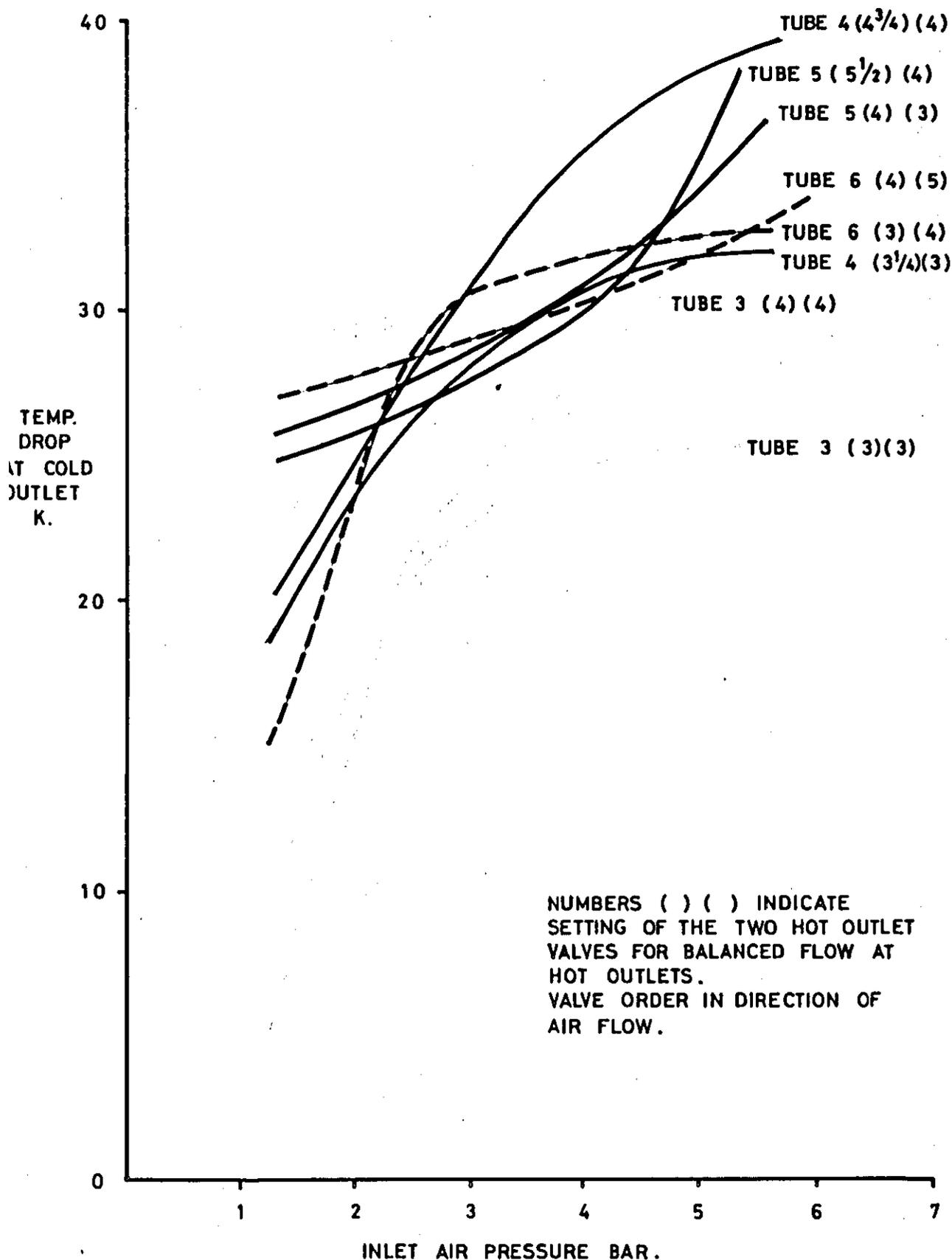


COMPARISON TESTS ON THREE VORTEX TUBES WITH DIFFERENT VALVE DESIGNS. RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET AIR PRESSURE WITH INCREASED OPENING OF HOT AIR VALVES. INLET AIR AND VORTEX TUBES AT 20 °C.

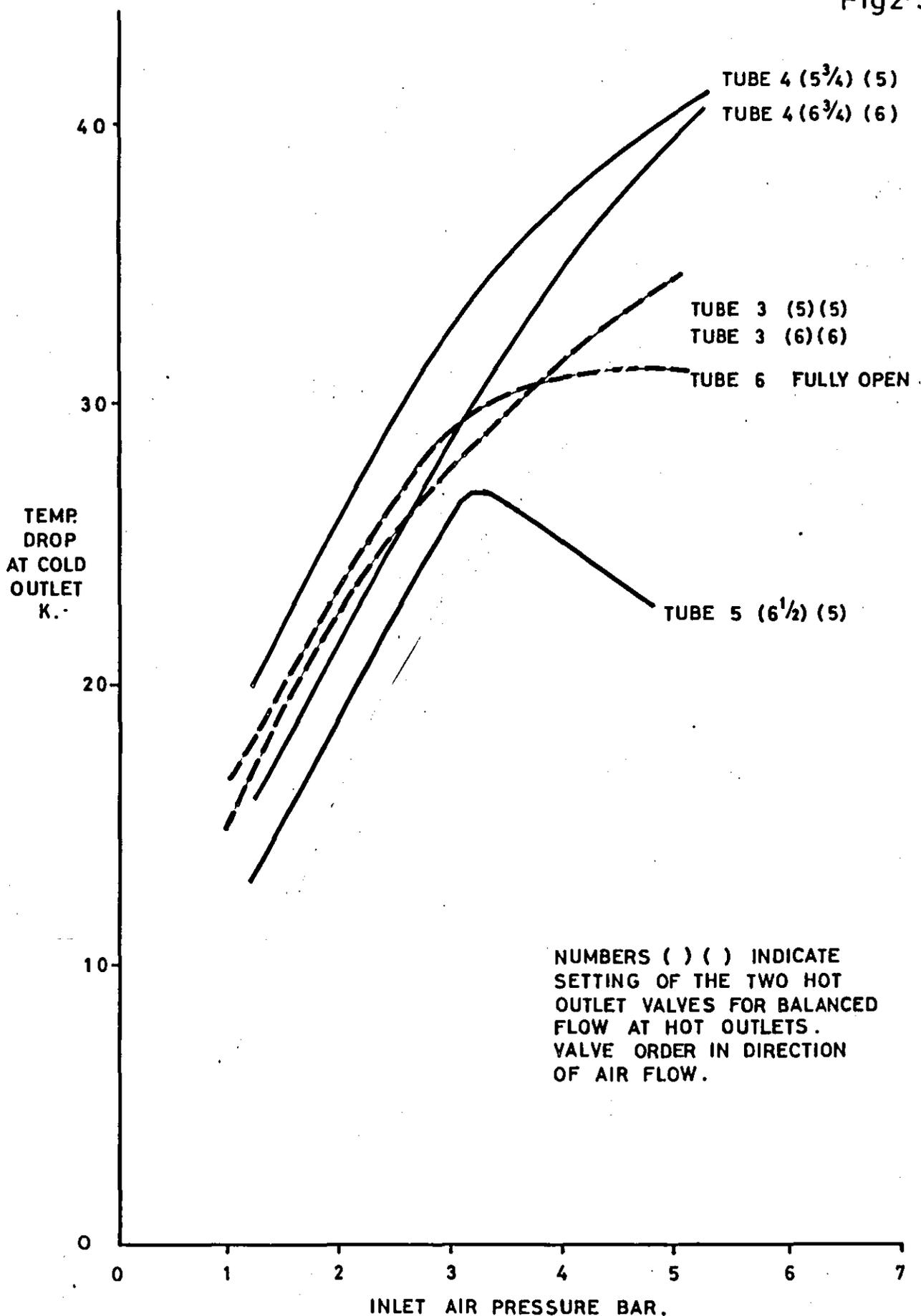
NUMBERS () () INDICATE SETTING OF THE TWO HOT OUTLET VALVES FOR BALANCED FLOW AT HOT OUTLETS. VALVE ORDER IN DIRECTION OF AIR FLOW.



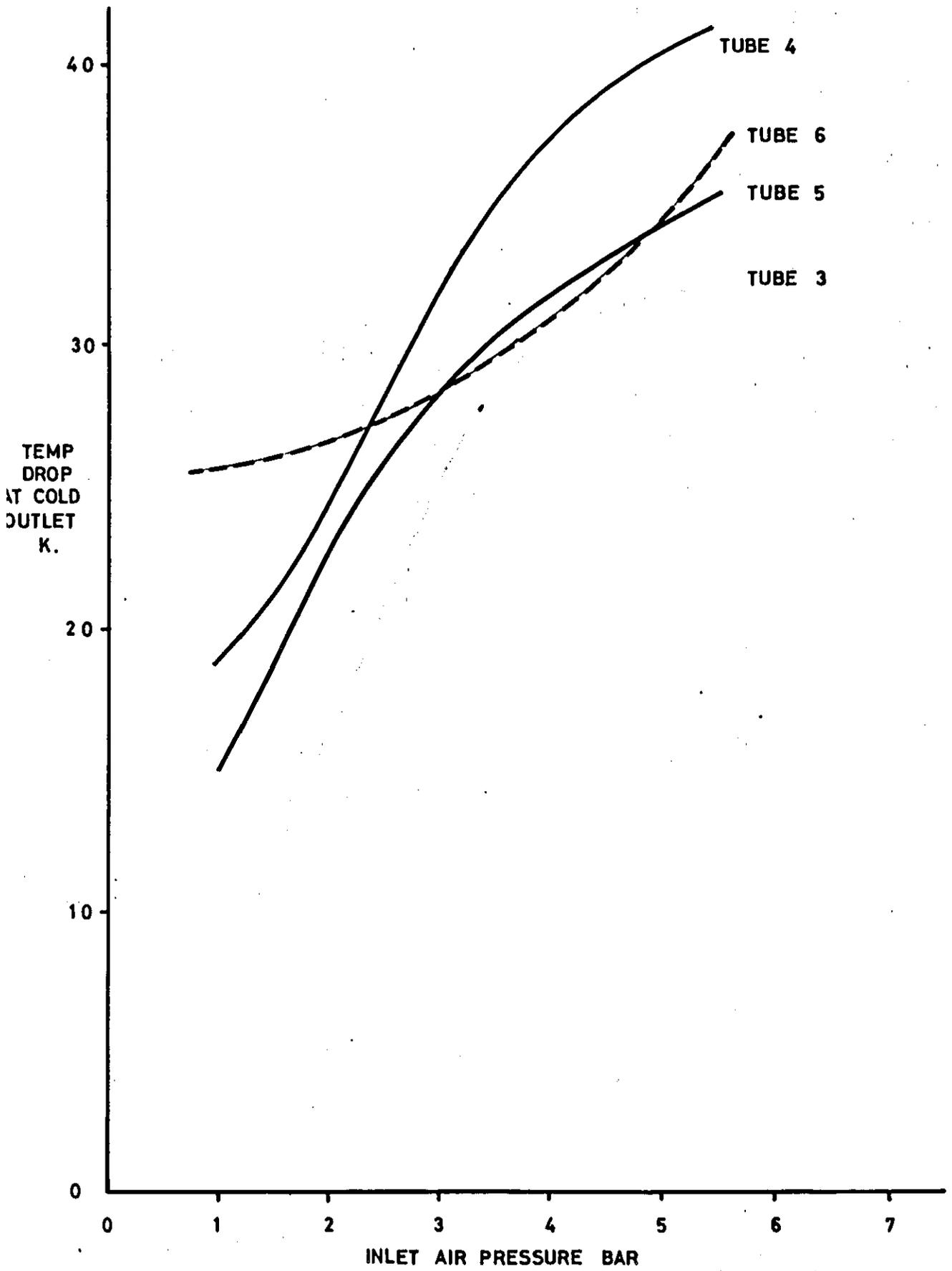
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES. INLET AIR TEMPERATURE 50°C. VORTEX TUBES MAINTAINED AT TEMPERATURE 60 °C.



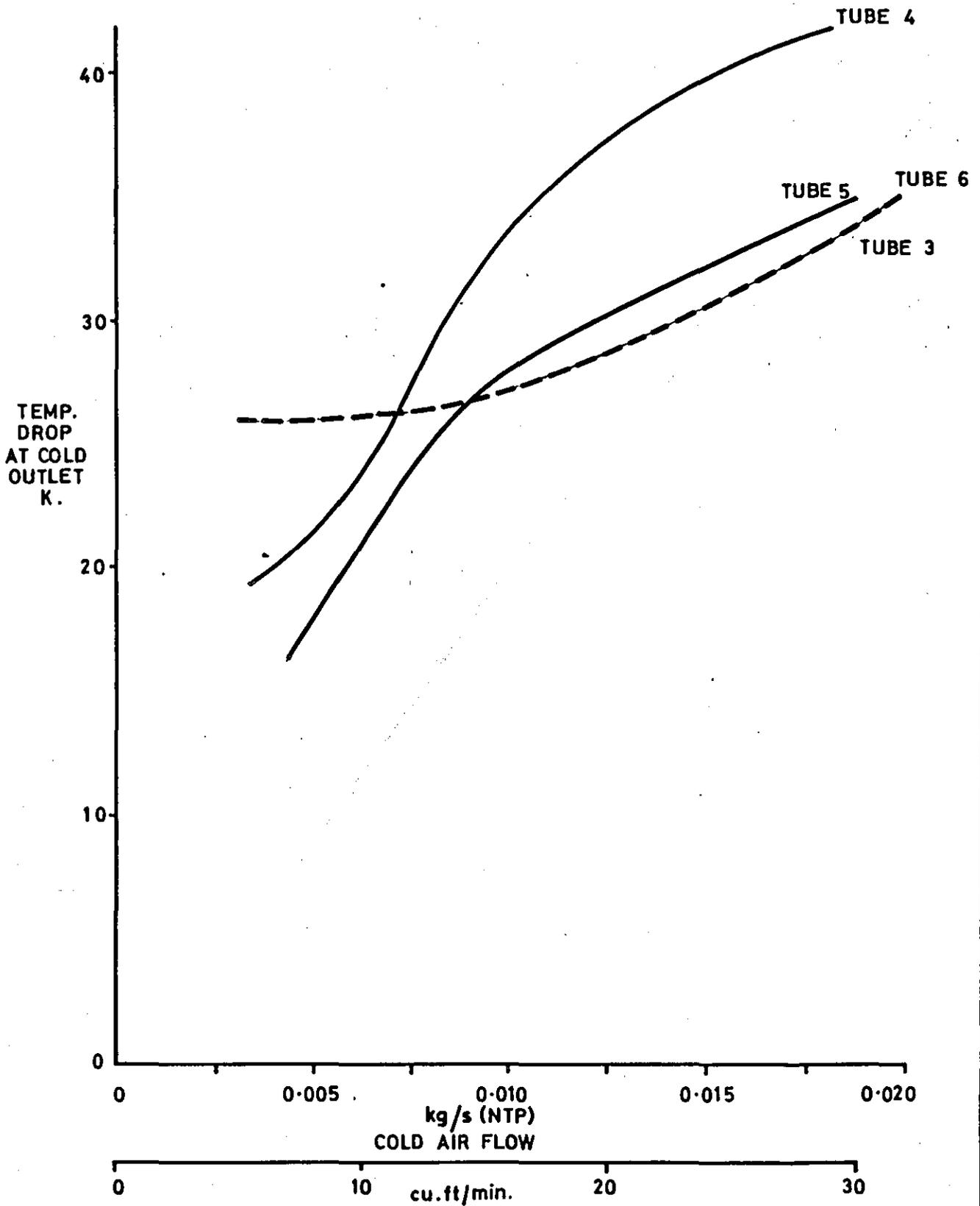
RELATIONSHIP BETWEEN AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES. INLET AIR TEMPERATURE 50°C. VORTEX TUBES MAINTAINED AT TEMPERATURE OF 60°C.



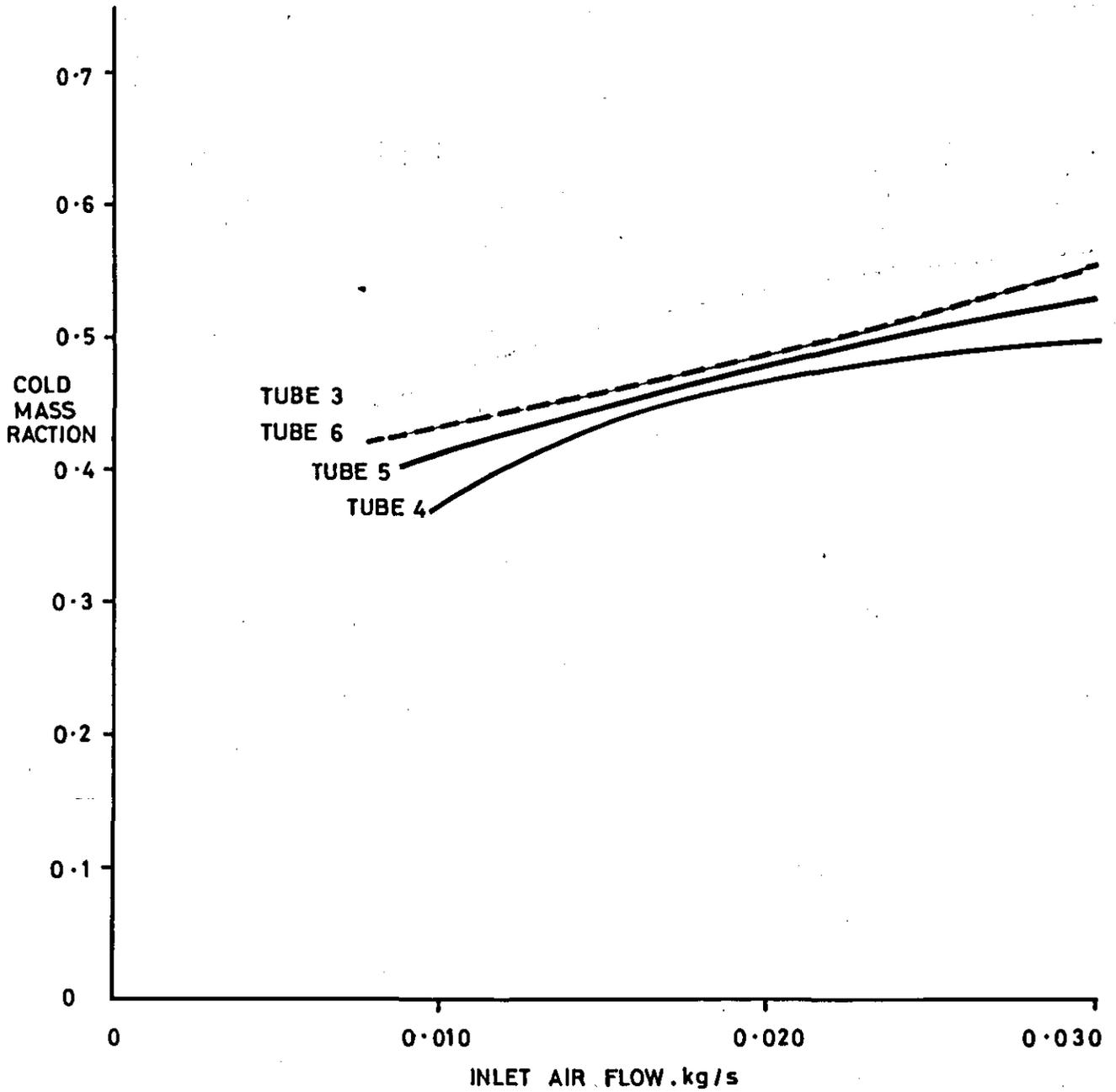
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES. INLET AIR TEMPERATURE 50°C. VORTEX TUBES MAINTAINED AT TEMPERATURE OF 60°C.



RELATIONSHIP BETWEEN INLET AIR PRESSURE AT A TEMPERATURE OF 50 °C AND MAXIMUM OBTAINABLE TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES. TUBES MAINTAINED AT A TEMPERATURE OF 60 °C.

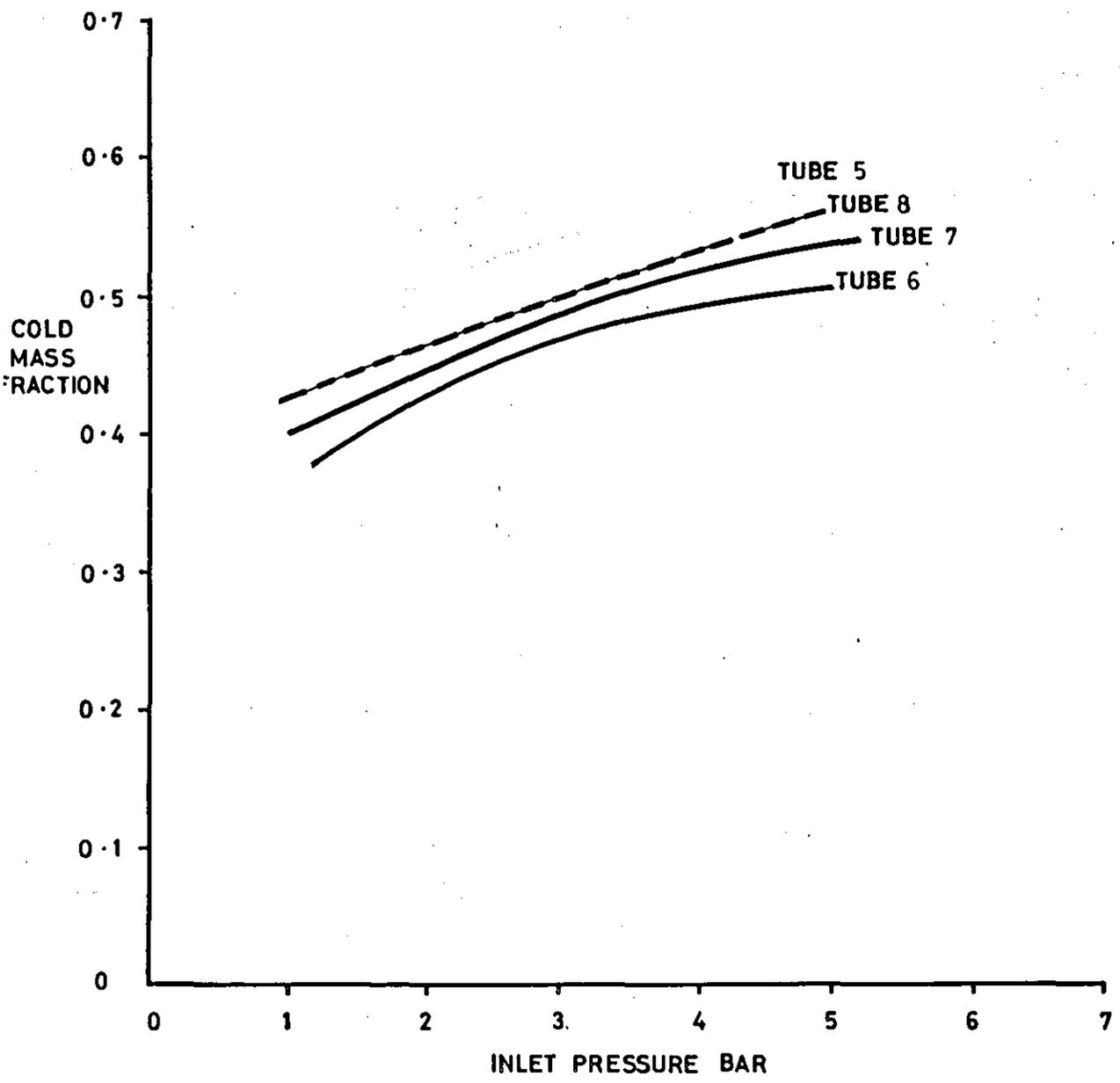


RELATIONSHIP BETWEEN COLD AIR FLOW AND MAXIMUM OBTAINABLE TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES. AIR INLET TEMPERATURE 50 °C. TUBES MAINTAINED AT A TEMPERATURE OF 60 °C.



RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET FLOW AT MAXIMUM TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES. AIR INLET TEMPERATURE 50°C VORTEX TUBES MAINTAINED A 60°C

FIG. 2.34



RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET PRESSURE AT MAXIMUM TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES. AIR INLET TEMPERATURE 50 °C. VORTEX TUBES MAINTAINED AT 60 °C.

Visual examination of the interior of the tubes showed that the moulded elastic vortex generators were bedded on to the rubber washers which because of misalignment intruded by varying amounts into the vortex chamber of each tube. It was also noted that the inlet air ports varied slightly in size and surface finish. An important advantage of the duplex tube however was established and the improved ratio of air flow to air input pressure was increased by a factor of 2.

Noise Levels of Vortex Tubes An attribute of the vortex tube operation is the level it emits from the hot outlet. This observation was confirmed subjectively during initial practical investigations and the following examination was made of the three designs of hot valve assemblies on both the single and duplex vortex tubes to establish the noise level measurements.

Experimental Procedure and Equipment Each type of tube was connected to the compressed air supply system. The sound level meter was placed 1 metre away from the tube, approximately the distance from the ventilator suit wearer's ear. Air was delivered to the single vortex tube in 0.5 bar increments over the range 2 to 10 bar to the single vortex tube and from 5.5 to 10.2 bar to the duplex tube at a constant flow rate of 28.3 l/min/sec. Noise level measurements were taken at each increment and the results are given in Tables 2.8 and 2.9 for the single and duplex vortex assemblies respectively.

Bruel and Kjaer equipment was used to measure the noise produced by the vortex tubes during the trials. This comprised a model 2203 precision sound level meter, incorporating a model 4131 one-inch diameter condenser micro-phone and a model 1613 octave filter set. The complete measurement system was calibrated both before and after the tests by subjecting the microphone to an accurately-known noise source derived from a model 4230 portable acoustic calibrator.

These series of tests also confirmed an advantage for the type 3 design of hot valve assembly.

AIR DELIVERY PRESSURE (BAR)	SPL dB	SL dB(A)	OCTAVE - BAND ANALYSIS dB									
			31.5Hz	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	16kHz
Type 1 Tube												
2	85	82	66	65	60	54	52	62	69	78	82	79
4	91	89	69	68	68	65	61	68	74	83	88	86
6	95	93	74	69	63	65	67	70	76	86	92	91
8	100	97	64	63	65	68	72	75	80	91	97	97
10	95	93	74	61	68	70	77	78	82	88	91	90
Type 3 Tube												
2	80	74	72	67	60	56	54	60	65	67	71	71
4	84	80	75	68	68	60	56	58	65	69	73	77
6	86	83	68	64	60	57	63	69	74	76	81	83
8	88	85	68	65	60	68	64	71	77	79	83	85
10	90	87	65	66	60	65	66	74	79	81	85	87

TABLE 2.8 Comparison of noise levels produced by the Types 1 and 3 Hot valve assemblies fitted on a single vortex tube

AIR DELIVERY PRESSURE (BAR)	Type 2 Tube		Type 1 Tube		Type 3 Tube	
	SPL dB	SL dB(A)	SPL dB	SL dB(A)	SPL dB	SL dB(A)
5.5	104	102	94	91	90	88
6.2	106	104	95	92	91	89
6.8	106	105	96	93	92	90
7.5	106	105	98	96	93	91
8.2	107	105	100	97	93	91
8.9	107	106	102	98	94	92
9.6	108	107	102	99	95	93
10.2	108	107	102	99	95	93

Table 2.9 Comparison of noise levels produced by the Types 1, 2 and 3

Hot valve assemblies fitted on duplex vortex tubes

SPL Sound pressure level

SL Sound Level

Finalised Design. As a result of field evaluation to provide

more comfort to personnel wearing a vortex tube assembly a necessary modification was to shorten the overall length of the previously tested duplex tubes by 40mm. To check that the performance characteristics had not been impaired the shortened tube B (Fig 2.35) was compared with Tube No 5, A, under atmospheric conditions using identical test conditions of inlet air temperature, flow and pressure. The inlet air was heated to a temperature of 50°C and the vortex tube was maintained at 60°C. At each stage of increasing air pressure, 2 bar/stage, the inlet air flow and hot outlet air flow were monitored together with the relative humidity

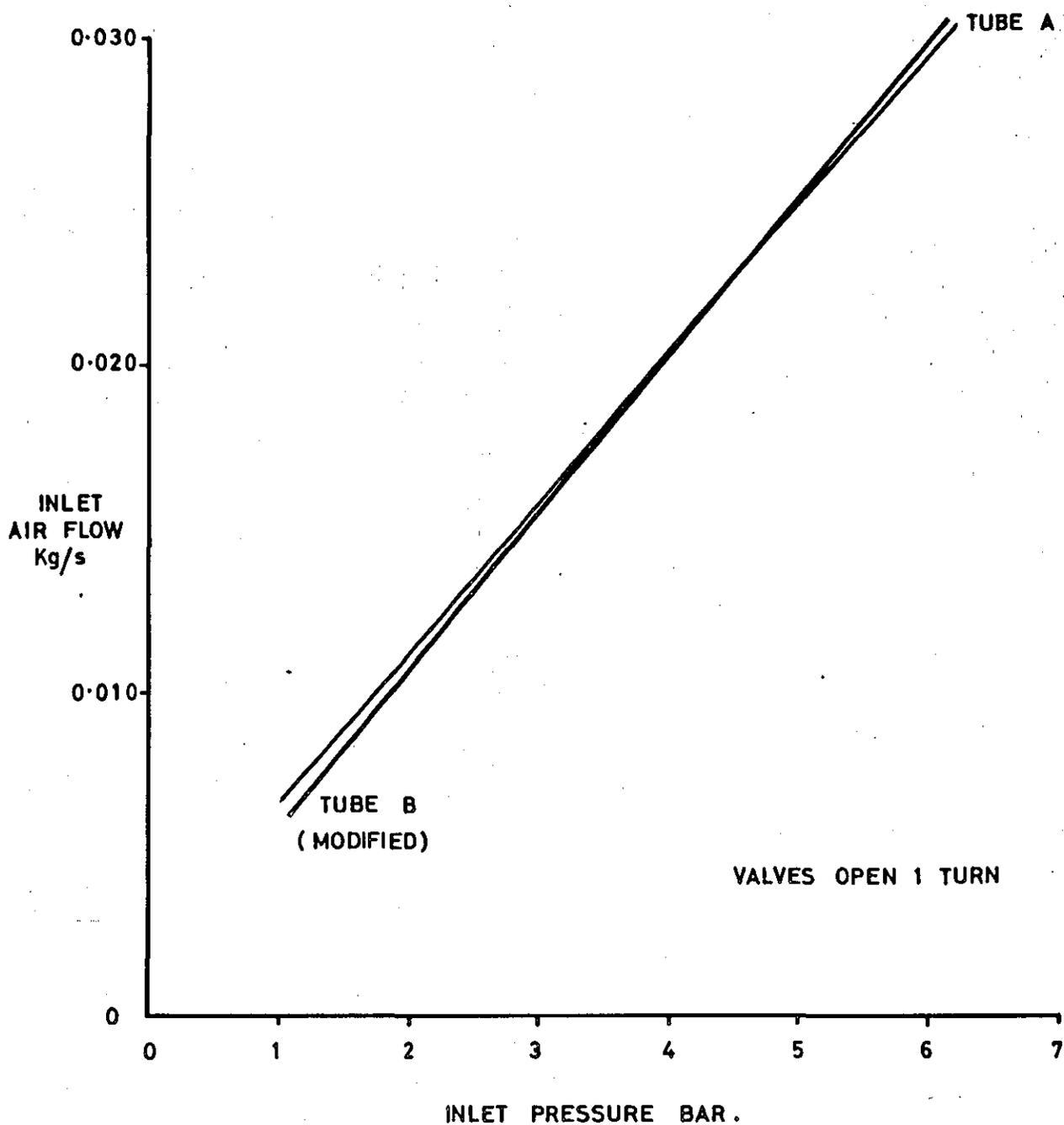
and the temperatures of the inlet and outlet cold air. Outlet mass flow of cold air was computed from the values obtained for inlet and hot air outlet flow measurements. Relative humidity of the input air varied between 13% and 25% during test and atmospheric pressure was 1020 millibars for the duration of the test.

The measurements on the comparison and performance tests are subject to the following estimated levels of uncertainty.

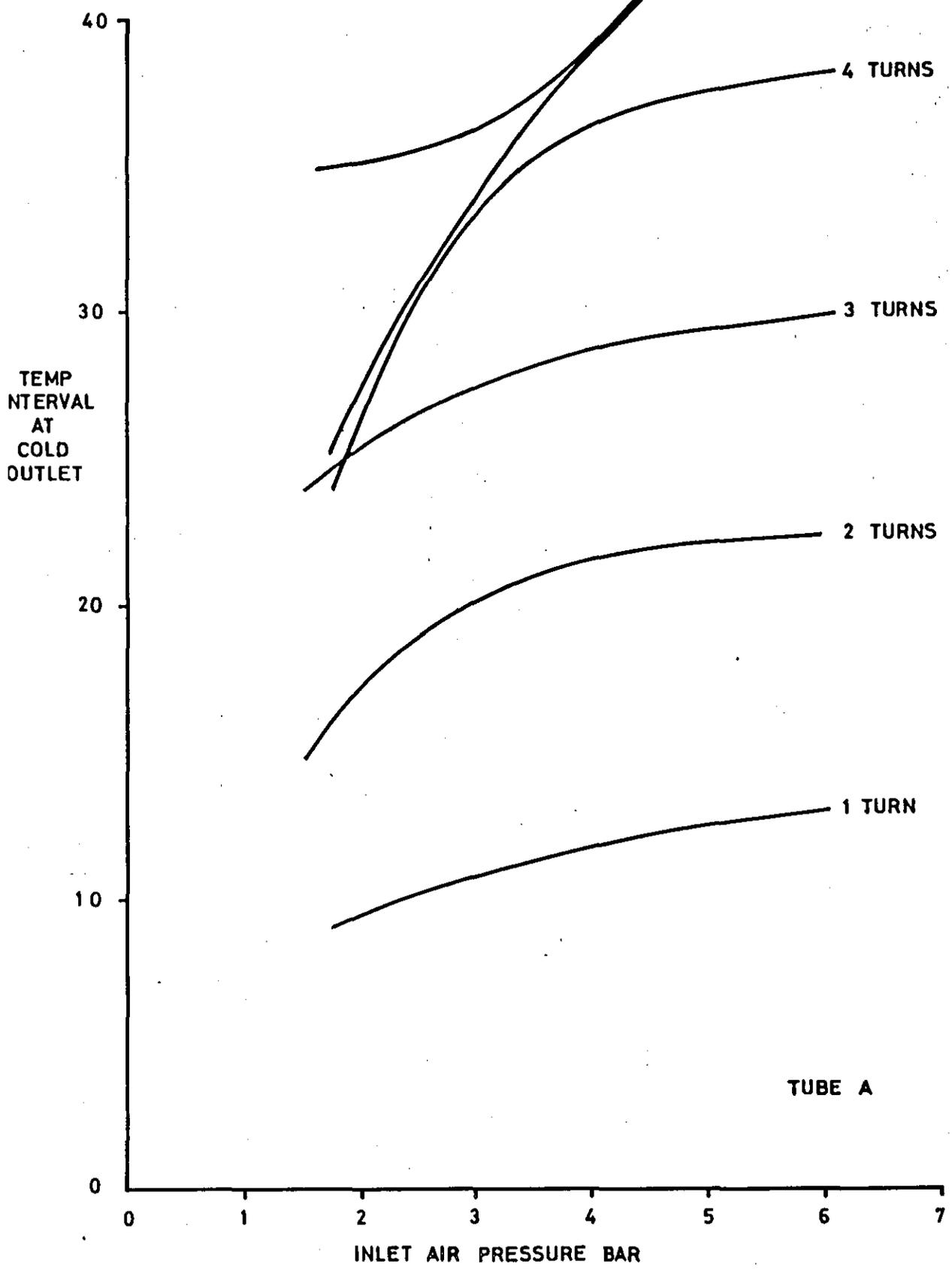
Hot Flow data	+ 4%
Hot pressure data	+ 3%
Cold mass fraction data	+ 5%
Inlet/cold outlet temperature interval	+ 2°K
Relative humidity	+ 5%

The preliminary test to check the inlet air pressure total hot flow characteristics showed that over the working range the characteristics were very similar (Fig 2.35). The relationship between inlet air pressure and temperature interval, Figs 2.36 and 2.37 indicate that the hot air valve control is less sensitive on the modified tube when more than half open but Figs 2.38 and 2.39 show the inlet pressure cold mass fraction characteristic to be similar in shape and magnitude. The modification which effectively shortened the length of the rotating air path has not significantly changed the characteristics and within the levels of accuracy for the measurement of the parameters and for the setting of the valve openings the performance of the shortened tube matches that of the original duplex vortex tube.

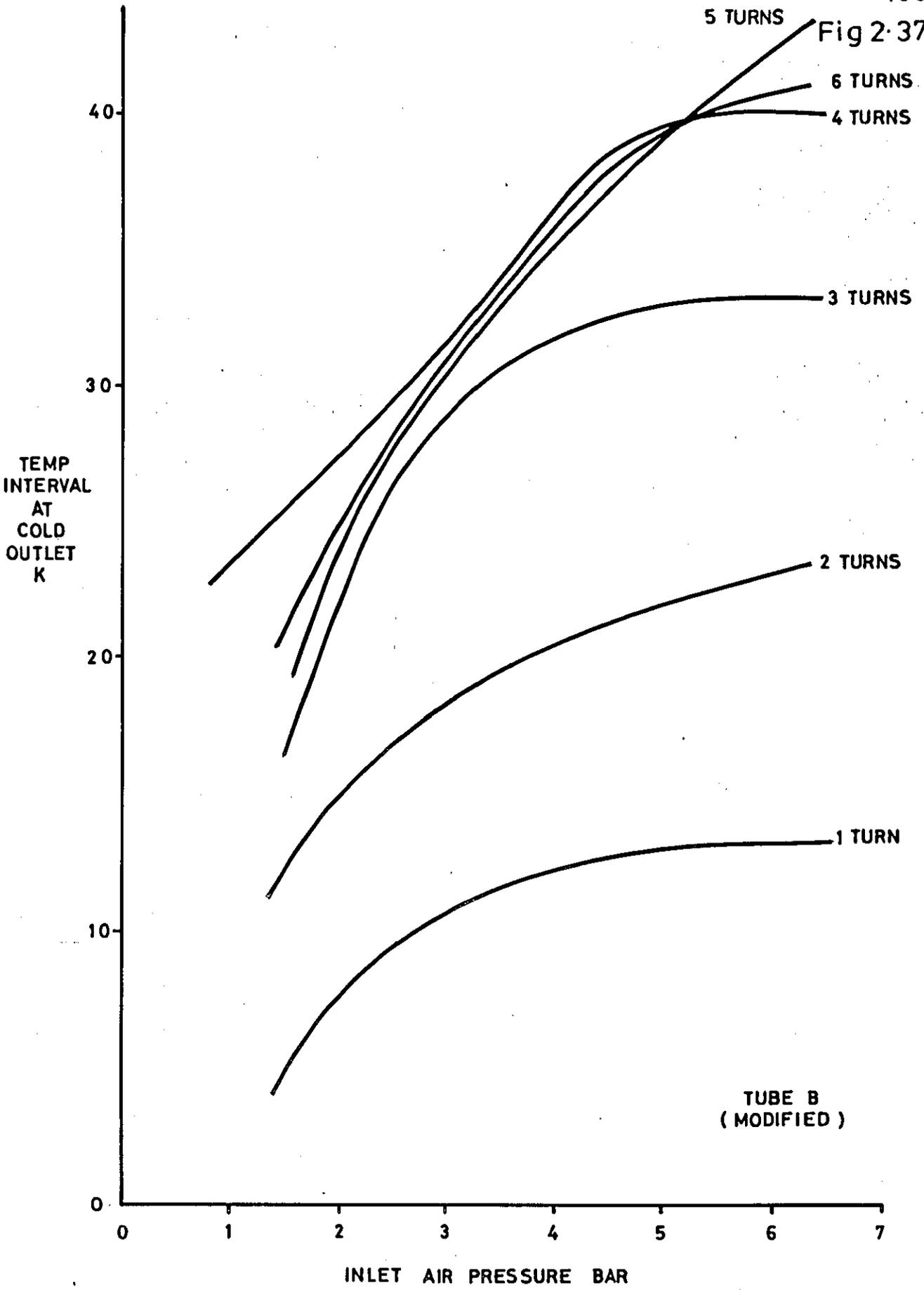
From the data established throughout these series of experiments it was possible to standardise the design of a duplex vortex tube for the micro-climate conditioning of a ventile suit assembly and this is shown in Fig 2.40. Comparison with the original Fulton design also shows an improved performance.



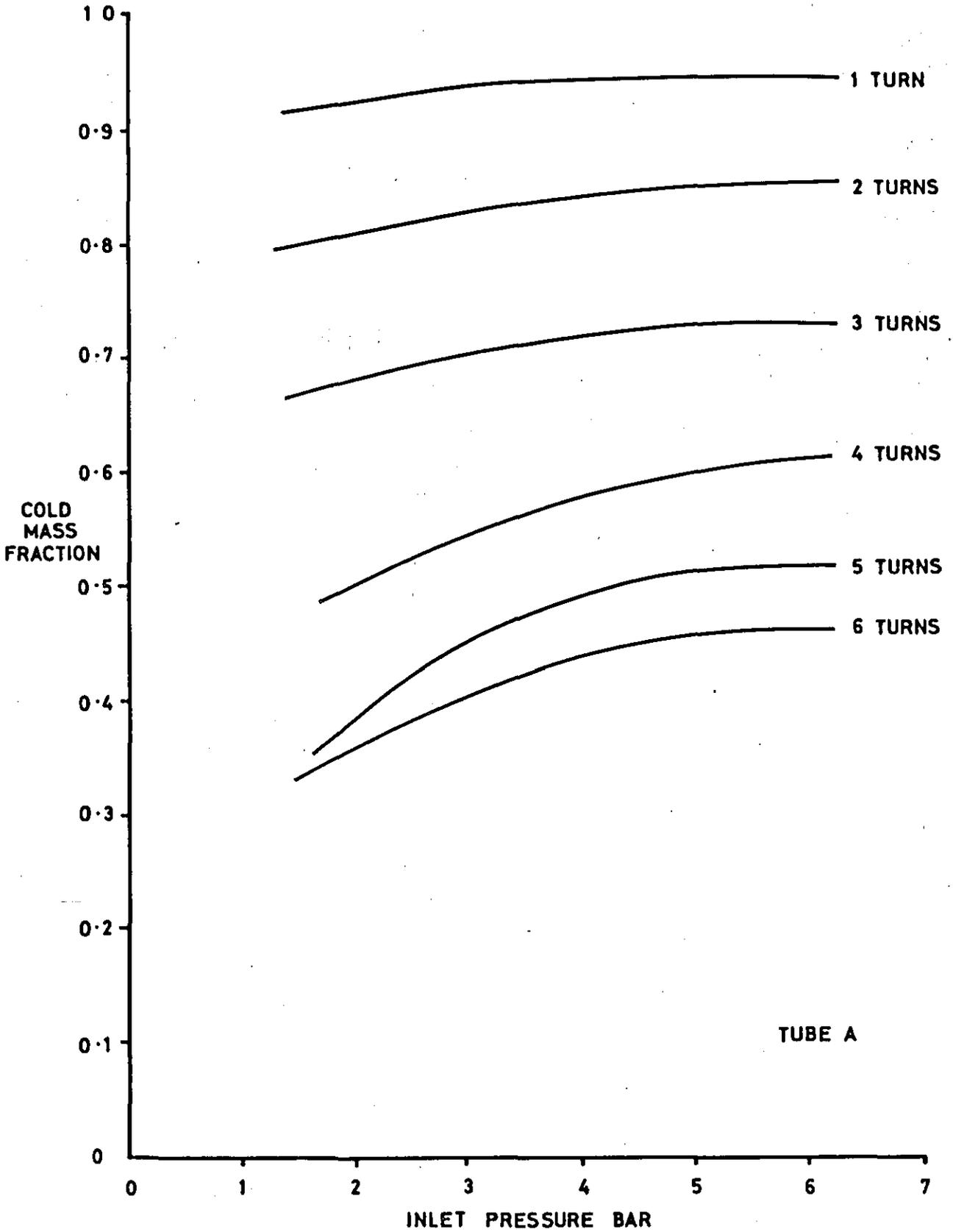
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND INLET AIR FLOW INLET AIR TEMPERATURE 50°C. VORTEX TUBES AT TEMPERATURE OF 60°C.



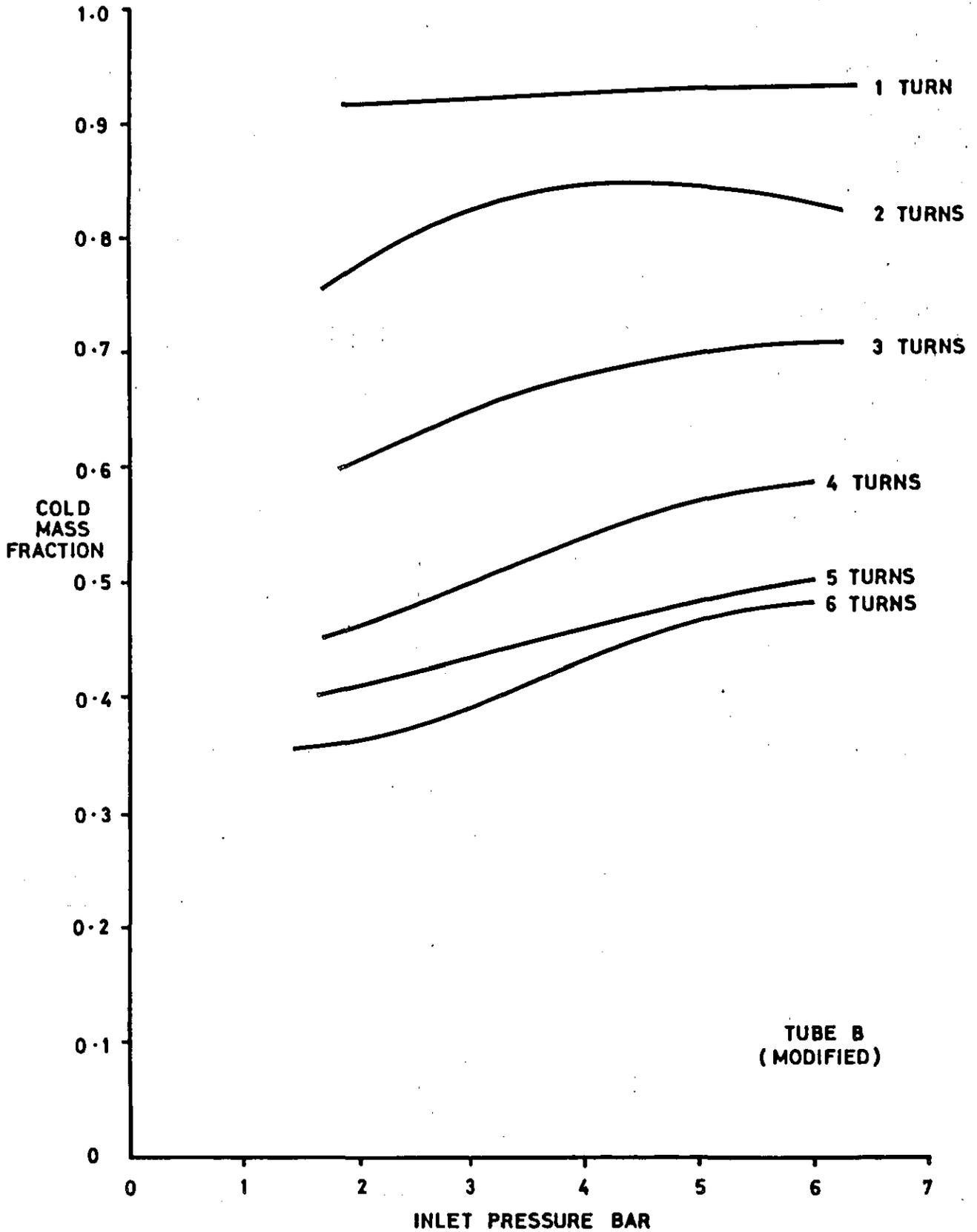
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE INTERVAL K WITH VARYING HOT VALVE OPENING. INLET AIR TEMPERATURE 50°C. VORTEX TUBE AT TEMPERATURE OF 60°C.



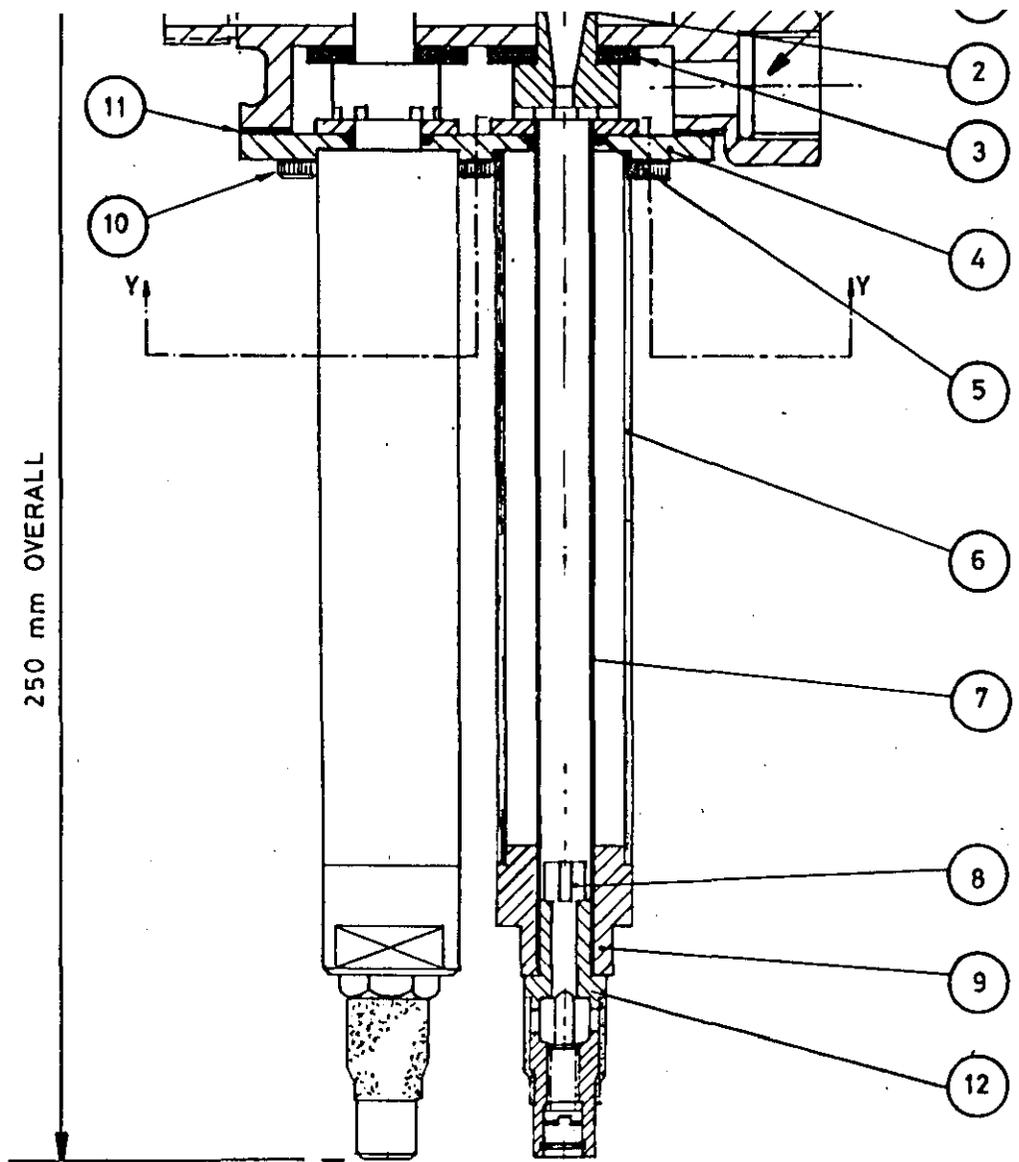
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE INTERVAL K WITH VARYING HOT VALVE OPENING. INLET AIR TEMPERATURE 50°C. VORTEX TUBE AT TEMPERATURE OF 60°C.



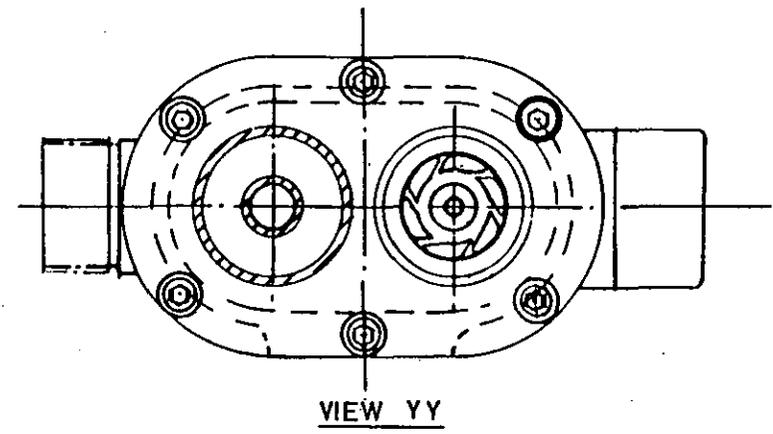
RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET AIR PRESSURE WITH VARYING OPENING OF HOT OUTLET VALVE .



RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET AIR PRESSURE WITH VARYING OPENING OF HOT OUTLET VALVE .



SEP/1971/LI



16				
15				
14				
13				
12	2	Combined Muffler & Adj. Valve	Brass Alumin ^{UM}	SCHRADER № 53006
11	1	Header Joint	C.A.F.	
10	6	Bottom Plate Securing Screws	Mild Steel	
9	2	Hot Valve Body AssY	Al Alloy	
8	2	Aerodynamic Brake	Brass	
7	2	Hot Tube	Brass	
6	2	Sleeve	Al Alloy	
5	2	'O' Ring	Rubber Nitrile	
4	1	Header Bottom Plate		Al Alloy
3	2	Washer	Rubber Nitrile	
2	2	Generator		Nylon Moulding
1	1	Header	Al Alloy Casting	L.M.4
REF	№ PER DUPLX TUBE	DESCRIPTION	MATERIAL	COMMENTS

Fig 2.40

2.4 Thermography. The temperature difference measurement on the Vortex tube assembly and the air distribution in the suit were also investigated by thermography using an Aga 750 Thermovision system and a platinum resistance temperature detector. During the observations polaroid photographs were taken and these are shown on Fig 2.41 for the suit and the vortex assembly.

In order to determine the surface temperature the platinum detector was placed in contact with the flat portion of the tube manifold. The effect of the material's emissivity was then calculated and applied to these measurements; Table 2.10.

Fig 2.41 shows in A. the duplex tube assembly and in B, C and D the shaded areas are the manifold, cold inlet and hot exhaust respectively, the scales at the left hand side indicating the isotherm levels attained in each case. It can be seen from Table 2.10 that the material emissivities must be considered to obtain accurate temperature measurements. If no correction for emissivity is made the resulting temperature will be lower than that actually present. Although not really captured by the reproduced polaroid prints (right-hand photographs in Fig 2.41) visual examination of the display monitor screen showed good cooling air distribution on the clothing assembly and this method can be used for quick assessment of this requirement.

Photo	Isotherm Level	Range	I	Difference	Measured Temp with Platinum Resistant Temp Detector	IR Temp No Correction for Emissivity	IR Temp with 'Assumed' Emissivities: A1 = 0.5 Brass
A		'CEGB'	DUPLEX	VORTEX	TUBE	ASSEMBLY	
					°C	°C	°C
B	0.26	50	13.0	-	23	23	23
C	0.375	50	18.75	5.75	35	29.5	From Cal: (1) 35.5
D	0.73	50	36.5	23.5	54	45.5	From Cal: (2) 55.5

= Absolute Isotherm Level for the Object Temperature, read from the Calibration Charts

or = Isotherm Difference between the object and Reference Temperatures

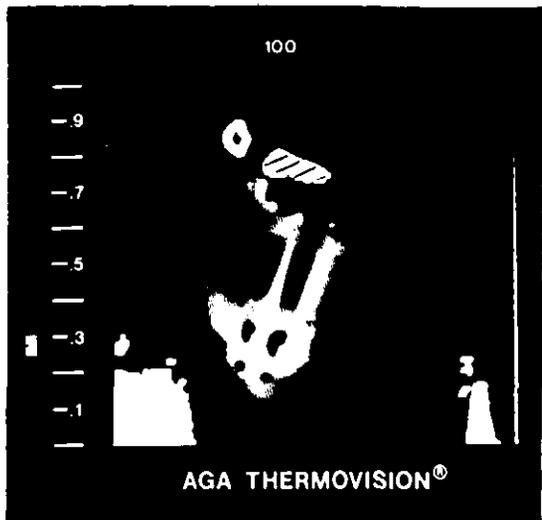
Table 2.10 Thermography Measurements Duplex Vortex Tube Assembly



A



1



B



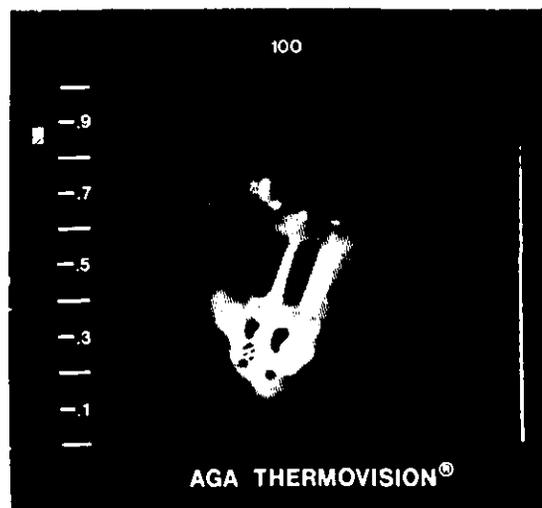
2



C



3



D



4

CALCULATIONS

Ref: Photographs A and B ($E_o = 0.5$ for A1 Assumed)

$$1) \quad I_o = \frac{i_{or}}{E_o} + I_r$$

Where these parameters are:

- T_o = object temperature
- E_o = object emissivity
- T_r = reference temperature
- E_r = reference emissivity
- T_a = ambient temperature ($E_o \approx 1$)
- i_{or} = image isotherm difference ($I_o - I_r$) observed between the thermal images of the object and reference temperatures
- I_o = absolute isotherm level for the object temperature read from a calibration chart
- I_r = absolute isotherm level for the reference temperature T_r read from a calibration chart
- I_a = absolute isotherm level for the ambient temperature T_a read from a calibration chart
- $I_o = \frac{5.75}{0.5} + 24.0$
- $I_o = 11.5 + 24.0$
- $I_o = 35.5$ From Calibration Charts - 35.5°C

Ref: Photographs C and D ($E_r = 0.5$ for A₁; $E_o = 0.5$ for Brass; Assumed)

$$2) \quad I_o = \frac{i_{or}}{E_o} = \frac{E_r I_r}{E_o} + \left(1 - \frac{E_r}{E_i}\right) I_a$$

Where these parameters are:

- T_o = object temperature
- E_o = object emissivity
- T_r = reference temperature
- E_r = reference emissivity
- T_a = ambient temperature ($E_o = 1$)
- i_{or} = image isotherm difference ($I_o - I_r$) observed between the thermal images of the object and reference temperatures
- I_o = absolute isotherm level for the object temperature T_o read from a calibration chart
- I_r = absolute isotherm level for the reference temperature T_r read from a calibration chart

T_a = absolute isotherm level for the ambient temperature T_a read from a calibration chart

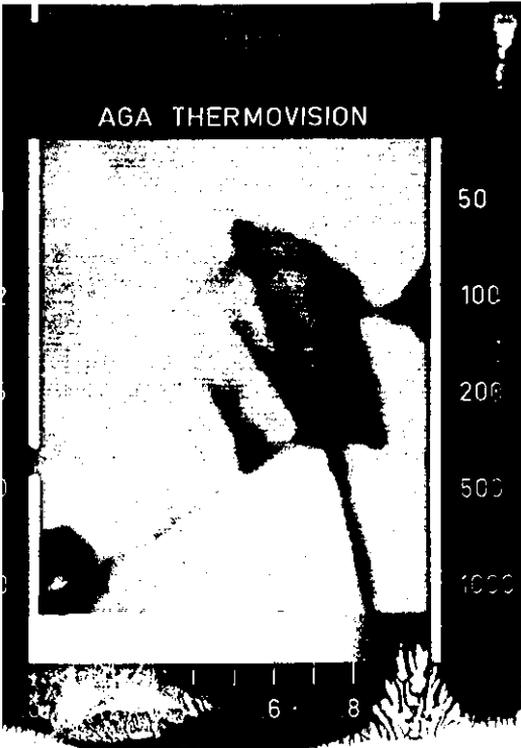
$$T_o = \frac{23.5}{0.6} + \frac{0.5}{0.6} 24.0 + (1 - \frac{0.5}{0.6}) 24.9$$

$$T_o = 39.2 + 20.0 + 4.16$$

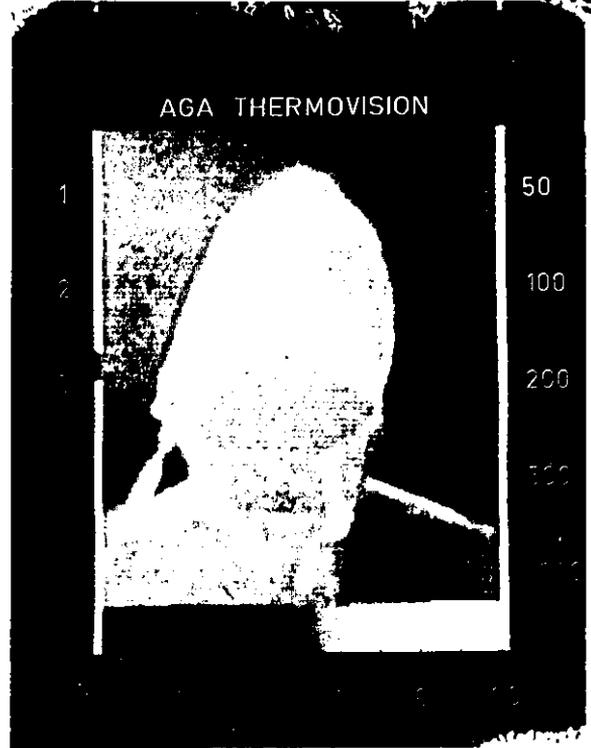
$$T_o = 63.36 \quad \underline{\text{From Calibration Charts}} = 55.5^{\circ}\text{C}$$

An infra-red analysis made of the conducting/ screening suits with a measured voltage and current applied, showed that 'hot spots' occurring in the suit seams were caused by the conducting tape. Fig 2.42 shows polaroid camera examples of this for an AC test of 6.5 amps at 7.2 volts which gave a calibrated temperature rise of 1°C to 5°C above ambient. Although not considered a serious defect it was a comfort factor that could not be determined by electrical measurement and indicated the need to distribute the conducting media more evenly through the base fabric and therefore supported the development of the material used in suits D and D1.

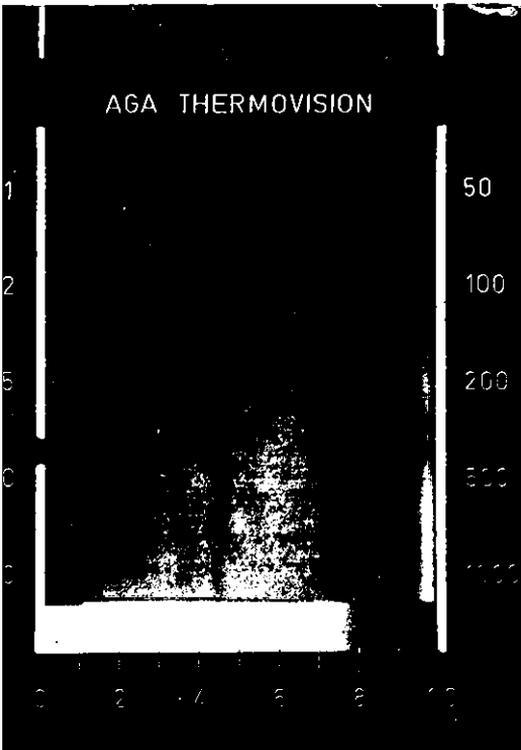
2.5 Ambulatory Monitoring. The evaluation of the specific effects of different intensities of work performed under various environmental conditions present a number of problems. Some of the influencing factors involved have been reviewed in Chapter 1 and the effects of these have been studied by many research workers using laboratory techniques to measure pulmonary ventilation, oxygen consumption, stroke volume cardiac output and body temperature changes. Evaluating the work load by measuring oxygen consumption is reasonably accurate and has been extensively used, but has several drawbacks in practical applications. For instance the equipment is rather clumsy and uncomfortable, so that some additional factors of physiological stress are encountered, which cannot be accurately evaluated by changes in oxygen consumption. Work intensities can also be evaluated by cardiovascular reactions, but it is impracticable to record blood pressure measurements during work except by expensive automatic devices. Noise levels in most industrial occupations are not low enough to permit



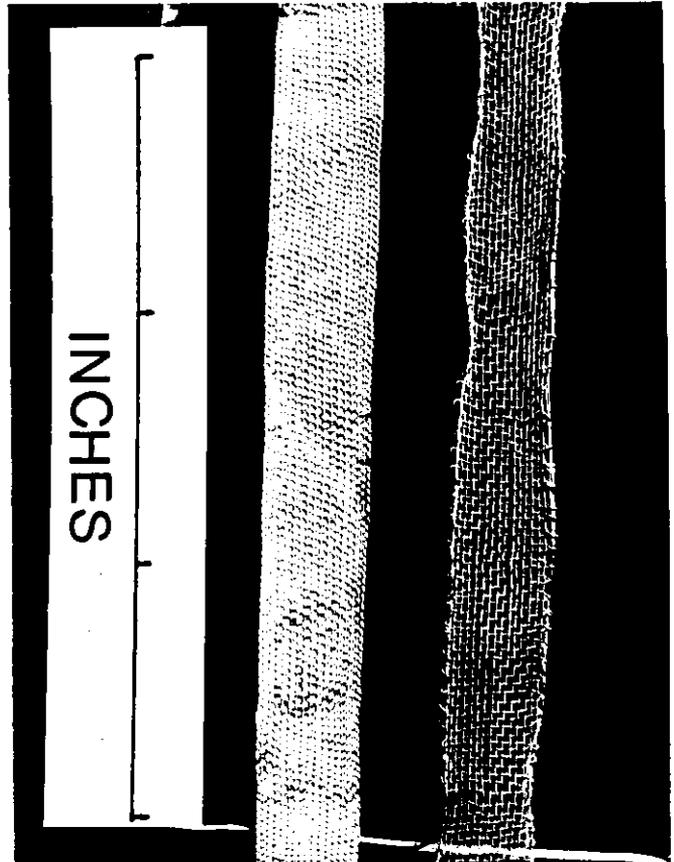
(a) Rear view of hood
(black is hot)



(b) Front view of hood
(white is hot)



(c) Rear seam showing spread
(black is hot)



(d) Examples of seam conducting tapes

EXAMPLE OF USE OF THERMOGRAPHY ON CONDUCTING/
SCREENING SUITS SHOWING THE EFFECTS OF
CONDUCTING TAPE SEWN INTO SEAMS OF GARMENT

accurate determination of the systolic and diastolic pressure. Measuring cardiac output would be ideal but the present methods are obviously impossible to use under industrial conditions.

It has, however, been shown in Section 1.3 that heart rate changes quite accurately reflect the physiological state during muscular activity. Consequently for monitoring subjects during the particular work activity, study of the heart rate reactions seems to offer a direct simple method. With its close relation to cardiac output and oxygen consumption within the range of many industrial occupations the heart rate can be utilised to gauge the stress imposed by muscular activity, if it can be obtained with minimal interference with the subject's freedom of motion and performance ability. The physiological measurement of ambulant subjects also presents a number of problems since no restriction should be imposed on activity. Littler et al (1972) reported on the use of a miniature four channel analogue tape recorder for continuous recording of electrocardiograms and arterial pressures in Unrestricted Man. Littler et al (1973) reported on the use of the device during motor car driving, and Cashman and Stott (1974) on its use as a semi automatic system for the analysis of 24 hour ECG recordings from ambulant subjects. The development and design of the recorder are described by Marson and McKinnon (1972) and McKinnon (1974) and in the proceedings of the first International Symposium on Ambulatory Monitoring edited by Hoffbrand et al (1976) a number of papers are presented on the use of miniaturised recording devices for Electrocardiography, Electroencephalography, Orthopaedics and blood pressure measurements in the area of clinical diagnostics. The systems used proved themselves to be flexible and reliable and a highly efficient means of gathering and analysing large samples of data in almost any working situation.

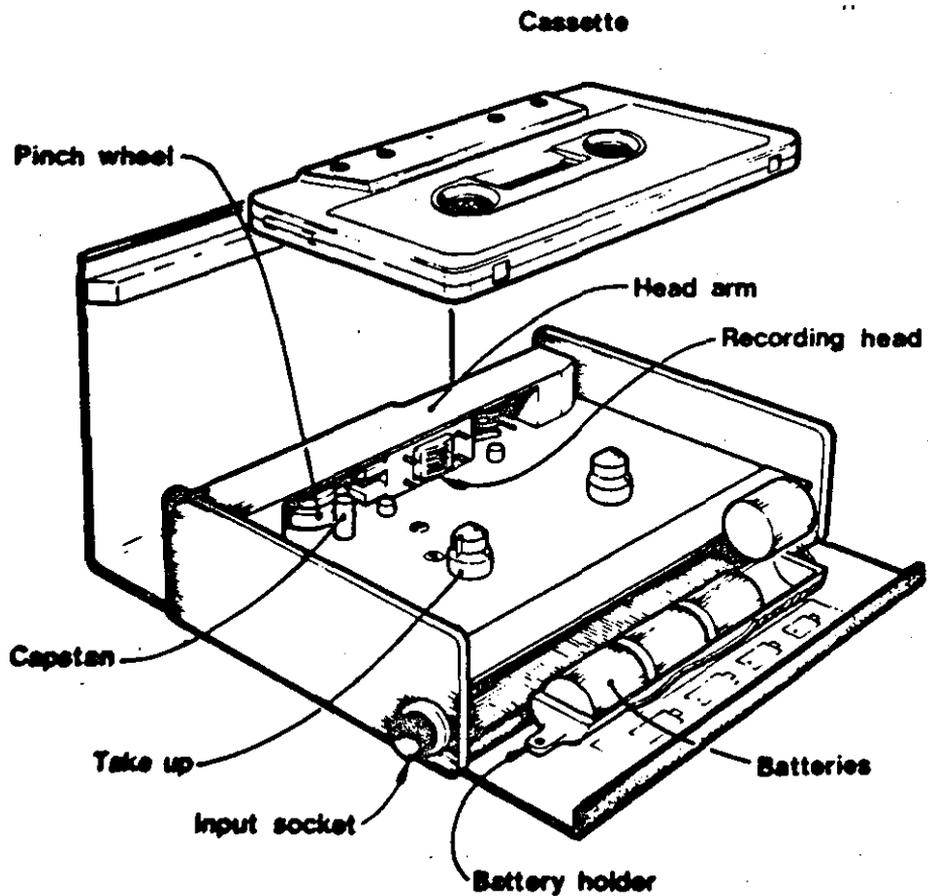
This section describes the development of an ambulatory monitoring system, from data acquisition through analysis to presentation

to acquire physiological data to enable the assessment of the effects of working in abnormal working environments. The parameters were to be related both to work and the environmental conditions to assess the maximum work capacity demand and degree of training which may become necessary to obtain this under the prescribed environmental conditions.

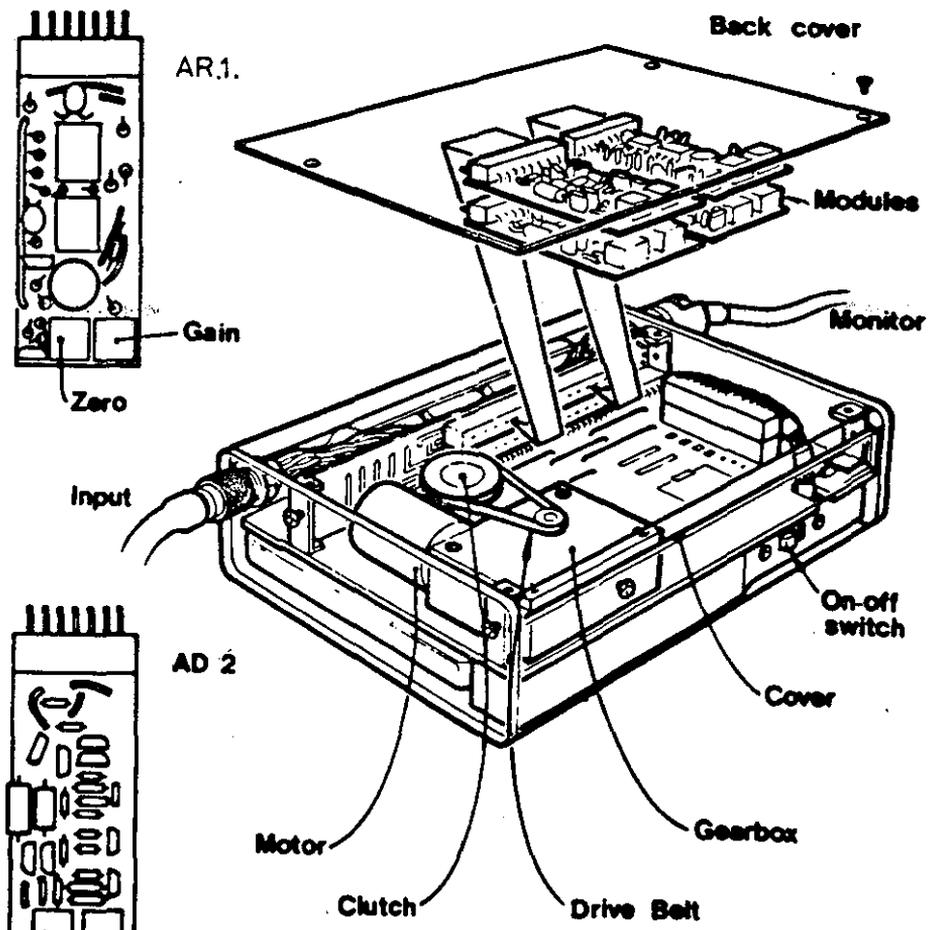
2.5.1 Data Acquisition System. The Oxford Microlog (Oxford Instrument Co) Miniature analogue four channel tape recorder was chosen, as it seemed to fulfil most of the criteria that were set for such a system to be acceptable in the particular industrial situation to be studied. Namely acceptable to the subjects, simple to fit, unobtrusive and reliable. One restriction was also imposed as to the use of the equipment, all measuring probes were to be surface mounted on the subjects. Fig 2.43 shows the instrument in an exploded view with the AD2 amplifier used for ECG recording and the AR1 temperature measuring module. Fig 2.44 shows the instrument with ECG electrodes, temperature thermistor and a monitoring unit, together with an instrumented subject.

The channels were used initially as follows:-

- channel 1 - To record an electrocardiogram for measurement of heart rate, used in conjunction with a standard two electrode system of self-adhesive pregelled silver/silver disposable electrodes (Mann Greatbatch Electronics).
- channel 2 - Undefined pending investigations into suitable probes and transducers for monitoring activities.
- channel 3 - To record skin temperature changes, used in conjunction with thermistor calibrated around $(35 \pm 10^{\circ}\text{C})$ bridge reading. The signal is amplified by a dc. module and the system has to be calibrated at the beginning and end of each application.
- channel 4 - To record a permanent timing pulse at 1 sec interval to enable real time analysis to be made and in particular to correlate recorded events in the work cycles with physiological responses. A 1Hz crystal

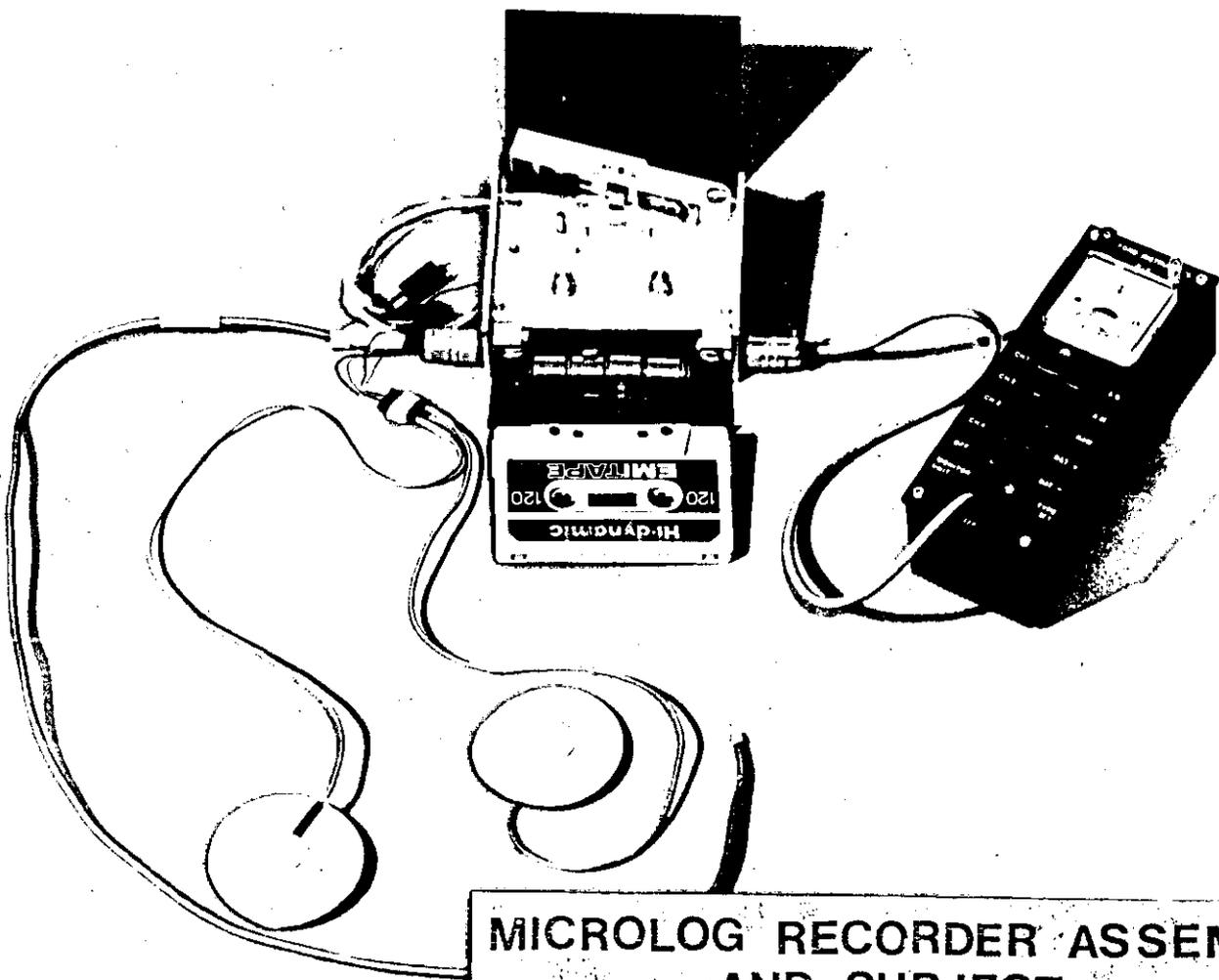
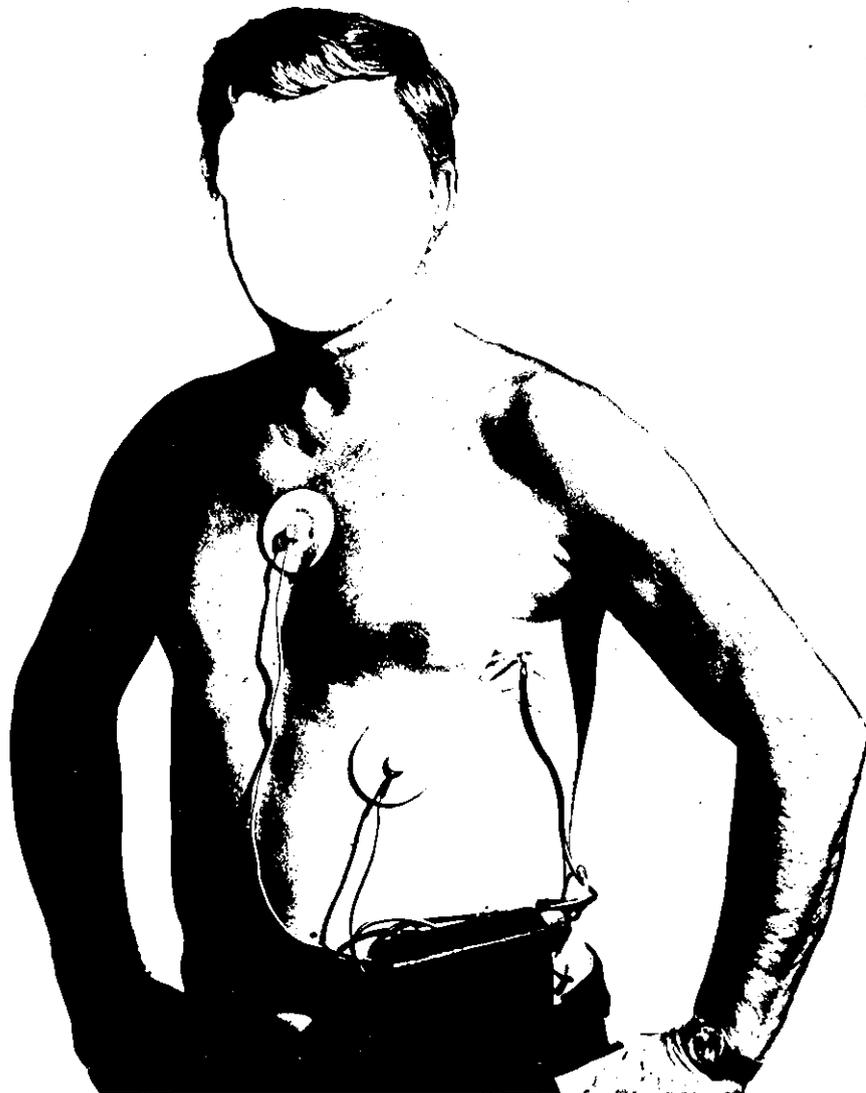


TOP VIEW



VIEW FROM REAR

THE MICROLOG RECORDER



**MICROLOG RECORDER ASSEMBLY
AND SUBJECT**

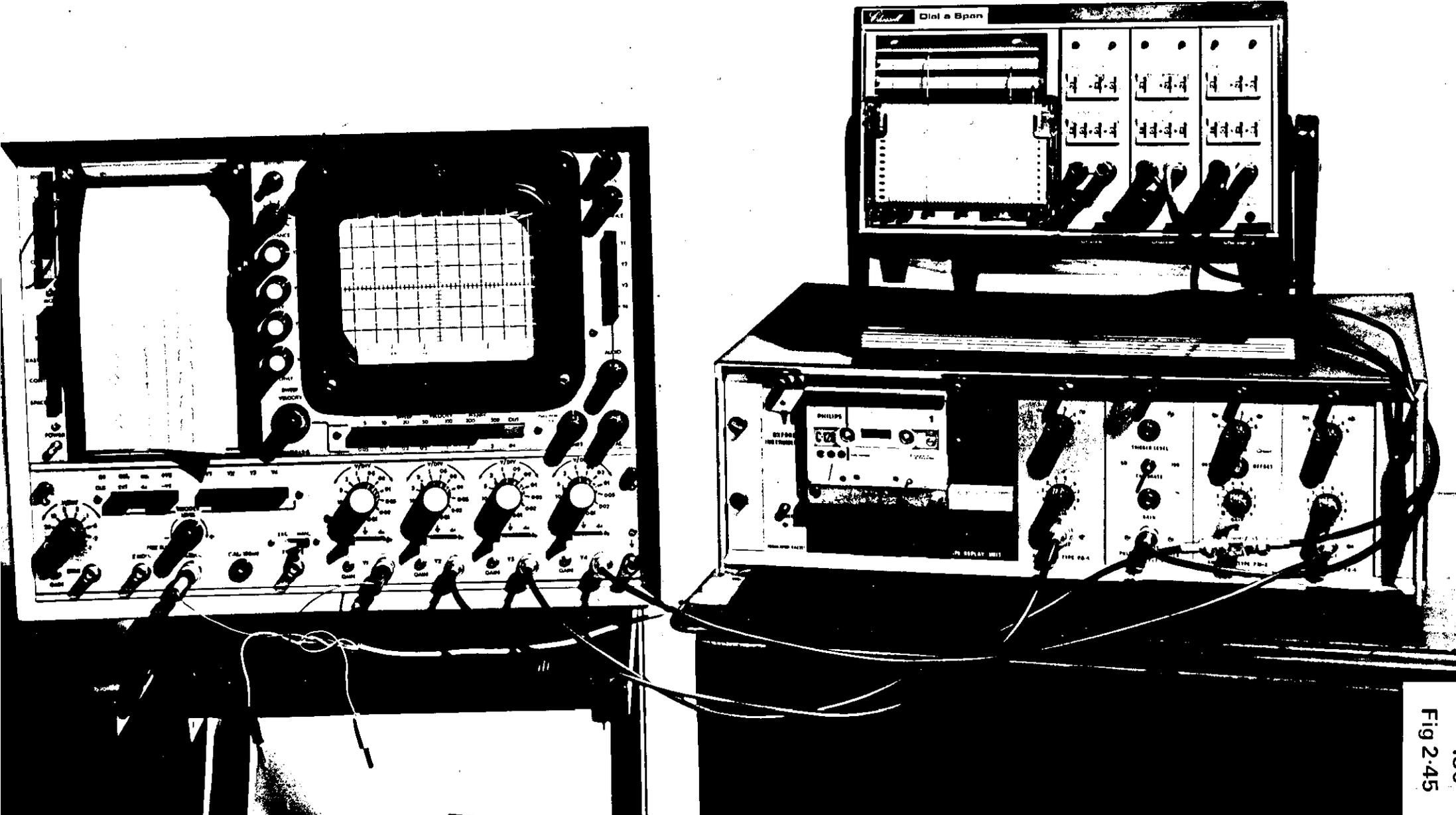
controlled oscillator is used, the output of which is recorded directly on to the tape.

2.5.2. Data Analysis System. This is shown on Fig 2.45 and incorporates the following instruments; a tape replay unit (Oxford Instruments Ltd) 3-pen electronic recorder (Chessel) and a 4 beam oscilloscope and UV recorder (Medilec). This facility provided both visual display and hard copy records of the measurements which had been put on magnetic tape by the 4 channel Microlog miniature recorder. The magnetic tape, which is stored in a cassette, being played back at 60 times the recording speed, information may be recorded for up to 24 hours on one tape.

The play back unit contained amplifiers which enabled higher signal levels to be displayed on the oscilloscope and chart recorder. The unit also included a frequency analogue converter which provided an analogue signal directly proportional to heart rate for chart recording or computer analysis, a trigger pulse of oscilloscope image clarity and a ramp signal whose length corresponds to the heart beat interval. The ramp signal could also be used to replace the oscilloscope's internal time base, this enabled the x-axis of the screen to be calibrated in terms of heart rate, as shown by the scale at the base of the visual display in Fig 2.45.

The oscilloscope had an ultra violet (uv) recorder built into it which could be used to record continuously or take signal pictures of the screen's image. The recorded information can be viewed on the screen providing a rapid assessment of the subject's physiological performance whilst simultaneously providing hard copy of the same information. Test signals of 50 and 100 BPM can be generated within the play back unit to calibrate the recorder and oscilloscope.

The play back unit's tape transport deck is equipped with a counter which is used to establish the tape position of any special



DATA ANALYSIS SYSTEM

Fig 2.45

features of the recording. Analysis of the UV trace is also made more accurate by the inclusion of the timing mark signal on the record which overcomes the possibility of errors from tape stretch.

2.5.3 Data Presentation System (with particular reference to heart rate). A solartron computer-based data logging system was programmed to analyse an analogue signal, which is directly proportional to heart rate produced by the microlog playback facility. The programme analyses this signal to provide information as to the length of time spent at specific heart rate. This enables previously recorded information to be tabulated for further analysis.

The programme No 1 is written in two parts, the first instructs the data acquisition system to read the analogue signal 7 times per 2 seconds. This data is reproduced onto punched paper tape which has been repunched by the programme with the recordings reference number and data together with the signal levels corresponding to 50 and 100 BPM.

The second programme No 2 reads data from the punched tape and enters into store the number of readings taken between 65 and 149 BPM in 5 BPM steps, ie 65 to 69, 70 to 74 and so on. The number of readings being directly related to heart rate as 1 second tape duration corresponds to 1 minute of site activity. If recording gives rise to erroneous signals these are rejected by the programme as invalid data. The information is then tabulated and printed by a teletypewriter and if required a histogram may also be printed.

The third programme produces a further analysis of heart rate over one minute intervals: an ICL 1900 computer processes data from the previously prepared punched tape, the resultant information being teletyped.

The three computer programmes are included at the end of this Section.

2.5.4 Use of the Data Acquisition System under Laboratory Conditions

The recording system was first evaluated under laboratory conditions. Two subjects who were trained in experimental physiology participated in the investigations, their physical characteristics are given in Table 2.11 below.

CODE	JT	MP
Sex	M	M
Age years	22	23
Height m	1.73	1.77
Weight Kg	68.91	75.3
Chest circumference cm	92	99
depth mm	226	188
width mm	274	377
Vital capacity 1	5.5	6.1

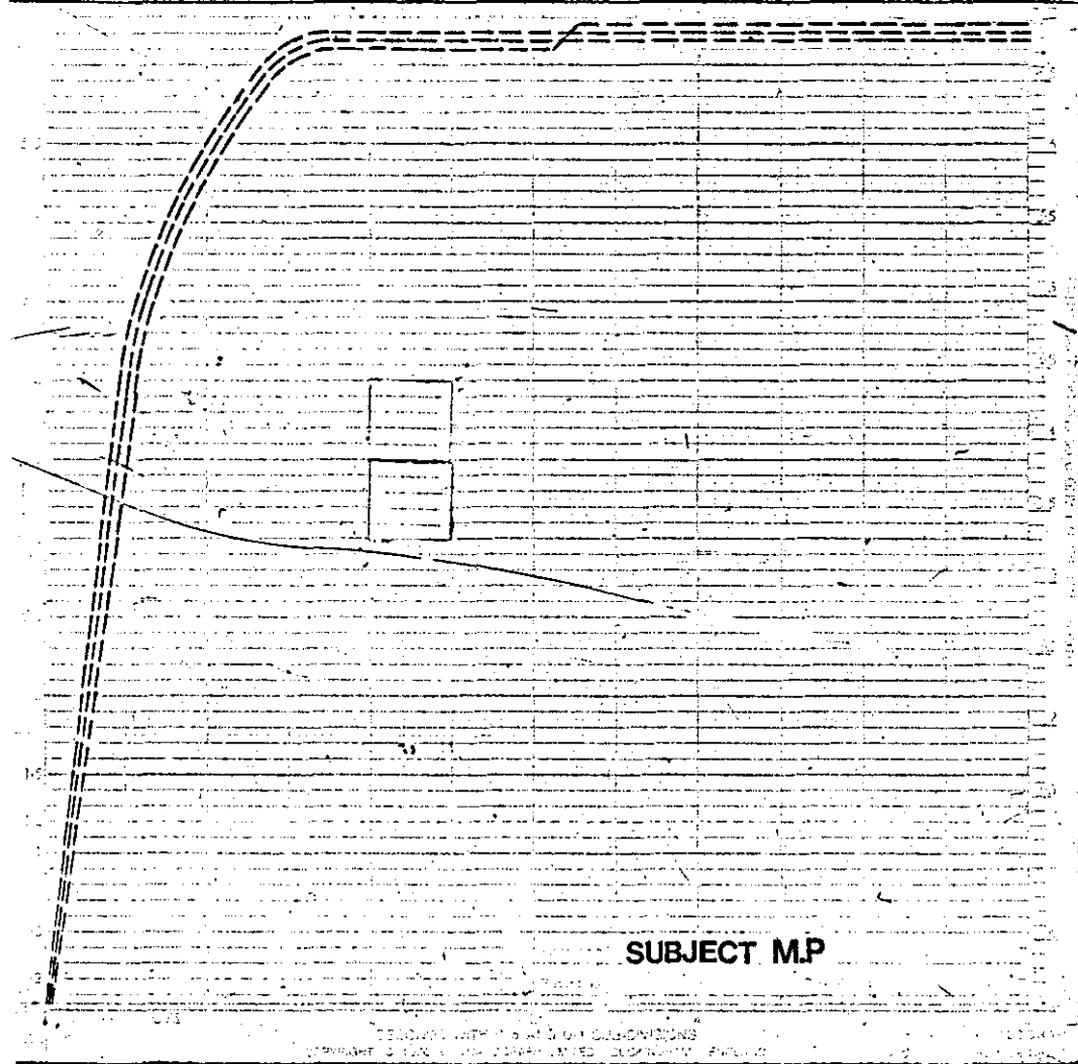
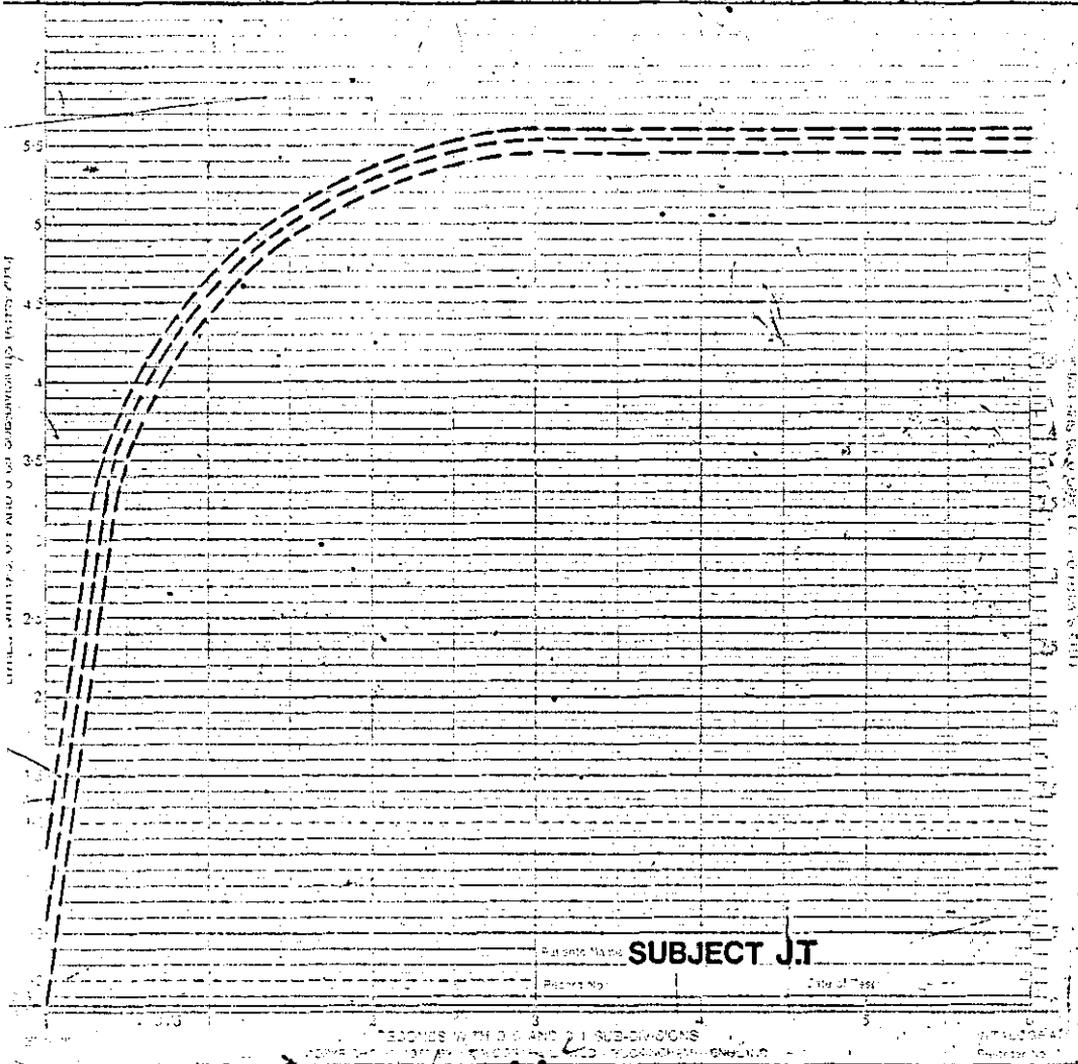
Table 2.11 Subject Data Laboratory Experiments

Chest measurements were taken with a Harper anthropometer and steel tape as follows:

- Circumference - at nipple line on expansion, arms relaxed at side
- Depth - at mid manubrium to the spinous process of dorsal vertebra
- Width - at mid axillary plane with probe in contact with ribs.

Vital Capacity was established with a Vitalograph Spirometer and the resultant Vitalograms are shown in Fig 2.46. The purpose of this investigation was to compare data recorded on the microlog recorded with data obtained when the subject was connected directly to an electrocardiographic recording device under increasing work-rate conditions. For this purpose a Cambridge twin pen electrocardiograph recorder and a cycle ergometer were used. The ergometer was equipped with an automatic work increasing device designed by Muller (1964) and was calibrated so that work at 90 For 1 minute revolutions per minute is equal to a power output of 10 watts

It was fitted with a whirling current braking system, i.e. the wheel had a copper tyre turning between the poles of



two strong permanent magnets, the work load being determined by the position of the magnets which were adjustable by dipping the copper tyre more or less deeply into the magnet gap. Pedalling speeds could be varied to 40, 60 and 90 revolutions/min and the height of saddle was adjustable to suit the height of subjects under test.

Prior to the commencement of this series of investigations a calibration test was carried out on the ergometers.

The sites for the three electrocardiograph recording electrodes were on the manubrium, xiphisternum and the space between the fifth and sixth ribs directly beneath the left nipple on a line drawn perpendicular from the left mid-clavicular position. The sites for the recorder electrodes were the top of the sternum and adjacent to the electrode placed in the fifth, sixth rib interspace.

Two cycle ergometers were placed side by side, the saddles were adjusted to suit the subjects height and a fixed work rate of 50 watts at 60 rpm was selected, synchronised pedalling between the subjects was obtained with the aid of a metronome. The subjects wearing cycling shorts and tee shirts, socks and training shoes were coupled to the electrode leads, electrocardiographic recorder switched on and rested for one minute in an upright position. Pedalling then commenced at the required rate 50 watts 60 rpm and continued for 5 minutes, when the automatic device was switched in to increase the work rate by 10 watts/min. After 25 minutes automatic device was switched out and subjects continued pedalling at 250 watts 60 rpm. At 30 minutes pedalling was stopped and the subjects rested until a steady state was noted. The leads from the electrocardiographic recorder were disconnected, the microlog recorder was continued to be worn by the subjects and they carried on with their normal activities and returned to the laboratory some 3 hours later and the experiment was repeated.

The results of the heart beat measurements are summarised in Table 2.12 and the recorded results compared favourably with those obtained from the analysis of the electrocardiographic pen recorder and UV prints Figs 2.47 to 2.55.

The analysis of the cassette tapes, based on computer programmes 1 and 2 is shown by presentation in a histogram form of heart rate distribution pages 195 and 198. As some 3 hours of unspecified activity is included in these results it is not possible to analyse them fully and they have only been included to demonstrate the availability of this method of data presentation. Analysis of the tapes based on computer programme 3 is shown by the computer print-outs, pages 196 and 199. From this it is possible to analyse the heart beats per minute relative to the work activity on a minute by minute basis and the areas of the controlled work exercise have been indicated accordingly. It can easily be seen that the increased heart rate can easily be related to the controlled increasing work rates.

To enable the recording device to be used as a monitoring instrument the small electronic circuit shown in Fig 2.57 was developed and used in conjunction with a storage oscilloscope gave a very good visual ECG display of the subject under test and enhanced also the versatility of the data acquisition system.

The analysis developed by this system is considered to provide the rational basis of a practical procedure for estimating the muscular work activity from the continuous heart rate record. It has the advantage of requiring the subjects to wear a very light apparatus. The procedure seems to be accurate and reliable enough for an extensive use in an actual work situation with moderate to heavy energy expenditures.

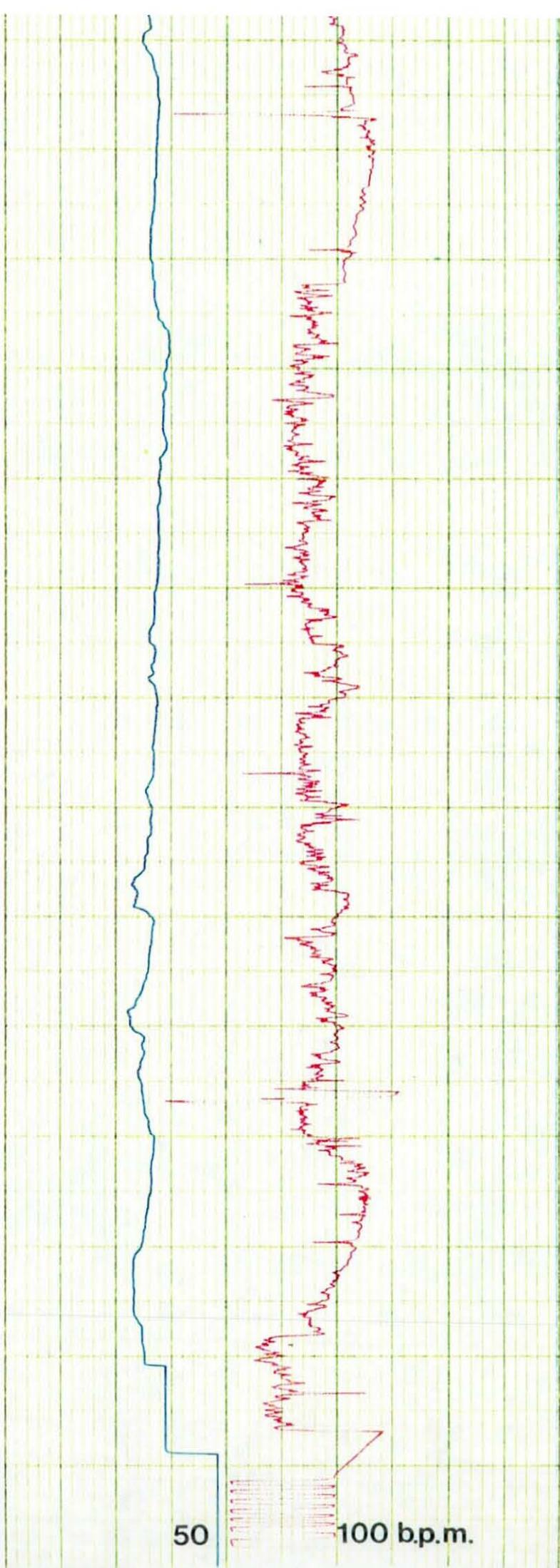


CHART No. 20003

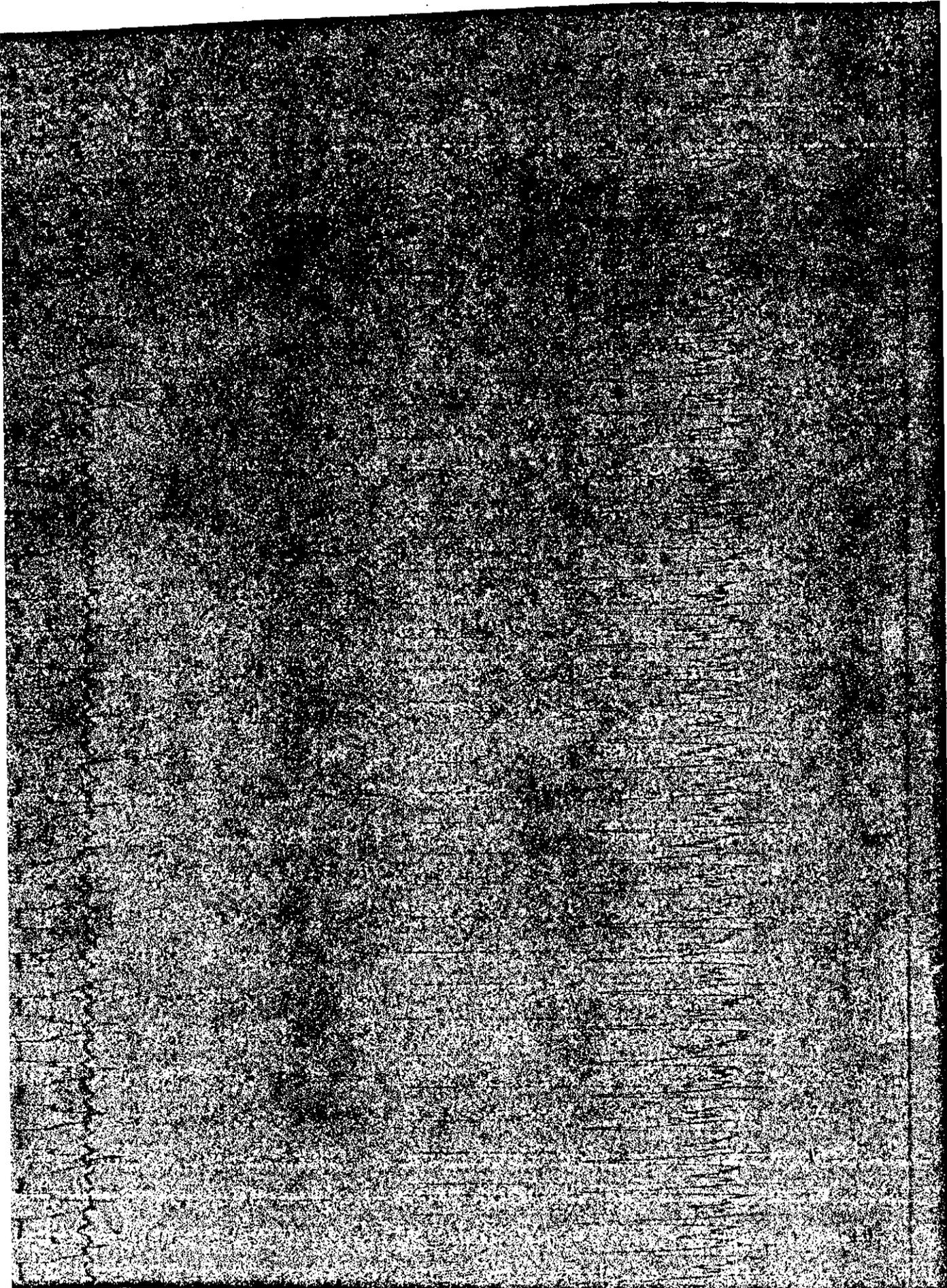
6/74

Cheswell

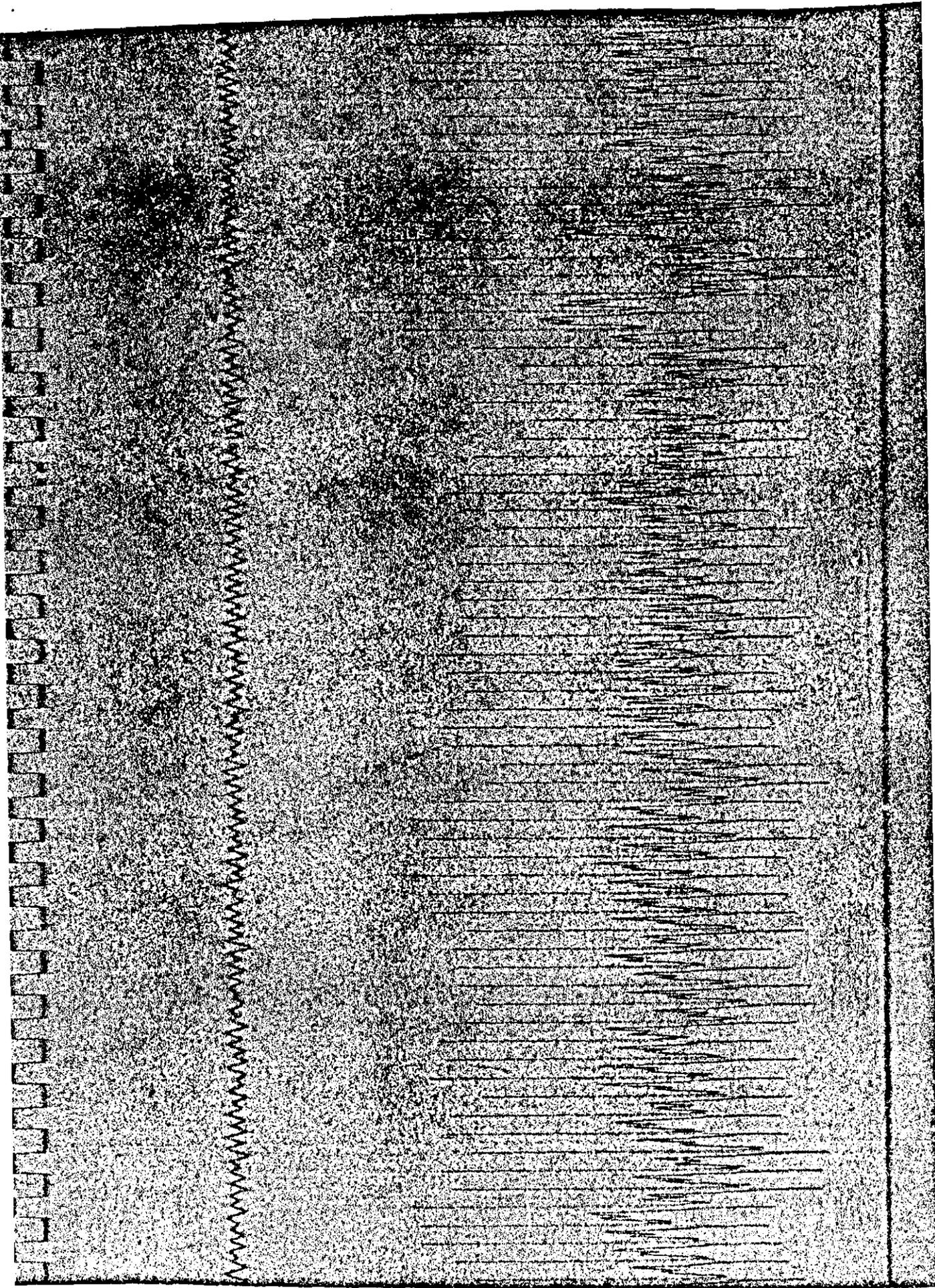
PEN TRACE
heart rate/time
subject: T.J.

50

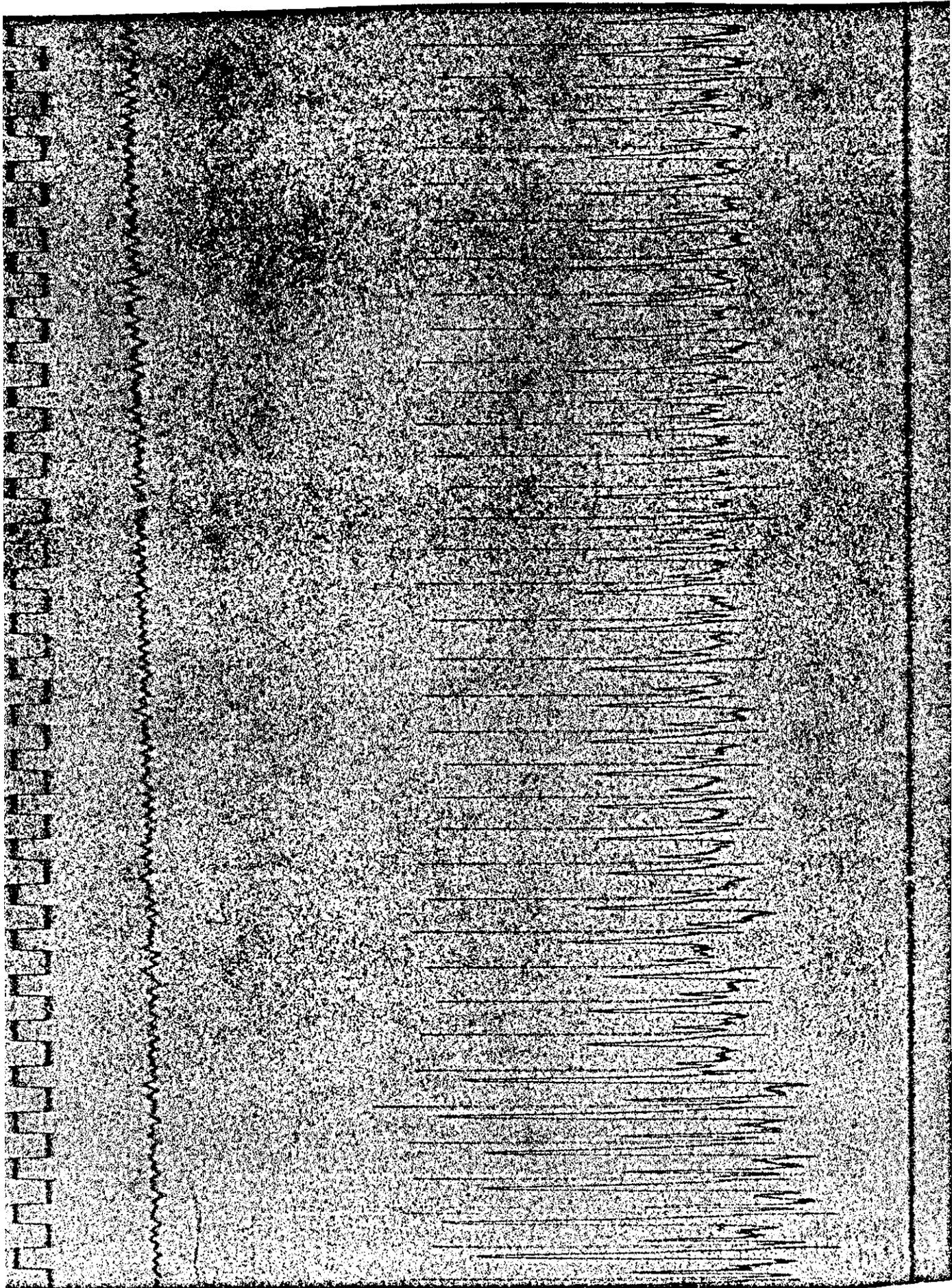
100 b.p.m.



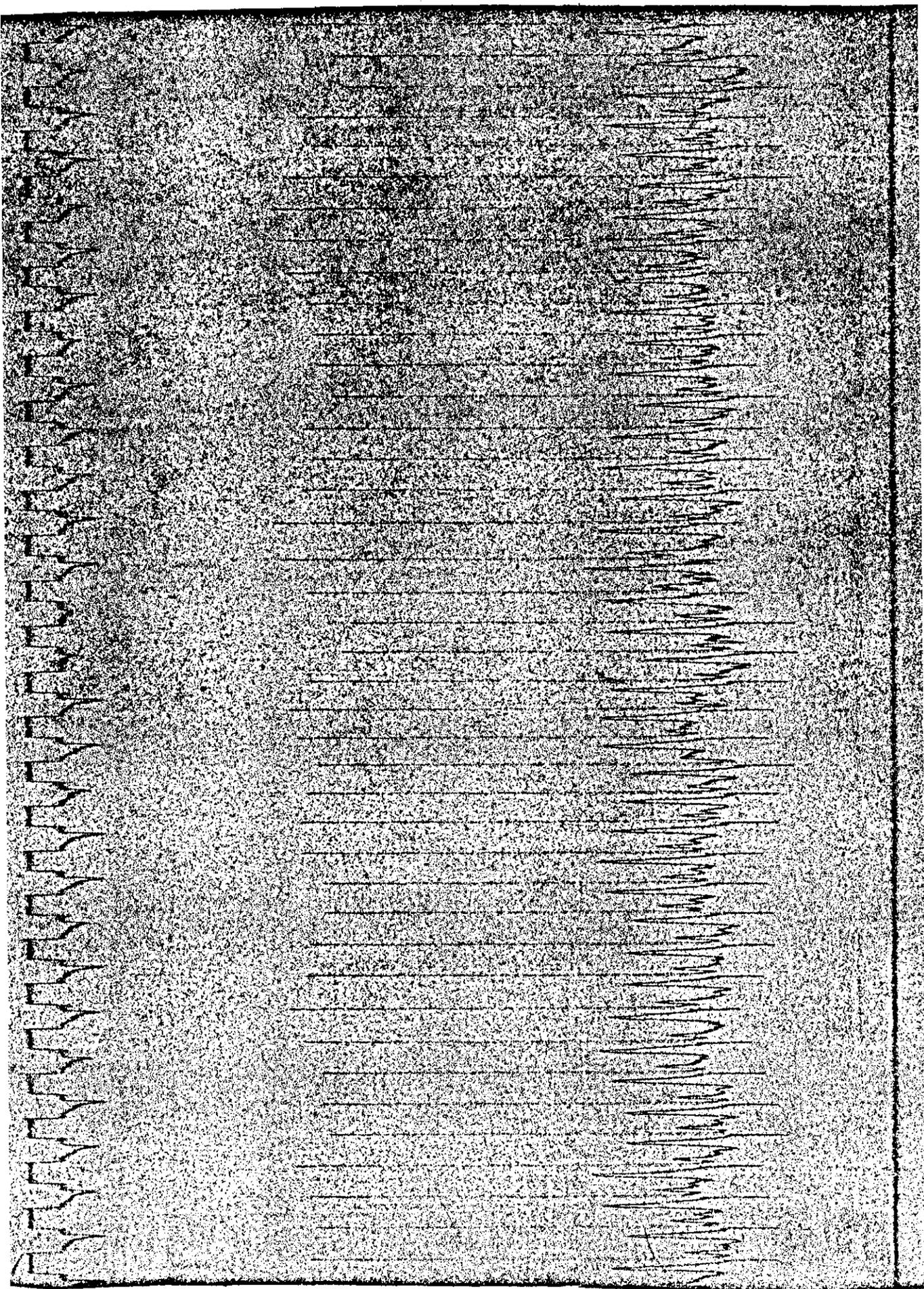
U.V. PRINT OUT-HEART RATE



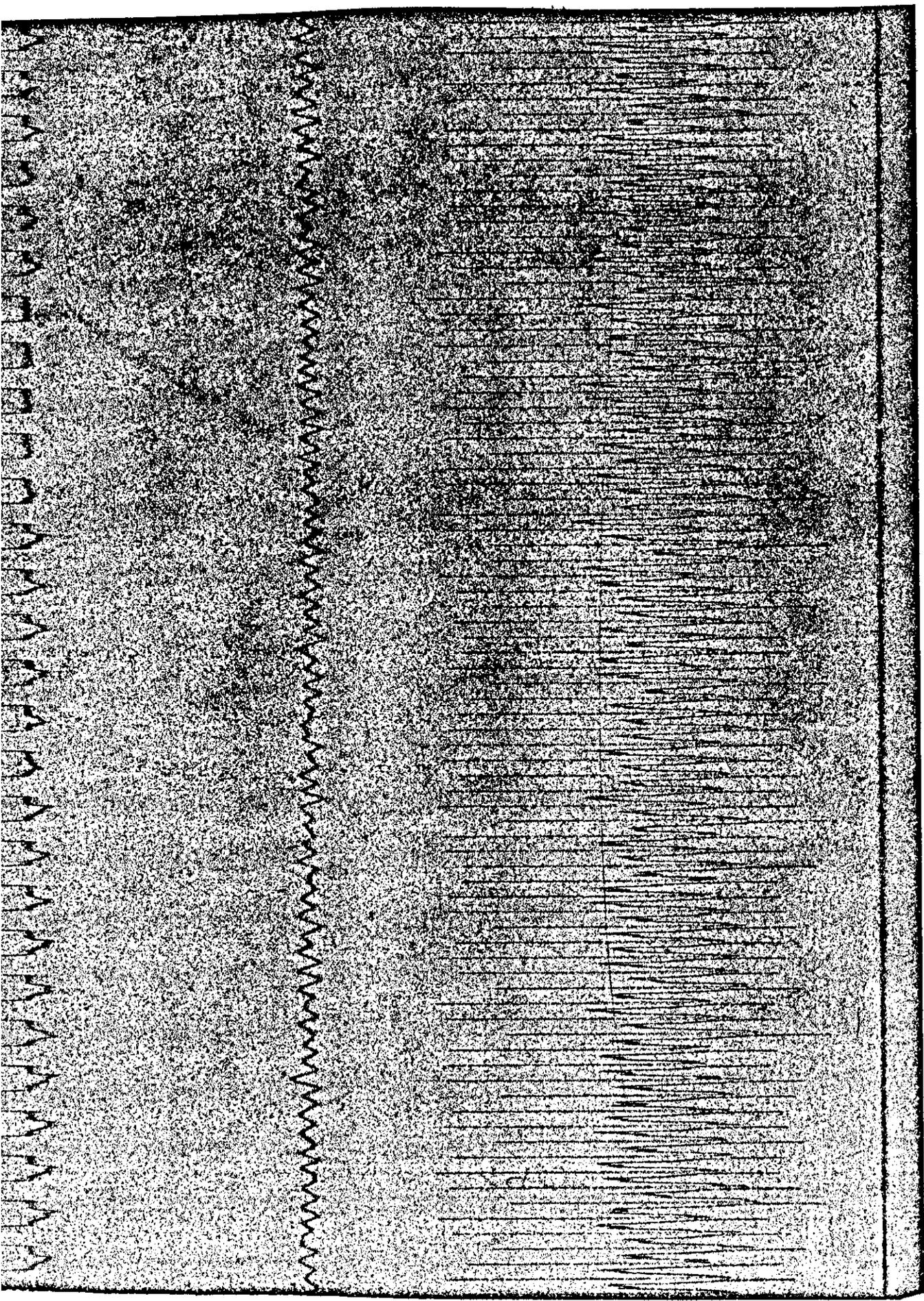
U.V. PRINT OUT-HEART RATE



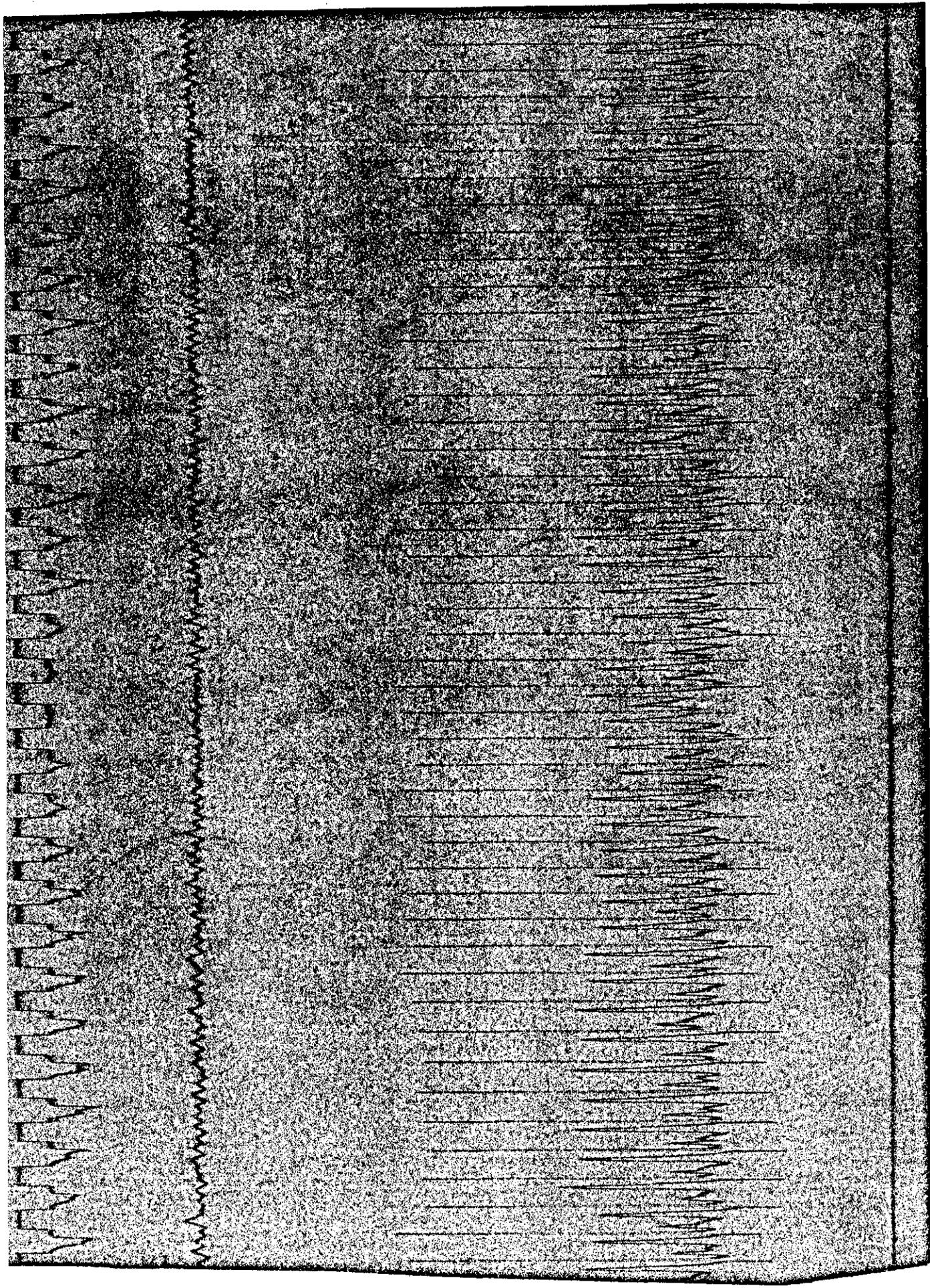
U.V. PRINT OUT-HEART RATE



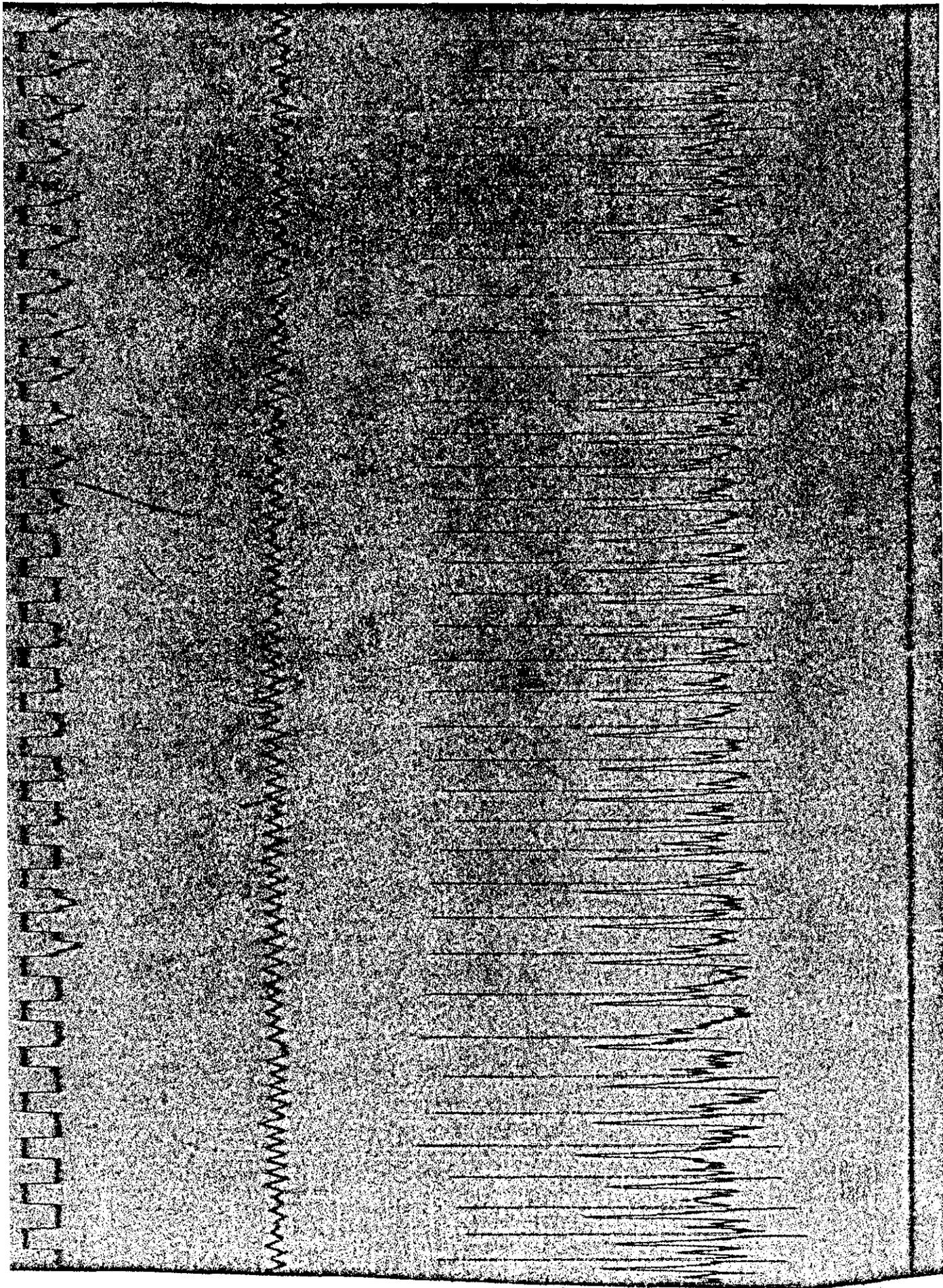
U.V. PRINT OUT-HEART RATE



U.V. PRINT OUT-HEART RATE



U.V. PRINT OUT-HEART RATE



U.V. PRINT OUT-HEART RATE

SUBJECT PM

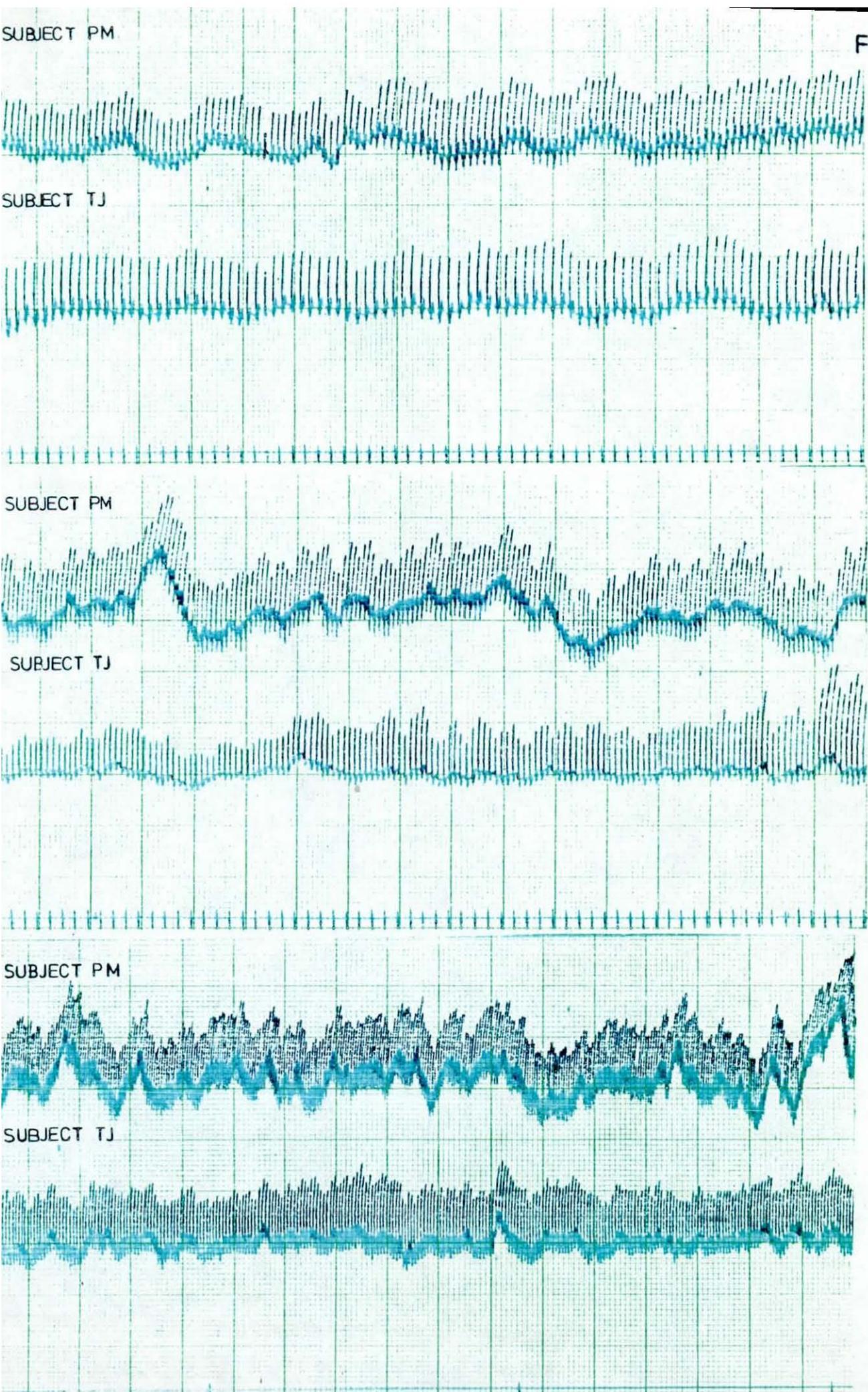
SUBJECT TJ

SUBJECT PM

SUBJECT TJ

SUBJECT PM

SUBJECT TJ



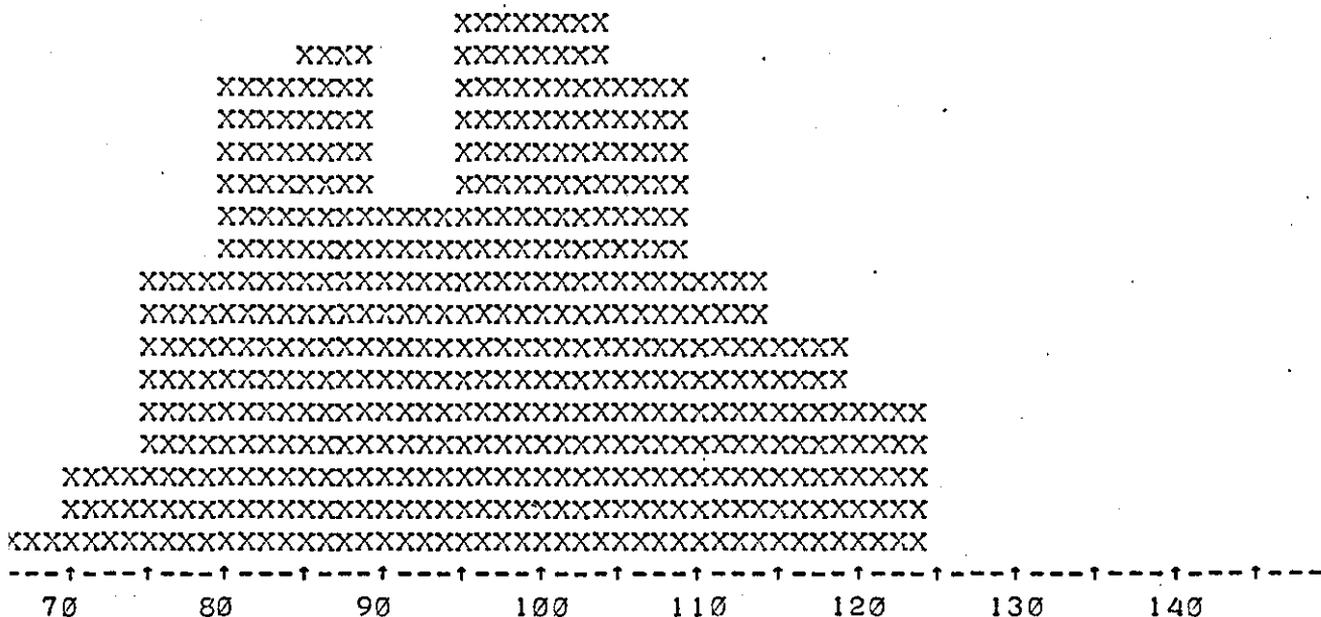
TAPE REFERENCE NO. 24 4 75 365

B.P.M.	DURATION	
65 - 69	3.5 MINS.	
70 - 74	7.9 MINS.	
75 - 79	19.8 MINS.	
80 - 84	31.9 MINS.	
85 - 89	33.8 MINS.	
90 - 94	23.6 MINS.	
95 - 99	35.4 MINS.	
100-104	35.4 MINS.	
105-109	31.3 MINS.	
110-114	18.8 MINS.	
115-119	15.0 MINS.	
120-124	10.5 MINS.	
125-129	1.9 MINS.	
130-134	.3 MINS.	
135-139	.6 MINS.	
140-144	.3 MINS.	
145-149	0.0 MINS.	
BELOW 65	4.1 MINS.	INVALID READING
ABOVE 149	0.0 MINS.	INVALID READING

TOTAL DURATION OF TEST : 275 MINUTES

HISTOGRAM OF HEART RATE DISTRIBUTION.

VERTICAL AXIS - DURATION IN MINUTES



2	78	32	109	62	105	92	100	122	86	152	88	182	86	212	108	242	108	272	112
3	71	33	110	63	97	93	101	123	83	153	96	183	78	213	111	243	107	273	110
4	70	34	109	64	92	94	103	124	86	154	86	184	78	214	108	244	100	274	122
5	71	35	106	65	96	95	106	125	85	155	82	185	83	215	110	245	105	275	0
6	73	36	112	66	89	96	107	126	85	156	83	186	78	216	111	246	109	276	108
7	71	37	114	67	101	97	105	127	79	157	86	187	92	217	110	247	107		
8	76	38	114	68	89	98	95	128	85	158	84	188	88	218	111	248	111		
9	77	39	115	69	99	99	97	129	85	159	76	189	83	219	111	249	106		
10	77	40	116	70	104	100	96	130	92	160	87	190	85	220	114	250	104		
11	76	41	116	71	101	101	94	131	96	161	81	191	81	221	114	251	105		
12	74	42	118	72	101	102	96	132	98	162	85	192	77	222	115	252	103		
13	72	43	115	73	103	103	87	133	106	163	84	193	82	223	115	253	105		
14	71	44	120	74	101	104	95	134	108	164	87	194	84	224	115	254	101		
15	70	45	119	75	98	105	86	135	104	165	89	195	85	225	117	255	99		
16	70	46	120	76	101	106	88	136	94	166	88	196	87	226	118	256	99		
17	70	47	119	77	102	107	87	137	91	167	84	197	90	227	119	257	100		
18	78	48	120	78	97	108	82	138	98	168	105	198	88	228	119	258	99		
19	74	49	115	79	88	109	82	139	102	169	91	199	90	229	120	259	106		
20	87	50	101	80	99	110	103	140	105	170	92	200	85	230	121	260	93		
21	86	51	101	81	86	111	79	141	102	171	95	201	88	231	121	261	97		
22	88	52	94	82	99	112	99	142	95	172	90	202	90	232	121	262	94		
23	93	53	101	83	97	113	104	143	91	173	87	203	90	233	121	263	99		
24	94	54	92	84	99	114	88	144	86	174	85	204	83	234	122	264	88		
25	97	55	87	85	93	115	83	145	83	175	90	205	85	235	122	265	99		
26	95	56	88	86	92	116	89	146	90	176	86	206	84	236	122	266	106		
27	101	57	84	87	89	117	91	147	99	177	78	207	105	237	113	267	104		
28	102	58	84	88	86	118	87	148	93	178	84	208	106	238	115	268	103		
29	101	59	89	89	80	119	87	149	88	179	79	209	104	239	111	269	104		
30	106	60	121	90	99	120	85	150	94	180	78	210	105	240	110	270	103		

Fig 2-56

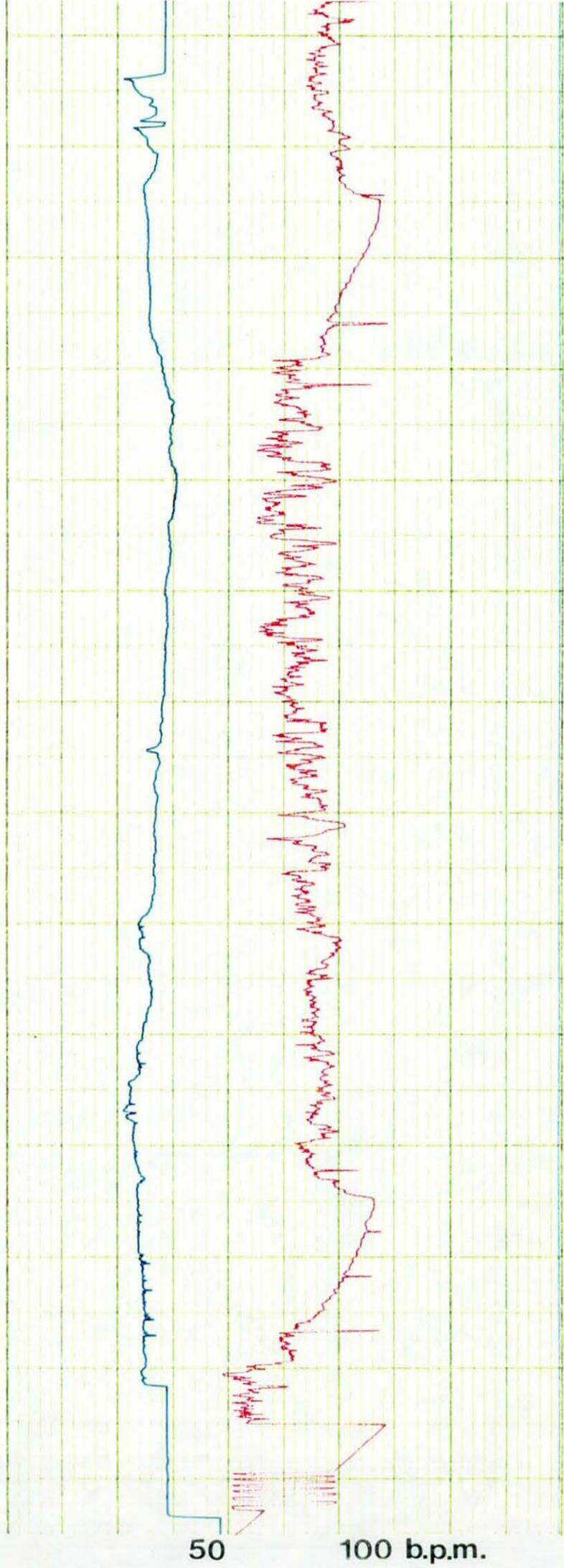


CHART No. 20003

6/74

Cheswell

PEN TRACE
heart rate/time
subject: P.M.

50 100 b.p.m.

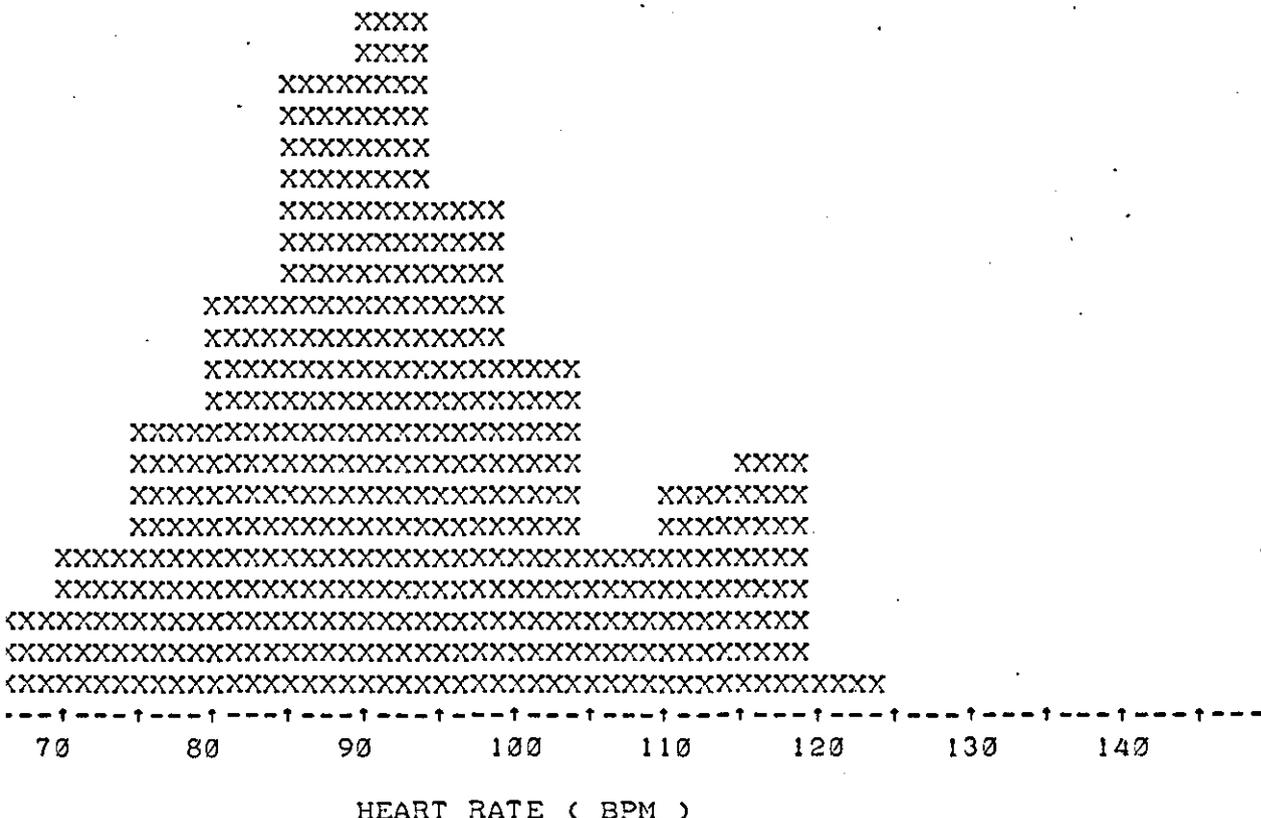
PE REFERENCE NO. 24 4 75 367

B.P.M.	DURATION	
65 - 69	6.4 MINS.	
70 - 74	11.5 MINS.	
75 - 79	18.2 MINS.	
80 - 84	27.2 MINS.	
85 - 89	40.9 MINS.	
90 - 94	44.5 MINS.	
95 - 99	33.9 MINS.	
100-104	22.7 MINS.	
105-109	10.5 MINS.	
110-114	15.6 MINS.	
115-119	16.0 MINS.	
120-124	2.2 MINS.	
125-129	1.6 MINS.	
130-134	0.0 MINS.	
135-139	0.0 MINS.	
140-144	0.0 MINS.	
145-149	0.0 MINS.	
BELOW 65	7.3 MINS.	INVALID READING
ABOVE 149	0.0 MINS.	INVALID READING

TOTAL DURATION OF TEST : 259 MINUTES

HISTOGRAM OF HEART RATE DISTRIBUTION.

VERTICAL AXIS - DURATION IN MINUTES



2	99	32	110	62	96	92	89	122	84	152	81	182	81	212	114	242	88
3	114	33	111	63	93	93	80	123	90	153	89	183	80	213	115	243	86
4	108	34	112	64	94	94	84	124	75	154	79	184	75	214	115	244	91
5	118	35	113	65	95	95	84	125	86	155	85	185	72	215	117	245	92
6	116	36	114	66	93	96	87	126	94	156	79	186	79	216	118	246	91
7	111	37	113	67	92	97	87	127	86	157	81	187	82	217	119	247	92
8	104	38	116	68	92	98	86	128	80	158	83	188	78	218	119	248	87
9	108	39	116	69	88	99	82	129	79	159	91	189	80	219	120	249	95
10	109	40	117	70	92	100	80	130	81	160	90	190	82	220	120	250	100
11	105	41	117	71	91	101	96	131	81	161	76	191	78	221	119	251	94
12	117	42	112	72	87	102	86	132	72	162	78	192	86	222	111	252	94
13	77	43	103	73	87	103	92	133	75	163	78	193	92	223	105	253	94
14	88	44	98	74	87	104	90	134	85	164	103	194	95	224	103	254	105
15	93	45	94	75	88	105	85	135	74	165	89	195	101	225	101	255	91
16	80	46	89	76	88	106	86	136	75	166	93	196	92	226	103	256	91
17	105	47	87	77	89	107	93	137	85	167	91	197	96	227	108	257	93
18	90	48	85	78	89	108	100	138	84	168	91	198	94	228	101	258	110
19	85	49	89	79	83	109	100	139	83	169	76	199	107	229	99	259	0
20	89	50	80	80	89	110	84	140	80	170	92	200	97	230	103		
21	90	51	85	81	90	111	84	141	84	171	97	201	100	231	103		
22	95	52	89	82	92	112	93	142	85	172	81	202	100	232	101		
23	93	53	97	83	95	113	92	143	74	173	94	203	101	233	103		
24	97	54	94	84	94	114	89	144	79	174	79	204	101	234	97		
25	99	55	85	85	100	115	86	145	84	175	71	205	103	235	98		
26	101	56	87	86	100	116	78	146	81	176	84	206	104	236	93		
27	110	57	90	87	99	117	86	147	86	177	78	207	106	237	95		
28	103	58	88	88	101	118	86	148	82	178	74	208	107	238	88		
29	107	59	96	89	94	119	85	149	88	179	78	209	109	239	90		
30	107	60	94	90	83	120	89	150	91	180	91	210	111	240	92		

COMPUTER PROGRAMME No.1

```

EM PROGRAM NO. 013 / ATP
EM ANALYSIS OF DATA ON PAPER TAPES FROM PROGRAM NO. 012 / ATP
EM TO SUMMATE VALUES WITHIN PRESET SIGNAL ZONES.
EM AND TO OUTPUT RESULTS IN TABULAR AND HISTOGRAM FORM.
JT @0 " PROGRAM NO. 013 / ATP"
JT @0††
JT@0"COMPUTER ANALYSIS OF PAPER TAPES FROM PROGRAM NO. 012 / ATP",††
JT@0 "IS HISTOGRAM OF RESULTS REQUIRED ? TYPE 1 FOR YES, 2 FOR NO : "
V @0 #21,S
JT @0 "LOAD PAPER TAPE IN HIGH SPEED READER,AND PRESS RETURN KEY"
V @0 #21,X
JT @0 #3†,"PROGRAM RUNNING",†
V @2 #41,F1,F2,F3
V @2 #61,F4
V @2 #7F3,A
V @2 #7F3,B
ET G=(A-B)/10
ETW1=0:LETW2=0:LETW3=0:LETW4=0:LETW5=0:LETW6=0:LETW7=0:LETW8=0
ET W9=0 : LET Y0=0 : LET Y9=0
ET Y1=0:LETY2=0:LETY3=0:LETY4=0:LETY5=0:LETY6=0:LETY7=0:LETY8=0
ET U=0
V @2 #7F3,V
F V=15.555 GOTO 320
ET U=U+1
F V>3 GOTO 260
F V>B-5*G GOTO 230
F V>B-6*G THEN LET Y4=Y4+1 : GOTO 150
F V>B-7*G THEN LET Y5=Y5+1 : GOTO 150
F V>B-8*G THEN LET Y6=Y6+1 : GOTO 150
F V>B-9*G THEN LET Y7=Y7+1 : GOTO 150
F V>B-10*G THEN LET Y8=Y8+1 : GOTO 150
ET Y9=Y9+1 : GOTO 150
F V<=B-4*G THEN LET Y3=Y3+1 : GOTO 150
F V<=B-3*G THEN LET Y2=Y2+1 : GOTO 150
F V<=B-2*G THEN LET Y1=Y1+1 : GOTO 150
F V<=B-G THEN LET Y0=Y0+1 : GOTO 150
ET W9=W9+1 : GOTO 150
F V>B+4*G GOTO 300
F V>B+3*G THEN LET W5=W5+1 : GOTO 150
F V>B+2*G THEN LET W6=W6+1 : GOTO 150
F V>B+G THEN LET W7=W7+1 : GOTO 150
ET W8=W8+1 : GOTO 150
F V<=B+5*G THEN LET W4=W4+1 : GOTO 150
F V<=B+6*G THEN LET W3=W3+1 : GOTO 150
F V<=B+7*G THEN LET W2=W2+1 : GOTO 150
ET W1=W1+1 : GOTO 150
V @2 #41,C,D
ET T=(60*C+D)/U
JT @0 "DATA READING COMPLETE"
JT@0 #4†,#14X,"COMPUTER ANALYSIS OF MICROLOG INFORMATION",††
JT @0 #14X,"-----",††
JT @0 #5X,"TAPE REFERENCE NO. ",#31,F1,F2,F3,#61,F4,†††
JT @0 #10X,"B.P.M.",#17X,"DURATION",††
JT @0 #9X,"65 - 69",#15X,#6F1,W2*T," MINS.",†

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JT @0 #9X,"70 - 74",#15X,#6F1,W3*T," MINS.",†
JT @0 #9X,"75 - 79",#15X,#6F1,W4*T," MINS.",†
JT @0 #9X,"80 - 84",#15X,#6F1,W5*T," MINS.",†
JT @0 #9X,"85 - 89",#15X,#6F1,W6*T," MINS.",†
UT @0 #9X,"90 - 94",#15X,#6F1,W7*T," MINS.",†
UT @0 #9X,"95 - 99",#15X,#6F1,W8*T," MINS.",†
JT @0 #9X,"100-104",#15X,#6F1,W9*T," MINS.",†
UT @0 #9X,"105-109",#15X,#6F1,Y0*T," MINS.",†
JT @0 #9X,"110-114",#15X,#6F1,Y1*T," MINS.",†
JT @0 #9X,"115-119",#15X,#6F1,Y2*T," MINS.",†
JT @0 #9X,"120-124",#15X,#6F1,Y3*T," MINS.",†
UT @0 #9X,"125-129",#15X,#6F1,Y4*T," MINS.",†
UT @0 #9X,"130-134",#15X,#6F1,Y5*T," MINS.",†
UT @0 #9X,"135-139",#15X,#6F1,Y6*T," MINS.",†
UT @0 #9X,"140-144",#15X,#6F1,Y7*T," MINS.",†
UT @0 #9X,"145-149",#15X,#6F1,Y8*T," MINS.",††
UT @0 #9X,"BELOW 65",#14X,#6F1,W1*T," MINS.",#7X,"INVALID READING",†
UT @0 #9X,"ABOVE 119",#13X,#6F1,Y9*T," MINS.",#7X,"INVALID READING",††
UT @0 #6X,"TOTAL DURATION OF TEST : ",#4I,60*C+D," MINUTES",††
UT @0 #30X,"-----",#2†
F S=2 THEN STOP
UT @0 #14X,"HISTOGRAM OF HEART RATE DISTRIBUTION.",†
UT @0 #14X,"-----",††
UT @0 #10X,"VERTICAL AXIS - DURATION IN MINUTES",††
UT @0 #5X,"I",†
IM J(16)
ET J(1)=W3*T : LET J(2)=W4*T : LET J(3)=W5*T : LET J(4)=W6*T
ET J(5)=W7*T : LET J(6)=W8*T : LET J(7)=W9*T : LET J(8)=Y0*T
ET J(9)=Y1*T :LET J(10)=Y2*T :LET J(11)=Y3*T :LET J(12)=Y4*T
ET J(13)=Y5*T:LET J(14)=Y6*T :LET J(15)=Y7*T :LET J(16)=Y8*T
OR E1=0 : LET E2=0 : LET H1=0 : LET H2=0 : LET K=0 : LET L=0
OR Q=1 TO 16
F J(Q)>125 THEN LET E1=1 : GOTO 650
F J(Q)>50 THEN LET E2=1
EXT Q
F E1=1 THEN LET H1=250: LET H2=50: LET K=40: LET L=10: GOTO 700
F E2=1 THEN LET H1=125: LET H2=25: LET K=20: LET L=5 : GOTO 700
ET H1=50 : LET H2=10 : LET K=8 : LET L=2
OR M=H1 TO H2 STEP -H2
UT @0 #4I,M,"-I"
OR N=M TO M-K STEP -L
F N=M GOTO 750
UT @0 #5X,"I"
F W2*T<N THEN OUT @0 #3X : GOTO 770
UT @0 "XXX"
OR P=1 TO 16
F J(P)<N THEN OUT @0 #4X : GOTO 800
UT @0 "XXXX"
EXT P
UT @0 †
EXT N
EXT M
UT @0 #5X,"-"
OR R=0 TO 15
UT @0 "----†"
EXT R
UT @0 "----",†,#8X
UT @0"70      80      90      100      110      120      130      140"
UT @0 #††,#25X,"HEART RATE ( BPM )",†††

```

27 - JULY - 76

COMPUTER PROGRAMME No.2

```

EN HEART BEAT MEASUREMENTS JAO-W 16-JULY-76
EN ANALYSIS OF DATA ON PAPER TAPES PRODUCED BY PROG 012/ATP,
EN TO PRESENT DATA ON A MINUTE BY MINUTE BASIS
UT 00 "HEART BEAT MEASUREMENTS JAO-W",11
UT 00 "ANALYSIS OF DATA ON PAPER TAPES OUTPUT BY PROG. 012/ATP",11
UT 00 "LOAD PAPER TAPE IN HIGH SPEED READER AND PRESS RETURN KEY"
V 00 #21,X
V 02 #41,F1,F2,F3
V 02 #61,F4
UT 00 #5X,"TAPE REFERENCE NO.",#31,F1,F2,F3,#61,F4,11
J 02 #7F3,A
J 02 #7F3,B
ET U=0
J 02 #7F3,V
V=15.555 GOTO 160
ET U=U+1:GOTO 130
I 02 #41,C,D
T T=(60*C+D)/U
UT 00 #5X,"AVERAGE DURATION OF RECORD:",#5F3,T,#3X,"MINUTES",11
UT 00 #5X,"TOTAL DURATION OF TEST:",#41,60*C+D,#3X,"MINUTES",11
UT 00 "RELOAD PAPER TAPE IN HSR AND PRESS RETURN KEY"
00 #21,X
02 #41,F1,F2,F3
02 #61,F4
02 #7F3,A
02 #7F3,B
T G=(A-B)/50
T N=0:LET Q=0:LET K=0:LET J=0:LET P=0:LET R=0:LET T1=0:LET E1=0
E1<>0 THEN GOTO 440
T*(K+J+1)>1.00+T1 THEN LET T1=1.00+T1-T*(K+J):GOTO 320
02 #7F3,V
V=15.555 THEN LET E1=1:GOTO 430
V>B+35*G THEN LET J=J+1:GOTO 260
V<B-45*G THEN LET J=J+1:GOTO 260
I Q=Q+V:LET K=K+1:GOTO 260
K=0 THEN LET P=0:GOTO 350
I Q=Q/K
Q>B THEN LET P=100-(Q-B)/G:GOTO 350
I P=100+(B-Q)/G
N=N+1
N<>1 GOTO 400
00 #101,#14X,"ANALYSIS OF HEART BEAT MEASUREMENTS ",1
00 #14X,"-----",11
00 #5X,"TAPE REFERENCE NO.",#31,F1,F2,F3,#61,F4,111
00 #41," MIN BPM MIN BPM MIN BPM"
00" MIN BPM MIN BPM",11
R=5 THEN OUT 001:LET R=0:GOTO 410
00 #4X,#41,N,#2X,#41,P:LET R=R+1
K=0:LET J=0:LET Q=0:GOTO 260
Q<>0 THEN GOTO 320
00 11,"ANALYSIS COMPLETE. 0-BPM INDICATES INVALID DATA!",111

```

 :RTW.NORW161

STING OF :PTW.SOURCEAHBM(1/) PRODUCED ON 13AUG76 AT 11.53.19

TPUT BY LISTFILE IN :RTW.NORW161 ON 1SEP76 AT 16.42.22

COMPUTER PROGRAMME No. 5

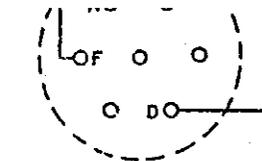
UMENT SOURCEAHBM

```

0      LIST(LP)
1      MAP
2      PROGRAM(AHBM)
3      INPUT 1=TRD
4      OUTPUT 2=LPC/160
5      COMPRESS INTEGER AND LOGICAL
6      TRACE 2
7      END
8      MASTER AHBM
9      INTEGER DD,MM,YY,REF,I,HRS,MIN,ACT,J,K,IX(30,12),
10     1      IY(1440),ISUB(12),L,M
11     REAL V50,V100,A,B,VAL,X(1440),AVGE,SUM
12     EQUIVALENCE (X(1),IY(1),IX(1,1))
13     50     READ(1,11) DD,MM,YY,REF,V50,V100
14     B = 50.7*(V100 - V50)
15     A = 100. - V100*B
16     I = 0
17     100    READ(1,22) VAL
18     IF (VAL.EQ.15.555) GO TO 200
19     VAL = A + B*VAL
20     IF (VAL.GT.149..OR.VAL.LT.65.) VAL = -1.
21     I = I + 1
22     IF (I.GT.1440) GO TO 1000
23     X(I) = VAL
24     GO TO 100
25     200    READ(1,33) HRS,MIN
26     AVGE = FLOAT(I)/(60*HRS+MIN)
27     ACT = 0
28     MINS = 0
29     I = I - 1
30     250    IF (ACT.GT.I) GO TO 400
31     SUM = 0.
32     MINS = MINS + 1
33     J = INT(MINS*AVGE) - ACT
34     L = J
35     DO 300 K = ACT+1,J+ACT
36     IF (X(K).NE.-1.) GO TO 280
37     L = L - 1
38     GO TO 300
39     280    SUM = SUM + X(K)
40     300    CONTINUE
41     IF (L.EQ.0) GO TO 350
42     IY(MINS) = NINT(SUM/L)
43     ACT = ACT + J
44     GO TO 250
45     350    IY(MINS) = 0
46     ACT = ACT + J

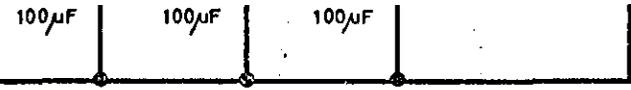
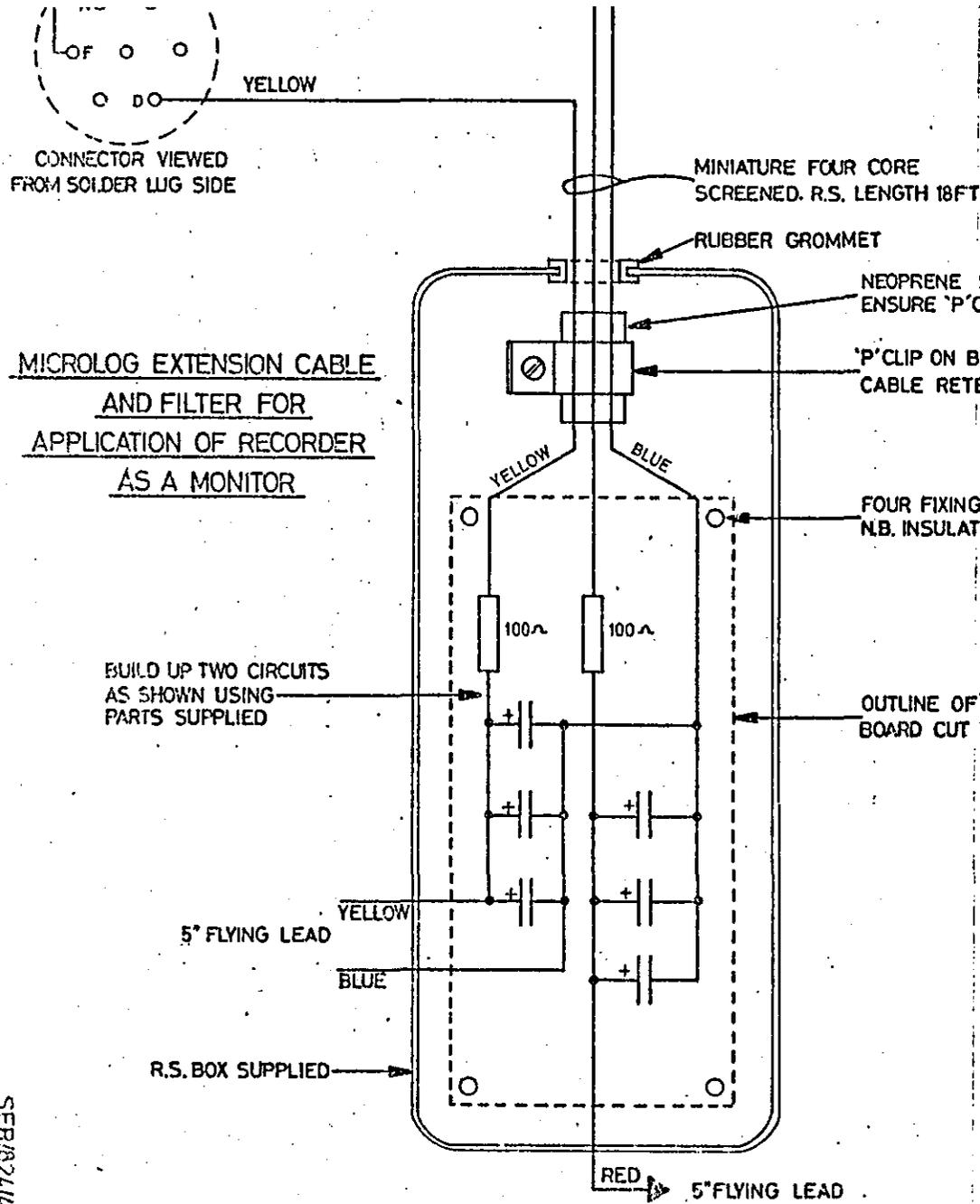
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```
47      GO TO 25C
48 400  WRITE(2,44) REF,DD,MM,YY
49      M = MOD(MINS,30)
50      K = (MINS-1)/30
51      WRITE(2,55)
52 410  DO 500 I = 1,MINO(30,MINS)
53      L = K
54      IF (I.LE.M) L = L + 1
55      IF (L.GT.12) L = 12
56      DO 450 J = 1,L
57 450   ISUB(J) = (J-1)*30 + I
58 500   WRITE(2,66) (ISUB(J),IX(L,J),J = 1,L)
59      PAUSE 'NEXT TAPE PLEASE'
60      GO TO 50
61 1000 PAUSE 'TOO MANY READINGS ON TAPE'
62      GO TO 50
63      11 FORMAT(3I0/I0/FO.0,FO.0)
64      22 FORMAT(FO.0)
65      33 FORMAT(2I0)
66      44 FORMAT('1TAPE REFERENCE NO.',I6,39X,'ANALYSIS OF HEART BEA
67      1EMENTS',49X,'DATE ',I2,2(' ',I2))
68      55 FORMAT('0',I2(' ',MIN,'BPM','))
69      66 FORMAT('C',I2(' ',I3,' = ',I3,' '))
70      END
71      FINISH
72 ****
73 ****
```

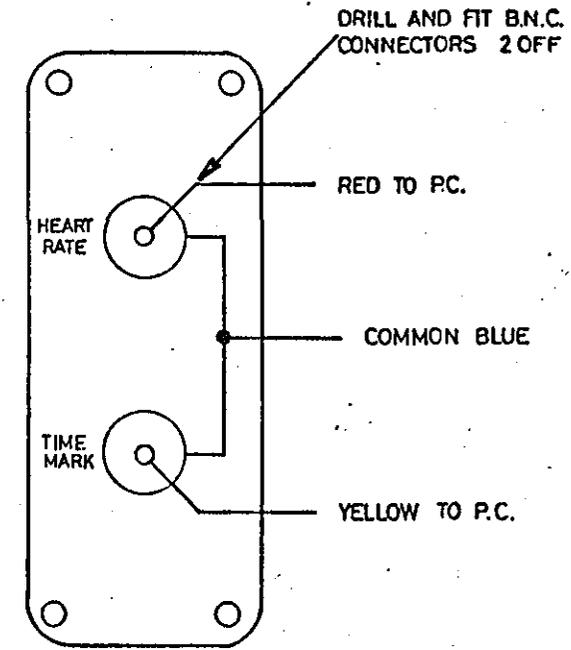


CONNECTOR VIEWED FROM SOLDER LUG SIDE

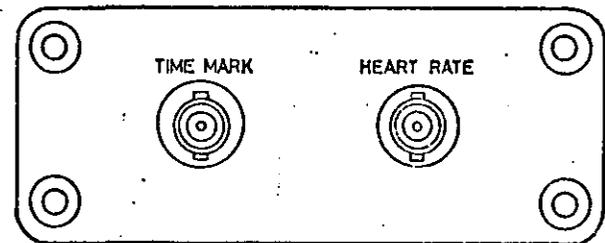
MICROLOG EXTENSION CABLE AND FILTER FOR APPLICATION OF RECORDER AS A MONITOR



EXPLODED VIEW OF CIRCUIT



REAR VIEW OF COVER



TOP VIEW OF COVER

SER102/114

WORK RATE WATTS	TIME min	1st TEST				2nd TEST			
		SUBJECT				SUBJECT			
		TJ		MP		TJ		MP	
		(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
0	0	72	72	77	77	85	85	80	80
50	1	94		88		84		82	
50	2	87		93		105		78	
50	3	86		80		106		86	
50	4	88		105		104		92	
50	5	93	92	98	96	105	105	95	94
60	6	94		85		105		101	
70	7	97		89		108		92	
80	8	95		90		111		96	
90	9	101		95		108		94	
100	10	102	102	93	92	110	110	107	108
110	11	101		97		111		97	
120	12	106		99		110		100	
130	13	107		101		111		100	
140	14	109		110		111		101	
150	15	110	110	103	101	111	110	101	100
160	16	109		101		114		103	
170	17	106		107		114		104	
180	18	112		109		115		106	
190	19	114		110		115		107	
200	20	114	114	111	110	115	116	109	108
210	21	115		112		117		111	
220	22	116		113		118		112	
230	23	116		114		119		114	
240	24	118		113		119		115	
250	25	115	114	116	116	120	120	115	114
250	26	120		116		121		117	
250	27	119		117		121		118	
250	28	120		117		121		119	
250	29	119		112		121		119	
250	30	120	120	103	104	122	122	120	120

Table 2.12 Comparative Heart Rate Data

Recorded by (a) Magnetic Tape and (b) Electrocardiographic Pen

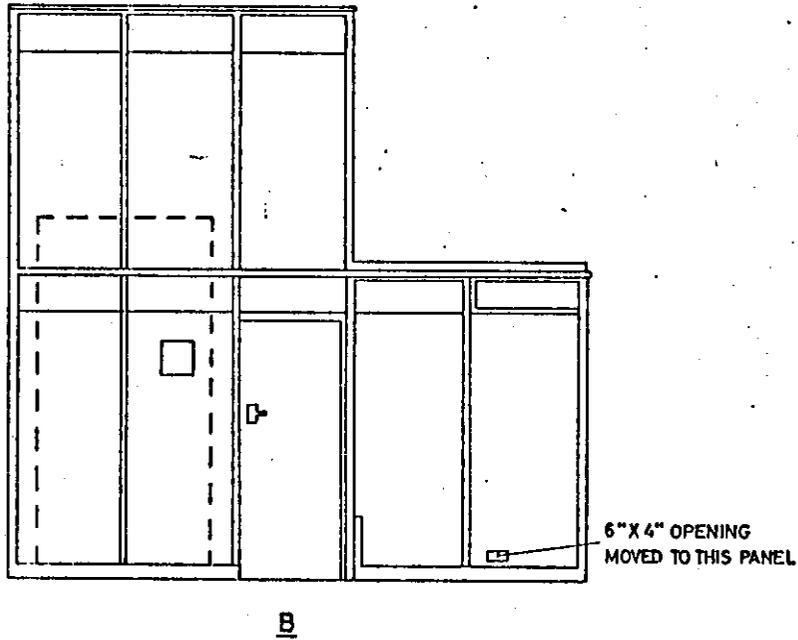
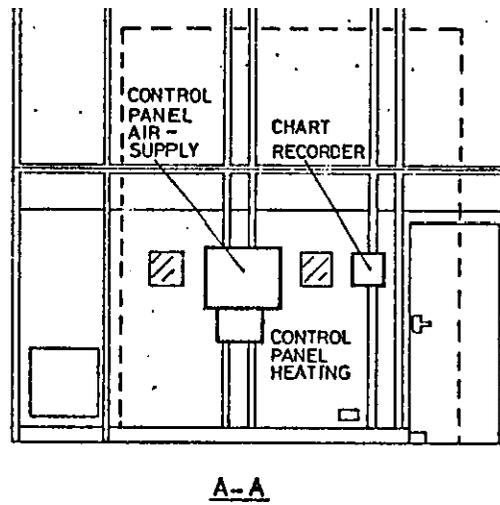
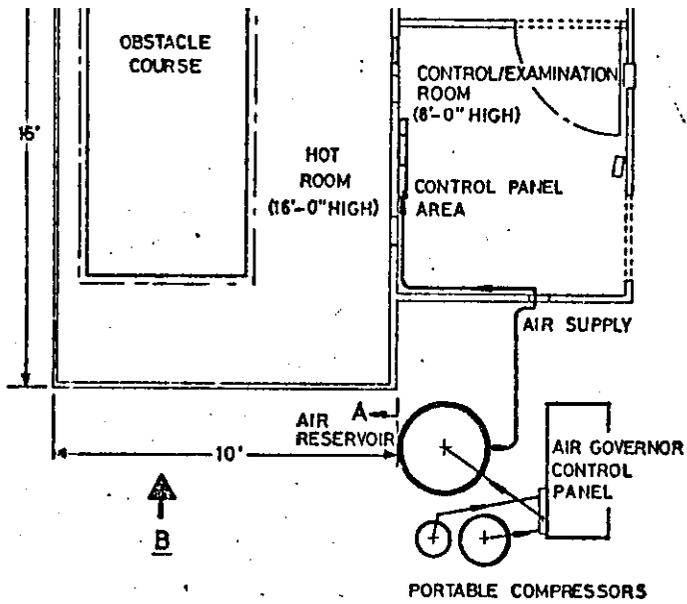
2.6. Field Research Studies on the Use of Hot Environmental Work Suit Assembly. Following completion of the development of the hot environmental clothing assembly a series of field research studies were undertaken based on detailed training procedures developed for human access into Advanced Gas Cooled Nuclear Reactors. The procedures are included as Appendices to this thesis and the four part programme was as follows:

- Part 1 (Appendix F) Boiler Familiarisation Facility - Hot Box
 Part 2 (Appendix G) Vessel Entry Access Route - Simulation Facility
 Part 3 (Appendix H) Vessel Access Demonstration - Cold Run
 Part 4 (Appendix J) Vessel Access Demonstration - Hot Run

2.6.1 Boiler Familiarisation Facility - Hot Box. The objectives of the first training stage were to give personnel an appreciation of a 60°C environment, to familiarise them with the various items of protective clothing and equipment associated with hot environmental work and to carry out simple work tasks in an environment similar to that expected in the reactor pressure vessel. The facility basically consists of 3 rooms, Control room, Change room and a Hot room as is shown in Fig 2.58. The Control room houses all essential control and alarm equipment; the three phase heating supply, communications and air flow/pressure are all monitored from this point, Fig 2.59. The Change room in addition to its prime function as a dressing/undressing area acts as a store for the air cooled suits and other protective clothing.

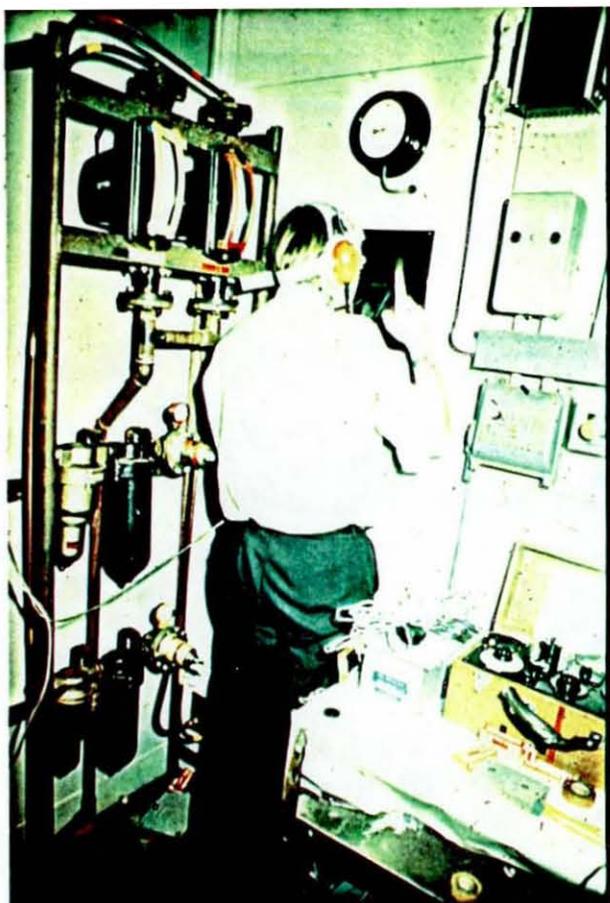
The Hot Room, which contains an obstacle course, Figs 2.58. and 2.60 can be heated up to a maximum temperature of 65°C in 1 hour. This is accomplished by air, driven by a fan, passing through a bank of heating elements of 21 kw capacity then percolating through the perforated ceiling. A suction grill situated near ground level completes the circuit. A cooling air system is designed for 2 person training. In order initially to train personnel, associated with the vessel access demonstration programme with a familiarisation of the various items of protective clothing and equipment under hot conditions, a programme was prepared both for entrants and for helpers, i.e. dressers and hose reel attendants, as follows:-

Vessel Entrants	Lecture	10 mins
	Layout of Hot Box	10 mins
	Demonstration of Equipment to be Used	15 mins
	Dressing	10 mins
	Practical work task	60 mins
	Undressing	10 mins
	Discussion	10 mins
	Total	2 hrs 5 mins



HOT TRAINING FACILITY

HOT FACILITY TRAINING



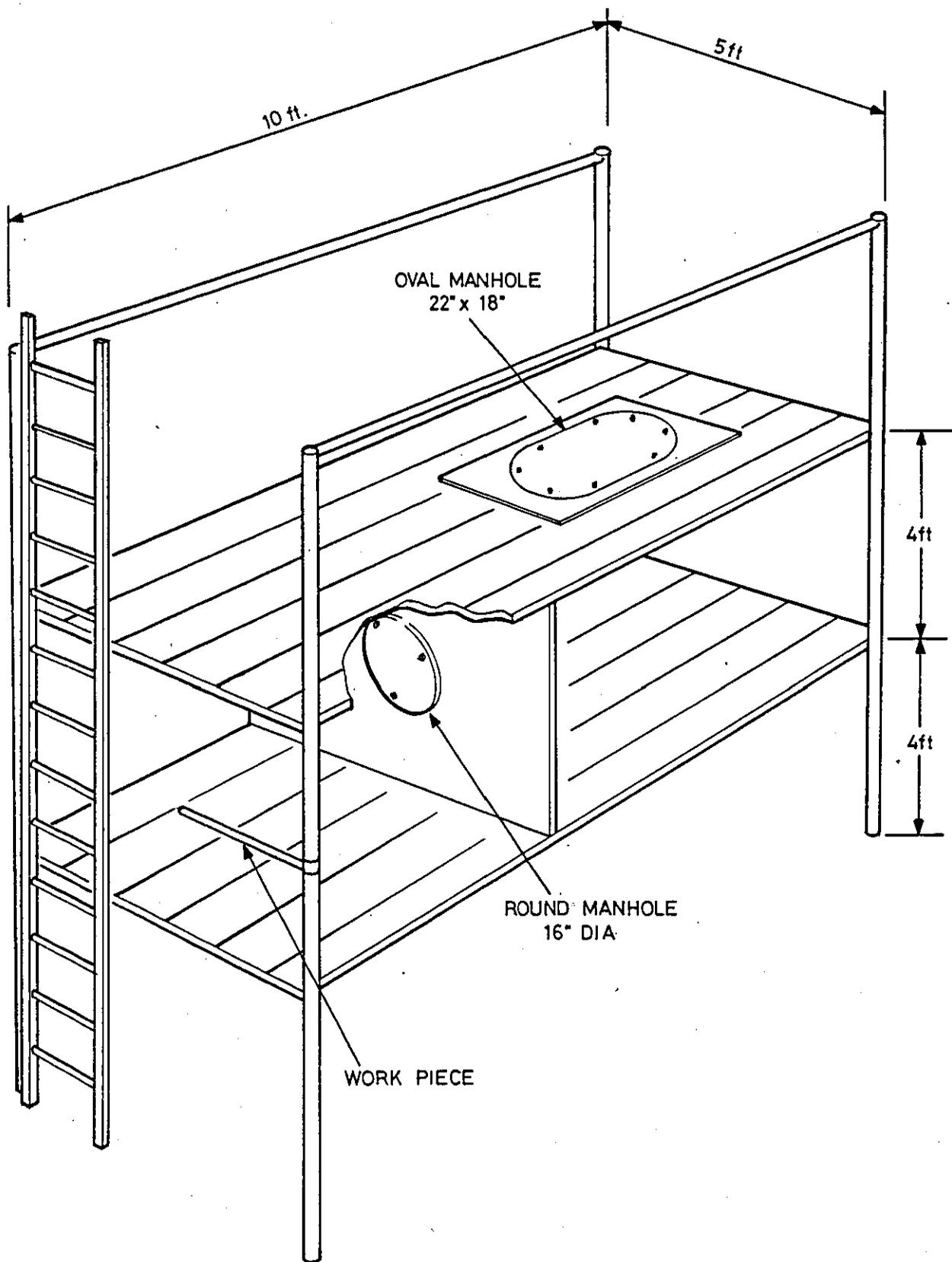
Control room



Ladder exercise



Obstacle course



OBSTACLE COURSE
HOT TRAINING FACILITY

Hose Reel	Lecture	10 mins
Attendants and Dressers	Layout of Hot Box	10 mins
	Operation of Hot Box	10 mins
	Demonstration of Equipment Used	15 mins
	Dressing/Undressing Procedures	20 mins
	Practical	30 mins
	Total	<u>1 hr 35 mins</u>

It was anticipated that only one session would be required in the Hot Box for each trainee.

The lecture was to cover the following topics:-

AGR Vessel Entry Route
 The Working Conditions Encountered
 The Need for Protective Clothing
 The Vessel Entry Procedure
 The Training Facilities and Programme

Following clearance by a Medical Officer the subjects spent a short time inside the hot room in normal clothing and experienced the air and metal surrounds at 60°C, a description of the obstacle course being given at this stage. Each item of protective clothing was described including the communication system and the change room attendants who acted as helpers were shown how to put on the environmental suit assembly and associated vortex tube and air hose.

In the change room the subjects stripped, were weighed and had their oral temperatures taken. They then dressed in issued cotton underwear. Attendants assisted the subjects to dress into suits ensuring that all the cooling tubes were in the right positions, socks, footwear and gloves were put on and taped to the suit. Communication sets comprising an ear defender head set and throat microphone were comfortably positioned and tested. The helmet was placed into position and closed and air flow into the suit was commenced. A final check of the communication and air systems was made and the comfort of the subject established.

Subjects then proceeded to the hot room in pairs. Once inside the hot room they released 6.7m of air hose from the hose reels and then walked up and down several times to acclimatise to the conditions. Each

then in turn, climbed up and down the ladder $5\frac{1}{2}$ times, then walked over to the top horizontally mounted manhole cover. Using the spanner provided they removed the 8 nuts, lifted and stowed the cover and descended through the manhole, assisting each other with the air lines, the vertically placed manhole cover was then removed and stowed in similar manner. Both then crawled through the access hole, again assisting each other with the air lines. Each in turn renewed a blade in a hand hacksaw and proceeded to saw through a 50mm scaffold pipe. On completion of the task they then returned to the ladder by the reverse route, replacing the manhole covers in position on the way. Finally $4\frac{1}{2}$ climbs on the ladder were made. On completion of the exercise, each retired to the change room under the Controllers instruction where their oral temperatures were taken. After undressing they towelled off and were reweighed to establish sweat loss during the exercise period. Throughout the exercise the two subjects were in communication with each other and the Controller, an instruction was given at the outset of the training that should they feel in any way distressed during the exercise they should stop and ask to be let out.

On completion of this training schedule a discussion took place on the experiences of the practical session. Each subject was given refreshment and a questionnaire to be completed during the following 48 hours - (see example pp 214 - 216).

A sample group of 12 subjects, see Table 2.13, participated in the initial investigations. Weight loss and temperature measurements are shown in Table 2.14 and a summary of their questionnaires is given in Table 2.15. Hand protection was inadequate and the air flow to the hood required further investigation; otherwise the suit assembly functioned as expected and the training schedule proved adequate.

Subject Code	Age Years	Weight Kg	Stature m	
1	JM	24	68.94	1.82
2	WV	25	76.2	1.79
3	CO	26	66.22	1.65
4	SG	28	63.5	1.7
5	PH	29	76.2	1.85
6	JB	30	76.2	1.7
7	JD	30	71.66	1.75
8	IM	33	67	1.78
9	AM	33	70.76	1.78
10	DF	34	74.39	1.75
11	IT	35	82.55	1.75
12	GF	37	71	1.73

Table 2.13 Subject Data - Training Facilities

SUBJECT CODE	Weight Kg		Loss gm	Temperature °C		Increases
	a	b		a	b	
JM	68.94	68.72	220	36.5	37.4	0.9
WV	76.2	75.98	315	36.3	37.0	0.7
CO	66.22	65.82	400	36	37.5	1.5
SG	63.5	63.28	216	36.4	37.5	1.1
PH	76.2	75.66	539	36.4	36.9	0.3
JB	76.2	75.45	750	36	36.6	0.6
JD	71.66	71.27	385	36.7	37.4	0.7
IM	67	66.82	180	36.2	37.0	0.8
AM	70.76	70.49	262	36.4	36.9	0.5
OF	74.39	74.07	318	36.3	37.2	0.9
IT	82.55	81.94	410	36.4	37.0	0.6
GT	71	70.67	325	36.3	37.1	0.8

(a) before

(b) after

Table 2.14 Weight Loss and Temperature Increase for 12 Subjects - Hot Box Training Facility

2.6.2 Vessel Entry Access Route - Simulation Facility. To further familiarise personnel with the various items of protective equipment associated with the vessel access route a simulation facility was designed to resemble the access route in the reactor pressure vessel, owing to the limitations of the building provided only two thirds of the route could be simulated. The ladder work structure of the facility was enclosed in a hardboard shaft and incorporated all the main real

HOT TRAINING FACILITY - QUESTIONNAIRE

IAN DOUGLAS MOODIE

AGE 33

HEIGHT (m) 5'-10" 1.78m

ASSIST FH MAINT ENG

WEIGHT (kg) 67 Kg

DATE 2 May 1973

the questions can be answered simply by writing YES or NO in the right hand column. If you give further details or if you have any criticism regarding the air-cooled suit and of the training, use the reverse side of the form.

QUESTIONS	ANSWERS
the number of previous training sessions in cooler familiarisation facility. If the answer is 0, complete questions 2 - 5.	NONE
Have you previously worn PVC clothing plus respirator?	YES
Do you find the air-cooled suit more comfortable than PVC clothing and respirator?))))
Have you previously made entry inside an SRU? If so, state what clothing etc was worn.) PVC and Double/Coveralls worn in) Charge machines, Sep Rooms and Cracker) Plants Tunnel and CCP:- <u>See Over</u>)
Do you find the air-cooled suit an improvement on PVC clothing etc.))
Is the air flow adequate to the following sites?	<p>During heavy breathing after 2nd</p> <p>NO - ladder exercise unable to draw enough air to give quick relief.</p> <p>NO - Too Directional.</p> <p>NO - Ditto</p> <p>NO - Ditto</p> <p>NONE)No provision in suit to cool either feet or hands.</p> <p>NONE)</p>
Is breathing difficult during the period inside the familiarisation facility?	YES

QUESTIONS	ANSWERS
Question 7 is YES, state at what stages of breathing became difficult.	During latter stages of 2nd ladder exercise and during additional steel specimen recovery exercise.
Do you perspire profusely during the training? at what Stage was the onset?	YES - On completion of 1st ladder exercise and cutting exercise.
Are the boots adequate in the hot environment?	YES
Are the gloves sufficiently heat resistant?	NO
Are the gloves sufficiently finger sensitive?	Wore short heavy cotton gloves but unable to do simple tasks.
Do you feel unwell at any stage of the training?	NO - Only short of breath after 2nd ladder exercise.
How do you feel at the end of the training?	Fairly tired and weakish in the thighs, very warm.
How do you feel after you had taken a shower and shower?	Even after shower continued to perspire for about $\frac{3}{4}$ hour.
How do you feel before the end of your shift?	Sensation of tingling in thighs after about 4 hrs - lasted about 2 hrs.
How do you feel after twenty-four hours?	Felt disinterested and lethargic next day.

REMARKS TO BE FILLED IN BY THE HOT TRAINING FACILITY CONTROLLER

Temperature 60°C

Flow Pressure at controls 4.5 bar .020 Kg/s

Type of training undertaken Normal Obstacle Course including Specimen Recovery.

Other relevant information _____

Degree of perspiring to hands, feet and head similar to that experienced in PVC in Sep Rooms but hot suit head gear more comfortable to wear except that sweat runs into the eyes causing extreme discomfort and impaired vision. Also the size of the hot suit head gear was strange and resulted in "de-capitation" when attempting to pass through manholes. One other feature of the head gear that caused a certain amount of discomfort was the rigidity of the unit to the body resulting in a flattened nose every time one bent forward. In fairness both latter points would probably resolve themselves as one became more accustomed to wearing the suit.

The suit was initially reasonably comfortable except for the directional air vents. However, as the tests proceeded, it became extremely heavy and cumbersome especially the vortex and the air hose connection. Trouble was experienced with the communication amplifier but the simple addition of a clip or pocket would eliminate this. The main cause of trouble throughout especially on the ladder was the air hose and one hand had to be used to "control" the hose throughout. As the cooling air is distributed to the limbs via single tubes it was possible to nip this tube during an activity causing starvation to the particular limbs.

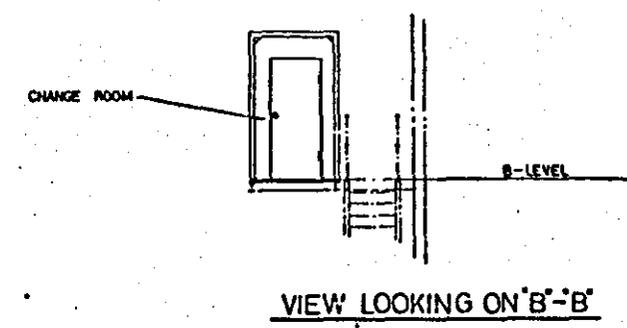
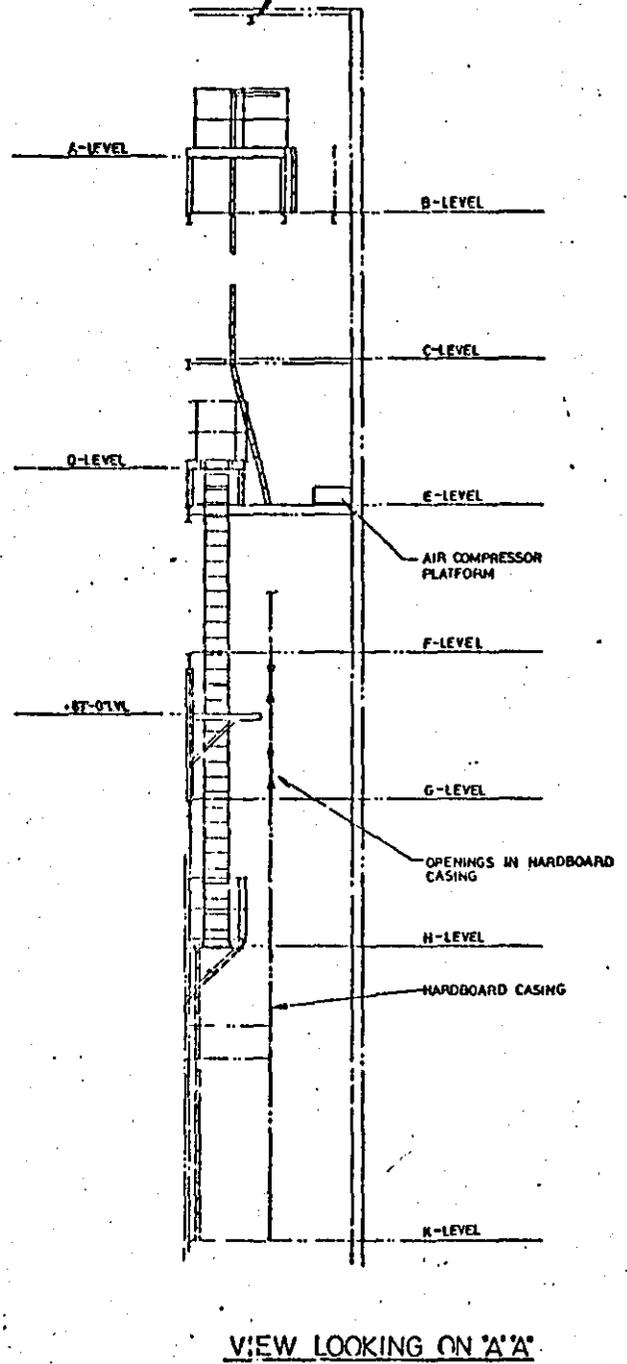
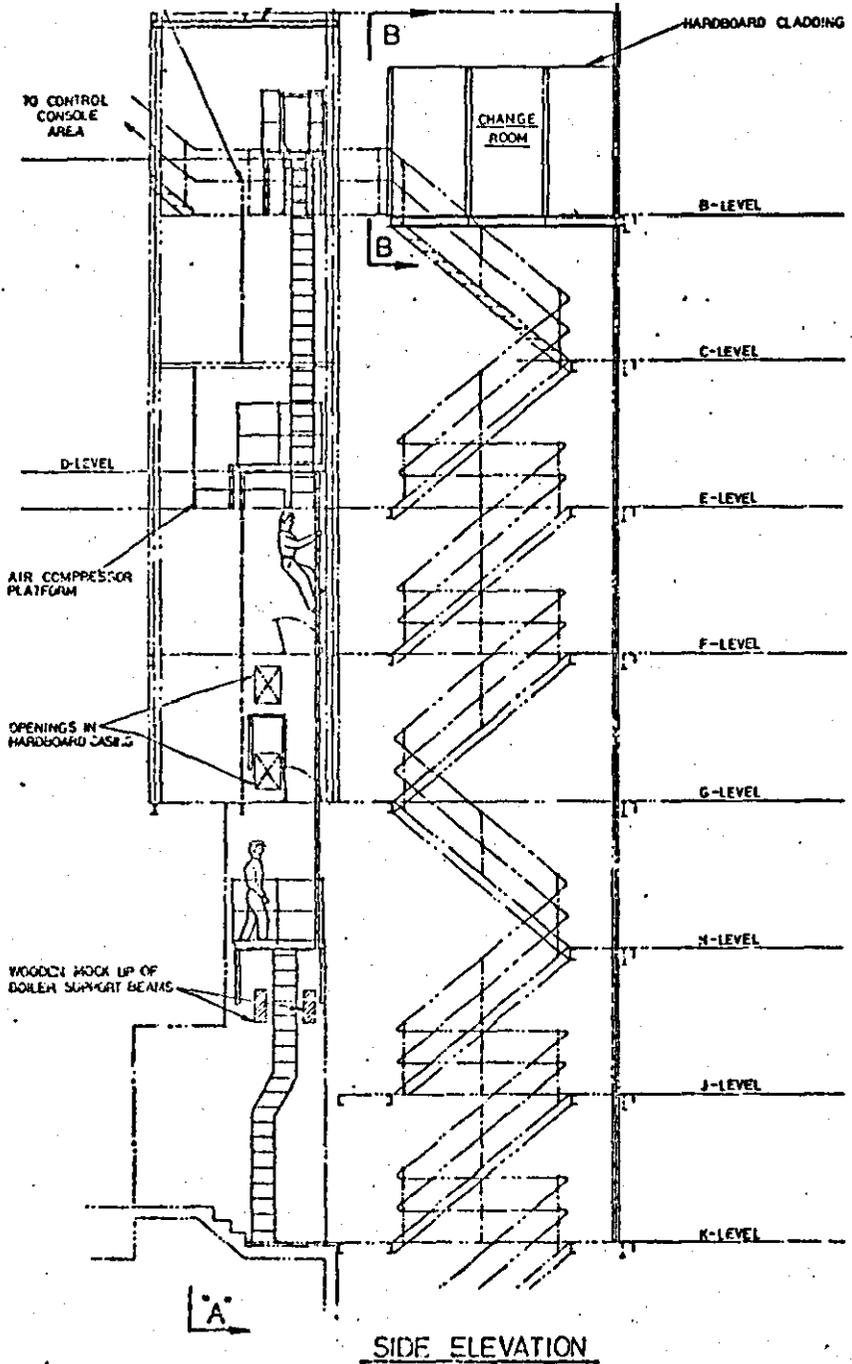
features of the pressure vessel access route, i.e. landings, inspection hatches, boiler support beam and the angled ladder round the housing of the gas circulator. The outline and dimensions and part of the simulator are shown in Figs 2.61, 2.62 and 2.63. No provision was made to simulate the hostile working environments of noise and elevated temperature 3Kw fan heaters were however provided at the bottom of the shaft to maintain temperature above ambient. Permanent lighting fixtures were installed inside the facility but were not to be used during training sessions except in emergency circumstances. All lighting during training was to be temporary and taken into the simulator by subjects under training as part of the training exercise.

The main purpose of this training programme was to establish and practise the access and certain emergency procedures in a simulated and safe environment and to provide entry teams with a more accurate impression of the distances to be covered and the difficulties which were to be encountered in the pressure vessel access route. The training programme prepared was as follows:-

Vessel Entrants:	Introductory Lecture	10 mins
	Outline of Facility and Equipment to be Used	10 mins
	Dressing	15 mins
	Practical work task	120 mins
	Undressing	10 mins
	Discussion	20 mins
	Total	3 hrs 5 mins
Hose Reel	Introductory Lecture	10 mins
Attendants and Dressers	Outline of Facility and Equipment	20 mins
	Practical	30 mins
	Total	1 hr

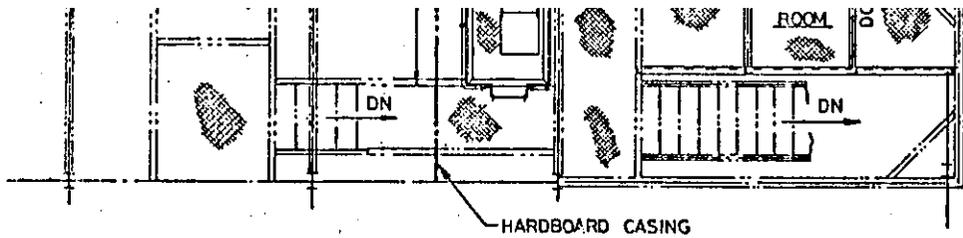
It was anticipated that because of the number of emergency procedures that were to be assimilated at least three sessions would be required for each vessel entrant.

These were to be team exercises of 4 trainees who had already undergone successfully the hot box training session.

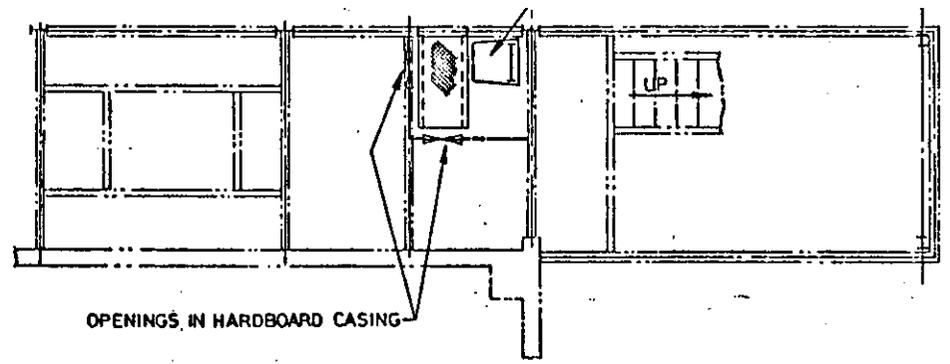


NOTE: A to E LEVEL (Simulates pile cap to peripheral walkway)
 D to K LEVEL (Simulates top of boiler interspac to floor)

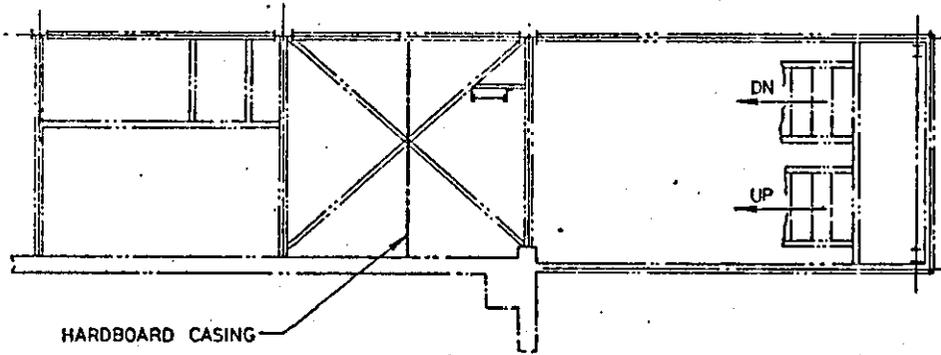
COLD ACCESS
REHEARSAL FACILITY



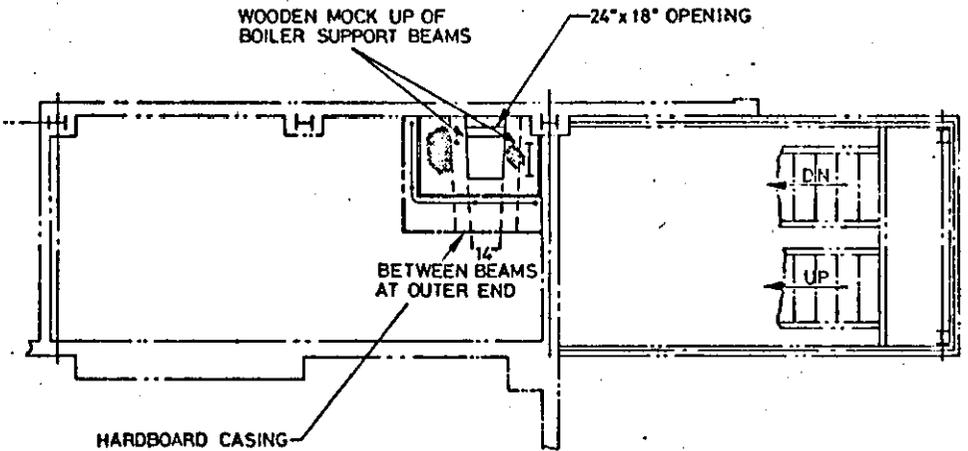
PLAN AT A- & B- LEVELS



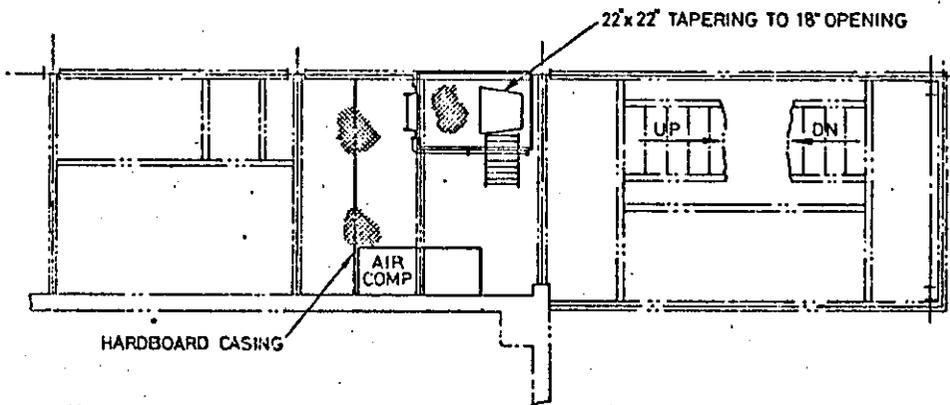
PLAN AT F & G LEVELS



PLAN AT C-LEVEL



PLAN AT H LEVEL



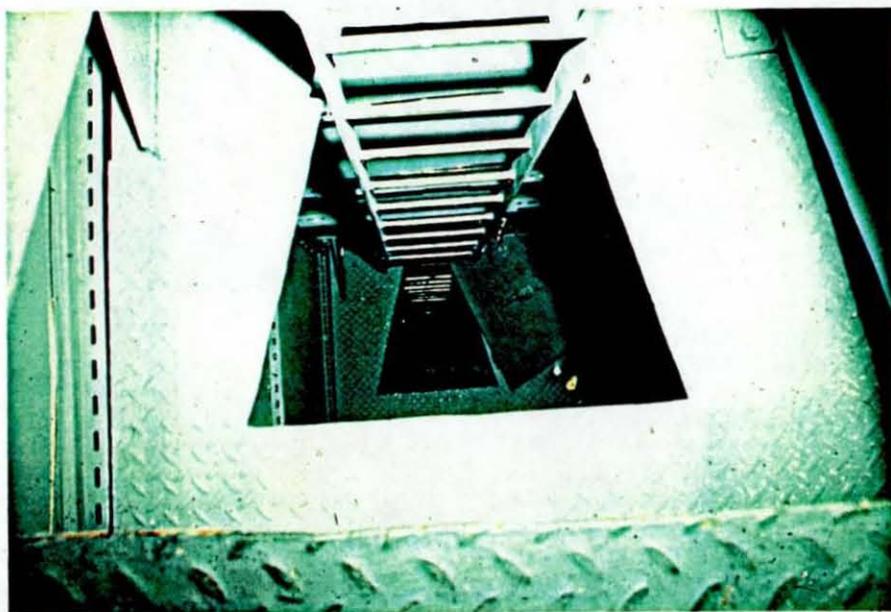
PLAN AT D- & E- LEVELS

COLD ACCESS
REHEARSAL FACILITY-PLAN VIEWS

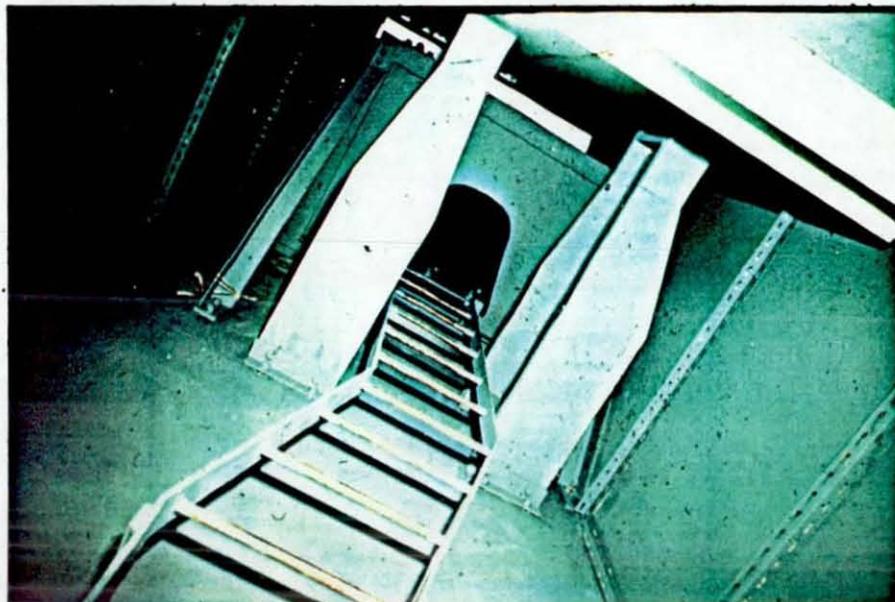
ACCESS ROUTE
SIMULATION



Anthropometric dummy



Level 'D'



Boiler
Support Beam

The training sequence was as follows:- All trainees reported to the Console on the A level at simulator. After lecture, demonstration and briefing, they proceeded to change room. An attendant assisted the team to don air-cooled suits, outer coveralls, boots, gloves and communication headsets. Entry team then proceeded from the change room to the area round entry point at level B. At this stage, the training Controller conducted final check on communications with team, hoist operator and hose reel attendants and ensured air flow/pressure was adequate. 1st and 2nd men ascended to entry platform and clipped on to a stop fall device on a safety line. A temporary lighting system was then lowered down to level E. 1st and 2nd men descended one at a time to level E, then released themselves from safety line, and ensured that the temporary lighting system was secured in position. 3rd and 4th men lowered any equipment required down by rope, then clipped onto safety line, and descended one at a time to level E, then released themselves from safety line. 1st, 2nd and 3rd men walked round the simulated boiler annulus carrying any equipment required for the lower part of the route then returned to the area around the boiler cheese-piece. 4th man assisted with airlines. 1st and 2nd men lower safety rope and temporary lighting to level F then clipped onto safety line and descended one at a time to level F, 3rd man remained above cheese-piece, 4th man further back along simulated boiler annulus assisted with airlines. 1st man opened hatch at level F, lighting and safety rope lowered to level G. 1st and 2nd men descended one at a time to level G, 3rd and 4th men assisting with airlines. 1st man using hammer opened and closed top inspection hatch, 2nd man opened and closed bottom inspection hatch. 2nd man opened hatch at level G, lighting and safety line was lowered down to 74' level. 1st and 2nd men descended one at a time to level H, 3rd and 4th men assist with airlines. Lighting and safety line was lowered down to level K, 1st and 2nd men descended to floor, 3rd and 4th men assisting with airlines. 3rd man lowered equipment required for survey or inspection. The team then followed the instructions laid down for the emergency procedures - as detailed in following section. Following successful emergency drill, the team, now at level B proceeded to change room. Attendants assisted in the undressing and de-briefing took place.

Three emergency procedures were developed (a) Exit without lighting and (b) Exit without communication and (c) Removal of a casualty (a 95 percentile anthropometric dummy) the sequence of the details of the entry (a) using the first 4 man team was as follows:-

(a) Exit Without Lighting. Controller informed all personnel that the temporary installed lights are about to be switched off. Following acknowledgement of signal by all team members, the lights were first flashed for 10 seconds then switched off. Hand torches were switched on. 3rd and 4th men informed Controller that the walkway and boiler cheese-piece were free of temporary obstacles and then assisted with airlines of 1st and 2nd men who left all tools and equipment on the floor, clipped themselves onto safety line and ascended to 1st platform one at a time, 3rd and 4th men illuminated the area with hand torches, 2nd man then ascended to 1st platform. 1st man ascended up to 2nd platform then up to top of cheese-piece at level V, this then allowed clear illumination for No 2 man to ascend from 1st platform to level B and release himself from safety line. All 4 men walked slowly round to bottom of top stage ladder. 1st and 2nd men clipped onto safety line and ascended one at a time to level A, hoist operator shining torch to assist the climb. 3rd and 4th repeat.

Every movement during the exit was only commenced after

instructions were given from the team to the hose reel operator to draw in air-line slack. 3rd and 4th men watched that the air-lines of their team members did not get caught up on any protrusions during their ascent.

(b) Exit Without Communication. Controller informed all personnel that an exit without communications was to be attempted. Following acknowledgement of signal by all team members, the lights were flashed for 10 seconds as a signal for evacuation. Communications between the team and hose reel attendant were switched off (though the Controller maintained contact with the team in case of difficulties). 3rd and 4th men ensured boiler cheese-piece was free of temporary obstacles then signal (3 pulls on the safety line) to the men on the level K that the route is clear. 1st and 2nd men left any tools or equipment on the floor. 1st man clipped onto safety line and proceeded slowly up to level B, stopping at each platform until the 'proceed' signal was again given. 4th man was signalled to hoist operator as to the rate the air-line was to be withdrawn from the facility. After first man had released from safety line at level B, the 2nd man proceeded up the ladder in similar fashion. 2nd and 3rd men walked slowly round to bottom of top stage ladder, 4th man ensuring the correct length of airline was available at all times. 1st and 2nd men clipped onto safety line and ascended one at a time to level A, hoist operator pulling up airlines as required. 3rd and 4th men repeat above.

(c) Exit with Casualty. A 95 percentile anthropometric dummy complete with air-cooled suit, airline, safety harness, etc, Fig 2.63 used to simulate a casualty was positioned at level K. Controller informed all personnel that a casualty exit was to be attempted. The Dummy was assumed to be the result of an injury to the 1st man, the 'real' 1st man now played the role of the 3rd man who had come down the boiler cheese-piece to assist. Therefore the 'real' 3rd man up at level B, did not participate in this exercise unless his help was required. Following acknowledgement of signal by all team members, the lights were flashed for 10 seconds as a signal for evacuation. 1st man informed Controller of casualty and requested that splints be sent in to bind legs. These were lowered by rope by hoist operator to 4th man, who in turn lowered down to level K. 1st and 2nd men bound Dummy's legs and requested use of air hoist for removal of casualty. Hoist rope was lowered down and fixed onto safety harness hook. Dummy was clipped onto safety line, 1st man also on the safety line moves onto ladder and signalled for air hoist to be operated at slow speed 4th man ensured that cheese-piece was free of temporary obstacles and that the airlines do not catch on any protrusions. With the 1st man leading, the Dummy was brought slowly up to level A. In case of any mishap to the Dummy, the 2nd man remained at level K until the Dummy was safely on level E. 2nd man clipped onto safety line and proceeded slowly up to level C. With the 4th man now leading, the Dummy was brought slowly up to the level B. 1st, 2nd and 3rd men remained at level E. The exercise was now officially complete, the Dummy was then lowered back down to level K. The 3rd man clipped onto safety line and descended to level K, released hoist rope from Dummy's safety harness, then returned to level E. 1st, 2nd and 3rd man ascended one at a time, on safety line, to level B.

A number of training periods described above were carried out and as a result of the debriefing discussions a number of small changes were

made, no particular criticism of the suit assembly was however made with one exception, the need for an improved air flow and distribution to the helmet. A safety/medical committee in reviewing the debriefings suggested that some of the work loads appeared to be high for a number of the operations and recommended that a physiological monitoring system should if possible be available for the vessel entry demonstrations. The background work to this is described in Section 2.5, Ambulatory monitoring.

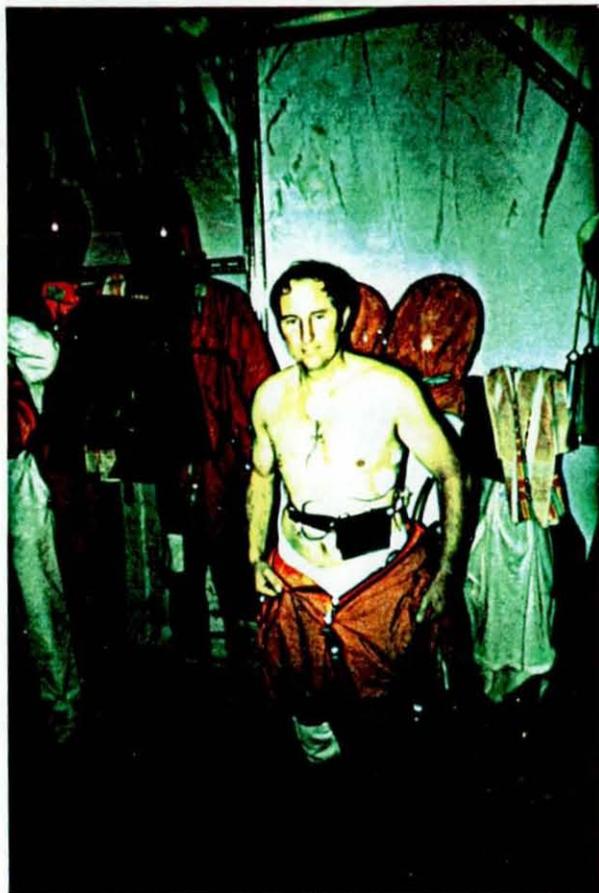
2.6.3 Vessel Access Demonstration - Cold Run. The full details of this training programme are given in Appendix H and the report of the three demonstrations are given in Appendix K. The purpose of each of these rehearsals was three-fold.

- (a) to familiarise the entry team with the access equipment and its use in the vessel environment.
- (b) to prove the adopted procedures for the vessel entry and, in particular the actions that must be followed under emergency conditions.
- (c) to assess the time involved in assembling and dismantling equipment on the Pile Cap and Vessel internals, and also in accomplishing each stage in the entry.

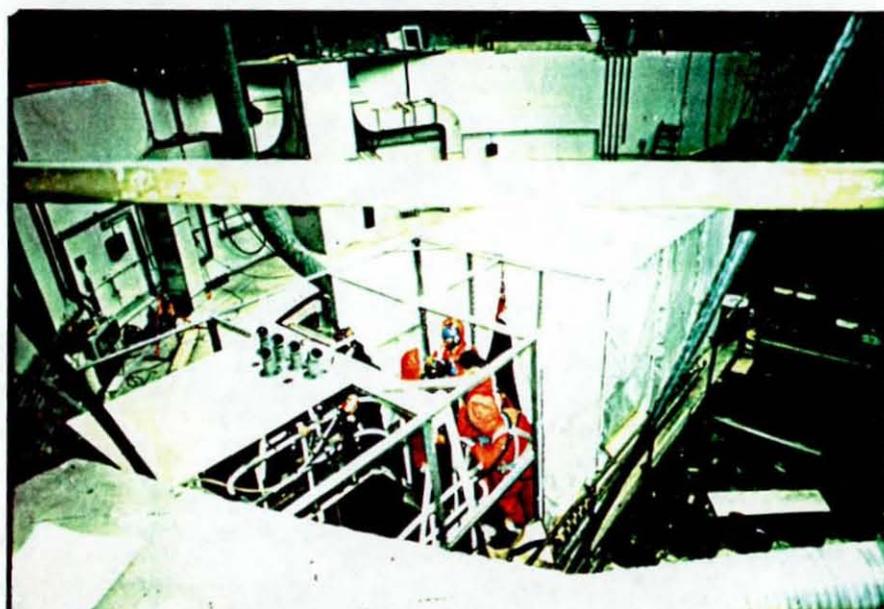
The ambulatory monitoring equipment was available for the first series of entries and 4 subjects were monitored on the first entry and two subjects on the subsequent entries. The access route is shown in Figs 1.16, 1.17 and 1.18 and the method of entry is outlined in Appendix G. Eight teams were to participate. The team consisted of 4 men who had successfully completed the training programmes in the hot familiarisation facility and vessel access simulator.

All were to enter the pressure vessel area and were supported by a Controller, two standby men, hoist operator, and hose reel attendant. The main objective for the team was for 2 of the 4 to open up the hatches down a boiler interspace and reach the reactor floor below the gas circulators see Fig 2.65. The remaining two were to assist with movement of air lines etc remaining on boiler walkway and top of boiler interspace. The maximum time allocated for each entry was set at 2 hours and it was

VESSEL ACCESS



Monitored subject

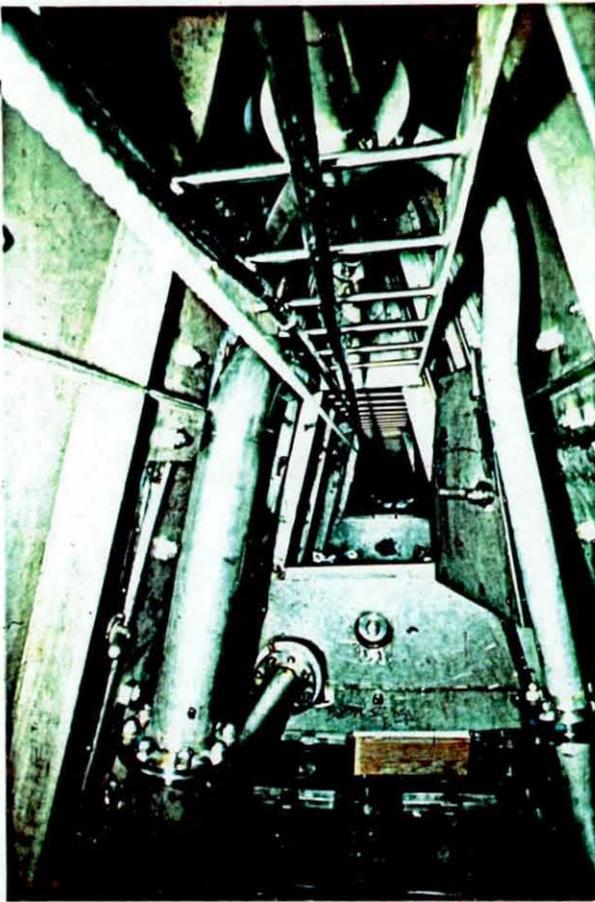


Pile cap
Change room



Boiler walkway

VESSEL ACCESS



Boiler interspace



Boiler supports



Below gas
circulator
reactor floor

anticipated that when teams had become familiar enough with the procedures a period within this time scale would be set aside for carrying out one of the emergency procedures previously rehearsed in the access simulator.

All members of the team were examined by a Medical Officer and during the dressing period ECG chest electrodes and temperature thermistors were mounted on the selected subjects, as shown in Fig 2.64. Subsequently only seven of the eight programmed 4 man teams entered the pressure vessel and carried out brief inspection exercise along the entire access route. Frequent faults in the communication system hampered the progress of all the entry teams and prevented one team from entering altogether. Because of these difficulties emergency procedures were not carried out. Brief details of each entry are given in Table 2.16 including the time to reach the reactor floor; total entry time and the full analysis of the data acquisition system for the four initial entrants is shown in the computer print outs pp 230 - 237. The analysis of subsequent data gave similar results for heart rate recordings; the body temperatures could not however be computed owing to thermistor problems.

The HE suit assembly functioned satisfactorily and the second and third training sessions were carried out after the re-design of the communication system had been completed. Four entries were made on the 2nd training period and six on the third. On all occasions the protective suit assembly functioned satisfactorily and the investigations progressed to the hot entry rehearsal stage.

2.6.4 Vessel Access Demonstration - Hot Run. The full details of this training programme are given in Appendix J and the report of the 6 entries are given in Appendix L. It was planned that several entries would be made into the pressure vessel at 60°C, the first two entries to install all the equipment and to establish the route and the remaining entries to carry out inspection procedures. Each team would spend not more than two

DATE	ENTRY NO	TOTAL TIME m	TIME TO REACH REACTOR FLOOR m	EMERGENCY REHEARSED
10 5 75	1/1	127	58	
"	2/1	86	57	
11 5 75	3/1	Cancelled - Communication failure		
"	4/1	67	40	
"	5/1	75	40	
"	6/1	86	46	
12 5 75	7/1	110	40	
"	8/1	114	37	
19 7 75	1/2	88		
"	2/2	91	35	Loss of air 2 men
20 7 75	3/2	105	34	Loss of communication
"	4/2	105	17 *	Removal of casualty
2 9 75	1/3	113	70	
"	2/3	92	32	
3 9 75	3/3	110	54	
"	4/3	68	17 *	Removal of casualty
4 9 75	5/3	81	40	
"	6/3	45 +		

* All equipment in position and access doors open

+ Terminated after 45 minutes due to loss of communications

Table 2.16 Summary of Cold Access Rehearsal Activities

hours in the vessel and at the end of each entry period would carry out an emergency procedure. The purpose of these rehearsals were as follows:-

(a) to demonstrate the feasibility of reactor vessel entry and inspection under hot conditions using hot environmental personal protective system.

(b) to gain entry to the reactor floor via boiler interspace and travel 180°.

(c) to compare in vessel air temperature measurements against installed thermocouples.

(d) to measure noise levels inside the reactor vessel.

(e) to assess the re-designed communication system.

Team arrangements were the same as for cold access. All members having successfully completed all the required training, were medically examined immediately prior to and immediately following an entry. All entrants were also fitted with the physiological data recorder

during dressing. A summary of the activities and the duration of access is given in Table 2.18 and example of the heart rate data acquisition is shown in the computer print-out.

DATE	ENTRY CODE	TOTAL TIME m	VESSEL TEMP °C	COMMENTS
9 9 75	1/4	30	53	Terminated Communication Failure
"	2/4	109	57	Team reduced to 3 after 45 mins*
10 9 75	1/5	71	60	" " " " " " "*
"	2/5	61	61	" " " " " " "*
11 9 75	1/6	95	62.4	2 men to reactor floor in 35m
"	2/6	116	62.4	2 men to reactor floor in 25m

* Failure of communication system on hose reel

Table 2.17 Summary of Hot Access Rehearsal Activities

The equipment faults were minor in nature but reduced the teams to three men on 3 occasions and it was not until the fifth entry that the base of the reactor was reached. However, the test did prove that a team of four people could spend a period of two hours in various areas of the reactor vessel carrying out inspections at a temperature of the order of 60°C without undue discomfort. At the de-briefing meeting after the hot access demonstration the only comments on the personal protective clothing system were an increase in size of inner suit, the visor to be more easily removable, hand and foot protection were inadequate, and the distribution of air flow in the helmet should be improved. Vortex tube operation and general body cooling was considered adequate by all subjects.

COMPUTER ANALYSIS OF MICROLOG INFORMATION

TAPE REFERENCE NO. 13 5 75 365

B.P.M.	DURATION	
65 - 69	0.0 MINS.	
70 - 74	0.0 MINS.	
75 - 79	0.0 MINS.	
80 - 84	.6 MINS.	
85 - 89	.9 MINS.	
90 - 94	9.9 MINS.	
95 - 99	14.7 MINS.	
100-104	10.5 MINS.	
105-109	8.9 MINS.	
110-114	8.3 MINS.	
115-119	5.7 MINS.	
120-124	5.1 MINS.	
125-129	5.4 MINS.	
130-134	4.8 MINS.	
135-139	.6 MINS.	
140-144	0.0 MINS.	
145-149	0.0 MINS.	
BELOW 65	0.0 MINS.	INVALID READING
ABOVE 149	0.0 MINS.	INVALID READING

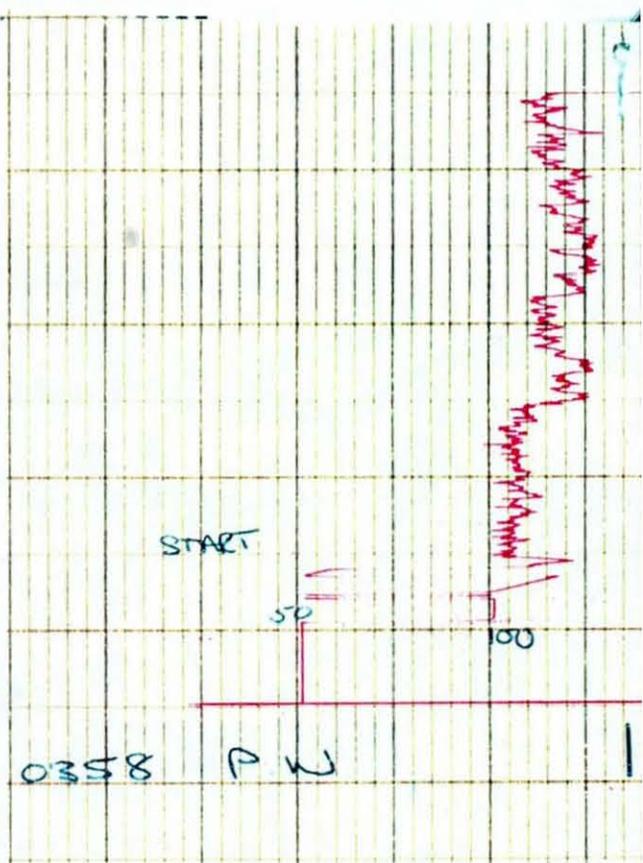
TOTAL DURATION OF TEST : 76 MINUTES

1	107	31	100	61	124
2	103	32	95	62	124
3	122	33	100	63	119
4	101	34	106	64	118
5	110	35	117	65	120
6	101	36	98	66	117
7	99	37	99	67	115
8	101	38	106	68	113
9	96	39	120	69	123
10	93	40	106	70	128
11	99	41	103	71	119
12	94	42	110	72	114
13	102	43	107	73	113
14	93	44	102	74	122
15	90	45	100	75	126
16	96	46	104	76	131
17	101	47	96		
18	102	48	108		
19	97	49	115		
20	100	50	115		
21	101	51	116		
22	101	52	110		
23	98	53	115		
24	102	54	105		
25	96	55	124		
26	102	56	109		
27	106	57	121		
28	100	58	122		
29	97	59	128		
30	92	60	127		

APE REFERENCE NO. 10 5 75 358

B.P.H.	DURATION
50 - 54	0.0 MINS.
55 - 59	0.0 MINS.
60 - 64	0.0 MINS.
65 - 69	0.0 MINS.
70 - 74	0.0 MINS.
75 - 79	0.0 MINS.
80 - 84	.3 MINS.
85 - 89	.9 MINS.
90 - 94	1.6 MINS.
95 - 99	3.2 MINS.
100-104	13.4 MINS.
105-109	43.9 MINS.
110-114	43.9 MINS.
115-119	40.0 MINS.
BELOW 50	0.0 MINS.
ABOVE 119	38.4 MINS.

TOTAL DURATION OF TEST : 186 MINUTES



HISTOGRAM OF HEART RATE DISTRIBUTION.

VERTICAL AXIS - DURATION IN MINUTES



50 60 70 80 90 100 110 120

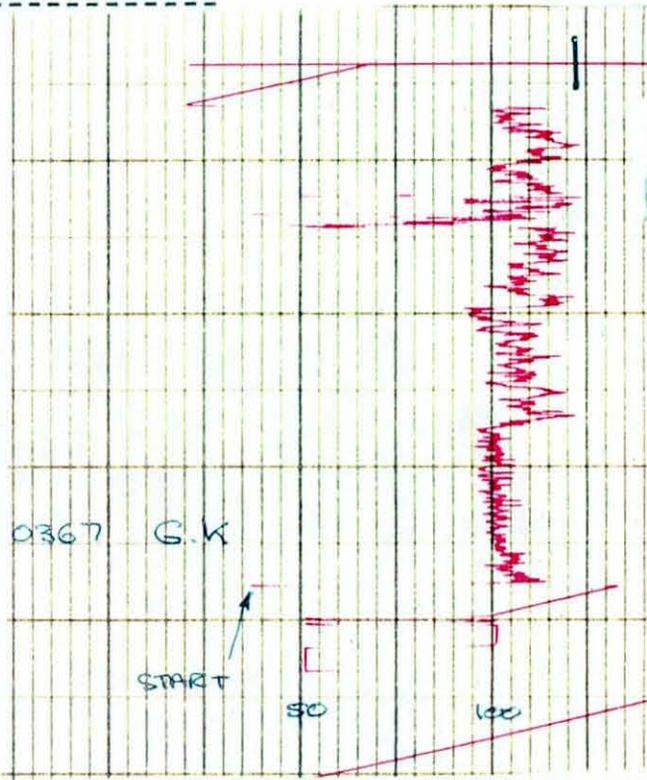
HEART RATE (BPM)

1 : 109	31 : 107	61 : 107	91 : 113	121 : 127	151 : 117	181 : 110
2 : 111	32 : 108	62 : 108	92 : 113	122 : 118	152 : 122	182 : 109
3 : 115	33 : 105	63 : 109	93 : 111	123 : 119	153 : 126	183 : 113
4 : 112	34 : 102	64 : 108	94 : 115	124 : 113	154 : 119	184 : 114
5 : 102	35 : 107	65 : 114	95 : 111	125 : 129	155 : 124	185 : 124
6 : 104	36 : 107	66 : 123	96 : 112	126 : 120	156 : 120	186 : 143
7 : 106	37 : 109	67 : 126	97 : 114	127 : 115	157 : 116	
8 : 106	38 : 107	68 : 127	98 : 111	128 : 124	158 : 114	
9 : 103	39 : 108	69 : 116	99 : 115	129 : 122	159 : 118	
10 : 104	40 : 105	70 : 116	100 : 111	130 : 121	160 : 113	
11 : 109	41 : 108	71 : 122	101 : 108	131 : 120	161 : 117	
12 : 100	42 : 106	72 : 118	102 : 115	132 : 125	162 : 110	
13 : 105	43 : 107	73 : 119	103 : 116	133 : 120	163 : 109	
14 : 106	44 : 105	74 : 121	104 : 111	134 : 117	164 : 114	
15 : 103	45 : 105	75 : 116	105 : 110	135 : 125	165 : 109	
16 : 105	46 : 107	76 : 117	106 : 109	136 : 124	166 : 115	
17 : 106	47 : 107	77 : 121	107 : 121	137 : 122	167 : 117	
18 : 108	48 : 104	78 : 125	108 : 124	138 : 118	168 : 118	
19 : 106	49 : 106	79 : 118	109 : 123	139 : 115	169 : 116	
20 : 107	50 : 105	80 : 127	110 : 122	140 : 115	170 : 123	
21 : 107	51 : 106	81 : 126	111 : 120	141 : 115	171 : 119	
22 : 108	52 : 102	82 : 119	112 : 118	142 : 117	172 : 114	
23 : 106	53 : 104	83 : 116	113 : 121	143 : 121	173 : 112	
24 : 109	54 : 105	84 : 116	114 : 114	144 : 122	174 : 109	
25 : 106	55 : 104	85 : 117	115 : 120	145 : 119	175 : 113	
26 : 106	56 : 104	86 : 114	116 : 125	146 : 118	176 : 111	
27 : 106	57 : 105	87 : 111	117 : 122	147 : 121	177 : 111	
28 : 110	58 : 117	88 : 117	118 : 118	148 : 117	178 : 117	
29 : 111	59 : 106	89 : 115	119 : 121	149 : 114	179 : 118	
30 : 104	60 : 110	90 : 112	120 : 121	150 : 117	180 : 116	

COMPUTER ANALYSIS OF MICROLOG INFORMATION

TAPE REFERENCE NO. 10 5 75 367

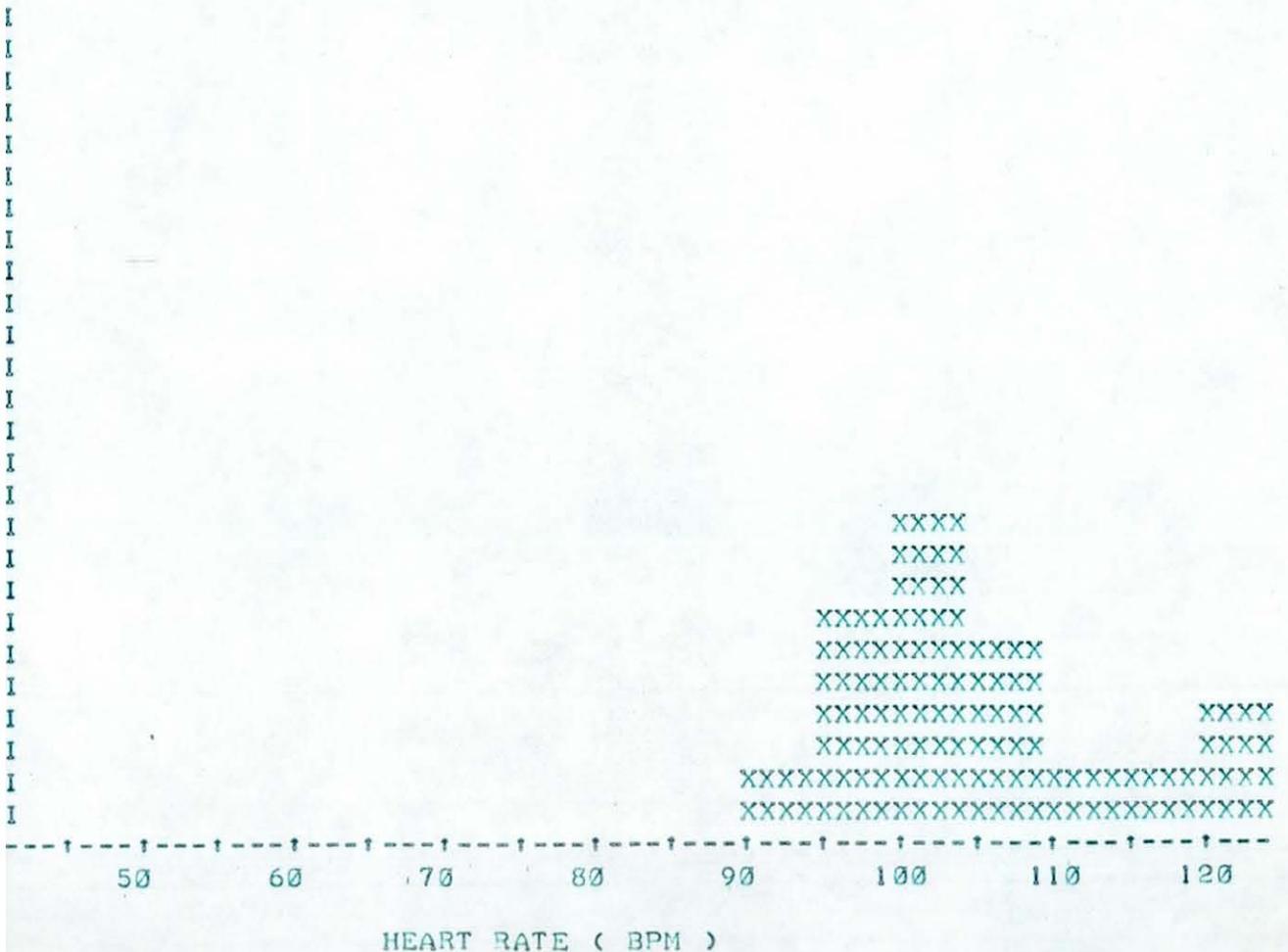
B.P.M.	DURATION
50 - 54	.3 MINS.
55 - 59	0.0 MINS.
60 - 64	.3 MINS.
65 - 69	0.0 MINS.
70 - 74	1.5 MINS.
75 - 79	.3 MINS.
80 - 84	1.5 MINS.
85 - 89	2.2 MINS.
90 - 94	10.5 MINS.
95 - 99	36.1 MINS.
100-104	51.8 MINS.
105-109	32.9 MINS.
110-114	13.7 MINS.
115-119	12.4 MINS.
BELOW 50	4.4 MINS.
ABOVE 119	21.4 MINS.



TOTAL DURATION OF TEST : 190 MINUTES

HISTOGRAM OF HEART RATE DISTRIBUTION.

VERTICAL AXIS - DURATION IN MINUTES



1	0	31	100	61	98	91	104	121	109	131	132	181	109
2	110	32	100	62	96	92	107	122	102	132	124	182	93
3	101	33	99	63	103	93	116	123	112	133	110	183	102
4	108	34	105	64	112	94	103	124	116	134	122	184	104
5	103	35	98	65	109	95	101	125	104	135	117	185	96
6	108	36	102	66	97	96	102	126	105	136	118	186	97
7	103	37	97	67	120	97	104	127	105	137	114	187	106
8	106	38	102	68	116	98	112	128	102	138	112	188	109
9	104	39	103	69	116	99	105	129	103	139	101	189	0
10	104	40	99	70	104	100	96	130	114	140	100	190	0
11	104	41	99	71	106	101	93	131	113	141	111		
12	105	42	110	72	114	102	99	132	115	142	108		
13	105	43	100	73	117	103	111	133	110	143	97		
14	104	44	97	74	109	104	100	134	114	144	100		
15	101	45	105	75	112	105	99	135	125	145	103		
16	100	46	97	76	120	106	97	136	108	146	105		
17	101	47	98	77	111	107	96	137	114	147	114		
18	101	48	100	78	113	108	91	138	117	148	117		
19	103	49	101	79	103	109	94	139	120	149	102		
20	100	50	111	80	97	110	106	140	106	150	96		
21	100	51	99	81	104	111	113	141	123	151	111		
22	96	52	100	82	112	112	112	142	111	152	113		
23	102	53	107	83	105	113	117	143	135	153	118		
24	101	54	97	84	99	114	113	144	119	154	115		
25	99	55	94	85	106	115	106	145	119	155	106		
26	100	56	101	86	103	116	100	146	127	156	107		
27	100	57	99	87	101	117	101	147	102	157	113		
28	100	58	101	88	107	118	103	148	94	158	108		
29	95	59	99	89	99	119	111	149	110	159	113		
30	104	60	100	90	108	120	114	150	120	160	107		

TAPE REFERENCE NO. 13 5 75 355

B.P.N.	DURATION	
65 - 69	.3 MINS.	
70 - 74	0.0 MINS.	
75 - 79	1.2 MINS.	
80 - 84	.6 MINS.	
85 - 89	4.4 MINS.	
90 - 94	22.8 MINS.	
95 - 99	58.7 MINS.	
100-104	53.6 MINS.	
105-109	29.2 MINS.	
110-114	17.3 MINS.	
115-119	8.9 MINS.	
120-124	4.4 MINS.	
125-129	3.8 MINS.	
130-134	1.6 MINS.	
135-139	1.6 MINS.	
140-144	1.9 MINS.	
145-149	0.0 MINS.	
BELOW 65	1.9 MINS.	INVALID READING
ABOVE 149	0.0 MINS.	INVALID READING

TOTAL DURATION OF TEST : 213 MINUTES

1	112	31	96	61	97	91	122	121	108	151	101	181	125	211	107
2	100	32	98	62	100	92	105	122	102	152	105	182	113	212	123
3	102	33	97	63	96	93	105	123	101	153	120	183	119	213	136
4	113	34	93	64	96	94	99	124	110	154	112	184	113		
5	105	35	90	65	93	95	99	125	102	155	109	185	122		
6	103	36	95	66	96	96	99	126	100	156	111	186	120		
7	100	37	100	67	97	97	96	127	97	157	108	187	125		
8	100	38	107	68	103	98	97	128	96	158	103	188	117		
9	97	39	117	69	102	99	104	129	91	159	104	189	121		
10	97	40	108	70	97	100	108	130	96	160	102	190	120		
11	102	41	101	71	98	101	131	131	106	161	110	191	112		
12	98	42	99	72	97	102	116	132	102	162	105	192	110		
13	103	43	100	73	94	103	114	133	105	163	111	193	113		
14	100	44	98	74	94	104	110	134	107	164	100	194	109		
15	98	45	99	75	98	105	109	135	107	165	95	195	99		
16	101	46	94	76	89	106	108	136	106	166	97	196	102		
17	99	47	99	77	90	107	113	137	110	167	99	197	100		
18	95	48	94	78	93	108	106	138	116	168	104	198	97		
19	103	49	107	79	96	109	105	139	106	169	100	199	98		
20	106	50	100	80	93	110	106	140	99	170	105	200	107		
21	107	51	109	81	96	111	102	141	101	171	101	201	108		
22	106	52	105	82	104	112	104	142	101	172	99	202	101		
23	105	53	99	83	104	113	106	143	101	173	113	203	101		
24	101	54	96	84	103	114	110	144	101	174	89	204	112		
25	109	55	97	85	111	115	102	145	97	175	113	205	113		
26	97	56	96	86	104	116	103	146	99	176	89	206	103		
27	96	57	98	87	101	117	102	147	97	177	98	207	107		
28	95	58	96	88	100	118	104	148	98	178	103	208	92		
29	95	59	98	89	111	119	102	149	109	179	126	209	114		
30	102	60	97	90	105	120	107	150	103	180	107	210	108		

CHAPTER 3DISCUSSION

3.1 Introduction. Some of the factors influencing the design and selection of personal protective systems for a given environment suggested in Chapter 1 are summarised by the following; (a) Environmental conditions, (b) Activity expected, (c) Duration and intensity of exposure and (d) Protective efficiency afforded by the systems available.

Effective protection from hostile conditions in the working environment depends on a sound understanding of the physical and biological factors governing the worker and his environment. It has been shown in the background review that indices are available for predicting the physiological strains produced by environmental and metabolic heat loads. The relative magnitudes of the several components of these suggests the kind of control measures that will be successful. It has also been shown that work activity control is not possible or complete without proper attention to the physiological needs of exposed personnel. Physiological strain of exposure is reflected in elevation of heart rate, in sweating and in elevation of body core and skin temperatures. In studies to be undertaken in the working environment it has also been suggested that measurements taken must be selected for their feasibility as well as their probable meaningfulness. The main objectives of this research topic were to establish the design parameters in the creation of a protective clothing assembly to enable work to be undertaken under conditions hostile to the human beings normal physiological functioning. Most systems that have been proposed to achieve micro environmental air conditioning for the human at work have required the use of special clothing; protective suits into which air is

delivered from an outside source. The delivery of cool respirable air to the human working in hostile environments poses some practical engineering problems. The transportation of cool air through a suitable length of hose to the wearer can result in reheating of the air if for instance it is exposed to a radiant heat source. A light weight device designed on the principle of the Ranque/Hilsch cooling effect - a vortex tube, can be used to facilitate control of air temperatures. The principle of operation of the vortex tube has been described and the initial investigations to establish a finalised design for a single and duplex vortex generator have been outlined in Chapter 2. Complimentary to this work and in order to be able to assess the physiological responses of men entering the pressure vessel of nuclear reactors of the Advanced Gas Cooled Design, the results of preliminary validation investigation are presented for an ambulatory monitoring system. A description has been given of the techniques used to extract heart rate data from continuous analogue tape recordings of the ECG with subsequent preparation of punched paper tape as a means of input into a digital computer to present data as a minute by minute analysis and as a histogram.

The following Section discusses the suggested basis of a system design for a protective clothing assembly to be used in conjunction with a cooling tube using the vortex principle.

3.2 Heat Balance Equation. The consideration of heat transfer within the micro-climate can be shown by the following heat balance equation:-

$$H_e + H_m = H_a + H_s$$

where H_e = Heat transmitted through the suit from environment

H_m = Metabolic heat

H_a = Sensible heat pick up by cooling air

H_s = Heat loss by sweating

To undertake a work load in a known environment, the first step in the design of the system is to assess the quantity and temperature

of the air to be supplied to the micro-environment. To meet the conditions the potential cooling capacity of the air (H_a) can be based upon the cooling air flow, its specific heat and the temperature difference and the air and skin temperatures.

The heat loss by sweating, H_s , can be limited by either of two considerations (a) the limiting of sweat rate to 1.4×10^{-4} Kg/sec or (b) moisture pick up of air flow through the clothing assembly.

Three factors influence this, namely the air flow, the inlet temperature and humidity. For a range of inlet air flows to a clothing assembly the capacity of the inlet air to remove heat plotted against inlet temperature is shown in Fig 3.1.

The sensible heat component, H_a , can be calculated from the following formula:-

$$H_a = F (T_s - T_i) 10^3 \text{ watts where } F = \text{air flow Kg/s}$$

$$T_s = 33^\circ\text{C}$$

$$T_i = \text{inlet temperature}$$

The heat loss by sweating H_s can be calculated from the following formula:

$$H_s = Q \times 2.41 \times 10^6 \text{ watts where } Q = \text{sweat loss Kg/s}$$

This sweat loss is taken as the lower of the two limiting criteria the (assumed) physiological limit of 1.4×10^{-4} Kg/s or the capacity of the air to take up moisture as shown in Fig 3.2 over a range of air flows at inlet temperatures of 10°C , 15°C , 20°C and 25°C of saturated and dry air. Fig 3.3 shows the combined heat removal capability of the inlet air $H_a + H_s$ under these conditions.

3.2.1 Heat Dissipation. The total heat to be dissipated $H_e + H_m$ is shown in Fig 3.4 and from this it can be seen that the pick up from the environment varies directly with the temperature. These curves were deduced using the effective insulation value $0.3^\circ\text{C m}^2\text{h/kcal}$ established in the original investigation described in Appendix C, page A6.8.

Metabolic heat is determined basically by the nature and extent of the work being carried out. The curves in Fig 3.4 show the heat dissipation appropriate for resting and typical grades of light, heavy work (mean rate) and heavy work (continuous). If after a given application, the environmental temperature and the postulated work load are known, then from Fig 3.4 the heat to be removed can be determined, this heat rate can be referred to Fig 3.3 and these curves used to determine the maximum inlet air temperature for a given inlet air flow. It is important to note that these curves represent the limiting condition; for a given inlet temperature the flow given is the minimum or alternatively for a given flow the inlet temperature shown is a maximum.

During the hot familiarisation investigations it was apparent that comfortable inlet conditions were generally obtained in the range 20°C to 25°C. Above this range some temperature discomfort can be expected below 10°C discomfort was also felt. The inlet air should be maintained therefore if at all possible, within this "comfort zone". However it is suggested that operation slightly outside this zone is acceptable provided the correct amount of cooling is being provided; this should have no safety implications.

3.3 Use of Vortex Tubes with Ventile Clothing Assemblies. The vortex tubes developed and described in Chapter 2 have a nominal supply requirement of 0.015 Kg/s single generator and 0.03 Kg/s duplex generator at 6 bar operating pressure, as shown in Fig 3.5. It was found in the investigations that the total flow through the vortex tube, that is to say the quantity demand on an air supply system is principally dependent upon the air pressure applied at the tube inlet. The position of the cold/hot control valve had a marginal effect on the flow for a given pressure at the inlet and under normal conditions of use the back

pressure prescribed by the ventilating clothing assembly had a slight effect. Allowances for these factors have therefore been made in the following performance information. Each tube has a control valve at the hot exhaust and it is necessary to set this control to ensure a comfortable temperature of air entering the clothing assembly. In most cases the control must be preset before a subject enters the high temperature zone. In these circumstances the presetting must be suitable for the vortex tube air inlet temperature at the work place (the elevated temperature) and Fig 3.6 shows the temperature interval, with varying inlet pressure for a range of hot valve openings using a duplex generator.

3.3.1 Setting of Vortex Tube Hot Valves. The heat load(s) to be dissipated in the clothing assembly will be known from the temperatures of the work environments and the physical effort to be expended at these. A typical graphic presentation is shown in Fig 3.4. Unless known to the contrary the air supply to the vortex tube should be assumed to be the temperature of the working environment. Figs 3.7, 3.8, 3.9 and 3.10 show the heat removal capabilities of single and duplex vortex tubes when the working environment temperatures are respectively 45°C , 50°C , 55°C and 60°C .

Referring to Fig 3.7 it will be seen that the curves are for a setting of the tubes with the valve at the hot exhaust end two turns open. As noted on the figure if these tubes are set with these valves four turns open the cold fraction temperature will be below 10°C and the wearer maybe uncomfortable. Fig 3.7 also indicates that if the inlet pressure is raised above 10 bar even if the valves are two turns open, again the temperature falls below 10°C . When the inlet temperature passes outside the normal comfort zone the curves are shown dotted and at various points the actual temperature of the inlet air is shown in

Fig 3.7 the notation 10°C and 9.5°C are shown on the curves when they pass through the 10 and 11 bar ordinates.

The capability of the air to remove heat from a man varies with inlet pressure and the rate at which the man is sweating. In practice, the man will sweat at a rate depending upon the heat that he needs to dissipate. For example, assume that the heat to be dissipated, due to his working rate plus the heat received from the environment is 500 watts and also assume that he has a twin vortex tube. If the tube inlet pressures are 8.9 bar, this load (500 watts) can be dissipated by the sensible heat pick up of the air alone and the man will not sweat. (See the 'no sweating' line). If the heat load rises to 840 watts, he will now have to sweat to increase his dissipation and will in fact need to sweat at a rate of 1.4×10^{-4} Kg/s (500 grams/h): this is the maximum considered allowable. Obviously at loads intermediate between these points, the sweat rate demanded will be an intermediate amount.

If the heat load is above the 'maximum (recommended) sweating' line the man could ultimately become distressed or could collapse. This may not occur at once, but it must be noted that the ability to sweat does diminish as the sweat glands fatigue. On the other hand, if the heat load falls below the 'no-sweating' line the man will begin to feel colder.

Thus in practice the pressure is regulated to keep the heat load between the maximum sweating lines. Before entry, the probable maximum heat load can be estimated and from this, Figs 3.7 to 3.10 as appropriate, will indicate whether single or twin tubes are necessary and the minimum pressure that will be needed at the vortex tube inlet. During use, the minute to minute regulation is achieved by the pressure alone on the instructions of the wearer. The heat load will vary from minute to minute and this can only be sensed by the wearer feeling too cold or too

hot. His instructions will be the only way of ensuring that the conditions are kept between the two limiting conditions of maximum and no-sweating.

It will be noted that Fig 3.6 and 3.8 are generally similar to Fig 3.7. In Fig 3.9 the fraction valve can be opened to 4 turns provided the too cold comfort limit is not reached. The 'no-sweating' lines have also been omitted as they are well below the heat loads expected in practice. In Fig 3.10, it will be noted that 'too hot' comfort limit of 25°C for suit inlet air will be encountered with control settings of 6 turns open or less.

The presence of moisture in the inlet air can upset the performance of vortex tubes. Excessive moisture can cause freezing in the generator and blockage of the tube. For safety reasons therefore the air should be partially 'dried' by a good after-cooler fed with cold water and followed by a moisture trap. When moist air is used from such a system the following allowances should be made when comparing with dry air.

Firstly, to obtain a performance margin, an ambient temperature 5°C higher than measured should be assumed before selecting the appropriate curves to use from Figs 3.7 to 3.10.

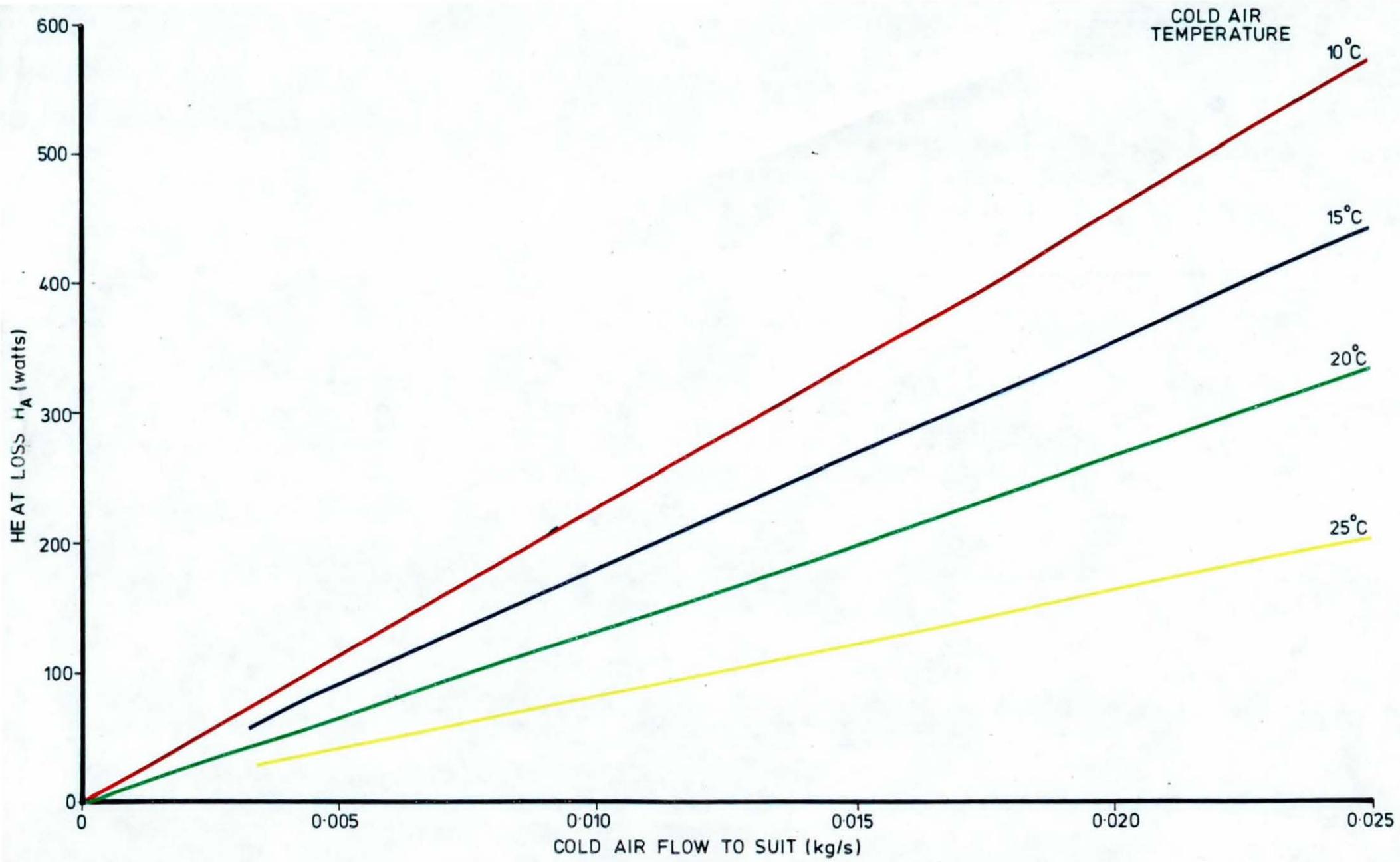
Secondly, to ensure an adequate temperature margin the lowest permissible opening of the vortex tube's fraction valve(s) should be used.

The preceding analysis is based upon the performance of the clothing assembly during tests in the climate laboratory (Appendix C) and has attempted to show how estimates can be made of the performance requirements of the assembly under various conditions of cooling. Many variables can effect the performance of the clothing assembly but if its usage can be fairly clearly envisaged the following list is suggested as the essential requirements that must be met under any conditions of use.

- (1) The wearer is fit and has been medically examined (Appendix A) and pronounced fit for the work to be undertaken.
- (2) The assembly will be worn in an atmosphere which is substantially air at atmospheric pressure.
- (3) Radiant heat to which the suit is subjected is not significantly above that which might be expected from the ambient environmental temperature. That is that a globe temperature roughly equal to the indicated temperature might be expected.
- (4) That the assembly is worn over underclothing only.
- (5) That the assembly is worn with suitable hand and foot protection.
- (6) That the maximum period for the assembly to be worn is limited to four hours.

3.4 Conclusion. The objectives of this research have been achieved. The basic principles of working in an abnormal thermal environment have been set out and solutions to the problems involved obtained by a design of protective clothing used in conjunction with a vortex tube.

Semi-empirical formulae have been derived and their accuracy checked within the maximum limit of 60°C so that the level of any thermal stress on the wearer of the protective assembly can be evaluated for a given work-load expectation. A satisfactory heat balance has thus been obtained and control has been exercised in a simple practical way.



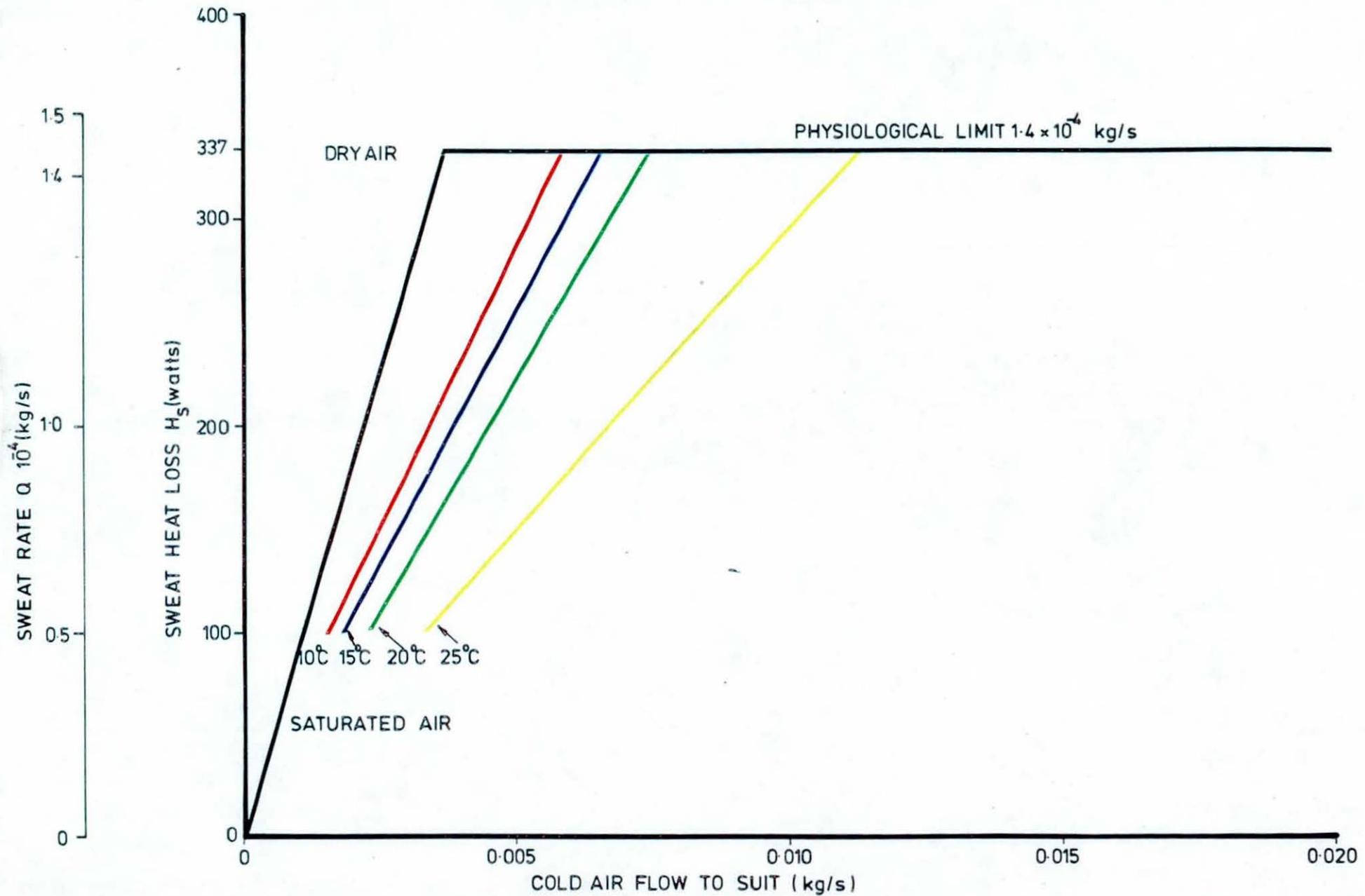
SENSIBLE HEAT LOSS

COLD AIR TEMPERATURE
10°C

15°C

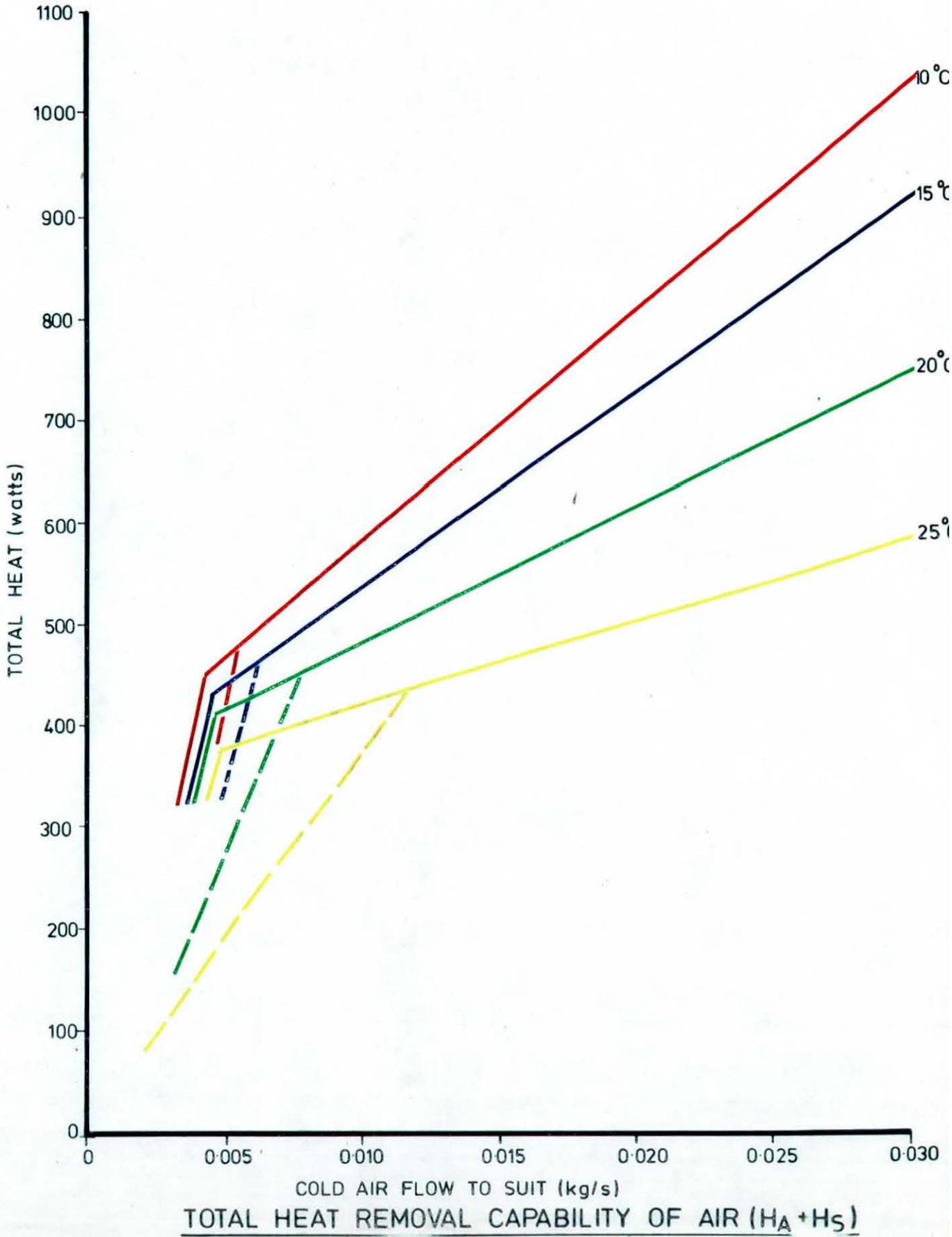
20°C

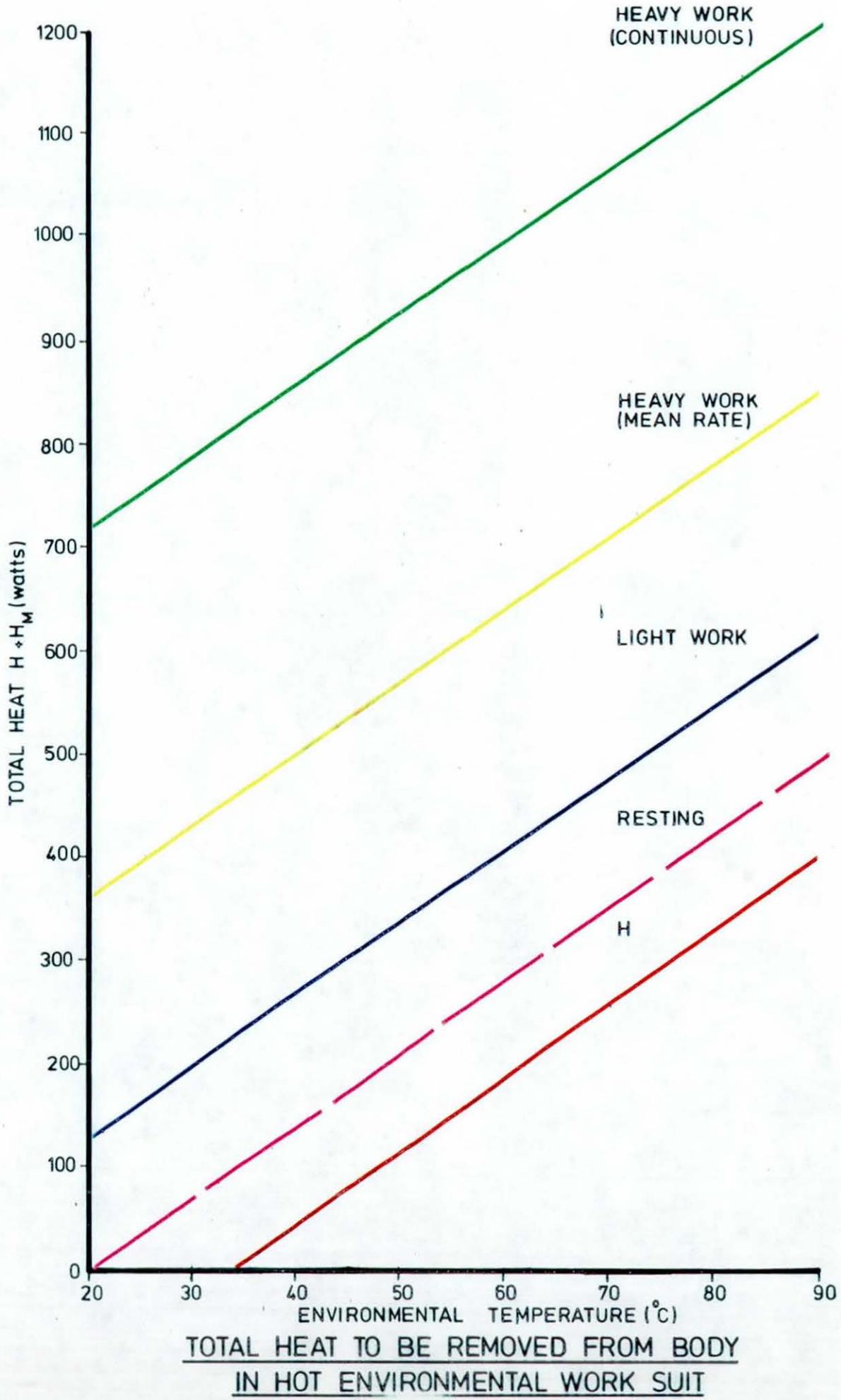
25°C



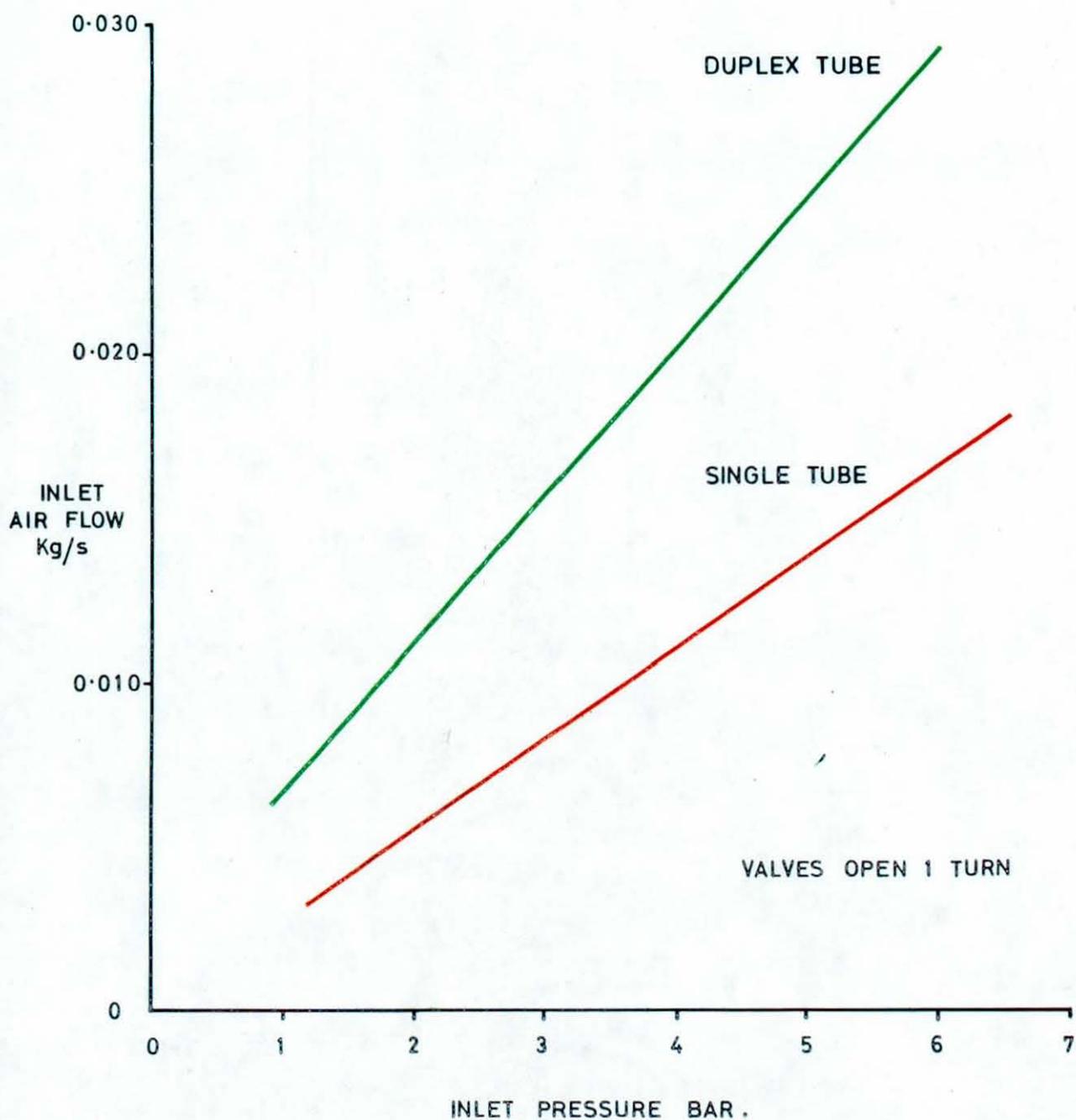
MOISTURE UPTAKE AND SWEAT HEAT LOSS

— DRY AIR
- - SATURATED AIR (REDUCED CAPABILITY AT LOW FLOWS)

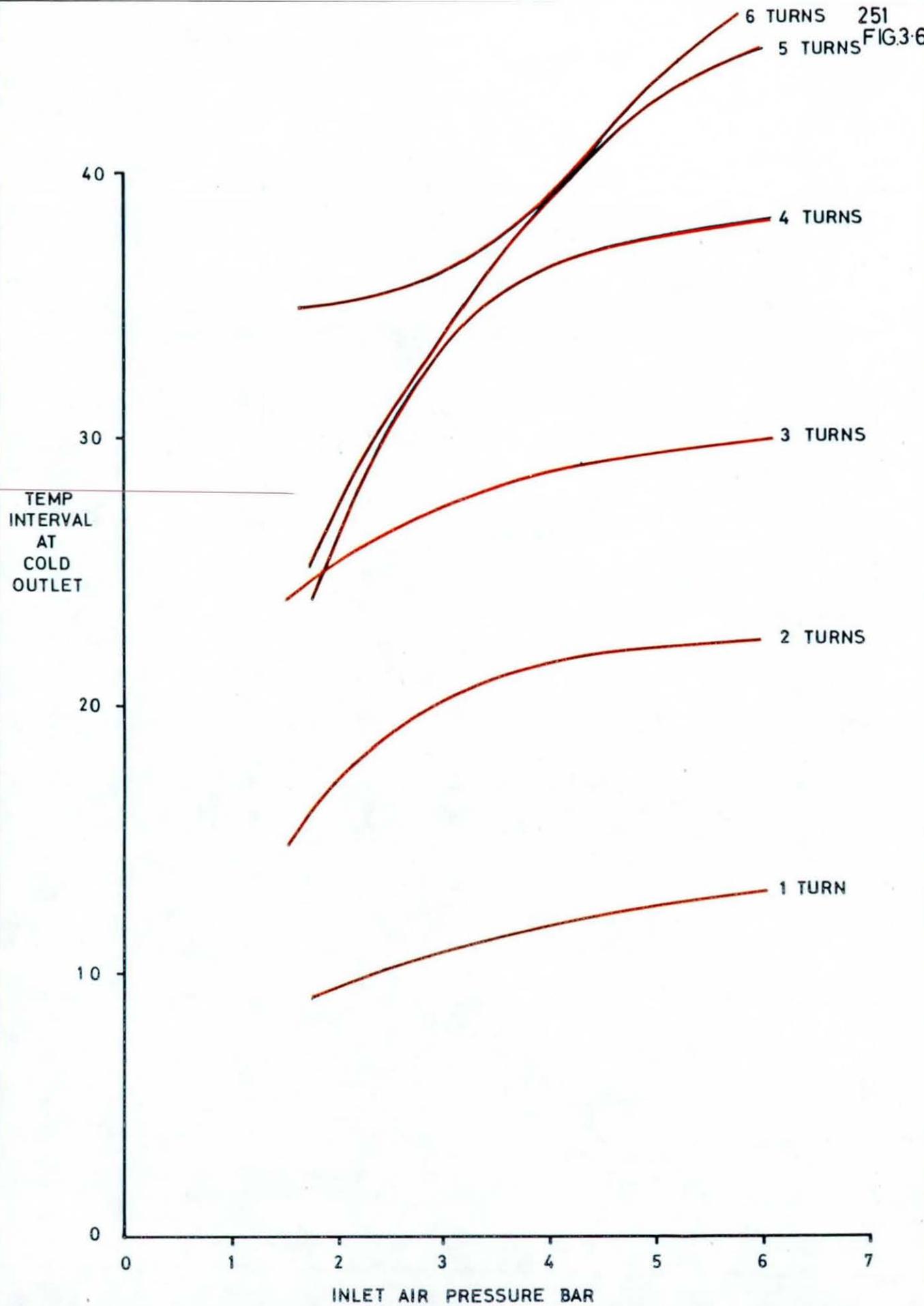




TOTAL HEAT TO BE REMOVED FROM BODY
IN HOT ENVIRONMENTAL WORK SUIT



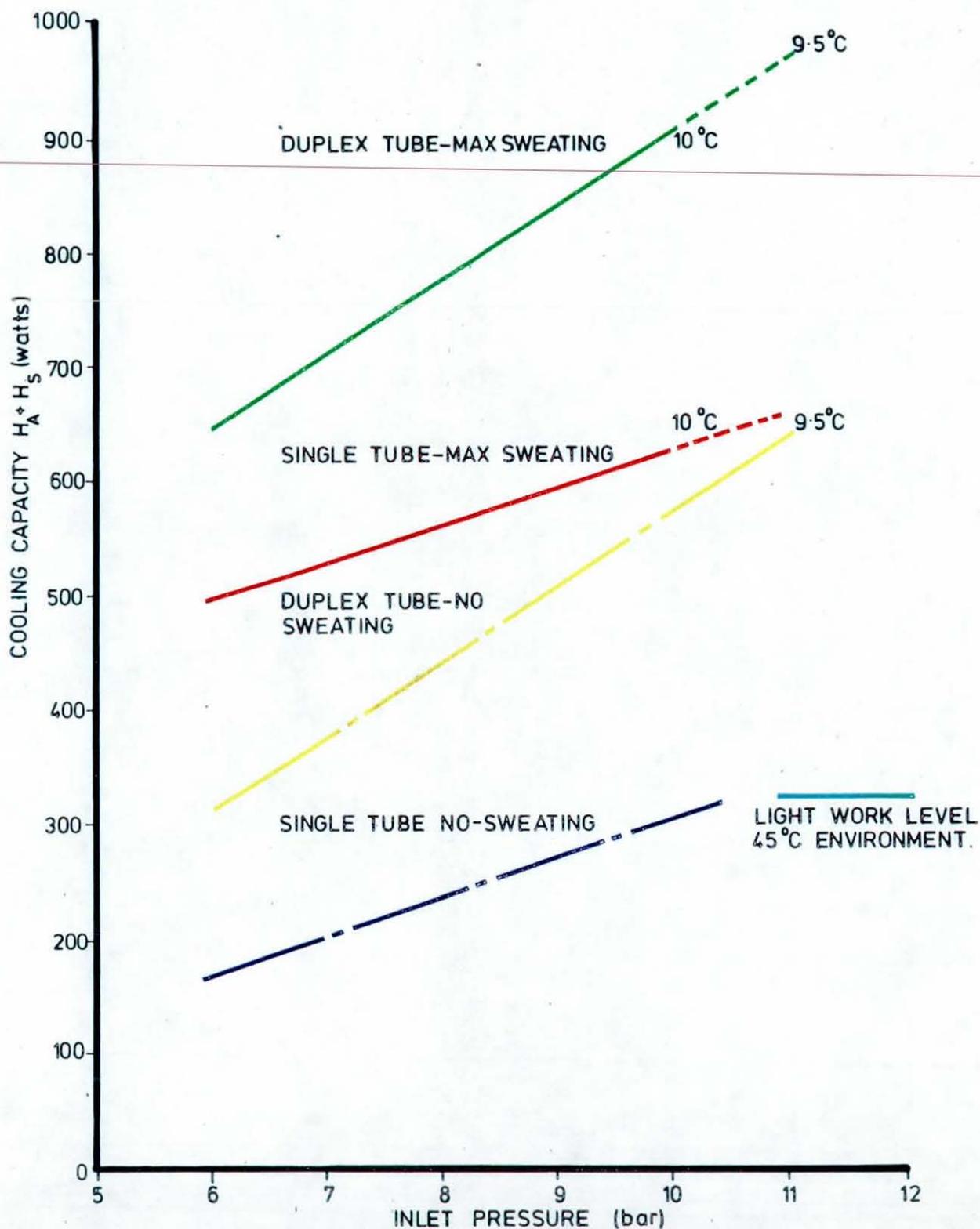
AIR CONSUMPTION OF TYPICAL SINGLE AND DUPLEX VORTEX TUBES



RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE INTERVAL K WITH VARYING HOT VALVE OPENING.

TUBES SET 2 TURNS OPEN

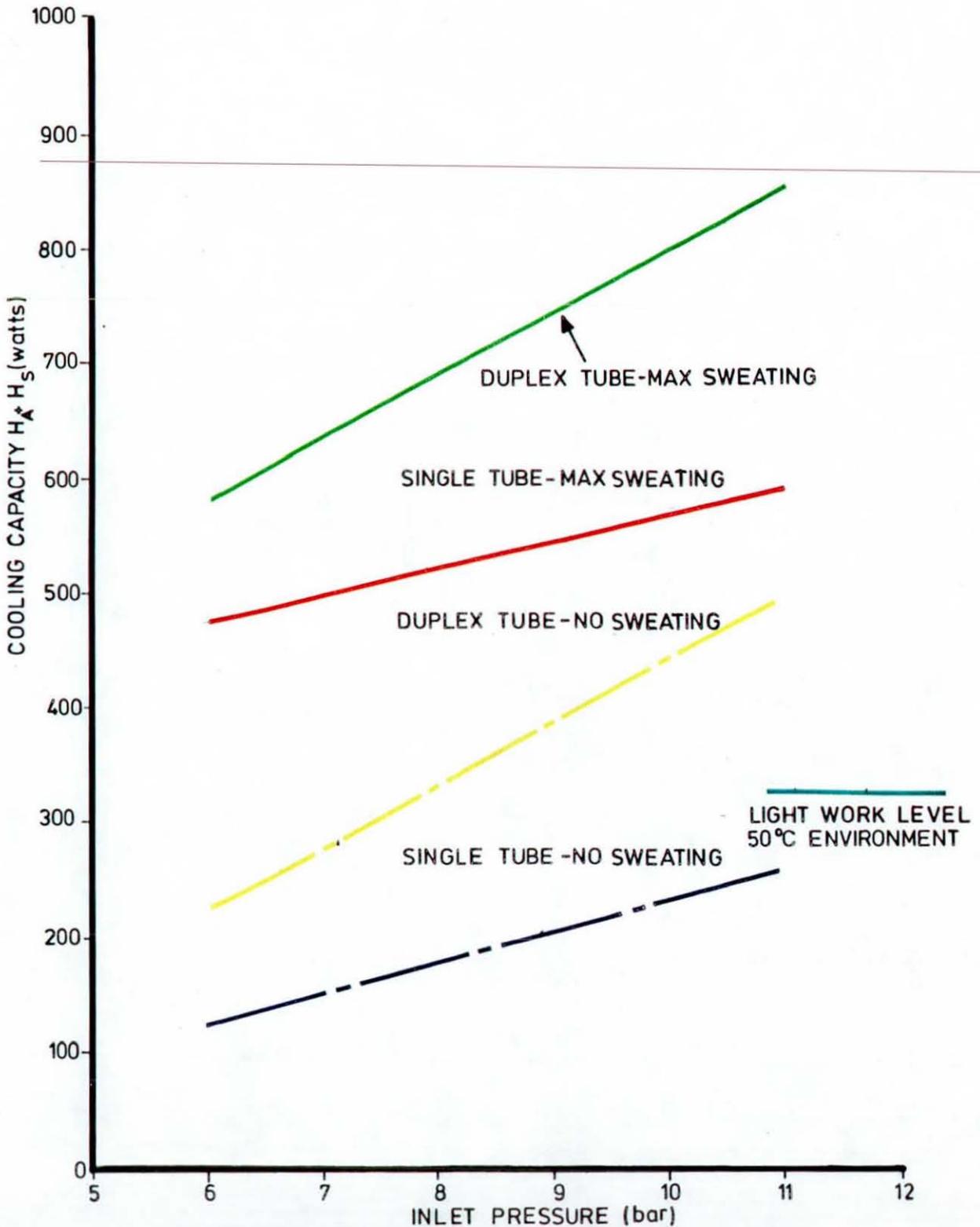
NOTE: SETTINGS OF 4 TURNS
OR MORE ARE OUTSIDE
COMFORT ZONE



COOLING CAPABILITY OF TUBES WITH DRY AIR SUPPLY. AIR INLET TEMPERATURE 45°C

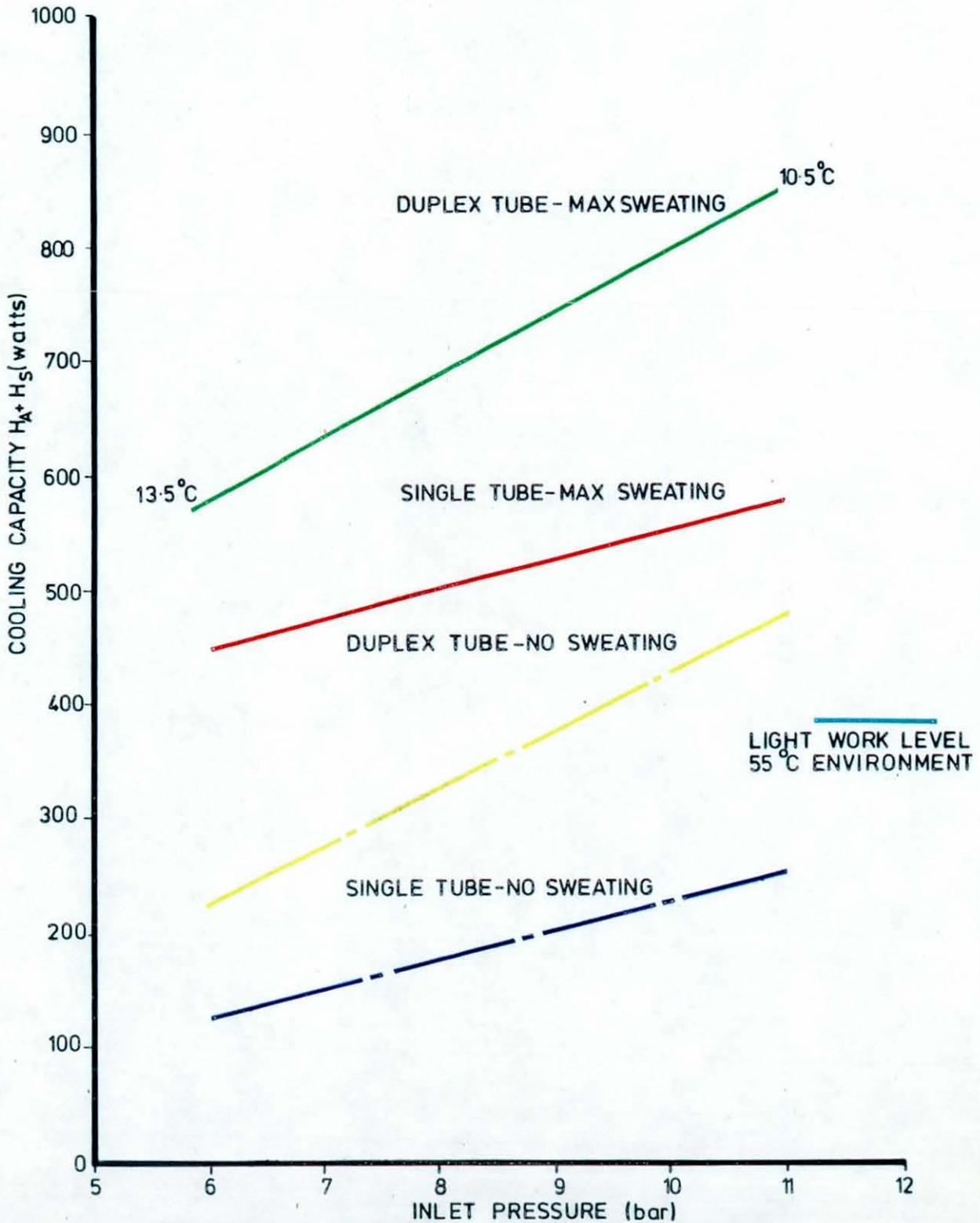
TUBES SHOULD NORMALLY BE SET TO 2 TURNS OPEN

NOTE: SETTINGS OF 4 TURNS OR MORE ARE OUTSIDE COMFORT ZONE



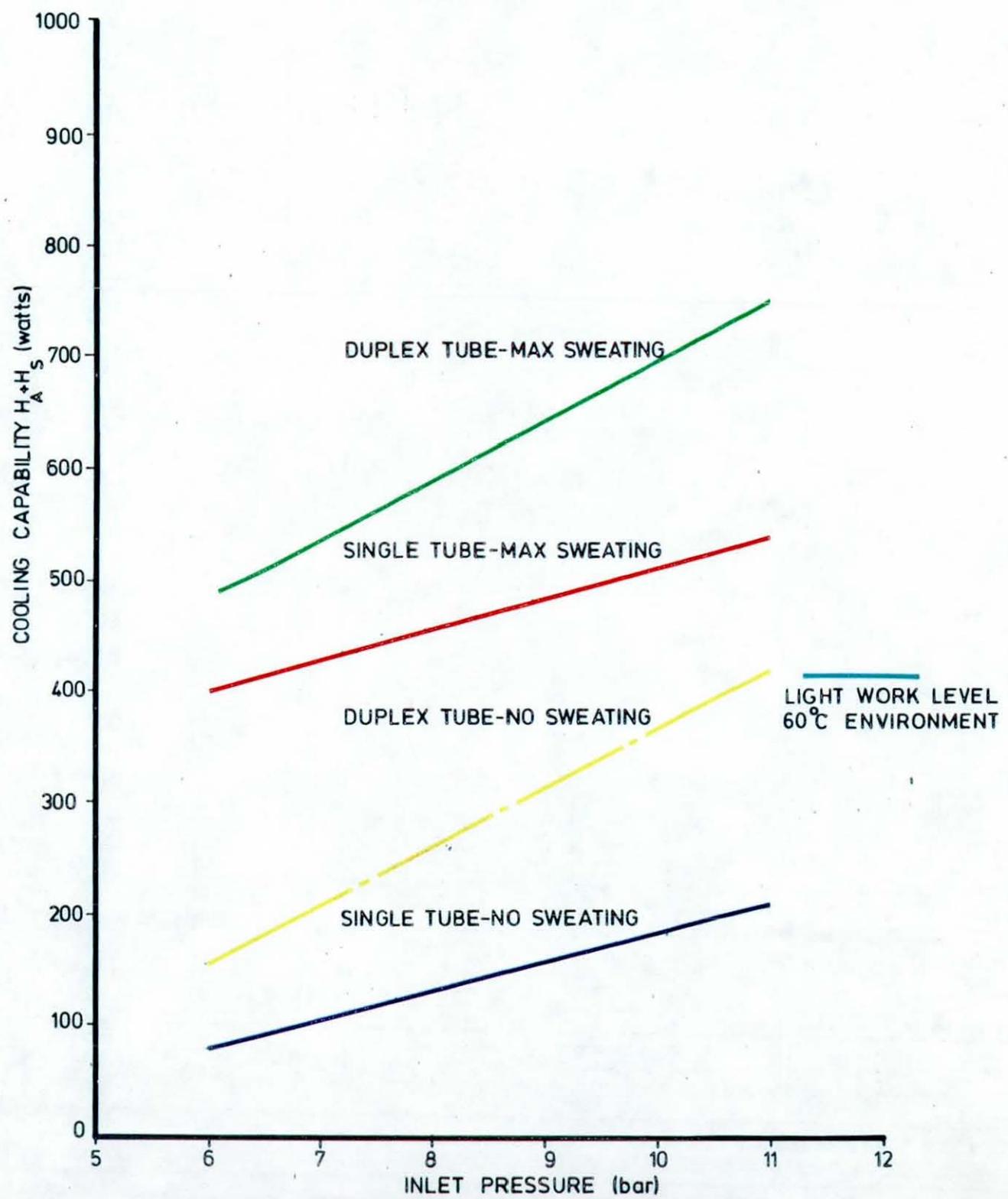
COOLING CAPABILITY OF TUBES-WITH DRY AIR SUPPLY. AIR INLET TEMPERATURE 50°C

NOTE: NORMAL SETTING WILL
 BE 4 TURNS OPEN 2 TURNS
 OPEN GIVES LOWER PERFORMANCE
 SETTINGS OVER 4 RESULTS IN
 COMFORT LEVELS BEING EXCEEDED
 WITHOUT BENEFIT TO PERFORMANCE



COOLING CAPABILITY OF TUBES-WITH DRY
AIR SUPPLY. AIR INLET TEMPERATURE 55°C

NOTE TUBES TO BE SET 6 TURNS
OPEN FOR MAXIMUM
PERFORMANCE AND TO KEEP
INLET TEMPERATURES INSIDE
COMFORT ZONE



COOLING CAPABILITY OF TUBES-WITH DRY
AIR SUPPLY. AIR INLET TEMPERATURE 60°C

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