VOLUME TWO

PHYSIOLOGICAL EVALUATION

OF

CLOTHING AND EQUIPMENT

FOR

USE IN HOSTILE WORKING ENVIRONMENTS

BY

JOHN DAVIES M Sc (LOUGHBOROUGH)

A Thesis

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

LOUGHBOROUGH UNIVERSITY OF TECHNOLOGY

SEPTEMBER 1977

APPENDICES

APPENDIX A

MEDICAL EXAMINATIONS AND HEALTH QUESTIONNAIRE

Medical examination of prospective workers in impermeable clothing or in hot conditions is necessary, if only to exclude certain individuals who may be more at risk from the effects of heat stress. But the work itself, apart from the high temperatures, is often difficult or in confined areas, and disabilities of the locomotor system, poor vision or auditory defects, and psychological disturbance such as claustrophobia may be limiting factors. Again some individuals have a skin sensitivity to rubber of plastics, or have difficulty in breathing in respirators, etc., and so cannot wear protective clothing.

Two forms of medical examination are necessary. The first (a) will be undertaken by the Medical Officer before a man is assigned to a job which may include work in hot conditions or the wearing of impermeable clothing, and the second (b) is a briefer interview before any such taks is undertaken.

(A) At the pre-employment examination, note should be made of any disabilities bearing on work in hot conditions and the necessary limitations imposed and the man's fitness for such work should be re-assessed annually or after any prolonged absence due to accident or sickness.

When the conditions are such that the advice of the Medical Service is necessary, the men concerned will require to be of a high standard of medical fitness and should have had special training in the work and the work and the wearing of any special clothing. Special tests, such as an exercise tolerance test, are advisable for these men.

The specific factors which will influence selection are :-

(i) Age   Unless the individual is expectionally fit, 45 years is the maximum age for work in hot conditions, and in no circumstances should anyone over the age of 50 years be accepted.

(ii) Physique   The man must be of good general physique. If obese and overweight as determined by standard height and weight tables and by skin fold thickness (not greater than 1 inch) he must be excluded from work in hot conditions.

Age and physique are probably not of such importance for work in impermeable clothing, though they must be taken into account. The following clinical and psychological conditions, however, are of importance for fitness to work in both hot conditions and in impermeable clothing.

(iii) Clinical Conditions

(a) The resting blood pressure should not be greater than 150/95.

(b) Cardiovascular disease, metabolic disease (eg thyrotoxicosis or diabetes) and fainting attacks are a bar to such work. A history of postural hypotension with a liability to faintness after prolonged standing, heavy lifting or stooping will exclude, since there will be a greater chance of heat syncope occurring.

(c) Chronic infection, in particular, sinusitis and otorrhoea, or ititis media, would exclude from employment unless and until curative procedures have been carried out.

(d) Chronic respiratory disease will exclude.

(e) Any form of anaemia (haemoglobin less than 90%) will require investigation and treatment before acceptance.

(iv) Psychological Conditions. Anxiety states, phobias (such as claustrophobia), or severer psychiatric illness will exclude from such work.

When selecting the men, a questionnaire can eliminate those obviously unsuitable for this work, leaving the remainder to be medically examined for final assessment. By this means the numbers requiring examination can be reduced and unnecessary examinations avoided.

An example for such a questionnaire (devised for general purposes rather than specifically for work in hot environments, yet suitable for the latter) will be found at the end of this appendix.

(B) At the interview, given immediately before any work is undertaken in an impermeable suit or in hot conditions, questions should be asked of the individual's fitness at the moment.

This interview will be conducted by the Medical Officer or Station Nurse (or in their absence by the Senior First Aider on duty), and if there is any doubt as to the man's fitness he should be barred from such work.

Conditions such as the following will definitely exclude him :-

Acute conditions such as upper respiratory infections, ear, nose and throat infections, gastro-intestinal upsets;

A "hand-over" from the taking of alcohol;

Lack of sleep or other cause of fatigue;

Skin conditions such as marked acne, active psoriasis, sun-burn;

Psychological stress, such as a recent bereavement, domestic
illness or upheaval, anxiety or depression;

Disabilities of the locomotor system.

Note

Brief Exposure to Heat

In some situations the work to be undertaken will only require a brief exposure to heat by personnel who are used to the work to be done. In these situations medical examinations are unnecessary provided the work period is less than 15 minutes and the temperature not more than 35°C (95°F). The usual rest period must be taken after each work period.

CMM

HEALTH QUESTIONNAIRE

Please fill in the personal details below and answer the health questions by putting a circle round the correct answer, or giving details where necessary.

Date .... Proposed employment ....

Full Name .... Date of Birth ....

Address .... Age ....

....

....

Present Occupation ....

Are you a Registered Disabled Person? YES NO

If "Yes", what is your Disabled Registration Number ....

Are you in receipt of a disability pension from any source? YES NO

Are there any medical reasons why you should not do shift work? YES NO

If "Yes", what are the reasons ....

....

How much time off work have you had due to sickness or injury in the last 3 years?

.... weeks.

Have you ever been rejected for life insurance? YES NO

Has a doctor ever told you that you suffered from:

High Blood Pressure?	YES	NO
Angina or Coronary Artery disease?	YES	NO
Heart trouble?	YES	NO
Peptic, gastric or duodenal ulcer?	YES	NO
Kidney or bladder trouble?	YES	NO
Diabetes?	YES	NO
Thyroid gland trouble?	YES	NO

Do you suffer from or have you ever suffered from:

Epilepsy?	YES	NO
Fainting attacks or blackouts?	YES	NO
Nervous breakdown, anxiety state, depression or mental illness?	YES	NO
Poliomyolitis (Infantile paralysis)	YES	NO
Rheumatic fever?	YES	NO
Varicose veins?	YES	NO
Haemorrhoids?	YES	NO
Tuberculosis?	YES	NO
Bronchitis or chronic cough?	YES	NO
Asthma?	YES	NO

Indigestion (for more than 1 week)?	YES	NO
Fibrositis, Rheumatism or Arthritis?	YES	NO
Lumbago, sciatica or slipped disc?	YES	NO
Dermatitis, eczema or other skin trouble?	YES	NO
Do you suffer from a rupture (hernia)?	YES	NO
Do you suffer from any ear trouble?	YES	NO
Is your hearing good in both ears?	YES	NO
Is your vision good in both eyes(with glasses if worn)?	YES	NO
Do you wear glasses?	YES	NO
Is your colour vision thought to be normal?	YES	NO
Are you receiving any treatment from your own doctor at present?	YES	NO
Are you suffering from any other disability or disease?	YES	NO

If the answer to either of the above questions is "Yes", give further details: -

....

....

....

....

....

Have you ever had an operation, or attended a hospital or nursing home for any accident or illness either for treatment or investigation?

YES NO

If "Yes", give further details ....

....

....

....

....

Have you ever lived outside the British Isles (apart from holiday abroad)?

YES NO

If "Yes", where and when - ....

....

....

Have you ever suffered from any illness contracted outside the British Isles (Malaria, dysentery, etc.) YES NO

If "Yes", give details - ....

....

....

....

I declare the answers to the above questions to be correct to the best of my knowledge and understand that the deliberate withholding of information will be regarded seriously, and I understand I may be required to submit to a medical examination.

Signed

APPENDIX B

CENTRAL ELECTRICITY GENERATING BOARD

SOUTH EASTERN REGION

ENGINEERING DEPARTMENT

PROJECT BRANCH

The Development of the CEGB VORTEX TUBE AND ASSOCIATED AIR HOSE

(With particular reference to the creation of micro-climates for use with protective clothing assemblies)

By

John Davies

Summary

This paper outlines a brief history of the Ranque vortex phenomena including the historical development of the vortex principle. The areas of theoretical analysis are given together with references of practical application of vortex tubes.

The development of the CEGB vortex tube is detailed with reference to its application in the creation of micro climates associated with protective clothing for personnel working in hostile environments.

Complimentary to the use of the vortex tube the suggested design and performance characteristics of a compressed air hose with the facility to transmit communication signals and physiological monitoring data is also given.

May 1977

CONTENTS

TABLES

FIGURES

FIGURES

FIGURES

THE VORTEX TUBE

"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

1 INTRODUCTION

The great amount of interest attaching to the vortex tube is readily apparent from the published research literature patents, government and industrial reports on the perplexing thermodynamic phenomenon on automatically obtaining from a compressible fluid (gas or vapour) under pressure a current of hotter and colder fluid without the help of any moving parts. This physical phenomenon displayed by the vortex tube is unique and unparalleled by any other known phenomenon. Given a source of compressed air or other gas the vortex tube affords the simplest and most direct known means of creating heat and cold. The development of vortex tubes capable of operating with sufficient efficiency and economy has been the quest of many with a view to revolutionize the fields of refrigeration, air conditioning, cryogenics, instrumentation and controls. The primary factor impeding its widespread utilisation has been its low thermodynamic efficiency, ie the high inlet pressure required to create the desired temperature changes.

This report outlines the historical development of the device from its invention to early application, the areas of theorectical analysis are given together with references to practical application of the vortex tube and concludes with the development of a vortex tube associated with the creation of micro climates for protection of personnel working in hostile environments.

2 THE INVENTION

On December 12 1931, George Joseph Ranque filed a French patent on what is now known as the "Ranque tube", "Hilsch tube", "Fulton tube", Vortex tube or the Vortex refrigerator. He showed two basic designs. Fig 1, 2, 3 and 4. These showed that the tangential entrance to the chamber could consist of a single nozzle a plurality of nozzles on a set of blades. He described how by adjusting the size of the cold air orifice or the restriction at the end of the hot tube, one may obtain a small quantity of very cold air or a larger quantity of moderately cold air. He mentioned that the temperature of the hot tube reaches its maximum when the end of the hot tube is entirely closed and that the more the pressure of the air supplied the colder is the cold air. He mentioned of having measured the pressure distribution inside the tube.

The theory Ranque gave in the patent (later rejected) is as follows: "The rotating gas spreads out in a thick sheet on the wall of the tube and the inner layers of this sheet press upon the outer layers by centrifugal force and compress them, thus heating them. At the same time the inner layers expand and grow cold. Friction between the layers is to be minimised to which end the uniflow design is considered advantageous. The sheet is envisioned as having a rather sharp inner boundary the centre of the tube being filled with quiet gas.

In December 1932, Ranque applied for and was granted in March 1934 a US patent. Ranque (1933) also read a paper to the Societe Francaise de Physique. Few details and no illustrations are given in this paper and he offered an explanation of vortex tube cooling different from that given in his patent and admitted withholding further information for purposes of secrecy. During the ensuing discussion Brun (1933) dismissed Ranques discovery on the grounds that he had confused static temperature with total temperature. No reply was published, deliberately it is thought to foster scepticism in order for further developments to be made of the invention but this resulted in little success.

3 THE RE-DISCOVERY

Following investigations of wartime German developments Hansell (1945) reported on the research of Rudolf Hilsch at Erlangen University, who began investigations using the vortex principle with a view to cooling underground mines and shafts. Although this particular application was not successful he was able to use the vortex tube as a substitute for the ammonia pre-cooler in his laboratory air liquifying plant. A working model and a thesis by Hilsch were taken to the USA and translated by Esterman of the Physics Department, Carnegie Institute of Technology. The thesis gave performance data and optimum dimensions for the vortex tube. Hilsch referred briefly to Ranque (1933) as the source of the idea but he appeared to be unaware of the patent. He arrived nevertheless at exactly the same design shown in certain of Ranques drawings. Because Ranques work had been virtually unknown it was widely assumed that Hilsch was the originator of the device and the name "Hilsch Tube" gained headway. Hilsch's thesis, the model and a paper by Milton (1946) started widespread attention and interest in the USA. The extreme simplicity of the device suggested that it might replace many of the more complicated refrigeration appliances and a large number of investigations were initiated and reported between 1946-1948.

At the Massachusetts Institute of Technology six contributions of importance (mainly experimental) were contained in the following six thesis. Mayer (1947) and Green (1947) gave overall performance data showing the effects of inlet air pressure cold orifice diameter and nozzle diameter. The first experimental results on the internal flow in a vortex tube were given by Reed (1947). He also included overall performance and the effects of altering the tube configuration and suggested that the vortex tube might be used to cool the cockpits of high speed jet propelled aircraft. Further performance results were given by Haddox (1947) and an attempt was made to vary the inlet air temperature. Corless (1947) also gave overall data and showed sediment flow pictures and the static pressure distribution over the cold outlet plate. Fattah (1947) used a convergent-divergent inlet nozzle and included overall performance data, visual flow, pressure and temperature measurements on the internal surfaces of the tube. In Canada, Johnson (1947) gave general confirmation to Hilsch's work and gave brief results when CO_2 and H_2 were used as the working fluid in place of air.

After the initial burst of enthusiasm research workers continued to make about a dozen contributions a year and those up until 1953 have been presented by Westley (1954) in a comprehensive bibliography of vortex tube publications giving a brief summary of their contents.

The objects of the investigations can be classified under four main headings:

(a) Explanation and theoretical prediction of the vortex tube performance

(b) Experimental investigations of the internal flow in the vortex tube as well as the overall performance.

(c) Modifications of the vortex tube configuration to increase the performance.

(d) Investigations of practical applications of the vortex tube to which the tube's advantage of simplicity is not over-ruled by the disadvantage of its high power consumption.

4 THEORETICAL ANALYSIS

The theories of Ranque and Hilsch are as follows:

Ranque (1931) states: "The compressed external layers only have a low velocity while the expanded central layers have the greatest part of their energy in Kinetic form and rotate at a very high angular velocity. In compressed fluids to a first approximation the angular velocity of each layer is inversely proportional to the square of its diameter.

"It follows that such a distribution of velocities gives rise to considerable friction between one layer and the next such that if the layers are long enough an equilibrium will tend to be established in which all the layers acquire the same angular velocity. Therefore there is a centrifugal migration of energy, the central layers giving their velocity to the external layers".

Hilsch (1946) states: "The air passing through the orifice has been expanded in the centrifugal field from the region of high pressure to the wall of the tube to a low pressure near the axis. During the expansion it gives a considerable part of its Kinetic energy to the peripheral layers through internal friction. The peripheral layers then flow away with increased temperature. If there were no internal friction the velocity of the air would increase to a supersonic value in the expansion from the circumference to the axis, sufficient pressure ratio being available. The internal friction is particularly effective in this range of velocities. It causes a flow of energy from the axis to the circumference by trying to establish a uniform angular velocity across the entire cross section of the tube".

Since 1946 writers of widely varying backgrounds have undertaken to explain the theory of the vortex tube but with infrequent success. This may be attributed to the fact that while the device itself is extremely simple the processes occuring in it are among the most difficult in gas dynamics.

Until the middle of 1947 explanations of the vortex tube process had only been suggested in general terms and there was no universal agreement or confirmation. The first important theoretical work was given by Kassner (1947), his analysis assumed that a free vortex was initially formed inside the vortex chamber at the inlet nozzle and that it was converted into a forced vortex as the air spiralled along the tube to the hot outlet. By making various assumptions the velocity and temperature in the resultant vortex was calculated. An estimate was then made of the tubes performance and this was compared with Hilsch's results.

D-ter Haar (1948) stated that the process was simple adiabatic cooling in passing through the pressure gradient caused by the centrifugal field, but this simplification did not appear to be acceptable. Burkhardt (1948) attempted to predict the vortex tube performance without detailed analysis of the internal flow, the theory being based on several plausible assumptions and on an empirical observation from Hilsch's work.

Fulton (1948/a) reported on the energy migration in the vortex tube. He endeavoured to solve the equations for a three dimensional compressible vortex which was subjected to viscous or turbulent shear. Approximate solutions and expression for the temperature drop across the vortex were given. Fulton also stated that Kassner (1947) gave fewer uncertainties and appeared to agree satisfactorily with his experiments. In considering the overall thermodynamics of the Vortex Tube Fulton (1948/b) pointed out that if the hot air from the tube was wasted then the power required to drive a vortex tube refrigerator would be of the order of 100 times that of a well designed competing machine of conventional type.

Corr (1948) in following the work of Fulton gave a summary of the work carried out at the GEC Research Division Schenectody between 1946-47. The work investigated the effect on performance of inlet pressure, tube configurations and it was the first to give experimental results on the multi-nozzle inlet chamber suggested by Ranques patent. Static pressure measurements were taken at the hot tube outlet and cold outlet diaphragm and when used as parameters for plotting tube performance, revealed several interesting features. Attempts were also made to investigate the internal flow using pressure and thermocouple probes. Other aspects included the use of a glass hot tube to observe flow lines on the internal wall, and a spectograph analysis of hot and cold air samples revealed no separation of the component gases. Humidity measurements indicated only negligible increase of water vapour in the hot air. The report concluded that the company did not contemplate any further work in this area, but research on the vortex tube was resumed and reported on by Vonnegut (1949) and (1950) and GEC (1950). A paper presented by Webster (1950) to the 45th Annual Meeting of the American Society of Refrigerating Engineer aroused some controversy on his explanation of the vortex phenomena and it appeared that much of the previous work was not generally known. Due to general ignorance of the available references, Fulton (1950) re-asserted some of the explanations given in 1948, and a comprehensive bibliography by W Curly and R MacGee (1951) was published.

5 EUROPEAN DEVELOPMENT

After the publication of Hilsch's paper most of the vortex tube investigations were carried out in America but from 1950 a number of contributions came from Europe.

One of the first attempts to use the vortex tube for a practical application in the United Kingdom was given in a report by the De-Haviland Aircraft Co Ltd (1950) and dealt with the applicability of the principle for the cooling of a Vampire cockpit when the aircraft was flying at low altitudes in tropical conditions. Air under pressure was to be supplied from the jet engine to the vortex tube. The report gave experimental data for tubes fitted with various inlet nozzles hot tubes and cold outlets and a tube was developed which satisfied the initial cooling requirements. It was however, considered inadequate to meet revised specifications called for to increased amount of cooling air. Elser and Hoch (1951) described experiments in which various gases and gas mixtures were used as the working fluid in the vortex tube. He recorded the temperature drop and also analysed samples of gases leaving the hot and cold outlets. Unlike Corr (1948) and Comassar (1951) it was found that separation differences of about 1% could occur between the hot and cold mixtures and it was concluded that it was possible that the vortex tube was superior, or at least equal to other separating devices. Elser and Hoch (1951) also tried to ascertain if a centrifugal field was necessary for the Ranque cooling effect. A somewhat similar but smaller cooling effect was observed in the temperature distribution across four parallel air jets when placed in echelon. Williamson (1951) published some practical notes on the design of a vortex tube and stated that an inlet chamber with multi-inlet nozzles and with a diameter larger than the hot tube diameter would give improved performance. The experimental results are difficult to compare with those of other investigations as the usual hot valve had been replaced by a fixed orifice which had the same diameter as the cold outlet. Sprenger (1951) gave an account of several mainly quantitative but new experiments including the verification of Hilsch's results and attempts at reducing the high noise level produced in the vortex. In order to investigate this effect Sprenger attached a tube containing lycopedium powder to the hot tube and detected an ultrsonic standing valve. The tests also included the measurement of temperature distribution along a simple vortex tube which had no hot flow and was without a cold diaphragm. Other novel features included the use of temperature indicating paints, vortex tubes constructed from celluloid or paraffin blocks, comparison of the internal flow pattern when working fluid was air or water and the effect of rotating the vortex hot tube whilst the inlet nozzle remained at rest. The report also cited that previous explanations of the vortex tube did not appear to be completely satisfactory and Sprenger (1952) suggests that the vortex tube cooling and heating phenomena was due to an ultrasonic effect which was not solely restricted to circular flow. The heating and cooling effects experienced in a modified Hartman type generator were quoted as an example.

One of the best theoretical contributions on the vortex tube was given by Van-Deemter (1952). The paper combined the conceptions of Hilsch (1947) and Prins (1948) and pursued an approach similar to that used by Fulton in which the temperature distribution in the vortex was determined by the ratio of work flux to heat flux but noted that the heat flux in turbulent circular flow was not solely proportional to the temperature gradient but included a term which was proportional to the radial acceleration.

Scheper (1951) presented data on internal flow and heat transfer and stated that part of the energy transfer was in the form of heat transfer from core to the wall stream due to the existence of a high static temperature at the core boundary. Westley (1953) described the results of tests to determine the effect of the hot valve setting, the cold outlet diameter the inlet nozzle size and the inlet pressure ratio's upon the temperature drop ratio characteristics of a vortex tube. The results showed that by matching the inlet nozzles and the cold outlet diameter to the inlet pressure ratio, it was possible to obtain over a wide pressure range a temperature drop which was 0.5 of the isentropic temperature drop. This work was augmented by Westley (1957) when additional performance data was given and data sheets were presented as an aid to the estimation of the performance of vortex tubes and to the design of vortex tubes with given characteristics and in particular to the optimum values of the vortex tube parameters which give maximum temperature drop. Eckert and Hartnett (1957) was of the opinion that there was a pumping of energy from the axis to the outer periphery due to the turbulence in centrifugal field and an increase in the static temperature from the axis outwards. Further the solid body rotation increased the total temperature at the periphery and hence a large temperature difference existed between the periphery and the axis. A tapping near the axis gave out cold air. Scheller (1957) reported high temperatures on the axis and lower on the wall, the maximum difference being 16°C while it was noted a difference of over 60°C between the diaphragm and the valve. Torochenshnikov (1958) stated that a uniflow tube ought to give results better than counterflow, a fact already stated by Ranque and Fulton, but noted that nobody had been able to develop a uniflow tube which is over half as efficient as the counterflow tube.

Hadebol (1959) reported that the static temperature was lowest at the axis and highest at the periphery of the core. However, lower static temperatures at the wall had been reported by some investigations. The vortex effect was also reported by Gulyaer (1965) but adds little to the work already reported.

6 OTHER AREAS OF CONTRIBUTION

Takahama (1965) suggested optimum values for efficient energy separation. Parulekar (1968) postulated a new hypothesis to explain the vortex phenomenon, but concluded that it would be necessary to build up a mathematical model to represent the physical pattern proposed. Takahama and Tinimoto (1974) reported on previous work and in particular on the measurement of energy separation of a vortex tube with a bend and found a decrease of energy separation in the bent vortex tube with a small radius of curvature.

7 SUMMARY OF RESEARCH OF THE VORTEX PRINCIPLE

Several theories have been proposed to explain the working of the vortex tube. Some involve only theoretical analysis, some are based on experimental investigations while in some cases the theoretical proposals have been verified experimentally. Some present only a physical picture of the phenomenon while others try to present mathematical models. However, no theory has so far explained the phenomena completely. Similarly it is not possible to determine the optimum proportions of various components of the tube on a theoretical basis not did it appear possible to predict the performance of the tube for a given set of inlet conditions. The contributions of Hilsch, Fulton and Van-Deemter to the invention of Ranque are considered to be the major contribution to the application of the vortex principle and from the basis of the experimental work of considering the vortex tube as an energy converter for a practical application of the vortex principle related to the creation of micro climates is given in Section 9.

8 PRACTICAL APPLICATIONS OF THE VORTEX TUBE

Most of the early practical applications of the vortex principle appear in the aircraft or refrigerating industry in the USA. Knoerschild (1948) reported on the application of the 'Hilsch tube to Aircraft and Missiles'; this was the first report to be concerned solely with the application of the vortex tube. Vonnegut (1949) made use of a novel application in which vortex tubes were used to eliminate the aerodynamic heating errors of free air temperature thermometers in aircraft. Webster (1950) on an application for refrigeration. Dornbund (1950) issued a very detailed report of work under US Government contract. Blaber (1950) reported briefly on a simple vortex tube constructed of perspex. Rushkin (1952) on more elaborate developments of the work of Vonnegut (1949). Packer (1952) Work being carried out for the US Navy Department to develop the vortex free air thermometer for use on aircraft over the range of Mach number 0.3 to 0.95. Applegate (1952) on the use of a vortex tube for cooling and pressuring an airborn 400 amp - 70 volt generator.

Work in the UK appears to be limited to the cooling of the Vampire Jet Pilot's cockpit by the De-Haviland Aircraft Co Ltd (1950) and Westley (1953) on the application of the vortex tube to be ventilated suit cooling in aircraft. The disadvantage of the device was that it was not as efficient as the more complicated refrigeration turbine and the latter had usually a larger available temperature drop. Green (1958) was granted a US patent for a Ventilated Suit Refrigeration Unit (Fig 4) embodying the vortex principle and cited. Ranques American Patent 1.952.281.

Alexander (1963) reported on the use of vortex tube cooling for Wearers of Industrial Protective Clothing. US Atomic Energy Commission Health and Safety Information Issue No 178 (1963) claimed that this application of the vortex tube was a key to major developments in the ventilation and cooling of protective clothing although no psychological data was included in the report. Lienhard (1964) reported on Man Cooling by a vortex tube device as a new method for personal protection of workmen on hot jobs. This system utilised a 19oz vortex tube device carried on a belt around the wearer's waist and operated on standard industrial compressed air as the sole source of power. It converted air at 6.8 bar and 50°C to a steady flow at 18°C. This cool dry air was dispersed over the upper trunk by perforated flexible tubing worn beneath ordinary cotton work clothing of special benefit for work under conditions of high humidity. The air was of breathing quality and may be delivered into a fabric hood if desired.

For the same work under the same test environmental conditions of heavy thermal stress use of the vortex tube cooling by acclimatised men resulted in (1) sweat loss reduced threefold, (2) total heart beat cost reduced by 25%, (3) rate of body temperature rise reduced by 50%. The psychological benefits by the means of cooling appeared to have been realised and were worthy of further study.

Fulton (1955 a & b) was granted US patents 3.173.273 and 3.208.229 relating to improvements in vortex tubes, Fig 5, 6, 7, 8 and 9, the former being filed in November 1962 and relates more specifically to the design and construction of vortex tubes capable of emitting colder and hotter streams of gas operating more efficiently, being more compact and more cheaply manufactured and being more readily applied to useful purposes. The following development work is based on and around this design of vortex tube.

9 EARLY USE OF VORTEX TUBE FOR PERSONNEL PROTECTION IN THE CEGB

In November 1965 the requirements for protective clothing to enable work to be carried out in hot environments was the subject of a special study. It was concluded that clothing giving protection for prolonged periods in environments at temperatures up to 60°C was advantageous. As no suitable equipment was available commercially a clothing assembly was developed.

This assembly was to use the vortex tube cooling principle for both cooling and breathing air Hodges (1967) details the early developments of the assembly and includes details of laboratory evaluation in an hot climatic chamber up to 80°C and established the psychological parameters of a 'micro-climate assembly' using the vortex tube cooling principle. For the initial investigations vortex tubes manufactured by Fulton Cryogenics USA and Vortair Engineering UK were used.

Performance data supplied by the manufacturers is shown in Table 1. A set of curves relating to vortex tube inlet pressures of 6.2, 5.17 and 3.4 bar at respective flows of .014, .012 and .008 Kgs is shown in Fig 10.

INLET PRESSURE BAR	COLD FRACTION										
	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 1 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

An investigation by Wilson (1968) on the Vortair duplex tube confirmed a close linear relationship with this data up to inlet pressures of 6 bar; 0.03 Kgs flow. Dunham (1968) also undertook experimental assessment of the Vortair tube to determine the performance characteristics and concluded that the performance of the tube was typical of this type of device but was very inferior to conventional heat pump cycles. It was apparent however that there may be specific applications where such disadvantages could be outweighed by the small physical size and the low cost of this particular design of vortex tube, in comparison with manufacturers data showed lower temperature differences. It was also reported that the tube emitted a loud high-pitched whine when free standing and further noise attenuation will possibly be desired. Northover (1972) assessed again the performance of a Vortair tube to establish performance over a range of operating conditions. These included variations of air supply pressure in the range 6-12 bar of ambient pressure at the tube outlets from 1-2 bar and of the moisture content of the inlet air from 0-10% by mass. The results of these tests showed that the cooling potential of the tube could be approximately doubled with an increase of inlet pressure from 6-12 bar and that the performance is sensitive to the ambient discharge pressure. It was also shown that the performance of the tube is virtually unaffected by moisture contents of up to 1% by mass in the inlet air but that above this figure the tube progressively iced up in the vortex generator region and thus ceased to function. Neal (1972) showed quite good agreement with that, of vortex tube tested by Northover (1972) when three vortex tube bodies and ten generators were tested in every possible combination of body and generator in order to ascertain the consistency of performance over a range of inlet pressures between 6 and 11 bar. These tests showed that in this particular design of vortex tube the cooling capacity was generally within limits of ± 6% about the mean and that the mean cooling capacity increases from 0.25 to 0.5kW over this range of inlet pressures used.

FURTHER DEVELOPMENTS OF THE VORTEX TUBE

With the advent of man access penetrations into the Advanced Gas Cooled Reactors (AGR) further development of the vortex tube became necessary. Design changes were made to the component parts of the Vortair Engineering Design and a duplex unit was developed in conjunction with R B Turned Parts Ltd. The basic component changes were associated with the Hot valve assembly as shown in Fig 11 and the vortex generator material using nylon moulding in place of machined aluminium to maintain consistency of performance. The noise from the hot valve was also investigated and a combined noise muffler and adjusting hot valve evolved.

A series of investigations were undertaken which compared stages of air control valve design and evaluated the performance of the duplex vortex tube under atmospheric conditions approximating to those expected in service.

A test rig as shown in Fig 12 was constructed and consisted of an air compressor with associated air filters and water jacketed air cooler supplying air to the bench mounted assembly. An air pre-heater was used for the performance tests which heated the inlet air temperature to 50°C. (This approximately simulated the estimated heat pick of the air flowing in the line to the micro-climate assembly). The air then passed through a flow 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 is subjected to the elevated environmental temperature to represent this condition the tube under test conditions was mounted in a 60° centigrade 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 man cooling distribution system the cold outlet air is connected to a ventile suit assembly worn by a manikin model.

11 PRINCIPLE OF OPERATION OF THE CEGB VORTEX TUBE

This section outlines the design and performance characteristics for vortex tubes of single and duplex generator arrangement. Fig 13 shows a cross section of a vortex tube with single generator arrangement. Compressed air applied to the tube enters an annular plenum 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 investigated are shown on Fig 11.

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 exhausted to atmosphere through circular aperatures 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 sealing on a semi circular machined sealing. An 'O' ring is fitted to the valve stem which prevented air leakage past the adjusting screw. The hot air exhausted through a sintered brass muffler gives a better air distribution than Type 1 or 2.

12 EXPERIMENTAL WORK AND RESULTS

This section describes the 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 11 to establish comparative data over a wide range of air pressure and air flow with varying settings of the hot outlet valves to propose and enable performance characteristics to be presented and a sealed design established.

Single Vortex Tube Two tubes were fitted with (a) Type 1 hot valve (Tube identified 1) and (b) Hot Valve Type 3 (Tube identified 2) were selected. The tubes were submitted to an air pressure test with the hot outlet valve closed and the cold 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 ventile suit assembly worn by a manikin model to simulate approximately the back pressure conditions.

The relative humidity of the input air varied between 17 and 30% and the atmospheric pressure was between 1019 and 1024 millibars for the tests with the NR valve in position. When the tests were repeated without the NR valve the values were 20% to 27% for relative humidity and 1011 millibars atmospheric pressure. The measurements are subject to the following levels of uncertainty:-

Air flow data	$\pm$ 4%
Air pressure data	$\pm$ 3%
Cold mass fraction data	$\pm$ 5%
Inlet/cold outlet temp drop	$\pm 2^{o}K$
Relative humidity	$\pm$ 5%

The characteristics obtained from the two series of tests are presented in Fig 14 to 18. 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 ventile assembly. The inlet pressure to inlet flow relationship Fig 14 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 bar and 10 bar inlet pressure.

Twin (or duplex) Vortex tube

To establish a specified design requirements 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 identified 3, 4 and 5 fitted respectively with Types 1, 2 and 3 hot valves assemblies. The results of these tests are shown in Fig 19, 20 and 21.

The preliminary test to determine the pressure/flow characteristics Fig 19 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 20 and the cold mass fraction to inlet pressure Fig 21 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 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 Fig 22 to 28. The cold outlet temperature drop against inlet pressure and flow characteristics as shown on Fig 22, 23 and 24 tended to be more scattered than was expected, but the cold mass fraction to inlet pressure relationship at the highest temperature interval are much closer together and more uniform in general shape. Although individual charactertistics varied widely below the maximum obtainable temperature interval at this point as shown by Fig 27 and 28 the performances are closely related. Visual examination of the interior of the tubes showed that the moulded plastic vortex generators were bedded on to the rubber washers which because of malalignment 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 viz the improved ratio of air flow to air input pressure was increased by a factor of 2.

13 NOISE LEVELS OF VORTEX TUBES

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

Each type of tube was connected to the compressed air supply system. The sound level meter was placed 1 metre away from the tube, this approximates the distance from the ventile suit wearer's ear position. Air was delivered to the single vortex tube in 2 bar increments over the range 2 to 10 bar for single vortex tube and 5.5 to 10.2 bar for duplex tube at a constant flow rate of 28.3 l/sec. Noise level measurements were taken at each increment and the results are given in Tables 2 and 3 for the single and duplex vortex assemblies respectively.

Bruel and Kjaer equipment was used to measure the noise levels 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 microphone 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.

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 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 3 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

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

14 FINALISED DESIGN

As a result of field evaluation to provide more comfort to personnel wearing a vortex tube assembly, a modification was found necessary by shortening the overall length of the previously tested duplex tubes by 40mm. To check that the performance characteristics had not been impaired the shortened tube identified B was compared with Tube now identified as Tube 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.

Air flow data	± 5%
Air pressure data	± 3%
Cold mass fraction data	± 5%
Inlet/cold outlet temperature interval	± 2K
Relative humidity	± 5%

The preliminary test to check the inlet air pressure total air flow characteristics showed that over the working range the characteristics were very similar as shown in Fig 29. The relationship between inlet air pressure and temperature interval Figs 30 and 31 indicate that the hot air valve control is less sensitive on the modified tube when more than half open but Figs 32 and 33 show the inlet pressure cold 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 matches those of the original duplex vortex tube.

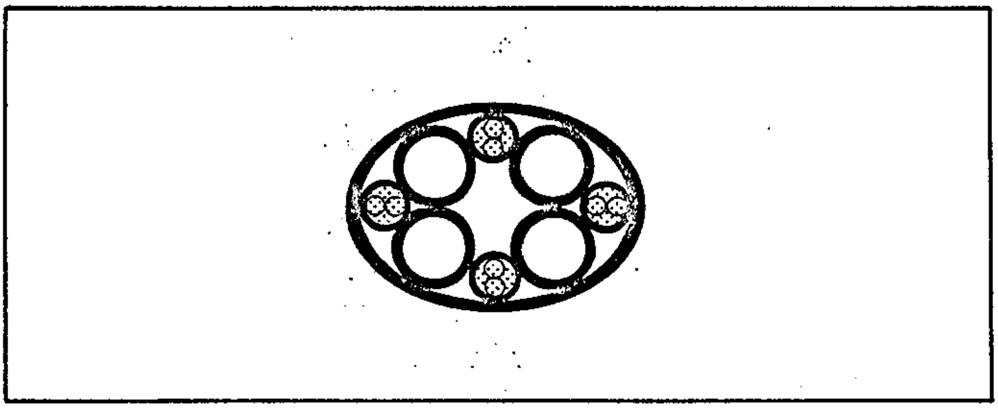
From the data established throughout these series of experiments it was possible to standardise the design of a duplex vortex tube for the micro climate conditioning of a ventile suit assembly and this is shown in Fig 34.

15 AIR HOSE

Complimentary to the use of the vortex tube is an air hose, necessary to carry the compressed air at the required pressure and mass flow. The design of the hose may be such that the ability to transmit communications signals and physiological monitoring data are a required feature, resulting in a composite design of electric cables and means of compressed air transfer. The following sections outline the investigations and evaluation of a composite compressed air/electric cable hose for use in abnormal working environments.

Commericl availability of air hose to meet the above requirements were extremely limited and initial investigations were based on a hose to the following specification.

Four polyethylene tubes in parallel 6.4mm bore each tube sheathed in a jacket thickness 3.175mm 4 pair screened communication cables placed around the tube bundle as shown in the following sketch.



Two important characteristics are necessary to ensure that the vortex tube assembly will operate correctly. These are mass air flow at a given pressure, the parameters were initially set at 0.03 Kg/s and 11.4 bar and a hose length of 75m being required to give free access to all parts of the working environment.

The following calculations based on Sterland (1974) using the above data are presented to establish performance characteristics.

16 DESIGN CALCULATIONS AND RESULTS

Pressure Drop with Required Flow

Gas velocity $V = \dfrac{\text{Volumetric flow rate}}{\text{Area}} =$

$$\frac{50}{4 \times 60} \times .0283 \times \frac{1}{11.4} \times \frac{\Pi\,(6.35 \times 10^{-3})^2}{4} \text{ m/s} = 16.3 \text{ m/s}$$

Reynolds number = $Re - \dfrac{DVd}{U}$

where D = density $- 11.4 \times 1.2 = 13.7$ kg/m^3

V = velocity = 16.3 m/s

d = pipe diameter = 6.35×10^{-3}m

U = viscosity = 1.81×10^{-5} Ns/m^2

$$Re = \frac{13.7 \times 16.3 \times 6.35 \times 10^{-3}}{1.81 \times 10^{3}} = 79{,}000$$

Assuming a relative roughness for the hose bore of .001 (ie a typical asphereity having a height of 6 x 10m and using the above Reynolds number, gives a friction factor, f of .025)

The pressure drop, for an incompressible isothermal flow is given by $P_D = \frac{fDV^2L}{2d}$

where L = tube length = 76m

which gives $P_D = \frac{.025 \times 13.7 \times 16.3^2 \times 76}{2 \times 6.35 \times 10^3}$ N/m^2 = 5.5 bar

This pressure drop is too large for the assumption of incompressibility to hold; in fact a check using compressible flow tables (Fanno line, for adiabatic flow) showed that the outlet of the pipe would be almost choked and that the static pressure would have to be about .5 bar.

Flow Rate with a Pressure Drop of 1.4 bar

In this case the mass flow can be calculated explicitly using a more exact equation which takes density changes into account, viz,

$$M = A\sqrt{\frac{P_1^2 - P_2^2}{2RT\,(\ln\,(P_1/P_2) + fL/2D)}}$$

where M = mass flow, kg/s

A = tube cross sectional area 31.6×10^{-6}m^2

R = gas constant = 287 J/kg $^\circ$K

T = absolute temperature = 293°K (20°C)

P_1= 11.4 bar

P_2= 10.0 bar

$$\text{Thus } M = 31.6 \times 10^{-6} \sqrt{\frac{30.2 \times 10^{10}}{168 \times 10^{3}\ (.13 + 150)}} \text{ Kg/s per tube}$$

$$= 3.34 \times 10^{-3} \text{ Kg/s per tube or } \underline{.013 \text{ Kg/s total}}$$

This flow rate would result in a Reynolds number of 44,000, an increase in friction factor and a decrease in flow rate to approximately .0128 Kg/s.

Length of Pipe for Required Flow Rate and Pressure Drop

The Fanno line relations give a pressure ratio and a friction/length function, F which depend on Mach number M. The required change in pressure ratio (11.4/10.0) can be used to find the outlet Mach number and the change in F can be used to find the length of pipe which would cause that change in pressure ratio.

Inlet Mach number = 16.3/340 = .048 (where the speed of sound is 340 m/s)

Inlet pressure ratio = 22.8 and $F_1 = 304$

Outlet pressure ratio = 22.8 x 10.0/11.4 = 20 giving outlet

Mach number .055 and $F_2 = 233$

$$\text{Length of pipe} = (F_1 - F_2)\ \frac{d}{f} = (304 - 233)\ 6.35 \times 10^{-3}/.025\text{m}$$

$$= \underline{14.7\text{m}}$$

Thus the required flow can only be passed along a hose up to 14.7m long if a pressure differential of 1.4 bar is not to be exceeded.

Using the formula demonstrated above the calculated required sizes of a flexible single or multi bore hose 76m long required to deliver 0.03 Kg/s have been calculated as shown in the following table.

Number of Bores	Bore Diameter mm
1	17:0
4	10:1
7	8:2
8	7:80
14	6:3

TABLE 4 Bore Diameters to Give Related 0.03Kg/s Flow at 10.4 bar Pressure

A practical evaluation of the hose specified was undertaken using the test rig shown in Fig 12, the results of this test are shown in Fig 35 showing that the air hose pressure drop in the hose was in excess of 50%. To supply the vortex tube design shown in Fig 34 with air at a pressure sufficient to provide the required cold fraction to a dynamic insulated ventile suit, the outlet pressure to a 76m length must be a minimum of 7 bar.

As the air supply hose will be used in an elevated temperature environment it is assumed that the temperature of the air flowing in the supply hose would be the same as the ambient temperature within the working environment, therefore requiring the use of the vortex device as part of the dynamic insulation clothing assembly. Using the hose specification given in Section 15 the following calculations based on Sterland (1974b) are presented to establish this assumption. The overall heat transfer coefficient is dependent on convection through the heated environmental air to the hose, conduction through the hose, convection from the hose to the cooling/breathing air and also upon radiation from the environment to the hose.

Heat Transfer from Environment Air to Hose

May be transferred by natural convection or by forced convection; the former gives lower heat transfer rates and therefore provides a lower limit.

The heat transfer coefficient depends on the Grashoff (Gr) and Prandtl (Pr) numbers. If the product Gr x Pr 10^8 or 10^9 the convective flow will be streamline. The Prandtl number is a property and for air is constant and about 0.73.

$$Gr = \frac{agtd^3D^2}{U^2}$$

where a = coefficient of expansion = 1/t for gases

g = gravitational acceleration = 9.81 m/s^2

t = temperature difference between body and air = 40^oC

d = overall diameter =.03m

D = density = 1 kg/m^3

U = viscosity = .2 x 10^{-4} Nm/s^2

$$Pr = \frac{UC_P}{K}$$

C_p = specific heat of air at constant pressure = 1005 $J3Kg^{o}C$

K = thermal conductivity of air = 28.8 $Wm/m^{2o}C$

The maximum value of Gr is therefore about 66,000 and the flow is streamline. Fischenden and Saunders (1950) show that for air the convective heat transfer for streamline flow is given by

$$h_1 = .24\ (t/d)^{.25}\ \ BTU/ft^2h^oF$$

$$or = .986\ (t/r_1)^{.25}\ W/m^{2o}C$$

where r_1 is the outside radius of the pipe.

Expressing h as a heat transfer per unit length of pipe

$$h_1^1 = 2\ \ r_1 \times .986\ (t/r_1)^{\ .25}\ W/m^oC$$

$$= 6.197\ r_1\ (t/r_1)^{.25}\ W/m^oC$$

In the case of the pipes originally proposed, forced convection caused by an air velocity of 1 m/s would give a heat transfer coefficient approximately three times the natural convection coefficient at entry to the reactor vessel. This ratio would be greater where the pipe was warmer and the temperature difference less.

<u>Heat Flow Across the Hose</u>

The standard relation for a thick walled hose is

$$h_2 = 2\ \ k_p/\ln\ (4_1/r_x)$$

where k_p is the thermal conductivity of the hose material

.21 $Wm/m^{2o}C$)Kaye and Laby 1968)

and r_2 is the internal diameter of the hose.

On a linear basis

$$h_2^1 = 8.251\ r_1/\ln\ (r_1/r_2)\ W/m^oC$$

Estimating r_2 for the proposed hose to be 18mm

gives $h_2^1 = 2.56\ W/m^oC$

Heat Transfer from Hose to Cooling/Breating Air

The relation for forced convection inside hose is $Nu = .023\ Re^{.8}\ Pr^{.4}$ where Nu is the Nusselt number $= \frac{hd}{K}$

Re is the Reynolds number $= \frac{DVd}{U}$

V is the velocity of the gas in the hose

DV = mass flow/area = $m/A = 4m/n \quad d^2$

(where n is the number of parallel pipes and d is their internal diameter)

$$Re = \frac{2 \times 10^5 m}{n \quad d^2}$$

Putting h_3 on a linear basis and evaluating the constants gives

$$h_3^1 = 12.6\ \frac{r_2}{d} \quad \frac{m}{nd2}^{.8}\ W/m^oC$$

For the given pipe with m = .01 Kg/s, h_3^1 is 28 W/m^oC

Radiation

The heat transfer by radiation is given by

$Q = es\ (T_1^{\ 4} - T_2^{\ 4})\ W/m^2$

where e is the emissivity of the surface, about .95

s is a constant = $5.6697 \times 10^{-8}\ Wm^{-2\,o}K^{-4}$

T_1 and T_2 are the absolute temperature of environment and hose surface respectively.

In the present case, assuming the surface temperature of the hose is 20°C, and the radiating surfaces of the reactor are at 60°C, the initial rate of heat transfer to the pipe is 25.4 W/m which is a significant contribution to the overall heat transfer rate.

Overall Heat Transfer

The overall heat transfer coefficient is

$$H^1 = \frac{1}{1/h_1^1 + 1/h_2^1 + 1/h_3^1} \quad W/m^oC$$

and the total heat transfer rate

$$Q_1 = H^1t + Q \ W/m$$

The temperature of the air in the pipe is determined from the differential equation

$$-\frac{dt}{dL} = \frac{Q_1}{mC_p} \qquad \underline{\text{Equation 2.1}}$$

where dL is an elemental portion of the length of hose.

The principle resistance to heat flow is matural convection; if the other resistances and radiation are ignored equation 2.1 may be simplified to

$$-\frac{dt}{t^{1.25}} = \frac{.278dL}{mC_p}$$

which may be integrated to give (upon substituting limits and rearranging)

$$t_2 = 1/ (1.106 \times 10^{-3} L/m + 1/t_1^{\ .25})^4 \qquad \underline{\text{Equation 2.2}}$$

where t_1 is the inlet temperature difference

t_2 is the outlet temperature difference

L is the length of the hose

The results of evaluating equation 2.2 are shown in Fig 36 and 37. Fig 36 shows the outlet temperature difference for an inlet temperature of 40°C plotted against mass flow. Fig 37 shows the variation of temperature along the hose at mass flows of 0.03 Kg/s and 0.01 Kgs.

Although a conservative figure has been assumed for heat transfer from the hose, ie natural convection where forced convection may well occur, and radiation was ignored in the calculation, the outlet temperature of the air is very close to the ambient temperature within the environment. Even in the most favourable conditions conceivable the temperature difference at the outlet is negligible. Contact of the hose with metal surfaces or the orientation of the pipe will have little absolute effect on the outlet temperature difference.

The outlet temperature of the cooling/breathing air will be substantially the same as the ambient temperature in the heated environment.

17 SPECIFICATION AND PROPOSED HOST DESIGN

On the basis of these results the following broad specification is proposed. Fig 38 shows a design concept to meet this.

(a) Hose material must be heat resistant to contact temperatures of 80^{o}C and to air flow temperatures of 60^{o}C.

(b) Kink resistant yet flexible to a minimum bending radius of 178mm.

(c) 76m continuous length - 15mm diameter air supply bore.

(d) 22.68Kg/30m maximum weight.

(e) 3 pairs of screened standard communication cables within the hose wall, resistance not more than 50 ohms per 30m.

(f) Individual hose lengths to be identified by colour coding.

(g) No objectionable odours to be released when operating at a temperature of 80^{o}C.

(h) Good mechanical strength.

(i) External surface should be able to be easily decontaminated.

(j) Smooth internal surface for minimum pressure drop.

(k) Air flow should be at least 0.031Kg/sec at a working pressure of 10.34 bar.

The following theoretical calculations based on the previous work are presented to support the design.

Pipe Diameter	$d =$	15mm
Length	$l =$	76m
Inlet pressure	$P_1 =$	11.4 bar
Density	$D =$	13.7 Kg/m^3
Mass Flow	$m =$	0.03 Kg/s
Velocity	$V =$	12.4 m/s
Viscosity	$U =$	$181 \times 10^{-5}\ N_s/m^2$
Reynolds No	$Re =$	140,000
Friction Factor	$f =$	.032
Pressure Drop	$PD =$	$\frac{fDV^2L}{2d}\ N/m^2$

$$= \frac{.5 \times .032 \times 13.7 \times 12.4^2 \times 76\ N/m^2}{.015}$$

$$= \underline{1.7 \text{ bar}}$$

$\frac{\text{Pressure Drop}}{\text{Pressure}} = \frac{1.7}{11.4} = .15$ $\therefore$ some change in density will occur

$\therefore$ take mean pressure @ $11.4 - \frac{1.7}{2} = \underline{10.55 \text{ bar}}$

mean density 12.68 Kg/m^3

$\therefore$ pressure drop $= 1.7 \times \frac{13.7}{12.68}$

$= \underline{1.84 \text{ bar}}$

Flow rate with pressure drop 1.84 bar

$$M = A \quad \frac{P_1^{\ 2} - P_2^{\ 2}}{2RT\ (\ln\ (P_1/P_2) + fl/2D}$$

$A \quad = \quad 176 \times 10^{-6} m^2$

$P_1 \quad = \quad 11.4$ bar

$P_2 \quad = \quad 9.56$ bar

$R \quad = \quad 287$ J/K $^{\circ}$K

$T \quad = \quad 293\ ^{\circ}$K $\qquad\qquad = \quad \underline{0.^{\circ}297\ \text{Kg/s}}$

18 ACKNOWLEDGEMENTS

The contribution of Mr R Frost and Mr B I Cowling of the Scientific Services Department, SE Region in the testing of vortex tubes is gratefully acknowledged, together with Mr P R Sterland of the Scientific Services Department, SW Region for permission to use the calculations on air hose performance characteristics and Mr E Willcox, SE Region Engineering Department for his skillful application of drafting techniques.

APPENDIX

BIBLIOGRAPHY

ALEXANDER J M et al (1963) Use of Vortex Tube for Cooling Wearers of Industrial Protective Clothing.
E I Du Pont de Nemours & Co, Atomic Energy Division
Report DP 861

APPLEGATE M (1952) Vortex Tube Applications
Proceedings of the Conference on Cooling of Airborne Electronic Equipment - Ohio State University
Eng: Series V XX1 No 2 p 207

BLABER M P (1950) A Simply Constructed Vortex Tube for producing Hot and Cold Air Streams.
J of Scien Ins V 27 p 168

BRUN E (1933) Comments on the Paper by G J Ranque. Journal de Physique et Le Radium V 4 No 6
Bulletin Be-Mensuel 16 p 122

BURKHARDT G (1948) Theoretischer Beitray Zur Arbeit von R Hilsch Uber Das Wirbelrohr.
Zeilschrift Fur Naturforschung V 3a No 1 p 46
RAE Library translation No 345 June 1951

COMASSAR S (1951) The Vortex Tube
J Am Soc Naval Eng V 63 p 99

CORLESS R J (1947) Experimental Investigations of Vortex Refrigeration
Thesis - Degree of Bachelor of Science in Mechanical Engineering from Massachusetts Institute of Technology

CORR J E (1948) The Vortex Tube
General Electric Co Research Division Schenectady
N Y Data Folder No 45289

CURLEY W & MAGGEE (1951) Bibliography of the Vortex Tube
J Am Soc Refrigerating Eng V 59 p 166

DE-HAVILLAND AIRCRAFT CO LTD (1950) Vortex Tube Cooler
Test Report No TR 100147. De Havilland Aircraft Co Ltd Hatfield Herts.

DORNBUND H (1950) Theoretical and Experimental Study of Vortex Tubes
A F Tech Report 6123 Republic Aviation Corporation
Contract No AF 33 (038) 5770 EO No 664

D-TER HAAR (1948) On the Working Principles of the Hilsch Gadget.
Det Kongelige Norske Videnskabers Selskab Forhandlonger
BD XX No 15 p 55.

DUNHAM F G: HUMPHREYS J F (1968) Vortex Tubes Electricity Council
Research Report ECRC/R99

ECKERT E and HARTNETT (1957) Experimental Study of the Velocity and Temperature Distribution in a High Velocity Vortex Type Flow Transfer
Trans: ASME V 79 No 4 p 751

ELSER K HOCH M (1951) Das Verhalten Verschiedener Gase Und Die Trennung Von Gasgemischen in Einem Wirbelrohr
Zulschrift Fur Naturforschung V 6a No 1 p 25-31

FATTAH (1947) An Experimental Study of Centrifugal Refrigeration Thesis - Degree of Bachelor of Science in Mechanical Engineering from Massachusetts Institute of Technology

FISHENDEN and SAUNDERS (1950) An Introduction to Heat Transfer
Oxford Press

FULTON C D (1948/a) Energy Migration of the Vortex Tube
Report of Term Project No 31 Course No 2 492
Dept Mechanical Engineering Massachusetts Institute of Technology

FULTON C D (1948/b) Thermodynamics of the Vortex Tube
Report of Term Project No 1 Course No 2, 452
Dept Mechanical Engineering Massachusetts Institute of Technology

FULTON C D (1950) Ranques' Tube
J Am Soc Refrigerating Eng V 59 p 473-479

FULTON C D (1951) Comments on the Vortex Tube
J Am Soc Refrigerating Eng: V 59 p 984

FULTON (1965/a) Vortex Tube
American Patent No 3 173 273

FULTON (1965/b) Vortex Tube
American Patent No 3 208 229

GEC (1950) Measuring Cloud Temperature
General Electric Company Educational Service News
Vol 11 No 6 p4

GREEN R L (1947) A Study in Centrifugal Refrigeration Thesis - Degree of Master of Science in Chemical Engineering from Massachusetts Institute of Technology

GREEN F H (1958) Ventilated Suit Refrigeration Unit
United States Patent Office No 2 819 590

GULYAER A (1965) Investigations of the Vortex Effect
Avtoreferat Institute of Physical Problems ANSSR Moscow

HARDEBOL L (1959) Stromcingenen Temperature Effecter in de werwelbuis
De-Ingenieur June 1959

HADDOX R (1947) Experimental Investigations of Centrifugal Refrigeration
Thesis - Degree of Bachelor of Science in Mechanical Engineering
from Massachusetts Institute of Technology

HANSELL C W (1945) Low Temperature Physics
Miscellaneous Developments in German Science and Industry
C-6 Report No 68 June 1945 p 29
Pub: Joint Intelligence Objective Agency Washington DC

HILSCH R(1946) Die Expansion von Gasen im Zentrificgalfed
als Kalteproziso
Zeitscher fur Naturforschung Vol 1 No 4 p 208

HILSCH R (1947) The use of the Expansion of Gases in a
Centrifugal Field as Cooling Process
Rev: SCI Instr V 18 p 108

HODGES W N (1967) Development of Protective Clothing for
Working in Hot Conditions
Draft Plant Operations Branch Report No O(P) NWH/18

JOHNSON A F (1947) Quantitative Study of the Hilsch Heat Separator
Canadian Journal of Research V 25 Sec F No 5 p 299

KASSNER R (1947) Friction Laws and Energy Transfer in Circular Flow
Technical Report No F-TR-2198-ND GS-USAF
Wright Patterson Air Force Base No 78

KAYE and LABY (1968) Tables of Physical and Chemical Constants
London - Longmans

KNOERSCHILD E (1948) Application of Hilsch Tube to Aircraft and
Missiles
Army Air Forces Air Material Cmd, Eng Div
Eg Lab Serial No MCREXE-664-510A GS USAF
Wright Patterson 128

LIENHARD W F et al (1964) Man Cooling by a Vortex Tube Device
Arch: Env Health Vol 9 p 377

MAYER B H (1947) Centrifugal Refrigeration Thesis - Degree of
Bachelor of Science from Massachusetts Institute of Technology
Chemical Engineering Dept

MILTON R M (1946) Maxwellian Demon at Work
Industrial and Engineering Chemistry V 38 No 5 p 5

NEAL S B H C KELLARD P O (1972) An Examination of the Variations in Performance between a Batch of Commercial Vortex Tubes of Nominally Identical dimensions
Central Electricity Research Report RD/2/N65/72

NORTHOVER E W KELLARD P O (1972) The Performance of a Commercial Vortex Tub e at Inlet Pressures from G-12 bar
Central Electricity Research Report RD/L/N4/72

PACKER L S (1952) Phase 'A' Report Vortex Free Air Thermometer Report No IH-775-P-1 Contract No (a) (S) 51-832-C
Physics Dept Cornell Aeronautical Lab Inc Buffalo NY

PARULEKAR B B et al (1968) A new hypothesis to explain the Vortex Special Phenomenon
J Refrigeration 12/68 p 326-329

PRINS J A (1948) Brief aan de Redactie
Nederland Tijdschrift Voor Natuurkunde
V 14 p 241

RANQUE G J (1931) Method and Apparatus for obtaining from a fluid under pressure two currents of fluid at different temperatures.
French Patent No 646020

RANQUE G J (1933) Experiences sur la ditente directorie avic productions simultanees d'un enchappement d'air chaud et d'un enchappement d'air froid
J Phys Radium (Series VII June No 6)

RANQUE G J (1934) Vortex Tube
American Patent No 1 952 281

RANQUE G J (1934) Method and Apparatus for obtaining from a fluid under pressure two currents of fluids at different temperatures.
United States Patent Office No 1 952 281

REED G A (1947) Vortex Tube Refrigeration
Thesis - Degree of Master of Science Dept Aeronautical Engineering from Massachusetts Institute of Technology

RUSHKIN S et al (1952) Vortex Thermometer for Measurement of True Air Temperature in Flight.
Naval Research Laboratory Annual Meeting
American Meteorological Society NY City Jan 1952

SCHELLER W A et al (1957) Ranque Hilsch Vortex Tube
Ind Eng Chem June 1957

SCHEPER G W (1951) The Vortex Tube - Internal Flow Data and Heat Transfer Theory
J Am Soc Refrigerating Eng V 59 p 985

SIBULKIN M (1961) Unsteady Viscous Circular Flow - Application to the Ranque Hilsch Vortex Tube
J Fluid Mechanics V 12 p 269

SPRENGER H (1951) Observations on the Vortex Tube
Zeilschrift fur Angewandte Mathematik und Physik V11 No 4 p 293
RAE Library Translation No 394

SPRENGER H (1952) Uber Chermische Effekte bei resonanzrohren
Referat gehalten anlasslich der Jahresversam-Mlung de-Scheizerishen Physikalisken Gesellschaft in Bern

STERLAND (1974/a) Assessment of Proposed Cooling/Breathing Air Pipes to Permit Reactor Vessel Entry (For use at Hinckley Pound B and Huntersten B Power Stations)
CEGB Report No SSD/SW/74/M4001

STERLAND (1974/b) Heat Transfer to Cooling/Breathing Air required to Permit Reactor Vessel Entry (For use at Hinckley Point B and Huntersten B Power Stations
CEGB Report No SSD/SW/74/M4005

TAKAHAMA H (1965) Studies on Vortex Tubes
Bulletin JSME V 8 p 433

TAKAHAMA H TANIMOTO K (1974) Study on Vortex Tubes - Effect on the Bend of a Vortex Chamber
Bulletin JSME V 17 No 108 p 740

TOROCHENSHNIKOV N S et al (1958) Investigations of Uniflow Vortex Tubes
J Tech Phys No 6 1958

UNITED STATES ATOMIC ENERGY COMMISSION (1963) Vortex Tube Key to major development in the Ventilation and Cooling of Protective Clothing at Savannah River Plant
Health and Safety Information No 178

VAN-DEEMTER J J (1952) On the Theory of the Ranque-Hilsch Cooling Effect
Appl Scient Res Section A Vol 3 No 3 p 174

VONNEGUT B (1949) Vortex Thermometer for Measuring True Air Temperature and True Air Speeds in Flight.
Occasional Report No 14 Project Cirrus
Contract No W-36-039-Sc38141 Report No PB 99102

VONNEGUT B (1950) Operation Cirrus Uses Principles of
Hilsch Tube to Measure Temperature
J Am Soc Refrigerating Eng V 58 p 267

WEBSTER D S (1950) An Analysis of the Hilsch Vortex Tube
J Am Soc Refrigerating Eng: V 58 p 163

WESTLEY R (1953) A Note on the Application of the Vortex
Tube to Ventilated Suits
College of Aeronautics Cranfield Tech Note Aero 1

WESTLEY (1954) A Bibliography and Survey of the Vortex Tube
College of Aeronautics Cranfield Note No 9

WESTLEY R (1955) Optimum Design of a Vortex Tube for
Achieving Large Temperature Drop Ratios
College of Aeronautics Cranfield Note No 30

WESTLEY R (1957) Vortex Tube Performance Data Sheets
College of Aeronautics Cranfield Note No 67

WILLIAMSON H A F (1951) Practical Notes on the Design of
a Vortex Tube
RAE Technical Note No Mech Eng 67

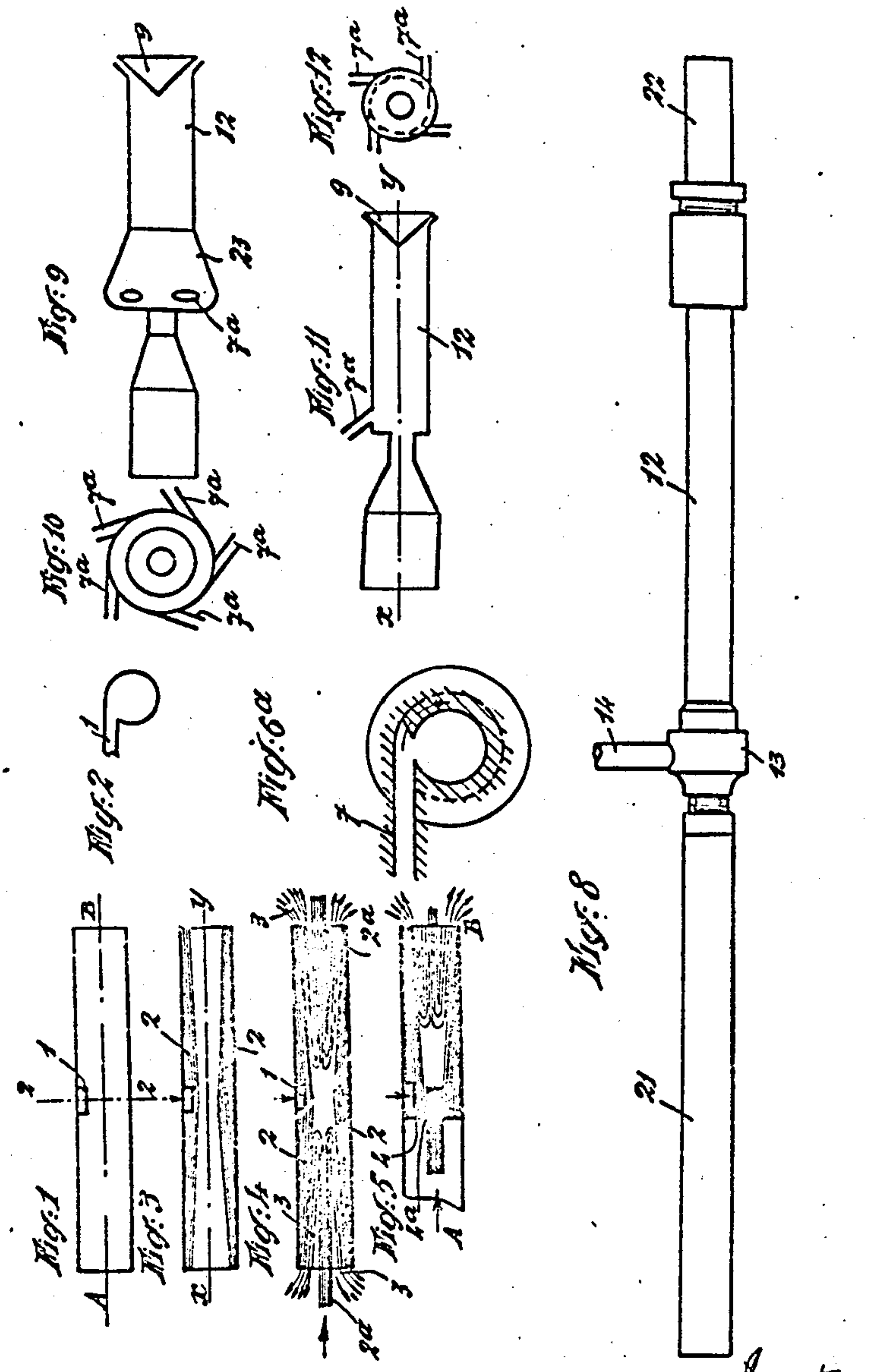
WILSON C BEAUMONT P (1968) Air Consumption and Cold Fraction
Temperature Drop Tests on a Vortair Twin Vortex Tube
Assembly
CEGB(SE Region) Plant Operations Branch Report
No INST/0/35.

March 27, 1934. G. J. RANQUE 1,952,281

METHOD AND APPARATUS FOR OBTAINING FROM A FLUID UNDER PRESSURE TWO CURRENTS OF FLUIDS AT DIFFERENT TEMPERATURES

Filed Dec. 6, 1932 3 Sheets-Sheet 1

FIG.1.



Inventor:
Georges Joseph Ranque,
by Mauro & Lewis,
attorneys.

RANQUES PATENT DRAWINGS Sheet.1.

SER/824/64

FIG. 2.

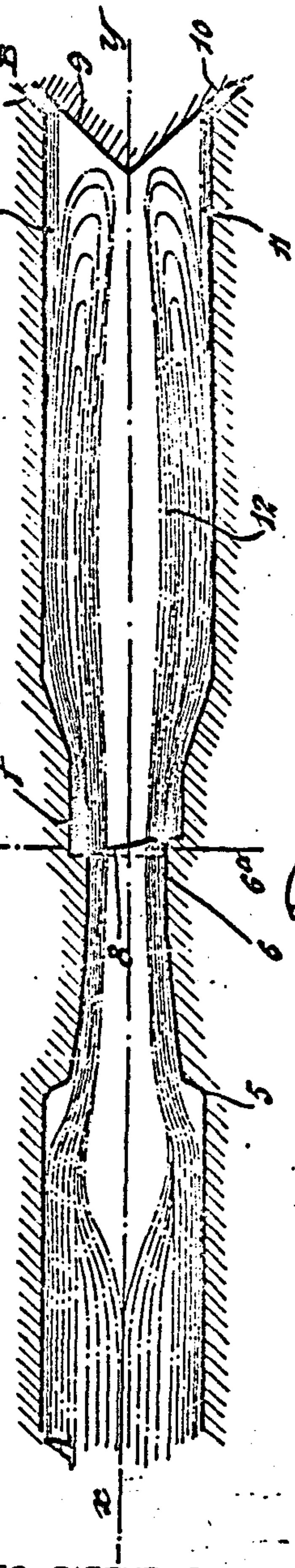


Fig. 6

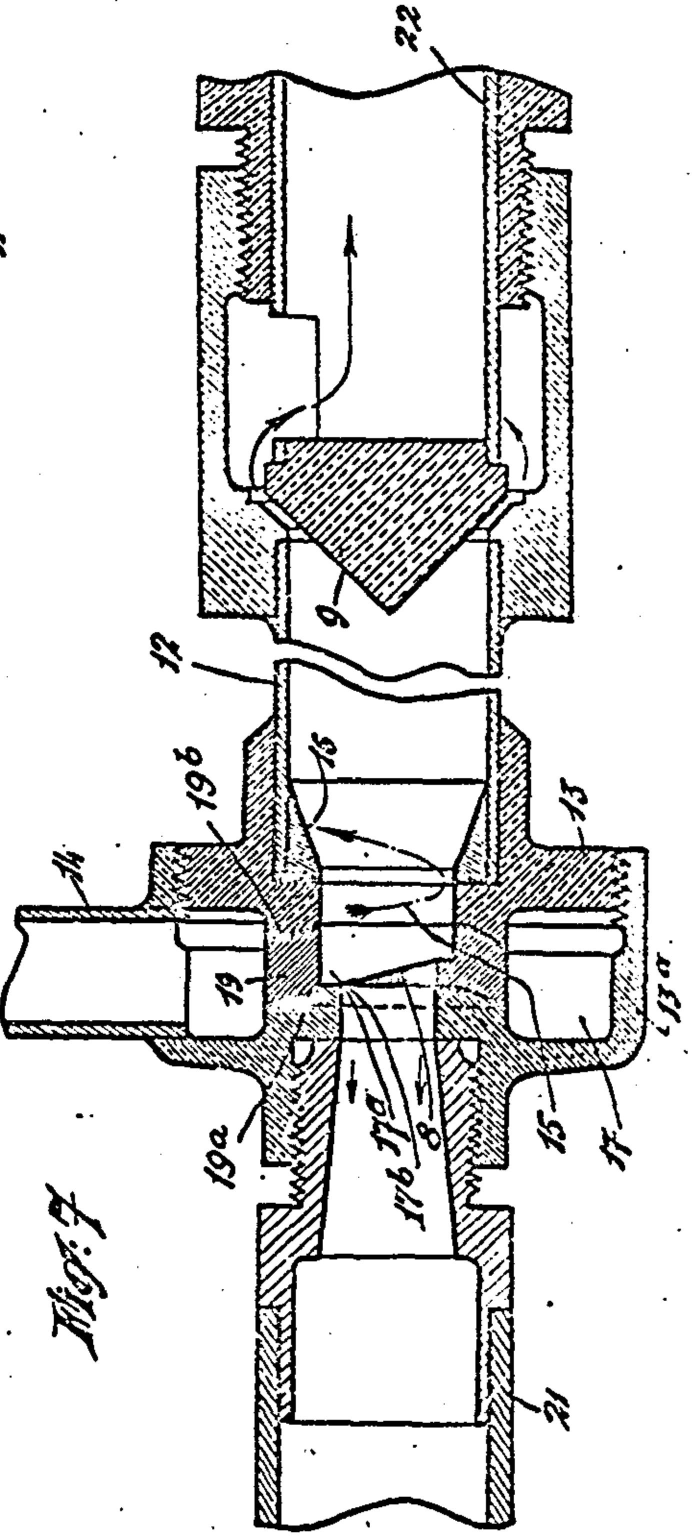


Fig. 7

Inventor:
Georges Joseph Ranque.
by Mauro & Lewis,
Attorneys.

FIG. 3.

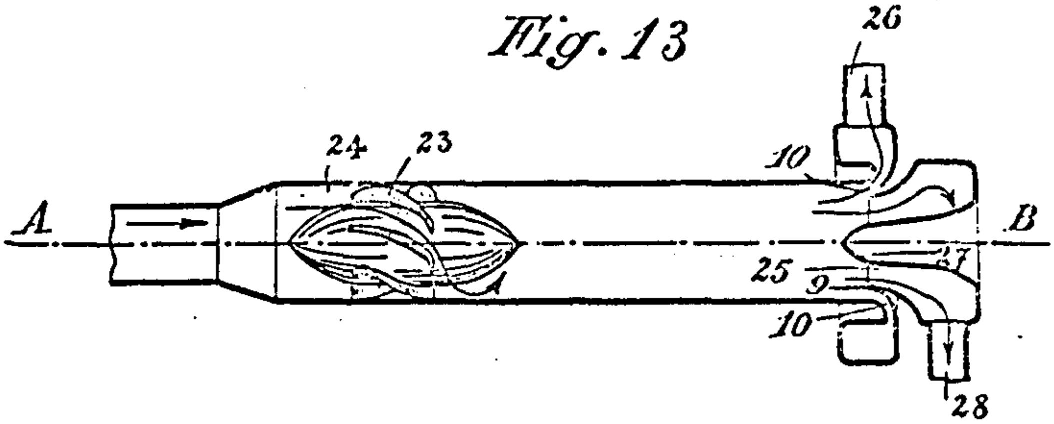


Fig. 13

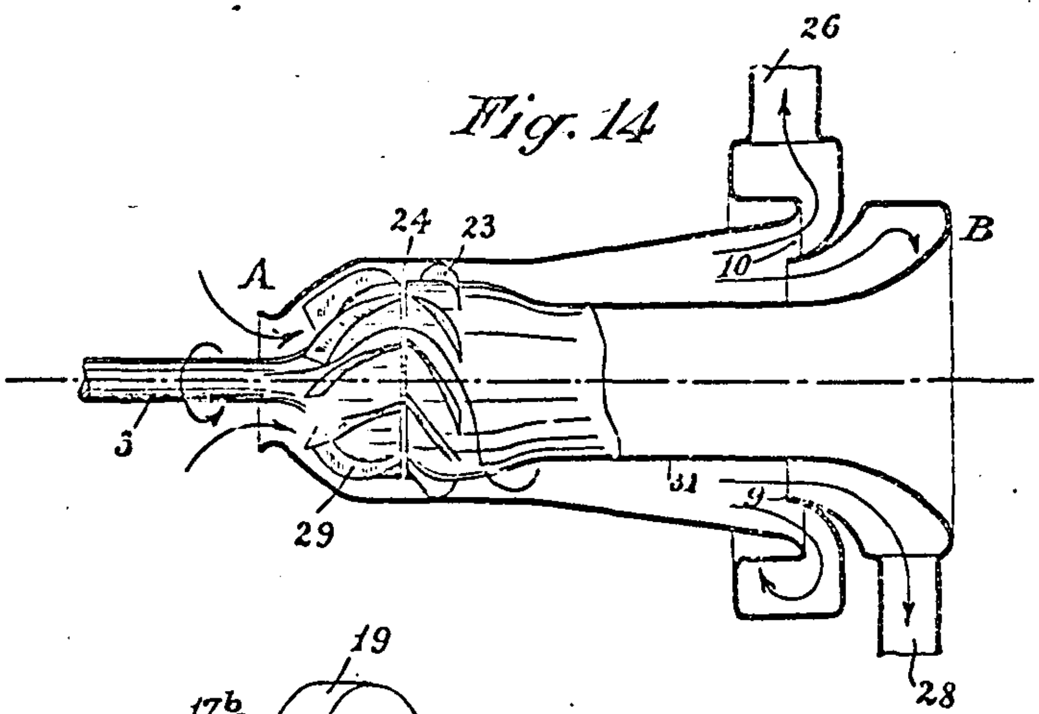


Fig. 14

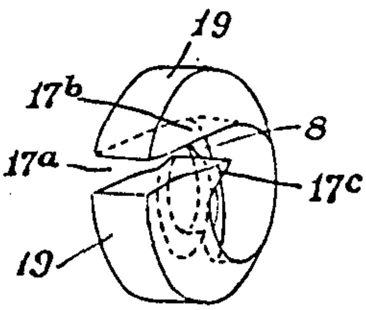


Fig. 7a

Inventor.
Georges Joseph Ranque,
by Mauro & Lewis.
Attorneys

RANQUES PATENT DRAWINGS
-Sheet 3

SER/824166

FIG. 4.

VENTILATED SUIT REFRIGERATION UNIT

Filed Aug. 21, 1953

Fig.1.

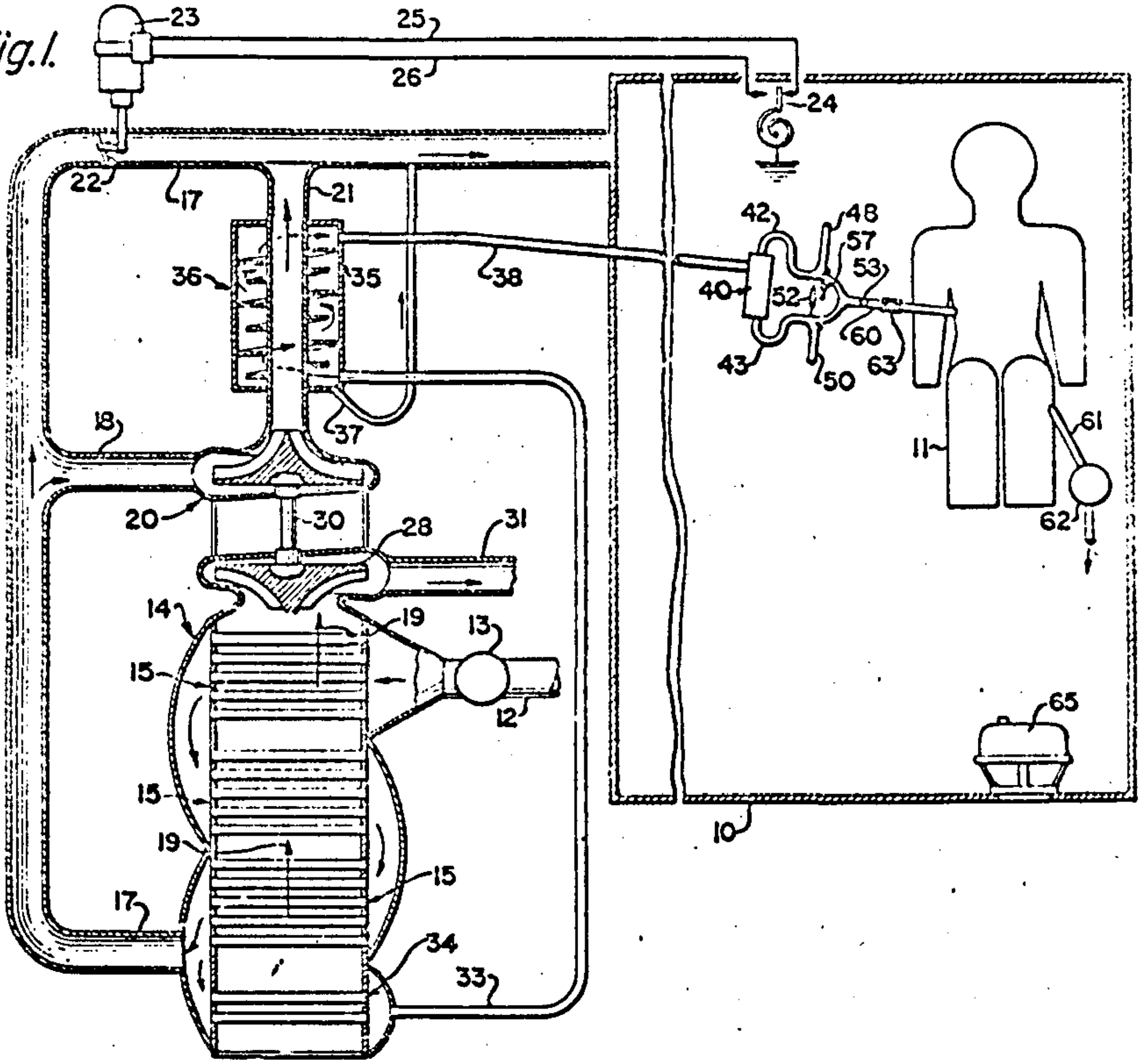
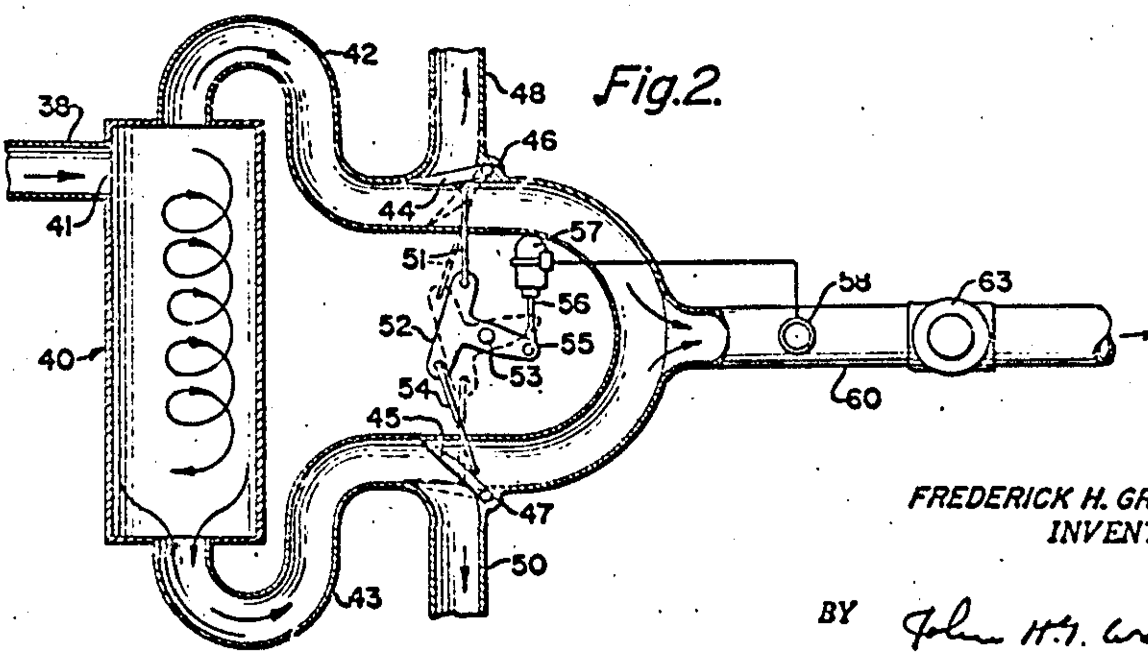


Fig.2.



FREDERICK H. GREEN,
INVENTOR.

BY John H. G. Wallace

GREENS PATENT DRAWINGS

SER/824/67

March 16, 1965

Filed Nov. 27, 1962

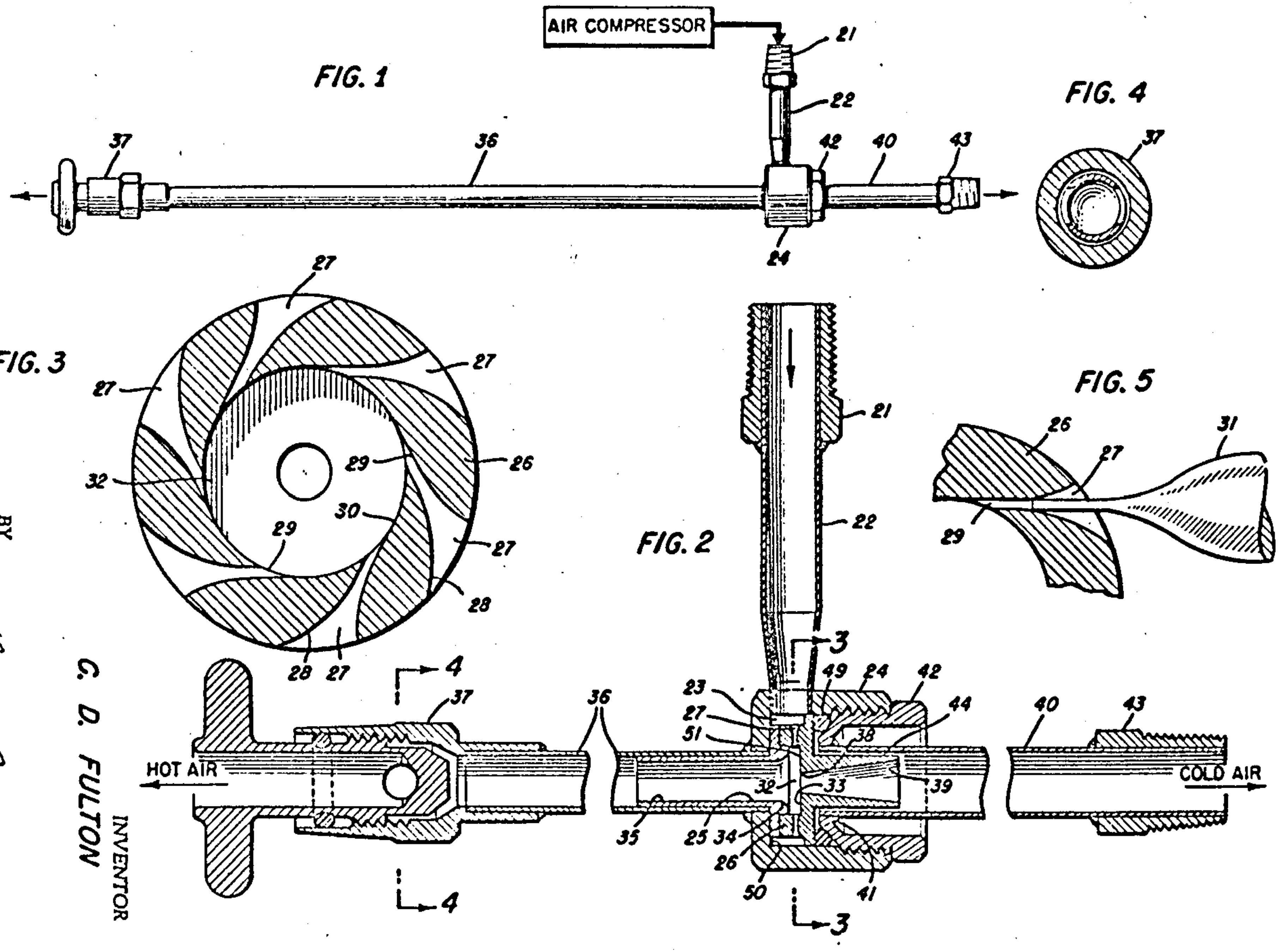
C. D. FULTON

VORTEX TUBE

3 Sheets-Sheet 1

3,173,273

FIG. 5.



G. D. FULTON

INVENTOR

BY

ATTORNEY

FULTONS PATENT DRAWINGS-Sheet 1

-45-

SER/824/68

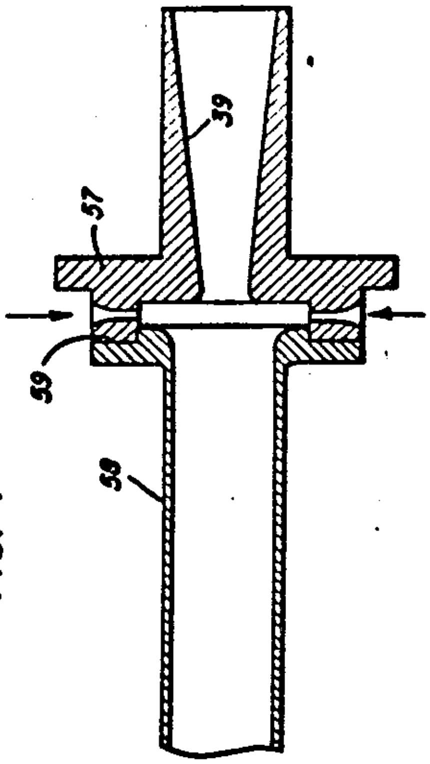


FIG. 7

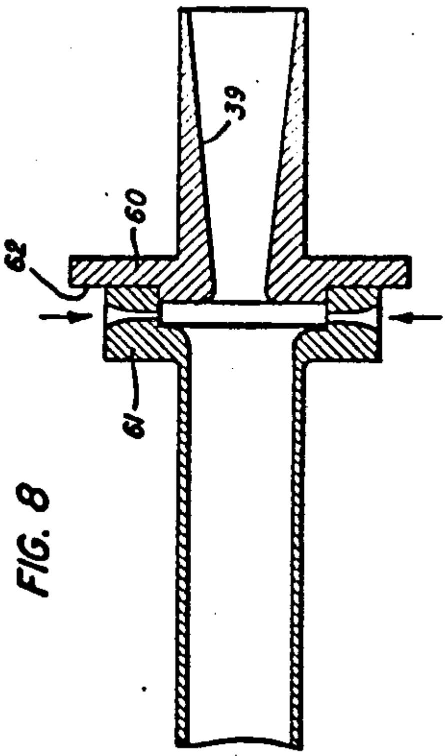


FIG. 8

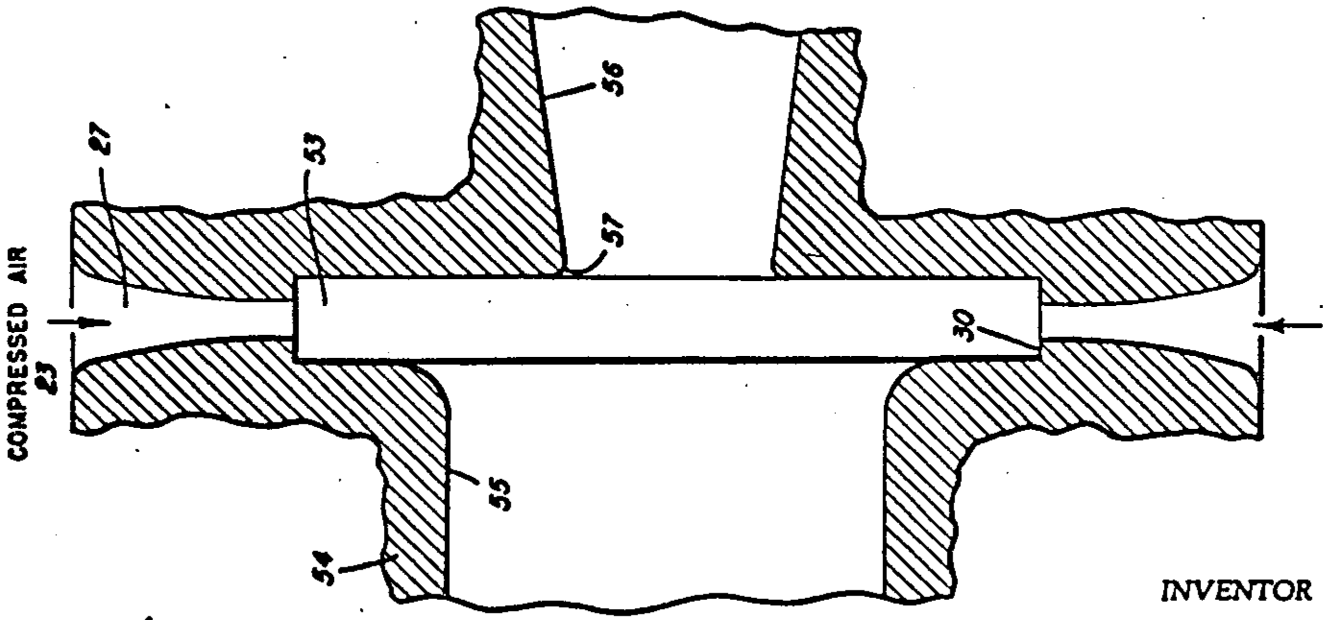


FIG. 6

INVENTOR

C. D. FULTON

BY

David Rabin

ATTORNEY

FULTONS PATENT DRAWINGS - Sheet 2

March 16, 1965 C. D. FULTON 3,173,273

VORTEX TUBE FIG. 7.

Filed Nov. 27, 1962 3 Sheets-Sheet 3

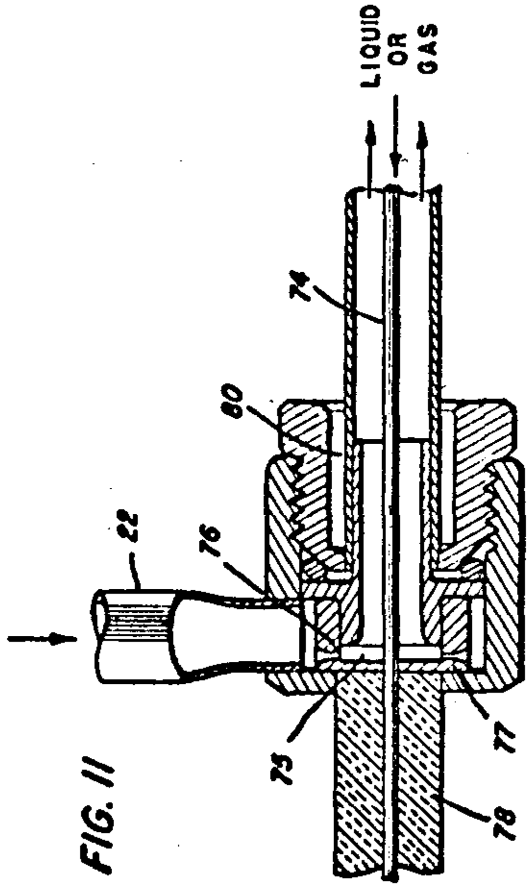


FIG. 11

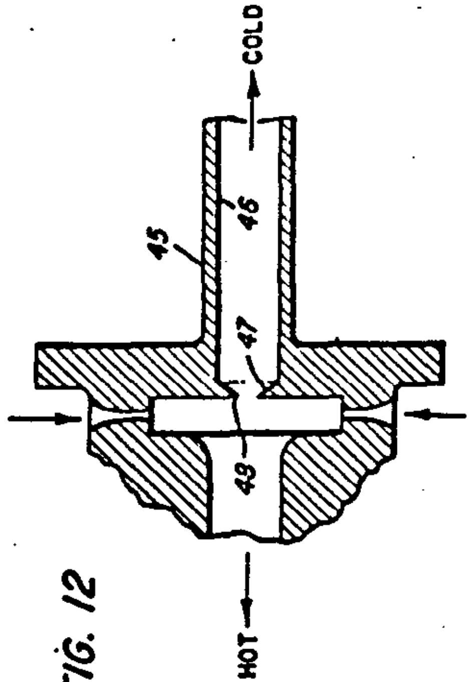


FIG. 12

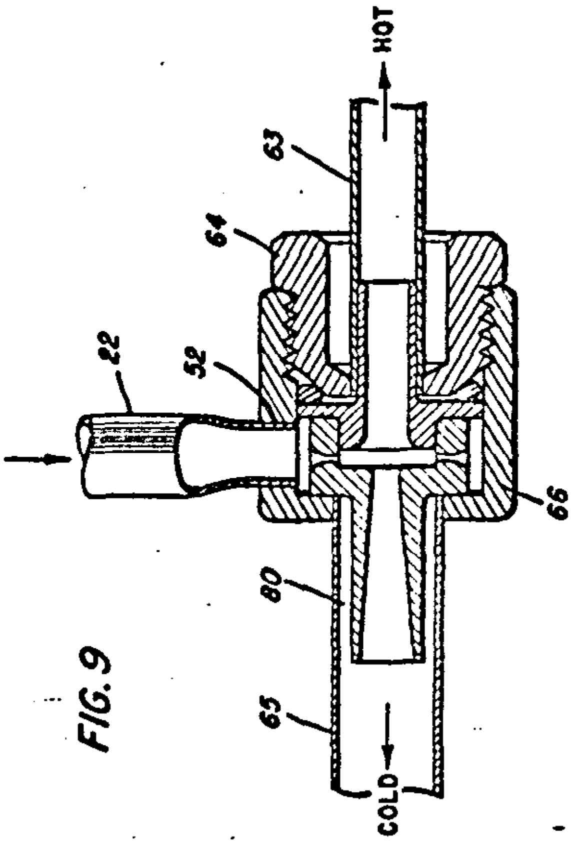


FIG. 9

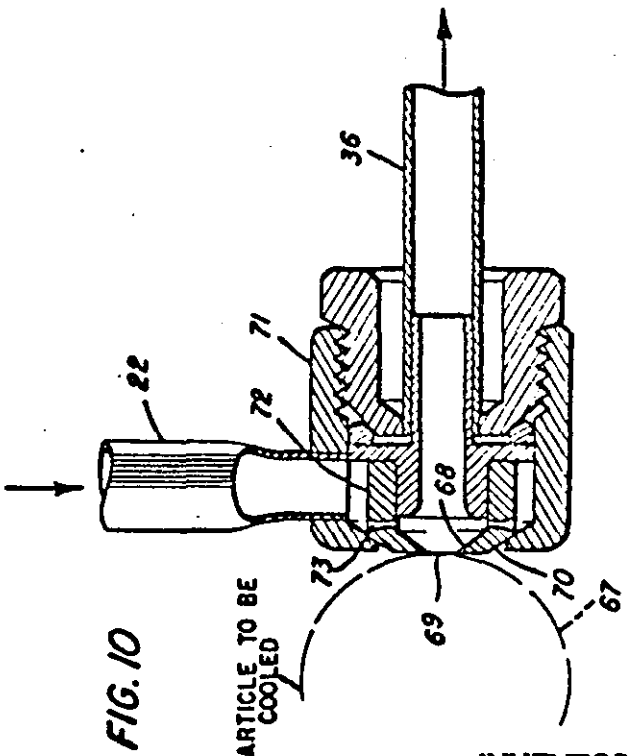


FIG. 10

INVENTOR

C. D. FULTON

BY

David Rabin

ATTORNEY

Sept. 28, 1965 C. D. FULTON 3,208,229

VORTEX TUBE

FIG.8.

Filed Jan. 28, 1965 2 Sheets-Sheet 1

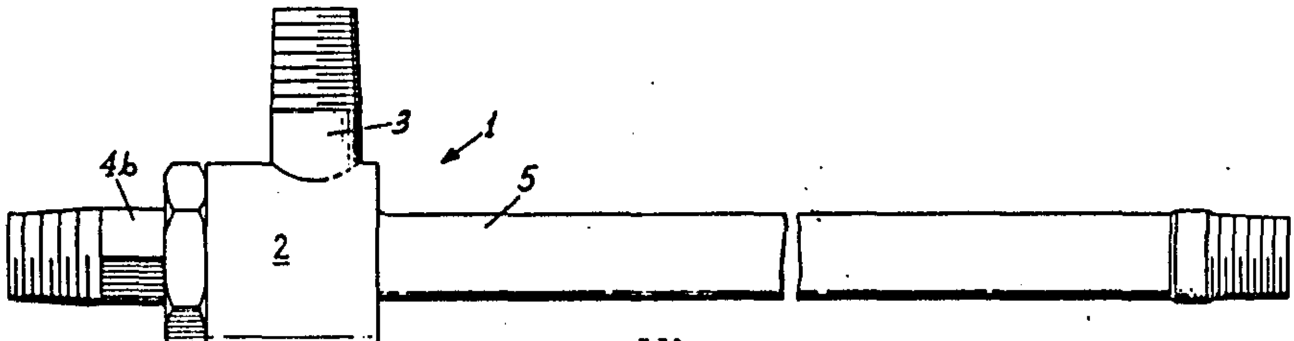


Fig. 1

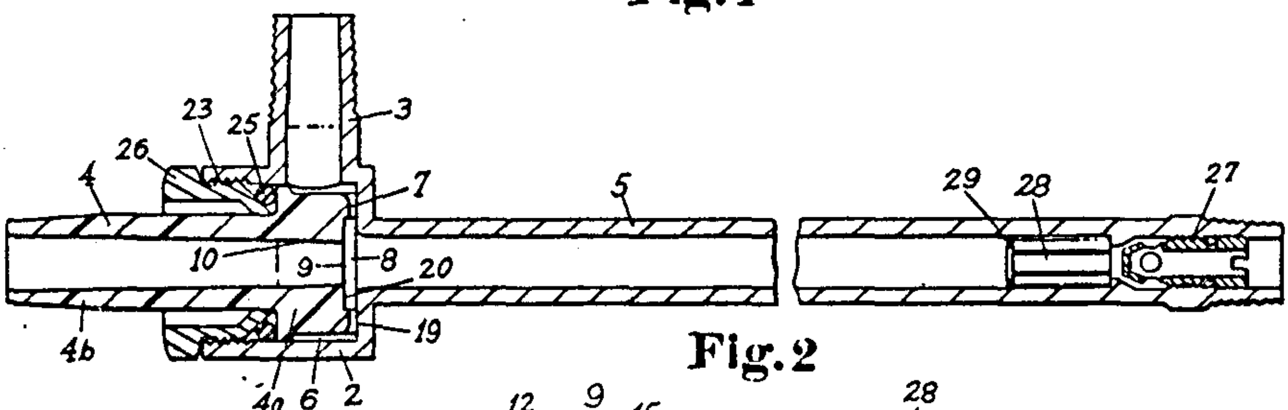


Fig. 2

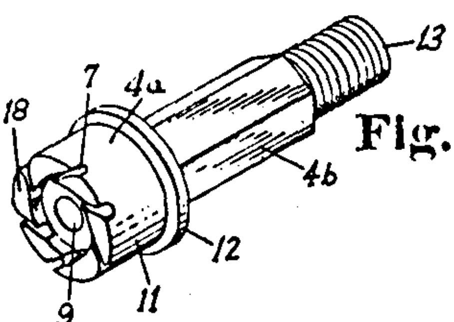


Fig. 3

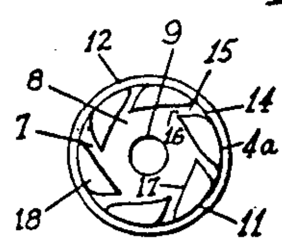


Fig. 4

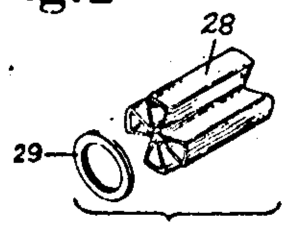


Fig. 6

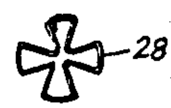


Fig. 7

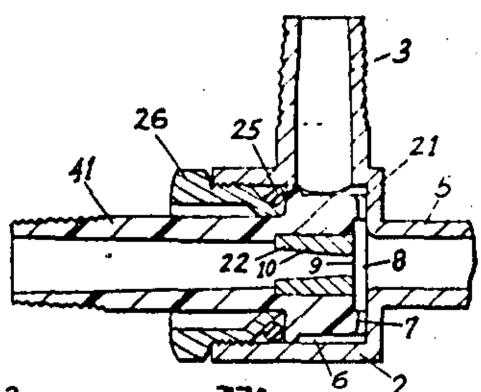


Fig. 5

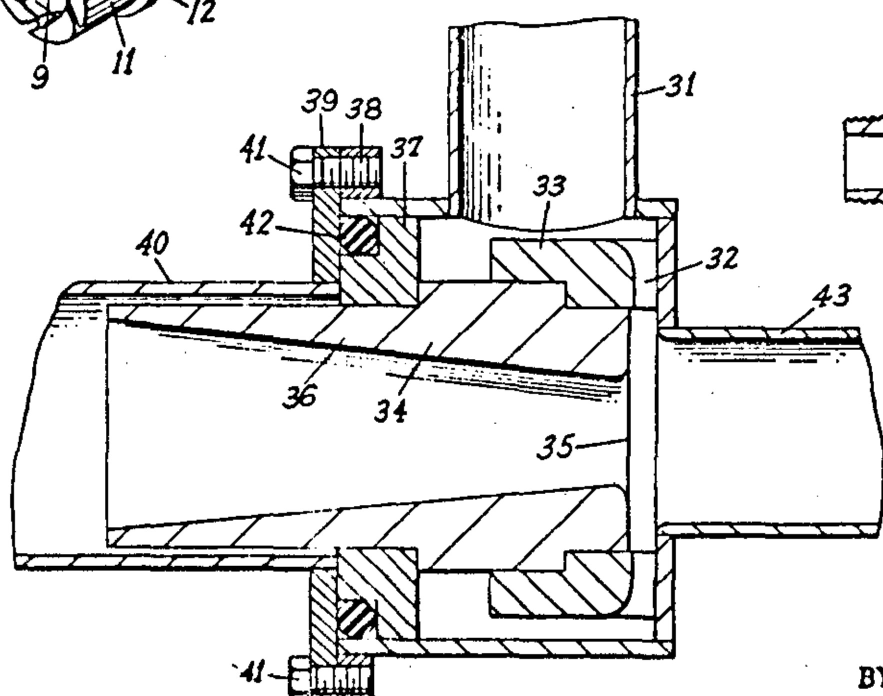


Fig. 8

FULTONS PATENT DRAWINGS -Sheet. 1.

INVENTOR
CHARLES D. FULTON,
BY Youngblut, Melville, Strauss & Foster
ATTORNEYS.

SER/824/71

FIG. 9.

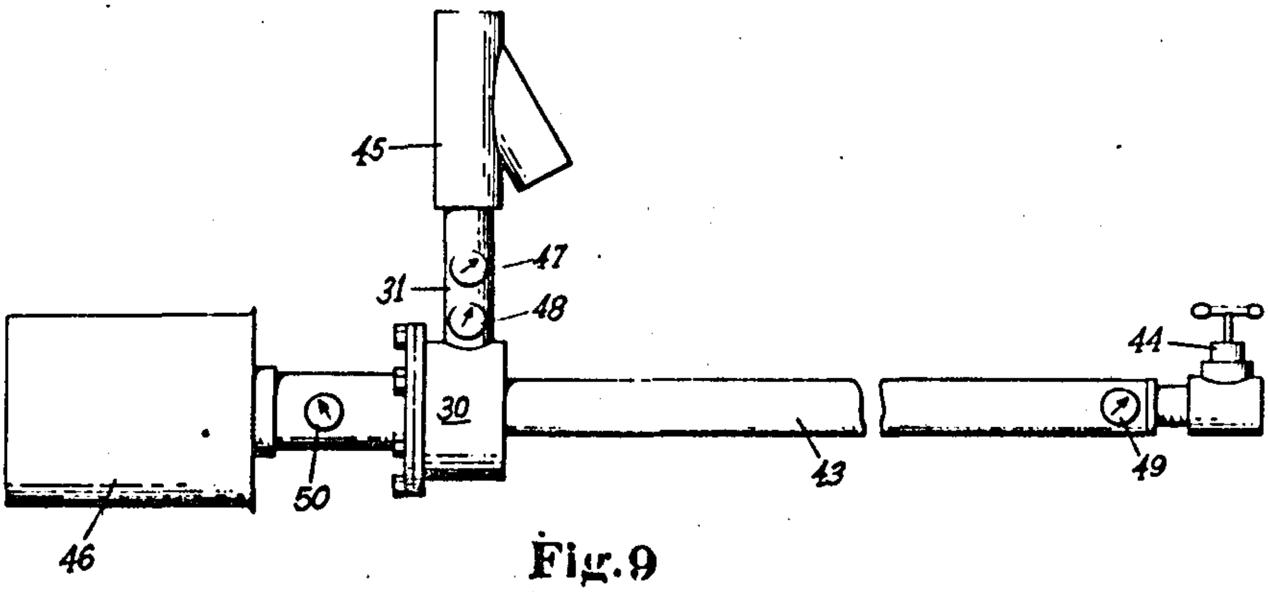


Fig. 9

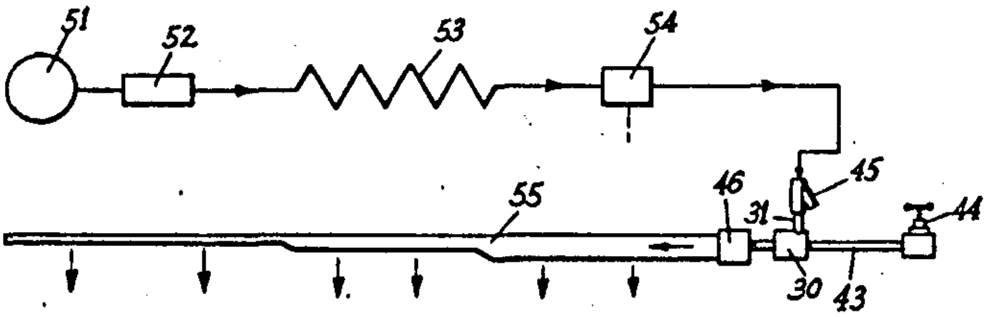


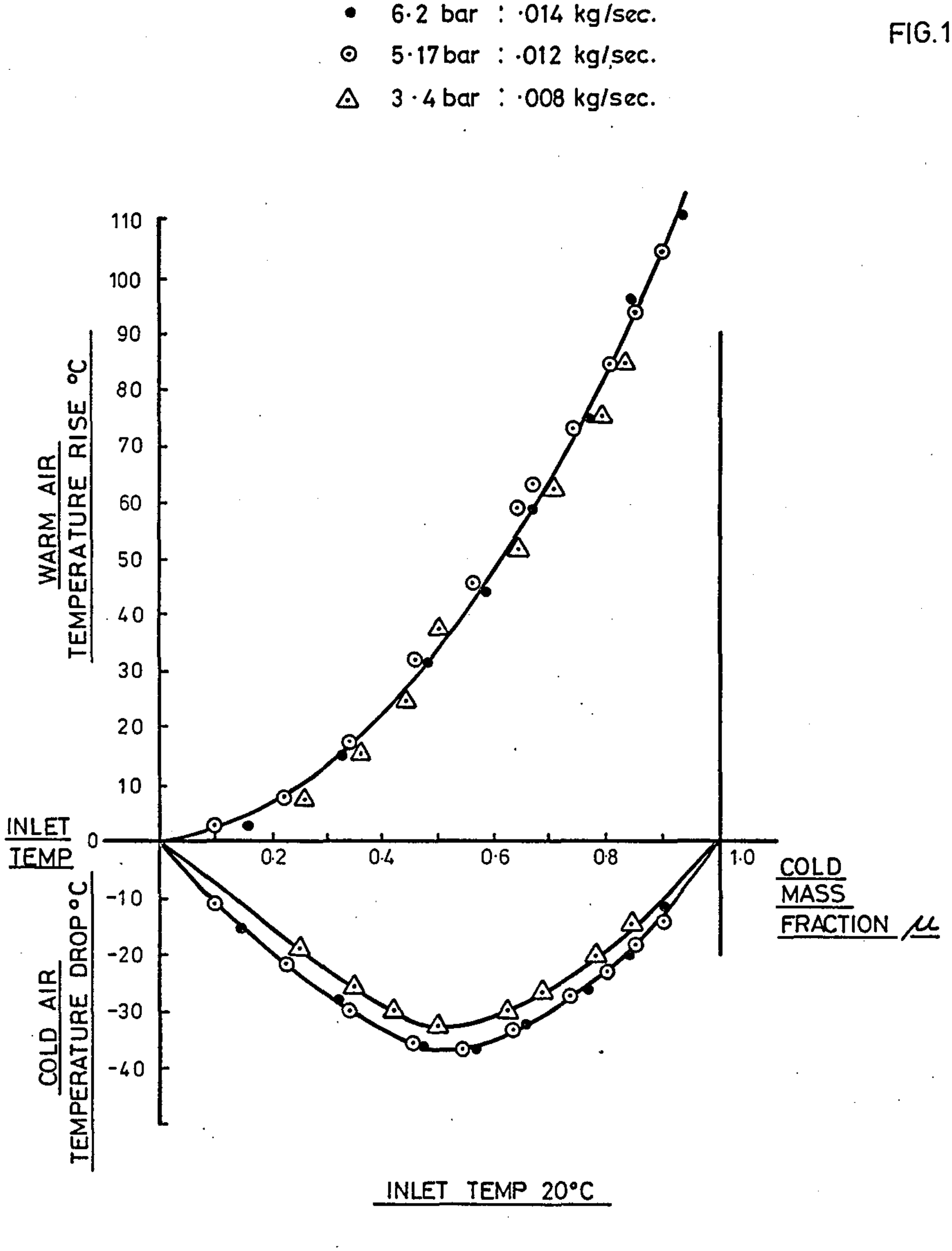
Fig. 10

FULTONS PATENT DRAWINGS - Sheet. 2.

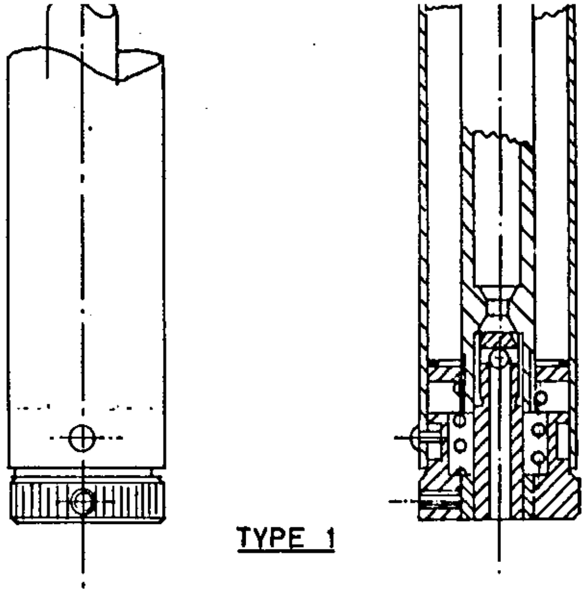
INVENTOR.
CHARLES D. FULTON,
BY Youngblut, Melville, Strasser & Foster
ATTORNEYS.

SER/824/63

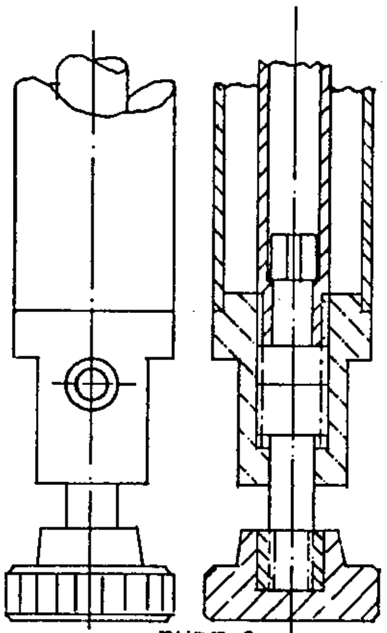
FIG.10.



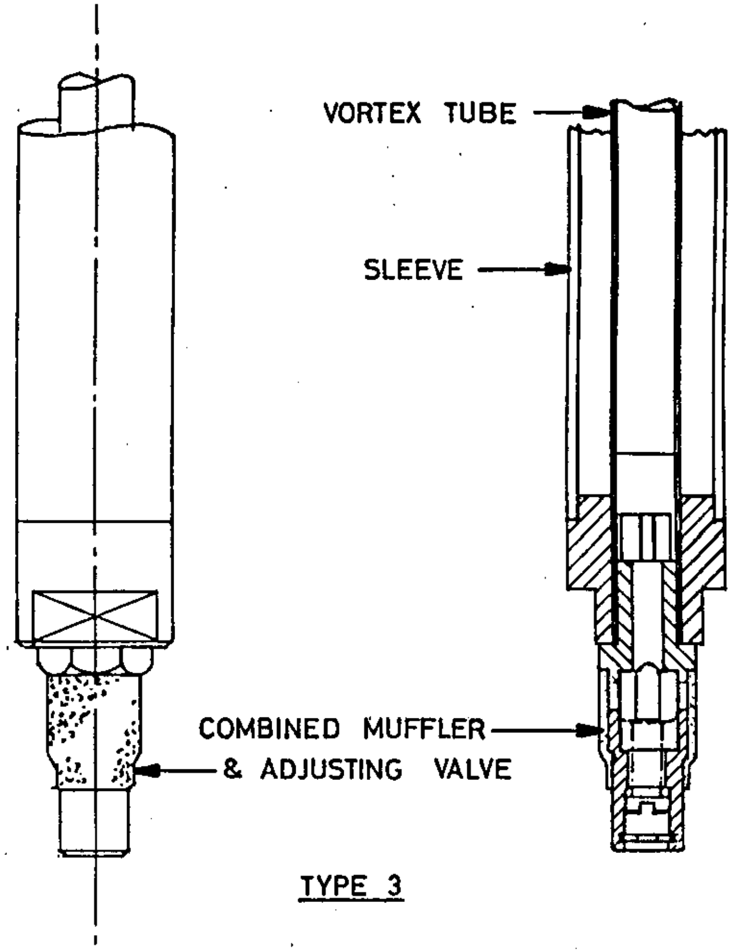
TEMPERATURE CHARACTERISTIC
COLD MASS FRACTION FOR VARIOUS PRESSURE FLOWS
(FULTON CRYROGENIC DATA)



TYPE 1



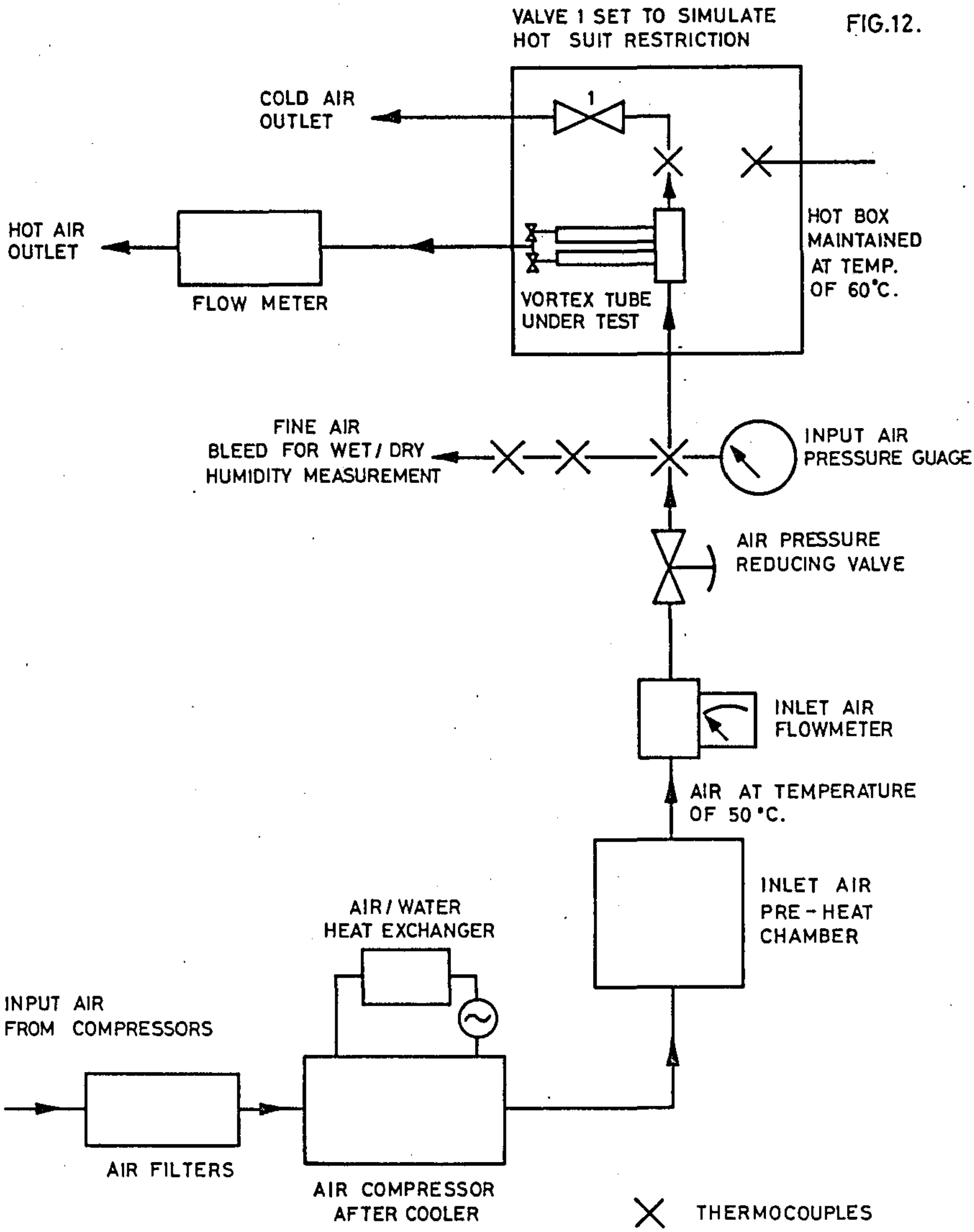
TYPE 2



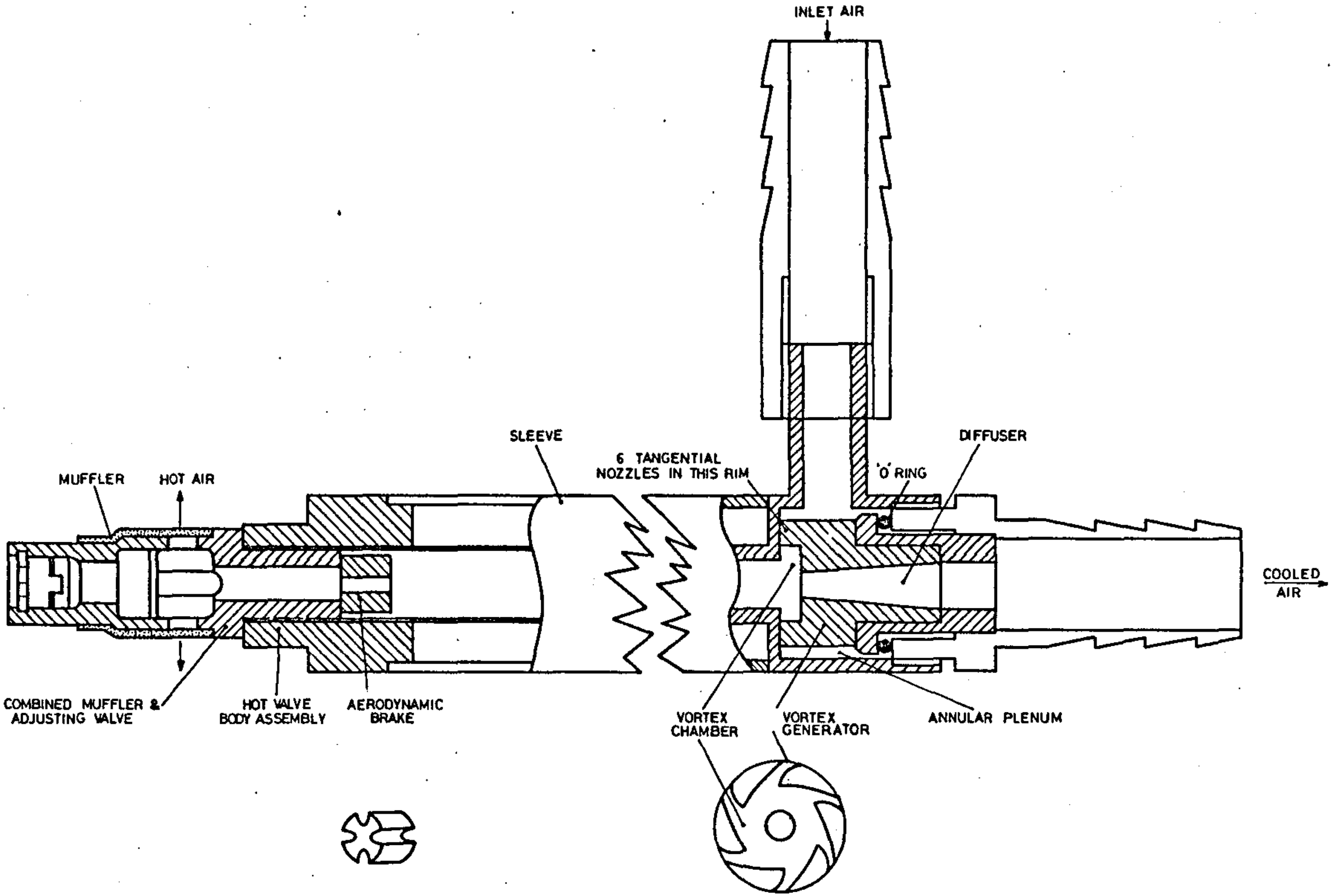
TYPE 3

HOT VALVE ASSEMBLIES FOR VORTEX TUBES

FIG. 11.



TEST RIG FOR VORTEX TUBE PERFORMANCE CHARACTERISTICS

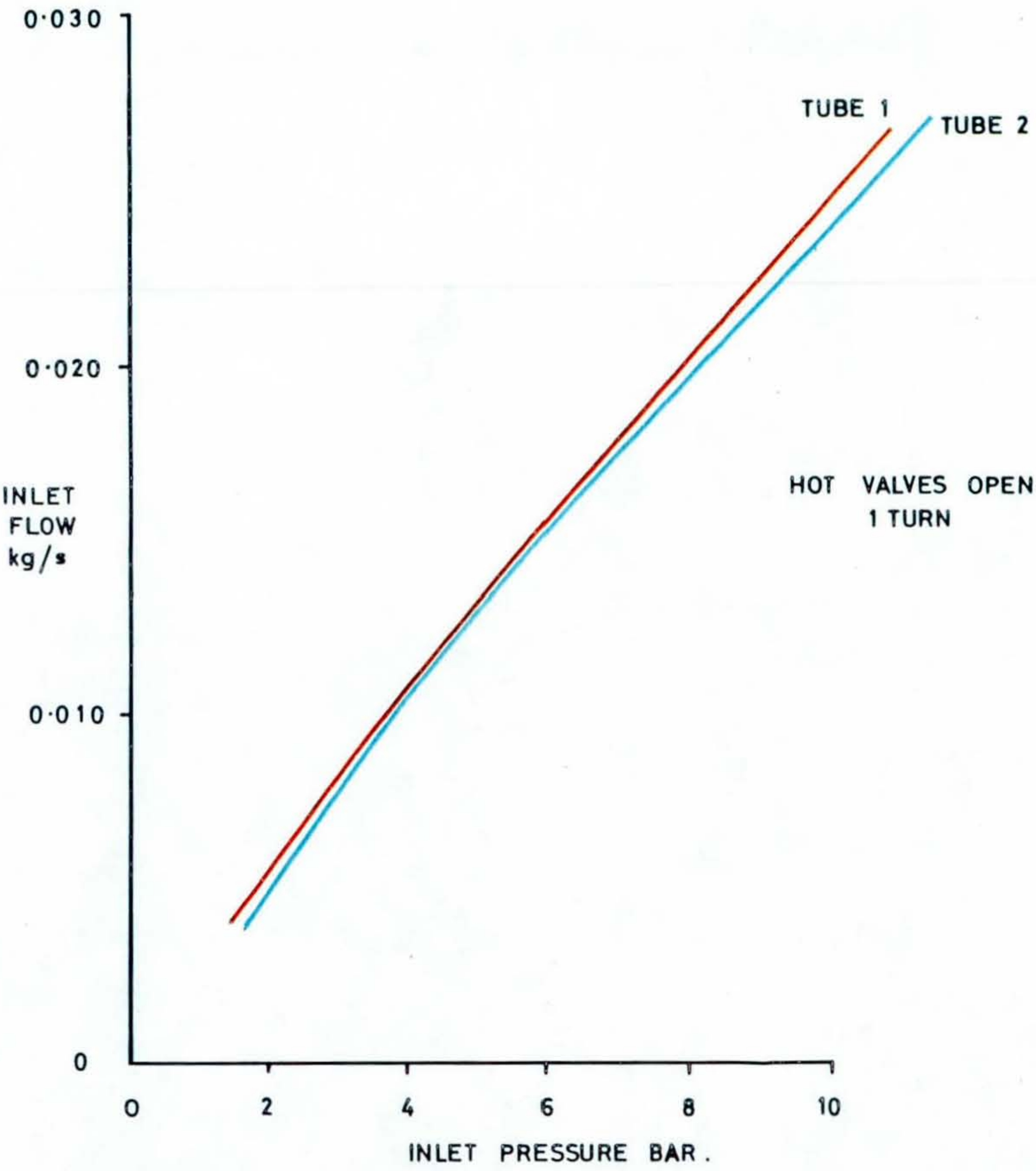


CROSS SECTION DIAGRAM OF SINGLE GENERATOR VORTEX TUBE

FIG.13.

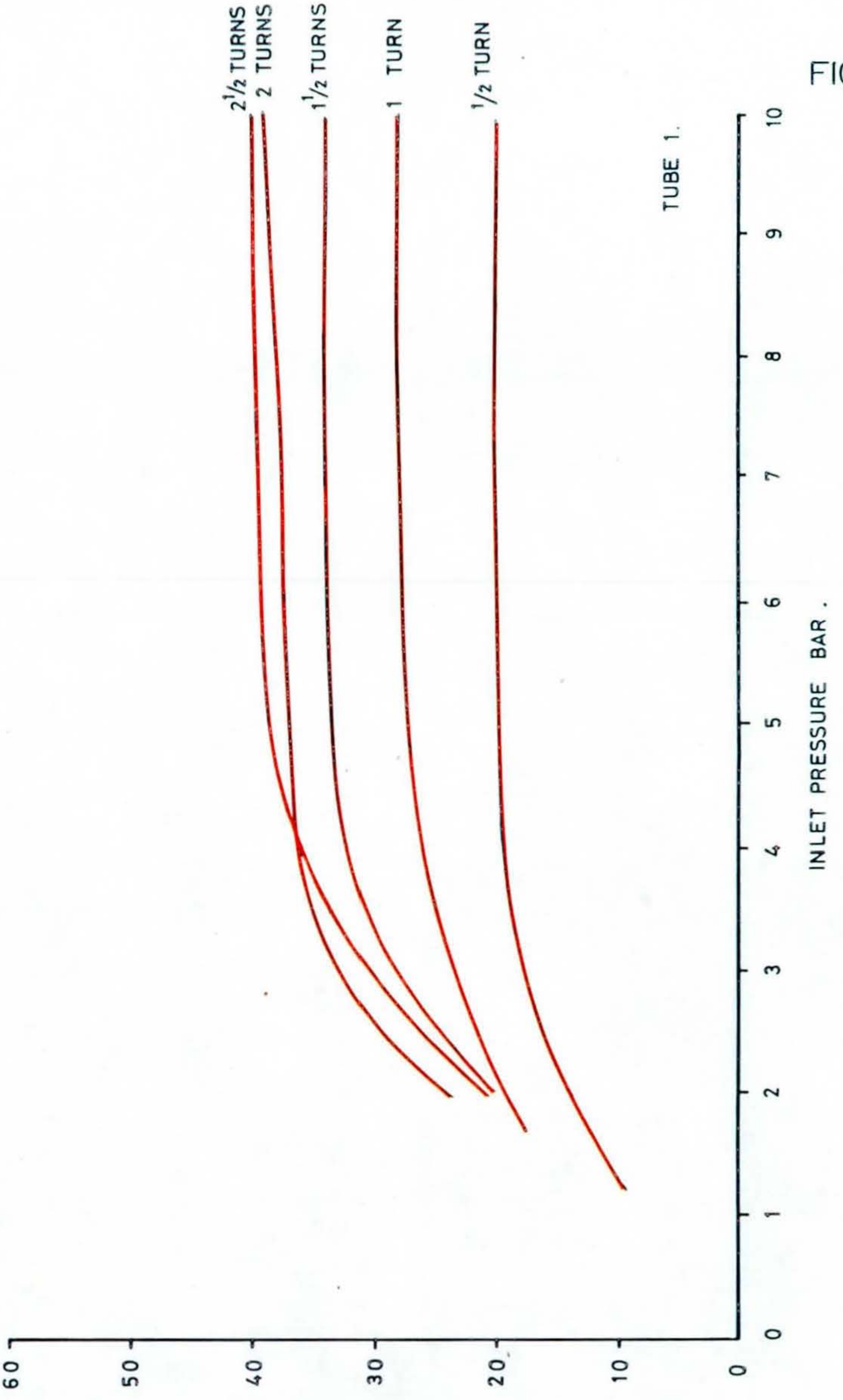
SER/824/36

FIG. 14.



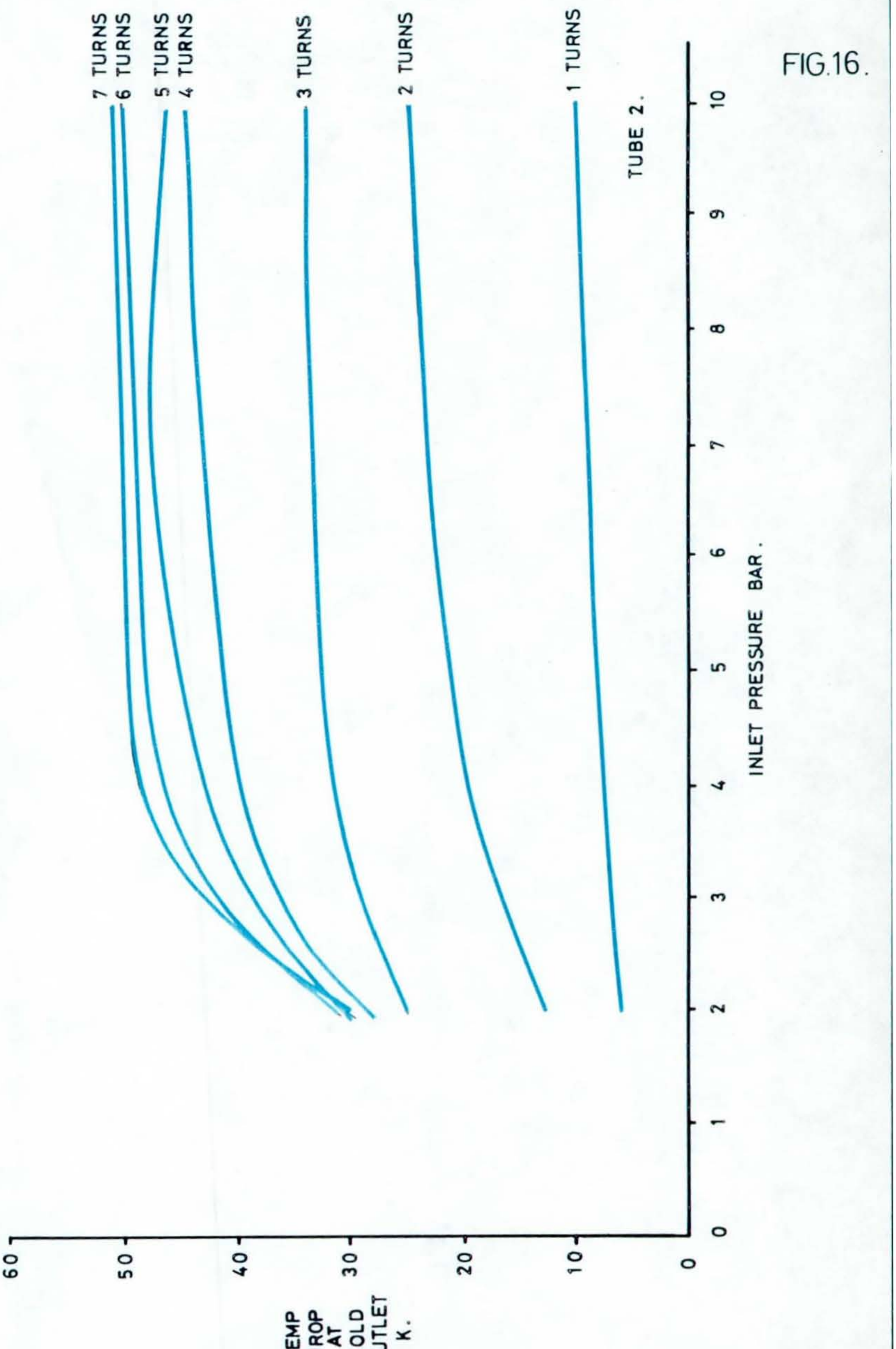
EVALUATION OF THE PERFORMANCE OF SINGLE BARREL VORTEX TUBES.
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND INLET AIR FLOW.
INLET AIR TEMPERATURE AT 50 °C. VORTEX TUBES AT 60 °C.

FIG.15.



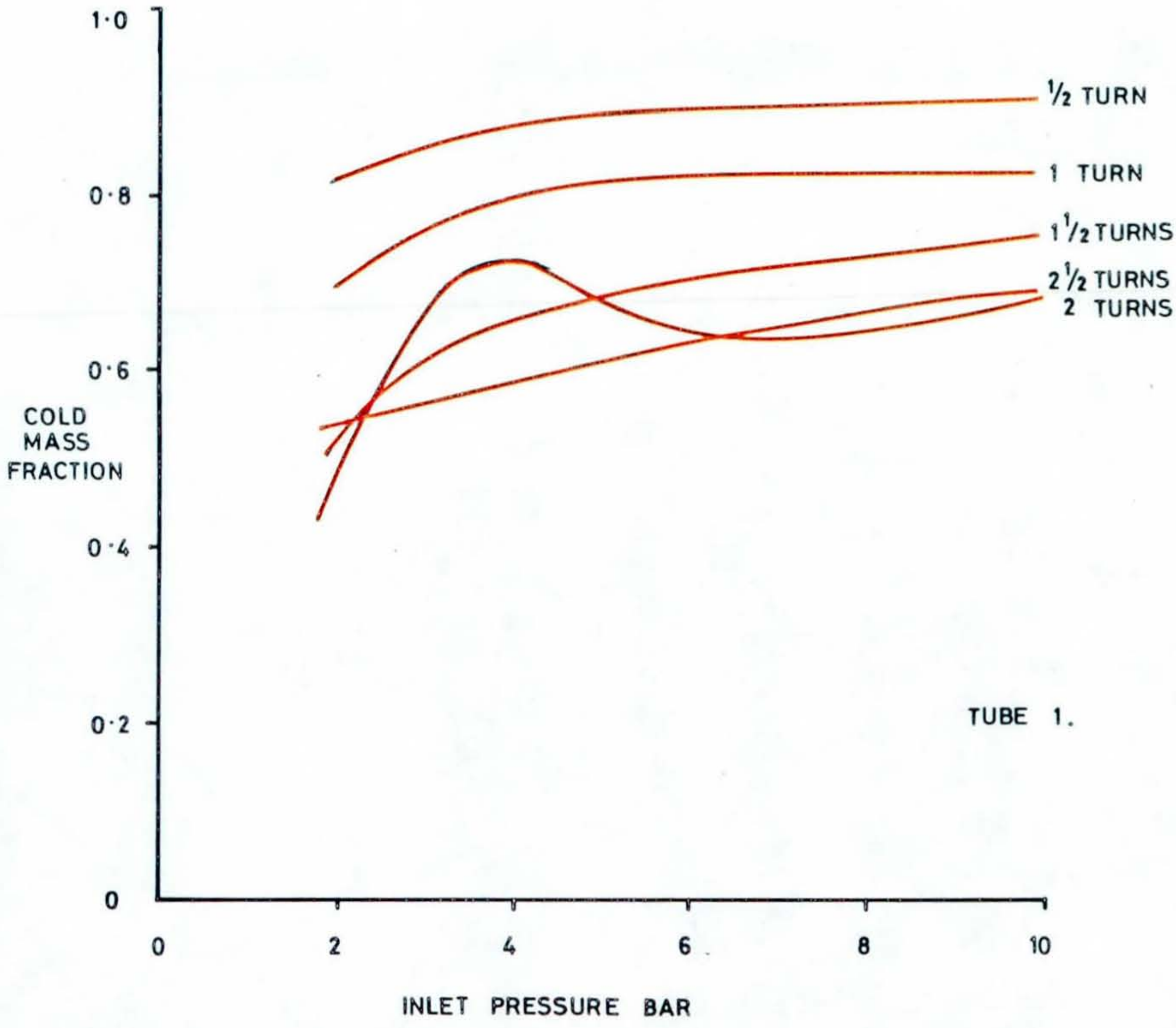
EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBE.
RELATIONSHIP BETWEEN TEMPERATURE DROP AND INLET AIR PRESSURE WITH INCREASING OPENING OF HOT AIR VALVE. INLET AIR TEMPERATURE 50 °C.
VORTEX TUBES AT 60 °C.

FIG.16.



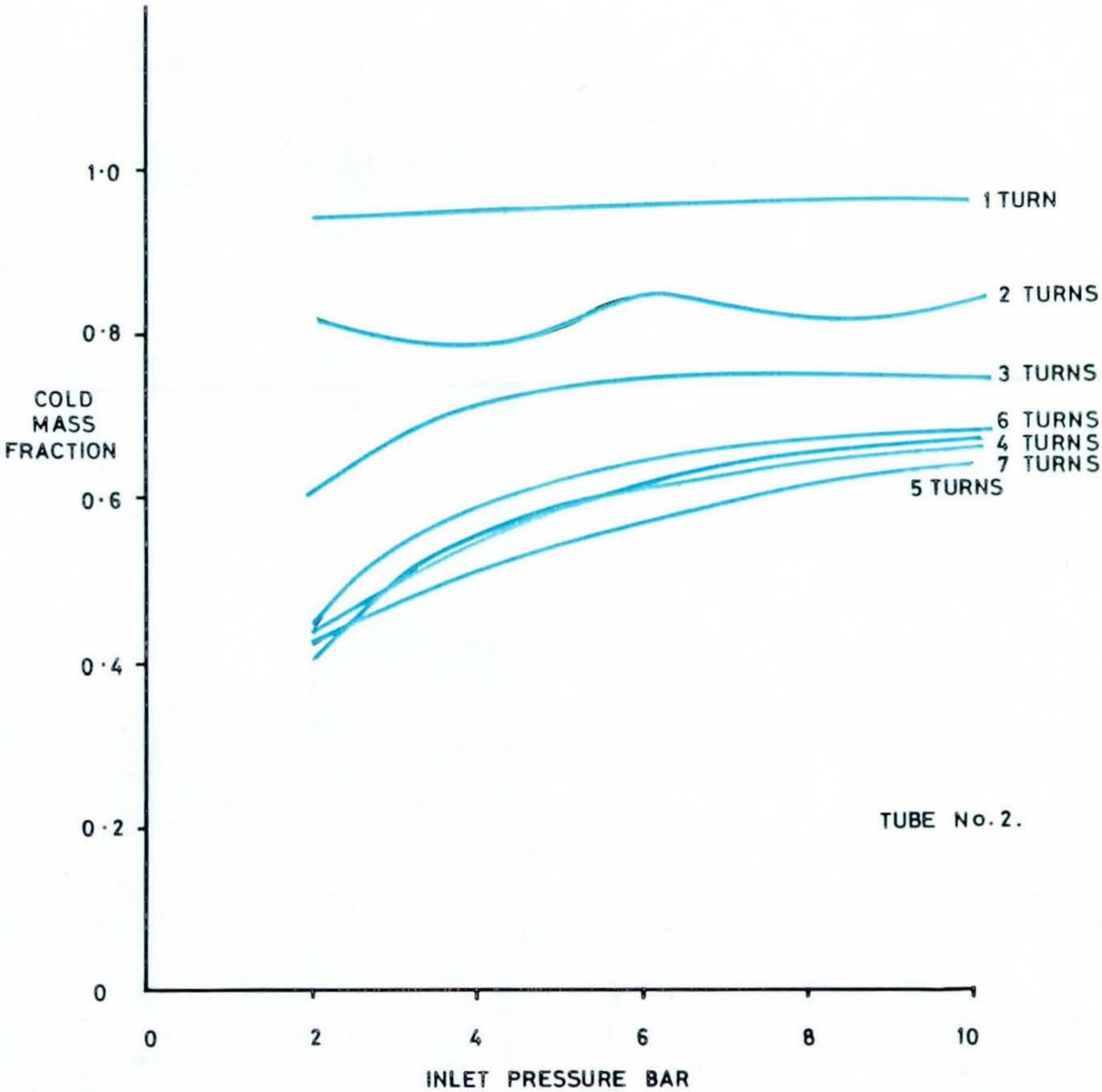
EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBE . RELATIONSHIP BETWEEN TEMPERATURE DROP AND INLET AIR PRESSURE WITH INCREASING RELATIONSHIP BETWEEN TEMPERATURE DROP AND INLET AIR PRESSURE WITH INCREASING OPENING OF HOT AIR VALVE. INLET AIR TEMPERATURE 50°C.
VORTEX TUBES AT 60°C .

FIG. 17.



EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBE .
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.

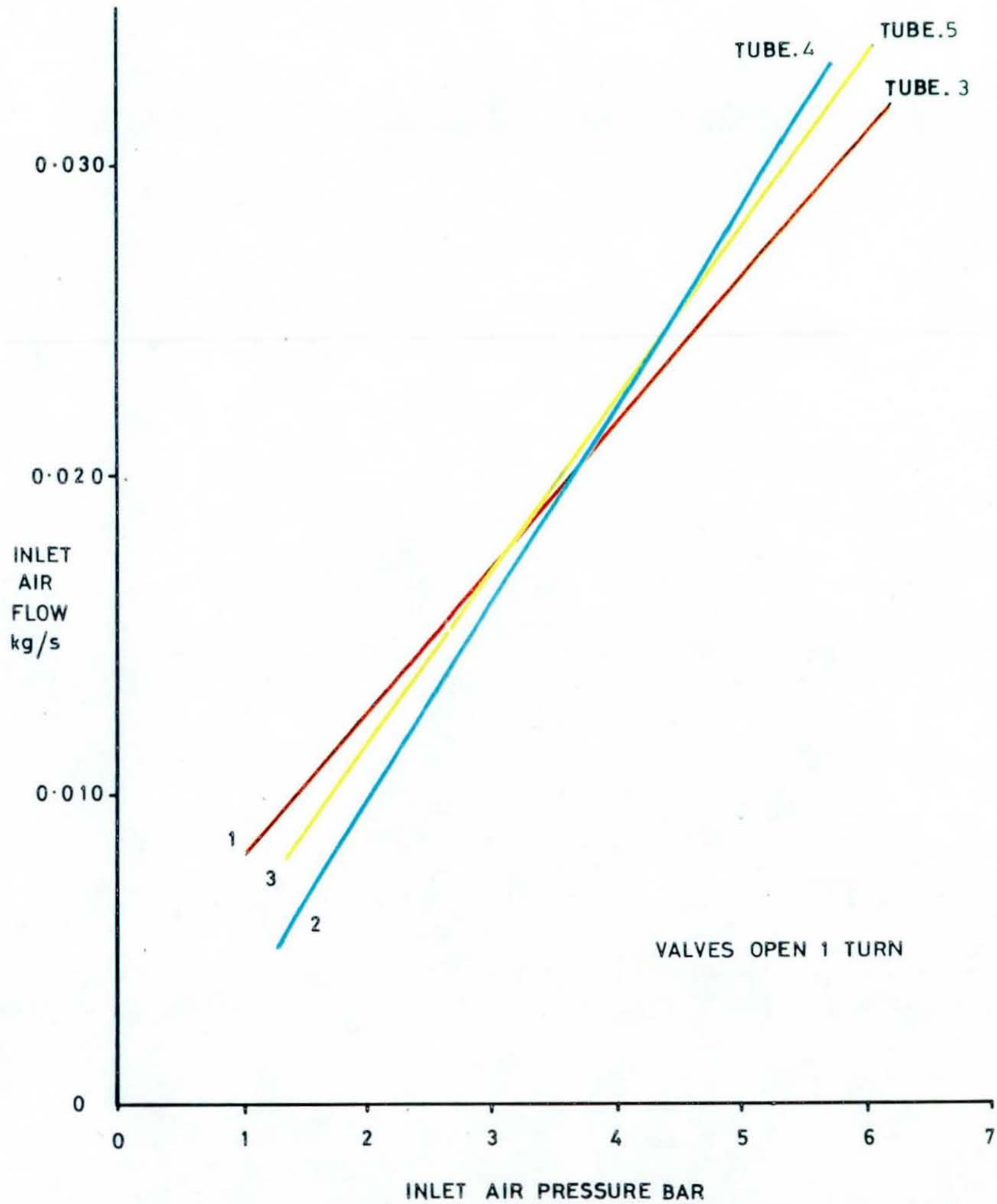
FIG. 18.



EVALUATION OF PERFORMANCE OF SINGLE BARREL VORTEX TUBE .
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 .

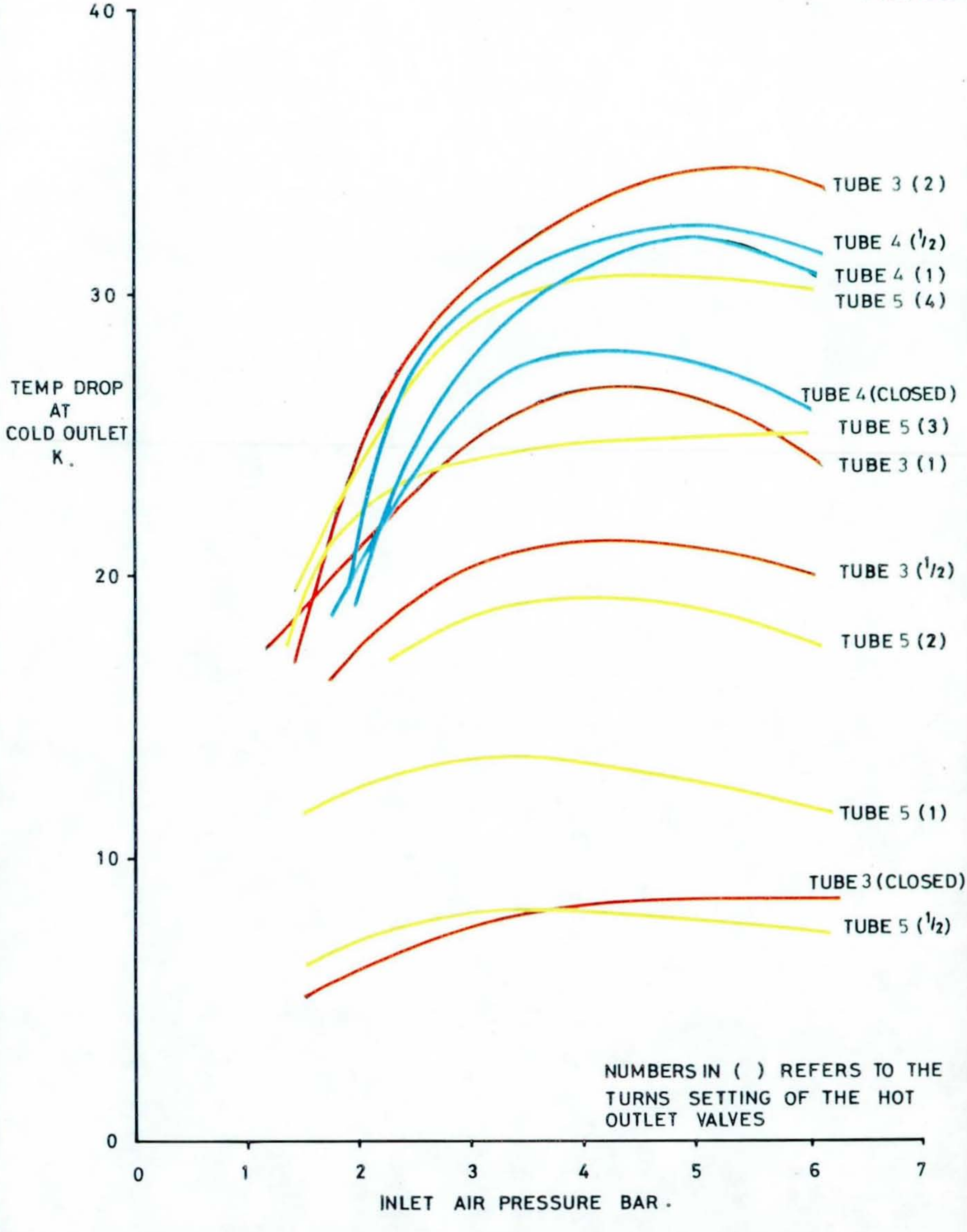
SER /824/ 21

FIG. 19.



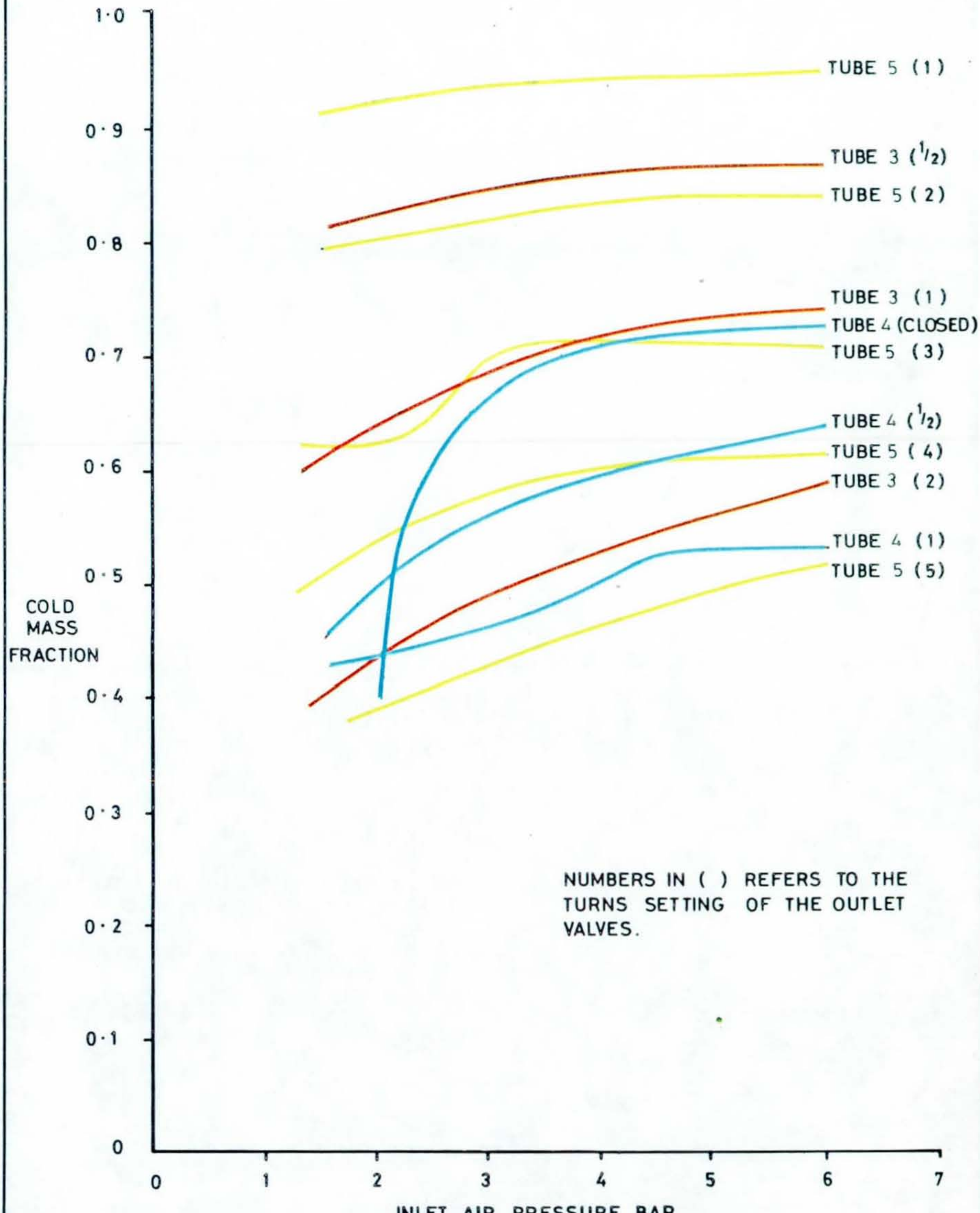
COMPARISON TESTS ON THREE TWIN VORTEX TUBES WITH DIFFERENT VALVE DESIGNS.
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND INLET AIRFLOW.
INLET AIR AND VORTEX TUBES AT 20 °C.

FIG. 20.

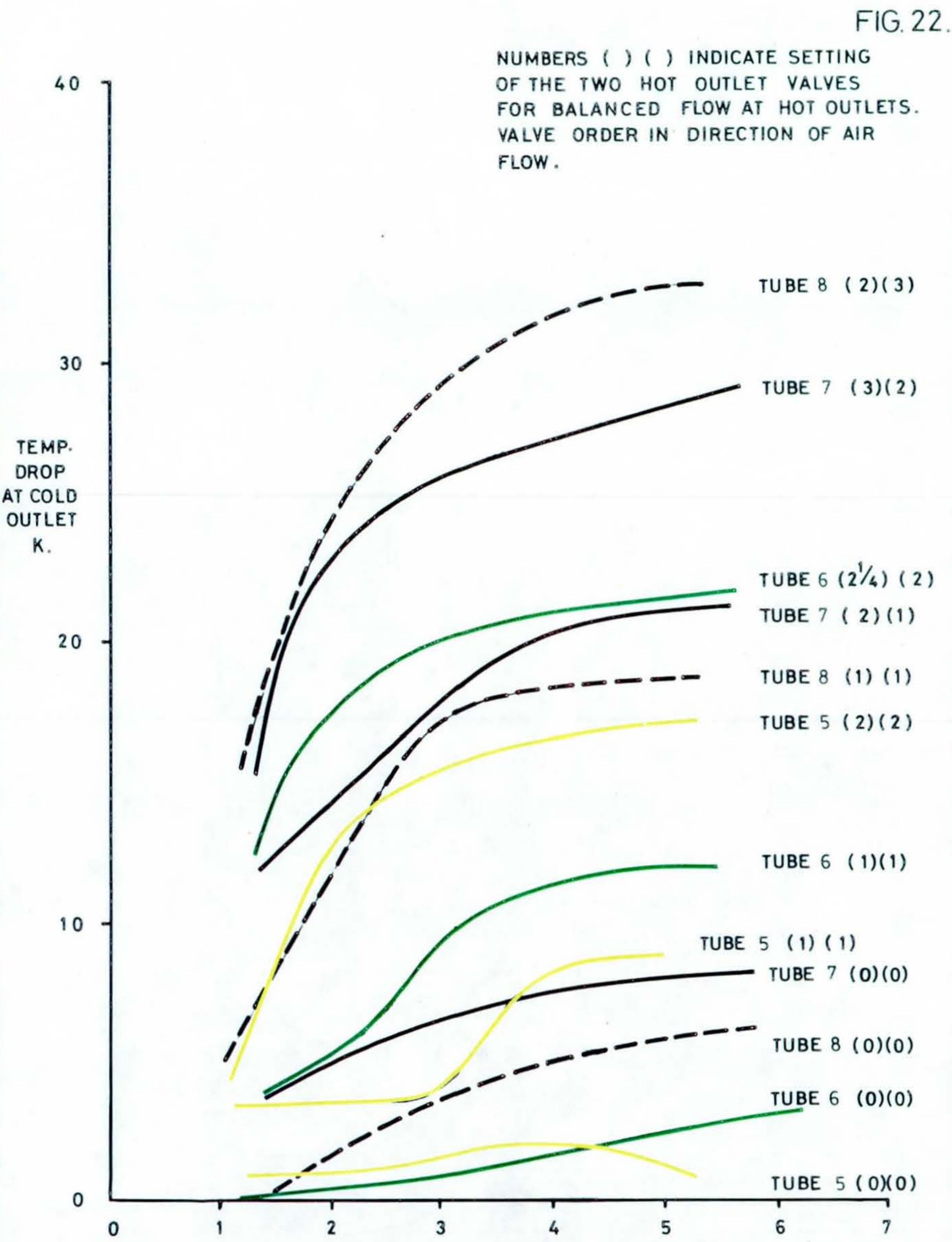


COMPARISON TESTS ON THREE TWIN VORTEX TUBES WITH DIFFERENT VALVE DESIGNS.
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES.
INLET AIR AND VORTEX TUBES AT 20 °C.

FIG. 21.

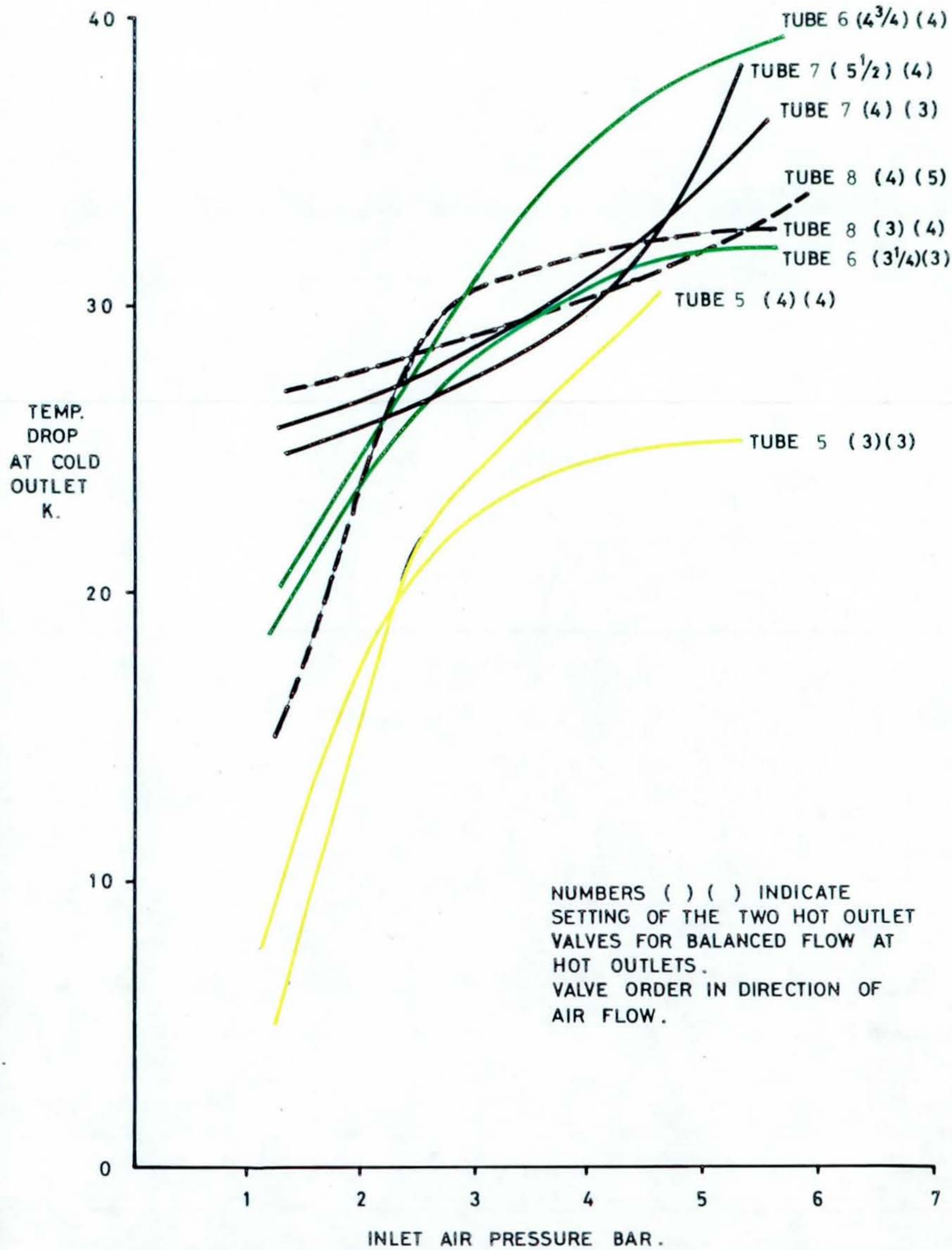


COMPARISON TESTS ON THREE VORTEX TUBES WITH DIFFERENT VALVE DESIGNS. RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET AIR PRESSURE WITH INCREASED OPENING OE HOT AIR VALVES. INLET AIR AND VORTEX TUBES AT 20 °C.

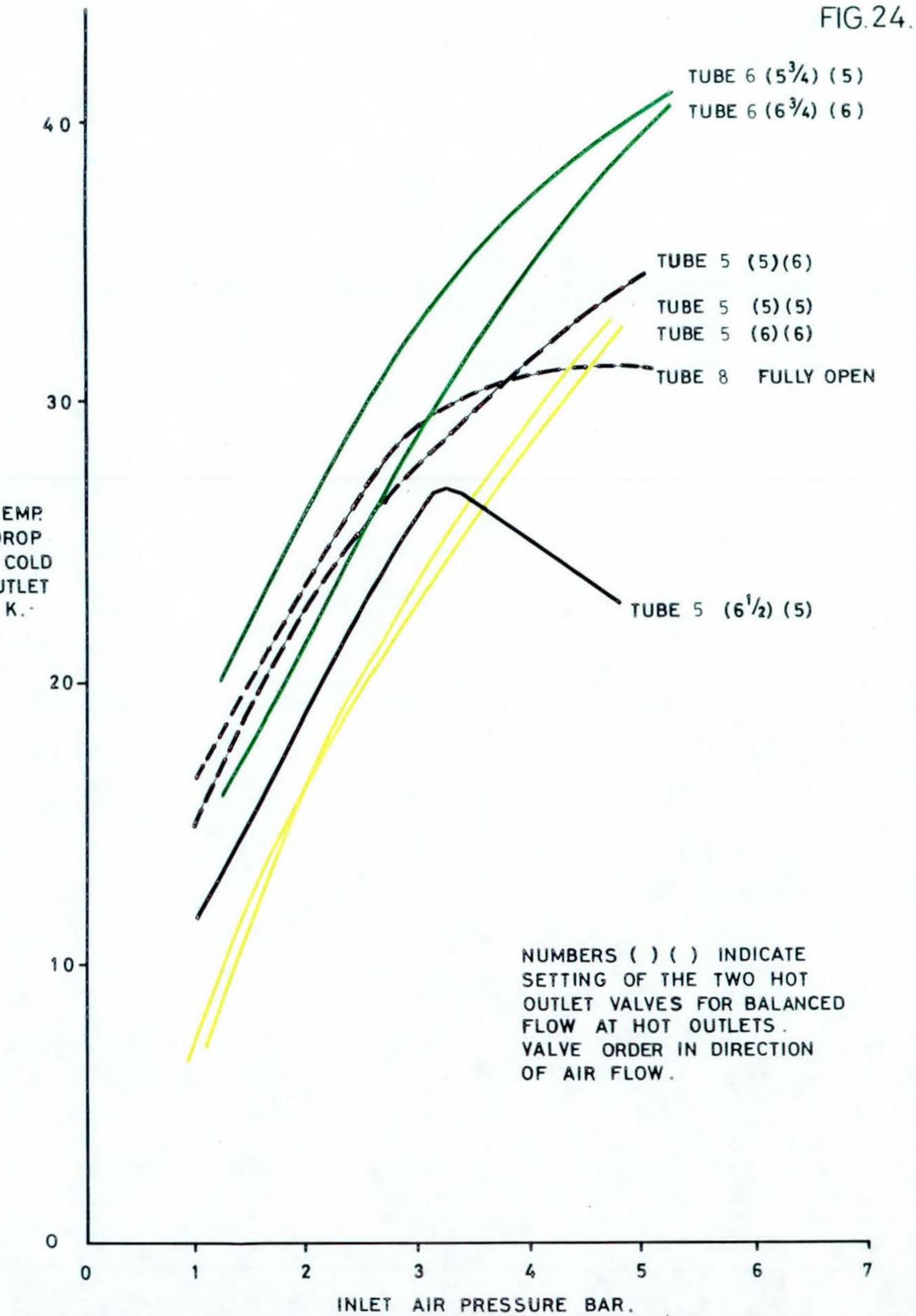


RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES FOR FOUR SIMILAR VORTEX TUBES. INLET AIR TEMPERATURE 50°C. VORTEX TUBES MAINTAINED AT TEMPERATURE 60°C.

FIG. 23.

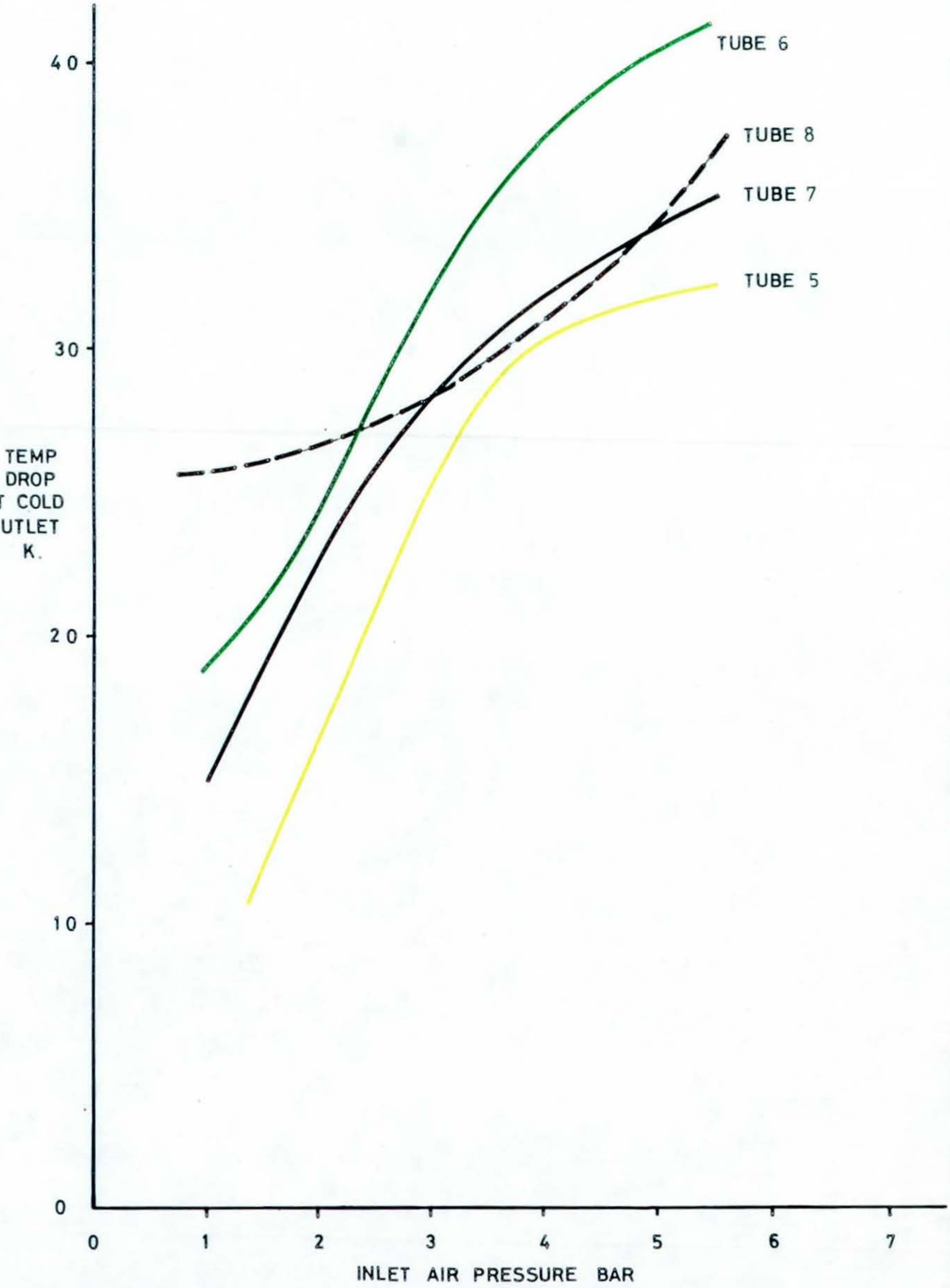


RELATIONSHIP BETWEEN AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES FOR FOUR SIMILAR VORTEX TUBES INLET AIR TEMPERATURE 50°C. VORTEX TUBES MAINTAINED AT TEMPERATURE OF 60°C



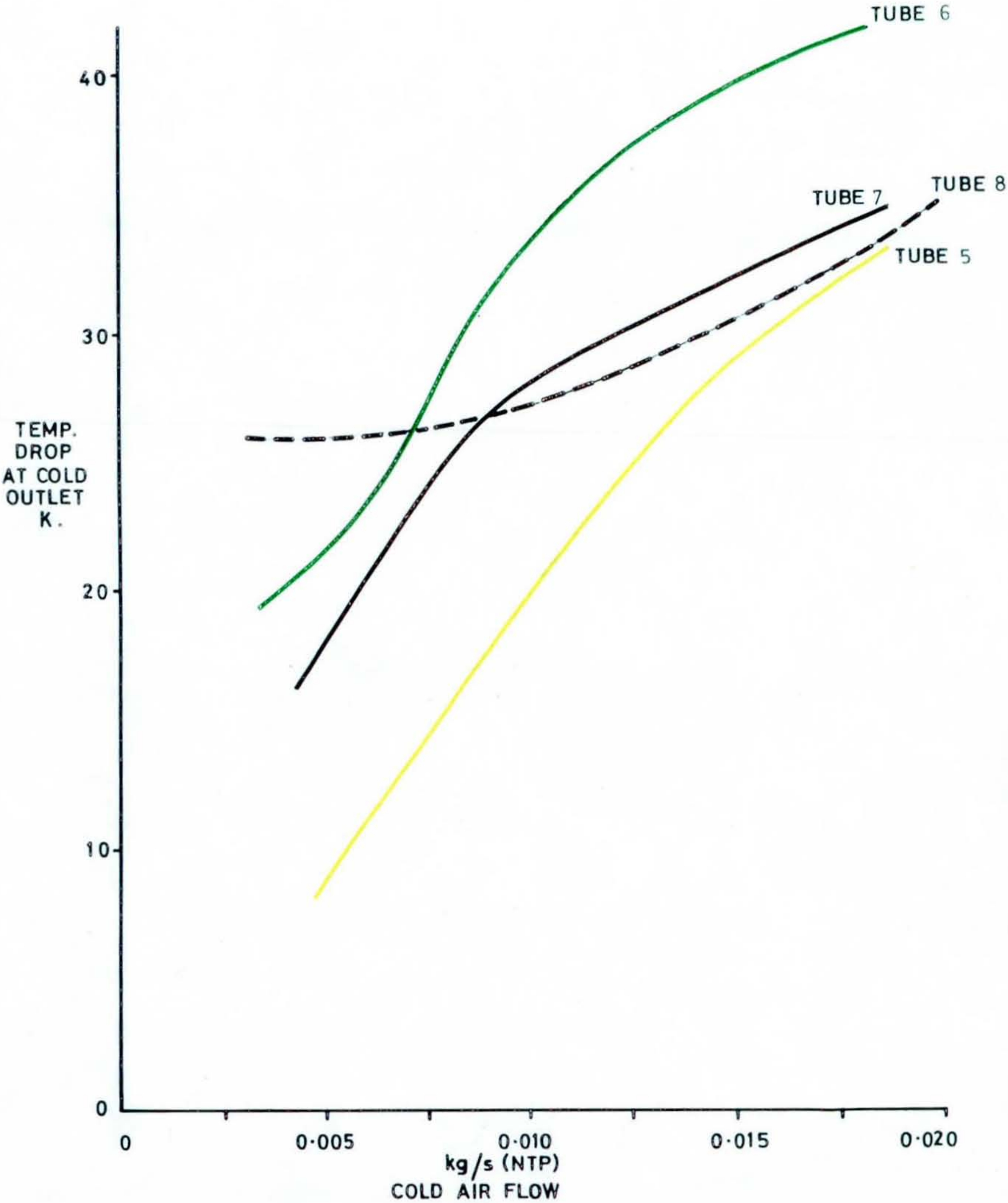
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE DROP WITH INCREASED OPENING OF HOT OUTLET VALVES FOR FOUR SIMILAR VORTEX TUBES INLET AIR TEMPERATURE 50°C. VORTEX TUBES MAINTAINED AT TEMPERATURE OF 60°

FIG. 25.



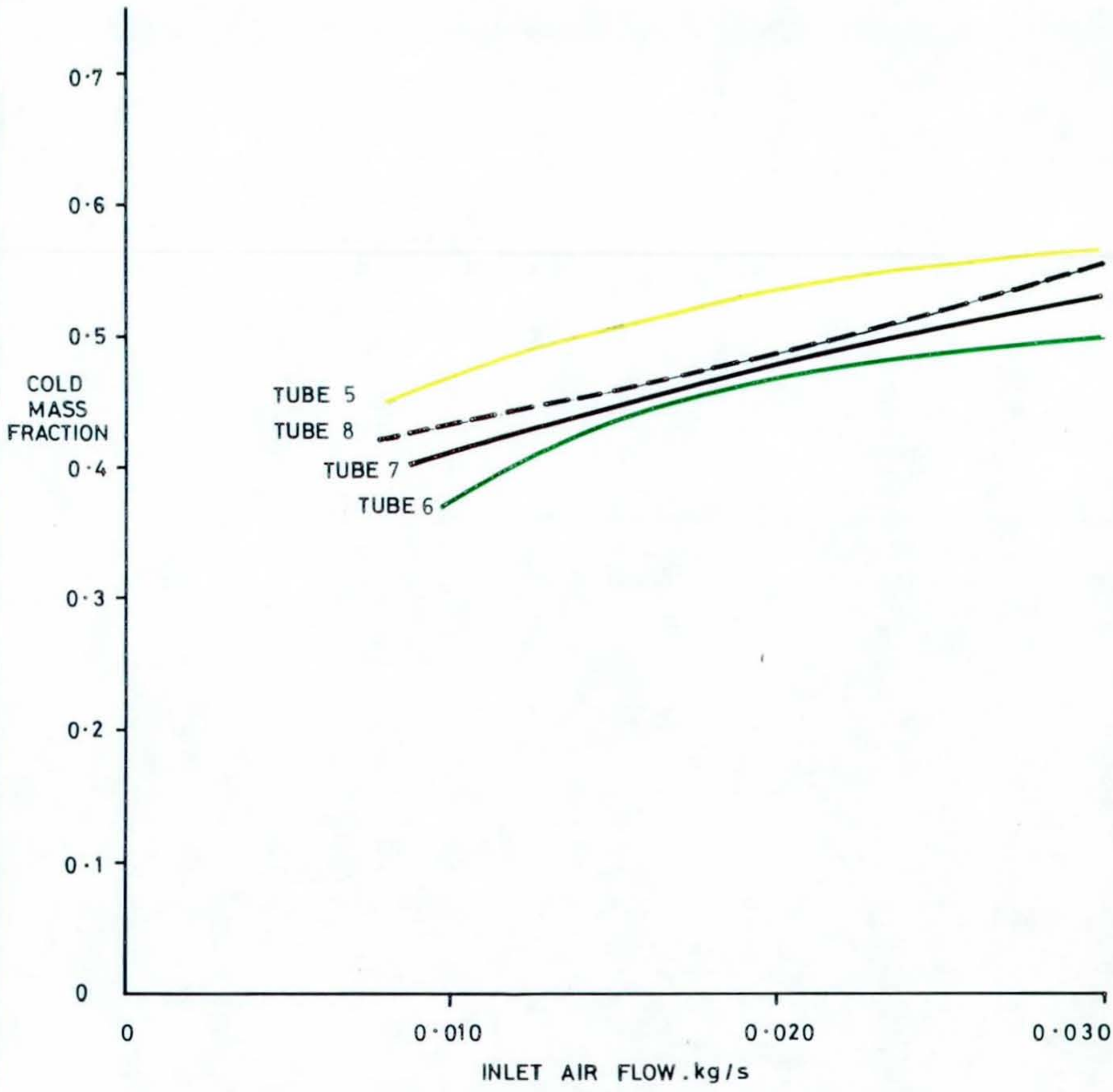
RELATIONSHIP BETWEEN INLET AIR PRESSURE AT A TEMPERATURE OF 50 °C AND MAXIMUM OBTAINABLE TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES. TUBES MAINTAINED AT A TEMPERATURE OF 60 °C.

FIG. 26.



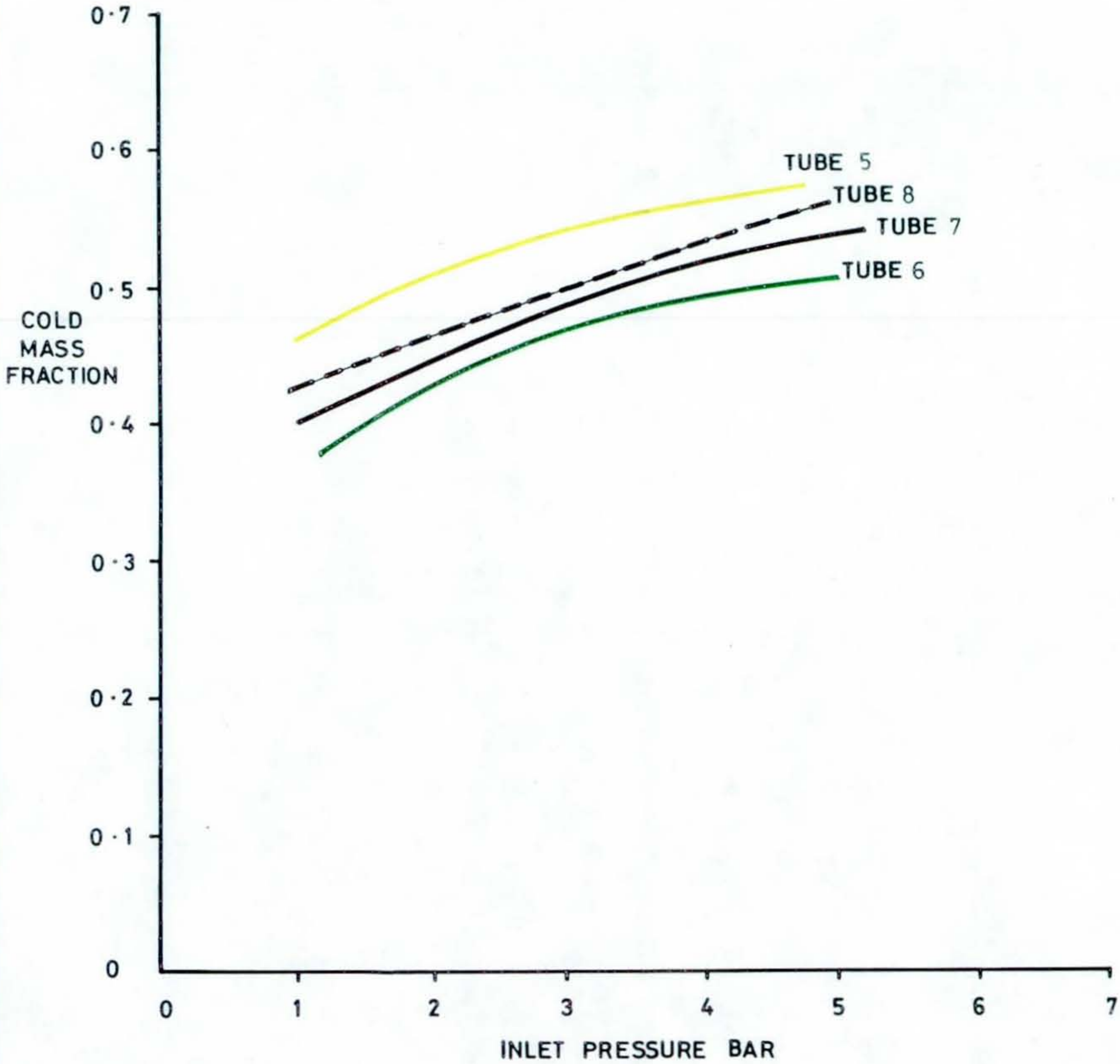
RELATIONSHIP BETWEEN COLD AIR FLOW AND MAXIMUM OBTAINABLE TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES.
AIR INLET TEMPERATURE 50°C. TUBES MAINTAINED AT A TEMPERATURE OF 60°C.

FIG. 27.



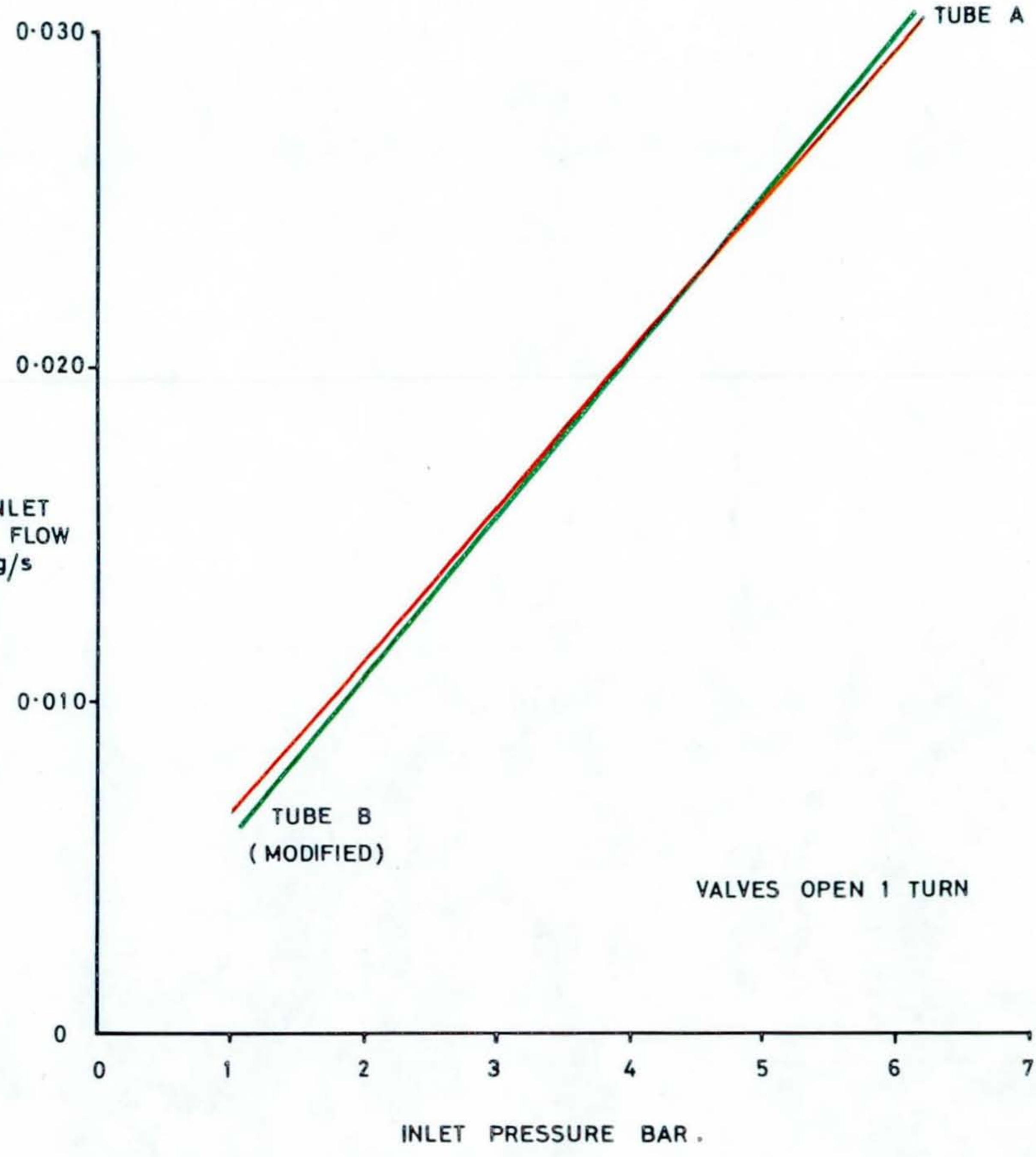
RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET FLOW AT MAXIMUM TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES.
AIR INLET TEMPERATURE 50°C VORTEX TUBES MAINTAINED A 60°C

FIG. 28.



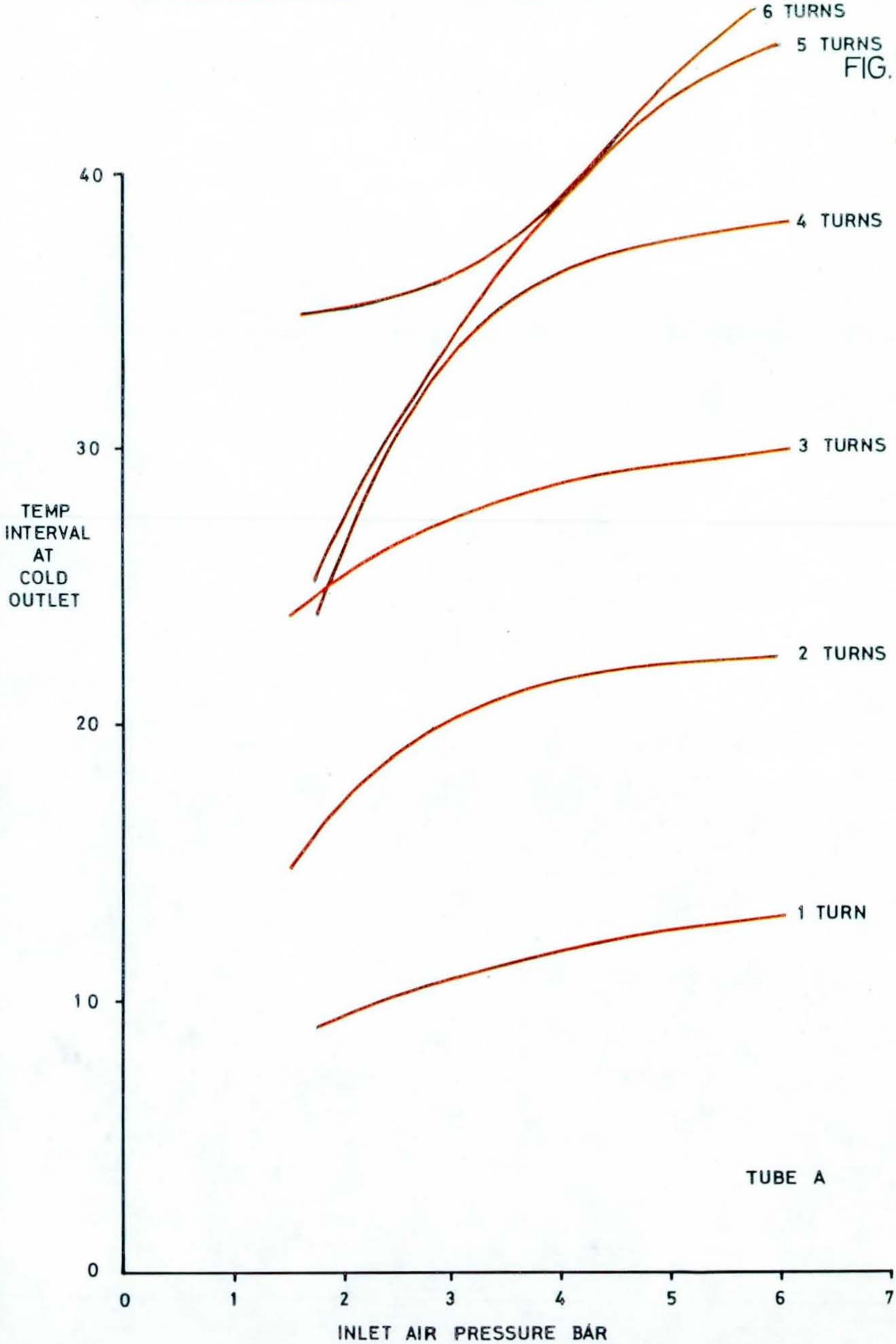
RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET PRESSURE AT MAXIMUM TEMPERATURE DROP FOR FOUR SIMILAR TYPE VORTEX TUBES. AIR INLET TEMPERATURE 50 °C. VORTEX TUBES MAINTAINED AT 60 °C.

FIG. 29.



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

FIG. 30.



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.

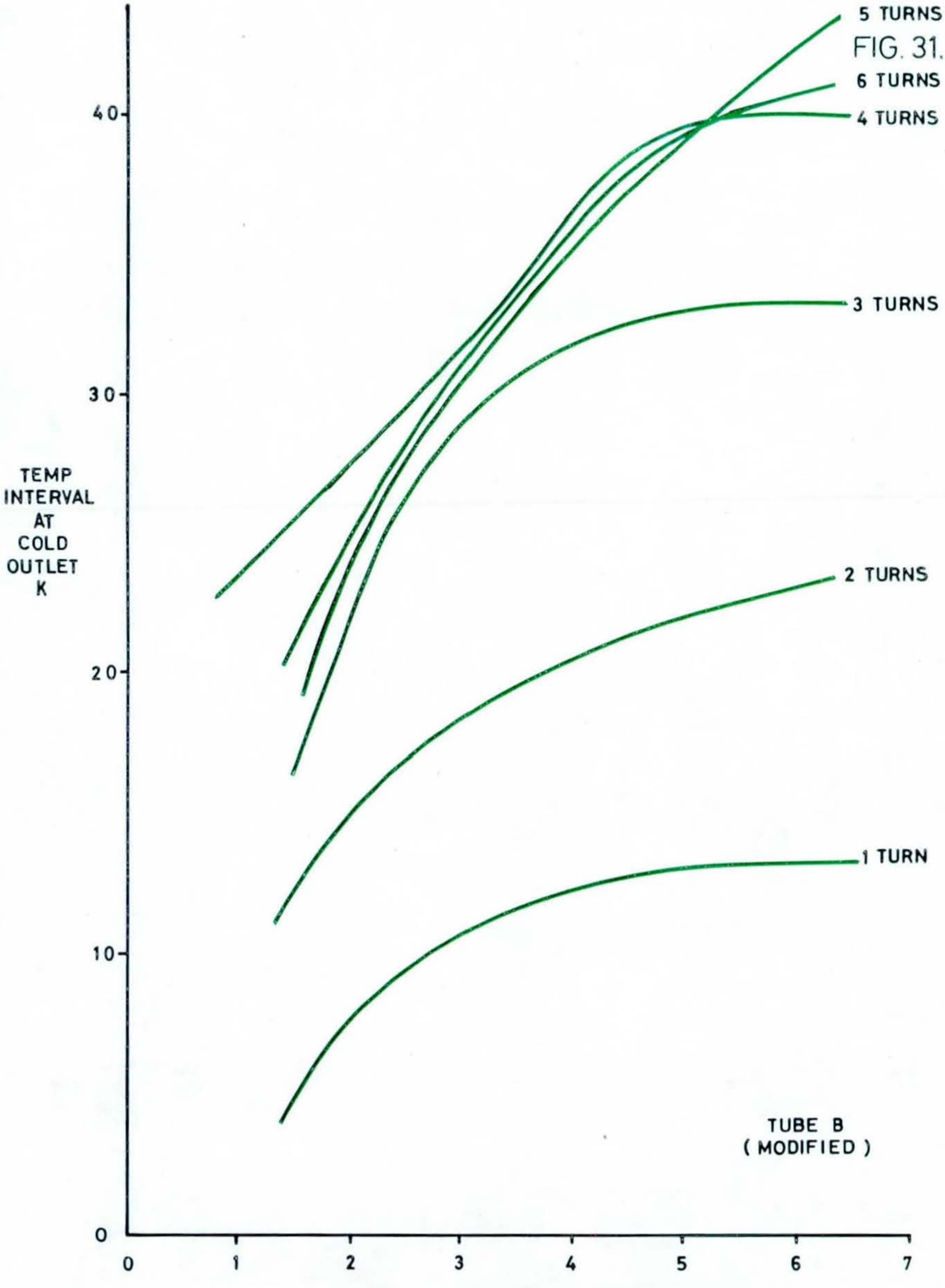
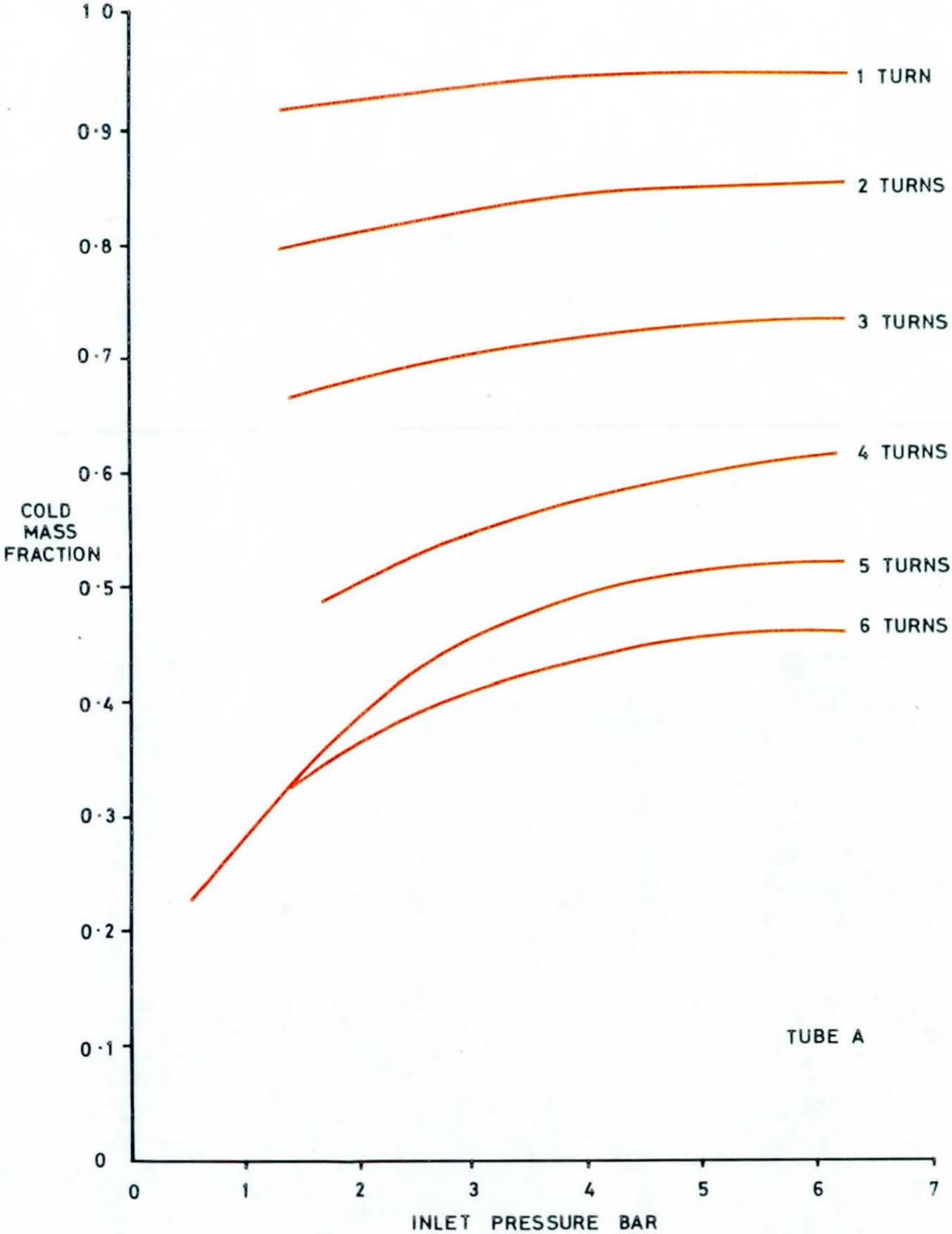


FIG. 31.

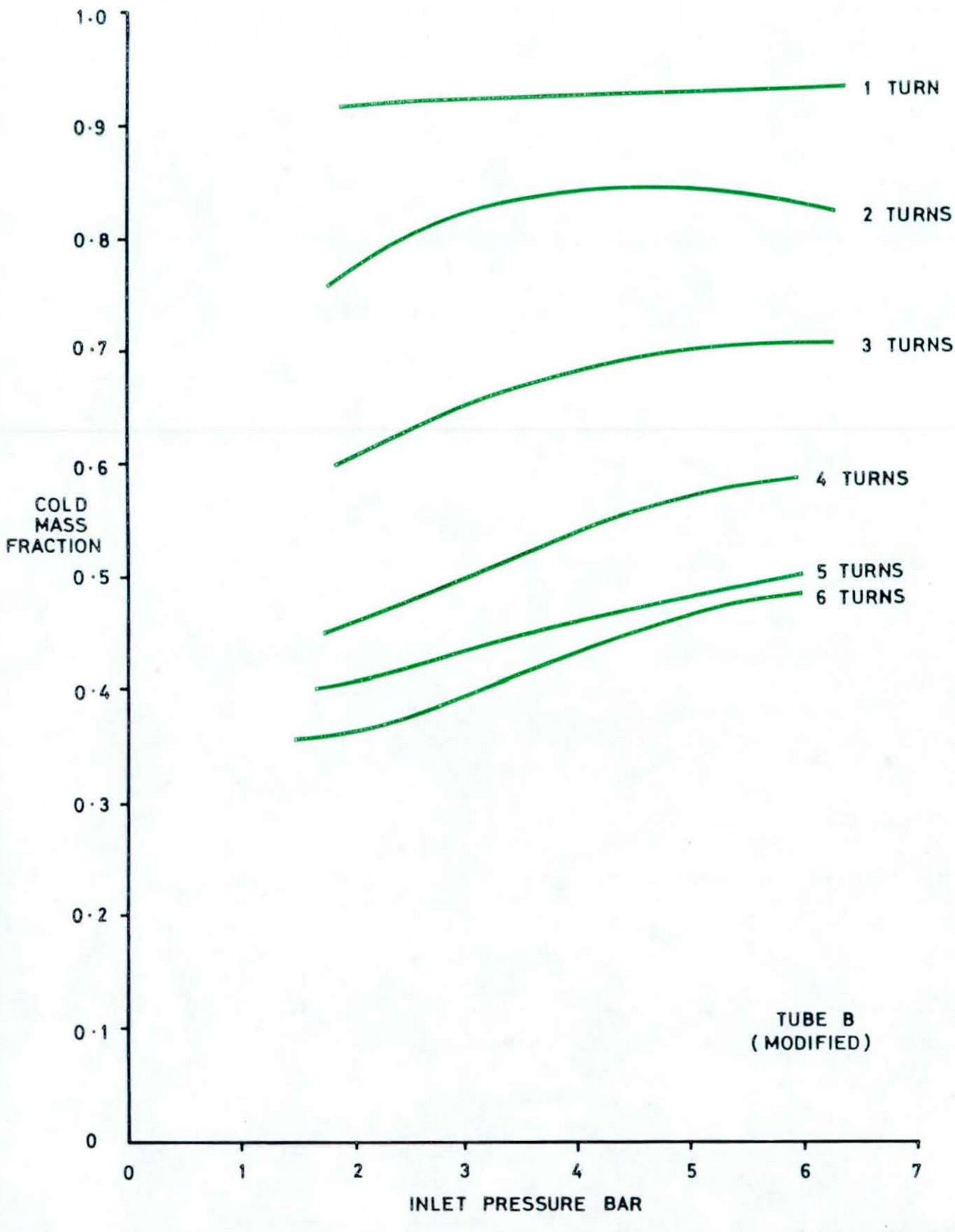
RELATIONSHIP BETWEEN INLET AIR PRESSURE AND TEMPERATURE INTERVAL K WITH VARYING HOT VALVE OPENING.
INLET AIR TEMPERATURE 50°C. VORTEX TUBE AT TEMPERATURE OF 60°C.

FIG. 32.

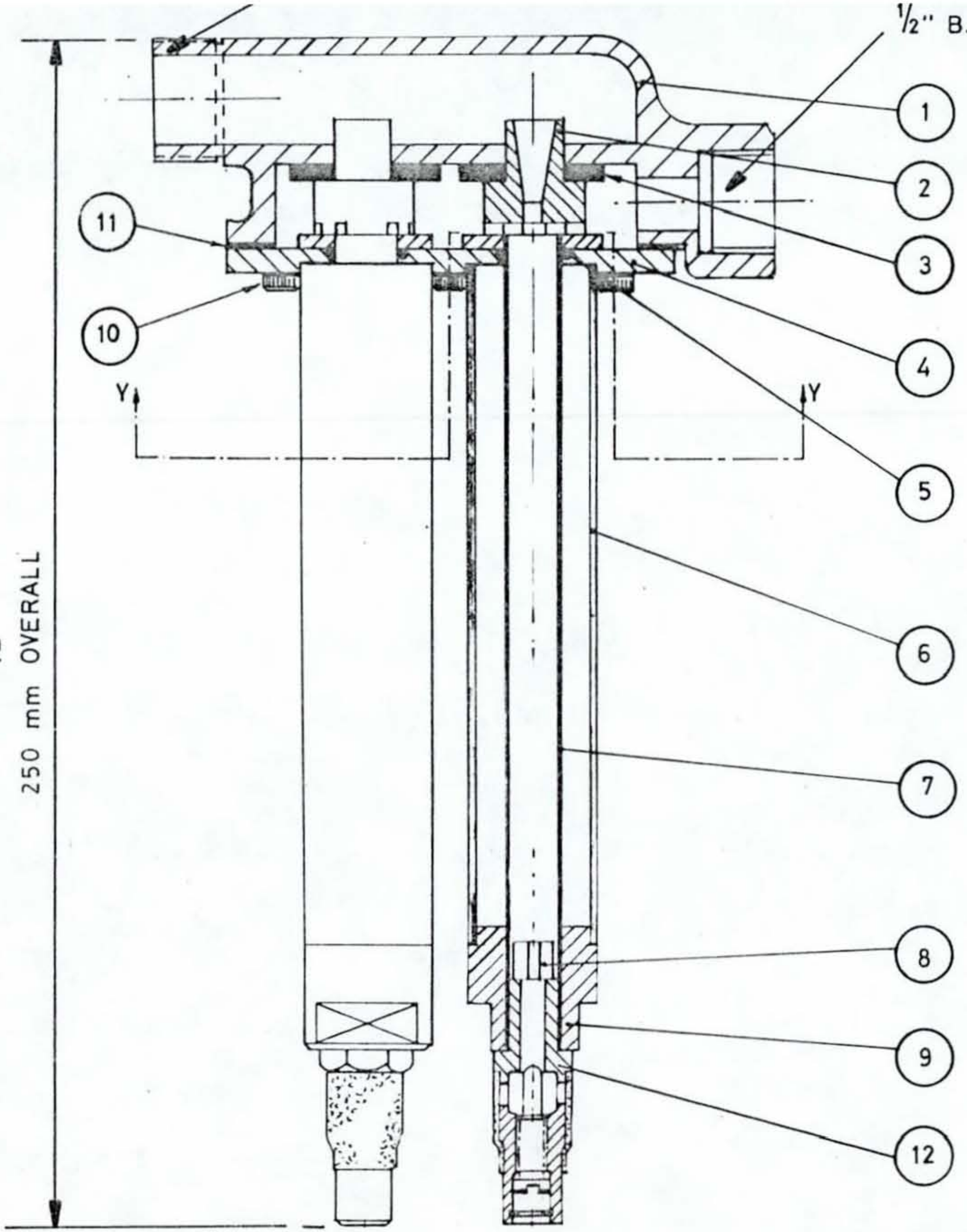


RELATIONSHIP BETWEEN COLD MASS FRACTION AND INLET AIR PRESSURE WITH VARYING OPENING OF HOT OUTLET VALVE.

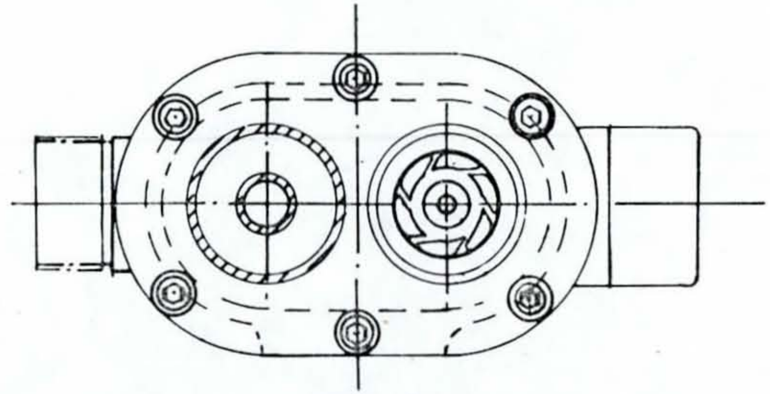
FIG. 33.



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



DUPLEX VORTEX TUBE

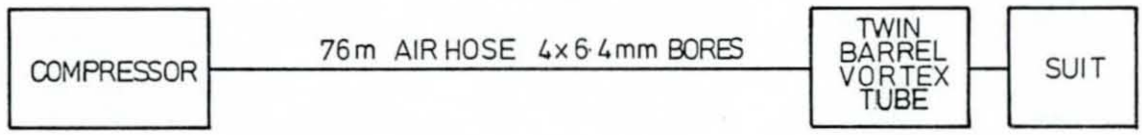


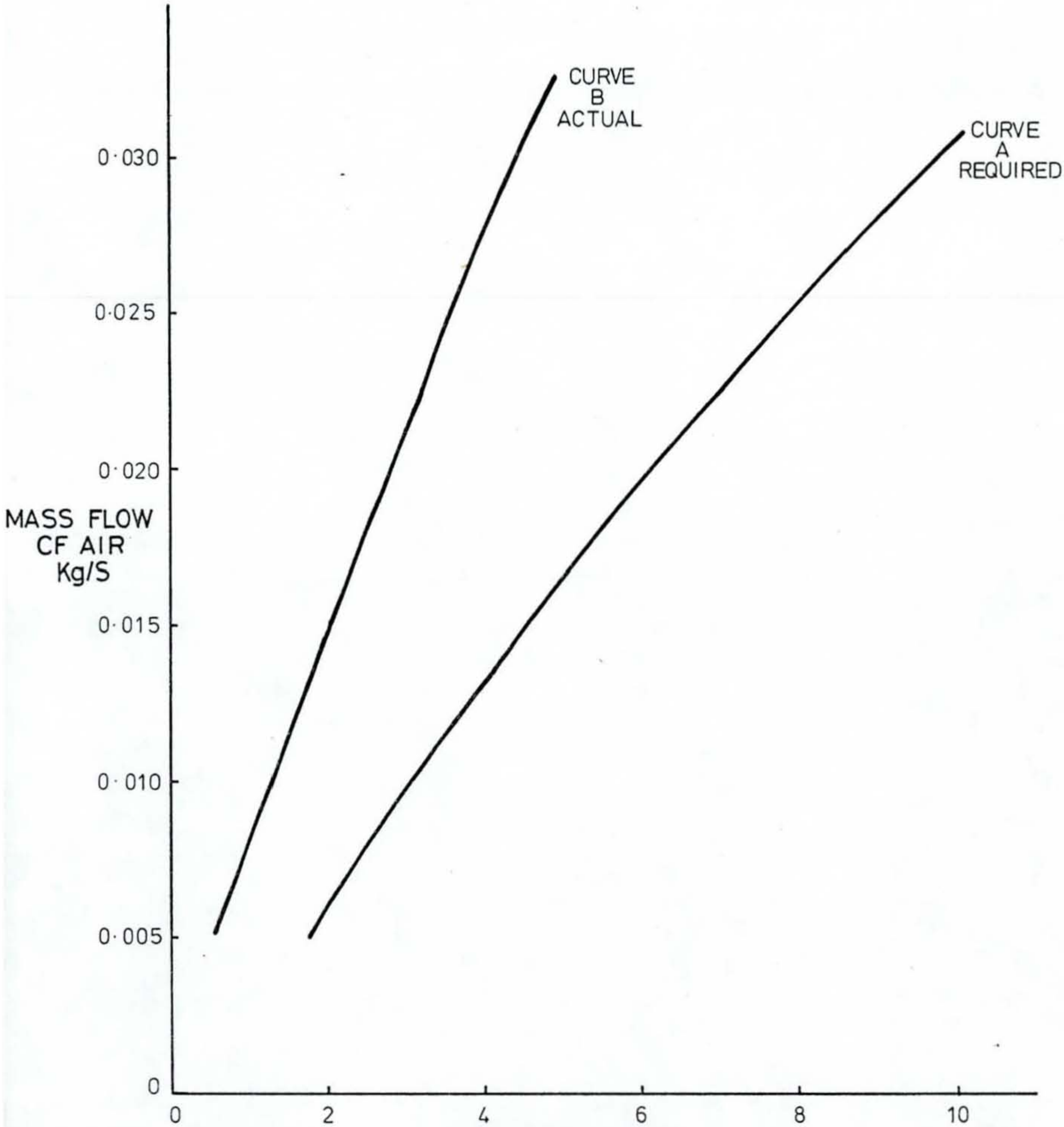
VIEW YY

REF	Nº PER DUPLEX TUBE	DESCRIPTION	MATERIAL	COMMENTS
16				
15				
14				
13				
12	2	Combined Muffler & Adj. Valve	Brass Alumin^m	SCHRADER Nº 53006
11	1	Header Joint	C.A.F.	
10	6	Bottom Plate Securing Screws	Mild Steel	
9	2	Hot Valve Body Ass'y	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

FIG. 34.

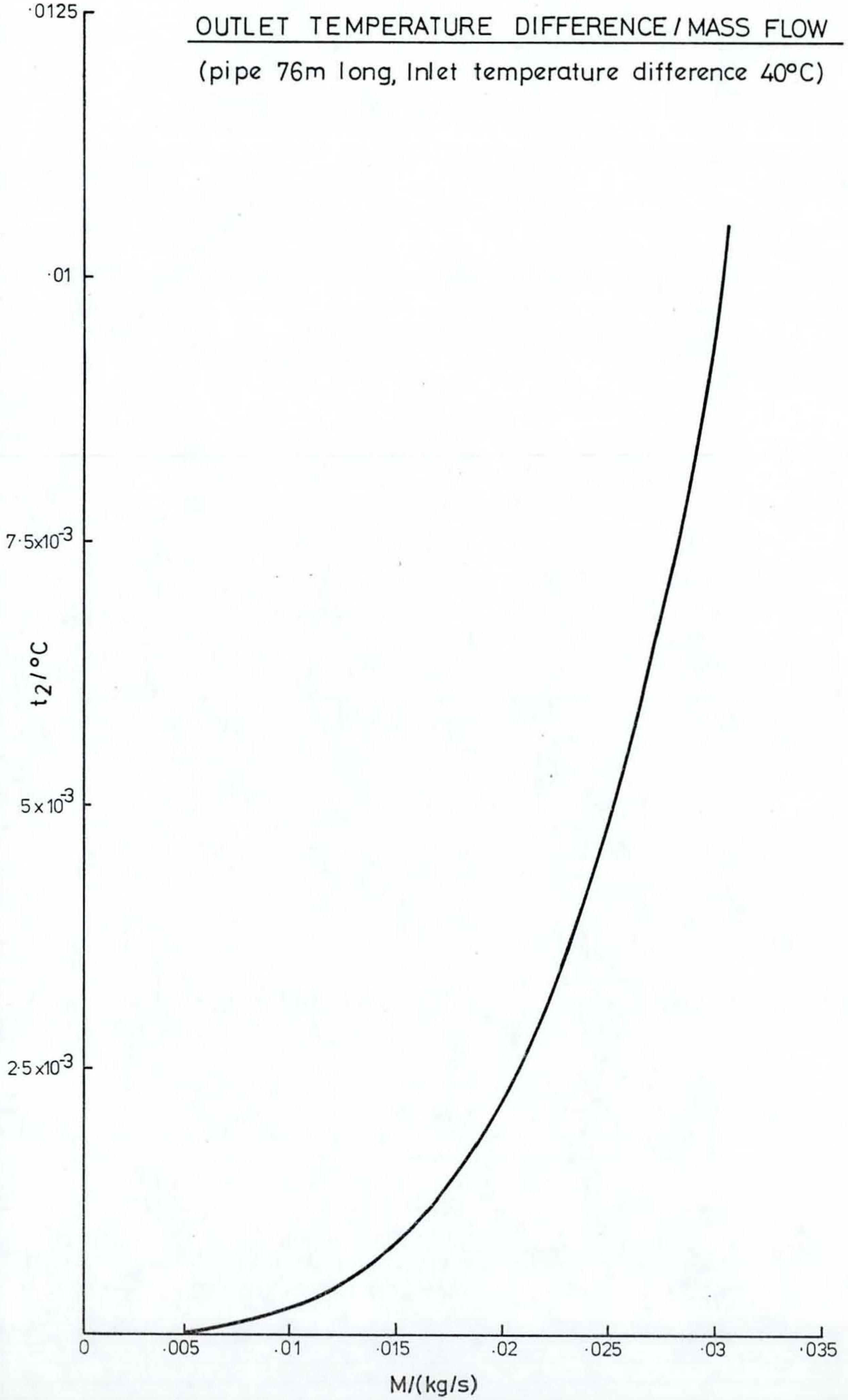
FIG. 35.





PRESSURE LOSS THROUGH AIR SUPPLY HOSE.
RESULTS OF A PRATICAL TEST USING 76m LENGTH OF 4x6·4mm BORES SUPPLY HOSE AND A TWIN BARREL VORTEX TUBE.
INLET AIR TEMPERATURE TO VORTEX TUBE 50°c

FIG. 36.


OUTLET TEMPERATURE DIFFERENCE / MASS FLOW
(pipe 76m long, Inlet temperature difference 40°C)
·0125
·01
7·5x10-3
5x10-3
2·5x10-3
t_2/°C
0
·005
·01
·015
·02
·025
·03
·035
M/(kg/s)

TEMPERATURE OF AIR ALONG HOSE

(initial temperature difference 40°c)

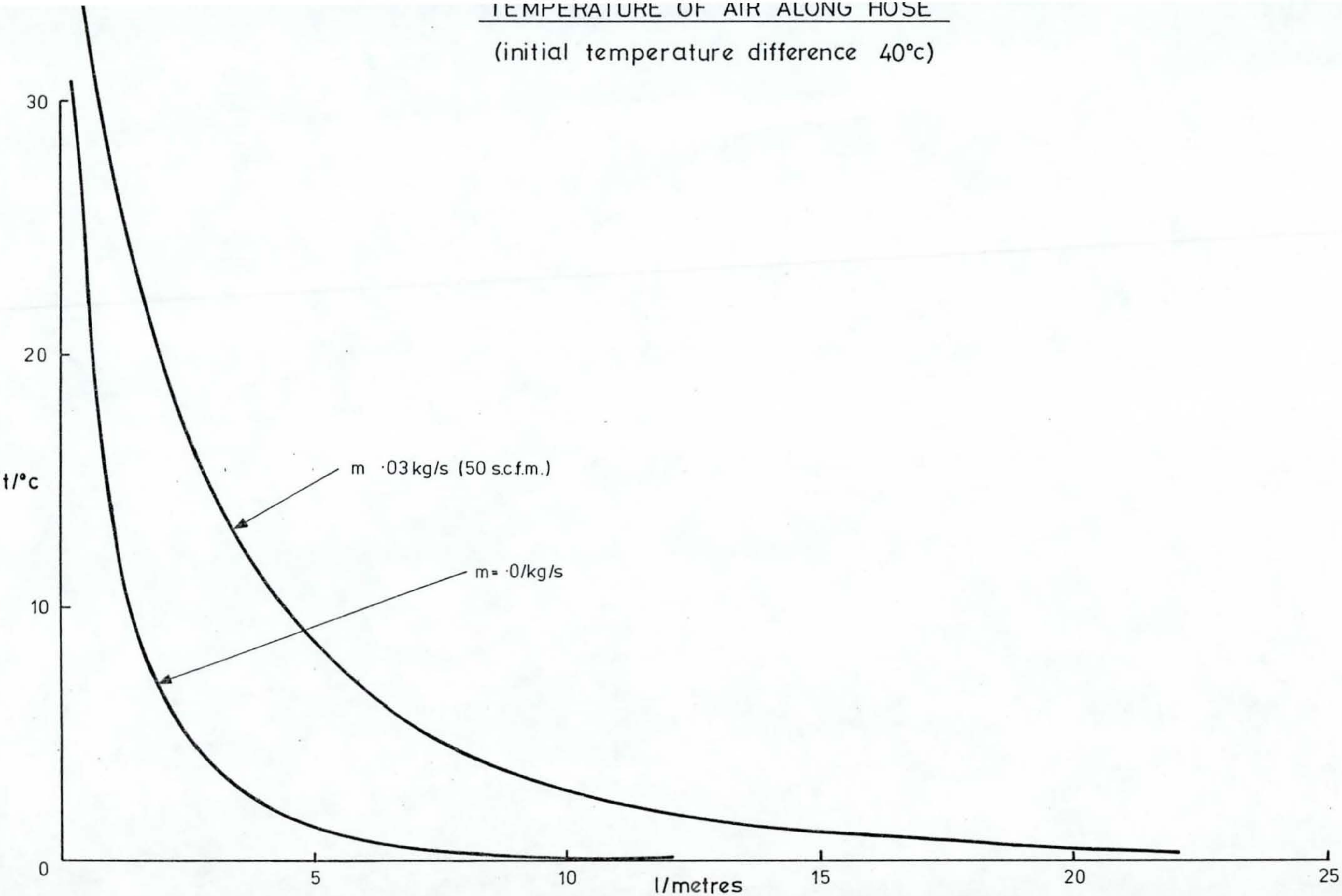
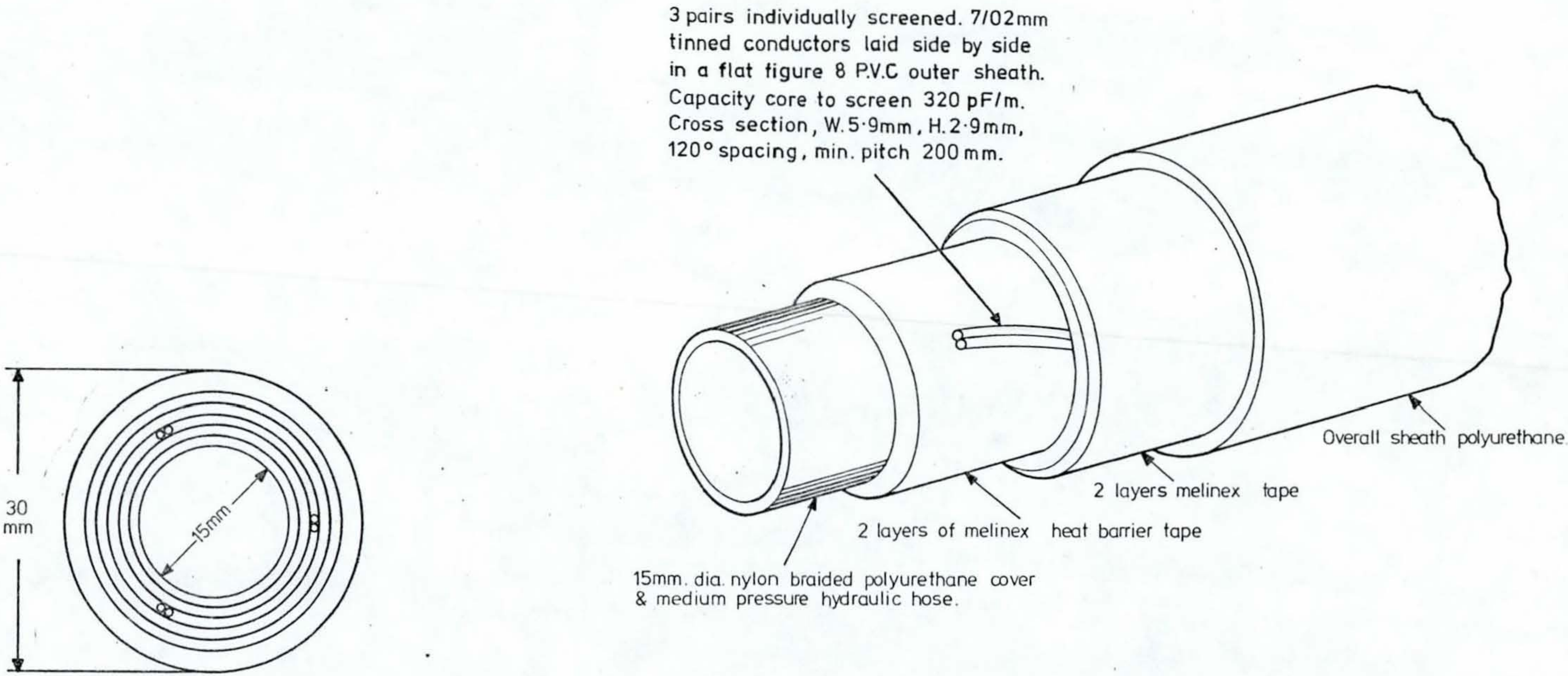


FIG. 37.



PROPOSED AIR/COMMUNICATION HOSE DESIGN.

FIG. 2·38

INTERIM REPORT BY THE WORKING PARTY CONCERNED WITH THE DEVELOPMENT OF PROTECTIVE CLOTHING FOR WORKING IN HOT CONDITIONS DECEMBER 1967

APPENDIX C

SUMMARY

The Working Party considered the requirements for protective clothing to enable work to be carried out in hot environments, which would offer advantage to the Board. It was concluded that clothing giving protection for prolonged periods in environments at temperatures up to 60°C was advantageous. As no suitable equipment was available commercially, a suit was developed in conjunction with Frankenstein Group Ltd. This used Vortex tubes (ref. 1) for both cooling and breathing air. The suit has been tested to 80°C in the hot climatic cell of the Institute of Aviation Medicine, Farnborough and tests of manoeuvreability have been carried out at stations. Ancillary equipment such as reflective coveralls, gloves, footwear, hoses etc. are available from commercial sources and a "catalogue" of suitable equipment is being drawn up for circulation within the Board. The suit and hood will be included in this list, and the cost of a complete outfit is estimated to be £150.

Proposals are made regarding further limited development work on the suit to enhance its performance in special circumstances.

Contents

Schedule of Figures

Protective Clothing for Working in Hot Conditions

1.0 Introduction

At Oldbury and later nuclear stations the boilers are enclosed, with the core, in a prestressed concrete pressure vessel. With this arrangement, shutdown cooling of the boiler gas passes is made more difficult and estimates indicate that temperatures in the range 20 - 50°C would be experienced during statutory inspections. To reduce maximum temperatures by a further 10°C would delay inspections by one week.

The economic penalties caused by the outage of modern thermal station boilers also led to the consideration of protective clothing to permit earlier access to the gas passes for inspection and to improve the efficiency of men working in hot conditions.

After consideration of the various types of suit developed for other similar applications a decision was made to develop an air-cooled suit of ventile material capable of being used in ambient temperatures of up to 60°C.

Two suits were made up to the Working Party's requirements by Frankenstein Ltd. in conjunction with M.S.A. Ltd. who provided vortex tubes for cooling the air feed into the suit. These vortex tubes take compressed air at about 100 lbf/in^2 fed by air line from a compressor installation and provide a cooled air supply at low pressure to the suit for both breathing and cooling purposes.

Following tests on the first two prototype designs of suit further development was found necessary and a redesign was carried out by Frankenstein Ltd. The new design was tested and found potentially satisfactory for many of the applications considered: for the purposes of this report it will be referred to as the Mark I suit.

2.0 Scope for Special Protective Clothing for Work in Hot Conditions

2.1 Requirements in Principle of a Protective Suit

2.1.1 Its use should offer a significant reward.

2.1.2 It should be safe, reliable and simple to use in the circumstances envisaged which could involve hazards for which the suit is no protection.

2.1.3 It should allow men to carry out the required work with the necessary precision and at an adequate rate.

These principles are used to assess qualitatively the following possible applications for such a protective suit.

2.2 Qualitative Assessment of Possible Applications of Protective Suits

2.2.1 For use after a nuclear reactor pressure circuit failure which releases hot Carbon Dioxide

The extent of the hot gas hazard in the vicinity of a nuclear reactor, following a pressure circuit failure, is difficult to assess, but it is considered that a limit can be set on it. If the gas temperature is significantly higher than 172°C it will be less dense than air at 20°C.

Even with inversion conditions in the atmosphere, local dispersion of the gas through ventilators and smashed windows should be rapid. Some hotter gas may be trapped at isolated points in the building and will commence to lose heat to the structure. Hence, by the time arrangements to use a protective suit could be made in such circumstances it is highly likely that the maximum temperature to be encountered would be about 170°C. Gas at temperatures below 170°C will be heavier than the surrounding air and will disperse. No significant thermal radiation hazard will be present.

Rescue

If a cooled ventilated suit is necessary after the time that will elapse before such emergency operations can be arranged, persons trapped in the area are likely to have succumbed to the asphyxiant gas or the heat, which must go together. If survivors, possibly injured, were found in air pockets, they could not be moved without being provided with similar suits. The difficulties of carrying additional suits possibly with connected hoses, dressing survivors, instructing them in the use of the suits and guiding them out of the area whilst they are likely to be in a state of shock makes such an operation a severe risk to rescuers and survivors. It is considered that a greater chance of survival would be presented by operations to disperse the hot carbon dioxide as quickly as possible, when self air apparatus would suffice, possibly combined with present available equipment which can be considered as a separate study.

Damage Control

The maximum foreseeable failure of the concrete pressure vessel circuits only involves a single penetration which will not cross gas flow lines. Therefore, air entry to the core after depressurisation should be small. (The main aim will be to return the reactor to service). If the incident is sufficiently serious to demand the use of hot suits, to allow rapid inspection, the proportion of the outage time saved by the use of the suit will be negligible.

Coupling this with the low probability of the incident makes the cost of developing a very high temperature suit and continually training personnel in its use unjustified.

Steel pressure vessel stations present a different problem. The maximum foreseeable incident is a duct failure with both valves in the damaged circuit remaining open. In this case the aims in order of importance are to maintain maximum cooling and to prevent the ingress of air to the breached circuit. This is to control a possible reactor transient following the incident.

Whilst the gas remains in sufficient quantity to maintain a temperature of 170°C it must be providing an efficient barrier against air ingress to the vessel and it would appear appropriate to carry out inspections of the breach without disturbing the gas. However, main circulator motors, pony motors and control equipment working in gas at such a temperature would be at risk and therefore to maintain maximum cooling of the reactor core the first aim must be to cool or disperse the gas. All possible ventilation should be provided long enough to drop the temperature of the gas which must already be losing heat to the building and its contents. When this is achieved the ventilation should be shut off as far as possible, when personnel could probably work in self air suits or air-line equipment without a cooled suit. At the most it would appear that a suit adequate for work in temperatures between 60° and 80° would be necessary.

2.2.2 <u>For Use in Inspecting Boilers in Concrete Pressure Vessels</u>

Calculations indicate that to delay Factories Acts inspections of the gas sides of boilers in concrete pressure vessels until temperatures are significantly below 60°C is unacceptable. To inspect under such conditions without a suitably cooled suit is likely to be abortive. A suit for work at 60°C appears to be a necessity. Access for this work does not appear to present a severe problem.

2.2.3 <u>For Use During Work on Boiler Furnaces and Internal Pressure Parts early after Shut-Down</u>

In the light of the likely development of rapid cooling techniques for boilers it is considered that the savings in time resulting from the use of cooled suits could be extremely marginal. <u>These rapid cooling techniques are to be explored further</u>.

In addition, other hazards to personnel in the boilers appear to override the protection of the suits. In the furnace bottom, falling slag is a likely danger and the restricted vision of the helmets of the suits do not assist in avoiding the danger. To consider the installation of lifting cradles in the furnace to raise men to the roof appears to offer an unacceptable risk of falls if they are wearing the suits and gloves which must impede their movements to some extent. In the upper passes of the boiler, the danger of men falling and lying on hot metal for which a practicable suit provides little protection, seems unacceptable. Finally, it is felt that the use of the suits would reflect adversely on the quality of precision repairs to the pressure circuits. It is felt that only inspection or non-precision work could be carried out by men wearing the suits. On this basis, the impact on the length of outages could be marginal, not justifying the additional hazards to personnel, the continual training of personnel or the administrative difficulties of the medical control required (see Appendix 3). Later passes of the boilers, precipitators, etc. where better walking areas may be available may benefit from the use of a cooled suit but here temperatures will be substantially lower.

Where it is possible for repairs to be carried out from outside the boiler casing the main, but simpler, problem is that of radiant heat. This appears to apply to all work in the turbine house. Simple shields, augmented by enveloping cold air from a mobile blower would appear to suffice.

2.3 <u>Basic Requirement</u>

On the basis of these considerations it is considered appropriate to limit the requirements for the suit to allowing a man to work comfortably for two hours in an ambient temperature of 60°C.

3.0 <u>Equipment and Tests</u>

3.1 <u>Suits</u>

The prototype suits are described in Appendix 3 and their deficiencies are recorded in the reports of tests given in Appendix 4.

Figure 3.1A illustrates the Mark I suit together with the Mark I hood: Figure 3.1B shows the suit minus hood to illustrate the neck and the connections for the air supply to the hood.

This suit consists of an inner suit of nitrogen blown foam, covered and quilted with a nylon cover (see Figure 3.1C). Cooling tubes of thick wall P.V.C. perforated at intervals are fitted on the inside of this garment and fed from a padded manifold. (See Figure 3.1D). The main air inlet enters the suit at a sharp angle to reduce the snagging hazard found on the prototype suits.

A coverall of close weave ventile cotton material is used outside the inner garment to act as a wear resistant and sacrificial item. This coverall, like the inner garment, is zip fronted and elasticised at wrists and ankles. The coverall also has penetrations for the inlet air tube and for the two connections onto the hood air distribution tubes. The Mark I hood is fastened onto the coverall by a long zip at the back and two short zips on the chest.

The Mark I hood has a moulded perspex visor which gives good 'all-round' visibility. The hood is however of the rigid type and thus does not move with the head: that is to say, it is similar to the helmet of a standard diving suit in this respect. This approach to hood design was taken for two principal reasons. Firstly, it overcomes the difficulty of 'sealing' hood to suit and secondly it keeps the head from continuous contact with visor or back causing local hot spots of skin. Padding of the hood serves to protect the head from heat and accidental contacts.

Tests were carried out on the suit in the hot cell at the Institute of Aviation Medicine, R.A.E., Farnborough. In these tests the subject simulated a steady light working effort by stepping on and off a 7" high step at a fixed rate. Tests were carried out at ambient temperatures up to 80°C, the subject being medically observed and the suit's requirement for air, in terms of quantity and temperature measured. In addition the general comfort afforded to the wearer was judged.

The results of these tests are given in Appendix 6. Generally the Mark I suit was found to be satisfactory. From measurements made the insulation value of the suit was estimated for use in system design calculations.

Further practical tests are being carried out on the suits to determine its suitability for carrying out certain work.

3.2 Vortex Tubes

The theory of vortex tubes is described in Reference 1. All tubes used to date have an air consumption of about 1.9 lb/min (25 s.c.f.m.) at a pressure of 100 lbf/in^2. Each tube has a control for varying the cold fraction quantity. Since adjustment of these controls is not easy for a suit wearer, it is intended that the fraction control should be set before entry. During entry adjustments are effected by controlling the air supply pressure to instructions from the wearer. For this purpose an attendant and control valve are sited immediately adjacent to the access point.

During the tests, three vortex tube assemblies have been used. For low temperature applications (55°C) a single vortex tube assembly of M.S.A. (Mine Safety Appliances Co. Ltd.) manufacture was used. At the higher temperatures assemblies using two tubes in parallel were used. One assembly was made by M.S.A. and the other by Vortair Engineering Ltd. Both assemblies were similar and are worn on a webbing belt looped on the coverall. The air hose drapes from the assembly which is worn on the back of the left hip as shown in Figure 2.2A. The assemblies are shown in Figures 3.2B - D.

The three tube assemblies used in the Farnborough tests were tested by the South Eastern Region Test and Efficiency Section. Results are given in Appendix 7.

4.0 Basis of System Design

4.1 Heat Balance Equation

Consideration of heat transfer at the man's skin shows that:-

Heat transmitted through the suit from environment (H) + Metabolic Heat (H_M) = Sensible Heat pick-up by cooling air (H_A) + Heat lost by sweating (H_S).

As the first step in the design of the system an assessment is necessary of the quantity/temperature of air to be supplied to the suit for the range of conditions of H and H_M envisaged in the application. For this, the potential cooling capacity of the air, ($H_A + H_S$) must be calculated.

4.2 Potential Cooling Capacity of Suit Inlet Air

The sensible heat cooling capability of the air (H_A) is simply based upon the cooling air flow, its specific heat and the temperature difference between inlet and the skin.

The heat lost by sweating (H_S) can be limited by either of two considerations. Firstly, the sweat rate must be limited to 500 grams per hour for medical reasons. Secondly, even though a given sweat rate is permissible for the man, it must be possible for the air flow through the suit to take up this amount of moisture. Three factors influence this, namely the air flow, the inlet temperature and the inlet humidity. For design purposes it will be assumed that the inlet air is saturated and thus the possible pick-up of moisture can be taken as the quantity of air flowing to the suit multiplied by the difference in saturated moisture burden of air at 33°C (skin temperature) and the inlet temperature. This is shown in Figure 4.2A.

For a range of inlet air flows, the capacity of the inlet air to remove heat has been plotted against inlet temperature in Figure 4.2B. The sensible heat component H_A is calculated from

$H_A = 6.51\, F(Ts - Ti)$ where H_A is in kCal/hour

F = Air Flow in lb/min

$Ts = 33^{\circ}C$ and Ti is the inlet air temperature in $^{\circ}C$

The "Sweat Loss" component is computed from

$H_S = Q \times 0.576$ kCal/h where Q is the sweat loss in grams/hour taken from the lower of the limiting criteria given in Figure 4.2A.

4.3 Heat to be Dissipated

The total heat to be dissipated, $H + H_M$, has been plotted in Figure 4.3A. It will be seen that the environmental heat pick-up varies directly with the temperature and has been deduced from the effective insulation value found in the tests ($0.3^{\circ}C\ m^2h/kCal$).

Metabolic heat is determined basically by the nature and extent of work being carried out. The curves show the heat dissipation appropriate for a typical man resting, doing light work (200 kCal/h) and doing continuous heavy work (680 kCal/h). This latter condition results in an excessive heat load which would be impossible to handle with the vortex tubes available. Fortunately, a man doing heavy work can only work in bursts such that the mean heat rate is only about 300 kCals/hr. For design purposes it is proposed to use 400 kCal/h for this condition, as shown in the graph.

4.4 Determination of Suit Requirements

Figures 4.2B and 4.2A have been plotted with common scales of heat rate. These are also reproduced in Figure 4.4A, which is a nomograph constructed to enable, in the first place, the suits requirements for air supply to be determined. This is used as follows.

For a given application, the environmental temperature and the postulated work mode will be known and thus, from the top right hand set of curves the heat to be removed can be estimated. This heat rate can then be transferred to the top left hand curves and the maximum inlet air temperature for given inlet air flows can be deduced.

This method is best illustrated by an example. In Figure 4.4A such an example has been marked on the nomograph and the condition shown is for "Entry for inspection only is required in an environmental temperature of 55°C".

Taking inspection as a "light work" condition, the heat to be remov is that shown for point X on the "light work" curve. Transferring this to the left hand curves, the temperature/quantity of inlet air requirements can be obtained. For a flow of 1 lb/min the temperature is given by point Y_1, a flow of 1.5 lb/min requires the temperature appropriate to Y_2 and so on. It should be remembered that these curves taken from Figure 4.2B represent limiting conditions. That is, for a given temperature the flow given is the minimum flow, whilst for a given flow the temperature shown is a maximum.

During the tests it was apparent that comfortable inlet conditions were obtained in the range 10 - 25°C. Below this range discomfort from differential temperatures applied to the skin was experienced. Above, the range, general temperature discomfort is to be expected. This range has been marked on the nomograph and in deciding appropriate flows and temperatur a temperature as close to 15°C as possible is preferred, and the appropriate minimum flow can consequentially be selected.

4.5 The Vortex Tube Capability

The two vortex tube manufacturers, M.S.A. and Vortair, have quoted basic performance data for their tubes similar to that claimed for the Fulton tubes in the U.S.A. This is given in Figure 4.5A. Air flow information has not been given but tests indicate an approximately linear pressure flow relationship. (Appendix 7).

A set of curves can be derived from this data, relating vortex tube inlet pressure, cold fraction temperature and flow and the cold fraction settings. These are illustrated for a twin tube assembly in Figure 4.5B.

4.6 Vortex Tube Requirements

Having determined the flow and related temperature requirements of the suit it is now possible to determine the vortex tube supply pressures and tube settings necessary to give the required suit inlet conditions and flow.

The bottom left hand set of curves on the nomograph relate the vortex tube performance, in temperature drop and cold air flow against the required inlet pressure and cold fraction settings. Curves A, B and C have been drawn for the same flows as in the top left hand curves. Thus both curves 'A' refer to a suit inlet flow of 1.0 lb/min.

In section 4.4 above the method of obtaining limiting flow and temperature conditions at suit inlet was demonstrated. For the example given these are Y_1, Y_2 etc. The suit inlet temperature requirement can now be readily converted to a vortex tube temperature drop by the nomograph between the top and bottom graphs. It will be seen that the connecting parameter is the temperature of air at the vortex tube inlet.

For the example illustrated it has been assumed that air at the vortex tube inlet has been heated to the "ambient" condition of 55°C. Thus the condition Z_1 on curve A, corresponding to suit inlet condition Y_1 can be obtained by drawing a vertical line down from Y_1 to the suit inlet air temperature axis; thence a straight line through the vortex tube inlet temperature (55°C in example) to the "Temperature drop" axis. From this axis a vertical line is drawn to the appropriate curve (A) and the point of intersection gives both the required vortex tube inlet air pressure and setting. The cold fraction setting needed for the tube control is obtained by interpolation between the (chain dotted) curves of "constant cold fraction settings" of the point of intersection Z. Thus, in the example the conditions could be met by a suit inlet temperature of (Y_2) 24.5°C and flow 1.5 lb/minute which requires a vortex tube inlet pressure (Z_2) of 56 lbf/in^2 and the tube set to give a cold fraction of 73%.

Similarly the pressure and settings needed to give the alternative limiting suit inlet conditions can be obtained. Thus Z_2 corresponds to Y_2 and so on.

By carrying out a few exercises to determine pressure requirements, it is readily apparent that a given situation demands a lower inlet pressure if a low cold flow and better temperature drop is selected. This cannot be taken to the limit however. As the suit is of ventile material a measure of dynamic insulation is achieved. The insulation value measured in the test is therefore only applicable at flow rates similar to that used in the test. For this reason no flows below 1 lb/min have been shown and flows of not less than 1.5 lb/min are recommended. Variation of the vortex tube settings during the tests tend to confirm this effect.

It will be seen that the calculation of the necessary minimum vortex tube inlet pressure and tube setting (to satisfy a given set of conditions) can be achieved quite simply by the use of the nomograph and a straight edge.

The nomograph 4.4A is based upon data issued by manufacturers. Tests on tubes have shown that the originally supplied tubes did not achieve the claimed performance. (Appendix 7). Manufacturers are currently investigating performance deficiencies and when available practical nomograms, similar to 4.4A but based on test data, will be constructed.

4.7 Hoses and Couplings

The variety of applications envisaged for the suit make it impossible to determine a single suitable hose design. In choosing a hose for a given application the following factors must be considered:-

(a) Length: A hose length necessary to reach the furthest point of work is obviously needed but it must be remembered that the length will influence the pressure drop, the weight to be handled by the wearer and/or helpers and the heat pick-up in the hose. That is to say, temperature at the vortex tube.

(b) Size: The bore of the hose will also influence the weight, the pressure drop and the heat pick-up.

(c) Material: The material of the hose will determine the wall thickness and its insulation properties: so weight and temperature at the vortex tube will again be affected. With material however another factor arises. When certain plastics are heated, even slightly, a plasticiser may be given off. One type of plasticiser which has been used in the manufacture of hoses, is the tri-cresyl phosphates, substances which can have seriously injurious effects on the human body. Care must be exercised that such hose materials are not used.

The outer hose surface can have an effect upon the temperature pick-up of the hose by convection or by conduction from hot surfaces with which it comes into contact. In addition hoses should be kink resistant and able to be subjected to physical stresses and abrasion caused by dragging.

Some data on pressure drops and weights of hoses is given in Appendix 9.

The flow and terminal pressure for the hose is obtained by the calculation of the vortex tube requirements by the method in 4.6 above. Using this data, the pressure drop in a hose can be estimated from its length and bore using the tables in Appendix 9. The suitability of various hoses can be judged by considering their pressure drops and such other characteristics as are also listed in the Appendix.

Couplings require very careful choice. For emergency release and rescue reasons the coupling onto the vortex tube or at a point near the vortex tube should be of the quick-release, quick-coupling type. For nuclear applications, particularly, self sealing couplings are most desirabl However, the most commonly used coupling, the Spembly ball coupling has an excessive pressure drop and is therefore not suitable for the high flows to the vortex tube.

Communication between the wearer and the attendant at entry to the zone is essential and therefore the hose should be capable of taking telecommunication cabling, either bound to it, or preferably within it. Couplings must also be chosen with this in mind.

Heat pick-up is unavoidable in the hoses and unless known to the contrary the air at vortex tube inlet should be assumed to be at the environmental temperature.

4.8 Compressed Air System

The selection and care of the compressor installation is discussed in Appendix 8. Siting of the compressor air intake is important to ensure that noxious fumes and moisture are not being sucked into the system. For this reason, motor driven rather than internal combustion engined compressors are preferable. The compressor and pipework must be sized to maintain adequate pressure and quantity of air available at the take-off points. To reduce hose lengths these points should be as close to the entry point as possible.

Where prolonged work is envisaged and where long hose runs are involved, flexible self sealing manifolds coupled to the system at the entry point should be considered. Such manifolds could be erected, in sections and personnel entering could uncouple from an entry hose and reconnect to the manifold. This method would involve extra preparatory work but would reduce the hose length to be manoeuvred at any one time and could substantially reduce pressure drops should this be critical.

As envisaged, the vortex tubes would be set before entry and thereafter the pressure at the point of entry varied to the requirements of the suit wearer. Figure 4.4A indicates how regulation by this means would work. If the temperature at which work is to be carried out is known a control valve setting can be pre-selected which will give a suitable flow to the suit (viz. 1.5 lb/min) during the steady operating conditions. The pressure to each hose line should be indicated and the attendant should be informed of the expected pressures to be called for. Should substantially higher pressures be requested by the wearer, a fault should be suspected and the wearer withdrawn until the equipment has been checked.

Receivers on the system should be so sized that, with regard to the number and capacity of compressors installed, a man can be safely withdrawn on failure of a single compressor. Adequate drainage or drying must be provided in order to avoid the possibility of slugs of water collecting in the hose and subsequently being forced along to the wearer.

5.0 Restrictions and Limitations

5.1 Physiological Limitations

In considering the heat loss due to sweating, a limit of 500 grams per hour has been fixed based on the following influencing factors. When first introduced into a high temperature environment, body temperature rises and as it does so, the tendency to sweat increases. However, the sweat glands fatigue, such that after a given time the sweat rate falls off. Generally there would be an increase in sweat rate during the first hour, a peak in the second hour and an increasingly steep fall away in the third and fourth hours. The rate at which the sweat rate declines varies according to the acclimatisation of the subject. As the fall off can be very rapid in the fourth hour, exposure should be limited by administrative control. The limit recommended is TWO HOURS.

Only medically approved personnel should be permitted to use the suit. In thermal stations, staff who are regularly employed in the plant will get some acclimatisation from the normal running environment. Care must be exercised to ensure that unacclimatised staff, (e.g. Technical staff who normally spend the majority of their time in an office) are not selected even though an inspection may seem to require the attention of a senior officer. Alternative techniques, such as photography or T.V., should be considered.

Personnel required to use the suit should be medically examined annually by a Board's medical officer. An examination of the man's current medical condition must also be carried out by a medical officer or the station nurse prior to commencement of hot working. This is to check that no untoward condition has developed (e.g. a heavy cold) since the annual examination. A note on these aspects is given in Appendix 3. Some form of administrative control should be established and practice drills in the suit are advisable for all registered 'hot-suit' workers.

5.2 Working Limitations

Based upon work carried out in other industries, the mean metabolic heat rate for a man doing heavy work is only about 300 kCals per hour, although peaks of 680 kCals/hour occur. For design purposes it has been assumed that a mean of 400 kCals/hour may be appropriate. However, peaks in physical output must be avoided as far as possible due to the increased possibility of collapse following a sudden peak of output. This is partially due to the rise in body temperature following a 'peak' not recovering quickly.

Work, likely to be carried out in suits, should be critically examined and any peaks avoided where possible. For example, plates should be hinged such that they can be swung open and do not have to be lifted off: power tools should be used in preference to hand tools.

5.3 Equipment Limitations

The visor of the Mark I hood is perspex which has a softening temperature of about 85°C. However, the suit has been used at 80°C for over an hour without any sign of the visor softening. At this temperature, due to internal air cooling, the visor was hot but not unbearable when touched by the wearer's forehead.

Limitations imposed by the achievable pressure and volume of air at the vortex tube inlet are likely to prove the principal limitation to the use of the suit.

During tests, discomfort to the hands and feet was most pronounced. Improved boots and gloves are discussed in Appendix 10, but it should be noted that these are likely to act as a limiting feature long before the suit

6.0 Discussion and Proposals

6.1 Application

The tests on the Mark I suit have shown that the design is satisfactory and applications considered practicable are as follows:-

(i) Access to and inspection of boilers in concrete pressure vessels at Nuclear Power Stations.

(ii) Access to, cleaning and repair work in electrostatic precipitators.

(iii) Access to otherwise safe parts of boilers for inspection of damage.

(iv) Access to isolated flue ducts for inspection purposes.

(v) Limited work in hot situations such as (iii) and (iv) above.

It is considered that:-

(i) The utilisation of the suit should be effected only after consultation with the Regional Medical Officer who is aware of requirements.

(ii) A Code of Practice should be established to be used in conjunction with the C.E.G.B. Safety Rules. This Code of Practice should detail rules of procedure, limitations of temperature and time and methods of assessing work to be carried out and system designs.

6.2 Development

The development of a suit for higher temperature applications is discussed in Appendix 11. As potential applications appear limited, until further experience with the current design of suits is obtained it is not proposed that the development of a suit for higher temperatures should be undertaken.

The existing Mark I hood gives only limited protection to the head. A hood incorporating better head protection may be an advantage, and further development is proposed.

The possibility of using reflective material in the coverall is being examined and its use, in conditions with significant radiant heat, should be considered.

6.3 Further Study

The contamination hazard that may exist in nuclear stations may render the suit, as it stands, unsuitable. It is proposed to examine the possibility of using suitable outer coveralls, which will permit the ventile material of the suit to pass air whilst retaining protection against the ingress of contamination.

One application for which the suit is unlikely to be suitable is the access to aircraft warning lights on chimneys. It is proposed that this application should be considered separately.

"Field trials" of the suit have been limited and it is felt that the first applications in the use of the suit should be carefully observed and reported.

In tests, limitations have been imposed by ancillary equipment such as hoses, gloves and boots. It is proposed that investigations into ancillary equipment should continue and a "catalogue" of suitable equipment should be drawn up for circulation within the Board.

7.0 References

1. Ranque - Hilsch Vortex Tubes, Fulton Cryogenics Bulletin No.2.

Composition of Working Party

The original composition of the Working Party which initially met on 5 November 1965 was as follows:

Chairman	Mr. A. Sherry	- Assistant Chief Operations Engineer, Operations Department H.Q.
	Dr. J.F. Erskine	- South Eastern Region
	Mr. R.A. Green	- Station Superintendent, West Thurrock Power Station
	Mr. P.H.G. Holbrook	- Station Superintendent, Wylfa Nuclear Power Station
	Dr. D.A. Wilson	- Nuclear Health and Safety Department, H.Q.
Secretary	Mr. E. McEvoy	- Plant Operations Branch, Operations Departmen H.Q.

Due to retirement, transfers etc. the following changes were made to the composition of the working party.

Chairman Mr. S.I. Ainsworth, Plant Engineer, Plant Operations Branch, H.Q. succeeded Mr. Sherry.

Dr. J.A. Bonnell, Deputy Chief Health and Safety Officer (Medical) and Mr. R.B. Pepper, Nuclear Health and Safety Department successed Dr. D.A. Wilson.

Mr. H. Tresise, Oldbury Power Station and Mr. J. Davies, Standards Branch, S.E. Region joined the working party in May 1966.

Mr. D. Lloyd, Midlands Region joined the working party in July 1967.

Secretary Mr. N.W. Hodges, Plant Operations Branch succeeded Mr. E. McEvoy.

The Working Party have received assistance, which they gratefully acknowledge from the following persons and organisations.

Mr. J. Exley	- Station Superintendent, Oldbury Power Station and his staff
Mr. J.L.M. Davies	- Safety Officer, (North) S.E. Region
Mr. E.J. Payton	- Senior Assistant Engineer (Efficiency and Testing S.E. Region
Mr. P. Scutt	- Station Superintendent, Northfleet Power Station and his staff

The Officer Commanding, Institute of Aviation Medicine, R.A.E. Farnborough and his staff.

Dr. Otto Edholm, Division of Human Physiology, Medical Research Council, National Institute for Medical Research, Hampstead.

Frankenstein Group Ltd., Hunt Lane, Broadway, Chadderton, Lancs.

Mine Safety Appliances Company Ltd., Queenslie Industrial Estate, Glasgow E.3.

Vortair Engineering Ltd., 78 Buckingham Gate, London S.W.1.

Bibliography

1. An analysis of environments compatible with thermal comfort in man. FPRC Memo 134.

   Flight Lieutenant J. Billingham and D. McK. Kerslake, Climatic Research Laboratory Institute of Aviation, Royal Air Force, Farnborough.

2. Heat Stress and Heat Disorders, C.S. Leithead and A.R. Lind (Cassell).

3. Use of Vortex tube for cooling wearers of industrial protective clothing.

   J.M. Alexander, J.J. Croley, R.R. Messick, A.E.C. Research and Development Report DP-861, Savannah River Laboratory.

4. The Vortex Tube, Vortair Engineering Ltd.

5. Heat-Protective Ventilated Jackets: A comparison of humid and dry ventilating air.

   G.W. Crockford and D.E. Lee, Brit. J. Industr. Med 1967, 24, 52.

6. Working in Heat, SAFETY No. 14, 1961.

Medical Examination of Personnel Working in Hot Environments

prepared by

Dr. J.A. Bonnell

With the advent of the Magnox type reactors in concrete, (i.e. Oldbury and Wylfa) it became apparent that men would be required to enter the concrete pressure vessel boiler shell at regular intervals for routine inspection and maintenance purposes in temperatures of up to 60°C.

Men called upon to wear the clothing developed specifically for work in conditions of up to 60-80°C must be of a high standard of physical fitness. Even though a man would take his own environment with him into these high temperature conditions, failure of the protective equipment might occur in which case he would be called upon to overcome the physiological stresses of the hot environment in order to get out.

Discussions have taken place with Dr. Edholm of the M.R.C. National Institute of Medical Research, Human Physiology Unit and members of his staff.

In assessing the suitability of personnel for this type of work it must be assumed that all workers are unacclimatised persons. It is, in fact, unlikely that any one person would be called upon to work at high temperatures sufficiently frequently or for any sustained period for acclimatisation to develop.

Medical examination of prospective workers in hot environments is a necessary part of the process of selection. This is likely to be a process of excluding certain individuals because of the presence of specific deviations from normal. In addition general physical disabilities, particularly of the locomotor system, poor vision and auditory defects, must be noted as well as any evidence of psychological disturbances such as a history of claustrophobia. Skin sensitivity to rubber or plastic materials would also constitute a bar to employment. Specific factors which would influence selection are (a) Age, (b) Physique (i.e. obesity), (c) Hypertension or hypotension (i.e. tendency to fainting attacks), (d) Infective foci, (e) Anaemia, (f) Skin disease.

The Board's Medical Advisory Committee have discussed this problem and recommended that the medical examination for fitness to undertake work in hot environments should be a pre-employment examination or prior to transfer to a job involving this type of work. In addition, each individual should be interviewed by a nurse or doctor immediately before work in hot environments is due to take place. This is to ensure there was no change in a person's health and also to exclude the presence of any temporary incapacity e.g. common cold, a minor upper respiratory tract or other infection, post-alcoholic "hangover". Severe sunburn markedly reduces sweating and would form a temporary bar to employment.

In order to highlight the importance of physical fitness it is unlikely that a person over the age of 45 years would be acceptable. Equally, obesity would form a complete bar to employment.

A4-1

Description of the Prototype Suits

The first prototype suit comprised a coverall of close weave ventile cotton material fitted with polythene cooling tubes for whole body cooling. Suitable padding was provided over the air inlet manifold into which air at freezing temperatures could be introduced. Wrist and ankles were elasticised to trap the air and thus by producing a very slight internal pressure in the suit it is kept from being in continual close contact with the body.

The second prototype suit consisted of an inner suit of nitrogen blown foam covered and quilted with a nylon cover: cooling tapes were fitted on the inside of this garment. An outer coverall, of material similar to the first prototype, was worn over the inner garment to act as a sacrificial wear covering.

Both suits were worn with a hood of similar material to the coverall to which breathing and cooling air was led from the suit. The visor initially comprised a single layer of 0.007" thick 'melimex'. As this was the maximum thickness of this material available, a 'double glazed' visor was substituted having an ⅛" air gap and a stiffened frame to prevent the melimex from crinkling and cracking. The double wall construction also gave additional protection to the face should it come in contact with the visor. The hood was attached to the suit using 'Velcro' fasteners. (Microscopic plastic hooks).

The second prototype suit and hood are illustrated in Figures A4-1 and A4-2.

Tests on the Prototype Suits

A. Tests in Hot Cell at R.A.E. Farnborough - May 1966

Test 1. First Prototype Suit with Single Vortex Tube

The hot tunnel was heated to 55°C (131°F) for the initial test. Long underwear was worn to prevent cold air impinging on the skin but this was found to be unnecessary and uncomfortable. String vest and briefs were worn for subsequent tests. It was necessary to ensure that the cooling tubes in the suit did not kink as the tubes were not sufficiently resilient to resume their normal shape.

The hood proved to give inadequate cooling, temporary modification alleviated the problem but further redesign was recommended.

Mittens of a non-ventile material were used but led to high perspiration from the hands. The cuffs of the coverall were fitted over the glove and the cooling tube to one arm was opened at the end and inserted into the glove but without any great improvement. The suit was found to be fairly comfortable and exercises to simulate physical effort did not lead to any discomfort.

Test 2. Second Prototype Suit with Single Vortex Tube

This test was conducted in a similar manner to Test 1. Due to the increased insulation this suit proved to be much more comfortable to wear than the first prototype.

The full range of air flows and temperatures to the suit were checked and with an air supply pressure of 80 lbf/in^2 available at the vortex tube the range was found to be from 1.45 lb/min at 23°C to the suit to 0.61 lb/min at 0°C. Outlet temperatures from the vortex tube are governed by the quantity of cold air taken from the tube, temperature drops varying inversely with this quantity.

It was found that the hot air fraction heats the casing of the tube and some insulation may be required with a tube in service.

As only 12' to 15' of hose was available for the initial test the temperature pick-up along the hose was not checked.

Having proved that the suit was reasonably acceptable and following minor modifications further tests were carried out. These comprised tests measuring pulse, body temperature and sweat loss, using a standard coverall at normal ambient temperature and simulating work for one hour, repeat tests using the suit and subsequent tests at 60°C and 80°C.

To simulate work a stepping routine onto a 7" step was carried out at a rate of 12-15 steps per minute for 8 minute periods with 2 minute rest to check pulse rate and body temperature. The weight loss was checked for the period of one hour.

Test 3. Test at Ambient Temperature in an Unventilated Coverall

Dry Bulb temperature 22.5°C Relative Humidity 41%
Air Velocity throughout tests 3-5 inclusive 300 feet/min.

Weight before test	74.065 Kgms
Weight after test	73.9 Kgms
Weight loss	0.165 Kgms

Time (mins.)	Pulse rate	Oral Temperature
0	70	36.4
10	80	36.3
20	80	36.5
30	78	36.6
40	78	36.5
50	80	36.8
60	80	36.5

This test was used to give basic and comparative data of the subject.

Test 4. Test at Ambient Temperature in Second Prototype Suit

Inner suit and coverall worn
Temperature conditions as for Test 3

Weight before test	74.450 Kgms
Weight after test	74.260 Kgms
Weight loss	0.190 Kgms

Time mins	Pulse rate	Oral Temp. °C	Pressure at tube p.s.i.g.	Suit inlet Pressure p.s.i.g.	Cooled Air Temp. °C
0	84	36.8	34	0.21	9
10	94	36.5	55	0.54	9
20	85	36.6	55	0.42	1
30	90	36.7	53	0.42	1
40	94	36.7	53	0.41	1
50	94	37.0	55	0.41	1
60	96	37.0	55	0.41	1

Test 5. Test at 60°C, Second Prototype with Double Vortex Tube

Dry Bulb Temperature 59.3°C. Wet Bulb Temperature 26°C.

Weight before test	74.115 Kgms
Weight after test	73.730 Kgms
Weight loss	0.385 Kgms

Time mins	Pulse rate	Oral Temp. °C	Cir. Pressure at tube p.s.i.g.	Suit inlet Pressure p.s.i.g.	Cooled Air Temp. °C
0	78	36.4	70	1.84	23
10	86	36.5	70	1.7	20
20	86	36.7	70	1.71	21
30	88	36.8	80	2.16	20
40	84	36	79	1.55	14
50	88	36.6	79	1.07	11
60	94	36.7	79	1.07	11

Test 6. Test at 80°C

Dry Bulb Temperature 80°C.

Weight before test	74.512 Kgms
Weight after test	73.973 Kgms
Weight loss	0.539 Kgms

Time mins	Pulse rate	Oral Temp. °C	Cir. Pressure at tube p.s.i.g.	Suit inlet Pressure p.s.i.g.	Cooled Air Temp. °C
0	86	36.4	100	1.9	14
10	98	36.8	100	1.44	14
20	102	36.8	100	1.42	15
30	104	36.8	100	1.42	18
40	104	36.8	100	1.42	18.3
50	112	36.4	100	1.42	19
60	120	36.6	100	1.41	19

The air supply to the suit during tests 5 and 6 was with 120' of ½" bore standard black rubber air hose, the 120' of hose being inside the temperature zone.

Air temperature in hose before chamber	- 23°C
Air temperature at vortex tube inlet	- 52°C
Temperature gain in hose at 80°C	- 29°C

Two hoods were available for the tests. Hood 1, used during the test had a cooling tube above the forehead and in front of the mouth. Hood 2, had a tube in front of the mouth only but with larger distribution holes. It was found however that the noise level in Hood 2 was too high and would require further modification. The suit pressure with varying air flow was taken.

Suit Flow/Pressure Test

The pressure was taken at the suit inlet tube.

Pressure p.s.i.g.	Flow Rate lb/min Using Hood 1	Flow Rate lb/min Using Hood 2
0.1	0.38	
0.2	0.54	0.57
0.3	0.65	
0.4	0.76	0.88
0.5	0.88	
0.6	0.95	1.08
0.8	1.11	1.22
1.0	1.26	1.45
1.2	1.46	1.63
1.4	1.55	1.80
1.6	1.68	1.95
1.8	1.83	2.06
2.0	1.95	2.18

Notes

1. The outer casing of the single vortex tube came adrift during Test 4 resulting in disconnection of the temperature control adjustment. This casing needs fixing and verification is required that the insulation between the inner and outer casing will be satisfactory at high temperatures.

2. A pocket is required on the inside of the coverall to hold a telecommunication amplifier and provision is required for the cable.

3. A throat microphone was used during the tests with an earclip earphone. The earphone is satisfactory but it is desirable that provision should be made in the hood to attach a noise cancelling boom type microphone.

4. A more satisfactory glove is required particularly for climbing vertical ladders etc. with the metal at higher temperatures.

5. Following Test 4, the skin temperature in the area of the suit inlet manifold was 21°C whereas the neck was 31°C and armpit 31.5°C. This suggests that the distribution holes require modification. The difference in skin temperature should not ideally exceed 3°C.

B. Test entry to Pressure Vessel at Oldbury Power Station - June 1966

Entry was made to one boiler from pile cap level to check the effectiveness and manoeuvreability of suit in a confined space.

The suit was connected via Spembly air line, telecommunication with boom type microphone and headguard earphones were used (not Amplivox).

Manhole entry and access to ladders and platforms was reasonably good. The greatest restriction was the initial entry tube of approx. 12' of 2' dia. In order to fit sealing plates around the top slot of the boiler entry a man must pass between tubes approximately 18" apart, in a crouched position. Interference with the hood occurred and there was a tendency for it to be pushed back. The hood was found to be too tall for ease of judgment and the top of the visor too square. A reduction in air supply to the hood occurred during entry to a tube bank interspace due to kinking of the plastic tube.

The following recommendations are made, some confirmed from previous tests:-

(1) Non-kink distribution hoses must be used.

(2) The hood requires reshaping to prevent catching and improve upward vision.

(3) Hood air distribution requires further experimentation.

(4) A longer apron or press clips required at the back fastening of hood.

(5) The plastic tube from manifold to vortex tube can get caught on sharp corners when squeezing through restricted spaces. The tube should be threaded through a slot in the coverall.

(6) A different form of air inlet from the "pipe fitting" elbow is required to prevent fouling.

(7) A pocket is required in the coverall for a telecommunication amplifier.

(8) Vortex tube insulation requires sealing to assist in decontamination of the tube.

Tests on the Mark I Suits

Introduction

Following tests on the prototype suits, the design was modified to give improved air distribution and better visibility and two modified suits and hoods were prepared for tests by Frankensteins Ltd. The modified suits were similar to one another except that one had an outer coverall of orange material and the other was in a grey finish.

Flow-pressure characteristics of the two suits were found to be closely similar. It was therefore assumed that they would be similar in performance and the orange suit alone was used in the climatic cell tests.

The subjects in these tests were C.E.G.B. employees who had been medically examined and cleared for work in hot environments.

Results

Test 1 Dry Bulb - 57 - 58.2°C
Wet Bulb - 25 - 24.8°C
Subject - Mr. Tresise (wearing vest, pants, rubber gloves, asbestos cotton gloves, rubber (short wellingtons)
Weight loss during test 180 grams.

Readings during test

Vortex inlet pressure p.s.i.g.	Suit inlet air Temp. °C	Suit inlet air press - p.s.i.g.	Suit flow lb/min
50	17.2	1.6	1.43
Insufficient cooling: inlet air pressure increased			
55	15.4	1.6	1.43
55	16.5	1.7	1.44
Vortex tube adjusted to give higher cold flow			
55	16.7	1.9	1.54
Subject's oral temperature still rising - cooling increased			
65	15.5	2.4	1.77
65	15.4	2.5	1.82
65	16.4	2.6	1.86

Check on vortex tube at end of test: rotameter indicated output of 1.98 lb/min.

Measurements on Subject Doing 7" step at 12 times/min.

Time (mins)	Pulse rate	T_{oral} °C	Comments
0	84/min	36°C	Pulse rate taken after ½ min. rest over
10	84	36.8	1 full minute in all cases
20	86	37.2	
30	88	37.4	Sweat visible on face
40	90	37.7	Sweat visible on face
50	98	37.5	Sweat visible on face
60	100	37.5	Sweat visible on face

Subject commented that cooling of hands and feet were the least satisfactory, otherwise cooling pretty uniform.

Test 2 Dry Bulb - 68°C - 68.4°C
Wet Bulb - 27.2°C - 27.4°C
Subject: Mr. Tresise (clothing as for Test 1)
Weight loss during test: 400 grams.

Readings during test

Vortex tube inlet pressure was constant 76 - 78 p.s.i.g.

Oral Temp. °C	Suit Inlet Air Temp. °C	Suit Inlet Press p.s.i.g.	Suit Flow lb/min
37.1	13.6	2.0	1.58
37.2	13.3	1.95	1.56
37.3	14.0	1.95	1.56
37.6	14.6	1.95	1.56
37.3	14.6	2.0	1.58
37.3	14.6	2.0	1.58
37.0	14.4	2.0	1.58

Check on vortex tube at end of test: rotameter indicated flow of 1.75 lb/min.

On entering hot-cell the inlet temperature was 3°C: the subject complained of poor distribution and discomfort at this time. As the temperature of suit inlet rose, due to hose pick-up, although less cooling was being applied the suit became comfortable.

It would appear from subjective judgment that the inlet temperature should be about 15°C for comfort and that at this temperature distribution in the suit is satisfactory.

The thermocouple reading oral temperature was left out of the mouth at times during the test. At these times, temperatures of about 25°C were registered.

Measurements on Subject Doing 7" step at 12 times/min.

Time (mins)	Pulse rate	T_{oral} °C	Comments
0	82	36.3	Pulse rate taken after ½ min. rest
10	90	37.1	over 1 full minute in all cases.
20	86	37.3	Sweat on face
30	88	37.3	Sweat on face
40	90	37.6	Sweat on face
50	98	37.3	Sweat on face
60	100	37.0	Sweat on face

Hands and feet again reported as the least comfortable.

Test 3   Dry Bulb - 79.0°C
Wet Bulb - 32.5°C
Subject: Mr. Westmorland
Weight loss during test 750 grams.

Readings during test

The vortex tube inlet pressure was initially 80 p.s.i.g. As heat pick-up in hoses became significant the pressure was raised to the highest available, namely 85 p.s.i.g.

Oral Temp. °C	Suit Inlet Air Temp. °C	Suit Inlet Air Press p.s.i.g.	Suit Flow lb/min
36.5	15	2.08	1.63
36.5	15	2.08	1.63
36.6	19.5	1.85	1.49
37.2	20.2	1.85	1.49
37.2	20.8	1.85	1.49
37.4	20.6	1.9	1.53
37.4	25.0	2.85	1.97
37.4	26.2	2.85	1.97
37.4	25.8	2.85	1.97

During this test, as heat pick-up in hoses became significant, it became apparent that insufficient cooling could be obtained from the vortex tube with the limited inlet pressure available. The subject was however able to endure the test for the full period. Subjective observations during the test were that it was generally warm and, in particular, warm to the face. Similar observations regarding distribution were made on entry when the temperatures were low (3°C inlet air).

Later in the test the subject touched the perspex visor with his face and found it "hot but bearable".

After 40 minutes in the cell some misting of the visor was reported. Hands and feet were subjected to great discomfort during this test. At the conclusion, the subject tried a certain amount of crawling over the steel decking of the cell.

Half an hour after the test the subjects pulse rate was still 120.

Measurements on Subject Doing 7" step at 12 times/min.

Time (mins)	Pulse rate	T_{oral} °C	Comments
0	100	36.5	
10	118	36.6	Sweat on face
20	120	37.2	Sweat on face
30	126	37.2	Sweat on face
40	128	37.4	Misting on visor reported
50	126	37.3	
60	130	37.4	

Back Pressure - Flow Characteristic of the Mark I Hot-Working Suits

A. Orange Suit

Back Pressure Pb p.s.i.g.	Corrected Flow lb/min
0.65	0.86
0.92	1.02
1.20	1.19
1.52	1.37
1.89	1.54
2.10	1.63
2.30	1.73
2.76	1.92
3.25	2.12
4.8	2.64

B. Grey Suit

0.5	0.74
0.82	0.98
1.14	1.19
1.57	1.40
2.03	1.64
2.59	1.86
3.19	2.10
4.08	2.33
4.73	2.63

These are plotted in Figure A6-1.

Interpretation of Test Results

Heat Removal by Air (H_a)

Taking the specific heat of air as 0.241, the heat flux for a man can be shown to be $6.51F(T_s - T_i)$ kcal/h.

Where F is the air flow in lb/min
T is skin temperature (for comfortable conditions taken as 33°C)
and T_i is the inlet air temperature in °C.

Metabolic Heat (H_m)

Typical values are:

Resting	- 350 BTU/h	=	88.2 kCal/h
Light Work	- 1250 BRU/h	=	215 kCal/h
Heavy Work	- 2700 BRU/h	=	681 kCal/h

Sweat Loss (H_s)

In these tests, results clearly indicate that significant sweat losses occurred and the heat loss through sweating can be estimated from the Latent Heat of water and equals Q x 0.576 kcals/h where Q is the sweat loss in grams/h.

Heat Input from the Environment (H)

If H is the total heat entering the suit and A is the effective body area then the heat transfer equation is

$$T_s = T_g + kI_a \left(T_G{}^4 - \left(T_s - Ic\,\frac{H}{A}\right)^4\right) - \frac{H}{A}\left(I_c + I_a\right)$$

where I_c = Clothing heat insulation resistance (°C.m².h/k.cal)
I_a = Boundary air heat insulation resistance (°C.m².h/k.cal)
T_s = Temperature of skin (°K)
T_g = Globe Temperature of ambient air (°K)
H = Clothing heat flow (kcal/h)
k = A constant based upon the Stefan Boltzman constant 4.9×10^{-8} k.cal/m².h °K⁴ and the man's surface area available for convective heat exchange.

The radiant heat component in the above equation was found to be small and was therefore ignored. Thus for practical purposes at the temperatures being considered.

$$T_s = T_g - \frac{H}{A}\left(I_c + I_a\right)$$

Thus $$H = \frac{(T_g - T_s)\ A}{I_c + I_a}$$

Heat Balance

For a heat balance, the heat lost by sweating added to the heat loss by convection to the air must equal the sum of Metabolic Heat and Heat input from the environment, i.e. $H_a + H_s = H_m + H$

i.e. $$H_a + H_s = H_m + H$$

Substituting in this equation the following is obtained,

$$6.51F(T_s - T_i) + Q.\ 0.576 = H_m + (T_g - T_s)A/(I_c + I_a)$$

of these factors, F, T_i, Q, T_g were measured in each test

T_s is normally taken as 33°C and A as 1.8 m^2

This leaves H_m and $(I_c + I_a)$ as "unknowns".

However H_m can be expected to be of the order of 200 kcal/h, but it is not necessarily the same in each of the tests under review. Different subjects were used but the same work routine was employed in all cases.

Test 2 was, by far, the test in which steadiest conditions were obtained, and for the conditions measured a value of $I_c + I_a = 0.3$°C m^2h/kcal is consistent with metabolic heat rates of 200 - 230 kcal/h.

The results of Test 1 are such that the calculated value of $I_c + I_a$ is considerably affected by the assumed value of H_m but the readings at the end of the test are equally consistent with a value of 0.3 for H_m in the order of 210 kcal/h.

The subject in Test 3 was different from the earlier tests. As the subject was heavier it is safe to assume that the metabolic rate should be higher in this test. Taking H_m = 250 kcal/h the results are again consistent with $I_c + I_a$ equal to 0.3.

<u>Test 1</u> F = 1.86 lb/min T_i = 15.5°C T_g = 58°C Q = 180 grams

$H_a = 6.51 \times 1.86\ (33 - 15.5) = 252$ kcal/h
$H_s = 0.576 \times 180 = 103$ kcal/h

$H_a + H_s = \underline{355\ \text{k.cal/h}}$

Assume H_m = 210 kcal/h and $I_c + I_a = 0.3$

$H = (58 - 33) \times 1.8/0.3 = 150$

$H_m + H = \underline{360\ \text{k.cal/h}}$

<u>Test 2</u> F = 1.57 lb/min T_i = 14.6°C Q = 400 grams T_g = 68°C

$H_a = 6.51 \times 1.57\ (33 - 14.6) = 188$ kcal/h
$H_s = 400 \times 0.576 = 226$ kcal/h

$H_a + H_s = \underline{414\ \text{k.cal/h}}$

Assume H_m = 210 kcal/h and $I_c + I_a = 0.3$

$H = (68 - 33) \times 1.8/0.3 = 210$

$H_m + H = \underline{420\ \text{k.cal/h}}$

Test 3 $F = 1.97$ lb/min $T_i = 25^{o}C$ $Q = 750$ grams $T_g = 79^{o}C$

$H_a = 6.51 \times 1.97 (33 - 25) = 102$
$H_s = 0.576 \times 750 = 432$

$H_a + H_s = \underline{534 \text{ kcal/h}}$

Assume $H_m = 250$ $I_c + I_a = 0.3$

$H = (79 - 33) 1.8/0.3 = 276$

$H_m + H = \underline{526 \text{ k.cal/h}}$

As a check, the results of the previous series of tests can be examined. The test routine was the same and the suit, being basically similar, can be assumed to have a similar insulation resistance.

Test 5 (preliminary series)

$F = 2.28$ lb/min $T_i = 20^{o}C$ $Q = 285$ grams $T_g = 60^{o}C$

$H_a = 6.51 \times 2.28 \times (33 - 20) = 193$
$H_s = 0.576 \times 285 = 164$

$H_a + H_s = \underline{357 \text{ k.cal/h}}$

Assuming $H_m = 210$ and $I_a + I_c = 0.3$

$H = (60 - 33) \times 1.8/0.3 = 162$

$H_m + H = \underline{372 \text{ k.cal/h}}$

Test 6 (preliminary series)

$F = 1.79$ lb/min $T_i = 19^{o}C$ $Q = 589$ grams $T_g = 80^{o}C$

$H_a = 6.51 \times 1.79 \times (33 - 19) = 163$
$H_s = 0.576 \times 589 = 339$

$H_a + H_s = \underline{502 \text{ k.cal/h}}$

Assume H_m is again 210 (same subject) and $I_a + I_c = 0.3$

$H = (80 - 33) \times 1.8/0.3 = 282$

$H + H_m = \underline{492 \text{ k.cal/h}}$

Conclusion

It is concluded that in the consideration of circumstances similar that experienced in the test, that is in temperatures up to $80^{o}C$ in moderate air streams, an insulation value of $0.3^{o}C\ m^2h/k.cal$ can be used.

Tests on Vortex Tubes

During the suit tests at Farnborough, doubts arose regarding the performance of the vortex tube assemblies. Temperature drops obtained did not match those published for Fulton tubes, as given in Table 4.5A. Tests were therefore carried out on the three assemblies, at Croydon by the Efficiency and Test Section, South Eastern Region. For each tube assembly the temperature drop - cold air flow relationship was plotted for various inlet pressures and control settings. The total air flow - inlet pressure relationships were also established. These are shown in Figures A7-1 to A7-6.

The results of the tests as shown in Figures A7-1 to A7-6 can be combined to give families of curves which principally show the vortex tube inlet pressures necessary to give a given cold flow at various temperature drops. These curves are given in Figures A7-7 to 9 and it will be seen that the effect of control settings can also be illustrated on these graphs.

These curves have been drawn in the same way as Figure 4.5B which is based upon the published data for a twin Fulton tube assembly and which also forms part of the nomograph Figure 4.4A.

It will be seen that the performance of the tested tubes differs significantly from that claimed for Fulton tubes. Both manufacturers have been contacted and are currently investigating the situation.

The Vortair assembly has been examined by the manufacturer and it has been established that a high flow 'low temperature drop' bushing had been used. For most applications it is probable that the alternative bushing would be more suitable. It was also found that the fraction control of one tube had been damaged.

It is also believed that the M.S.A. tubes had been fitted with bushings of the wrong size for the application but this has yet to be confirmed.

Quality of Breathing Air

The following extract is included for guidance and is taken from document 66/29936 Draft British Standard Recommendations on "The Selection, Use and Maintenance of Respiratory Protective Equipment".

Air-Line Breathing Apparatus

A8.1 Air-Lines and Air Hoses

(a) Before being put into use, the air-line or hose should be examined externally and tested for freedom from dirt and blockages.

(b) In use the wearer should take precautions to prevent the air-line or hose fouling on projections.

(c) The intake end should be positively fixed in a position from which clean, fresh air can be drawn.

(d) The length of air-line or hose used should not exceed that appropriate for the diameter and type of hose.

A8.2 Compressed Air Supply

Types of Service. Excepting self-contained apparatus, there are three methods of providing air for breathing purposes:

(a) Separate mask air service. The provision of a mask air service, separate from the normal works air service, is the best methods of supplying air for personal protection and should always be considered for installation in new works or where major alterations justify it.

(b) General works air service. Mask air service may be taken from the general works air supply, but should be used only after special precautions against contamination have been taken.

(c) Portable air supply units. Where mask air is required infrequently or in an emergency, or in remote or isolated places, a portable air supply unit should be used.

A8.3 Requirements for all systems of compressed air for air-line breathing apparatus

(a) Air Purity. A sample of air supplied to the wearer should not contain impurities in excess of the limits given in Table 1:

Carbon monoxide	10 parts per million (11 milligrams/cubic metre)
Carbon dioxide	500 parts per million (900 milligrams/cubic metre)
Oil	1 milligram/cubic metre
Odour and Cleanliness	The air should be free from all odour, and contamination by dust, dirt or metallic particles and should not contain any other toxic or irritating ingredients. (See note below)

NOTE: Odour and cleanliness of compressed air is difficult to check accurately without special equipment. A rough check may be made by smelling the delivered air, and by noting any discolouration or wetness when the air is passed gently through a wad of tissue or filter paper.

(b) Compressors. Compressors, particularly the exhaust valves, should be well maintained and should not be allowed to overheat as a dangerous amount of carbon monoxide or other noxious substances may be produced by the decomposition of lubricating oils.

(c) Air supply. The capacity of any air service for personal protectio should be calculated on a minimum requirement of 6 cu.ft. (170 litres) per person per minute.

(d) Pressure in rubber tubing. The pressure of air admitted to any rubber tubing connected to personal protective apparatus should not exceed 25 lbf/in^2 (1.76 kgf/cm^2) and should never be at a pressure less than 5 lbf/in^2 (0.35 kgf/cm^2).

(W.P. Note: In this application the pressure in the supply hose will be in excess of 25 lbf/in^2: protection is afforded to the wearer by the vortex tube which reduces the pressure admitted to the suit).

(e) Flexible tubing. Flexible kink-resistant tubing of rubber or other similar material used in connection with air supply to a mask should be manufactured to a specification which ensures it will withstand the maximum pressure of 25 lbf/in^2 (1.76 kgf/cm^2) to which it may be subjected.

(W.P. Note: A higher pressure than 25 lbf/in^2 is needed in the specification before vortex tubes).

(f) Air temperature and humidity. Air supplied to the mask or hood should normally be at a comfortable breathing temperature within the range of 15°C to 25°C. The wearer's comfort is considerably influenced by the humidity of the air breathed and it is recommended that 85 per cent should not be exceeded.

(g) Air intake. The air intake provided for any mask air service should be so sited and constructed as to avoid the entry of contaminated air into the system and ensure a sufficient supply of clean air. The use of filters on any intake should be of secondary importance to the foregoing requirements.

(h) Avoidance of stale air and moisture. Arrangements should be made to avoid the pocketing of stale air in pipe lines, and the use of ring circuits and/or controlled leak-offs helps to guard against this hazard. Provision should also be made, at appropriate places, to drain away water from any pipe line.

(j) Air supply in an emergency. Every system of air supply employed should incorporate a receiver of sufficient capacity to enable a person to escape from an irrespirable atmosphere, in the event of a failure of the prime mover supplying the air.

(k) Warning device. Arrangements should be made to warn the user of any mask air service whenever there is danger of the supply of air becoming inadequate.

(l) Connection or coupling points. The number of connection points provided in any service should be sufficient to avoid the use of excessive lengths of flexible tubing. Couplings should for preference be of the "instantaneous" type and different from those used for other compressed air services.

In certain cases it may be desirable to install a filter, drain, pressure gauge and control valve adjacent to each connection point or group of connection points.

(m) Materials of construction. In order to ensure a supply of clean air to the mask, the materials of construction of all parts of the system, after and including the final filter, should be non-corrodible.

A9-1

Hoses and Couplings

Hoses

Three types of rubber hose, manufactured by Uniroyal Ltd. (Tyre and General Products Division) have been examined and appear to be suitable from a mechanical point of view. Arranged in order of their resistance to kinking, the 3 types were as follows:-

1. Rayon spiral reinforced air hose (H.P.) Type RS3356
2. Three braid reinforced hose Type R3350
3. Rayon braided reinforced hose Type R3350

All of these hoses have bore tolerances of $^{1}/32"$ and factors of safety on pressure of 4:1.

Data for the various types are as follows:-

1. Rayon spiral reinforced: Type RS3356

Nom. Bore	Rated Pressure (lbf/in^2)	Weight (lb/100 ft.)
$\frac{1}{2}$"	300	25.65
$\frac{5}{8}$"	285	29.9
$\frac{3}{4}$"	275	38.75

2. Two braid reinforced hose: Type R3350

Nom. Bore	Rated Pressure (lbf/in^2)	Weight (lb/100 ft.)
$\frac{1}{2}$"	225	25
$\frac{5}{8}$"	225	30
$\frac{3}{4}$"	225	38

3. Three braid reinforced hose: Type R3350

Nom. Bore	Rated Pressure (lbf/in^2)	Weight (lb/100 ft.)
$\frac{1}{2}$"	300	29
$\frac{5}{8}$"	275	35
$\frac{3}{4}$"	275	44

Samples of the above hose have been heated to 80°C, 100°C and 120°C and kept at those temperatures for a week. The sample heated to 80°C showed some hardening but had retained a measure of flexibility. It is therefore felt that rubber hoses of these types will be satisfactory albeit for a limited exposure life.

Hose Pressure Drops

The nominal pressure drops given in Table A7-1, attached, can be used as a guide. These are, strictly speaking, for pulsating flow in smooth bore hoses. For rough bore hoses the pressure loss may be 50% greater. For steady flow the loss is to be expected to be pessimistic.

Size of Hose	Gauge Pressure at Line	Cubic Feet Free Air per Minute Passing Through 50 ft. Lengths of Hose												
		20	30	40	50	60	70	80	90	100	110	120	130	140
		Loss of pressure in lb. per sq. in. - 50 ft. hose Length												
½"	50	1.8	5.0	10.1	18.1	-	-	-	-	-	-	-	-	-
with	60	1.3	4.0	8.4	14.8	23.4	-	-	-	-	-	-	-	-
Coup-	70	1.0	3.4	7.0	12.4	20.0	28.4	-	-	-	-	-	-	-
lings	80	.9	2.8	6.0	10.8	17.4	25.2	34.6	-	-	-	-	-	-
at	90	.8	2.4	5.4	9.5	14.8	22.0	30.5	41.0	-	-	-	-	-
Each	100	.7	2.3	4.8	8.4	13.3	19.3	27.2	36.6	-	-	-	-	-
End	110	.6	2.0	4.3	7.6	12.0	17.6	24.6	33.3	44.5	-	-	-	-
¾"	50	.4	.8	1.5	2.4	3.5	4.4	6.5	8.5	11.4	14.2	-	-	-
with	60	.3	.6	1.2	1.9	2.8	3.8	5.2	6.9	8.6	11.2	-	-	-
Coup-	70	.2	.5	.9	1.5	2.3	3.2	4.2	5.5	7.0	8.8	11.0	-	-
lings	80	.2	.5	.8	1.3	1.9	2.8	3.6	4.7	5.8	7.2	8.8	10.6	-
at	90	.2	.4	.7	1.1	1.6	2.3	3.1	4.0	5.0	6.2	7.5	9.0	-
Each	100	.2	.4	.6	1.0	1.4	2.0	2.7	3.5	4.4	5.4	6.6	7.9	9.4
End	110	.1	.3	.5	.9	1.3	1.8	2.4	3.1	3.9	4.9	5.9	7.1	8.4
1"	50	.1	.2	.3	.5	.8	1.1	1.5	2.0	2.6	3.5	4.8	7.0	-
with	60	.1	.2	.3	.4	.6	.8	1.2	1.5	2.0	2.6	3.3	4.7	5.5
Coup-	70	-	.1	.2	.4	.5	.7	1.0	1.3	1.6	2.0	2.5	3.1	3.8
lings	80	-	.1	.2	.3	.5	.7	.8	1.1	1.4	1.7	2.0	2.4	2.7
at	90	-	.1	.2	.3	.4	.6	.7	.9	1.2	1.4	1.7	2.0	2.4
Each	100	-	.1	.2	.2	.4	.5	.6	.8	1.0	1.2	1.5	1.8	2.1
End	110	-	.1	.2	.2	.3	.4	.6	.7	.9	1.1	1.3	1.5	1.8
1¼"	50	-	-	.1	.2	.2	.3	.4	.5	.7	1.1	-	-	-
with	60	-	-	-	.1	.2	.3	.3	.5	.6	.8	1.0	1.2	1.5
Coup-	70	-	-	-	.1	.2	.2	.3	.4	.4	.5	.7	.8	1.0
lings	80	-	-	-	-	.1	.2	.2	.3	.4	.5	.6	.7	.8
at	90	-	-	-	-	.1	.2	.2	.3	.3	.4	.5	.6	.7
Each	110	-	-	-	-	-	.1	.2	.2	.3	.4	.4	.5	.6
End	110	-	-	-	-	-	.1	.2	.2	.3	.3	.4	.5	.5

TABLE A9-1

Ancillary Equipment and Clothing

No tests have been carried out on gloves, footwear or emergency rescue equipment. Arrangements for practical evaluation are being made of equipment listed below which has been selected from commercially available sources and appears likely to meet requirements.

A. Equipment for use with Mark I suit

Footwear

A boot with one or more socks, according to the temperatures should be used.

The following socks are available from C.E.G.B. Stores Standard 06/09 - Personal Clothing, Detail Code Numbers:

06/09/351 to 355	Nylon socks
06/09/361 to 365	Socks cotton/nylon
06/09/381 to 384	Stockings (Seaboot - oiled yarn)

The following boots are available:

James North and Sons Ltd. "NORSTAR" Moulders Foundry Boot (Quick Release) Type ST303.

Certain boots from Wilkins and Denton Ltd., 'Totector' range are likely to be suitable for lower temperature applications.

Tebbut and Hall 22G/901 (used for R.A.F. rescue).

Gloves

The following gloves are available:

James North and Sons Ltd. "NORTHERM" Type N133 (Large), Type N143 (Medium).

(These are to be added to C.E.G.B. Stores Standard 06/19 Gloves).

Underclothes

During tests, ordinary underclothes have been used. "Factory Clothing" type vests and pants were used in one test, whilst 'string' vest and lightweight pants were used in others. Heavy underclothing was tried but found uncomfortable during a further test.

B. Equipment for use with Mark I suit in radiactive contaminated areas

Footwear

The following boot is available from C.E.G.B. Stores Standard 06/15 Footwear: Code 06/15/412-419 Boots Rubber (White Half Length Knee).

Gloves

The gloves quoted in 'A' above can be used inside rubber gloves.

The possibility of 'dipping' these gloves is also being examined.

C. Emergency Equipment

Suits (including Gloves and Helmet)

Bell Asbestos and Engineering Ltd.
Bestobel Type K55 Salamander Fire Suit
Bestobel Type K56 Lightweight Rescue Suit
(styled to accommodate a self air set internally)
(Note the K55 is the heavier version)

Bristol Uniforms Ltd. - Bristol Fire Fighting Suit

Footwear

Fitted Boots:-

Bell Asbestos K67 (This is an aluminised version of the Tebbut and Hall 22G/901)

Overboots

Bell Asbestos and Engineering Ltd.
Bestobel
Bestobel K66 (Ankle and Knee lengths)

D. Specification for Mark I Suit issued by the Frankenstein Group Limited

SPECIFICATION FOR THE BEAUFORT DYNACOOL SUIT

TRADE NAME:- The suit will be called the BEAUFORT DYNACOOL SUIT MK.1. This suit has previously been known as either (a) THE M.S.A. COOLING SUIT or (b) THE BEAUFORT COOLING SUIT.

PURPOSE:- The purpose of this assembly is to provide adequate cooling and breathing for the wearer when working in ambient temperatures of up to 70°C, giving good mobility and visibility.

METHOD OF COOLING:- The principle employed is one of dynamic insulation. Dry, dust free air is supplied to the suit at a pressure of approximately 100 p.s.i. the air is cooled by a vortex system and fed into the suit, the hot air from the vortex tubes being exhausted to atmosphere.
The assembly is designed and calibrated to allow the wearer to maintain a medium work rate of 4.5 K.cal/min.

DESCRIPTION:- The suit assembly is in three pieces comprising the following:-

(a) A one piece outer suit with front entry, closed with a sliding fastener. The material is a closely woven cotton fabric with very good abrasion resistance.

(b) A foam insulated inner suit made from ¼" polyurathane foam sandwiched between two layers of woven nylon, as the outer suit also front entry closed with a sliding fastener.

(c) An inner and outer hood of the same fabrics as the suit joined together around the neck and studded together through a perspex visor which affords excellent all round vision.

The inner and outer suits are donned separately, the hood is then positioned and secured in position to the outer suit by sliding fasteners fitted to the skirt of the hood and across the chest and back of the outer suit.
An aperture on the front left waist provides entry for the air distribution system, and fitted inside the inner suit is a padded flap to provide insulation against localised chilling of the body by the air distribution manifold.
Tunnel tapes are fitted throughout the inside of the inner garment, through which the air distribution system tubes are passed to ensure an even air flow within the suit.
Air is fed through feed tubes from the manifold to the hood which provides both cooling and air for breathing purposes.
The air distribution system consists of a weft P.V.C. manifold with a ¾" bore inlet, and 9 air distribution tubes which are ¼" bore P.V.C. The tubes are strategically perforated to allow an even flow of air over the body.
The vortex tube assembly, which is attached to a webbing belt, is joined to the air distribution manifold by a 1" bore flexible tube, and provides cooled air at the correct flow and temperature. The tube can be fitted with a control knob for personal adjustment if so required.

<u>SIZES:-</u>

The suit is manufactured in three sizes, small, medium and large as detailed below:

		HEIGHT	CHEST
Small	Up to	5 ft. 8 ins.	38 ins.
Medium	Up to	5 ft. 11 ins.	41 ins.
Large	Up to	6 ft. 2 ins.	44 ins.

More detailed information may be obtained from:

THE FRANKENSTEIN GROUP LIMITED
RESEARCH AND DEVELOPMENT DIVISION
HUNT LANE
CHADDERTON
LANCS.

A11-1

Potential of suits for higher temperatures in conventional stations

A suit capable of being used at temperatures in excess of the limit of 60°C may permit earlier access and thus reduce 'down-time'. Tests to establish the temperatures in forced cooled boilers were carried out at West Thurrock and Northfleet. The results of two such tests are given in Figures A11-1 ~~and A11-2~~.

Reports from a number of stations indicate that access to some parts of a boiler can normally be achieved after 10 to 15 hours. Use of the Mark I suit, would permit prolonged access with temperatures some 30°C higher than with no protection. Judging from cooling curves this represents about $3\frac{1}{2}$ to 4 hours earlier. Earlier access than this is likely to be prevented by considerations of safety. Hazards, not from temperature, but from boiler pressure or, in the case of coal fired boilers, falling slag are likely to make earlier entry undesirable.

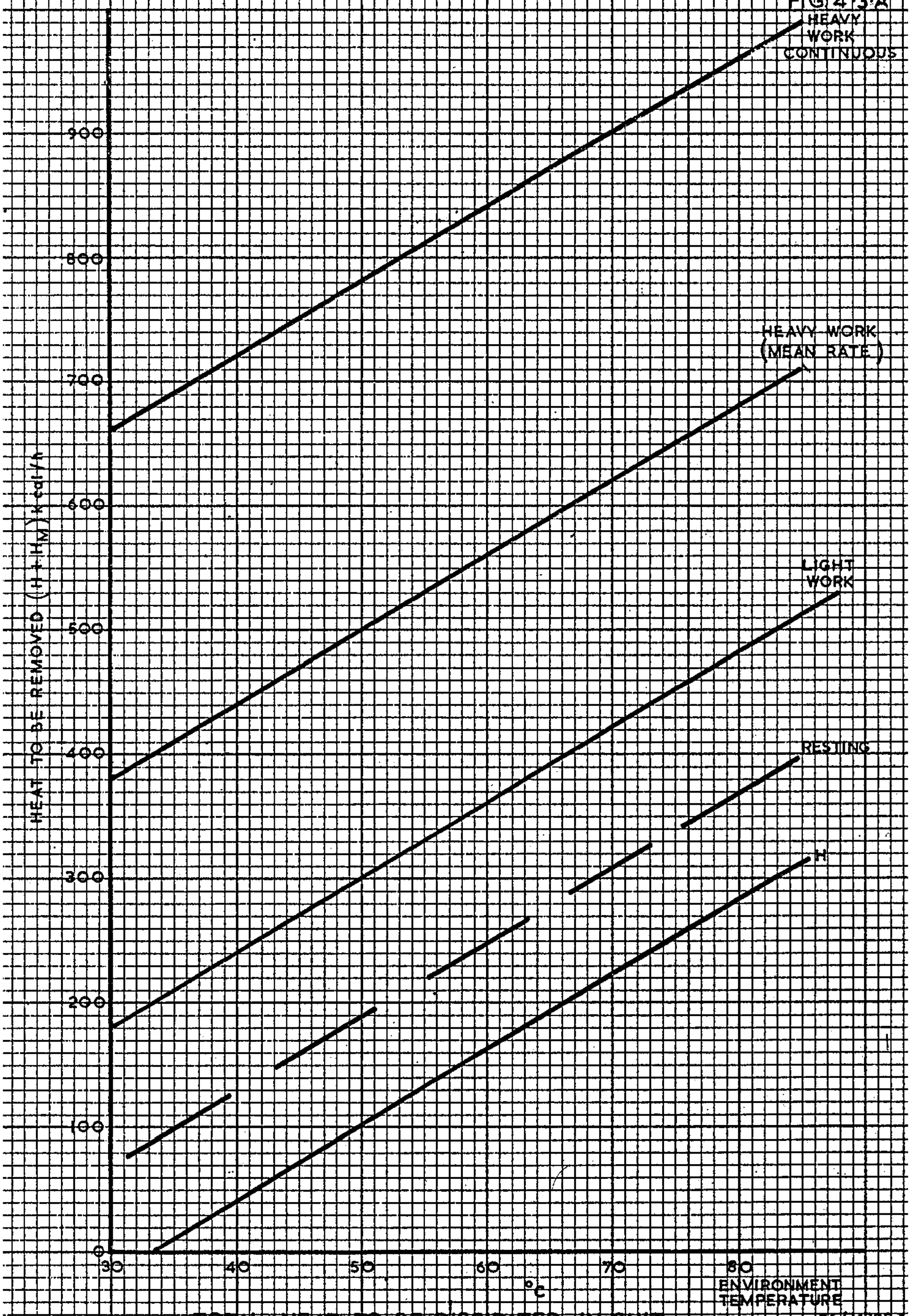
FIG. 3.1A MARK I SUIT WITH MARK I HOOD

FIG. 3.1B MARK I SUIT SHOWING NECK AND HEAD CONNECTIONS

FIG. 3.1C MAN IN INNER SUIT

CENTRAL ELECTRICITY GENERATING BOARD HEADQUARTERS

FIG 4·3·A



TOTAL HEAT TO BE DISSIPATED IN SUIT

96/1139A

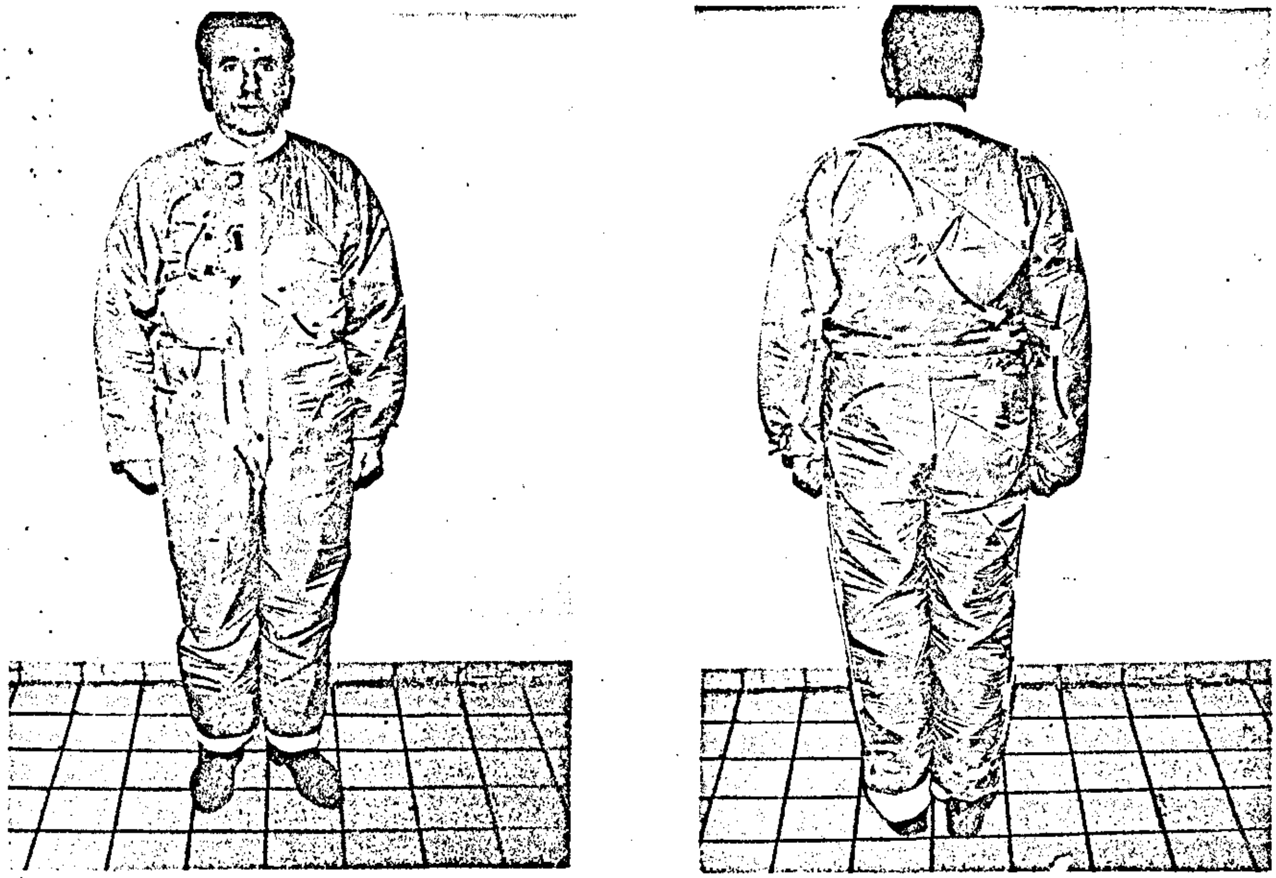


FIG. 3.1D INSIDE VIEWS OF INNER SUIT

FIG. 3.2A SUIT, REAR VIEW SHOWING VORTEX TUBE ON BELT

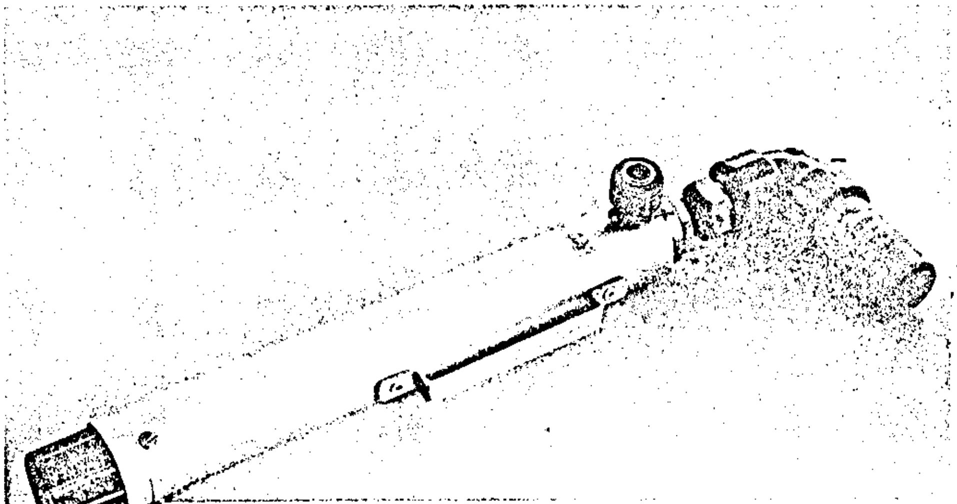


FIG. 3-2B
M.S.A. SINGLE VORTEX TUBE ASSEMBLY

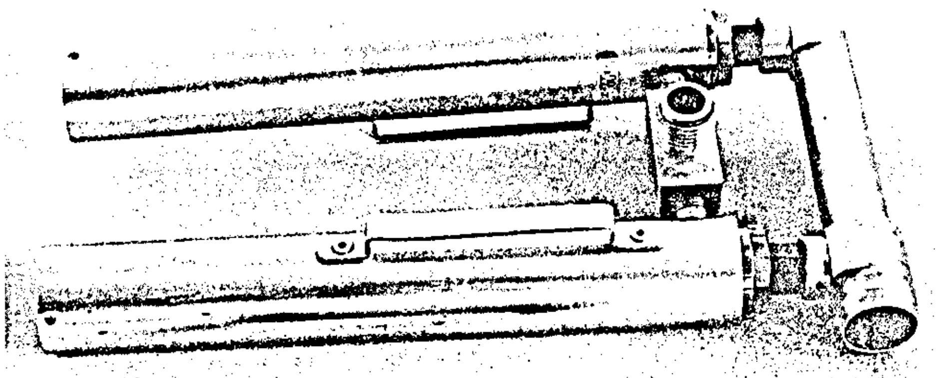


FIG. 3-2C
M.S.A. TWIN VORTEX TUBE ASSEMBLY

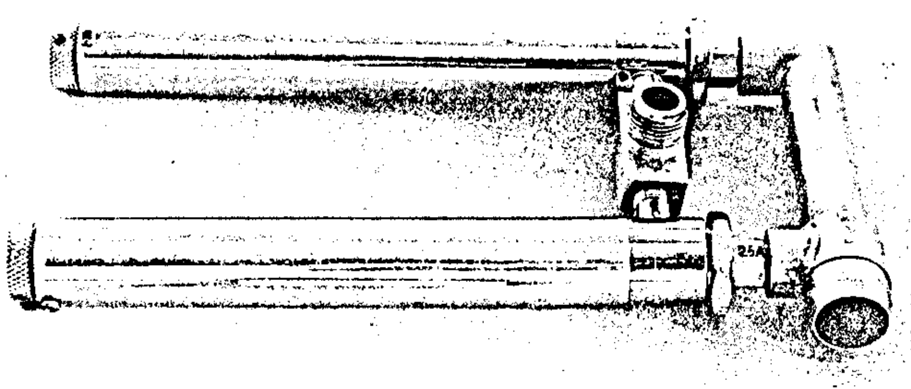
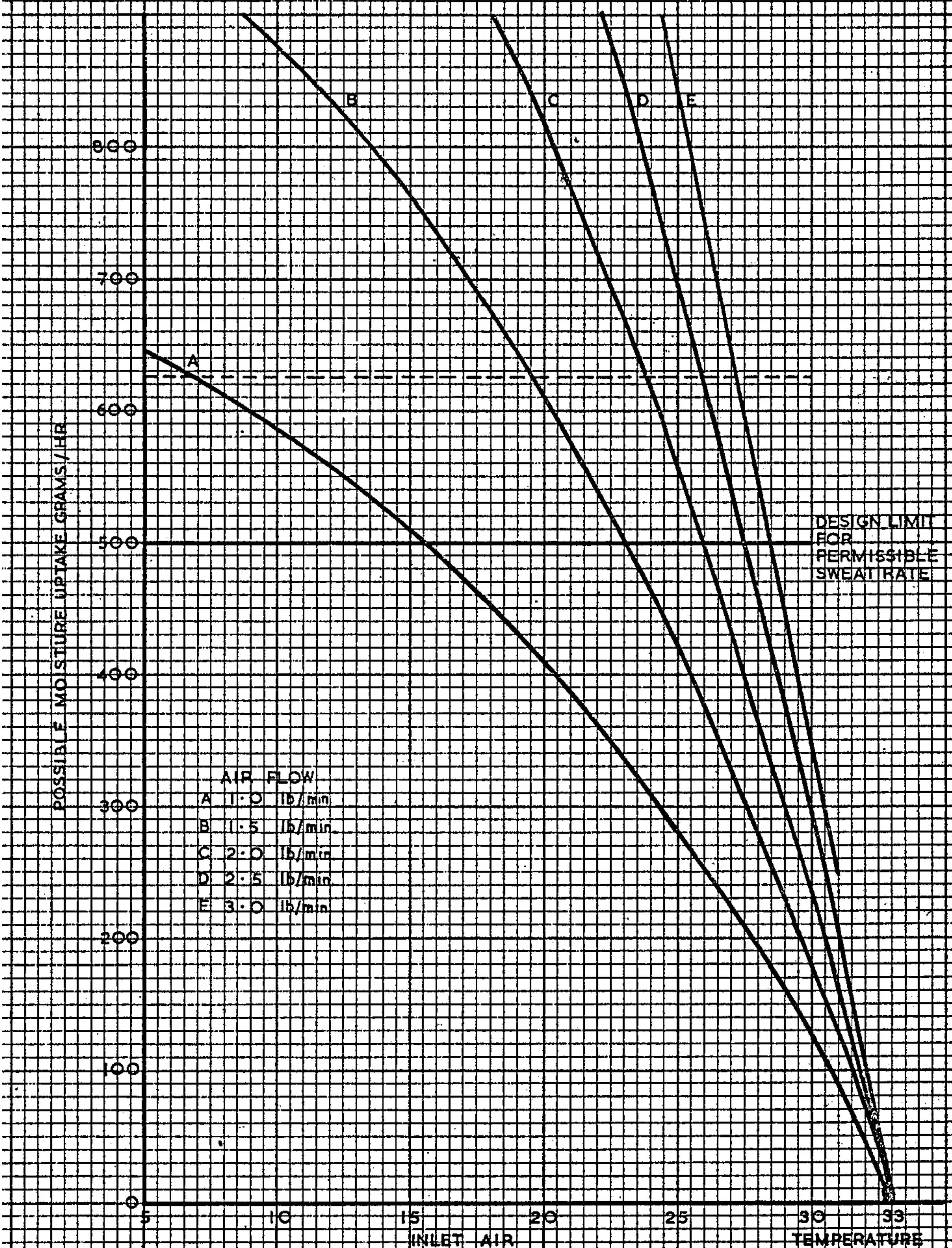


FIG. 3-2D
VORTAIR TWIN VORTEX TUBE ASSEMBLY

FIG. 4.2.A.

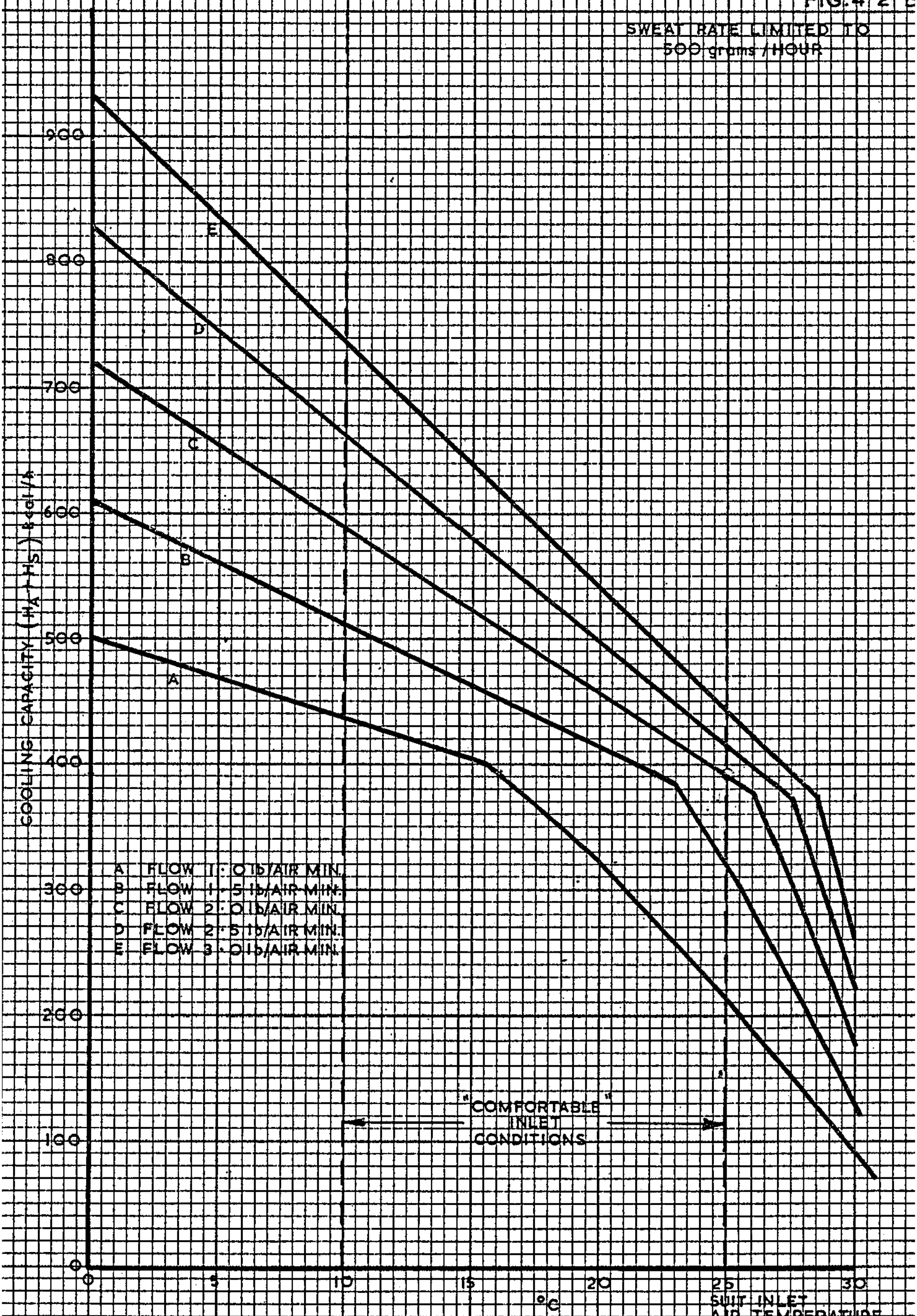


POSSIBLE MOISTURE UPTAKE IN AIR

96/11395

CENTRAL ELECTRICITY GENERATING BOARD HEADQUARTERS

FIG. 4.2.B

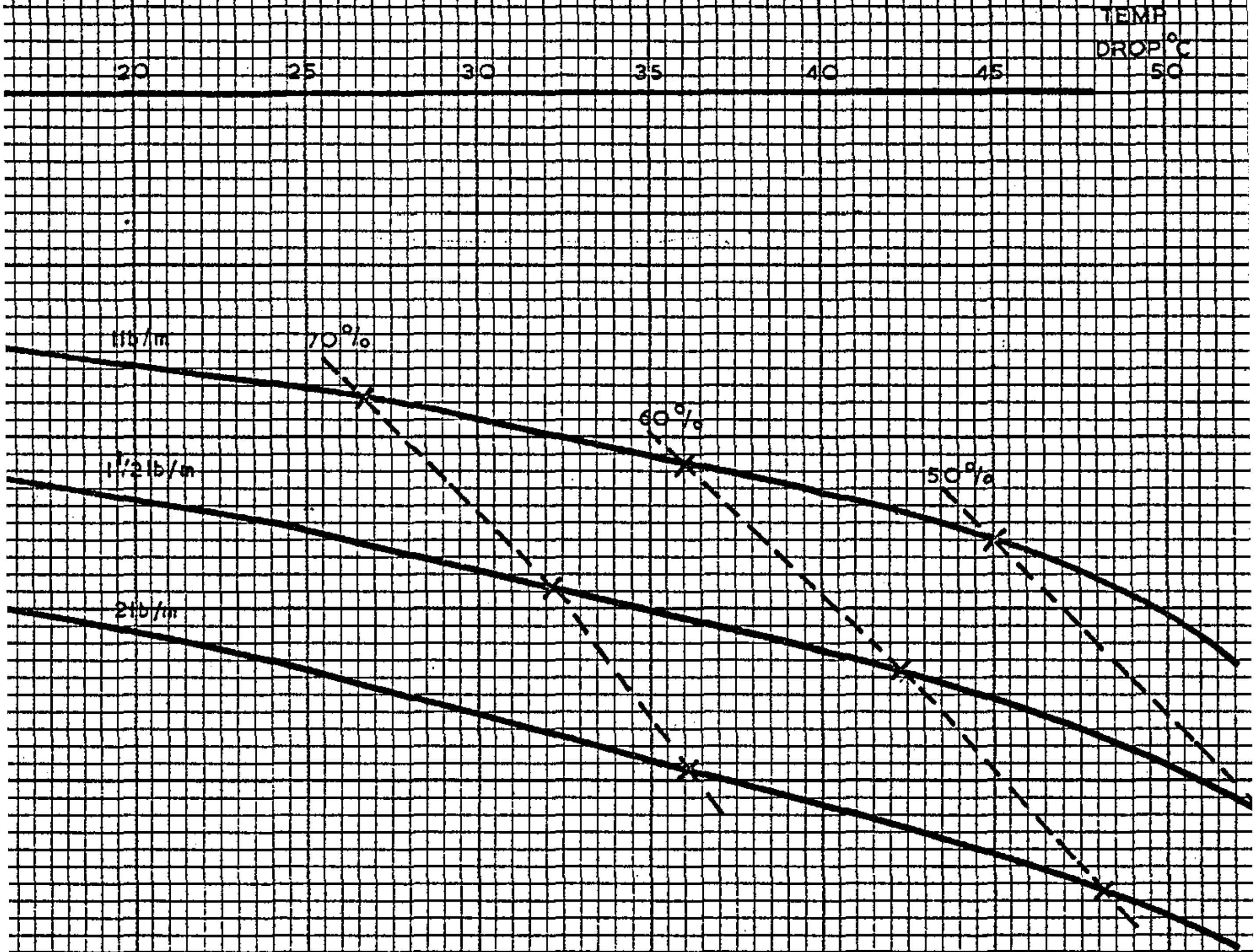


POTENTIAL COOLING CAPACITY OF SUIT INLET AIR

96/11397

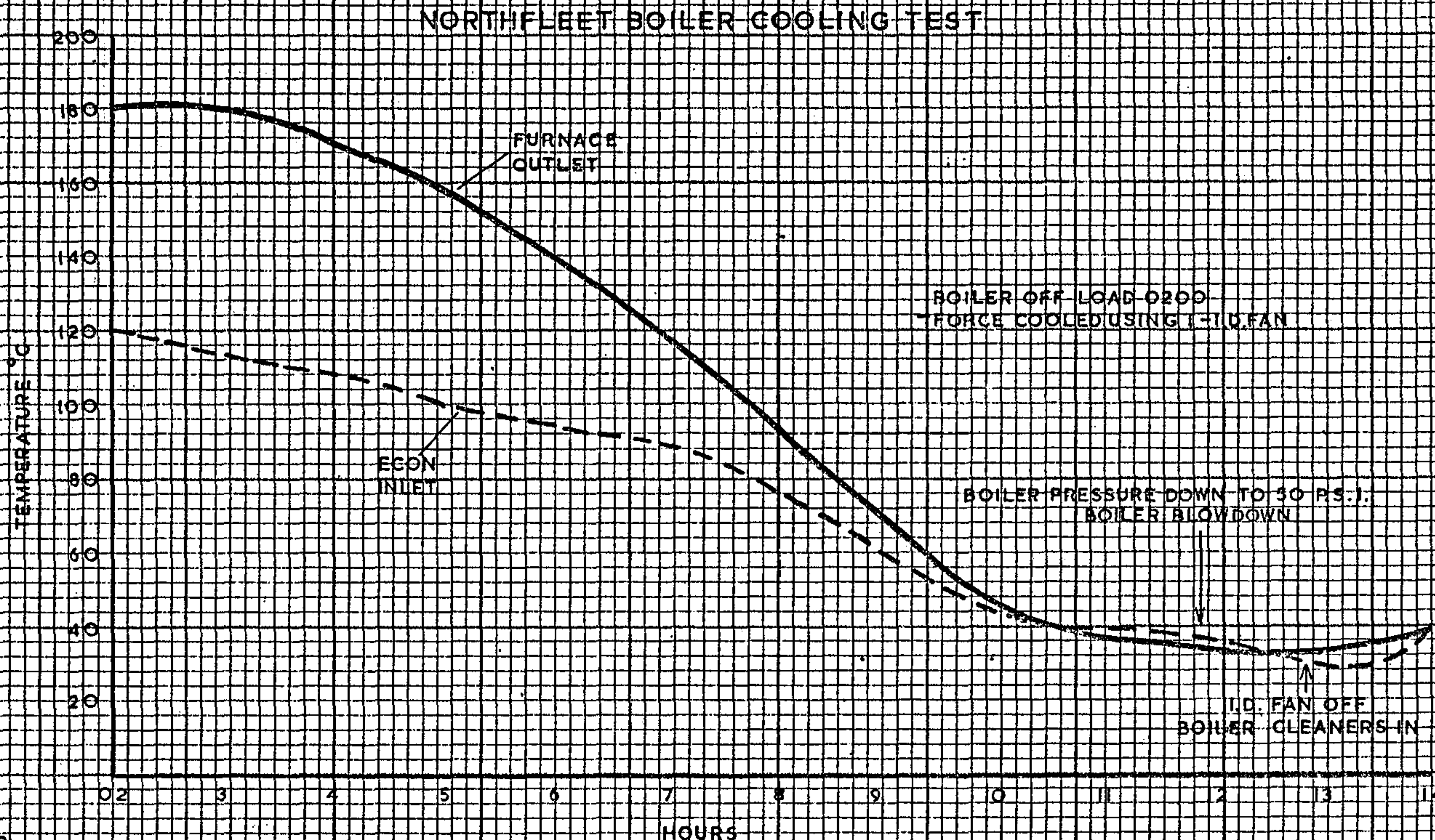
NTRAL ELECTRICITY GENERATING BOARD HEADQUARTERS

FIG.4·5B



RFORMANCE CHARACTERISTICS FOR TWIN FULTON VORTEX TUBES.

96/11932



CENTRAL ELECTRICITY GENERATING BOARD

HEADQUARTERS

FIG. AII-2

96/1142 3A

FIG. A. 4-1
PROTOTYPE 2 SUIT IN TEST CELL, R.A.E. FARNBOROUGH

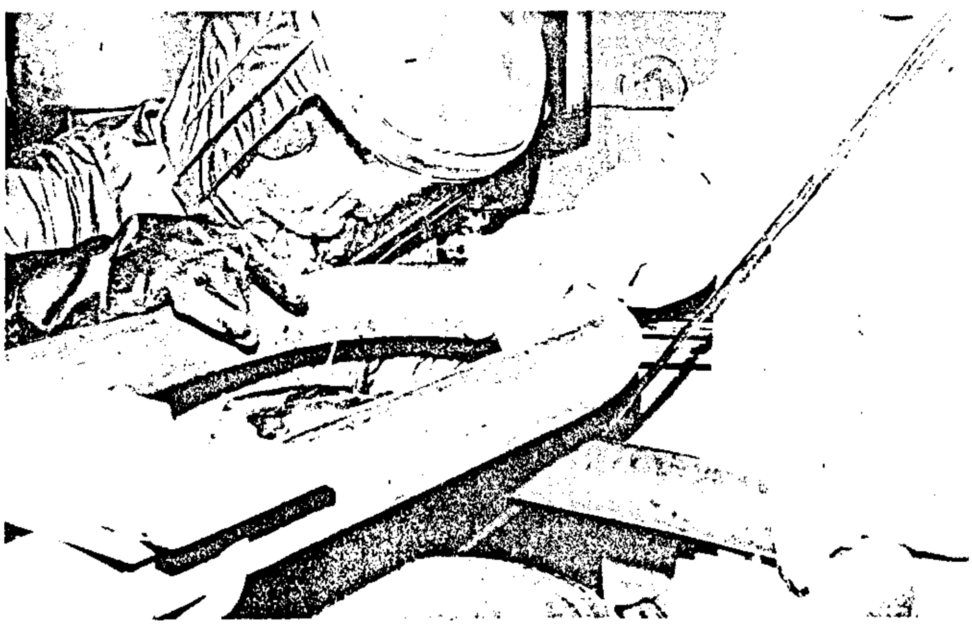
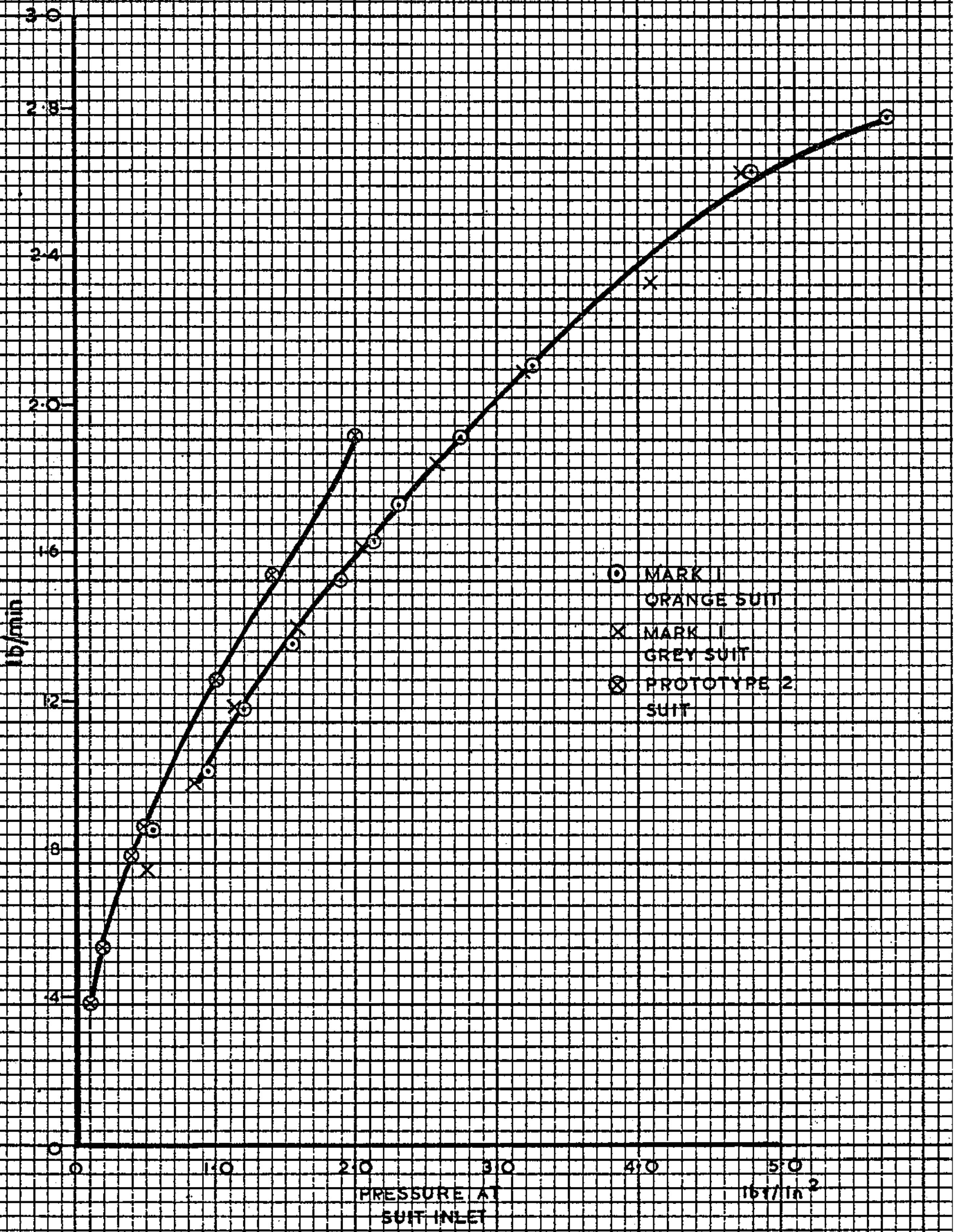


FIG. A. 4-2
PROTOTYPE 2 SUIT-OLDBURY BOILER ACCESS

CENTRAL ELECTRICITY GENERATING BOARD HEADQUARTERS

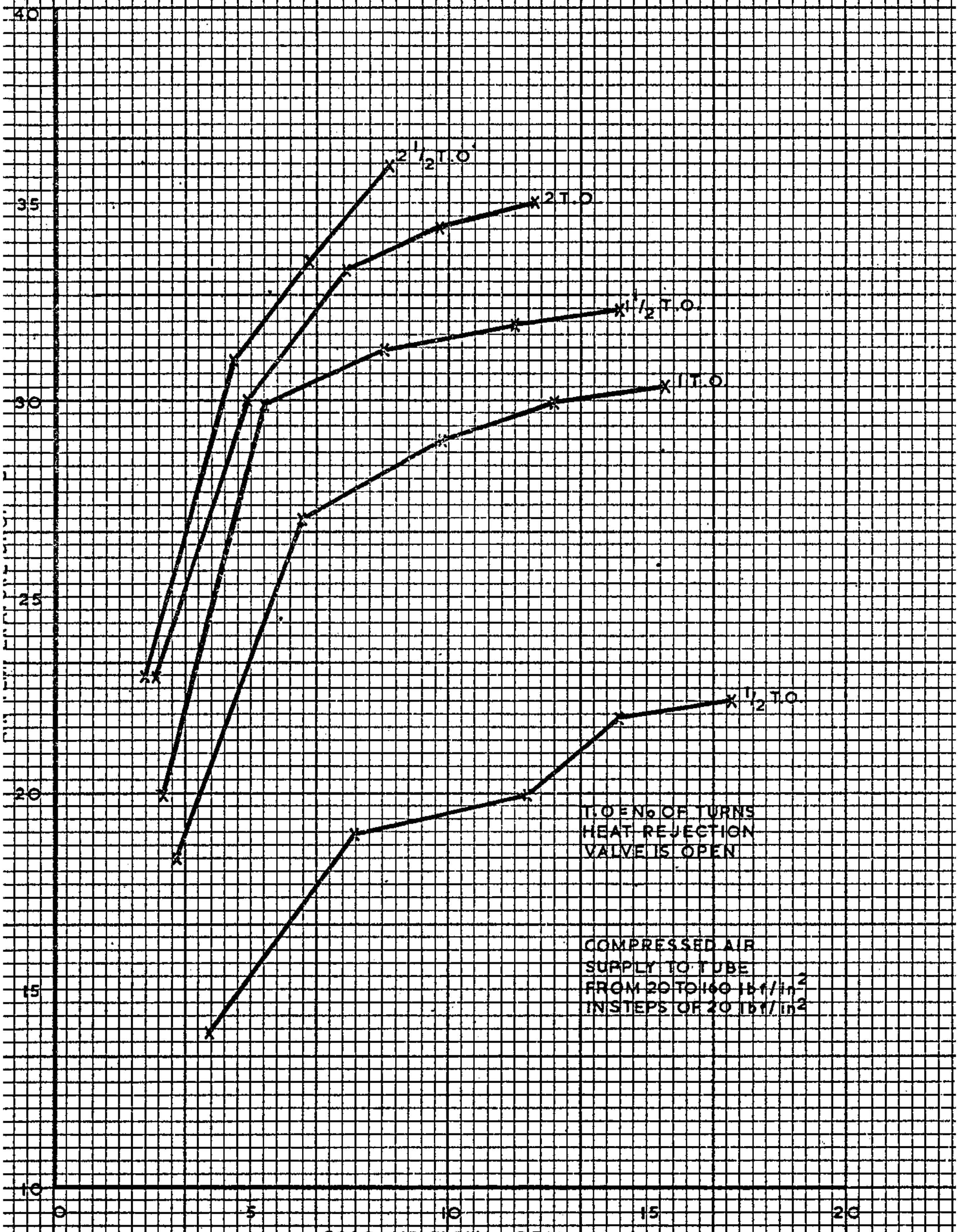
FIG. A6-1



SUIT INLET PRESSURE — SUIT INLET FLOW

96/11396A

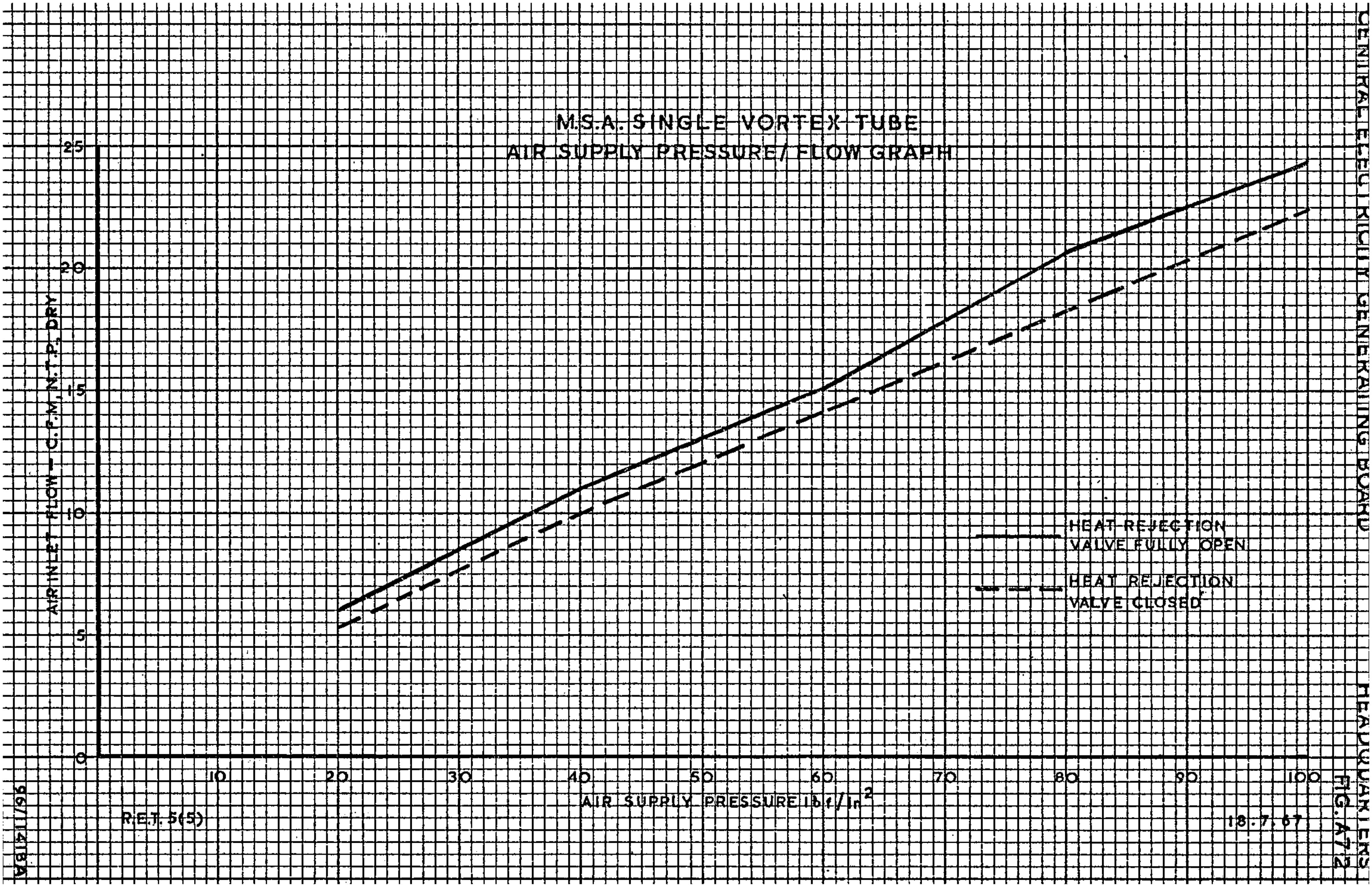
FIG. A7·1



M.S.A. SINGLE VORTEX TUBE
TEMPERATURE DROP/COLD AIR FLOW

R.E.T.S. (S) 18·7·67

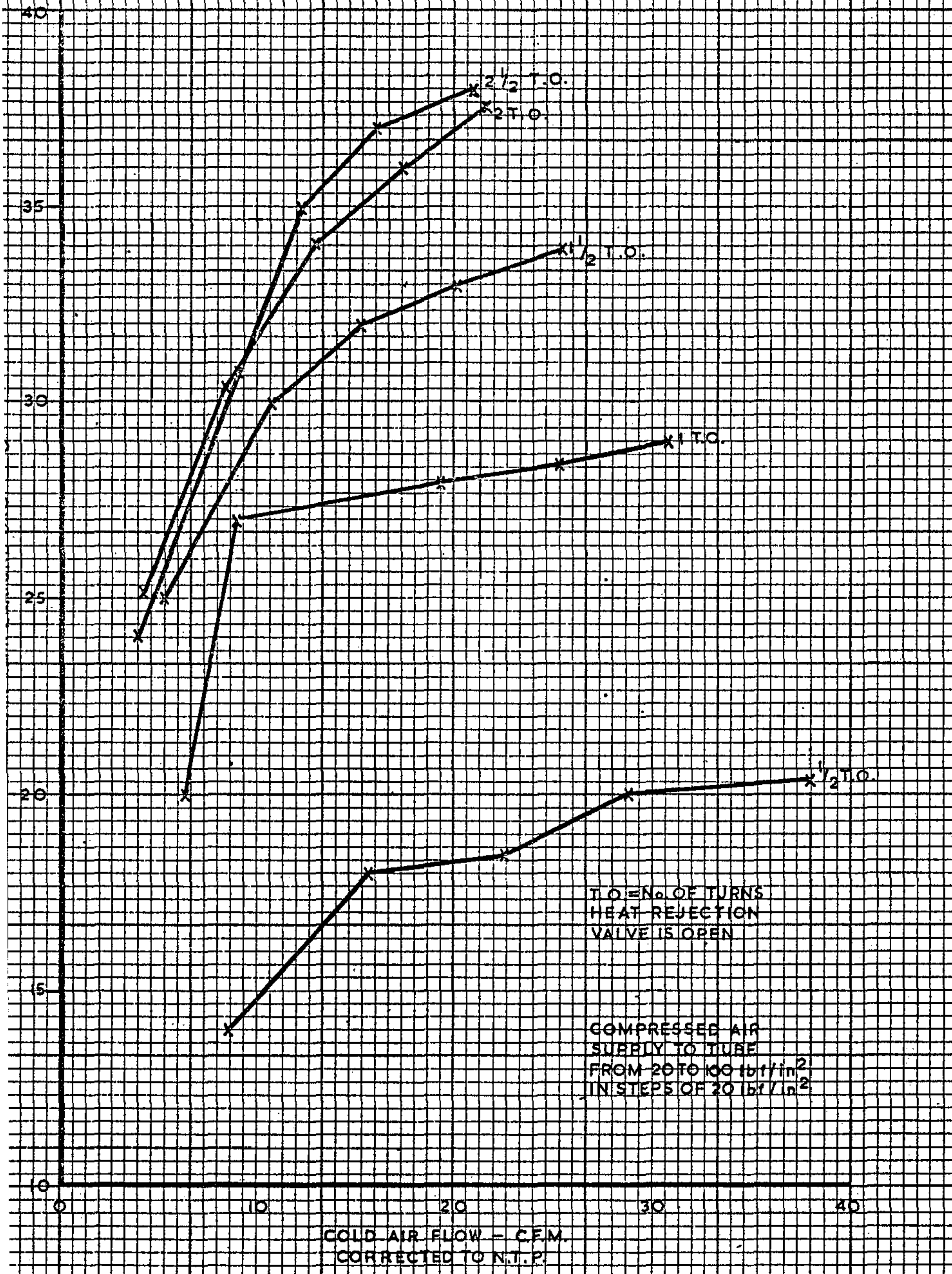
96/11417A



M.S.A. SINGLE VORTEX TUBE
AIR SUPPLY PRESSURE/ FLOW GRAPH
AIR INLET FLOW — C.F.M. N.T.P. DRY
25
20
15
10
5
0
10
20
30
40
50
60
70
80
90
100
AIR SUPPLY PRESSURE lbf/in²
HEAT REJECTION VALVE FULLY OPEN
HEAT REJECTION VALVE CLOSED
R.E.T. 5(5)
18.7.67
CENTRAL ELECTRICITY GENERATING BOARD HEADQUARTERS
96/1418A

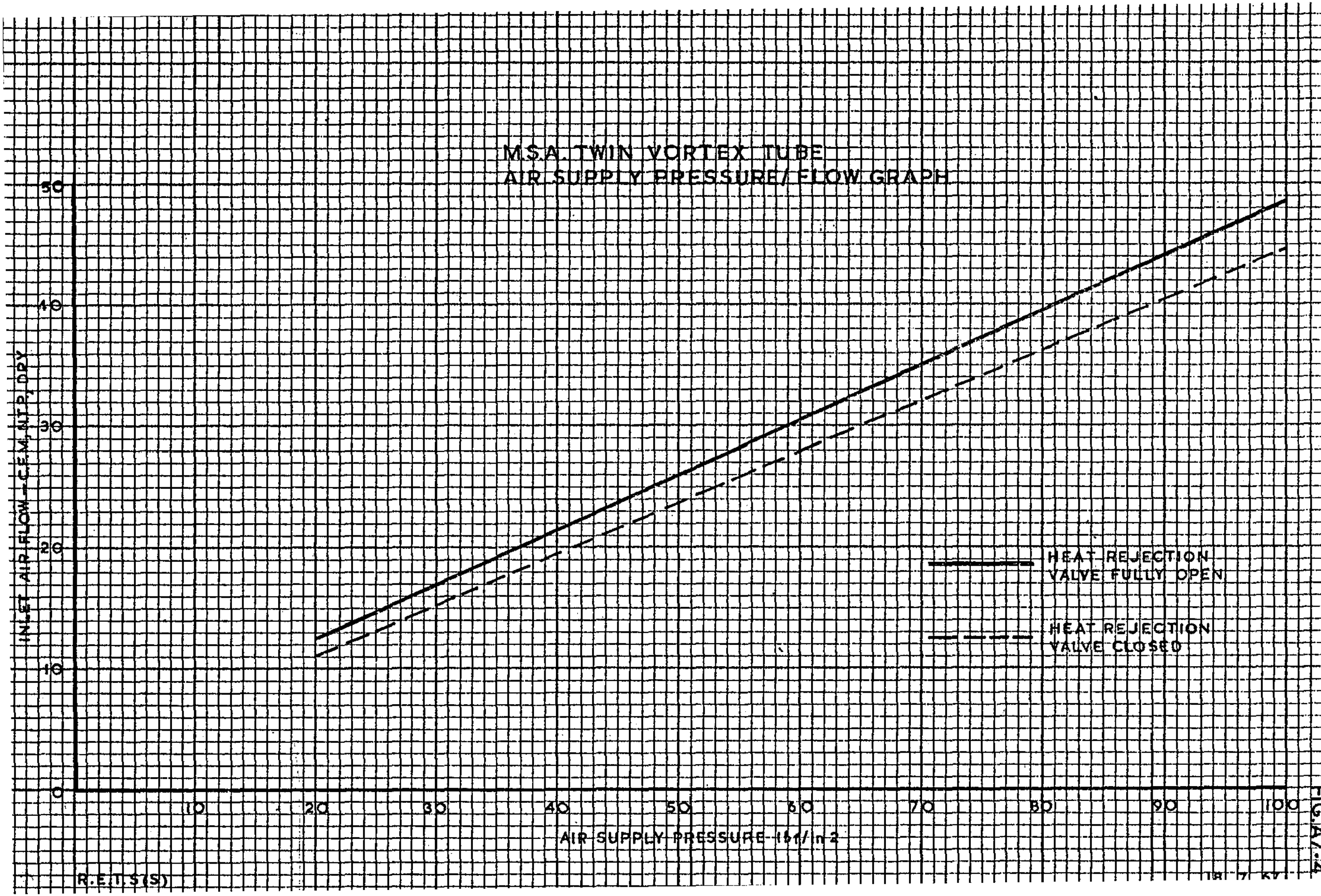
FIG. A72

FIG. A7·3



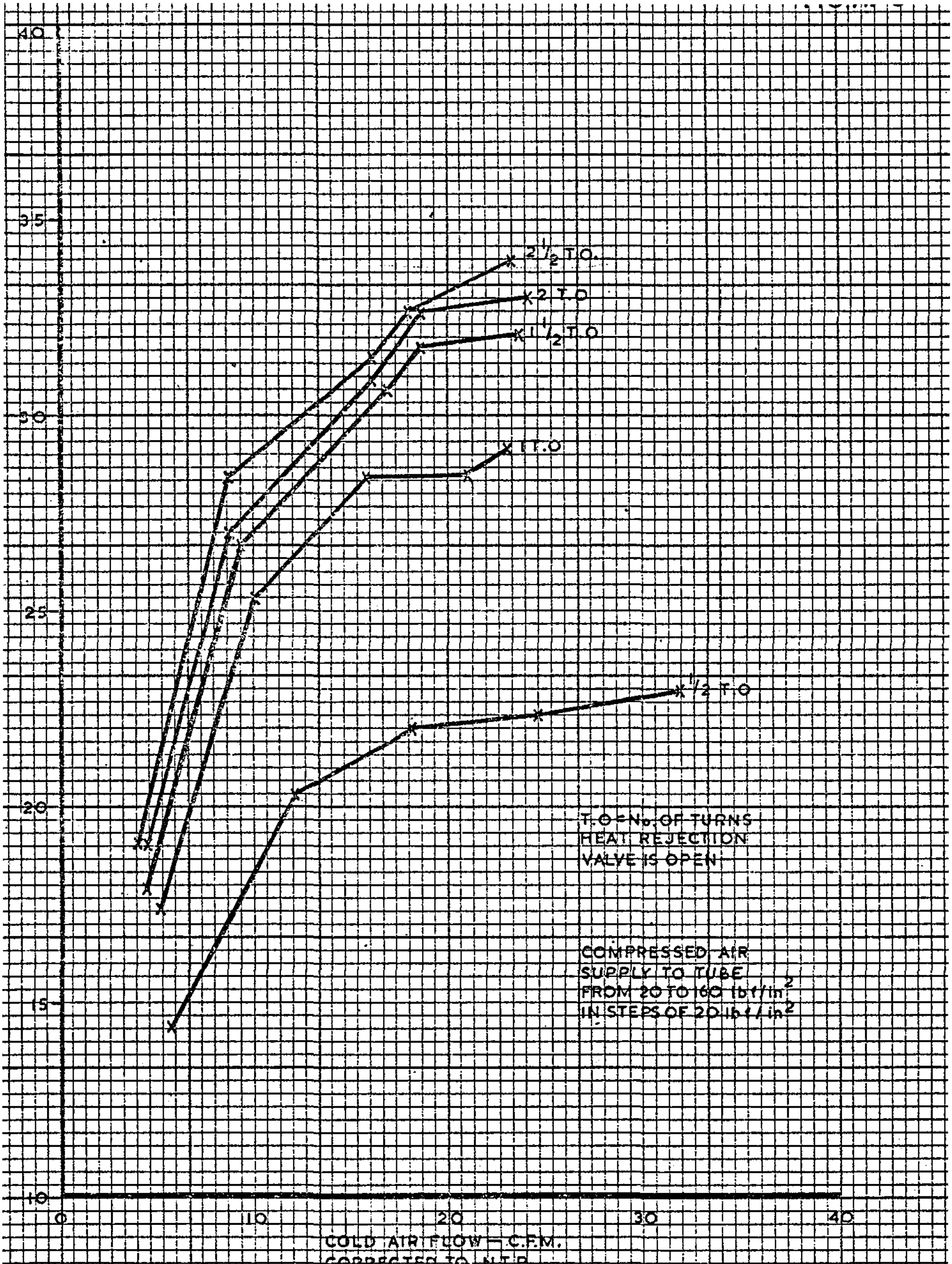
M.S.A. TWIN VORTEX TUBE
TEMPERATURE DROP/COLD AIR FLOW

R.E.T.S. (S) 18·7·67



CENTRAL ELECTRICITY GENERATING BOARD HEADQUARTERS

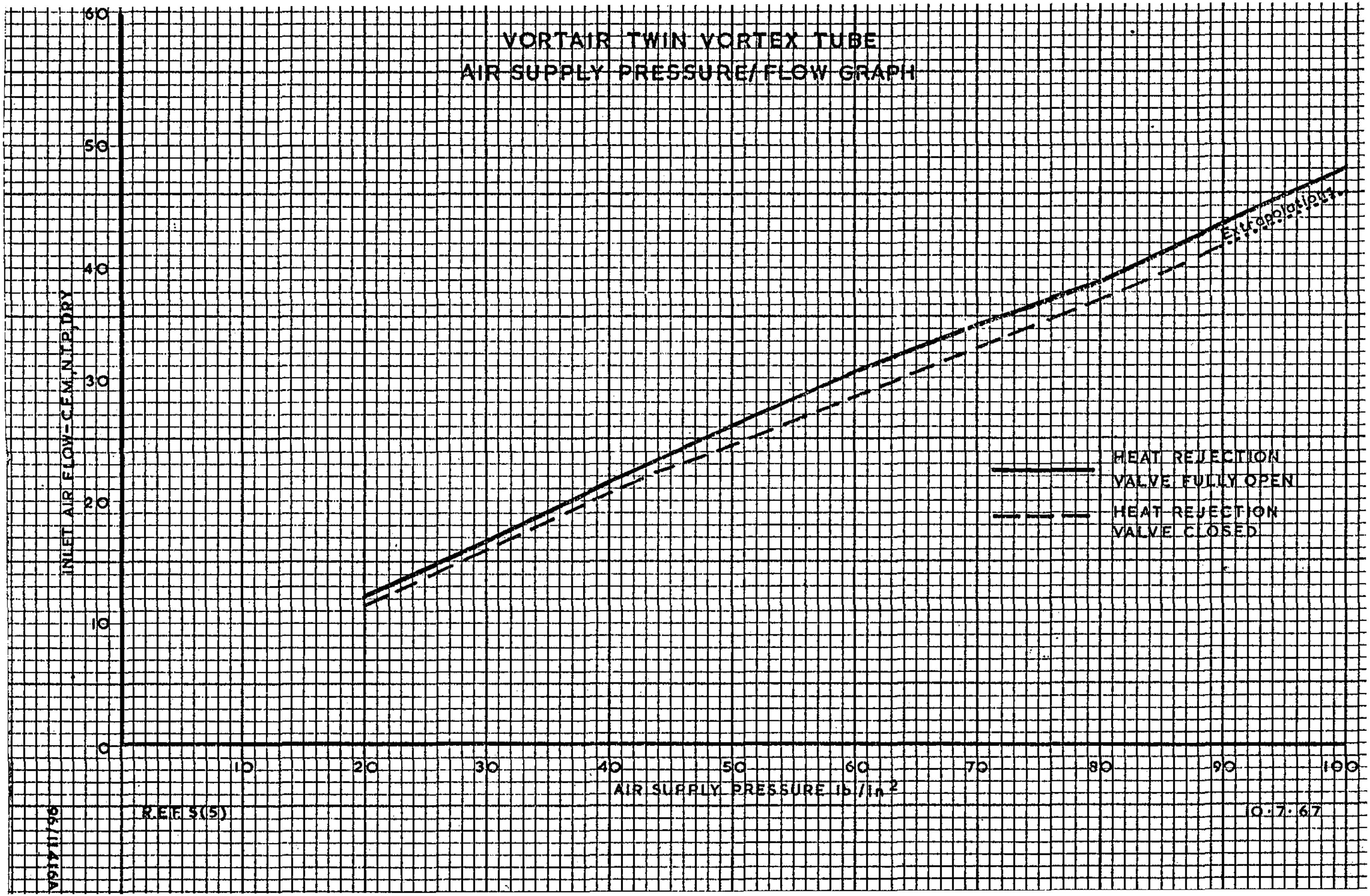
FIG. A7.4



VORTAIR TWIN VORTEX TUBE
TEMPERATURE DROP / COLD AIR FLOW

R.E.T.S.(S) 18·7·67

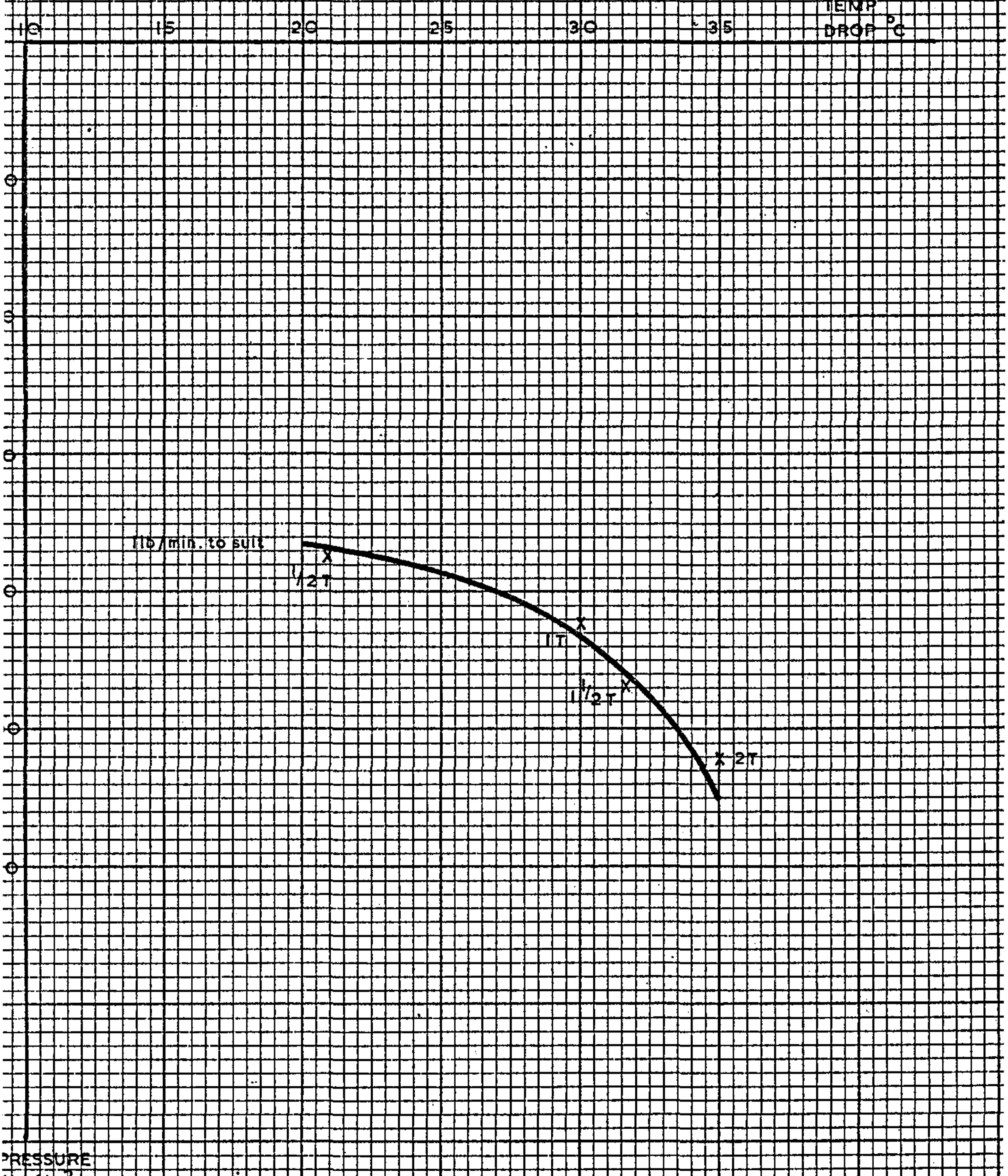
96/11415A



VORTAIR TWIN VORTEX TUBE
AIR SUPPLY PRESSURE/FLOW GRAPH
INLET AIR FLOW - C.F.M. N.T.P. DRY
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
100
AIR SUPPLY PRESSURE lb/in²
HEAT REJECTION VALVE FULLY OPEN
HEAT REJECTION VALVE CLOSED
Extrapolation
R.E.F. 5(5)
10·7·67

ITRAL ELECTRICITY GENERATING BOARD HEADQUARTERS

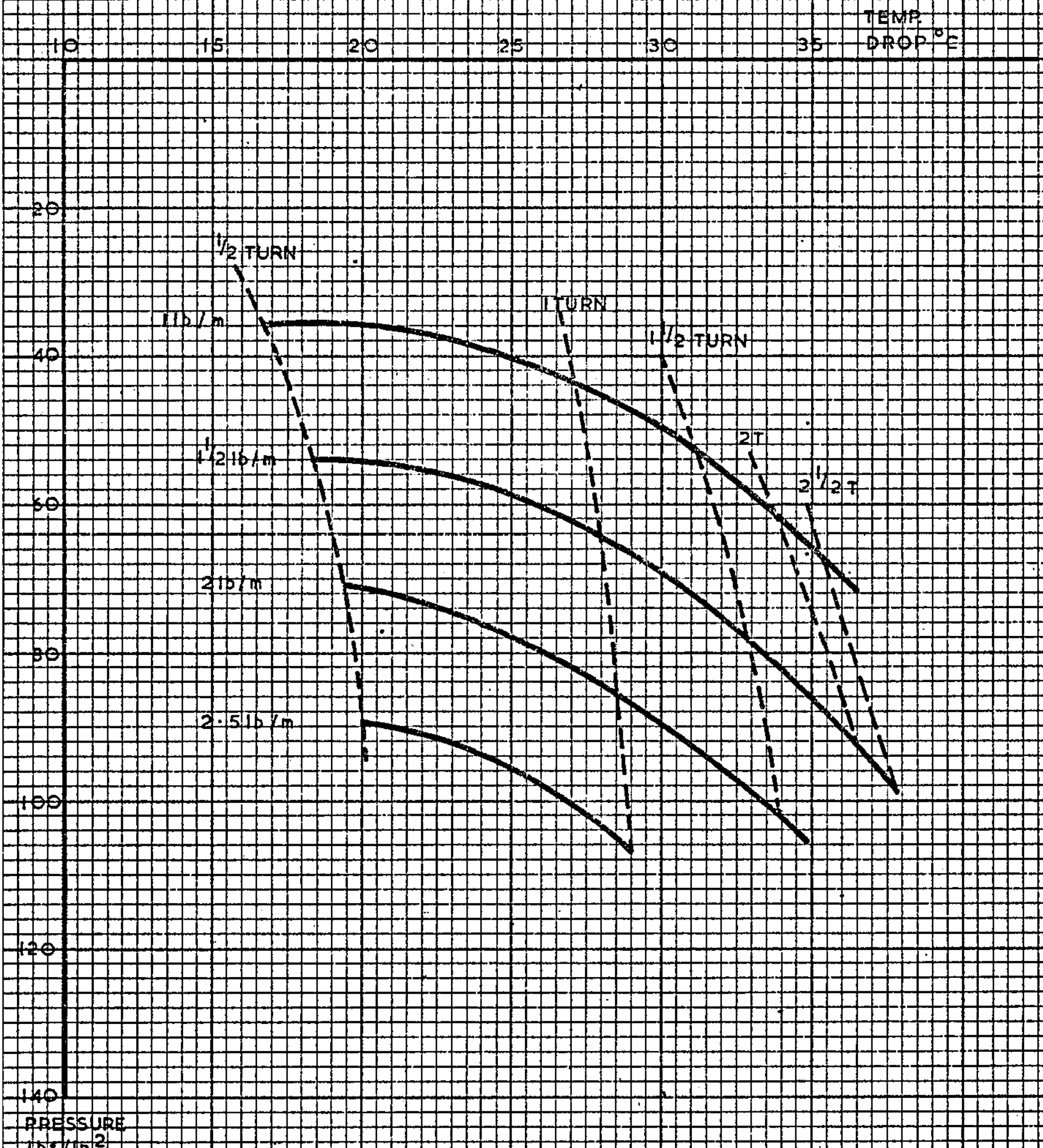
FIG. A7·7



M.S.A. SINGLE VORTEX TUBE CHARACTERISTIC AS MEASURED

90/11933

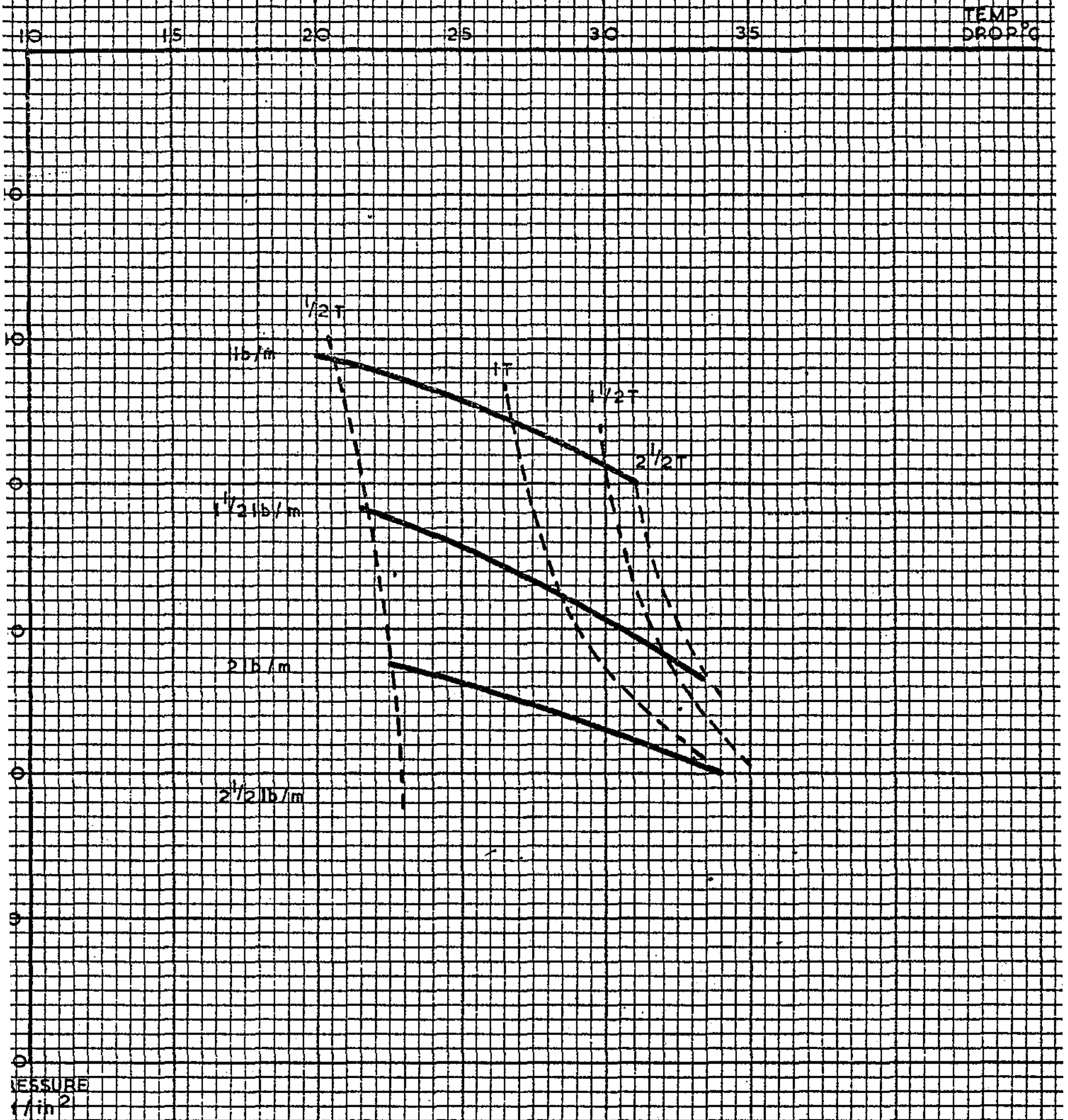
FIG.A7: 8



M.S.A. TWIN VORTEX TUBE CHARACTERISTIC AS MEASURED.

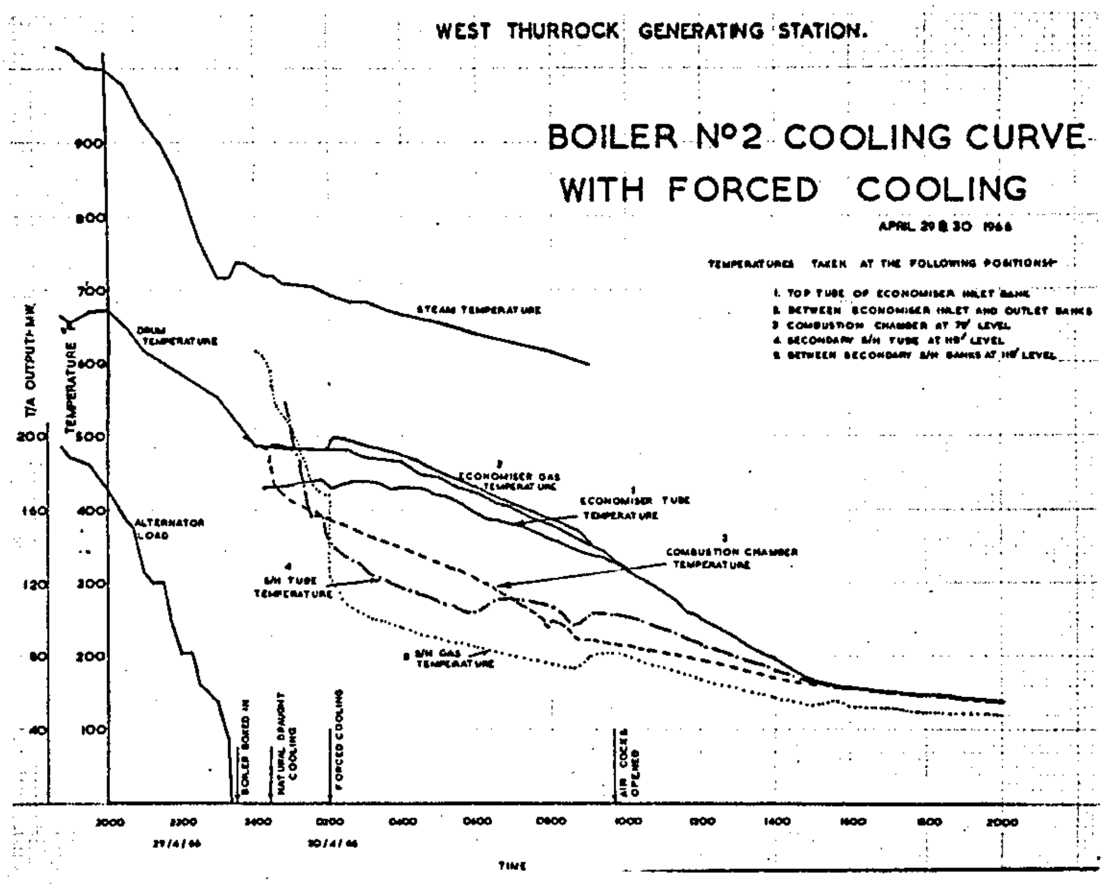
96/11934

FIG.A7·9



VORTAIR TWIN VORTEX TUBE CHARACTERISTIC AS MEASURED.

96/11935



WEST THURROCK GENERATING STATION.
BOILER Nº2 COOLING CURVE WITH FORCED COOLING
TEMPERATURES TAKEN AT THE FOLLOWING POSITIONS:-
1. TOP TUBE OF ECONOMISER INLET BANK
2. BETWEEN ECONOMISER INLET AND OUTLET BANKS
STEAM TEMPERATURE
DRUM TEMPERATURE
ALTERNATOR LOAD
ECONOMISER GAS TEMPERATURE
ECONOMISER TUBE TEMPERATURE
COMBUSTION CHAMBER TEMPERATURE
S/H TUBE TEMPERATURE
S/H GAS TEMPERATURE
T/A OUTPUT - MW
TEMPERATURE °F
BOILER BOXED IN
NATURAL DRAUGHT COOLING
FORCED COOLING
AIR COCKS OPENED
TIME

FIG. A11-1

CEGB STANDARD 060803.

ISSUE 1 JUNE 1976 APPENDIX D

HOT ENVIRONMENT WORKSUIT

CONTENTS

Published and printed by
Technical Documentation Branch
Engineering Services Department, CEGB
Walden House, 24 Cathedral Place, London EC4P 4EB
108/A

APPROVED BY STANDARDS COMMITTEE

HOT ENVIRONMENT WORKSUIT

FOREWORD

This Standard has been developed from the investigations carried out by the CEGB Working Party (Interim Report O(P)/NWH/18), into the requirements for protective clothing to enable work to be carried out in hot environmental conditions.

1. SCOPE

This Standard determines the materials, design and construction, assembly, size and colour, marking, standard sample and pattern for hot environment worksuits consisting of the following:

(i) Inner suit.
(ii) Air distribution system.
(iii) Outer suit.
(iv) Detachable hoods.

The suit shall be capable of protecting the wearer when working for periods of 2 hours in an ambient temperature of 60°C, when provided with an adequate supply of compressed air for both cooling and breathing purposes.

2. REFERENCES

This Standard makes reference to, or should be read in conjunction with, the following documents:

BS 2F.57, 'Scoured Cotton Fabrics for Aeronautical Purposes'.
BS F.118, 'Lightweight Nylon Fabrics for Aeronautical Purposes'.
BS 2571, 'Flexible PVC Compounds'.
DTD.481E, 'Braided Nylon Cordage: 60 Denier Yarn'.
DTD.829A, 'Nylon Webbing'.
Specification UK/AID/926/3, 'Close Cotton Fabric for Flying Clothing'.
O(P)/NWH/18, 'Interim Report by the Working Party concerned with the Development of Protective Clothing for Working in Hot Conditions'. Dec. 1967.

3. COMMON REQUIREMENTS

3.1 Materials

All materials used shall comply with Attachment A.

3.2 Positioning

All positions (such as left, right, upper and lower) are relative to the wearer.

3.3 Sealed Sample

Any manufacturing details not defined in this Standard shall be in accordance with the sealed sample held by the manufacturer at his works and available for inspection by authorized officers of the CEGB.

3.4 Minimum Standard of Manufacture

The workmanship and finish shall be of the best quality, the minimum standard of which shall be as the sealed sample.

3.5 Finish

3.5.1 Synthetic Fabrics

The ends of all nylon and terylene parts shall be heat sealed to prevent fraying, except the quilted material seams of the inner suit and hood, which shall be raised over and stitched.

3.5.2 Fittings

All fittings shall be suitably stayed and securely attached in the correct positions as on the sealed sample.

3.6 Sewing

Terylene thread, 250 denier, with minimum breaking strength of 4.5 kg, shall be used in the making-up of this suit, the colour to match materials being sewn. All sewing shall be neatly and securely finished off. Should any break occur in a line of sewing, stitching shall recommence 25 mm before the point of breakage.

3.7 Stitching

The number of stitches shall be not less than 8 and not more than 10 stitches per 25 mm. All machine stitching shall be carried out on a lock-stitch machine.

3.8 Sliding Fasteners

Sliding fasteners shall be of the continuous spiral, polyester type with black cotton tape.

3.8.1 Each sliding fastener shall be securely and evenly attached to the material with two rows of sewing spaced 6 mm apart; unless otherwise stated, the turned edge of the material shall be at least 3 mm from the chain of the fastener.

3.8.2 When attaching the tape of the fastener, care shall be exercised to avoid stretching the material. When sewn in, the fasteners shall be flat and free from puckering.

3.8.3 The ends of the tape shall be firmly secured to the garment, except for the hood sliding fasteners, which shall be left free for 25 mm.

3.8.4 Each sliding fastener shall have the stitching reinforced by a strip of self-fabric on the reverse side, except for locations where the fabric has already been doubled.

3.8.5 The pull tags shall consist of stay material threaded through the wire loop of the sliding fastener, folded over, and a piece of 16 mm wide, 50 mm long, type 18 loop strip fastener stitched to the material.

3.9 Assembly

Fig. 1 shows the assembled suit.

3.9.1 Air Distribution System

The supply tubes shall be threaded through the aperture, and the distribution tubes through the loops and apertures, as shown on the sealed sample. The flap shall be closed over the manifold.

3.9.2 Inner and Outer Suits

With the inner suit inserted into the outer suit, the air supply tube shall be threaded through the tunnel, and the hook and loop strip fastened.

3.10 Marking

A durable label made from scoured cotton fabric conforming to BS 2F.57 shall be provided clearly and permanently marked with the information given below, in letters and figures of an 'x' height not less than 5 mm. The labels shall be firmly sewn, on all four sides, to the inside back of the inner and outer suits and hood.

Hot Environment Suit	
Manufacturer	BEAUFORT
Date	
Contract CEGB/NAT/	0000
Serial No.	

3.11 Washing Instructions

Washing and cleaning instructions shall be provided by the manufacturer with each suit.

4. INNER SUIT

4.1 Materials

4.1.1 Suiting

Nylon fabric of approved type conforming to BS F.118, Ref. 8684, shall be sewn to sheets of 6 mm thick polyester foam of approved type (density 3.8 to 5 kg/m^3), in 150 mm squares at 45° to the warp, to form a quilt from which the lining shall be made.

The outer cover shall be made from nylon fabric of approved type conforming to BS F.118, Ref. 8684.

4.1.2 Ventilation Tube Loops

Ventilation tube loops of 25 mm wide nylon webbing of approved type shall be used.

4.1.3 Aperture Facings

The hood ventilation apertures shall be faced with woven cotton fabric of approved type conforming to Specification UK/AID/926/3, Type L.28 (except for waterproof tests).

4.1.4 Hook and Loop Fasteners

Hook and loop strip fasteners, 16 mm wide, of approved type shall be used.

4.1.5 Sliding Fastener

The sliding fastener shall be of approved type as follows:

One heavyweight, double-ended, continuous spiral, polyester sliding fastener having non-lock, closed bridge sliders fitted with a wire ring, of lengths as follows:

Suit Size	Fastener Length mm
Small	535
Medium	585
Large	635
Extra Large	685

4.2 Design

The inner suit shall be a one-piece foam insulated suit with front entry, closed with a sliding fastener. Webbing loops for supporting the air ventilation tubes and a flap for holding the manifold shall be sewn inside the suit.

4.3 Construction

4.3.1 Suiting

4.3.1.1 The outer cover shall be cut and assembled from nylon fabric with 10 mm seams raised over and stitched.

4.3.1.2 The lining shall be cut and assembled from the quilting material with 10 mm flat seams. The lining and cover shall be bagged and stitched out 6 mm at the cuffs, neck and ankles.

4.3.2 Sliding Fastener

The sliding fastener shall be attached with two rows of stitching.

4.3.3 Ventilation Tube Loops

Nylon webbing of cut length 50 mm shall be sewn in the positions indicated on the sealed sample to form loops for holding the air ventilation tubes.

4.3.4 Manifold Flap

Two layers of quilt shall be sewn and bagged out to form a flap for the manifold in the heart position. The open edges shall be turned in and sewn together. The hook half of the hook and loop strip fastener shall be sewn to the flap to mate with the loop half sewn to a stay of fabric. A 38 mm diameter aperture shall be faced with a stay, which shall be sewn through both layers of the suit, and the flap shall be sewn through the stay with a gap left for passage of the air distribution tubes.

4.3.5 Hood Ventilation Apertures

A 30 mm diameter aperture on each side of the front shall be faced with cotton fabric to Specification UK/AID/926/3, Type L.28, to correspond to the apertures on the outer suit.

4.4 Size and Colour

The suit shall be manufactured from orange cotton fabric in four sizes, small, medium, large, and extra large as detailed in Table 1.

Table 1 Suit sizes

Size	Height			Chest	
	mm	*ft*	*in*	*mm*	*in*
Small, up to	1730	5	8	960	38
Medium, up to	1800	5	11	1040	41
Large, up to	1880	6	2	1120	44
Extra Large, up to	1930	6	4	1170	46

4.5 Marking

A durable label made from scoured cotton fabric conforming to BS 2F.57 shall be provided clearly and permanently marked with the information given below, in letters and figures of an 'x' height not less than 5 mm. The label shall be sewn firmly, on all four sides, to the inside of the inner suit just below the identification label.

$\boxed{\text{Medium}}$ Inner Suit	
Suitable for Men	
Max. Height	$\boxed{\text{1800 mm}}$
Max. Chest	$\boxed{\text{1040 mm}}$

5. AIR DISTRIBUTION SYSTEM

5.1 Materials

5.1.1 Manifold

The manifold shall be of approved type consisting of manifold body, ventilation tubes and connectors.

5.1.1.1 Ventilation tubes of approved type shall be of polyvinyl chloride (PVC), to BS 2571, Class 3. The two tubes for supplying air to the hood shall be 9.5 mm bore and 13.8 mm outside diameter, and shall have a softness number of 30. The other seven tubes shall be 6.35 mm bore and 9.52 mm outside diameter.

5.1.1.2 Hood tube connectors shall be of approved type.

5.1.2 Connecting Hose

The 22 mm bore rubber hose connecting the manifold to the supply tube shall be of approved type.

5.1.3 Supply Tube Coupling

The coupling joining the connecting hose to the supply tube shall be of approved type.

5.1.4 Adhesive

The adhesive shall be of approved type.

5.2 Design

The air distribution system consists of a reinforced rubber hose, connecting the supply tube to the manifold, which then distributes the air by nine strategically perforated PVC tubes positioned to allow an even flow of air over the body. See Fig. 2.

5.3 Construction

5.3.1 Ventilation Tubes

Except for the two tubes supplying air to the hood, the ends of the tubes shall be heat sealed, and have 1.5 mm diameter holes punched through the tube giving two holes per pitch. Punching of the holes shall commence 20 mm from the free end of the tubes. Details of tubes are given in Table 2.

Table 2 Ventilation tube details

Tube reference		Tube length for suit size				No. of holes (2 per punch)	Pitch for suit size			
No.	Position	Small mm	Med. mm	Large mm	Ex. Large mm		Small mm	Med. mm	Large mm	Ex. Large mm
1	Left Arm	1195	1270	1350	1425	10	100	108	114	120
2	Right Arm	1320	1425	1575	1680	10	100	109	117	124
3	Back Body	1125	1125	1125	1125	10	100	100	100	100
4	Right Leg	1350	1450	1550	1650	14	100	109	117	124
5	Left Leg	830	910	960	1060	18	50	56	61	66
6	Groin	495	495	495	495	8	100	100	100	100
7	Front Body	300	300	300	300	10	38	38	38	38
8	Head	216	216	266	266	0	–	–	–	–
9	Head	170	170	170	170	0	–	–	–	–

Note: For identification of tubes refer to Fig. 2

5.4 Subassembly

The manifold, hood connectors and connecting hose shall be assembled and bonded with the approved adhesive. The hose joint to the manifold shall include a rigid insert of 20 mm length.

6. OUTER SUIT

6.1 Materials

6.1.1 Suiting

The outer suit shall be assembled from woven cotton fabric of approved type conforming to Specification UK/AID/926/3, Type L.28.

6.1.2 Knitted Nylon Elasticated Cuffing

The material of the cuffing shall be knitted part 2/100/34 (false twist nylon), into which is laid 3369 covered rubber thread, or an approved equivalent, and shall be fast dyed black.

6.1.2.1 Wrist cuffs shall be made from cuffing 90 mm wide, i.e. half the circumference.
6.1.2.2 Ankle cuffs shall be made from cuffing 125 mm wide, i.e. half the circumference.

6.1.3 Hook and Loop Fasteners (Velcro)

Hook and loop strip fasteners, 16 mm wide, of approved type shall be used.

6.1.4 Suit Sliding Fastener

The sliding fastener shall be of approved type as follows:

One heavyweight, double-ended, continuous spiral, polyester sliding fastener having non-lock, closed bridge sliders, of lengths as follows:

Suit Size	Fastener Length *mm*
Small	610
Medium	635
Large	660
Extra Large	685

6.1.5 Hood Sliding Fasteners

The continuous spiral, polyester sliding fasteners shall be of approved type as follows:

6.1.5.1 Front, Right Chest – Half of a 200 mm long, heavyweight, open end fastener with a non-lock, closed bridge slider fitted with a wire ring.
6.1.5.2 Front, Left Chest – Half of a 200 mm long, heavyweight, open end fastener without slider.
6.1.5.3 Back – Half of a 455 mm long, heavyweight, open end fastener without slider.

6.1.6 Waist-belt

The waist-belt shall be made from 50 mm wide terylene webbing of approved type.

6.1.7 Buckle and Slide

Buckle and slide shall be of approved type.

6.1.8 Hose Tunnels

The hose tunnels shall be assembled from woven cotton fabric of approved type conforming to Specification UK/AID/926/3, Type L.28.

6.2 Design

The outer suit shall be a one-piece suit with front entry; closed with a sliding fastener, having a waist-belt. Halves of sliding fasteners for attaching the hood shall be sewn across the chest and back of the suit. See Fig. 3.

6.3 Construction

6.3.1 Suiting

6.3.1.1 The outer suit shall be assembled from woven cotton fabric with run and fell seams.

6.3.1.2 The total seaming allowance is 30 mm. The knee shall be pleated, and the neck shall be faced with a bias strip of self-fabric. The ends of the legs and sleeves shall be faced with a self-fabric.

6.3.2 Wrist Cuffs

The knitted nylon elasticated cuffing shall be sewn to strips of woven cotton fabric, with run and fell seams to form an inner cuff assembly, which shall be turned under and sewn to the inside of the sleeves with two rows of stitches.

6.3.3 Ankle Cuffs

The knitted nylon elasticated cuffing shall be sewn to strips of woven cotton fabric, with run and fell seams to form an inner cuff assembly, which shall be turned under and sewn to the inside of the legs with two rows of stitching.

6.3.4 Suit Sliding Fastener

The sliding fastener shall be attached with two rows of stitching.

6.3.4.1 Tongue

Woven cotton fabric shall be sewn and bagged out to form a tongue, edge sewn, and reinforced with five equally spaced vertical rows of stitching. The tongue shall be attached to the suit with the second row of stitching attaching the sliding fastener to the suit.

6.3.5 Hood Sliding Fasteners

Three half-sections of open-ended sliding fasteners shall be sewn to the suit for attaching the hood as follows:

(i) One half of a 200 mm sliding fastener with the slider shall be sewn to the right-hand side of the chest. One half of a similar sliding fastener, but without the slider, shall be sewn to the left-hand side of the chest with the end stops flush with the turned edge of the suit fabric. Both sliders shall close towards the centre of the suit, and the outer ends of the tape shall be left free for 25 mm.

(ii) One half of a 455 mm sliding fastener without the slider shall be sewn to the back of the suit, and each end shall be left free for 25 mm.

6.3.6 Fixing of Sliding Fasteners

Hook strip fasteners of 50 mm length shall be sewn on to the outer suit to mate up with the lengths of strip fasteners attached to the pull tags on the sliding fasteners when in the closed position.

6.3.7 Waist-belt

The waist-belt shall be looped through the male half of a buckle and slide for 50 mm, and sewn with a box tack using terylene thread. Two loops shall be made with a double row of stitching, and positioned as on the sealed sample. The free end of the belt shall be threaded through the female half of the buckle. The end shall be turned 20 mm and sewn with a double row of stitching.

6.3.8 Waist-belt Tunnel and Loops

These attachments shall be positioned as on the sealed sample:

6.3.8.1 A tunnel of woven cotton fabric with the ends turned back for 13 mm shall be sewn to the suit with the edges turned under. The ends shall be reinforced on the inside of the suit with stays of self-fabric.

6.3.8.2 Two belt loops made from woven fabric shall be sewn to the suit and reinforced on the inside with stays of self-fabric.

6.3.8.3 Two tie tapes, 455 mm long and made from 10 mm wide webbing, shall be sewn centrally in the suit, one at each end of the waist-belt tunnel.

6.3.9 Epaulette

A self-material epaulette complete with tie tape shall be sewn on the right-hand side of the suit. The attachment shall be positioned as on the sealed sample.

6.3.10 Hose Tunnel and Aperture

A hose tunnel shall be made up from three strips of woven cotton fabric as follows:

(i) The seams shall be sewn and raised. The free end of the centre panel shall be turned back 13 mm and bagged under for 115 mm, leaving an extension of 25 mm for the hook and loop strip fastener. The loop half of the hook and loop fastener shall be attached to the free end such that it has to be folded when securing.

(ii) A 45 mm diameter aperture shall be self-faced, and the hook half of the hook and loop fastener shall be attached through the facing to mate with the hook half on the tunnel.

(iii) The tunnel shall be attached to the suit with the edges turned in as far as the aperture facing, and the edges of the free end shall be finished with a narrow hem.

6.3.11 Hood Ventilation Apertures

Apertures of 30 mm diameter in each side of the front, positioned as on the sealed sample, shall be self-faced.

6.4 Colour and Size

The suit shall be manufactured from orange cotton fabric in four sizes; small, medium, large, and extra large as detailed in Table 3.

Table 3 Suit sizes

Size	Height			Chest	
	mm	*ft*	*in*	*mm*	*in*
Small, up to	1730	5	8	960	38
Medium, up to	1800	5	11	1040	41
Large, up to	1880	6	2	1160	44
Extra Large, up to	1930	6	4	1170	46

6.5 Marking

A durable label made from scoured cotton fabric conforming to BS 2F.57 shall be provided clearly and permanently marked with the information given below, in letters and figures of an 'x' height not less than 5 mm. The label shall be sewn firmly on all four sides to the inside of the outer suit just below the identification label.

Medium	Inner Suit
Suitable for Men	
Max. Height	1800 mm
Max. Chest	1040 mm

7. HOOD, SEMI-RIGID

7.1 Materials

7.1.1 Inner Hood

The inner hood shall be made from nylon fabric of approved type conforming to BS F.118, Ref. 8684, sewn to sheets of 6 mm thick polyester foam of approved type (density 3.8 to 5 kg/m^3), in 50 mm squares at 45° to the warp, to form a quilt.

7.1.2 Outer Hood

The outer hood shall be made from woven cotton fabric of approved type conforming to Specification UK/AID/926/3, Type L.28.

7.1.3 Semi-rigid Insert

7.1.3.1 Two layers of neoprene foam shall be constructed in panels to form the shape of the hood. The foam shall be of the type approved.

7.1.3.2 Panels of glass fibre 75 mm square shall be manufactured to the approved drawing held by the manufacturer, and drilled as shown for attachment to the cushioning material.

7.1.4 Ventilation Tube Connectors

Ventilation tube connectors shall be of approved type.

7.1.5 Ventilation Tubes

The ventilation tubes of approved type shall be of polyvinyl chloride (PVC), to BS 2571, Class 3. The two tubes that connect to the manifold tubes shall be clear, 9.5 mm bore and 13.8 mm outside diameter, and shall have a softness number of 30. The other three tubes shall be black, 8 mm bore and 11.5 mm outside diameter.

7.1.6 Hood Tube Connectors

Hood tube connectors shall be of approved type.

7.1.7 Visor

A visor of approved type made from polymethyl-methacrylate (perspex), not less than 5 mm thick, shall be provided, as illustrated in Fig. 4.

7.1.8 Adhesive

The adhesive used shall be of approved type.

7.1.9 Hook and Loop Fasteners (Velcro)

Hook and loop strip fasteners 16 mm wide, of approved type shall be used.

7.1.10 Sliding Fasteners

The continuous spiral, polyester sliding fasteners shall be of approved type as follows:

7.1.10.1 Front, Right Chest – Half of a 200 mm long, heavyweight, open-end fastener without slider.

7.1.10.2 Front, Left Chest – Half of a 200 mm long, heavyweight, open-end fastener with a non-lock, closed bridge slider fitted with a wire loop.

7.1.10.3 Back – Half of a 455 mm long, heavyweight, open-end fastener with a non-lock, closed bridge slider fitted with a wire loop.

7.1.11 Stays

Stays shall be of approved type.

7.1.12 Stay Loops

Stay loops of 20 mm wide cotton or spun nylon webbing of approved type shall be used.

7.2 Design

7.2.1 The hood shall be detachable, joined to the outer suit by sliding fasteners, and fed from the inner suit ventilation pipes via quick release connections. The hood shall consist of a cowl made from the same fabrics as the suit, and incorporate a perspex visor which shall be removable for cleaning, afford excellent all-round vision and have sufficient room for the user to turn his head.

7.2.2 To facilitate quick release of the visor a flap is situated at the centre front of the cowl and is retained by hook and loop fasteners. Webbing pull loops are attached to the cowl flap and visor.

7.2.3 A semi-rigid insert shall be used in conjunction with the hood, and it shall consist of two layers of neoprene foam with an interply of interlocking glass fibre panels. The glass fibre panels shall be held in position to the outer layer by the approved method. The two layers of neoprene are stuck together with a band of adhesive 15 mm wide around the periphery. The insert can then be placed between the inner and outer layers of the hood. The hood is illustrated in Fig. 4.

7.3 Construction

7.3.1 Inner Hood

7.3.1.1 The cover and quilt of the inner hood shall be bagged out and around the neck. The edges around the face section shall be sewn to a facing of woven cotton fabric, which shall be bagged on to the outside with a single row of stitching. A strip of loop strip fastener shall be sewn on to the facing with two rows of sewing.

7.3.1.2 Two strips of bias cut nylon fabric shall be sewn and bagged out to form two tunnels, with the ends under. The tunnels shall be sewn inside the hood with one row of stitching in the positions as on the sealed sample, with the edge of the tunnel along the row of stitching which bagged the facing on to the outside.

7.3.2 Outer Hood

The edges of the outer hood shall be faced with self-fabric, and the loop half of the hook and loop strip fastener attached to the face portion with two rows of stitching.

7.3.3 Subassembly

The cushioning panels shall be butt-jointed using the approved adhesive. Each of the interply panels shall then be fitted to the outer cushioning layer by the approved method. The inner layer shall be stuck to the outer layer as described in 8.2, 'Design'.

7.3.4 Ventilation Tubes Assembly

The 9.5 mm bore ventilation tubes shall be connected to the hood connectors and bonded with the approved adhesive. The other ends of the tubes shall then be fitted to the 'Y' connectors. The 8 mm bore black PVC tubes, suitably perforated, shall be fitted to the other ends of the 'Y' connectors, the ends of the tubes at the top of the hood being heat sealed. See Fig. 4.

7.3.5 Stays

Stays shall be attached to the hood with cotton or spun nylon webbing, which shall be folded under the ends of the 368 mm long shoulder stays, the 445 mm long centre back stay, and the 190 mm long side back stays.

7.3.6 Sliding Fasteners

7.3.6.1 The halves of the two 200 mm sliding fasteners shall be sewn to the front edge of the hood to mate with the halves attached to the outer suit.

7.3.6.2 The half of the 455 mm sliding fastener shall be sewn to the rear edge of the hood to mate with the half attached to the outer suit.

7.3.7 Visor

The hook half of the hook and loop strip fasteners shall be attached to the inside and outside of the visor rim with the approved adhesive.

7.3.8 Subassembly

The hood shall be assembled as follows:

(i) The inner hood shall be placed inside the outer hood, with the bottom seam of the inner hood alongside the rows of stitching which attach the cowl to the outer hood. The two shall be sewn together with a single row of stitching.

(ii) The ventilation tubes shall be threaded through the tunnels of the inner hood.

(iii) The visor shall be inserted between the inner and outer hoods, and the hook and loop strip fasteners fastened.

7.4 Colour and Size

The hood shall be manufactured from orange cotton fabric in one size only.

8. HOOD, RIGID

8.1 Materials

8.1.1 Inner Hood

The inner hood shall be made from nylon fabric of approved type conforming to BS F.118, Ref. 8684, sewn to sheets of 6 mm thick polyester foam of approved type (density 3.8 to 5 kg/m^3), in 50 mm squares at 45° to the warp, to form a quilt.

8.1.2 Outer Hood

The outer hood shall be made from woven cotton fabric of approved type conforming to Specification UK/AID/926/3, Type L.28.

8.1.3 Ventilation Tube Connectors

Ventilation tube connectors shall be of approved type.

8.1.4 Ventilation Tubes

The ventilation tubes of approved type shall be of polyvinyl chloride (PVC), to BS 2571, Class 3. The two tubes that connect to the manifold tubes shall be clear, 9.5 mm bore and 13.8 mm outside diameter, and shall have a softness number of 30. The other three tubes shall be black, 8 mm bore and 11.5 mm outside diameter.

8.1.5 Hood Tube Connectors

Hood tube connectors shall be of approved type.

8.1.6 Visor

A visor of approved type made from polymethyl-methacrylate (perspex), not less than 5 mm thick, shall be provided, as illustrated in Fig. 4.

8.1.7 Adhesive

The adhesive used shall be of approved type.

8.1.8 Hook and Loop Fasteners (Velcro)

Hook and loop strip fasteners, 16 mm wide, of approved type shall be used.

8.1.9 Sliding Fasteners

The continuous spiral, polyester sliding fasteners shall be of approved type as follows:

8.1.9.1 Front, Right Chest – Half of a 200 mm long, heavyweight, open-end fastener without slider.
8.1.9.2 Front, Left Chest – Half of a 200 mm long, heavyweight, open-end fastener with a non-lock, closed bridge slider fitted with a wire ring.
8.1.9.3 Back – Half of a 455 mm long, heavyweight, open-end fastener with a non-lock, closed bridge slider fitted with a wire ring.

8.1.10 Stay Loops

Stay loops of 20 mm wide cotton or spun nylon webbing of approved type shall be used.

8.1.11 Rigid Helmet

The rigid helmet shall be constructed from glass fibre laminate to the approved drawing held by the manufacturer.

8.2 Design

The hood shall be detachable and consist of a cowl made from the same fabrics as the suit, having the rigid helmet fitted between the inner and outer layers and a perspex visor which shall afford excellent all-round vision and have sufficient room for the user to turn his head. The hood shall be attached to the outer suit by sliding fasteners, and fed from the inner suit ventilation pipes via quick release connections. Provision shall be made for removing the visor for cleaning.

8.3 Construction

8.3.1 Inner Hood

8.3.1.1 The cover and quilt of the inner hood shall be bagged out and around the neck. The edges around the face section shall be sewn to a facing of woven cotton fabric, which shall be bagged on to the outside with a single row of stitching. A strip of loop strip fastener shall be sewn on to the facing with two rows of sewing.

8.3.1.2 Two strips of bias cut nylon fabric shall be sewn and bagged out to form two tunnels, with the ends under. The tunnels shall be sewn inside the hood with one row of stitching in the positions as on the sealed sample, with the edge of the tunnel along the row of stitching which bagged the facing on to the outside.

8.3.2 Outer Hood

The edges of the outer hood shall be faced with self-fabric, and the loop half of the hook and loop strip fastener attached to the face portion with two rows of stitching.

8.3.3 Ventilation Tubes Assembly

The 9.5 mm bore ventilation tubes shall be connected to the hood connectors and bonded with the approved adhesive. The other ends of the tubes shall then be fitted to the 'Y' connectors. The 8 mm bore black PVC tubes, suitably perforated, shall be fitted to the other ends of the 'Y' connectors, the ends of the tubes at the top of the hood being heat sealed. See Fig. 4.

8.3.4 Rigid Helmet

The rigid helmet shall be constructed in accordance with the requirements as stated on the approved drawing held by the manufacturer.

8.3.5 Sliding Fasteners

8.3.5.1 The halves of the two 200 mm sliding fasteners shall be sewn to the front edge of the hood to mate with the halves attached to the outer suit.

8.3.5.2 Half of the 455 mm sliding fastener shall be sewn to the rear edge of the hood to mate with the half attached to the outer suit.

8.3.6 Visor

The hook half of the hook and loop strip fasteners shall be attached to the inside and outside of the visor rim with the approved adhesive.

8.3.7 Subassembly

The hood shall be assembled as follows:

(i) The inner hood shall be placed inside the outer hood, with the bottom seam of the inner hood alongside the rows of stitching which attaches the cowl to the outer hood. The two shall be sewn together with a single row of stitching.
(ii) The rigid helmet shall be placed between the inner and outer fabric layers of the hood.
(iii) The ventilation tubes shall be threaded through the tunnels of the inner hood.
(iv) The visor shall be inserted between the inner and outer hoods, and the hook and loop strip fasteners fastened.

8.4 Colour and Size

The hood shall be manufactured from orange cotton fabric in one size only.

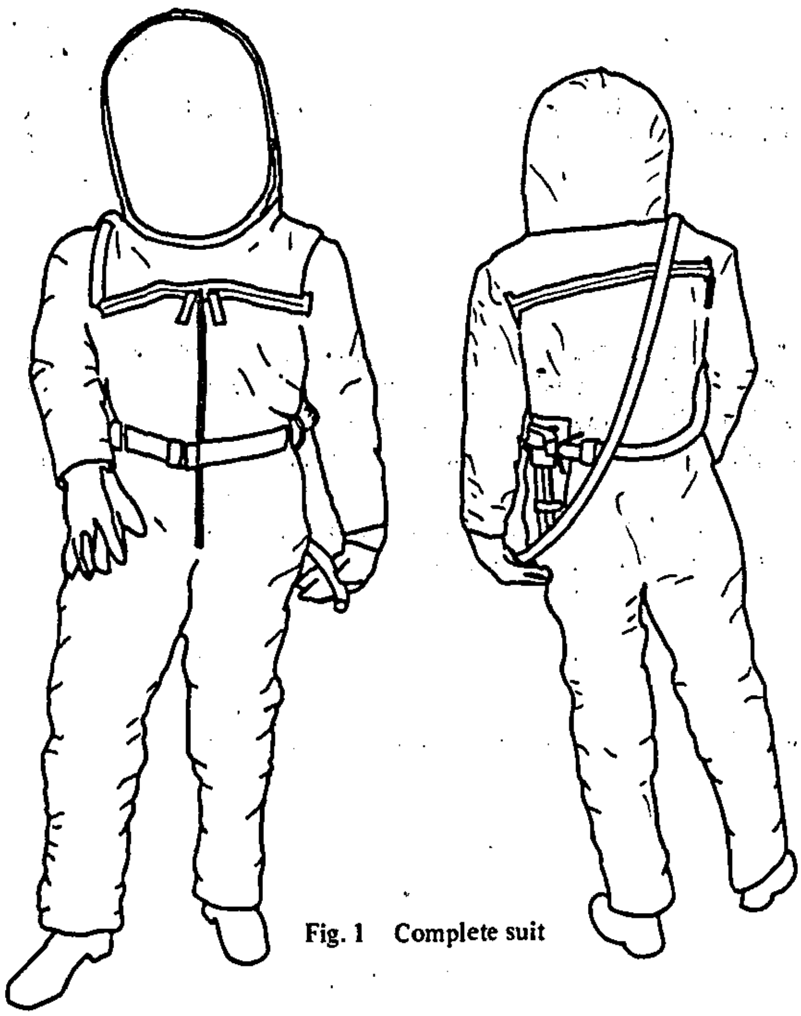


Fig. 1 Complete suit

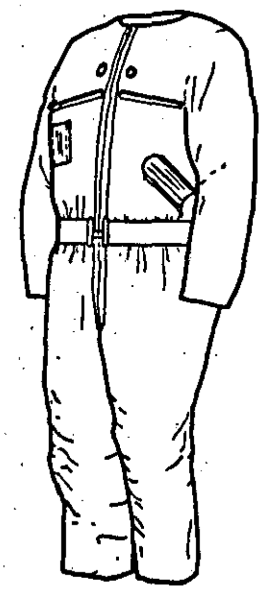


Fig. 3 Outer suit

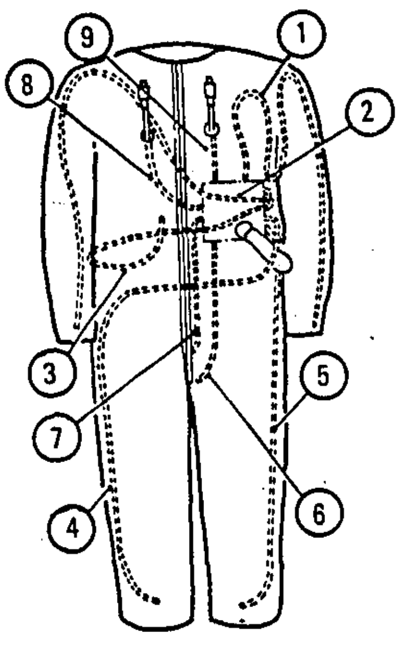


Fig. 2 Inner suit (showing air distribution system)

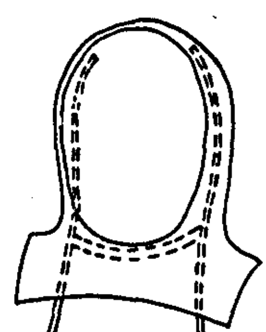


Fig. 4 Hood

LIST OF PRODUCTS COMPLYING WITH CEGB STANDARDS	HOT ENVIRONMENT WORKSUIT AND FOOT AND HAND PROTECTION	0608L2
		Issue 1
	CEGB *Standard* 060803	June 1976
		Page 1 of 2

This list, issued by the Standards Engineer, CEGB Headquarters, London, summarizes the products for which notifications of compliance with CEGB Standards have been issued to the manufacturers concerned at the request of the Developer. It gives additional information thereto under the heading 'Special Conditions' where applicable. The list is subject to revision, and therefore a check on the current Issue Number should be obtained by writing to the Standards Engineer, Headquarters, CEGB, Courtenay House, 18 Warwick Lane, London EC4P 4EB.

The issue of this list does not relieve the Contractor from responsibility for performance of the products specified.

Hot Environment Worksuit manufactured by:

Beaufort (Air-Sea) Equipment Ltd.
Beaufort Road
Birkenhead
Cheshire

Special Conditions

The following products shall be used in the manufacture of this suit.

Description	Manufacturer
Adhesive, TK5000	Tivoli Kay Ltd.
Buckle and Slide, Ref. AL.2378/sht. 1	Aerolex Ltd.
Connectors, Hood	
Female Size	Circlex Ltd.
Male Size	Circlex Ltd.
Y piece, MY10	Portex Ltd.
Cuffs	
Ankle, A8 125 mm lay flat tube	Lenton Products, Nottingham
Wrist, A1 90 mm lay flat tube	Lenton Products, Nottingham
Fabrics	
Cotton, woven to Specification UK/AID/926/3, Type L28, except waterproofness	Beaufort (Air-Sea) Equipment Ltd.
Nylon to BS F.118, Ref. 8684	Beaufort (Air-Sea) Equipment Ltd.
Fasteners	
Hook and Loop Velcro, Type 18	Selectus Ltd.
Sliding Polyester, black sliders with wire ring	Optilon Ltd.

Description	Manufacturer
Polyester Foam, density of 3.8 to 5 kg/m^3	Harrison Jones, Royton
Connecting Hose, 412 DAS, or PFS 5501	Dunlop Beaufort (Air-Sea) Equipment Ltd.
Manifold Inflation Tube Housing D2325	Beaufort (Air-Sea) Equipment Ltd.
Neoprene proofed nylon 2½ oz. double textured fabric - PFS 7786	Beaufort (Air-Sea) Equipment Ltd.
Stiffener, white PVC (Rigid) 0.020 in thick Cobex	B.X. Plastics, Leestone Road, Manchester
Stays, Nulybone, No. 143	Steel and Busks Ltd.
Terylene Thread, natural to Specification UK/AID/971-TT4	Worthington Ltd. Portland Mill
Tubing	
PVC Clear	
9.5 mm bore - 800/000/525	Portex, Hythe, Kent
6.35 mm bore - 800/000/450	Portex, Hythe, Kent
PVC Black	
8 mm bore - 800/021/350	Portex, Hythe, Kent
Perspex Visor	Orbex Ltd., Manchester
Webbing, Cotton or Spun Nylon	
Nylon, WR. 490	W. Ribbons, Surrey
Terylene, WR. 780T to RFD 353	W. Ribbons, Surrey
Glass Fibre Helmet	E.G.D. Ltd. - Nelson
Glass Fibre Panels	E.G.D. Ltd. - Nelson
Neoprene Sheet, Type 3, 6.5 mm single skin superflex	Sub-Aqua Products Ltd., Eastleigh

CEGB STANDARD 060806

ISSUE 1 MARCH 1977 APPENDIX E

CONDUCTIVE SUITS – LIVE LINE WORKING

CONTENTS

Published and printed by
Technical Documentation Branch
Engineering Services, CEGB
Walden House, 24 Cathedral Place, London EC4P 4EB
108/F

APPROVED BY STANDARDS COMMITTEE

CONDUCTIVE SUITS – LIVE LINE WORKING

FOREWORD

The purpose of this Standard is to provide clothing designed for the protection of personnel making contact with live metal in the course of 'bare hand', live line working, on overhead lines operated at voltages up to and including 400 kV.

The clothing, in the form of coverall type suits, is made up from an electrically conductive material.

Having regard to the working environment, the suits are designed to be flexible, light in weight and unrestrictive to the wearer.

Boots, shoes or overgloves worn with the suits shall be electrically conductive.

It should be noted that in accordance with the metrication of the clothing industry the relevant dimensions are given in centimetres.

1. SCOPE

This Standard determines the materials, design and make-up, sizes, marking, tests and quality control requirements of electrically conductive suits comprising coverall with integral hood and visor(s), gloves and oversocks.

Appendix A of this Standard shows the details of the bonding lead terminal and the method of attachment. The terminal is to be provided and attached by the CEGB on receipt of the suit from the manufacturer.

2. REFERENCES

This Standard makes reference to the following documents:

BS 381C, 'Colours for Specific Purposes'.
BS 2043, 'Method for the Determination of Wool Fibre Fineness by the use of a Projection Microscope'.
BS 2471, 'Methods of Test for the Mass per Unit Length and per Unit Area of Woven or Knitted Fabrics'.
BS 2862, 'Methods for the Analysis of Woven Fabric Construction'.
BS 2864, 'Methods for the Analysis of Woven Fabric Construction'.
BS 2865, 'Methods for the Analysis of Woven Fabric Construction'.
BS 4202, 'Determination of the Dimensional Changes of Fabrics containing Wool on Soaking in Water'.
BS 4407, 'Methods of Test for Quantitative Chemical Analysis of Fibre Mixtures'.
BS Handbook No. 11, 'Methods of Test for Textiles'.
ASTM D 2261–71, 'Tearing Strength of Woven Fabrics by the Tongue Method'.
IWS TM 155, 'Quantitative Analysis of Binary Blend containing Wool and One Named Non-protein Fibre'.

3. MATERIALS AND PERFORMANCE

3.1 Coveralls, Gloves and Oversocks

3.1.1 Coveralls, gloves and oversocks shall be made up from materials to the construction given in Table 1. Alternative materials, having an equivalent performance, will be considered by the CEGB, but certain synthetic materials and materials whose electrical conducting properties are provided by metallic coating or impregnation, will not be acceptable.

Table 1 Construction and Performance

Property		Requirement	Test Method
Fibres	Wool	21.7 micron dia.	BS 2043
	Stainless steel	8 micron dia.	–
Yarns	Count (tex)	R49 tex/2	BS 2865
	Twist singles	650(Z) turns/m	BS 2864
	Twist folding	530(S) turns/m	BS 2864
Fabric	Weave (twill)	2/2	–
	Blend (wool/steel)	75/25 per cent (±2 per cent)	BS 4407 and IWS TM 155
Weight		215 gm/m^2	BS 2471
Ends		220/100 mm	BS 2862
Picks		193/100 mm	BS 2862
Breaking load	Warp	300 N	BS 2862
	Weft	290 N	BS 2862
Extension at break	Warp	13 per cent	BS 2862
	Weft	12 per cent	BS 2862
Tear strength	Warp	21.6 N	ASTM D 2261–71 and
	Weft	27 N	IWS TM 155
Abrasion resistance		23 000 (min)	BS Handbook No. 11 (Martindale Test)
Shrinkage (dry cleaning conditions)		2 per cent max. (warp and weft)	BS 4202

3.1.2 Dyeing and finish shall be orange to BS 381C, Ref. 592.

3.2 Bonding Lead

The bonding lead shall comprise a flexible, knitted mesh of stainless steel in stocking form. Wire gauge shall be 0.15 mm (38 S.W.G.), warp 28 stitches/10 cm, weft 36 stitches/10 cm with a finished width of approximately 2 cm.

3.3 Seams

Seams shall be stitched with a polyester/cotton blend thread (J and P Coates, Reference KOBAN Ticket 75 – soft finish, or equivalent).

4. DESIGN AND MAKE-UP

Generally the design and make-up shall be in accordance with a Standard Pattern which will include any properties or qualities not defined herein. The Standard Pattern may be made available by application to the Standards Engineer, Headquarters.

Suits shall comprise a coverall, with integral hood and visor(s), gloves and oversocks as detailed in 4.1 to 4.4.

A general arrangement of the suit is shown in Fig. 2.

4.1 Coverall

4.1.1 The coverall shall have set-in sleeves made in two pieces, and a full fly lancer front with overlap fastening on the right side of the body. The overlap shall be 15 cm wide at the shoulder, finishing 15 cm from the crotch seam. The front shall be closed by a full length, non-metallic, zip fastener of the continuous spiral type (Optilon Reference 500/72/880, or equivalent) with the overlap secured by four press studs and top button, interposed with 'Velcro' strip not less than 2 cm wide. Reinforcement, of the same material as the suit, shall be applied externally at the seat and inside leg, and be suitably cross-stitched. The leg reinforcement shall extend below knee level. An external flapped pocket 15 x 15 cm shall be set in the left breast position, the flap being closed by 2 cm wide 'Velco' strip. The coverall shall be provided with a hanging loop and label, see 6, 'Marking'.

4.1.2 To permit effective adjustment to the suit arm and leg length, three sets of metal press studs spaced 4 cm between sets shall be provided on each arm and leg of the coverall. In the lowest position, gloves and oversocks shall overlap the coverall by not less than 11 cm and 22 cm respectively. The number of press studs per set shall be three and five for arms and legs respectively. All press studs shall be backed by reinforcement with the suit material.

4.1.3 The hood shall be provided with a visor(s), 7 x 20 cm peak, and shall accommodate a padded head protector which may be built into the hood. The hood shall measure 45 cm from edge to edge. The visor(s) shall cover the throat and lower face of the wearer and be fastened by 'Velcro' strip not less than 2 cm wide.

4.1.4 A bonding lead, overall length 70 cm shall be provided on the suit as shown in Fig. 2. The lead shall be sleeved with suit material and securely sewn into the side seam of the suit for a length of 8 cm. Details of the bonding lead and sleeve are shown in Fig. 1.

4.1.5 A loop (similar to a belt loop), 4 cm long x 2 cm wide, shall be provided adjacent to the bonding lead to support the bonding terminal (see Appendix A) when not in use.

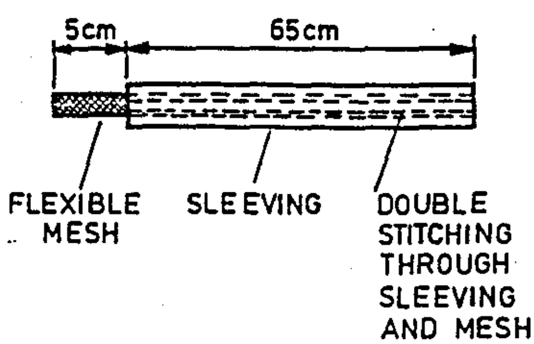


Fig. 1 Bonding lead

GEN/11/2/12357

4.2 Gloves

Gloves shall be of the gauntlet type with cuffs fitted with 2 cm wide washproof elastic braid, sewn into the hem. The cuffs shall be provided with three press studs for attachment to the coverall sleeve (see 4.1.2), the material being turned to give double thickness where the press studs are located.

4.3 Oversocks

Oversocks shall be calf length with cuffs fitted with 2 cm wide washproof elastic braid sewn into the hem. The cuffs shall be provided with five press studs for attachment to the coverall leg (see 4.1.2), the material being turned to give double thickness where the press studs are located.

4.4 Seams

Seams shall be 'twin needle' or 'run and fell' with approximately 40 stitches/10 cm.

5. SIZES

5.1 Coveralls

5.1.1 Coveralls shall be made up in the two sizes given in Table 2, accommodating the height ranges as follows:

Medium: 1.7 to 1.78 m (5 ft 7 in to 5 ft 10 in)

Large: 1.78 to 1.85 m (5 ft 10 in to 6 ft 1 in)

Table 2 Coverall Dimensions

	Minimum Dimensions *cm*	
	Medium	*Large*
	CEGB Code Number 06/08/004	CEGB Code Number 06/08/005
Chest of suit (buttoned)	132	145
Neck to crotch	94	107
Inside leg	76	81
Sleeve	83	91
Seat	132	147
Upper leg width	76	81
Width at knee	58	63
Width at leg bottom	46	51

5.1.2 The variations in each size range shall be achieved by adjustments of the effective arm and leg lengths as referred to in 4.1.2.

5.2 Gloves

Glove dimensions shall comply with Table 3.

Table 3 Glove Dimensions

	Dimensions cm CEGB Code Number 06/08/010
Tip of second finger to gauntlet cuff	38
Tip of forefinger to crotch of thumb	13
Tip of thumb to crotch of thumb	7
Across palm at crotch of thumb	13
Across cuff opening	16

5.3 Oversocks

Oversocks shall be available in the two sizes given in Table 4.

Table 4 Oversock Dimensions

	Minimum Dimensions *cm*	
	Medium	*Large*
	CEGB Code Number 06/08/014	CEGB Code Number 06/08/015
Toe to heel of sole	28	33
Width of sole at ball of foot	11	13
Width of sole at heel	8	10
Sole to top hem of sock	43	43
Point of toe to top hem	53	58
Side of upper	42	42

6. MARKING

Coveralls, gloves and oversocks shall be provided with labels, not less than 75 x 25 cm, sewn along all four sides. The labels shall be indelibly marked with the following information:

- (i) 'DRY CLEAN ONLY'.
- (ii) Manufacturer's Identification,
- (iii) Serial Number,
- (iv) Size – Medium or Large, (for coveralls and oversocks only),

and allow space for the addition of the wearer's name.

Subject to complying with 7, 'Tests' the coverall label shall also be marked to indicate CEGB approval.

7. TESTS

7.1 Material

A sample of each material run shall be tested to confirm the stainless steel/wool percentage as specified in Table 1, and examined to show a uniform distribution of the steel fibres.

7.2 Suits

Electrical continuity of each completed suit shall, before despatch from the manufacturer's works or approved test house, be certified by resistance measurements as shown in Fig. 3. The resistance between the extremity points, and between extremity points and the bonding lead 'T', shall not exceed 25 ohms.

8. QUALITY CONTROL

The first production suit checked and approved by the CEGB's Engineers against this Standard and the Standard Pattern will form a Sealed Sample. The suit will be retained at the manufacturer's works and be made available at any time for inspection by the CEGB's Authorized Officers. The CEGB reserve the right to withdraw the Standard Pattern at any time.

9. APPLICATION TO CONTRACTS

The extent to which this Standard shall apply will be as stated in the Contract between the CEGB and the Contractor.

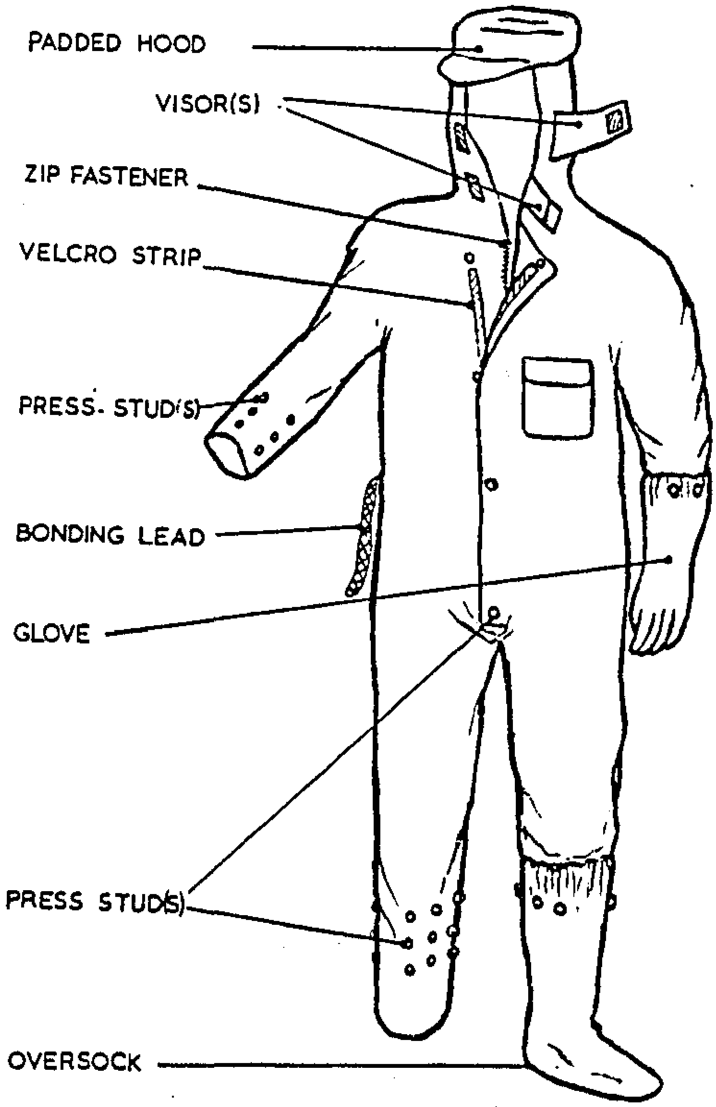


Fig. 2 General arrangement of suit

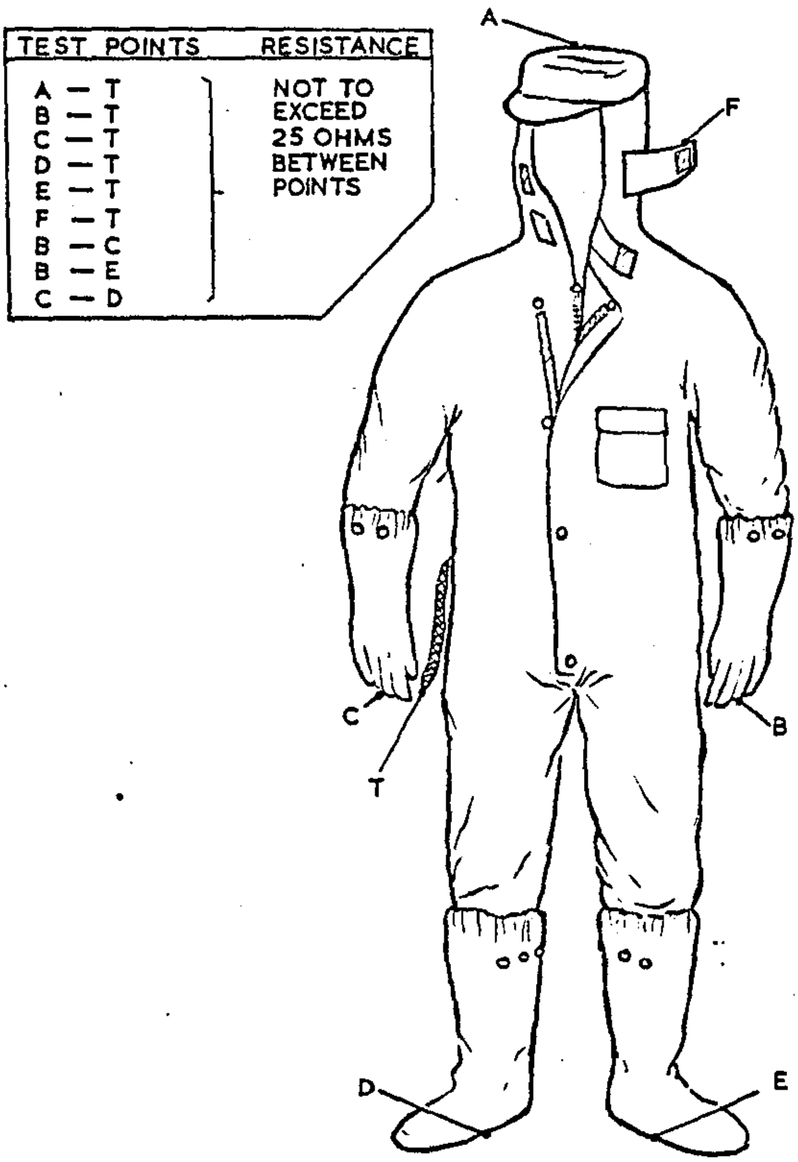


Fig. 3 Test points

APPENDIX A

BONDING LEAD TERMINAL

A1. DETAIL OF BONDING TERMINAL

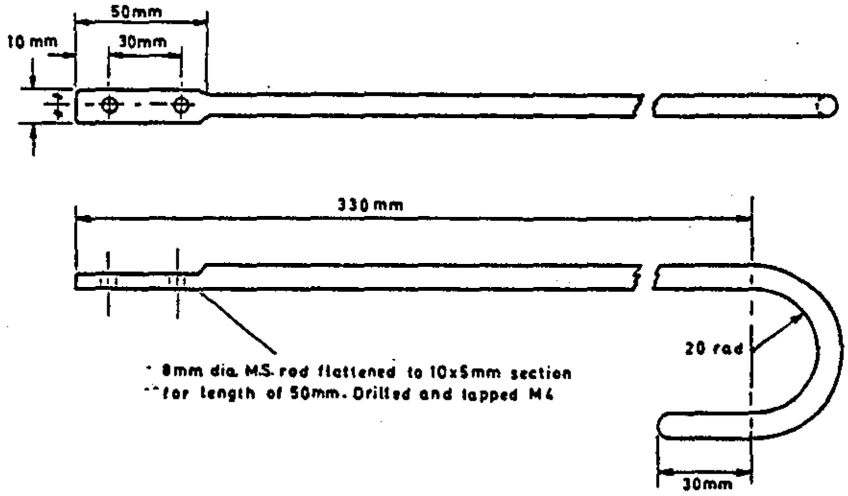
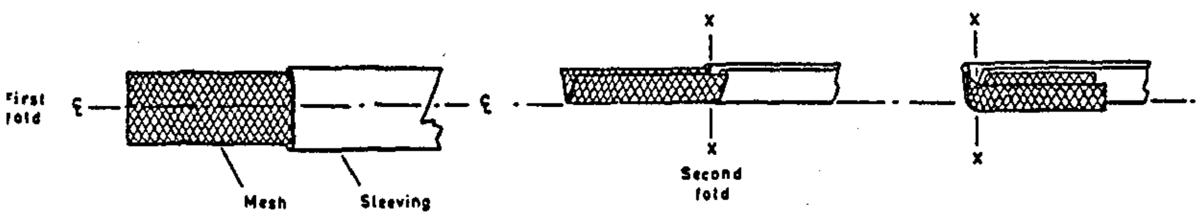


FIG. A1 68/6419

A2. PREPARATION OF BONDING LEAD

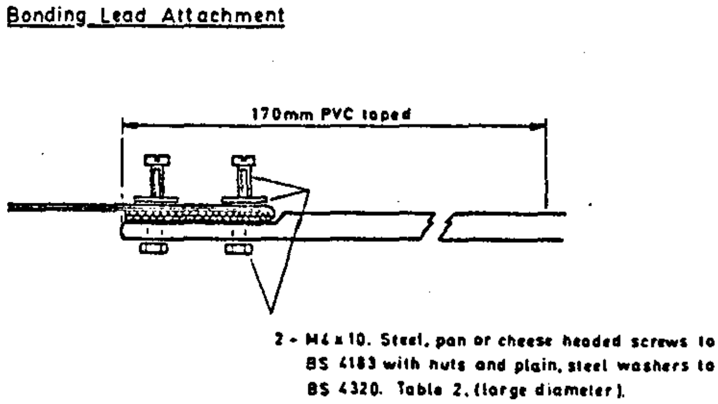


68/6419

FIG. A2

A2.1 First, fold along centre-line of mesh and sleeving to give double material thickness. Second, fold along XX returning mesh along sleeving to give four thicknesses of mesh through section.

A3. BONDING LEAD ATTACHMENT



68/6419

FIG. A3

A3.1 Bonding lead prepared as in Fig. A2, placed with mesh adjacent to terminal palm and secured with screws, plain washers and locking nuts. Connection and bonding terminal to be wrapped with double layer of PVC tape for length of 170 mm.

APPENDIX F

COMMISSIONING TEST SCHEDULE

BOILER FAMILIARISATION FACILITY - THE 'HOT' BOX

CONTENTS

1 INTRODUCTION

In 'B' Nuclear Power Station the boilers are contained with the reactor core in a thick prestressed concrete vessel. Thus the post shutdown cooling period of the boiler gas passes will be much longer than the 2-3 days for the 'A' Station magnox reactors. In fact, calculations have shown that with all 8 circulators running, the reactor core outlet temperature will fall to 60°C after 8 days, 50°C after 16 days and 40°C after 36 days post shutdown.

The economic penalties caused by the outage of modern thermal power station units led the C.E.G.B. and S.S.E.B. to pursue the development of protective clothing which would allow access to the boiler gas passes at the earliest opportunity i.e. when the vessel temperature may be in some regions (gas baffle dome area) as high at 60°C, 8-10 days post shutdown.

In 1971, a Hot Box facility was built at 'A' to give personnel experience and confidence in wearing the special protective clothing in an ambient temperature of 60°C. The training procedures adopted for the Hot Box form the basis for this document.

This training in the Hot Box is the first of 3 separate exercises which will lead up to a full scale hot entry after the second commissioning hot run on Reactor 3.

The complete training programme is covered in four parts of this C.T.S. These are as follows:-

Part 1 - Boiler Familiarisation Facility - the Hot Box.

Part 2 - Vessel Entry Access Route Simulation Facility.

Part 3 - Vessel Access Demonstration - Cold Run.

Part 4 - Vessel Access Demonstration - Hot Run.

2 OBJECTS OF TRAINING

2.1 To give personnel an appreciation of a 60°C hot environment.

2.2 To familiarise personnel with the various items of protective clothing associated with hot environmental work.

2.3 To carry out simple tasks in an environment of 60°C, similar to what is expected to be undertaken in the Hunterston 'B' pressure vessel.

3 THE HOT BOX

(a) Description

The boiler familiarisation facility or hot box, as it is commonly termed, is situated in the turbine hall basement at Hunterston 'A'.

Basically it consists of 3 rooms, Control Room, Change Room and Hot Room. The dimensions of each are shown in Fig.1.

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.

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 - see Fig.2 may 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.

(b)/

3 THE HOT BOX (Cont'd)

(b) Operation

The procedure for initiating the heating system is detailed in Appendix I. All the relevant switches are contained on the electrical panel in the Control Room.

The cooling air system is designed for a 2 - man training programme. A 65 s.c.F.m. air compressor plus receiver are situated adjacent to the Hot Box on the Turbine Hall basement main walkway. Air is piped into the Control Room via a channel in the floor. This pipe then bifurcates, each line entering an air flow meter on the air control panel. Downstream the air passes through filters and pressure regulating valves and terminates at the 2 points inside the Hot Room. The start-up and operation of the air system is detailed in Appendix 2. Normally no adjustment of the valves is required as they have been pre-set to give maximum air flow 32 - 34 c.F.m. at a pressure of 85 - 90 p.s.i.

The air quality must be within the acceptable limits of impurities in breathing air as defined in BS 4275. These levels are shown below:-

Impurity	Acceptable Quantities
Carbon monoxide	5 p.p.m. (5.5 mg/m^3)
Carbon dioxide	500 p.p.m. (900 mg/m^3)
Oil	0.5 mg/m^3
Odour and cleanliness	Air should be free from all odour and contamination by dust, etc.

Oil contamination checks are undertaken regularly by the Station Chemistry department.

4 PROTECTIVE CLOTHING

It is accepted that if work is to be carried out in temperatures in excess of 40°C (104°F) special clothing incorporating some form of cooling is essential. In the mid - 60's the C.E.G.B. pursued the development of an air-cooled suit capable of being used in ambient temperatures of up to 70°C.

In principle, dry, dust free air is supplied to the suit at a pressure of at least 80 p.s.i. and is cooled by a vortex system to a temperature suitable to the wearer (an air temperature range 12-25°C is considered desirable). It is then fed around the suit and helmet via a network of P.V.C. tubes, and dispersed perpendicular to the body. The wearer is therefore surrounded by cooled air, which is moving away from the body and continually replenished from the supply to the suit. A description of the suit and other essential items is given below.

(a) Air Cooled Suit

The suit assembly, named the Beaufort Dynacool 70 suit, consists of four parts: an outer suit, a foam insulated inner suit, a hood and a vortex tube.

The outer suit is made of a close weave ventile cotton material and acts basically as a wear resistant and sacrificial item.

The/...

4 PROTECTIVE CLOTHING (Cont'd)

(a) Air-Cooled Suit (Cont'd)

The inner suit is made of 6 mm thick expanded polyurethane foam, sandwiched between two layers of woven nylon. As with the outer suit, it is fitted with a front entry zip. 6 mm bore P.V.C. tubes are threaded through fabric tunnels sewn to the inside of the suit. The tubes are routed and perforated to ensure an even flow of air over the body. The suit has penetrations for the flexible inlet air tube from the Vortex tube and for the two connections onto the hood air distribution tubes.

The shape and style of the helmet has been altered several times and a variety of types are now available:-

Mark II - narrow, soft-backed.

Mark III - large, bulbous, fibre-glass backed helmet, too large for most constricted parts of the Hunterston 'B' vessel entry route.

Mark IV - a smaller version of Mark III.

Mark V - similar in shape to the Mark II and containing a variety of small rubber panels fitted into the back of the helmet to give safety protection and a degree of flexibility when negotiating narrow spaces.

The outer rear cover of the helmet is made from a layer of outer suit fabric, lined with the inner suit insulation. The front has a moulded perspex visor which gives reasonable visibility. Being of a rigid type, the helmet does not move with the head.

Diagrams of the various parts of the suit are shown in Fig.3, a, b, and c.

The Vortex tube assembly is fastened into a holster belt round the waist. Because of the high temperature environment, an assembly consisting of two tubes in parallel is required to supply the necessary cooled air flow.

The vortex tube assembly is connected to the suit by a 2.5 cm rubber bore tube.

The principle of the vortex twin-tube is as follows:- compressed air at a pressure greater than 80 p.s.i. enters the assembly through tangential nozzles, which inject it at sonic speed into a chamber to create a vortex spinning at up to half a million revolutions per minute. The centre of the vortex is cold air which flows out through a small hole to the cold air discharge tube. The remainder of the air spirals along the two long tubes growing hot in the process and is then discharged through two valves at the far end. This restriction imposes enough pressure on the vortex chamber to drive the air out of the cold end. It is essential that air first entering into the vortex tube assembly is dry and at least the above pressure otherwise the tube will not drop the temperature sufficiently to achieve the necessary cooling. Each tube has a fraction valve at the hot exhaust end and for optimum heat removal it has been found that both valves must be set at about $1\frac{1}{2}$ turns open:

i.e. with both valves shut, a lot of cold air is driven into the suit; with both valves full open, a much smaller amount of colder air is driven into the suit.

In practice, somewhere in-between these two extreme settings ($1\frac{1}{2}$ turns open) has been shown to distribute a good flow of air at a temperature of 15-18°C. Furthermore, the noise as well as feel of the air at this setting, psychologically, reassuring.

4 PROTECTIVE CLOTHING (Cont'd)

(a) Air-Cooled Suit (Cont'd)

Finally the suit is manufactured in two sizes, to fit wearers of the measurements listed below.

	Max. Height	Max. Chest
Medium	5'8"	38"
Large	6'2"	44"

(b) Gloves

Gloves, basically, must be both heat-resistant and reasonably finger-sensitive. The normal station issue rubber and cotton gloves do not fulful the first condition whereas the recognised heat-resistant gloves made from asbestos or leather material tend to be too bulky and stiff to satisfy the second condition.

Until a suitable type is found all trainees will be given 2 pairs of gloves to wear, a thin cotton inner pair in case sensitivity is required and a aluminised calf leather outer pair for heat protection. In practice so far, this composite arrangement has been satisfactory.

(c) Boots

Finding a comfortable, heat-resistant boot has so far proved difficult. Various types of leather boots have been tried without success. At present, all training is being undertaken using the normal station issue of Surgeon's boots and, as with the gloves, proving reasonably successful.

To improve the insulation of the boot sole, a 5 ply mesh plastic insole and special nylon boot sock are included as part of the standard training clothing issue.

(d) Air-Lines

The chosen air-line for the Hunterston 'B' vessel entry must satisfy a stringent specification. Ideally it should be a lightweight, heat-resistant flexible non-kinkable hose of bore not less than 15 mm and capable of withstanding a pressure of 200 p.s.i.

The air-line which will be used for training consists of four tubes each of nominal bore 0.3 mm enclosed in an outer flexible sheath. 3 pairs of screened cables are threaded between the tubes, two pairs for use in the communication system and the third acting as a spare. The total length of the air-line is 50 feet.

(e) Communication System

During the training session, both entrants are in constant communication with the Controller and each other.

The system is more cumbersome than that used in the other training facilitie and consists of an 'Anticoustic' ear-defender headsets coupled up to an amplifier which is tucked under the suit belt. In the other facilities the amplifier is part of the control unit and therefore does not handicap the trainees as can be the case in the Hot Box.

5/...

5 TRAINING SCHEDULES

In order initially to involve all personnel associated with the vessel entry demonstration programme, with a familiarisation of the various items of protective clothing in hot conditions a training programme has been prepared both for the entrants and for the helpers i.e. dressers and hose-reel attendants. The total time involved for each group is given below.

(a) Training for Vessel Entrants

		Time
(i)	Lecture	10 mins.
(ii)	Layout of Hot Box	10 mins.
(iii)	Demonstration of protective clothing and communications	15 mins.
(iv)	Dressing	10 mins.
(v)	Practical	1 hour
(vi)	Undressing	10 mins.
(vii)	Discussion	10 mins.
		2 hrs. 5 mins.

This schedule is shown diagrammatically in Figs. 4 and 5.

(b) Training for Helpers

		Time
(i)	Lecture	10 mins.
(ii)	Layout of Hot Box	10 mins.
(iii)	Operation of Hot Box	10 mins.
(iv)	Demonstration of protective clothing and communications	15 mins.
(v)	Dressing/Undressing Procedures	20 mins.
(vi)	Practical	30 mins.
		1 hr. 35 mins.

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

6 METHOD OF TRAINING

(a) Lecture

The lecture will cover the following topics:-

(i) Hunterston 'B' A.G.R. Vessel entry route

(ii) The Working Conditions Encountered

(iii) The Need for Protective Clothing

(iv) The Vessel entry Procedure as described in Part IV of the C.T.S.

(v) The Training Facilities and Programme

(b)/...

6 METHOD OF TRAINING (Cont'd)

(b) Layout of Hot Box

All trainees will spend a short time inside the Hot Room in normal clothing and experience the air and metal surrounds at 60°C. A description of the obstacle course, Fig.2, will be given at this stage.

(c) Demonstration of Protective Clothing and Communications

Each item of protective clothing will be described. Change room attendants who will be acting as helpers, will be shown how to assemble an air-cooled suit and associated air-line system.

(d) Dressing Procedure

(i) Wearer to strip down to station underwear.

(ii) C.R.A. will assist wearer to slide legs into air-cooled suit, making sure that the tubing in the legs are not tangled.

(iii) Pull top half of suit over the shoulder, noting again that the tubing in the arms are not tangled.

(iv) After final check of tubing around the chest area, zip up the front of the suit.

(v) Don boots plus insole and insulating sock, ensure tubing is fully down, and tape boots to suit.

(vi) Fasten safety belt and check Vortex tube is seated correctly in holster.

(vii) Plug in coloured air-line to Vortex tube and note flow to helmet, arms and feet.

(viii) Fit ear defender headset and throat microphone comfortably and switch on communications.

(ix) Test communications.

(x) Don 2 pairs of correct gloves and tape to suit.

(xi) Place helmet carefully over headset and connect up to the 2 air-tubes.

(xii) Zip up the helmet to front and back of the suit.

(xiii) Final check of communications and air systems.

(e) Practical Session in Hot Room

(i) Once inside the Hot Room, both trainees will first free up to 20 feet of air-line from the reels then walk up and down several times to acclimatise to the conditions.

(ii) Each in turn will climb up and down the ladder 5½ times, then walk over to the top horizontally mounted manhole cover.

(iii) Using spanner provided, remove the 8 nuts, lift and stow the cover.

(iv) Descend through the manhole assisting each other with the air-lines.

(v) The vertical placed manhole cover is removed and stowed in similar manner.

(vi)/...

6 METHOD OF TRAINING (Cont'd)

(c) Practical Session in Hot Room (Cont'd)

(vi) Crawl through the manhole again assisting each other with the air-lines.

(vii) Each in turn will first renew the hacksaw blade then saw through a 2" scaffolding pipe.

(viii) Both will then return to the ladder by the reverse route, replacing the manhole covers in position en route.

(ix) Finally $4\frac{1}{2}$ climbs on the ladder.

(x) The exercise is now completed and each will retire to the changeroom on the Controller's instructions.

Throughout the exercise, the two trainees will be in communication with each other and the Controller. The Controller will instruct each trainee before starting that should he feel in any way distressed, then the exercise be stopped immediately.

(f) Undressing Procedure

(i) Unzip helmet and disconnect both air-tube connections.

(ii) Remove helmet and ear defender headsets.

(iii) Remove both pairs of gloves, place in bin.

(iv) Remove boots, insoles and insulating socks, place in bin.

(v) Disconnect air supply to Vortex tube.

(vi) Undo safety belt.

(vii) Unzip and remove air-cooled suit, place in bin.

(viii) Dress in transit clothing.

During a discussion on the practical session, the trainees will be given a refreshment and asked to fill in a questionaire (see Appendix 3) which must bereturned in due course to the Controller. It is recommended that the trainees make use of the shower facilities which are available.

(g) Operation of Hot Box

Changeroom attendants will be shown how to operate the heating and compressed air systems for the Hot Box. Full instructions of each are given in Appendices 1 and 2.

7 RESPONSIBILITY

S.S.E.B. are responsible for providing, maintaining and operating all equipment and training sessions in the Hot Box.

F/MA

8. APPENDICES

1. Hot Box - heating procedure.

2. Hot Box - air system.

3. Questionnaire

9. DIAGRAMS

1. Layout of Hot Box.

2. Obstacle Course.

3. Air-cooled suit.

4. Training team entry procedure.

5. Training team withdrawal procedure.

APPENDIX 1

HOT BOX - HEATING PROCEDURE

PROCEDURE

The various units on the control panel are indicated on a RED display board placed at top of the panel. The temperature control setting (° Fahrenheit) is a black knob situated just above this display board and must on no account be turned to higher than 140°F as there are various limit switches incorporated into the electrical circuit which will come into operation above this maximum setting and cut off the heating.

The hot room temperature is indicated on a meter above the R.H.S. square window in the control room.

1. Ensure that the Emergency door in the hot room leading to the Turbine Hall is unlocked.

2. Shut the louvre boards on the outside of the heating air extraction system.

3. Set the temperature control to the desired room temperature (Note, the above restriction).

4. With reference to the Red indicator board, SWITCH on (1) Heater Isolator Unit (2) Control Switch and (3) Fan Isolator Unit. All three switches are in the bottom row of the control panel. Finally, press the green 'START' knob of the Fan contactor.

If the heating system is operating, a red light will glow in each of the three heater control units (Red, Blue and Yellow phases). Once the room has reached the required temperature, these lights will switch on and off intermittently.

CLOSE DOWN

1. Switch off (1) Heater Isolator Unit, (2) Control Switch and (3) Fan Isolator Unit.

2. To switch off the heating alone and retain the fan running, press in the RED heater lock off knob. To blow cold air into the room, close the air vent in the Hot Room and open the air vent at the Turbine Hall side. To restart the heating, reverse the air vents and reset the heater lock off switch.

APPENDIX 2

HOT BOX - AIR SYSTEM

PROCEDURE

Two connections for air lines are situated inside the Hot Room. The air flow and pressure in each line is governed by the air control panel in the control room. Normally, no adjustment will be necessary as the valves have been set to give maximum air flow (32-34 cFm) and pressure (85-95 p.s.i.). A filter is incorporated in each system to remove any moisture.

(1) Switch on the mains to the compressor.

(2) Switch on the compressor.

(3) Allow 5 minutes for the pressure in the air receiver to reach 80 p.s.i. then open the valve at the receiver base for a few seconds to remove any water present.

(4) Check the air pressure in the two lines on the control panel (85-95 p.s.i.).

(5) Adjust both valves on each Vortex tube to 1½ turns out from the 'full-in' position.

(6) Connect the system to run for 15 minutes before starting dressing personnel in the suit. This will ensure that the air systems are completely clean.

(7) Dress personnel - See Text.

FIGURE I

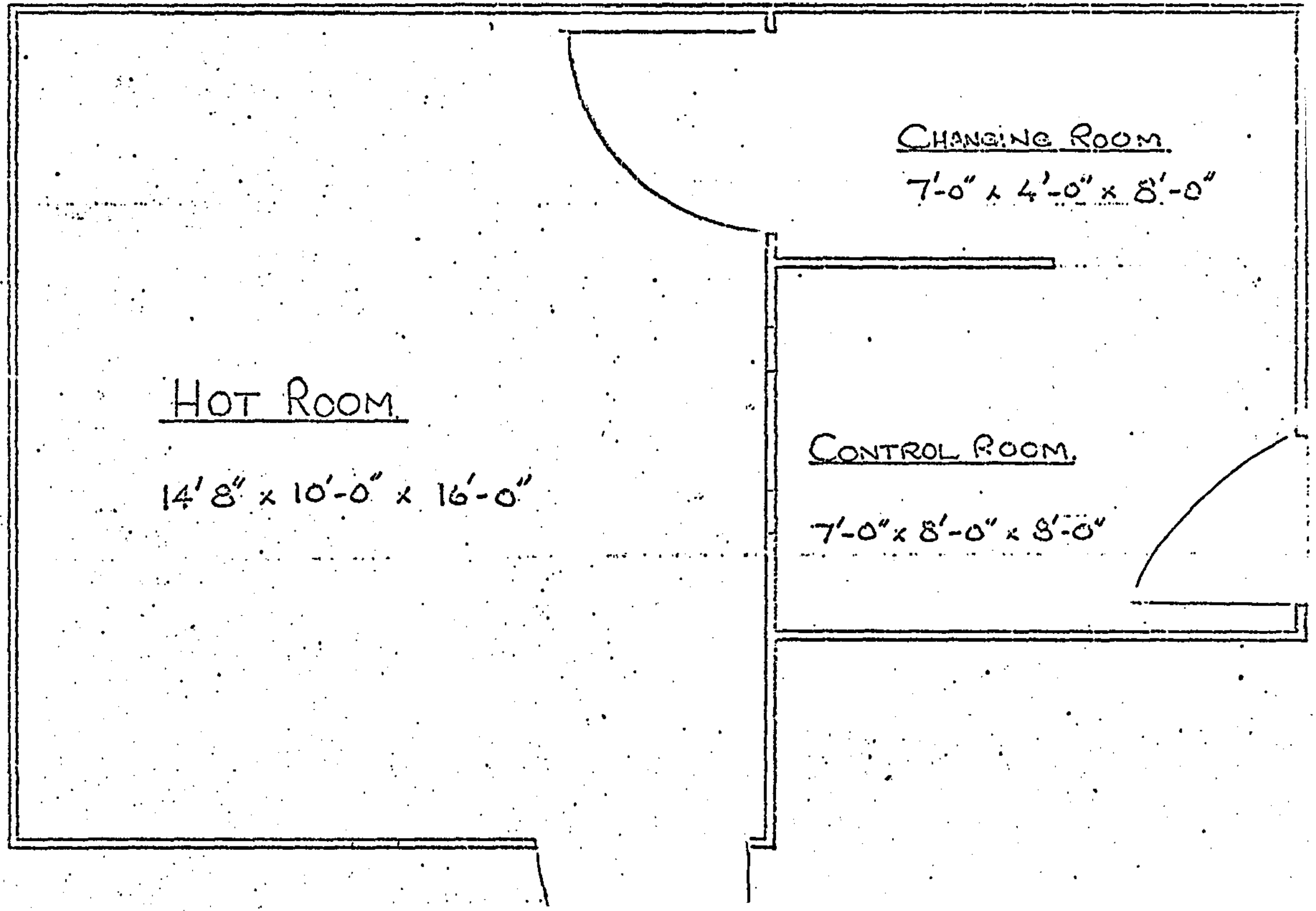

CHANGING ROOM
7'-0" x 4'-0" x 8'-0"
HOT ROOM
14'8" x 10'-0" x 16'-0"
CONTROL ROOM
7'-0" x 8'-0" x 8'-0"

FIGURE 2

OBSTACLE COURSE INSIDE (HOT BOX)

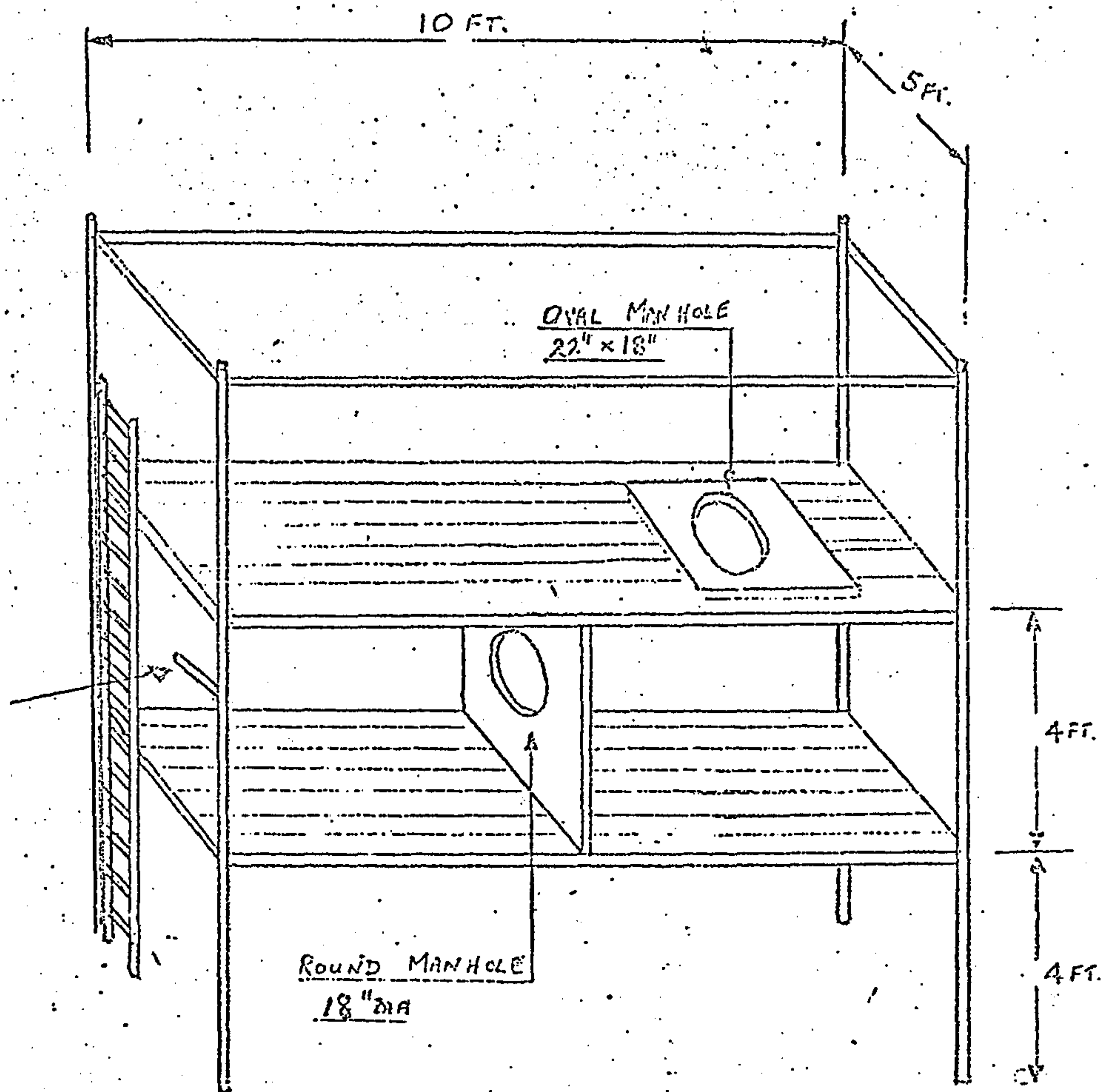


FIG. 3 - AIR-COOLED SUIT

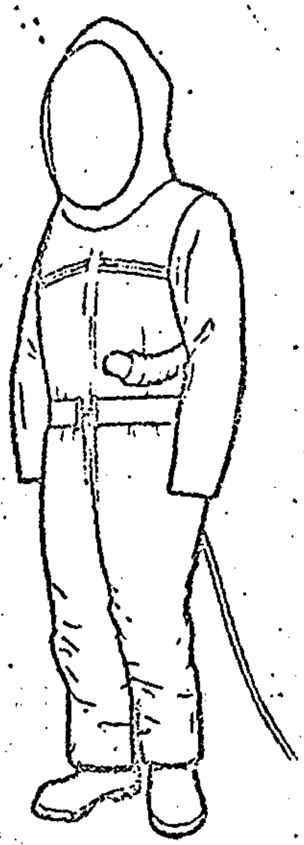


Fig. A Complete Suit

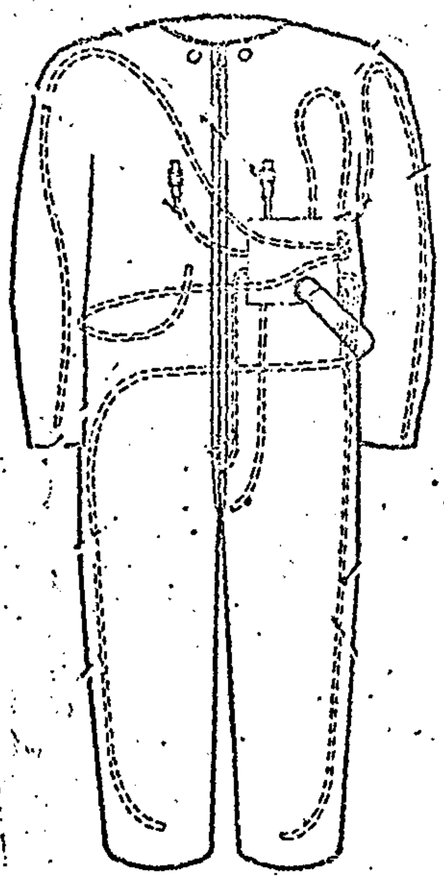


Fig. B Inner Suit

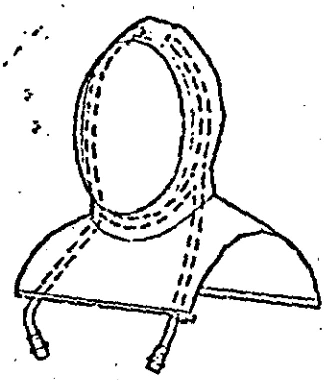


Fig. C Hood

FIGURE 4

BOILER FAMILIARISATION FACILITY

TRAINING TEAM ENTRY PROCEDURE

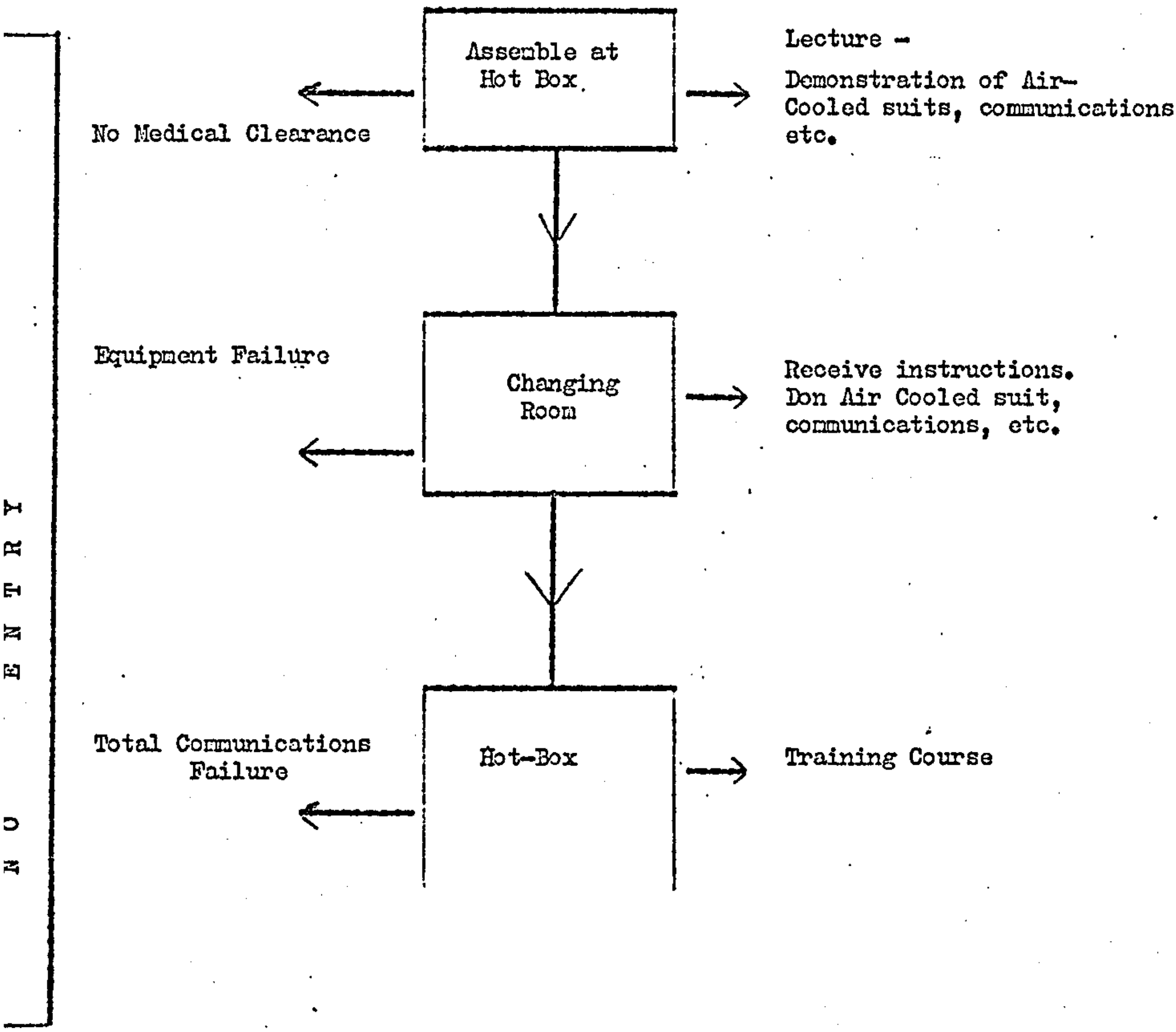
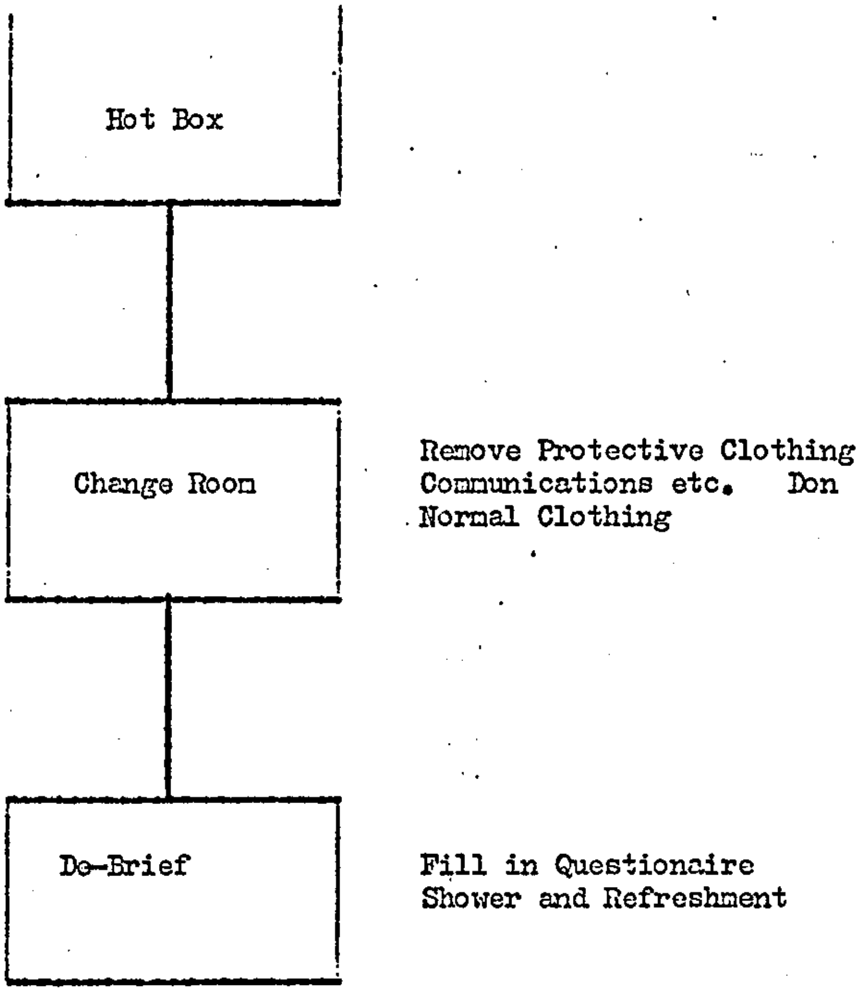


FIGURE 5

BOILER FAMILIARISATION FACILITY

TRAINING TEAM WITHDRAWAL PROCEDURE



APPENDIX G

COMMISSIONING TEST SCHEDULE

VESSEL ENTRY ACCESS ROUTE SIMULATION FACILITY

CONTENTS:

OBJECTS OF TRAINING

, To further familiarise personnel with the various items of protective clothing ssociated with hot environmental work.

To establish and practice the access and emergency procedures in a .mulated and safe environment.

, To provide entry teams with a more accurate impression of distances) be covered and difficulties which will be encountered in the vessel ccess route.

3. ACCESS ROUTE SIMULATION FACILITY

This facility has been constructed alongside the Charge Machine Maintenance Building rehearsal shaft on . It has been designed to resemble the access route in the Hunterston 'B' pressure vessel but because of the building limitations, it is only $\frac{2}{3}$rds in height of the latter.

The ladderwork structure of the facility is enclosed in a hardboard shaft and incorporates all the main realistic features of the 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 of the ladderwork is shown in Fig. 3.

A Control Console similar to the model to be used on is positioned on the 114' level. The communication system and air flow/pressures are monitored at this point by the trainee Controller under the supervision of the training programme co-ordinator.

Compressed breathing air delivered along $2\frac{1}{2}$" galvanised steel pipework from the compressor mounted at ground level to the rear of the building is divided into 4 lines at the Console. These lines extend down to the C.M.M.B. hoist room on the 98' level where the hose reels are situated. During training sessions an attendant is on duty at this point to supply airlines on demand via the communication system.

A second attendant is positioned above the entry point at the 117' level to operate the air-operated hoist if required for lowering equipment or for removing a casualty. The air-operated hoist is suspended from a support beam fixed close to the roof of the building above the entry point. A safety line is compulsory for all entrants and it is also fastened onto the beam.

A change room is provided at the top of the stairs at the 114' level with ample space for storage of all equipment.

No provision is made to simulate the hostile environments of noise and high temperature that will be present in the vessel. 3 kw fan heaters have however been provided both at the bottom of the hardboard shaft and in the change room to maintain the temperature above ambient during cold weather.

Permanent lighting fixtures have been installed inside the facility but will not normally be used during a training session except in emergency circumstances. Temporary lighting identical to the circuitry for installation in the pressure vessel will be used for all training sessions.

4. EQUIPMENT

(a) Compressor

The compressor, together with an after-cooler and air receiver, is housed in a temporary building at ground level on the south side of the C.M.M.B.

It is an Ingersoll Rand Model 25B Type 40 compressor, air cooled with a free air delivery of 128 cFm, maximum working pressure 125 p.s.i. The discharge air pressure has been adjusted to give only 100 p.s.i. The electrical supplies for the compressor is contained on a switchboard in the C.M.M.B. Machine Workshop.

Operating instructions are given in Appendix 1.

(b) Control Console

The control console provides the Controller with the same information which he will get from the 'B' Station console during vessel entry.

The compressed breathing air pipework is fitted into the console after passing through a coarse and fine filter. The air pressure and temperature are noted at this stage. If the air pressure falls, a red light comes on in the centre of the console. Four valves fixed into the front upper panel of the console allow the Controller to set the desired flow of air to each trainee; rotameters are provided on each line to indicate the air flow.

The communication interoom unit enables the Controller to be in contact with up to 10 personnel but as there will be no back-up emergency team during the training sessions, only 6 lines will be in use:- 4 inside the facility, 1 hose reel attendant and 1 hoist operator. The proper use of communications, including the recognised form of address code, is vital to the success of the vessel entry programme and although the basic procedures are outlined in Appendix 2, these will certainly be modified in the course of time through experience gained in this training facility.

A time-elapsed clock will also be fitted into the console to correspond to the 'B' Station console.

(c) Protective Clothing

The air-cooled suits, gloves, boots, etc. are all as described in Part 1 of this document.

(d) 'Casualty'

An anthropometric 95th percentile dummy has kindly been loaned by Dr. Borwick, National Engineering Laboratory, East Kilbride, for use in the carrying out of the emergency procedures where a casualty is involved. Trainess must not attempt to carry the dummy up the ladder, it weighs 217 lbs.

(e) Air-Operated Hoist

A ½ ton air-operated hoist is suspended from a support beam above the facility entry point on the 117' level. It is intended primarily for the removal of a casualty but may also be used in circumstances when it is not possible to move equipment into and out of the facility by rope i.e. the 90 lb. tripod support beam which is positioned above the boiler cheesepiece will require the hoist.

(f) Safety Lines

All ladderwork will be undertaken attached to an Everest safety line. The line will be fixed to the support beam above the entry point. The correct method of tying will be clearly displayed adjacent to the support beam.

5. TRAINING PROGRAMME SCHEDULE

(a) Access Route Simulation Facility - Schedule for Personnel

Introductory Lecture	10 mins.
Outline of Facility, Console and Protective Clothing	10 mins.
Dressing	15 mins.
Practical	2 hours
Undressing, Discussion	20 mins.
	2 hrs. 55 mins.

(b) Schedule for Change Room Attendants - Dressers, Hose Reel Attendants, Hoist Operators

Introductory Lecture	10 mins.
Outline of Facility, Console and Protective Clothing	20 mins.
Practical	30 mins.
	1 hour

At this stage of the training programme, it is envisaged that because of the number of emergency procedures that must be thoroughly practiced, all trainees for the simulation facility will require a minimum of 3 sessions. Change room attendants, being small in number, will participate at very regular intervals.

6. METHOD OF TRAINING

(a) Personnel

The composition of a training team will be as follows:-

Console

'B' Station Operations Engineer as training Controller, assisted by training programme co-ordinator.

Change Room

2 change room attendants to assist with dressing/undressing. The duties of change room attendants are given in Part 1 of this C.T.S.

Hose-Reels

One of the above C.R.A.'s will operate the hose reels on the 98' level during the training session.

Hoist

The second C.R.A. will operate the hoist during the training session.

Training Team

A team will always consist of 4 trainees who have already undergone a training session in the Hot Box.

The initial training sessions may well show that a second supervisor is required to assist and/or observe the progress of the trainees in the facility.

(b) Training Session - See Figs. 1 and 2

1. All trainees will report to the Console on the 117' level, C.M.M.B.

2. After lecture, demonstration and briefing, proceed to change room.

3. The C.R.A.'s will assist the team to don air-cooled suits, outer coveralls, boots, gloves and communication headsets.

4. C.R.A.'s will check air supply to suit and aommunications to console.

5. Hoist operator (C.R.A.) will log any tools i.e. hammer, instruments, dummy camera, hand torch, required for access.

6. Entry team will proceed from the change room to the area round entry point at 114' level. At this stage, the training Controller will conduct final check on communications with team, hoist operator and hose reel attendant (now in position at 98' level) and ensure air flow/pressure is adequate.

7. 1st and 2nd men ascent to 117' entry platform and clip on to Everest safety line.

8. The temporary lighting system will be lowered down to 98' level.

9. 1st and 2nd men descent one at a time to 98' level, then release from safety line.

6. METHOD OF TRAINING (Cont'd.)

10. 1st and 2nd men ensure that the temporary lighting system is secured in position

11. 3rd and 4th men lower any equipment required down by rope, then clip onto safety line.

12. 3rd and 4th men descent one at a time to 98' level, then release from safety line.

13. 1st, 2nd and 3rd men walk round the simulated boiler annulus carrying any equipment required for the lower part of the route. 4th man assists with airlines.

14. 1st, 2nd and 3rd men return to the area around the boiler cheesepiece.

15. 1st and 2nd men lower safety rope and temporary lighting to 90' level.

16. 1st and 2nd men clip onto safety line and descent one at a time to 90' level, 3rd man remains above cheesepiece, 4th man further back along simulated boiler annulus to assist with airlines.

17. 1st man opens hatch at 90' level, lighting and safety rope lowered to 82' level.

18. 1st and 2nd men descent one at a time to 82' level, 3rd and 4th men assist with airlines.

19. 1st man using hammer opens and closes top inspection hatch, 2nd man opens and closes bottom inspection hatch.

20. 2nd man opens hatch at 82' level, lighting and safety line is lowered down to 74' level.

21. 1st and 2nd men descent one at a time to 74' level, 3rd and 4th men assist with airlines.

22. Lighting and safety line is lowered down to 58' level, 1st and 2nd men descend to floor, 3rd and 4th men assist with airlines.

23. 3rd man lowers any equipment required for survey or inspection.

24. The team will now follow the instructions laid down for one of the emergency procedures - see Section 7.

25. Following successful emergency drill, the team, now at 114' level will proceed to change room.

26. C.R.A.'s will assist in the undressing.

27. Discussion.

28. Termination of training session.

7. EMERGENCY PROCEDURES

(a) Exit Without Lighting

1. Controller informs all personnel that the temporary installed lights are about to be switched off.

2. Following acknowledgement of signal by all team members, the lights are first flashed for 10 seconds then switched off.

3. Hand torches are switched on.

4. 3rd and 4th men inform Controller that the 98' walkway and boiler cheesepiece are free of temporary obstacles and are in a position to assist with airlines of 1st and 2nd men.

5. 1st and 2nd men leave any tools or equipment on the floor, clip onto safety line.

6. 1st man ascends to 1st platform, 3rd and 4th men illuminate the area with hand torches.

7. 2nd man ascends to 1st platform.

8. 1st man ascends up to 2nd platform then up to top of cheesepiece at 100' level, this will then allow clear illumination for No. 2 man. No. 1 releases safety line.

9. 2nd man ascends from 1st platform to 100' level and releases safety line.

10. All 4 men walk slowly round to bottom of top stage ladder.

11. 1st and 2nd men clip onto safety line and ascent one at a time to 117' level, hoist operator will shine torch to assist the climb.

12. 3rd and 4th repeat above.

Note: Every movement during the exit can only commence after instructions are given from the team to the hose reel operator to draw in air-line slack. 3rd and 4th men must watch that the air-lines of their team mates do not get caught up on any protrusions during the Steps 6 - 9.

(b) Exit Without Communication

1. Controller informs all personnel that an exit without communications will be attempted.

2. Following acknowledgement of signal by all team members, the lights will be flashed for 10 seconds as a signal for evacuation.

3. Communications between the team and hose reel attendant will be switched off though the Controller will maintain contact with the team in case of difficulties.

4. 3rd and 4th men will ensure boiler cheesepiece is free of temporary obstacles then signal (3 pulls on the safety line) to the men on the 58' level that the route is clear. 1st and 2nd men leave any tools or equipment on the floor.

5./.....

7. EMERGENCY PROCEDURES (Cont'd.)

5. 1st man clips onto safety line and proceeds slowly up to 100' level, stopping at each platform until the 'proceed' signal is again given. 4th man will signal to hoist operator as to the rate the air-line will be withdrawn from the facility.

6. When 1st man has released from safety line at 100' level, the 2nd man will proceed up the ladder in similar fashion.

7. 2nd and 3rd men walk slowly round to bottom of top stage ladder, 4th man ensuring the correct length of airline is available at all times.

8. 1st and 2nd men clip onto safety line and ascend one at a time to 117' level, hoist operator pulling up airlines as required.

9. 3rd and 4th men repeat above.

(c) Exit With Casualty

The dummy complete with air-cooled suit, airline, safety harness, etc. will be in position at the 58' level.

1. Controller informs all personnel that a casualty exit will be attempted. Note: If the Dummy is assumed to be the result of an injury to the 1st man, the 'real' 1st man will in fact now play the role of the 3rd man who has come down the boiler cheesepiece to assist. Therefore the 'real' 3rd man up at the 100' level will not participate in this exercise unless help is required.

2. Following acknowledgement of signal by all team members, the lights will be flashed for 10 seconds as a signal for evacuation.

3. 1st man informs Controller of casualty and requests that splints be sent in to bind legs.

4. Splints are lowered by rope by hoist operator to 4th man, who in turn lowers down to 58' level.

5. 1st and 2nd men bind Dummy's legs and request use of air hoist for removal of casualty.

6. Hoist rope once lowered down is fixed onto safety harness hook.

7. Dummy is clipped onto safety line, 1st man also on safety line moves onto ladder and signals for air hoist to be operated at slow speed 4th man will ensure that cheesepiece is free of temporary obstacles and that the airlines do not catch on any protrusions.

9. With the 1st man leading, the Dummy is brought slowly up to the 100' level. In case of any mishap to the Dummy, the 2nd man will remain at the 58' level until the Dummy is safely on the 98' level.

10. 2nd man clips onto safety line and proceeds slowly up to 100' level.

11. With the 4th man now leading, the Dummy is brought slowly up to the 114' level. 1st, 2nd and 3rd men remain at 98' level.

12. The exercise now officially over, the Dummy is then lowered back down to the 58' level.

13. The 3rd man clips onto safety line and descends to 58' level, releases hoist rope from Dummy's safety harness, then returns to 100' level.

14. 1st, 2nd and 3rd man ascent one at a time, on safety line, to 114' level.

8. RESPONSIBILITIES

S.S.E.B. are responsible for providing, maintaining and operating all equipment and training sessions in the Vessel Entry access route simulation facility

9. APPENDICES

1. Operation of Compressor.

2. Communication Intercom System.

10. DIAGRAMS

1. Training Team Entry Procedure.

2. Training Team Withdrawal Procedure.

3. Ladderwork.

BF/LM/9.8.74

APPENDIX 1

CHARGE MACHINE MAINTENANCE BUILDING REHEARSAL FACILITY - OPERATION OF COMPRESSOR

The compressor, situated in the S.E. corner outside the C.M.M.B., is an Ingersoll-Rand Model 25B Type 40, air cooled with a free air delivery of 128 c.f.m. at a maximum working pressure 125 p.s.i.g.

Electrical Operating Instructions

The switchboard is in the C.M.M.B. Machine Workshop adjacent to the Compressor housing.

1. Ensure all isolating switches are ON.

i) Main supply isolator at 415V bus bars.

ii) After-cooler isolator.

iii) Compressor isolator.

iv) 415V compressor control supply isolator.

v) 110V indication supply isolator.

2. Ensure overloads are reset (stop and/or reset buttons).

3. Ensure emergency stop button is reset (situated on C.M.M.B. wall in compressor housing).

4. To START:- Operate START button on after-cooler starter.

i) After-cooler will start.

ii) Compressor will start on star connections and after prescribed time will switch to delta.

Note: Compressor will not start until after-cooler contactor is operated.

5. Compressor is fitted with constant speed control and will maintain prescribed air pressure between required limits as set on 'Aux.' valve on side of receiver. Under this system, the compressor motor will continue to run although no air is being delivered to the receiver.

6. To STOP both After-Cooler and Compressor:-

operate either a) After-cooler stop button; or
b) Emergency stop button.

To STOP Compressor only:-

operate Compressor stop button
(to restart Compressor, operate start button).

7. Overload trips

i) On After-Cooler - will trip both After-Cooler and Compressor

ii) On Compressor - will trip compressor only.

Note: With After-Cooler running, resetting of the compressor O/L trip button will restart compressor.

8./.....

8. To start After-Cooler and Compressor separately:-

i) Ensure both After-Cooler and Compressor Stop buttons are operated.

ii) Close all isolators in (1) above.

iii) Start After-Cooler.

iv) Start Compressor.

APPENDIX 2

COMMUNICATION INTERCOM SYSTEM

The control panel consists of eight microphone switches with indicator lamps, two headset sockets, record output socket and main switch and indicator lamp.

The microphone switches operate so as to switch off the headset in the up position when the indicator lamp will function.

When operating these lever keys they should be switched quickly otherwise the amplifier input impedance is affected.

Points to Note

1. Monitor Socket - used only for headset monitoring, the microphone will not operate in this socket.

2. Controller Socker - care must be taken when the headset is removed from head to ensure that no feedback is produced. The headset provided for this operation is fitted with a microphone switch.

3. Record Socket - is a standard jock socket. The output to this socket is taken from the amplifier output and is attenuated to give the correct recording level on the radio output of a good quality tape recorder (i.e. 10 mV at 100k ohm approx).

4. Headset Output Sockets - are numbered 1 - 8 to correspond to the switch number on the front control panel.

5. Volume - the volume level is adjusted with the preset control situated behind the black plastic grammet directly under the record output socket.

Procedure

1. All team members will be designated by the colour of their airlines.

2. In case of communication difficulty, the following standard phonetic code must be used:-

A	Alpha	N	November
B	Bravo	O	Oscar
C	Charlie	P	Papa
D	Delta	Q	Quebec
E	Echo	R	Romeo
F	Foxtrot	S	Sierra
G	Golf	T	Tango
H	Hotel	U	Uniform
I	India	V	Victor
J	Juliet	W	Whisky
K	Kilo	X	X-Ray
L	Lima	Y	Yankee
M	Mike	Z	Zulu

3. The correct form of address is given below:-

Initiating/.....

Initiating a Call

(a) 'Calling'

(b) To team, state airline colour, otherwise proper title

(c) 'this is'

(d) own call sing

(e) 'over'

Replying to a Call

(a) Call sign of member initiating call

(b) 'from'

(c) own call sing

(d) 'go ahead'

(e) 'over'

Calling Procedure

(a)	CALLING	One station to another to establish contact.
(b)	TO	One station to another.
(c)	OVER	Message finished and requiring an immediate reply. To be used at the end of every message except at end of the final message of an exchange.
(d)	OUT	Exchange of messages completed. No reply expected.
(e)	GO AHEAD	Pass your message.
(f)	STAND BY	Wait till called, keep listening.
(g)	WAIT	Wait till air is clear, you are interrupting.
(h)	CLOSING DOWN	To be given when switching off.
(i)	ROGER	I have received your last message.
(j)	WILCO	Your last message received, understood and will be complied with.
(k)	SAY AGAIN	Your message is not received/understood, repeat the message.
(l)	I SAY AGAIN	To be used at the beginning of a repeated message.
(m)	URGENT MESSAGE	To be used only in exceptional circumstances when it is necessary to interrupt a message.
(n)	CHECK	Repeat message/instructions to ensure that they have been correctly received.
(o)	CORRECTION	An error has been made in this transmission. The correct version is ....

FIGURE 1

VESSEL ENTRY REHEARSAL SHAFT

TRAINING TEAM ENTRY PROCEDURE

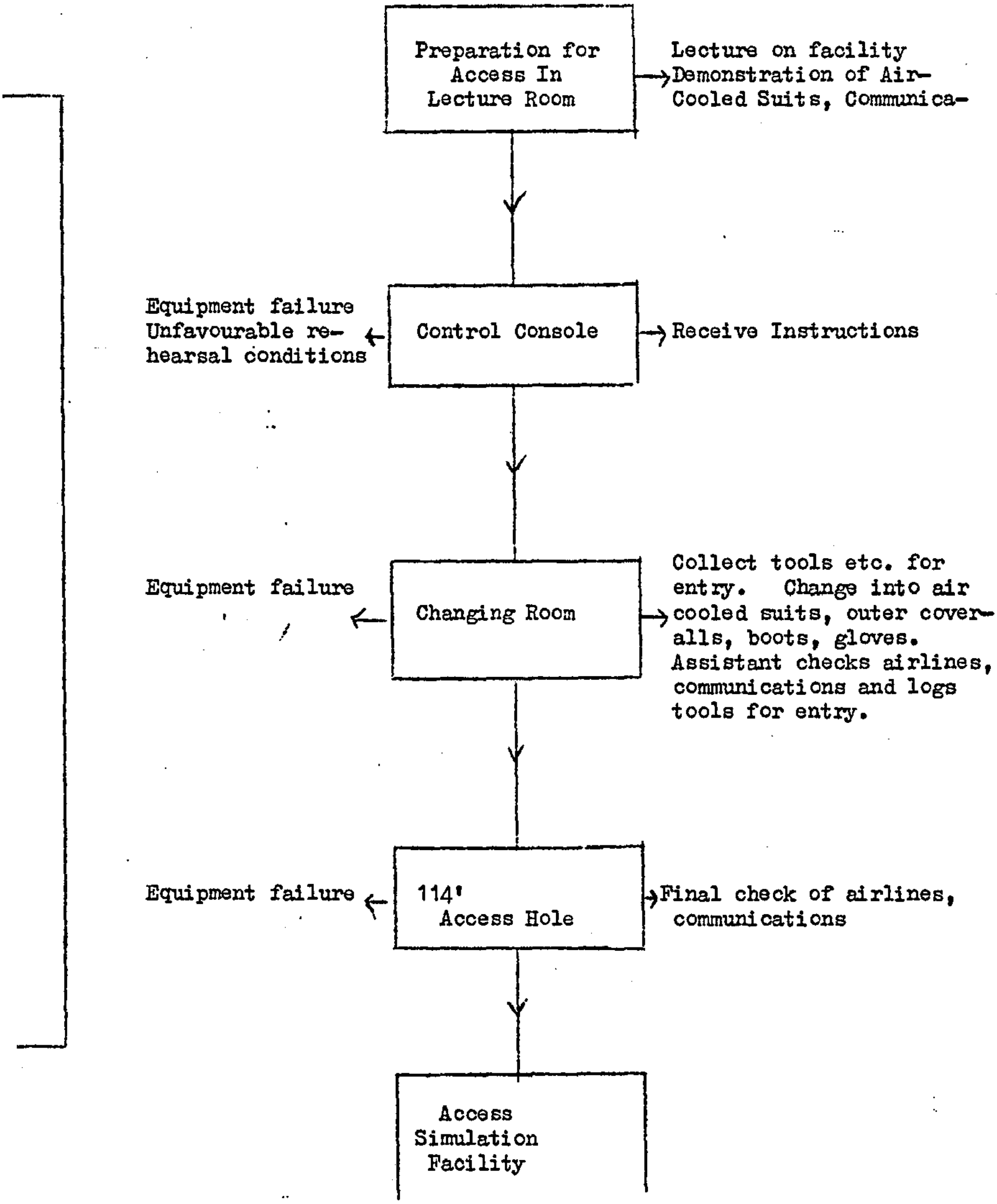
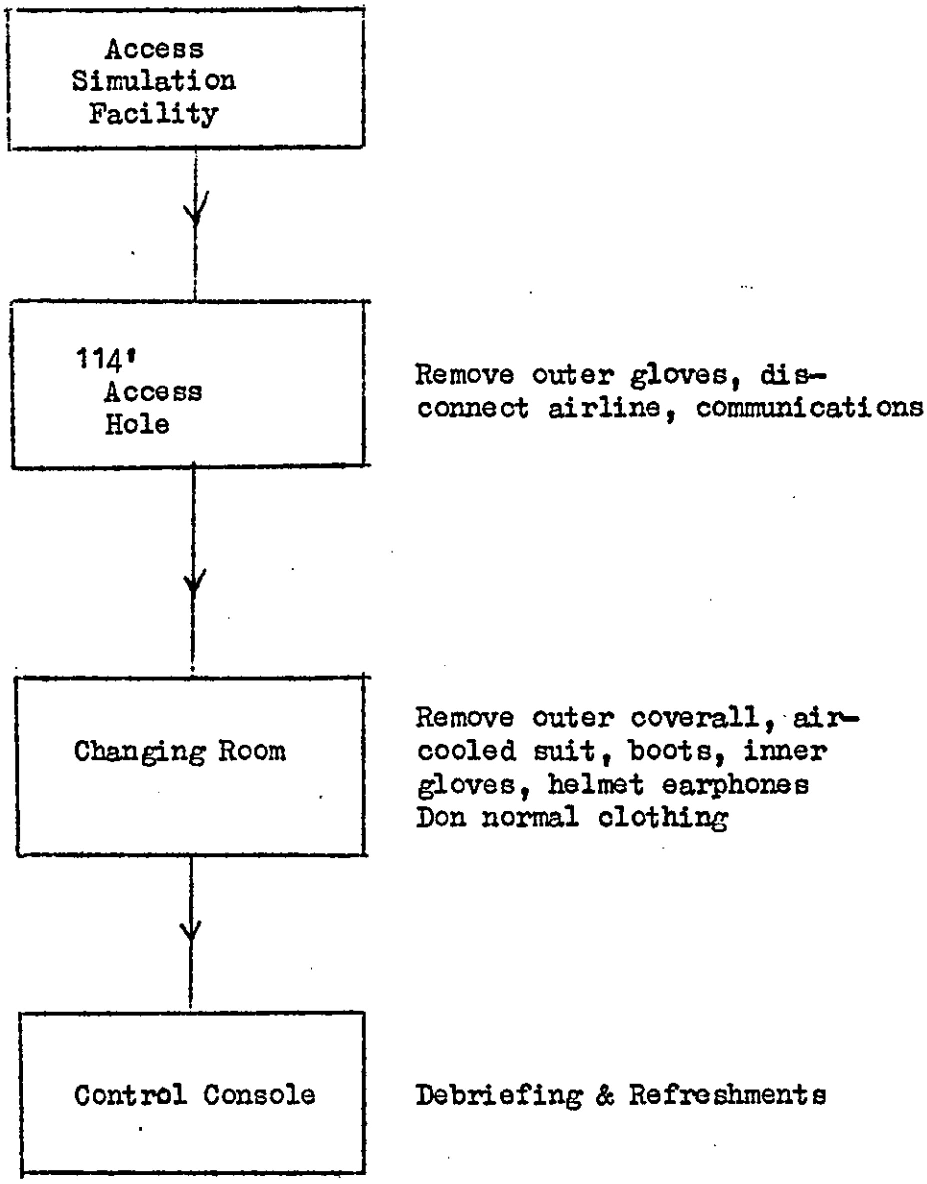
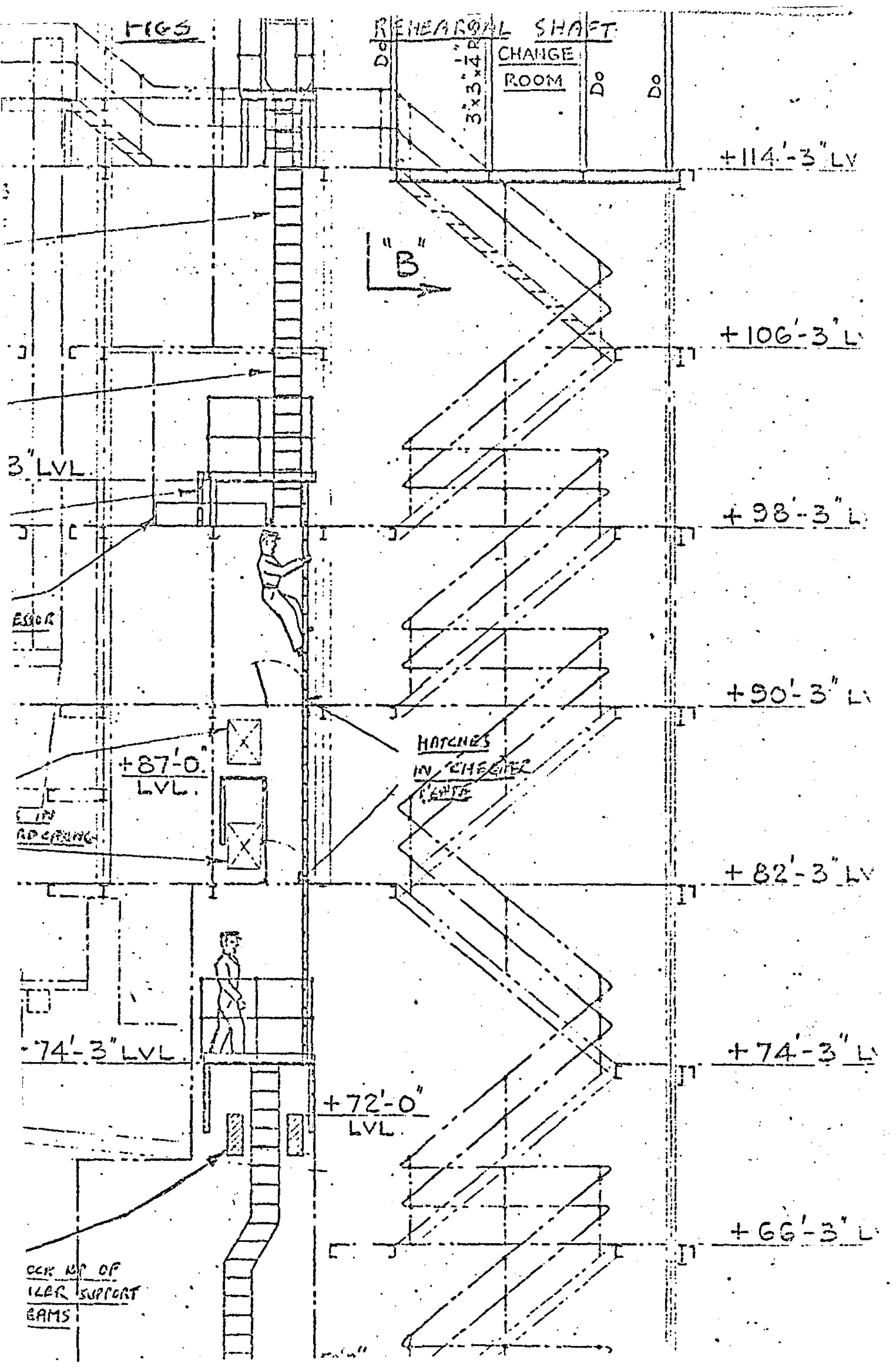


FIGURE 2

VESSEL ENTRY REHEARSAL SHAFT

TRAINING TEAM WITHDRAWAL PROCEDURE





HIGS
REHEARSAL SHAFT
CHANGE ROOM
3"x3"x1/4" R
Do
Do
Do
+114'-3" LV
"B"
+106'-3" L
3" LVL
+98'-3" L
ESSOR
+90'-3" L
HATCHES IN CHEQUER PLATE
+87'-0" LVL.
+82'-3" LV
+74'-3" LVL
+74'-3" L
+72'-0" LVL
+66'-3" L
BEAMS

APPENDIX H

COMMISSIONING TEST SCHEDULE

COLD RUN VESSEL ACCESS DEMONSTRATION

CONTENTS

1 INTRODUCTION

It is planned that during the combined engineering tests in Reactor 3 after the 2nd Hot Run a full scale entry program will be carried out from the pile cap at the 270° access penetration using four-man entry teams in air cooled suits with the Reactor at a temperature of 60°C.

At a convenient time prior to this demonstration, a full scale rehearsal will be carried out in cold conditions in Reactor 4. Several entries will be made on two separate weekends, the 1st entry team installing lighting, support beams and safety lines and establishing the access route to the vault floor with subsequent teams carrying out inspection duties with T.V. cameras and visual inspection of boiler tubes etc. Each team will spend no more than 2 hrs. in the vessel and at the end of each entry period one of the emergency procedures to be described in this document will be carried out. The portable access equipment will be logged in and out of the vessel and the last entry team will ensure that it is all removed and the vessel left in its original condition prior to the access penetration being boxed up.

2 OBJECTS OF PROCEDURE

(1) To familiarise personnel with access equipment and its use in the correct environment.

(2) To prove the feasibility of the vessel entry procedure and in particular the emergency procedures.

(3) To make an assessment of the time involved in assembling and dismantling the auxiliary equipment for the pile cap prior to and after the vessel entry.

3 PREPARATION FOR THE TEST

3.1 Equipment

The following equipment will have been tested and made available on the pile cap prior to entry.

(i) Reactor Instruments as required.

(ii) Compressed breathing air system including 40 emergency air bottles.

(iii) Atmospheric dehumidification plant.

(iv) Telephone communications to control console and hose reel attendants.

(v) Vessel entry control console.

(vi) Electrical power supplies at Pile Cap level.

(vii) Clean conditions tent and 'A' frame.

(viii) Main and Pile Cap change rooms.

(ix) Pile Cap crane, slings and lifting equipment.

(x) Temporary access ladders.

(xi) Staging and temporary platforms

(xii) In vessel lighting.

(xiii) Air cooled protective suits and air flow check equipment.

(xiv) Hose reels and air lines.

3 (Cont'd)

(xv) In vessel communications.

(xvi) Safety equipment Appendix 1.

(xvii) Health Physics ancillary equipment Appendix 2 as appropriate.

(xix) CO_2 monitoring equipment fitted into pipework behind gas circulator gauge board.

3.2 Permit-to-Work

Entry to the vessel will be under the jurisdiction of

4 STATE OF PLANT

Thermal insulation plug not inserted, 270° and 90° penetrations available CO_2 distribution system isolated from vessel.

Air conditioning system as used during normal commissioning in service.

5 METHODS OF TEST

5.1 Access to the vessel will be through the man-access penetration on the pile cap at 270°, the 90° penetration being used as an emergency exist. Fo: the cold run the shield plug, impact sleeve, thermal insulation plug and the access manhole cover will be removed and the access route will be established

5.2 Erection of Vessel Access Equipment

As per C24.04.9.32.02.09 Part 4 5.3

5.3 Preparation for Vessel Access

All personnel entering vessel will have been passed medically fit, however, no certificates will be issued since entry will take place in cold conditions Personnel entering vessel will follow the entry procedure as shown in Fig. 3. Dependant upon whether gas circulators are running noise level checks will be made and circulators will be switched off in the quadrant being used for acce:

COLD RUN

5.4 Vessel Entry to Establish Access Route and for Lighting and Safety Installation

1 Personnel

The composition of this initial entry team will be as follows :-

a) Console - 1 Assistant Charge Engineer as controller.

1 Grade 9 Engineer for plant duties as required by Controller.

1 Grade 10X Engineer responsible for communications and logging personnel in and out of vessel.

b) Clean Conditions Tent - 2 change room attendants responsible for dressing undressing vessel entrants and logging material in and out of vessel.

Duties of the C.R.S.s are given in Appendix 4.

5.4 (Cont'd)

c) 124' Hose Reel Gantry (In separate tent) – 1 hose reel attendant dressed in single coveralls and face mask in constant communication with personnel in vessel.

d) Vessel Entry Team – 1 A Health Physicist

2 –)
3 –) Personnel to be decided closer to the date
4 –)

2 The vessel entry team will report to the Controller at the Console, receive instructions and proceed to clean conditions tent (Note it is assuming that the personnel in the team have carried out the correct procedures leading up to their arrival on the Pile Cap as shown in Fig. 3).

3 Don air-cooled suits, outer coveralls, boots, gloves, and communications head sets.

4 Check air supply to suit and communication to Console under the assistance of the change room attendants.

5 Log hand torch, and tools required for access.

6 4 man entry team proceed through to the area round penetration. At this stage, the assistant controller will conduct a final check of communications with both team and hose reel attendants.

7 1st and 2nd men descend one at a time to the annular platform at the 77' level using safety line. During the descent the 2nd man will secure the ladder.

8 The 3rd and 4th men supervise the lowering by air hoist of the lighting equipment.

9 2nd man installs lighting around annular platform and selected cheesepiece.

10 The support beam, 1 safety line with 4 attachments, air hoist, tools and extra air line can then be lowered to the annular platform under supervision of 3rd and 4th men.

11 3rd and 4th men descend one at a time to 77' annular platform using safety lines.

12 Three men, 1st, 2nd and 3rd, carry support beam and gear to selected quadrant and 4th man ensures that no problems exist with the air lines.

13 2nd man fixes support beam and attaches air hoist and safety lines.

14 1st and 2nd man, using safety line, descend one at a time to platform in cheesepiece at 73' level, 3rd man positions himself at top of cheesepiece (79' level).

15 2nd man opens hatch at 73' level. Lighting and safety lines are lowered to 63'4" level.

16 1st man using safety line descends to 63' level while 4th man positions himself at foot of 270°C access ladder to ensure air lines are paid out and that lighting is made available to be lowered down cheesepiece.

17 2nd man using safety line descends to 63'4" level and opens 2nd hatch. Lighting and safety lines are lowered through the hatch down to 41'8" level.

5.4 (Cont'd)

18 1st man using safety line descends to 41'8" level.

19 2nd man using safety line descends to 41'8" level and opens third hatch. Lighting and safety lines are lowered to the vault floor.

20 Safety air line is lowered from 77' annulus to vault area.

21 1st and 2nd men using safety lines one at a time descend to vault floor.

22 For withdrawal, 4th man places himself beneath 270° access ladder at 77' level to form a chain for removal of air lines. 1st and 2nd man clip on to everest safety lines and one at a time ascend to 79' level using the same ladder as was used for the descent. Hatches are left open and lighting left in situ.

23 1st, 2nd and 3rd men travel round annular platform to join 4th man beneath 270° access ladder.

24 All personnel are withdrawn from the vessel one at a time and using safety lines.

5.5 Vessel Entry for Familiarity with Access and Inspection Equipment

Access to the following areas is proposed.

1) Above the gas baffle.

2) Boiler interstitial spaces.

3) Gas circulator inlet plenum areas quadrant C vault area.

The following is written for the 4 man team entry.

1. As per 5.4.2.

2. " 5.4.3.

3. " 5.4.4.

4. " 5.4.5 + two cameras

5. " 5.4.6.

6. 1st and 2nd men descend access ladder to annular platform at 77' level using safety line. 3rd and 4th men stay at pile cap level and assist with the lowering of T.V. camera and datum reference jig to the 77' level.

7. 3rd and 4th men then descend one at a time the ladder to the 77' level using safety line.

8. 1st, 2nd and 3rd men traverse round to the quadrant to be inspected, 4th man remains below 270° access ladder.

9. 1st and 2nd men descend one at a time between boiler units to 73' level using safety line.

10. 3rd man remains at 79' level platform to assist with air lines and lowering gear.

11. 4th/...

5.5 (Cont'd)

11 4th man, when not employed with air lines is taking T.V. camera shots under direction of controller with ref. to appendix 5.

12 1st and 2nd men descend one at a time to 69' level using safety line, open inspection cover to boiler unit. Carry out a brief inspection and take photographs.

13 If requested by Controller a Caesium collection plate in the form of a Jubilee clip is removed from boiler tubes and replacement clip is screwed on.

14 Close inspection cover and descend to 63' level one at a time using safety lines and proceed with 2nd boiler tube inspection, removing cover and taking photographs.

15 Close inspection cover and descend one at a time to 25' level using safety line.

16 Inspect vault area for gross damage and a series of photographs are taken.

17 2nd T.V. camera is lowered to 1st and 2nd men in vault area. T.V. camera work is then carried out by 1st man in the vault under the supervision of the controller with ref. to appendix 5.

18 4th man at 77' annular platform, continues to take photographs round the annular platform.

19 After inspection is complete T.V. camera is raised to 79' level with 3rd man controlling hoist.

20 1st and 2nd men return to 79' level one at a time using the same descent route and clipping on to safety line.

21 1st, 2nd and 3rd men descend on to 77' annular platform and traverse round to the bottom of 270° access ladder carrying T.V. camera and tools.

22 For the ascent the 4th man is positioned at the foot of the 270° access ladder to assist with air lines.

23 3rd and 4th men ascend one at a time the access ladder to the pile cap using the safety line and assisted by hose reel man.

24 1st and 2nd men supervise the removal of all equipment logged in at start f 2nd entry using air hoise on A frame where necessary.

25 1st and 2nd men ascend the access ladder one at a time to the pile cap using safety line.

After step 18 of 5.5 each inspection entry team will carry out one of the emergency procedures described in Appendixes 7,8,9,10.

5.6 <u>Final Entry and Removal of In-Vessel Equipment</u>

1 As per 5.4.2 to 5.4.6.

2 1st and 2nd men descend access ladder one at a time to annular platform at 77' level using safety line, 3rd and 4th men stay at pile cap level and assist with air lines and lower gear associated with this final entry.

3 3rd and 4th men descend ladder one at a time to 77' level.

5.6 (Cont'd)

4 Three men traverse round to the quadrant used for previous entries taking gear with them. 4th man remains below access opening.

5 Three men ascend ladder onto platforms between boiler units at 79' level.

6 1st and 2nd men descend ladder one at a time to 25' level. The 3rd man remains at 79' level to assist with air lines and removal of lights.

7 1st and 2nd men ascend to the 41' level, one at a time, lighting and safety line and spare air line are withdrawn to just above this level.

8 Lower and seal hatch at 41' level.

9 Repeat 5.6.7 and 5.6.8 at 63' level and 73' level and withdraw to 79' level.

10 Remove safety line, hoist and extra air line from support beam; finally remove support beam.

11 The three men then descend onto the 77' annular platform and traverse round to the bottom of the access ladder carrying the items mentioned in 5.6.10 plus lighting equipment. Several journeys may be necessary.

12 The 1st and 2nd men then ascend the access ladder one at a time to the pile cap level assisted by the hose reel men.

13 The 3rd and 4th men then supervise the removal of all access gear from the vessel, the 'A' frame air hoist will be used as necessary.

14 The 3rd and 4th men then ascend the ladder one at a time.

15 Cross check all equipment with log books i.e. vessel completely cleared of all access gear and personnel.

5.7 Post Entry Procedure

As per 5.8 CTS Part 4 apart from decontamination procedures and P.T.W. considerations.

5.8 Dismantling of Vessel Access Equipment

As per 5.9 CTS Part 4.

Omit step 4

Step 5 No decontamination procedures to be carried out.

5.9 Termination of Programme

Control of Gas Circulators etc. reverts to T.N.P.G. under commissioning programme.

6 RESPONSIBILITY

As per CTS Part 4 6.1.

7 SAFETY ASPECTS

7.1 General/...

7 (Cont'd)

7.1 General

All personnel entering the vessel during this demonstration will be passed medically fit on the day of entry.

7.2 Equipment

As per CTS Part 4 7.2.

7.3 Temperature

Reactor will be maintained at ambient temperature.

7.4 Communications

As per CTS Part 4 7.4.

7.5 Noise

As per CTS Part 4 7.5.

7.6 Carbon Dioxide

Carbon dioxide system will be completely isolated under T.N.P.G. P.T.W.

7.7 Breathing Air System

As per CTS Part 4 7.7

8 REFERENCES

1 Reactor Vessel Testing P.O.P. C24.04.9.31.02.

2 Reactor Vessel Temperature Pressure and Moisture Control, Clean up and Thermal Movements C24.04.9.32.02.03.

3 Vessel Inspection C24.04.9.32.02.01.

4 Reactor Vessel Access for Commissioning Purposes C24.04.9.32.02.08.

5 Atmospheric and Pressurised Noise Measurements C24.04.9.32.02.05.

6 Reactor Shutdown Equipment C24.04.9.22.01.01.

7 Post Hot Run Vessel Access Demonstration C24.04.9.32.02.09 Part 4.

9 APPENDICES

1 First Aid and Safety Equipment.

2 Health Physics Equipment.

3 Control Console Connections.

4 Duties of Change Room Attendant.

5 Vessel Internal Inspection Schedule.

6 Personnel Shift Cover During Entry.

Emergency/-

9 (Cont'd)

7 Emergency Withdrawal Procedures following loss of air.

8 Emergency Withdrawal Procedures following loss of commmunications.

9 Emergency Withdrawal Procedures following loss of lighting.

10 Emergency Withdrawal Procedures following casualty.

10 DIAGRAMS

APPENDIX 1

SAFETY EQUIPMENT INVENTORY

1	In-Vessel	Number
	$\frac{1}{4}$ ton hoist	1
	$\frac{1}{2}$ ton hoist	1
	Support beam	1
	Safety lines	2
2	First Aid Equipment	
	Ordinary Stretcher	1
	Neil Robertson Stretcher	1
	Safety line	3
	Automan	1
	Oxygen cylinder	2
	Air-cooled suit, including full in-vessel gear	1
	Hamper containing bandages	1
	splints (air-cushioned)	
	blankets	
	elestoplast	
	scissors	

APPENDIX 2

HEALTH PHYSICS EQUIPMENT INVENTORY

Beaufort Air-Cooled Suits - L	6	Leads (Contam. probe)	6
- M	6	Plastic Bags - L	12
Vortex Tubes	12	Plastic Bags - M	24
		Plastic Bags - S	24
Vortex Tube Belt holder	12	Paper Tissues	12
Cotton Oversuits	24	White Tape	6
Surgeon's Boots - 6/7	24 prs.	Cellotape	3
		Atidim	3
- 8/9	24 prs.	Storage Bins & Lids	12
- 10/11	12 prs.	Waste Bins	3
Household Gloves - L	24 prs.	Boot Barrier 3 ft.	2
		Table	1
Household Gloves - M	24 prs.	Benches	2
Household Gloves - S	24 prs.	Chairs	3
Cotters Gloves - L	12 prs.	Hosereels	8
Cotters Gloves - M	12 prs.	Couplings	16
Communication Headsets	12	Jubilee Clips	6
		Screwdrivers	3
Safety Harness & Anchor	12	Equipment Log Book	1
Safety Ropes	6		
Cupboards	2		
Thermometer & Lanyards	6		
Torches & Lanyards	6		
Hammers	3		
Spanners	3		
Rope (60')	3		

APPENDIX 3

CONNECTIONS TO CONTROL CONSOLE

APPENDIX 4

DUTIES OF CHANGE ROOM ATTENDANTS

1 Stock Tent

After the erection of the tent by M.M.D. personnel of , the inside of the tent will be furnished by 2 change room attendants in the manner shown in Figure 2.

A complete list of Health Physics Equipment is given in Appendix 2. All these items will be obtained by the 2 C.R.A.s and arranged inside the tent.

Similarly the safety equipment as listed in Appendix 1 will be positioned on the Pile Cap as shown in Figure 2.

2 Vessel Entry Equipment Check

a) Check all communication systems using master control switch on Console.

b) Test air-cooled suits on air-flow test rig.

3 Dress/Undress Entry Teams

Further communication, air flow checks will be carried out during the dressing procedure.

4 Log Entry Equipment

A C.R.A. will be responsible for the logging of entry tools and instruments taken into the Vessel.

5 Removal of Dirty Clothing

At the end of each entry session, the C.R.A. will return all dirty clothing to the laundry and replenish with clean items.

The above list is a summary of the duties. Full details will be given in a Departmental Instruction.

APPENDIX 5

VISUAL PHOTOGRAPHIC AND T.V.

1 Gas Baffle

Doubler plates, shrouds, boiler beam support hangers.
Lower cylinder supports to boiler shield wall.
P.V. insulation termination rig.

2 Boiler Unit

Casings (corner fillet welds), supports (welds, pins and links) gas seals, headers, tube bends, 9% chrome hanger shrouds and T_1 gas pipework.

3 Boiler Unit Supports

Outboard end of boiler support hanger beams and suspension arrangement.

4 Boiler Feed Penetration

Welds.

5 Decay Heat Inlet and Outlet Penetration

Welds.

6 Decay Heat Manifold within P.V.

Welds.

7 Superheater Penetrations

Welds.

8 Reheater Hangers

Welds.

9 Vault

Quadrant division plate assemblies and seals.

10 Insulation

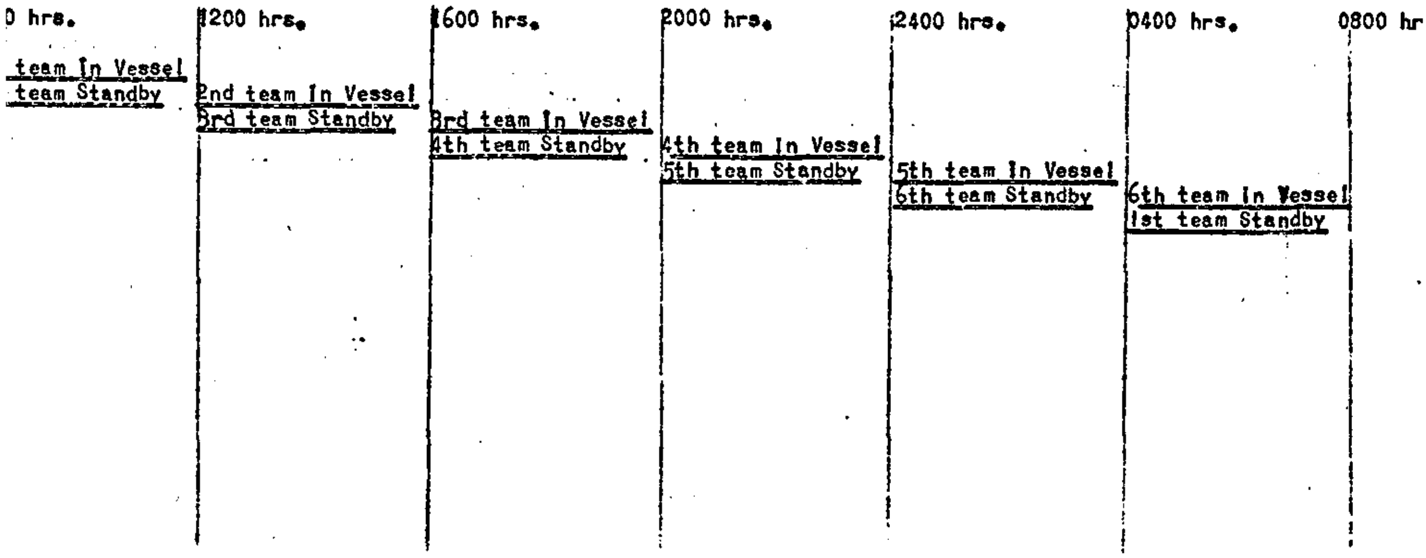
P.V. liner, gas baffle.

11 Gas Clean Up Circuit Pipework

APPENDIX 6

PERSONNEL SHIFT COVER DURING ENTRY

In order to provide a standby team of 4 men, ready at all times when there is a team in the vessel, the following shifts will be worked to provide a 4 hour overlap. Each shift will comprise 4 men and starting and finishing times for a 24 hour period are shown below.



The 2 hour entry period can commence at any time during the 4 hours allowed for entry provided the standby team is fully prepared to cover the entry.

Personnel who are involved (i.e. controller etc.) but are not actually entering vessel will follow the normal shift rota but will have a 1 hour overlap at change of shift.

APPENDIX 7

EMERGENCY WITHDRAWAL PROCEDURES FOLLOWING LOSS OF AIR

PROGRAMME - 4 man Vessel entry team undertaking an inspection of P.V. internals as detailed in C.T.S.

DISTRIBUTION OF PERSONNEL - Console - 2 Controllers
Standby Team - 4 on Standby/2 fully dressed
Clean Conditions Tent - 2 dressers
Hose-reel Attendants - 2 on 124' level
Vessel-entry Team - Nos. 1 and 2 - at 25' level
No. 3 - at 79' level above cheesepiece
No. 4 - at 77' level

EMERGENCY - Sudden loss of breathing/cooling air to one of the entry team.

This failure could occur through the following faults :-

(a) Rubber hose connection inside air-cooled suit broken. Sufficient air should still be available for exit from Vessel as per normal.

(b) Coupling or connector adjacent to Vortex tube broken or released. With assistance, parts can be re-joined or spare air-line substituted.

(c) Vortex tube separated from suit hose i.e. jubilee clip released. Remedial work is unlikely and withdrawal must then be carried out without air.

(d) Air-line split or broken on route. Spare air-line to be substituted.

If any of the above faults affect the No. 3 or No. 4 and cannot be rectified, he withdrawal process should pose no problem for the 4-man team (Note - withdrawal means a complete team withdrawal). The procedure detailed below is therefore written for one of the two at the farthest point inside the Vessel i.e. No. 2.

PROCEDURE FOR WITHDRAWAL

If any member of the team loses his air supply (experience has shown that this is immediately apparent through sudden loss of air noise), he must at once inform the Controller if still in communication. If communications have also failed, he will instead signal or touch his nearest colleague who, in turn, will inform the Controller.

. Controller will instruct No. 1 to examine the terminal area of the affected air-line, No. 3 and 4 to standby to assist for possible withdrawal.

. If air supply cannot be restored, team will prepare for withdrawal :-

a) Nos 3-4 remove all unnecessary obstacles from route i.e. spare and/or broken airline, camera jigs.

b) No. 3 lowers down air-hoist chain to 25' level. It is intended that he air-line hoist be used in the cheesepiece only in the climb where space permits adequate view from the 79' level i.e. above the boiler gas seal to op. In addition, the hoist will not be used during negotiation of the narrow age at each platform.

Appendix 7 (Cont'd)

3 No. 2 attaches to safety line and hoist chain hook and proceeds slowly up to the platform at the boiler gas seal, followed by No. 1. All equipment except the hand torches are left behind on vault floor.

4 No. 3 operates air-hoist as required during the ascent.

5 No. 4 instructs hose-reel attendants when air-line slack must be taken up.

6 At 79' level, No. 2 is released from safety line and air hoist and his condition reported to Controller.

7 P/C air-hoist chain lowered by a hose-reel attendant to 77' level.

8 No. 2 connected to chain and safety line, then raised to P/C.

9 No. 1, 3 and 4 follow up by ladder in that order.

APPENDIX 8

EMERGENCY WITHDRAWAL PROCEDURE FOLLOWING LOSS OF COMMUNICATIONS

PROGRAMME - 4-man Vessel entry team undertaking an inspection of P.V. Internals as detailed in C.T.S.

DISTRIBUTION OF PERSONNEL - Console - 2 Controllers
Standby Team - 4 on Standby/2 fully dressed
Clean Condition Tent - 2 dressers in tent
Hose-reel Attendants - 2 on 124' level
Vessel-entry Team - Nos. 1 and 2 - at 25' level
No. 3 - at 79' level above cheesepiece
No. 4 - at 77' level

EMERGENCY - Sudden loss of communications to one or more of entry team.

This failure could occur through the following faults :-

(a) Complete communication power failure at Console end. If power cannot be quickly restored, Controller must signal to team to prepare for withdrawal (The signal, in this case, will be 5 x 3 secs. flashing of lights).

(b) Broken or loose connection to one of the team. Most probable place is connector adjacent to air-line terminal point which can in most cases, be fixed by the team member's nearest colleague. If connector broken, spare air-line may be used. If not, withdrawal procedure as detailed below.

(c) Air-line split or broken in route. Spare air-line to be substituted.

If any of the above affect No. 3 or No. 4 above and cannot be rectified, the withdrawal process should pose no problem for the 4-man team (Note - withdrawal means a complete team withdrawal). The procedure detailed below is written for a complete communications power failure but also covers for a fault existing in only one line, that of one of the two at the farthest point inside the Vessel i.e. No. 2.

PROCEDURE FOR WITHDRAWAL

1. If communication failure is complete and cannot be restored, Controller will signal to the entry team.

2. Team will prepare for withdrawal -

(a) Nos. 1 and 2 move towards appropriate cheesepiece and connect up to safety line.

(b) Nos. 3 & 4 remove all unnecessary obstacles from route i.e. camera jigs.

3 No. 2 ascends to 1st platform, No. 3 and No. 4 pull in slack air-line.

4 No. 2 ascends to 2nd platform, No. 3 and No. 4 continue to supervise as above.

5 No. 1 ascends to 1st platform, Nos 3 and 4 as above.

Appendix 8 (Cont'd)

6 No. 2 ascends to 3rd platform, followed by No. 1 to 2nd platform, Nos. 3 & 4 as above.

7 No. 2 ascends to 79' level, releases from safety line, then down to 77' level.

8 No. 1 ascends to 79' level, releases from safety line, then down to 77' level.

9 No. 4 proceeds to below main man access and signals to attendant above to pull in slack of all 4 air-lines.

10 All 4 members then connect up to safety line and leave the vessel under the guidance of the attendant on the P/C.

APPENDIX 9

EMERGENCY WITHDRAWAL PROCEDURES FOLLOWING LOSS OF LIGHTING

PROGRAMME - 4 - man Vessel entry team undertaking an inspection of P.V. Internals as detailed in C.T.S.

DISTRIBUTION OF PERSONNEL -

Console	-	2 Controllers
Standby Team	-	4 on Standby/2 fully dressed
Clean Conditions Tent	-	2 dressers
Hose-reel Attendants	-	2 on 124' level
Vessel entry Team	-	Nos. 1 and 2 - at 25' level No. 3 - at 79' level above cheesepiece No. 4 - at 77' level

EMERGENCY - Sudden loss of in-Vessel temporary installed lighting.

This failure could occur through the following faults :-

(a) Failure of the Stations electrical supply to P/C. This is considered extremely unlikely and, if did occur, the Station standby diesel generators would operate.

(b) Break in the cabling, possibly through mishap on P/C. Again this is considered highly unlikely.

(c) Fault in the circuitry inside the Vessel.

The withdrawal procedure below is given in the unlikely event of a failure in the in-vessel lighting system. Each Vessel entrant carried a hand-torch on a lanyard as part of the inspection equipment.

PROCEDURE FOR WITHDRAWAL

1 Following information received as to the failure of the lighting, the Controller will inform team members to prepare for withdrawal.

(a) No. 3 and No. 4 inspect boiler walkway (77' level) and remove temporary obstacles i.e. camera jigs from the route.

(b) No. 1 and No. 2 proceed slowly to appropriate cheesepiece and connect up to safety line.

2 No. 3 reports to Controller that walkway and cheesepiece are free of temporary obstacles.

3 Controller instructs No. 2 to ascend to 1st, the 2nd platform. Nos. 1 and 3 illuminate the cheesepiece with hand torches. Hose-reel attendants pull in air-line as instructed.

4 No. 1 ascends to 1st platform.

5 No. 2 ascends to 3rd platform, then to 79' level, thus allowing clear illumination of cheesepiece for No. 1

6 No. 3 disconnects from safety line and descends to 77' level, No. 1 ascends to 79' level.

Appendix 9 (Cont'd)

7 No. 1 disconnects from safety line and descends to 77' level, followed by No. 3.

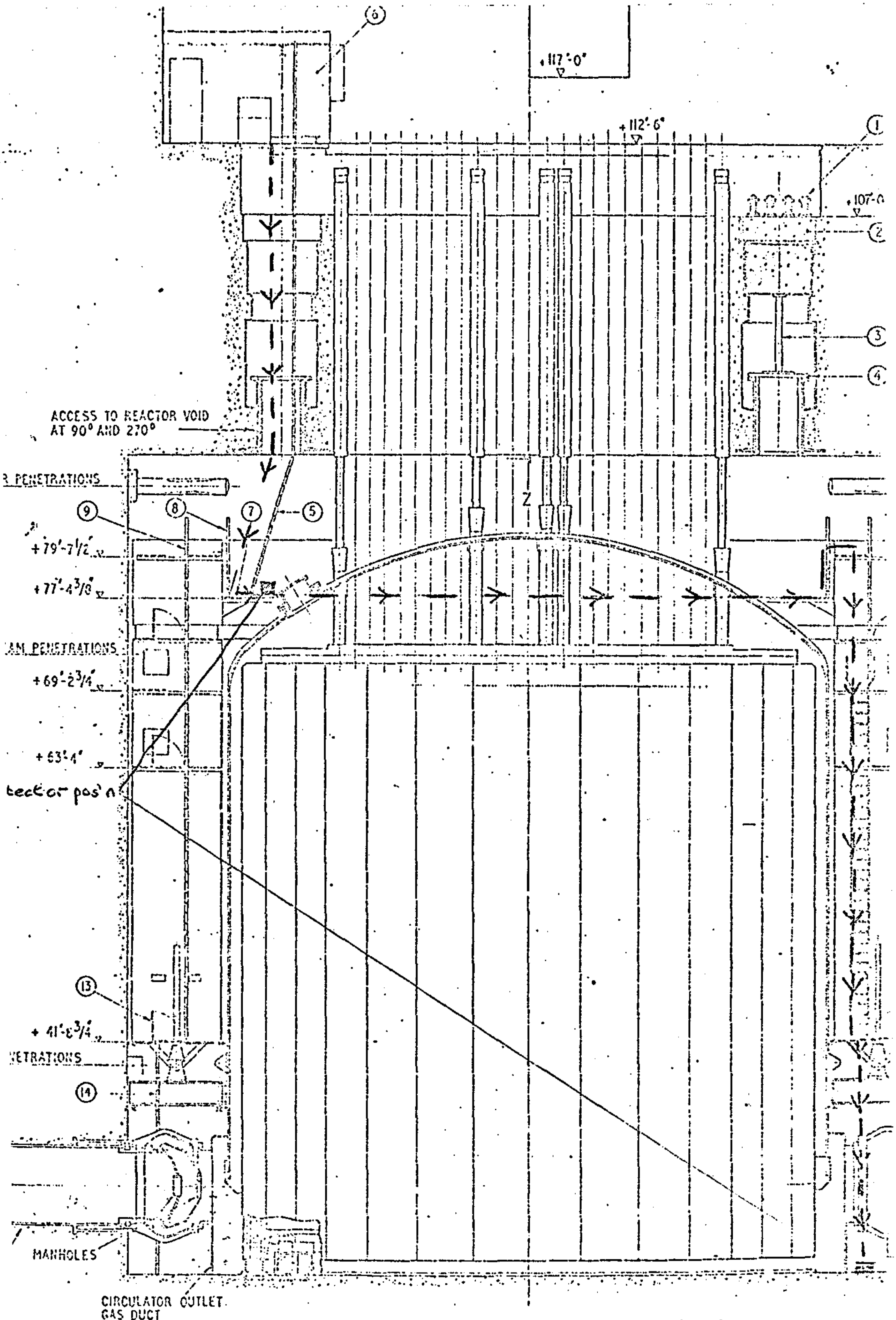
8 All members proceed one at a time to ladder at main access, air-lines being drawn in accordingly.

9 All members then connect up to safety line, and leave the Vessel one at a time. P/C attendant will assist with illuminating the access penetration.

Appendix 10

Emergency Withdraeal Procedures Following Casualty

The proper procedures for removing a casualty from the Vessel will be formulated from the experience gathered in the access simulation facility using the 'dummy' - see Part 2 of this C.T.S. At present the basic philosophy for removingan injured person is outlined in Part 2, Section 7 (c).



SECTIONAL ELEVATION ON 'X-X'
(CIRCULATORS SHOWN OFF TRUE CENTRES)

Fig 1

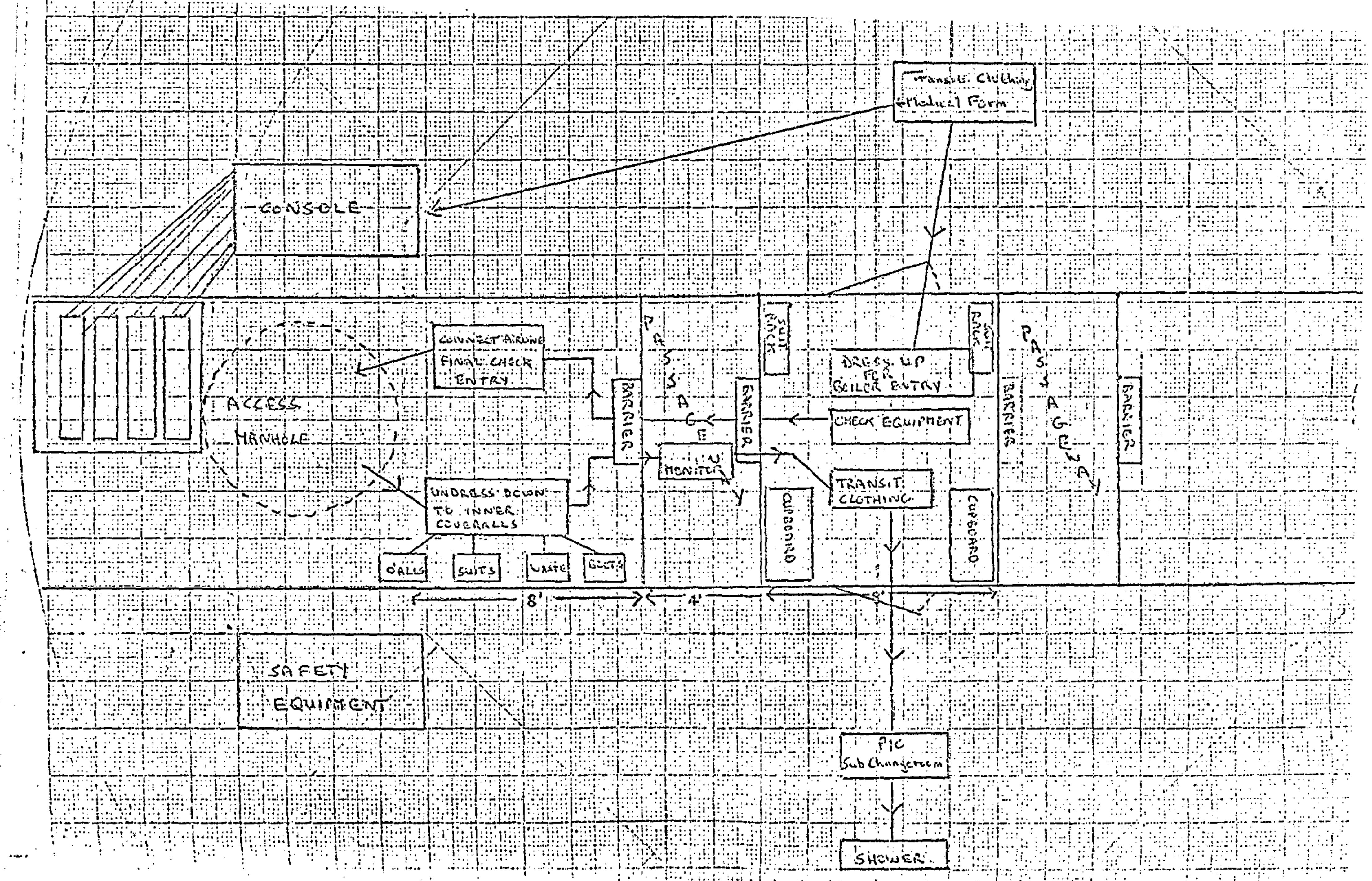

Transit Clothing
Medical Form
CONSOLE
CONNECT AIRLINE
FINAL CHECK
ENTRY
ACCESS
MANHOLE
PASSAGE
BARRIER
BARRIER
UNDRESS DOWN
TO INNER
COVERALLS
O'ALLS
SUITS
WASTE
BOOTS
MONITOR
SUIT RACK
SUIT RACK
DRESS UP
FOR
BOILER ENTRY
CHECK EQUIPMENT
TRANSIT
CLOTHING
CUPBOARD
CUPBOARD
BARRIER
PASSAGEWAY
BARRIER
8'
4'
8'
SAFETY
EQUIPMENT
PIC
Sub Changeroom
SHOWER

FIGURE 3

INSPECTION PARTY – ENTRY PROCEDURE

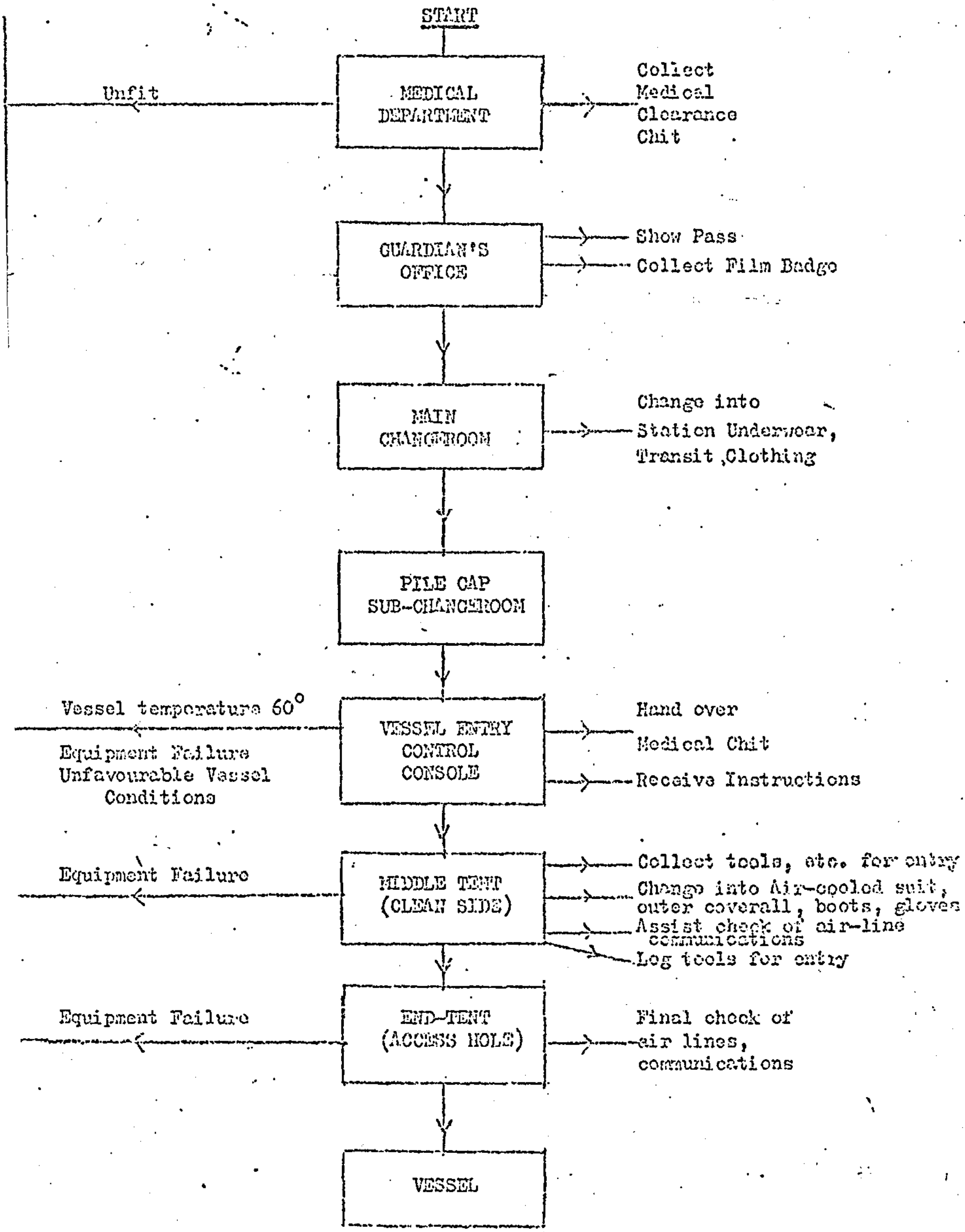


FIGURE 4

INSPECTION PARTY - WITHDRAWAL PROCEDURE

VESSEL

↓

END-TENT (ACCESS HOLE)
→ Remove outer gloves, disconne[ct] air-line, communications
→ Remove outer coverall, air-cooled suit to ankles
→ Sit on barrier, remove boots, outer coveralls, air-cooled suit, inner gloves, helmet, ear phones

↓

PASSAGEWAY
→ Don overshoes

↓

MIDDLE-TENT (CLEAN SIDE)
→ Remove inner coverall
→ Don transit clothing

↓

VESSEL ENTRY CONTROL CONSOLE
→ De-briefing
→ Medical Check
→ Record entry time

↓

PILE CAP SUB-CHANGEROOM
→ Take salt tablets, refreshment

↓

MAIN CHANGEROOM
→ Shower, dress into normal clothing

↓

GUARDIAN'S OFFICE
→ Hand in Film Badge.

NOTE: withdrawal from the vessel will be under the Controller's command, each entrant identified by coloured air-lines. Small items of equipment will be withdrawn by rope.

APPENDIX J

COMMISSIONING TEST SCHEDULE

POST 2ND HOT RUN VESSEL ACCESS DEMONSTRATION

CONTENTS:

1. INTRODUCTION

During the combined engineering tests in Reactor 3, provision has been made after the 2nd Hot run, to carry out a full-scale vessel entry programme. This may well be the sole opportunity the SSEB will have to prove access equipment and procedures that will be adopted for subsequent entries into the reactor vessels during shutdown maintenance periods.

Several entries will be undertaken during this demonstration programme. The initial entry will combine the opening up of the vessel and access route down to the vault area at 25' level with a Health Physics survey, and installation of safety and lighting equipment. Subsequent entries will involve general inspections, familiarisation of equipment and finally a partial box-up and removal of all equipment from inside the vessel. All entries will be made from Pile Cap level via the penetration at 270° and will consist of 4 man teams each being restricted to a 2 hour in-vessel period.

This document sets out the state of the reactor and associated plant prior to vessel entry at 60°C and details the establishment of portable equipment on Pile Cap together with the access procedures to be carried out in the demonstration programme.

Associated documents are referenced below:-

1. Reactor Vessel Testing P.O.P.

2. Reactor Vessel Temperature, Pressure and Moisture Control, Clean-up and Thermal Movements

3. Vessel Inspection

4. Reactor Vessel Access for Commissioning Purposes

5. Atmosphere and Pressurised Noise Measurements

6. Reactor Shutdown Equipment

7. Half Station Commissioning Programme

8. Vessel Access Demonstration

2. OBJECTS OF TEST

21. Full dress rehearsal of vessel entry and inspection procedures to demonstrate the feasibility of the reactor vessel entry process.

2.2 To gain entry to the furthest part of the vessel from the top entry penetration at 270°, i.e. quadrant C. between boiler units 3C1 and 3C2 and establish a route down to the vault area at 25' level.

2.3 To confirm the following:-

(a) In-vessel air temperatures against installed thermocouple temperature measurements.

(b) In-vessel CO_2 concentration against measured external sampling points.

(c) Noise level measurements obtained under CTS C24.04.9.32.02.05.

(d) Vessel entry communication system.

(e) Man exit without air supply.

. PREPARATIONS FOR ACCESS

.1 General

he vessel entry demonstration programme will be inserted between Events 41 nd 43 in the half station commissioning programme (C24.04.9.70.01) - see ig. 1. It is assumed that all relevant Plant Item Test Schedules and ommissioning Test Schedules will have been completed by the start of the nd Hot run.

.2 Equipment

he following items of equipment will have been tested and, if portable, vailable on Pile Cap by Event 41 in the half station commissioning programme.

i) Shutdown sequence equipment (CTS - C24.04.9.22.01.01).

ii) Boiler feed pumps supplying cooling water to boiler units as required. Condensate coolers are operating (ref. Vessel Temperature, Pressure and Moisture Control, Clean-up and Thermal Movements C24.04.9.32.02.03).

iii) Reactor instrumentation as applicable for this demonstration.

iv) Blowdown system and Suction pumps.

v) Compressed breathing air system including 40 emergency air bottles.

vi) The atmospheric dehumidification plant standing by with flexible delivery ducting for connection to man access penetration at 90° position.

vii) 8 Circulators available for temperature control and air circulators.

viii) Telephone communications to C.C.R. and compressor stations from P/C.

ix) Vessel Entry Control console.

x) Electrical power supplies at Pile Cap level.

(xi) Clean conditions tent and 'A' frame.

(xii) Main and Pile Cap Changerooms.

(xiii) Pile Cap crane, slings and lifting equipment.

(xiv) Temporary access ladders.

(xv) Staging and temporary platforms.

(xvi) Temporary extension tube with knockout panel and air delivery tee.

(xvii) Insulation plug special storage stool.

(xviii) In-vessel lighting.

(xix) Air-cooled protective suits and air flow check equipment.

(xx) Additional protective clothing.

(xxi) Hose reels and air-lines.

(xxii) In-vessel communication system with headsets containing ear defenders.

(xxiii) CO_2 concentration detectors.

(xxiv) Radiation dosemeters.

(xxv) Noise measuring instrument.

(xxvi) Safety equipment - see Appendix 1.

(xxvii) Health Physics ancillary equipment - see Appendix 2.

(xxviii) Tools associated with man access.

(xxix) T.V. and photographic equipment

(xxx) CO_2 monitoring equipment fitted into pipework behind gas circulator gauge board.

3.3 Permit-to-Work System

Entry to the vessel will be under the jurisdiction of the SSEB permit-to-work procedure.

. INITIAL STATE OF PLANT

.1 2nd Hot run complete.

.2 Vessel being controlled to 60°C according to CTS C24.04.9.32.02.03.

.3 The two gas circulators in C quadrant will be shut down prior to the tart of the vessel access demonstration.

.4 Channel outlet gas thermocouples showing readings between 56-60°C on he data-logger and held at this temperature.

.5 Reactor vessel depressurised, less than 0.5% CO_2 in vessel.

.6 Man-access penetrations closed with permanent closures.

.7 Breathing air system in operation, operator positioned at compressor tation.

.8 External CO_2 sampling point available (at a gas circulator gauge board).

.9 Vessel isolated from CO_2 + N_2 distribution system - see Appendix 6.

.10 Temporary extension tube, knockout panel and air delivery tee to essel access opening available at 90°.

5. METHODS OF TEST

5.1 General

Access to any part of the vessel will be through the man-access penetration on the Pile Cap at 270°. The penetration at 90° will be used as an emergency exit. During the 2nd Hot run the shield plugs and impact-sleeve will not be fitted (see Fig. 2 - items 1, 2 and 3 will not be in place). The access manhole cover is the primary seal (Fig. 2 - item 4). On the access penetration at 90° the access manhole cover and thermal insulation plug will have to be removed before air purging can take place. The removal procedure will be repeated for the man access penetration at 170° by SSEB.

5.2 Access to Vessel by 270° Penetration

1. Remove the required number of peripheral floor slabs and any temporary floor covering over access manhole.

2. Lower CO_2 detector to primary closure plate. Check that CO_2 is not present.

3. Install the access ladder retaining beam on the top of the penetration and afterwards lower the top section of the access ladder to land on the primary closure plate.

4. Secure access ladder.

5. Isolate P.V. cooling water system to cover plate and disconnect pipework.

6. Remove the plug from the leak detection tube and attach manometer. Observe the manometer to ensure that the pressure in the compensating tube is atmospheric.

7. If above atmospheric, start the two suction pumps at the gas blowdown plant.

8. SSEB issue PTW(M) to remove access manhole cover plate and thermal insulation sleeve when manometer indicates pressure is at atmospheric or below.

9. Remove studs and bolts securing the primary closure plate.

10. Using charge hall crane engage lifting equipment and attach to primary closure plate.

11. Remove access ladder and retaining beam from top of the penetration after personnel have withdrawn from access penetration.

12. Remove primary closure plate and transfer to temporary storage position. Check CO_2 concentration.

13. Install ladder, retaining beam and secure.

14. Using charge hall crane engage lifting equipment and attach to insulation plug.

15. Remove access ladder and retaining beam from top of the penetration after personnel have withdrawn from access penetration.

16./.....

2 (Cont'd.)

). Remove insulation plug and transfer to special stool provided. CO_2 tector lowered in 5.2 2 will continuously monitor level in access netrations.

'. Start 2 suction pumps at the gas blowdown plant, if not already running see 5.2.7). Start atmospheric dehumidification plant after connecting up) tee piece at temporary extension tube at 90° access manhole.

}. Install ladder, retaining beam and secure at top of penetration.

). Cancel PTW (M) issued at stage 5.2.8. CO_2 +N_2 systems remain isolated.

). Vessel purging (see Note 2 below) now begins, continue purging until $)_2$ concentration measured by the external gas sampling points is less than .5%.

l. Install safety rails around man access penetration at 270° on Pile Cap.

2. SSEB issue PTW(M) for erection of vessel access equipment.

ote: 1. T.N.P.G. will open up the 90° penetration to fit the temporary extension tube. Thus both operations will be carried out in parallel using the charge hall crane.

2. Alternative method for purging the vessel using the site temporary compressors may be utilised.

.3 Erection of Vessel Access Equipment

he layout of the vessel access equipment on R'3' Pile Cap is shown in Fig. 3.

. Using charge hall crane, position 'A' frame over 270° penetration.

. Using charge hall crane, position airline reels on stressing gallery bove 270° penetration.

. Erect clean conditions tent over 270° man access penetration.

. Using charge hall crane, position the Control Console adjacent to the lean conditions tent.

. Connect the following items to the Console:-

(a) 2 breathing air systems manifolds.
(b) 40 emergency air bottle system.
(c) Air-line reels.
(d) Electrical power, control and alarm supplies.
(e) Telephone communications to C.C.R. compressor plant room.

ote: Full details of the procedures for above are given in Appendix 3.

. Furnish tent i.e. barrier, table, cabinets, clothing bins, 'A' frame, ton safety hoist etc.

. Bring Control Console into operation, test the equipment shown in .3.5 and also communications to the air-cooled suits.

5.3 (Cont'd.)

8. Control Console will now be manned by SSEB operator.

9. Inventory check of Health Physics and Safety equipment - See Appendices 1 and 2.

10. Cancel SSEB PTW(M) issued under 5.2.22.

5.4 Preparation for Vessel Access

All personnel entering the Vessel will have initially been passed medically fit for hot environment work and, in addition, will have to be certified fit by the Medical Department on the day of entry. Certificates will be issued to this effect which will be presented to the Vessel Entry Controller at the Console on arrival on Pile Cap. The procedure which each man-entrant must observe is detailed in Fig. 4; this figure also indicates conditions under which personnel will be barred from entry.

1. Check CO_2 concentration in the Vessel is below 0.5% from external sampling points.

2. Check channel gas outlet thermocouple readings from the data logger show readings of between 56° - 60°C.

3. Shut down the 2 gas circulators in C quadrant.

4. Issue Health Physics Sanction Survey of Vessel access route.

5. Lower 2nd CO_2 detector to annular platform at 77' level, alarm point set at 0.5%

5.5 Vessel Entry for Health Physics Survey and Lighting Installation

1. Personnel

The entry teams will start working the shift rota shown in Appendix 8 at least 24 hours prior to the 1st entry. It is not anticipated that the other personnel involved including the N.J.I.C. dressers, hose-reel attendants will operate the same rota but obviously some overlap will be required to avoid periods of non-attendance.

The composition of the initial entry team will be as follows:-

(a)	Console	- 1 Assistant Charge Engineer as Controller 1 Grade 9 Engineer for isolations and permit to work requirements 1 Grade 10X Engineer responsible for communications and logging personnel in and out of vessel.
(b)	Clean-conditions tent	- 2 change room attendants responsible for dressing/undressing Vessel entrants and logging material in and out of Vessel. The duties of the C.R.A.'s are given in Appendix 4.
(c)	124' Pile Cap Gantry	- 2 hose reel attendants.

(d)/.....

.5 (Cont'd.)

i) Vessel entry team - 1 - a Health Physicist
2 -)representatives from Station Operations &
3 -)Maintenance N.J.B. staff, Board Headquarters
4 -)Metallurgists, TNPG and CEGB.

. Vessel entry team will report to the Controller at Console, hand over edical certificate, receive instructions and proceed to clean-conditions ent (it is assumed that the team have carried out the correct procedures eading up to arrival on Pile Cap - see Figure 4).

. Don air-cooled suits, outer coveralls, safety harness, boots, gloves nd communication head sets.

. Check air supply to suit and communication to Console under the ssistance of change room attendants and Assistant Controller.

. Log health physics instruments, noise level instrument, hand torch, O_2 detector, thermometer (attached by lanyard to the Health Physicist) and ools required for access.

. 4 man entry team proceed through tent to the area round penetration. t this stage the Assistant Controller will conduct a final check of ommunications with both team and hose reel attendants.

. 1st and 2nd men descend to the annular platform at the 77' level using afety line. During the descent, the 2nd man will secure the ladder. adiation and temperature readings will be taken at approximately 10' ntervals during the descent. CO_2 detectors and noise level instrument owered down.

. Health Physics survey for radiation, CO_2, temperature and noise will e carried out on the annular platform.

. 3rd and 4th men descend to the annular platform at the 77' level using afety line and supervise the lowering by air hoist of the lighting equipment, upport beam, 2nd air hoist, 2nd safety line, tools for opening up hatches nd spare air-line for emergency purposes.

0. 3rd and 4th men install lighting around annular platform and selected heesepiece.

1. 1st, 2nd and 3rd men carry support beam plus gear to selected cheese-iece and 4th man ensures that no problems exist with the air lines.

2. 2nd and 3rd men fix support beam and attach air hoist and safety line.

3. 1st and 2nd men, using safety line, descend one at a time to the latform in cheesepiece at 73' level, 3rd man positions himself at top of heesepiece (79' level). Radiation, CO_2 and noise instruments lowered down.

4. 2nd man opens hatch at 73' level. Lighting and safety line lowered to 3' level. Radiation, CO_2, temperature and noise measurements taken.

5. 1st man descends to 63' level, instruments again lowered down. adiation, CO_2, temperature and noise measurements taken.

6. 2nd man descends to 63' level. 3rd man is still positioned at 79' evel watching progress, 4th man on annular walkway ensuring that the air-ines are being paid out properly.

5.5 (Cont'd.)

17. 2nd man opens hatch. Lighting and safety line lowered through to 42' level.

18. 1st man descends to 42' level, instruments again lowered down. Radiation, CO_2, temperature and noise measurements taken.

19. 2nd man descends to 42' level and opens hatch. Lighting and safety line lowered to the vault floor.

20. 1st man descends to vault floor. Instruments lowered. 2nd man descends to vault floor. Both men can now unclip from safety line.

22. Radiation, CO_2, temperature and noise measurements taken in quadrant. CO_2 detector left on vault floor beneath the selected cheesepiece.

23. For withdrawal, 4th man places himself beneath 270° access ladder on annular walkway i.e. to reform the chain for removal of air lines. 1st and 2nd men clip on to safety line and one at a time ascend to 79' level using the same ladder as was used for descent. Spare air-line and CO_2 detector left in vault. Radiation and noise instruments pulled up to 79' level by 3rd man. Hatches are left open and lighting left in situ. Tools not required for future inspection surveys are withdrawn up to 79' level.

24. 1st and 2nd men on reaching 79' level unclip from safety line. 1st, 2nd and 3rd men traverse round annular platform to position of 4th man, bringing the already mentioned instruments and tools.

25. All personnel plus instruments and tools are withdrawn from the vessel one at a time and using safety lines.

26. Sanction to Survey cancelled.

27. Health Physics certificate issued.

28. PTW issued for inspection purposes.

5.6 Vessel Entry for Familiarity with Access and Inspection Equipment

Access will be made to the following areas:-

1) above the gas baffle
2) boiler interstitial spaces
3) gas circulator inlet plenum area.

Appendix 5 lists the probable details for inspection by both visual and photographic means.

Each inspection team will again consist of 4 personnel, one will be a Health Physicist and the remainder will be selected from the various departments given in 5.5.1.

One of the 4 in each team will volunteer to climb out of the Vessel from the vault area near the end of the 2 hour entry with his air supply cut off by a valve conveniently placed for the person himself to reconnect the air if he so desires. Also, he will be accompanied by a team-mate throughout the ascent.

1. As per 5.5.2.

2. As per 5.5.3.

3./.....

5.6 (Cont'd.)

3. As per 5.5.4.

4. Log radiation instrument, tools and inspection equipment i.e. photographic and T.V. cameras.

5. As per 5.5.6.

6. 1st and 2nd men descend access ladder one at a time using safety line to annular platform. 3rd and 4th men then lower down radiation instrument, tools, T.V. and photographic equipment and datum reference jig to the 77' level.

7. 3rd and 4th men then descend one at a time to the 77' level using the safety line.

8. 1st, 2nd and 3rd men traverse round to the quadrant to be inspected, 4th man remains below 270° access ladder.

9. 1st and 2nd men descend one at a time between boiler units C1 and C2 to 73' level using safety line.

10. 3rd man remains at 79' level platform to assist with air lines and lowering gear.

11. 1st and 2nd men descend one at a time to 69' level, open inspection cover in boiler. 1st man takes a radiation measurement. 2nd man carries out inspection of boiler tubing and takes photographs. If requested by Controller, remove 2 Caesium -137 collection plates (i.e. jubilee clips fitted onto a support strut on the superheater bank).

12. Close 1st inspection cover and 1st and 2nd men now descend one at a time to 63' level. 2nd boiler inspection cover opened and 5.6.11 above is repeated.

13. Close 2nd inspection cover and descend one at a time down to vault floor, instruments and tools being lowered down by the 2nd man.

14. Inspect vault area for gross damage and take a series of photographs. During steps 5.6.8 and 5.6.13, the 4th man will at the discretion of th e Controller, take T.V. camera shots around the 77' walkway.

15. 3rd man collects T.V. camera from 4th man and lowers it down to the vault floor. 1st and 2nd men then carry out T.V. camera work under the supervision of the Console Controller.

16. 3rd and 4th men using a second camera and datum reference jig take photographs round the annular platform.

17. With 3rd and 4th men again in position on the 79' and 77' levels to form a chain, the T.V. camera and all equipment are raised up from the vault floor.

18. The Controller announces that the emergency signal (flashing of lights) will now be operated as a demonstration. A further announcement will be made informing all concerned that one of the two men (to be named) in the vault area will ascend up to the 77' annular walkway with his air supply cut off.

19./.....

5.6 (Cont'd.)

19. On the order from the Controller, 1st (or 2nd) man closes air supply valve adjacent to his vortex tube but retains communication. He then proceeds up the ladder slowly, attached to the safety line, assisted from above and below by his partner.

20. When 1st and 2nd men reach 77' level, Controller confirms that volunteer is able to continue with or without air.

21. 1st, 2nd and 3rd men traverse round to bottom of 270° access ladder.

22. The volunteer then proceeds up the ladder slowly, attached to the safety line, and assisted by his partner (1st or 2nd).

23. 3rd and 4th men bring T.V. camera, equipment and tools round to bottom of 270° access ladder.

24. 3rd man then ascends ladder, using the safety line. T.V. camera, equipment and tools then follow.

25. Finally 4th man withdraws from vessel using safety line.

5.7 Final Entry and Removal of In-Vessel Equipment

1. As per 5.5.2 — 5.5.4.

2. Log hand torches and tools required for final box-up.

3. 1st and 2nd men descend access ladder one at a time, using safety line, to annular platform at 77' level. 3rd and 4th men then lower gear associate with final entry.

4. 3rd and 4th men descend ladder one at a time using safety line to 77' level.

5. 1st, 2nd and 3rd men traverse round to the appropriate cheesepiece taking gear with them. 4th man remains below access opening.

6. 1st and 2nd men descend ladder to 25' level using safety line. The 3rd man remains at 79' level to assist with airlines, removal of lights, CO_2 detector and spare airline.

7. 1st and 2nd men ascend to 41' level. CO_2 detector and spare airline drawn up to 79' level. Lighting and safety line withdrawn to 41' level.

8. Lower and seal hatch at 41' level.

9. Repeat 5.7.7 and 5.7.8 at 63' level and 73' level, and withdraw to 79' level.

10. Unclip from safety line, remove safety line and hoist from support beam. Finally dismantle and remove support beam.

11. The 1st, 2nd and 3rd men then descend on to the 77' annular platform and traverse round to the 4th man carrying the items mentioned above. Several journeys may be necessary particularly with the lighting.

12. The 1st and 2nd men then ascend, using safety line, one at a time, to the Pile Cap level.

13/.....

5.7 (Cont'd.)

13. All the access gear is then removed from the 77' level by the 'A' frame hoist.

14. When the Assistant Controller confirms that all equipment which has been used in the demonstration programme, has been logged in, the 3rd and 4th men withdraw from the vessel, using the safety line, one at a time.

15. Remove spare air-line from vessel. Disconnect safety line and air hoist from 'A' frame.

5.8 Post Entry Procedure

The withdrawal procedure is shown in Fig. 5. This procedure covers removal of air-cooled suits, contamination check, medical check, de-briefing and changing into normal clothing at the Main Change Room.

When all vessel access personnel have passed out of the clean conditions tent, the P.T.W.(M) for Vessel access and inspection will be cancelled. The temporary covers removed under 5.2.1 will be replaced.

5.9 Dismantling of Vessel Access Equipment

1. Shut down the Breathing Air Compressors and disconnect the 40 emergency air bottle system.

2. Disconnect the following from the Control Console:-

a) 2 breathing air system manifolds.

b) Air line reels.

c) Electrical power, control and alarm supplies.

d) Telephone communications.

3. Remove all non-contaminated Health Physics equipment and Vessel Entry ancillary equipment (e.g. First Aid equipment).

4. Dismantle the clean conditions tent and seal the tent lining and framework in polythene.

5. As the above is being implemented, the Health Physics Department will survey the Pile Cap area, including all in-vessel equipment. Contaminated articles will be sealed in polythene bags and despatched to be decontaminated.

6. Using the charge hall crane remove the following items from Pile Cap:-

a) Control Console.

b) Air line reels.

c) 'A' frame.

5.10 Termination of Programme

At the termination of this Vessel Entry Demonstration, the cooling of the vessel will proceed to obtain a vessel temperature of 35°C according to the Half Station Commissioning Programme, under the nominated T.N.P.G. Controller. The two Gas Circulators in C quadrant can be restarted, if required, for further cooling duty.

6. RESPONSIBILITIES

6.1 will be responsible for:-

a) Fitting and removal of all flanges, man-access penetration seals, ladders, etc., as required at the 270° access penetration.

b) On final box-up, security of access penetrations in cheesepiece and reinstatement of temporary cover over 270° access penetration at Pile Cap level.

c) Installation of man-access equipment including control console, clean conditions tent, lighting and communications.

d) Co-ordination of access procedures under this document.

e) Preparation of documents for full dress rehearsal access procedure.

f) Logging of access operations.

g) Co-ordination of TNPG and Contractors' staff during access procedures.

h) Provision of Test Controllers responsible for the progress of access to whom all questions regarding the demonstration programme will be referred.

i) Provision of access teams.

j) Preparation of test reports on the vessel access demonstration programme.

k) The operation of plant and systems taken over for routine operation in accordance with P.I.O.I.'s/S.O.M.'s provided, acting as the authorised agents of T.N.P.G.

l) Chemical sampling of reactor gas if required.

m) Routine maintenance of plant taken over for routine operation in accordance with the P.I.M.I.'s or manufacturer's information provided.

6.2 Commissioning Department will be responsible for:-

a) Arranging vessel cooling, blowdown and other systems to give in-vessel conditions required for the start of this demonstration.

b) Provide a member of staff to liaise with SSEB controller during the demonstration programme.

c) Safety and security on completion of this programme after cancellation of Vessel entry P.T.W.

6.3 Construction Department will be responsible for:-

a) Make available reactor ancillay equipment, i.e. pile cap crane and driver.

7. SAFETY ASPECTS

7.1 General

All personnel entering the vessel during this demonstration programme will have initially been passed medically fit for hot environmental work and in addition will have to be certified fit by the Medical Department on the day of entry.

7.2 Equipment

A complete list of the First Aid Equipment placed at Pile Cap is given in Appendix 1. Additional in-vessel safety equipment is listed below:-

a) 1 x $\frac{1}{2}$ Ton safety hoist attached to 'A' frame above access penetration. (This will also be used to raise and lower equipment).

b) Everest safety line attached to 'A' frame.

c) Support beam over cheesepiece.

d) 1 $\frac{1}{2}$ $\frac{1}{4}$ Ton safety hoist attached to support beam. A spare hoist will be available at Pile Cap level.

e) Everest safety line attached to support beam.

f) All entrants will wear a safety harness with attached safety anchor.

g) An additional air-line lowered down to vault area.

7.3 Temperature

Vessel air temperature will be maintained at a level no greater than 60°C by circulating water through the boilers. The temperature above the gas baffle dome will be continuously logged when personnel are in the vessel.

7.4 Communications

1. All personnel inside the vessel will be in direct communication with the vessel controllers at the Console at all times.

2. Direct communication from Console to:- a) C.C.R. b) Compressor Station.

7.5 Noise

Ear defenders are incorporated in the communication headsets, and will reduce the background noise level by at least 25 dB(A).

7.6 Carbon Dioxide

1. CO_2 concentration of the vessel atmosphere will be measured prior to and continuously during all entries by external sampling.

2. CO_2 detectors will be placed at strategic points within the vessel.

7.7 Breathing Air System

1. Breathing air system including the 40 emergency air bottle system will be in service, the latter auto cut-in will have been checked prior to 1st entry.

2. One operator will be on duty at the compressor station during all entries.

7.8/.....

7.8 Nuclear

Fuel loading will commence in R3 in Event 24 in the Half Station Commissioning Programme. Although there will be no radiation or contamination hazard to the vessel entrants in this demonstration, all the normal radiation/contamination precautions will take place:-

a) all entrants will wear a film badge and other dosimeters.

b) initial entry will be mainly a Health Physics survey.

c) all subsequent entries will include a Health Physicist in the team.

8. REFERENCES

1. Half Station Commissioning Programme C24.04.9.70.01.

2. Reactor Vessel Testing P.O.P. C24.04.9.31.02.

3. Reactor Vessel Temperature, Pressure and Moisture Control, Clean-up and Thermal Movements C24.04.9.32.02.03.

4. Vessel Inspection C24.04.9.32.02.01

5. Reactor Vessel Access for Commissioning Purposes C24.04.9.32.02.08.

6. Atmospheric and Pressurised Noise Measurements C24.04.9.32.02.05.

7. Reactor Shutdown Equipment C24.04.9.22.01.01.

8. Vessel Access Demonstration - Cold Run C24.04.9.32.02.09 Part 3.

9. <u>APPENDICES</u>

1. First Aid and Safety Equipment.
2. Health Physics Equipment.
3. Control Console Connections.
4. Duties of Change Room Attendant (C.R.A.).
5. Vessel Internal Inspection Schedule.
6. Permit-to-Work (P.T.W.) and Isolations.
7. Permit-to-Work (P.T.W.) Procedures.
8. Personnel Shift Cover During Entry.

10. DIAGRAMS AND DRAWINGS

1. Relevant section of revised Half Station Commissioning Programme.

2. Man Access routes within the Main Pressure Vessel.

3. General Layout of Vessel Access Equipment at Pile Cap.

4. Inspection Party - Entry Procedure.

5. Inspection Party - Withdrawal Procedure.

APPENDIX 1

SAFETY EQUIPMENT INVENTORY

1.	In-Vessel	Number
	$\frac{1}{4}$ ton hoist	1
	$\frac{1}{2}$ ton hoist	1
	Support beam	1
	Safety lines	2
2.	First Aid Equipment	
	Ordinary Stretcher	1
	Neil Robertson Stretcher	1
	Safety line	3
	Automan	1
	Oxygen cylinder	2
	Air-cooled suit, including full in-vessel gear	1
	Hamper containing bandages splints (air-cushioned) blankets elastoplast scissors	1

APPENDIX 2

HEALTH PHYSICS EQUIPMENT INVENTORY

Beaufort Air-Cooled Suits - L	6	- Air	2
- M	6	- Trit	
Vortex Tubes	12		
Vortex Tube Belt holder	12	Batteries - spare U11	24
Cotton Oversuits	24	- spare U2	24
Surgeon's Boots - 6/7	24 prs.	- spare PP9	12
- 8/9	24 prs.	- spare 996	12
- 10/11	12 prs.	Air Sampling Paper	1 Box
Household Gloves - L	24 prs.	Leads (Contam. probe)	6
Household Gloves - M	24 prs.	Plastic Bags - L	12
		Plastic Bags - M	24
Leather Gloves - L	12 prs.	Plastic Bags - S	24
Leather Gloves - M	12 prs.	Paper Tissues	12
Cotton Gloves - L	12 prs.	White Tape	6
Cotton Gloves - M	12 prs.	Cellotape	3
Communication Headsets	12	Antidim	3
Safety Harness & Anchor	12	Storage Bins & Lids	12
Safety Ropes	6	Boot Barrier 3 ft.	2
Cupboards	2	Table	1
Thermometer & Lanyards	6	Benches	2
Torches & Lanyards	6	Chairs	3
Hammers	3	Hosereels	8
Spanners	3	Couplings	16
Rope (60')		Jubilee Clips	6
Instruments - 0030	3	Screwdrivers	3
- RM2 + BP4	3	Equipment Log Book	1
- CO_2			

APPENDIX 3

CONNECTIONS TO CONTROL CONSOLE

APPENDIX 4

DUTIES OF CHANGE ROOM ATTENDANTS

1. Stock Tent

After the erection of the tent by M.M.D. personnel of SSEB, the inside of the tent will be furnished by 2 change room attendants in the manner shown in Figure 3.

A complete list of Health Physics Equipment is given in Appendix 2. All these items will be obtained by the 2 C.R.A.'s and arranged inside the tent.

Similarly the safety equipment as listed in Appendix 1 will be positioned on the Pile Cap as shown in Figure 3.

2. Vessel Entry Equipment Check

a) Check all communication systems using master control switch on Console.

b) Test air-cooled suits on air-flow test rig.

3. Dress/Undress Entry Teams

Further communication, air flow checks will be carried out during the dressing procedure.

4. Log Entry Equipment

A C.R.A. will be responsible for the logging of entry tools and instruments taken into the Vessel.

5. Removal of Dirty Clothing

At the end of each entry session, the C.R.A. will return all dirty clothing to the laundry and replenish with clean items.

The above list is a summary of the duties. Full details will be given in a Departmental Instruction.

APPENDIX 5

VISUAL PHOTOGRAPHIC AND T.V.

1. Gas Baffle

Doubler plates, shrouds, boiler beam support hangers.
Lower cylinder supports to boiler shield wall.
P.V. insulation termination rig.

2. Boiler Unit

Casings (corner fillet welds), supports (welds, pins and links) gas seals, headers, tube bends, 9% chrome hanger shrouds and T_1 gas pipework.

3. Boiler Unit Supports

Outboard end of boiler support hanger beams and suspension arrangements.

4. Boiler Feed Penetration

Welds.

5. Decay Heat Inlet and Outlet Penetration

Welds.

6. Decay Heat Manifold within P.V.

Welds.

7. Superheater Penetration

Welds.

8. Reheater Hangers

Welds.

9. Vault

Quadrant division plate assemblies and seals.

10. Insulation

P.V. liner, gas baffle.

11. Gas Clean Up Circuit Pipework

Bellows assemblies on the inlet and outlet pipework.

APPENDIX 6

PERMIT-TO-WORK (P.T./W) SYSTEM AND ISOLATIONS

1. The P.T.W. is given in Appendix 7.

2. During the reactor vessel cooling and depressurisation, (Fig. 1, Item 18) the CO_2 distribution system will be isolated and depressurised where appliaable. The following valves will be isolated:-

R3/G/1		R3/CO_2/97
R3/G/2		R3/CO_2/977
R3/G/5		R3/CO_2/103
R3/G/6		R3/CO_2/107
R3/G/9		R3/CO_2/109
R3/G/10		R3/CO_2/110
R3/G/67	(BCD purge)	R3/CO_2/124 + another
R3/G/88	(R.T.V. CO_2 supply)	R3/CO_2/153
	(flux scanning)	R3/CO_2/156 + another

For blowdown purposes, the following valves will be left available:-

(i) For temperatures above 200°C (Iodine Adsorption Filter limitations).

R3/G/1	R3/G/10 (closed)
R3/G/6	R3/G/88
R3/G/9 not necessary if bypass pipework available.	

(ii) For temperatures below 200°C, the valves R3/G/10 and R3/G/88 are required for blowdown and purging requirements.

3. The autoclave system will be isolated (or blocked off) details not yet available.

4. Charge m/c down shop leads isolated via the interlock system (R3).

5. The nitrogen injection lines will be isolated (1½" N.B. and 3" N.B.). Valve references will be given at a later date.

6. To avoid any release of CO_2 into R4 pressure vessel, the following construction blanking plates will be fitted:-

(i) Standby filling line upstream of valve R4/CO_2/110.

(ii) R4 circulator gland supply line downstream of valve R4/CO_2/107.

(iii) Inlet to bypass pipework, R4, upstream of valve R4/CO_2/98.

(iv) Inlet to emergency iodine adsorption filter 3B, R4 side, upstream of valve R4/G/67.

(v) Blowdown side of dryer post filter 4, upstream of valve R4/G/88

(vi) 20.7 bar (300 psig) services supply line to R4 maintenance purge station downstream of valve R4/CO_2/133.

NOTE/.....

NOTE: The position of this blanking point has to be identified. Additional isolation may be required depending on above.

(vii) On $1\frac{1}{2}$" N.B. nitrogen, injection line upstream of tee into R4 circulator gland supply line.

(viii) Oxygen and methane inlets to the recombination unit upstream of valves $R4/O_2/8$ and $R4/CH_4/5$.

7. Additional isolations may be required depending upon the state of the plant and commissioning requirements. A more detailed list of isolations will be made available at a date prior to the vessel entry programme.

8. Breathing Air System - the supply isolating valves to the services of this system will be locked shut.

( ) CO_2 DISTRIBUTION SYSTEM ISOLATED / REACTOR VESSEL DEPRESSURISED, TEMP. 60°C → ( ) CO_2 SURVEY OF MAN ACCESS PENETRATION → ( ) ISSUE P.T.W.(M) TO REMOVE PRIMARY CLOSURE PLATE & INSULATION SLEEVE → ( ) REMOVE PRIMARY CLOSURE PLATE AND INSULATION SLEEVE → ( )

( ) CANCEL P.T.W.(M) AFTER CLOSURE PLATE AND INSULATION SLEEVE REMOVAL → ( ) PURGE REACTOR VESSEL TO GIVE A CO_2 CONCENTRATION LESS THAN 0.5% → ( ) STABILISE TEMP. AT 60°C → ( )

INSTALL SAFETY RAILS → ( ) ISSUE P.T.W.(M) TO ERECT VESSEL ACCESS EQUIPMENT → ( ) ERECT VESSEL ACCESS EQUIPMENT → ( ) CANCEL P.T.W.(M) AFTER ACCESS EQUIP'T ERECTION → ( ) COMPLETE BLOWDOWN SYSTEM ISOLATION

( ) ISSUE H.P. SANCTION TO SURVEY (ACCESS ROUTE) → ( ) H.P. SURVEY OF ACCESS ROUTE → ( ) ISSUE H.P. CERTIFICATE → ( ) ISSUE P.T.W.(M) FOR MAINTENANCE AND INSPECTION PURPOSES → ( ) VESSEL ENTRY DEMONSTRATION → ( )

( ) CANCEL P.T.W.(M) AFTER DEMONSTRATION → ( )

PERMIT-TO-WORK PROCEDURE

APPENDIX 7

APPENDIX 8

PERSONNEL SHIFT COVER DURING ENTRY

In order to provide a standby team of 4 men, ready at all times when there is a team in the vessel, the following shifts will be worked to provide a 4 hour overlap. Each shift will comprise 4 men and starting and finishing times for a 24 hour period are shown below.

hrs.	1200 hrs.	1600 hrs.	2000 hrs.	2400 hrs.	0400 hrs.	0800 hrs.
team In Vessel team Standby	2nd team In Vessel 3rd team Standby	3rd team In Vessel 4th team Standby	4th team In Vessel 5th team Standby	5th team In Vessel 6th team Standby	6th team In Vessel 1st team Standby	

The 2 hour entry period can commence at any time during the 4 hours allowed for entry provided the standby team is fully prepared to cover the entry.

Personnel who are involved (i.e. controller etc.) but are not actually entering vessel will follow the normal shift rota but will have a 1 hour overlap at change of shift.

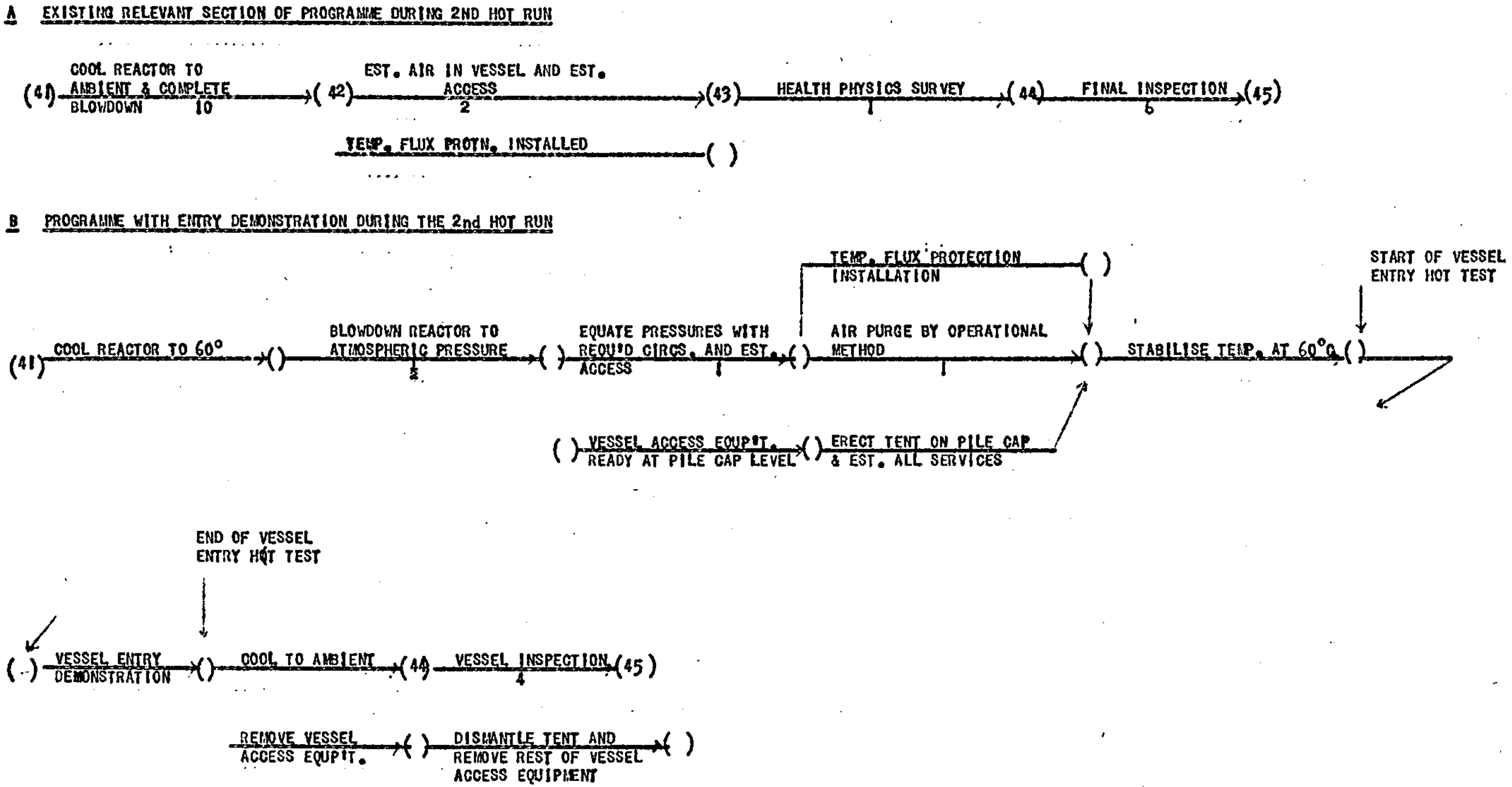
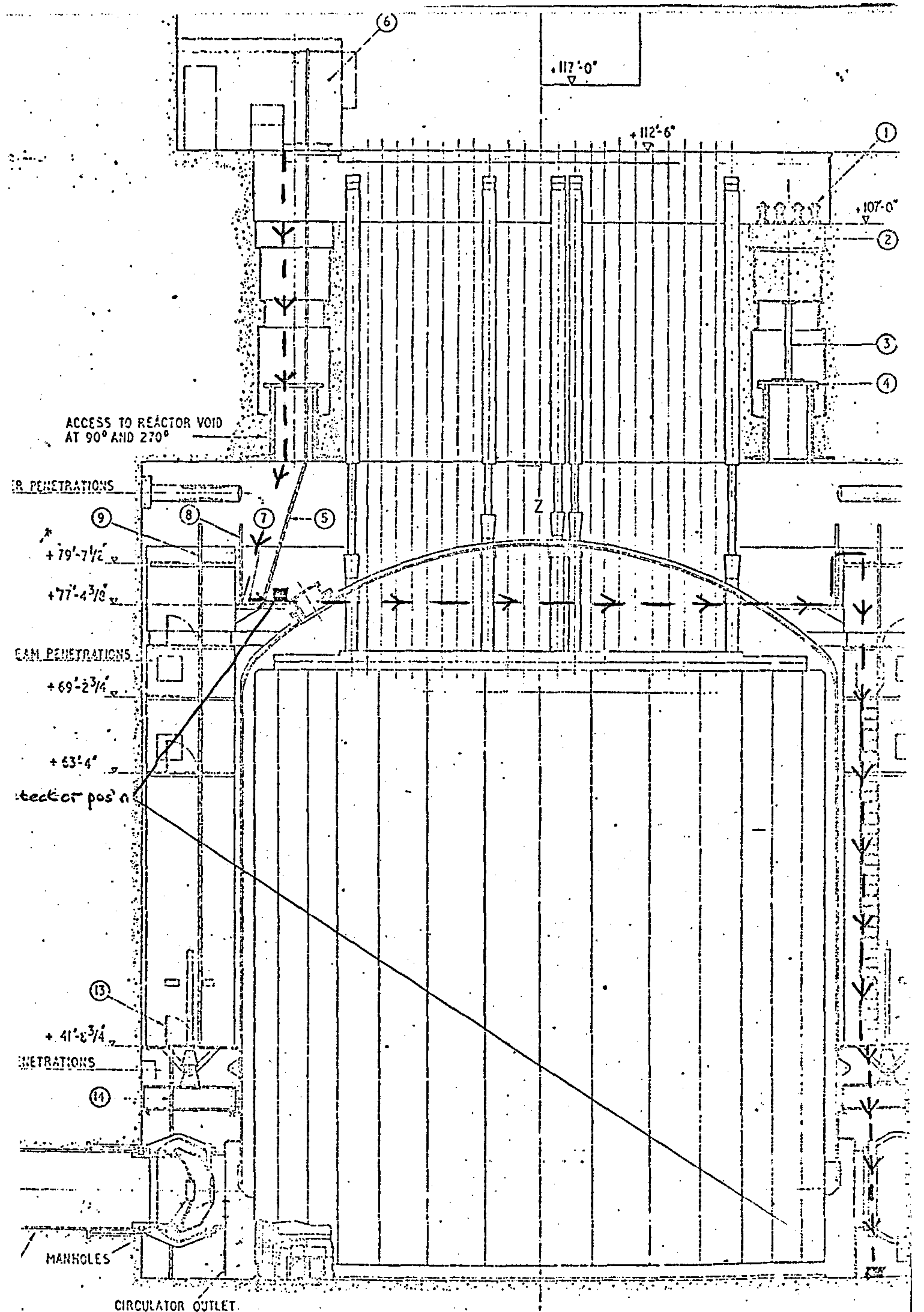

A EXISTING RELEVANT SECTION OF PROGRAMME DURING 2ND HOT RUN
(41)
COOL REACTOR TO AMBIENT & COMPLETE BLOWDOWN
10
(42)
EST. AIR IN VESSEL AND EST. ACCESS
2
(43)
HEALTH PHYSICS SURVEY
1
(44)
FINAL INSPECTION
6
(45)
TEMP. FLUX PROTN. INSTALLED
( )
B PROGRAMME WITH ENTRY DEMONSTRATION DURING THE 2nd HOT RUN
(41)
COOL REACTOR TO 60°
( )
BLOWDOWN REACTOR TO ATMOSPHERIC PRESSURE
( )
EQUATE PRESSURES WITH REQU'D CIRCS. AND EST. ACCESS
1
( )
TEMP. FLUX PROTECTION INSTALLATION
( )
AIR PURGE BY OPERATIONAL METHOD
1
( )
STABILISE TEMP. AT 60°C
( )
START OF VESSEL ENTRY HOT TEST
( )
VESSEL ACCESS EQUP'T. READY AT PILE CAP LEVEL
( )
ERECT TENT ON PILE CAP & EST. ALL SERVICES
END OF VESSEL ENTRY HOT TEST
( )
VESSEL ENTRY DEMONSTRATION
( )
COOL TO AMBIENT
(44)
VESSEL INSPECTION
4
(45)
REMOVE VESSEL ACCESS EQUP'T.
( )
DISMANTLE TENT AND REMOVE REST OF VESSEL ACCESS EQUIPMENT
( )

FIGURE 1



SECTIONAL ELEVATION ON 'X X'
(CIRCULATORS SHOWN OFF TRUE CENTRES)

Fig 2

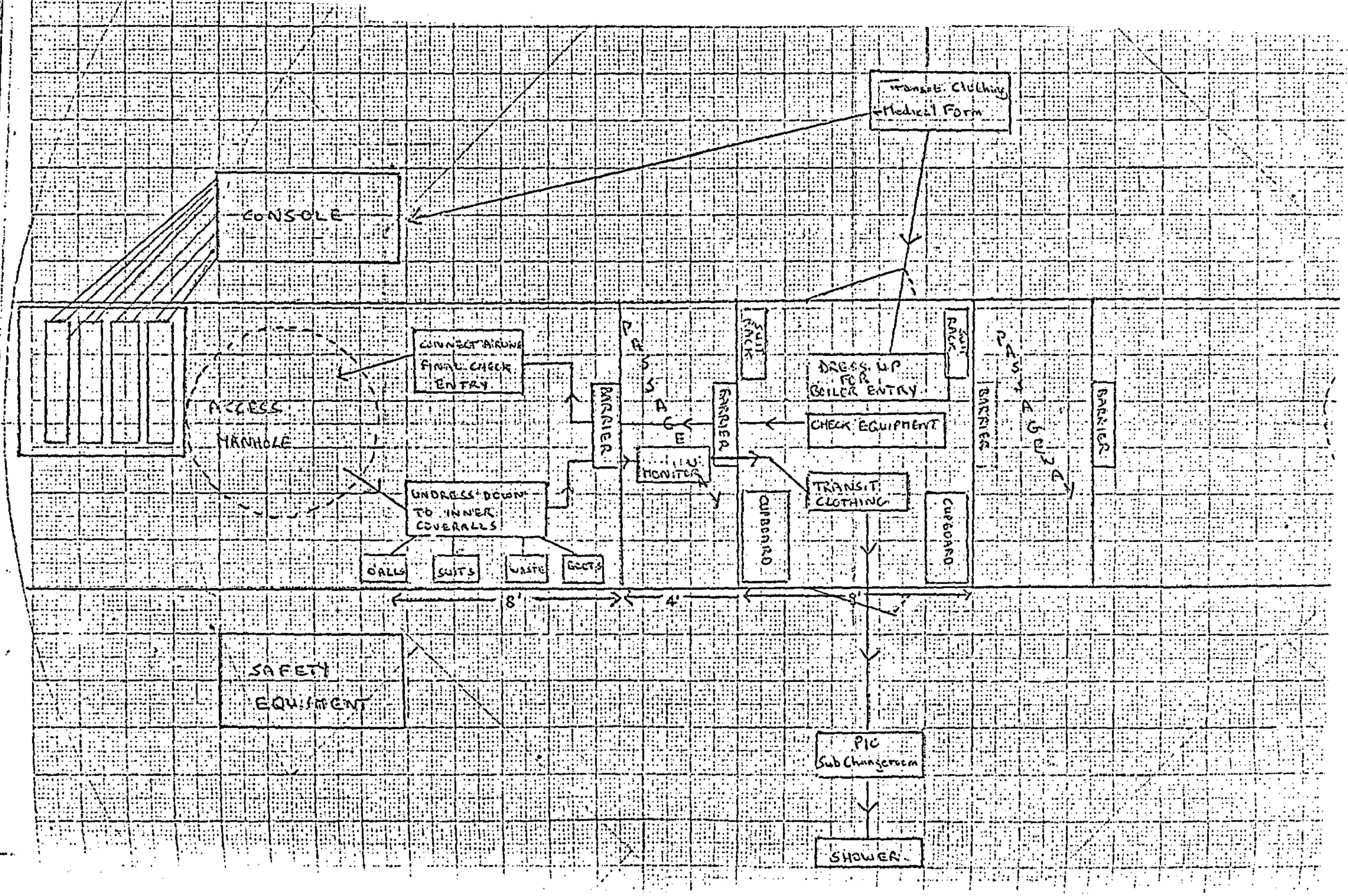

Transit Clothing
Medical Form
CONSOLE
CONNECT AIRLINE
FINAL CHECK
ENTRY
ACCESS
MANHOLE
BARRIER
PASSAGE
BARRIER
SUIT RACK
DRESS UP FOR BOILER ENTRY
SUIT RACK
CHECK EQUIPMENT
BARRIER
PASSAGEWAY
BARRIER
MONITOR
TRANSIT CLOTHING
CUPBOARD
CUPBOARD
UNDRESS DOWN TO INNER COVERALLS
OALLS
SUITS
WASTE
BOOTS
8'
4'
8'
SAFETY EQUIPMENT
PIC
Sub Changeroom
SHOWER

FIGURE 4

INSPECTION PARTY - ENTRY PROCEDURE

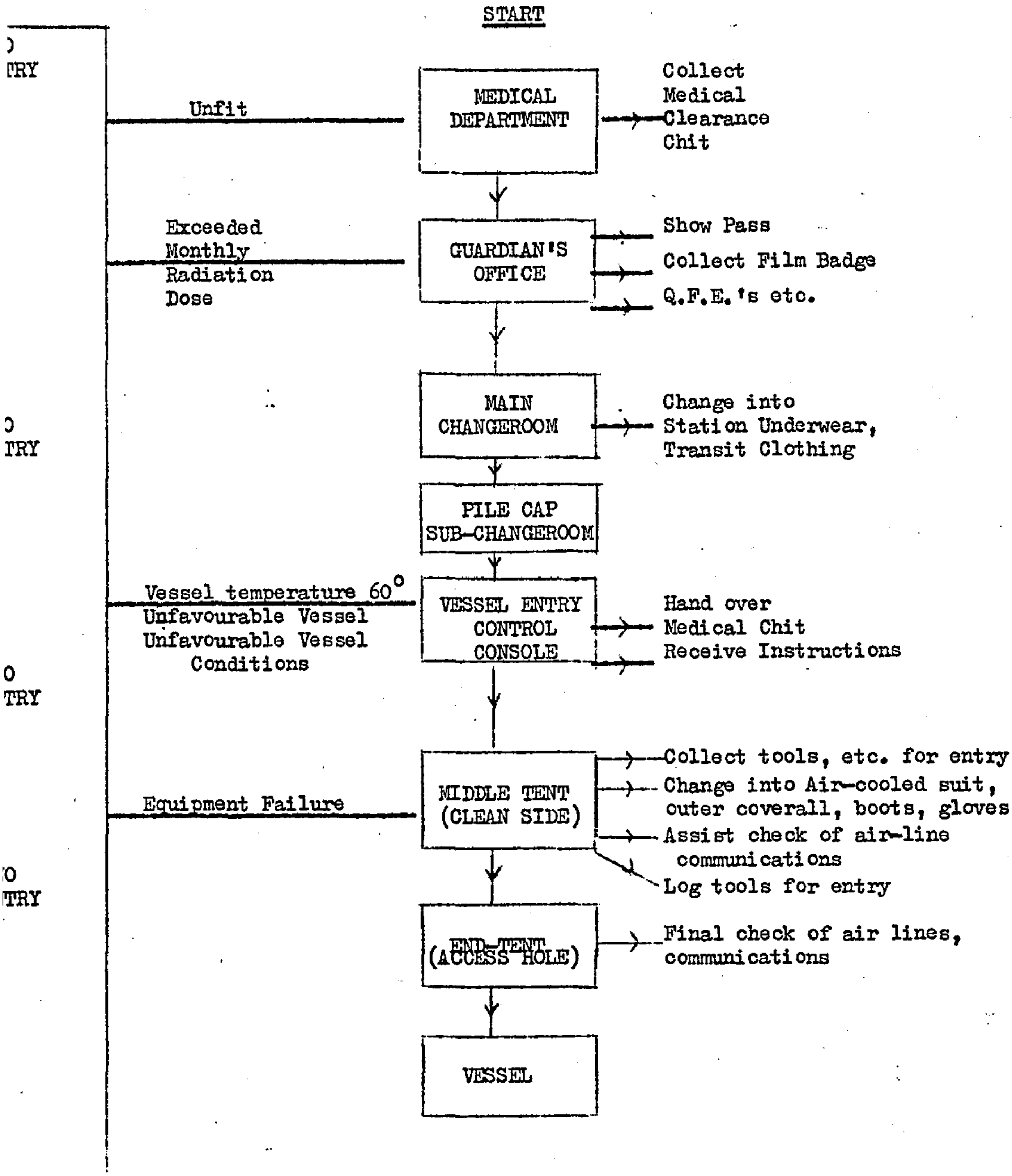


FIGURE 5

INSPECTION PARTY - WITHDRAWAL PROCEDURE

VESSEL

↓

END-TENT (ACCESS HOLE)
- → Remove outer gloves, disconnect air-line, communications
- → Remove outer coverall, air-cooled suit to ankles
- → Sit on barrier, remove boots, outer coveralls, air-cooled suit, inner gloves, helmet, ear phones

↓

PASSAGEWAY
- → Don overshoes
- → Contamination check by probe

↓

E: withdrawal from the sel will be under the troller's command, each rant identified by oured air-lines. Small ms of equipment will be hdrawn by rope.

MIDDLE-TENT (CLEAN SIDE)
- → Remove inner coverall
- → Don transit clothing

↓

VESSEL ENTRY CONTROL CONSOLE
- → De-briefing
- → Medical Check
- → Record entry time and QFE radiation dose

↓

PILE CAP SUB-CHANGEROOM
- → Take salt tablets, refreshment

↓

MAIN CHANGEROOM
- → Shower, dress into normal clothing

↓

GUARDIAN'S OFFICE
- → Hand in Film Badge, QFE etc.

1 INTRODUCTION

As detailed in "Vessel Access Demonstration - Cold Run C24.04.9.32.02.09 Part 3" following vessel access training in the 'A' Station Turbine Hall Hot Box and the C.M.M.B. Rehearsal Facility and prior to the Reactor Hot Access Entry, Cold Access Demonstrations would be carried out. It was programmed that several entries would be made, the first entry team installing lighting, support beams, safety lines, etc. and establishing the access route to the sub-boiler annulus with subsequent teams carrying out inspection duties with T.V. cameras and visual inspection of boiler tubes, etc. Each team will spend not more than two hours in the vessel and at the end of each entry period will carry out an emergency procedure.

Three man-access demonstrations under cool conditions were held in Reactor 4 prior to the first Hot run man-access programme in September 1975.

2 OBJECTS OF THE DEMONSTRATIONS

The purpose of each of these rehearsals was threefold:-

(i) to familiarise the entry team with the access equipment and its use in the vessel environment.

(ii) to prove the adopted procedures for the vessel entry and, in particular, the actions that must be followed under emergency conditions.

(iii) to assess the time involved in assembling and dismantling equipment on the Pile Cap and Vessel internals, and also in cocomplishing each stage in the entry.

3 DATES OF THE COLD MAN-ACCESS DEMONSTRATIONS

(i) 10 - 12 May, 1975, 8 teams, 1 entry per team

(ii) 19 - 20 July, 1975, 2 teams, 2 entries per team

(iii) 2 - 4 September, 1975, 3 teams, 2 entries per team

4 TEAM SELECTION

All members were examined by the Board's Medical Officer and cleared for work in hot environmental conditions.

The final selection of teams was based simply on availability. Holidays and 'A' Station Overhaul commitments considerably reduced the number of teams for the 2nd and 3rd demonstrations.

A list of entry team members is given in Appendix 1.

Initially a team consisted of four men, all of whom entered the vessel, and the Controller, two standby men, Hoist Operator and Hose Reel Attendant were supplied from personnel available from the other entry teams. However it was decided that the Controller must be a member of the team and the team strength was increased to five to account for this, a team now consisting of a Controller plus four Entry Men. Again the two Standby men, Hoist Operator, and Hose Reel Attendant were supplied from personnel of the other entry teams.

5 MAN-ACCESS ROUTE

The man-access route is shown in Fig. 1 and the method of entry outlined in C.T.S. C24.04.9.32.02.09 Part 3.

For/

5 MAN-ACCESS ROUTE (Cont'd)

For each entry team, the main objective was for 2 of the 4 man team to ope the hatches down a boiler interspace and reach the sub-boilers annulus (25 with the remaining 2 at the 77' level assisting with movement of airlines. maximum time allocated for each entry was set at 2 hours and it was antici that when teams had become familiar enough with the procedures, a period w this timescale would be set aside for carrying out one of the emergency pr

6 STATE OF PLANT

Access to the R4 Vessel was through the man-access penetration on the Pile at 270°, the 90° penetration being used by T.N.P.G. Contractors. No arra were made for a demonstration of the removal of the shield plug, impact sl thermal insulation plug and access manhole cover and provision must be mad the inclusion of this important procedure at some later date.

(i) Clean Conditions Tent and 'A' Frame

The layout of flooring across the Pile Cap for the 1st demonstration was n completed in time for erection of the clean conditions tent, though, on th hand, it was not then appreciated that the tent erection would require 30 of work. When eventually erected, it was found that the tent structure r more strengthening than the design had allowed for.

The portable 'A' frame above the man-access penetration was not available initially and then found to be of insufficient height for removal of a cas

(ii) Compressed Brething Air System

The air system was fully checked prior to the tests and moisture and oil contamination levels monitored.

The emergency air bottle bank was not available.

(iii) Telephone Communications

A telephone was installed at the Console.

(iv) Control Console

The Control Console was sited on the S-W Stressing Gallery Roof. Electri circuitry modifications were completed in time.

(v) Electrical Power Supplies at Pile Cap Level

Completed in time.

(vi) Main and Pile Cap Changerooms

Were not required for the tests.

(vii) Pile Cap Crane, Slings and Lifting Equipment

The 2 ton hoist was available and used in place of the 'A' frame for some tests.

Pile Cap crane was not available for transferring the hose-reel drum frame

(viii)/...

6 STATE OF PLANT (Cont'd)

(viii) Temporary Access Ladders

A wooden ladder was used in the 1st test as part of the access penetration ladder Thereafter, a 2-section metal ladder was used.

(ix) In-Vessel Lighting

Normal construction in-vessel lighting used for the 1st two tests, thereafter boosted by the vessel entry portable lighting.

(x) Air-Cooled Suits, etc.

Sufficient stocks of all items of protective clothing plus safety equipment were available in time.

(xi) Hose-Reel Drum and Airlines

The hose reels were sited on the S-W Stressing Gallery Roof near the Control Console. The minimum number for the tests were made available.

(xii) CO_2 Monitoring Equipment

CO_2 measurements were not required.

7 SUMMARY OF TESTS

Only brief details of each entry are given, including time to reach 25' level and total entry time, and any serious equipment failures or incidents. Details of Emergency Exercises carried out are given in Appendix 2.

(i) 10 - 12 May 1975

The final decision to start the test was given on the 9 May following a 2-man entry down to the sub-boiler annulus witnessed by the Board's Medical and Safety Officer.

Subsequently, seven of the eight programmed 4-man teams entered the pressure vessel and carried out brief inspection exercises along the entire route. Frequent faults in the communications system hampered the progress of all the entry teams and prevented one team from entering. Because of these difficulties, emergency procedures were not carried out.

1st Entry: Time taken for two men to reach the 25' level was 58 minutes. Total time for entry was 2 hours 7 minutes.

2nd Entry: Time to reach 25' level was 57 minutes and total time was 1 hour 26 minutes.

3rd Entry: Cancelled due to communications problems.

4th Entry: Time to reach 25' level was 40 minutes and total time was 1 hour 7 minutes.

5th Entry: Time to reach 25' level was 40 minutes and total time was 1 hour 15 minutes.

6th Entry:/...

7 SUMMARY OF TESTS (Cont'd)

6th Entry: Time to reach 25' level was 46 minutes and total time was 1 hour 26 minutes.

7th Entry: Time to reach 25' level was 40 minutes and total time was 1 hour 50 minutes.

8th Entry: Time to reach 25' level was 37 minutes and total time was 1 hour 54 minutes.

(ii) 19 - 20 July 1975

The four programmed four-man team entries were carried out and emergency proc were rehearsed on three of these entries.

1st Entry: Bottom hatch was not opened due to communications difficulties, total time was 1 hour 28 minutes.

2nd Entry: Time to reach 25' level was 35 minutes and total time was 1 hour 31 minutes. An emergency exit due to loss of air was rehearsed two men and difficulties were encountered with airlines and safe line becoming entangled.

3rd Entry: Time to reach 25' level was 34 minutes and total time was 1 hour 45 minutes. An emergency exit due to loss of communications wa rehearsed and no problems were encountered.

4th Entry: Time to reach 25' level was 17 minutes (as all equipment was in position and all manholes were open) and total time was 1 hour 4 minutes. The removal of a casualty was successfully rehearsed, the total time taken for this exercise was one hour.

(iii) 2 - 4 September 1975

The six programmed four-man team entries were carried out. Due to communica and other difficulties emergency procedures were only rehearsed on two entrie

1st Entry: Time to reach 25' level was 70 minutes and total time was 1 hour 53 minutes. The loss of air to one man was rehearsed successfu

2nd Entry: Time to reach 25' level was 32 minutes and total time was 1 hour 32 minutes.

3rd Entry: Time to reach 25' level was 54 minutes and total time was 1 hour 50 minutes.

4th Entry: Time to reach 25' level was 17 minutes and total time was 1 hour 8 minutes. The removal of a casualty was rehearsed and was not completely successful due to air supply and communications difficulties.

5th Entry: Time to reach 25' level was 40 minutes and total time was 1 hour 21 minutes.

6th Entry: Exercise terminated after 45 minutes due to loss of communicatio

8/...

8 COMMENTS ON TESTS

Numerous equipment faults occurred during these tests and were discussed fully at the combined Debriefing Meeting for the Cold and Hot Access Demonstrations held on the 18 September 1975. The main defects are listed and included as an Appendix to the Hot Access Demonstration Report.

Full details of the Emergency Exercises which were carried out are given in Appendix 2.

The tests showed however that the first two members of the team would reach the 25' level inside the reactor in a time of approximately 40 minutes and this would leave a period of an hour to carry out inspections, etc. without exceeding a total entry time of two hours.

The safety aspect causing the most concern during the Cold Tests was loss of air supply. A back-up air or oxygen system have not yet been selected and ordered and the manufacturers modified helmets, which allow the visor to be removed in an emergency, were not ready in time for the Cold Tests, although they were delivered for the Hot Access Tests. A hasty station modification to the existing helmets did not work dependably and assistance was sometimes required in removing a visor.

9 FUTURE PROGRAMME

Further Cold Access Rehearsals are essential to:-

1) Train additional team personnel in a reactor.

2) Test modifications to the communications system.

3) Test Alterations to the vessel entry equipment.

4) Test the T.V. camera equipment inside a reactor.

5) Prove the bottled air system.

6) Prove additional life support systems.

AJ/MA/7.11.75

APPENDIX 1

ENTRY TEAMS - COLD RUN REHEARSALS

1 1st Cold Run Rehearsals, 10 - 12 May 1975

Team 1
J. Broughton
G. Moore
G. King, Dungeness
P. Woods, Dungeness

Team 2
R. Longhorn
T. McDermott
J. Wilson
B. Gornall

Team 3
C. Owens
W. Watson
P. Brinkley
C. Campbell

Team 4
C. McDonald
C. Campbell
J. Edwards, Hinkley Poin
K. McLeod, Scottish Boil

Team 5
J. Livingstone
A. Johnstone
R. Davies
J. Sydee

Team 6
I. Moodie
J. Frew
K. Staples
I. Maxwell, Hinkley Poin

Team 7
B. Gornall
J. Jackson
J. Scully
A. McMillan

Team 8
P. Wightman
I. Henderson
W. Ruddy
R. Mottram

2 2nd Cold Run Rehearsal, 19 - 20 July 1975

Team 1
C. McDonald
P. Wightman
I. Moodie
J. Smith
K. McLeod, Scottish Boilers

Team 2
J. Broughton
C. Owens
R. Davies
P. Brinkley
A. McMillan

3 3rd Cold Run Rehearsal, 2 - 4 September 1975

Team 1
C. McDonald
C. Owens
P. Brinkley
J. Wilson
J. Jackson

Team 2
P. Wightman
I. Moodie
J. Edwards, Hinkley Poin
I. Maxwell, Hinkley Poin
J. Smith

Team 3
J. Livingstone
R. Davies
K. Staples
I. Henderson
E. Hamilton, Scottish Boilers

APPENDIX 2

EMERGENCY PROCEDURES - COLD RUN REHEARSALS

10 - 12 May 1975

No emergency procedures carried out due to faults in communications.

19 - 20 July 1975

2nd Entry: An emergency exit due to loss of air was rehearsed with two men. On "loss of air" they disconnected their airlines and started to exit from the vessel. The first man reached the boiler walkway without difficulty, but the airlines and safety line became entangled with the second man and he dragged them all with great difficulty to the boiler walkway level, where another team member removed his helmet for him (removeable visors were not available at this time).

3rd Entry: An emergency exit due to loss of communications was rehearsed without any difficulties.

4th Entry: The removal of a casualty was successfully rehearsed. This was carried out according to the written procedure and took one hour to remove the casualty.

2 - 4 September 1975

1st Entry: An emergency exit due to loss of air was rehearsed by one man (with considerable breathing apparatus experience) and no difficulties were encountered.

4th Entry: The removal of a casualty was rehearsed and was not completely successful due to communications difficulties and to the loss of air to one of the team members removing the casualty and the exercise was abandoned when the casualty had been lifted to the boiler walkway level.

1 INTRODUCTION

It was programmed that several entries would be made into the Hot Reactor, the first two entries to install all the equipment and to establish the route and the other entries to carry out inspection procedures. Each team would spend not more than two hours in the vessel and at the end of each entry period would carry out an emergency procedure.

2 OBJECTS OF THE ENTRIES

The purpose of these entries was:-

1. To demonstrate the feasibility of reactor vessel entry and inspection procedures under hot conditions.

2. To gain entry to the sub-boiler annulus on the far side of the vessel.

3. To compare in-vessel air temperature measurements against installed thermocouples.

4. To measure noise levels inside the vessel.

5. To test the vessel entry communications system.

3 DATES OF THE HOT MAN-ACCESS DEMONSTRATION

9 - 11 September 1975 3 teams, 2 entries per team.

4 TEAM SELECTION

Five-man teams as for the Cold man-access on 2 - 4 September 1975, consisting of one Controller and four entry men. Two standby men, hoist and hose reel attendants supplied from other teams. A list of entry team members is given in Appendix 1.

All members had previously been examined by the Board's Medical Officer and cleared for work in hot environmental conditions. In addition all were examined by a Board Doctor immediately prior to and immediately following an entry. All entrants were also fitted with a physiological data recorder.

5 MAN-ACCESS ROUTE

As for Cold access demonstrations. (See Figure 1)

6 STATE OF PLANT

Access to R4 vessel was made through the man-access penetration on the Pile Cap at 270°C. The shield plug, impact sleeve, thermal insulation plug and access manhole cover had already been removed.

All other conditions as C24.04.9.32.02.09 Part 4 3.2 with the exception of:-

ii) Boiler feed pumps not required.

iv) Blowdown system and suction pumps not required.

v) Compressed breathing air system available but not tested.

viii) Only two circulators available.

xii) Main and Pile Cap changerooms not required.

xiii)/...

6 STATE OF PLANT (Cont'd)

xiii) Pile Cap crane not required.

xxiii) CO_2 detectors not required.

7 CHANGES IN EQUIPMENT

The only changes in equipment from the Cold Access Demonstration were:-

1) Martindale Safety Harnesses used.

2) Manufacturer's modified helmets (removeable visor) were available time and were used.

8 SUMMARY OF TESTS

1st Entry: Entry cancelled after 30 minutes due to communications failure All equipment in vessel, but not installed. Vessel temperature 53°C (by installed thermocouples).

2nd Entry: Team reduced to three after 45 minutes due to communications f Total entry time 1 hour 49 minutes. Lighting installed aroun walkway. Noise, temperature and radiation measurements taken, photograp survey; davit and hoist installed. Vessel temperature 57°C Hg in glass thermometer) 54.8°C (by installed thermocouples)

3rd Entry: Team again reduced to three after 45 minutes due to communicat difficulties. Because of limited number of hose reels availa due to faults, no standby personnel were dressed up and hence descent was made down the boiler interspece. Total entry tim 1 hour 11 minutes.

Vessel temperature 60°C (by installed thermocouples).

4th Entry: Photographic and temperature surveys. First man reaches gas level but unable to open hatch. Second man out after 45 minu due to burst hose connection at suit. Remainder of team then drawn. Total entry time 1 hour 1 minute. Vessel temperatur (by installed thermocouples).

5th Entry: Entire route opened up. Two men at 25' level in 35 minutes. of team reach 25' level. Photography, noise and temperature measurements. Total entry time 1 hour 35 minutes. Noise 73 at A2.

Vessel temperature 62.4°C (by installed thermocouples)

6th Entry: Two men reached the 25' level in 25 minutes, then personnel we changed around. Inspection for possible oil spillage. Clos hatches and withdraw lights up interspace. Total entry time 56 minutes. Vessel temperature 62.4°C (by installed thermoco

9 COMMENTS ON TESTS

Again numerous equipment faults occurred during the tests and were similar those encountered during the Cold Run. Only one fault was attributed to t increase in temperature - the failure of the plastic air hose to the hois above the cheesepiece, and this was replaced by a rubber hose, which functi satisfactorily for the remainder of the Hot Run.

Duc/...

9 COMMENTS ON TESTS (Cont'd)

Due to the equipment failures, the 25' level was not reached until the 5th Entry, instead of the 2nd Entry as programmed and consequently the entire Hot Access Programme was drastically curtailed, and no emergency exercises were carried out.

However the tests 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 etc. with a vessel temperature of the order of 60°C, without undue discomfort. Apart from the actual faults which occurred with the equipment, many areas were discovered where the equipment was not ideal for working at these temperatures and a considerable amount of work has still to be done on vessel access equipment before it can be finalised. The vessel access equipment was discussed in detail at the Vessel Entry Debriefing on the Cold and Hot Access Demonstrations on 18 September 1975 and the comments from that meeting are included in Appendix 2.

10 FUTURE PROGRAMME

Further Hot Access Rehearsals are essential to:

1) Train additional team personnel in a Hot Reactor.

2) Test new or modified communications equipment in a Hot Reactor.

3) Test new vessel entry equipment in a Hot Reactor.

4) Prove the bottled air system in a Hot Reactor.

5) Prove the additional life support systems in a Hot Reactor.

6) Prove the T.V. cameras and equipment in a Hot Reactor.

7) Test emergency procedures in a Hot Reactor.

APPENDIX 2

SOUTH OF SCOTLAND ELECTRICITY BOARD

HUNTERSTON NUCLEAR POWER STATION

NOTES ON VESSEL ENTRY DEBRIEFING MEETING ON 18 SEPTEMBER 1975

GENERAL

Almost all the comments made by the Team Members concerned shortcomings in the equipment, apart from the "financial" side of the entries.

EQUIPMENT

Clothing:

Suit	-	More sizes required to fit all personnel. Alteration to convoluted hose to suit new vortex tube position. Safety harness to be built-in.
Helmet	-	Removable visor still not reliable. Possibility of heat reflecting coating on visor (safety aspects? Air flow to helmet must be increased.
Boots	-	Not suitable for 60°C. Air required to feet.
Gloves	-	Not suitable for 60°C. Air required to hands. Must have gauntlets.
Polo Caps	-	Satisfactory, but still not a perfect solution.

Air Supply

Connections	-	All to be improved if possible, and tested before use.
Airlines	-	Suitable, but working near limit of performance. Some hoses damaged but probably 'fair wear and tear' considering the operating conditions.
Vortex tubes	-	Suitable, but need new connectors.
Vortex tube holders	-	To be modified.
Hose reels	-	Improve air supply connection to centre.

Communications

Connections	-	Not dependable.
Amplifier	-	Redesign to prevent overloading or replace.
Throat mikes	-	Not very successful, try other systems.
Headsets	-	Tight fit inside helmet, otherwise suitable.
Hose reels	-	Temporary modification not suitable - redesign.

Safety Equipment, etc./...

EQUIPMENT (Cont'd)

Safety Equipment, etc.

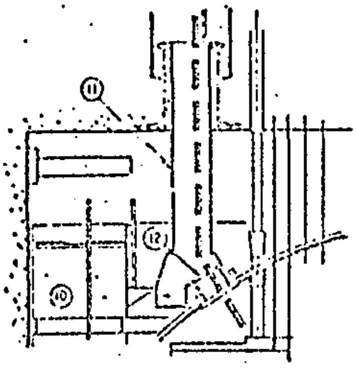
Safety Line	-	Non-stretch line required.
Arrestors	-	Worked satisfactorily.
Harness	-	Martindale harness best to date.
'A' Frame	-	To be redesigned.
Hoists	-	Lighter hoists to be located and purchased.
Vessel Lighting	-	Not suitable, suffered some heat damage.
Torches	-	Search for suitable torches continues.
Secondary Air (or oxygen) supply	-	Still being discussed by Medical and Safety Sub-group.

Standby Team

Control Support Systems	-	To be duplicated for standby team to prevent common fau with entry team.

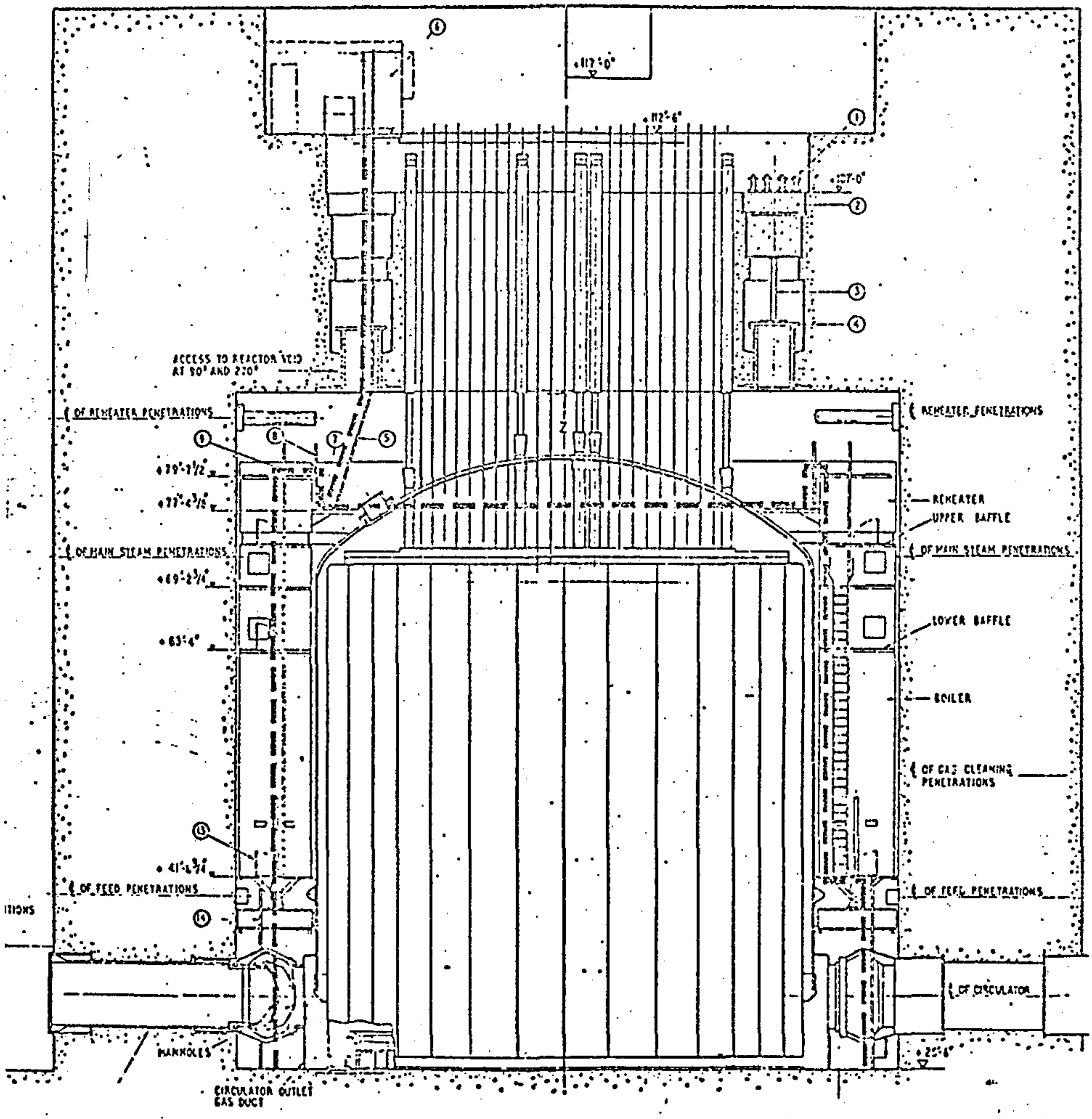
AJ/MA/15.10.75

FIGURE 1



PART SECTIONAL ELEVATION SHOWING ACCESS TO AREA WITHIN GAS BAFFLE DOME

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 DOOR IN BOILER SEALING PLATE
14	ACCESS LADDER



MAN ACCESS ROUTES

MAN ACCESS ROUTES TO, AND WITHIN, THE MAIN PRESSURE CIRCUIT