Study of the physiological effects of wearing breathing apparatus

RG Love, JBG Johnstone, J Crawford, KM Tesh,
RA Graveling, PJ Ritchie, PA Hutchison,
GZ Wetherill

November 1994
IOM Report TM / 94 / 05

Report No. TM/94/05
HOME OFFICE CONTRACT SC/89 42/247/1

INSTITUTE OF OCCUPATIONAL MEDICINE

STUDY OF THE PHYSIOLOGICAL EFFECTS OF WEARING BREATHING APPARATUS

by

RG Love, JBG Johnstone, J Crawford, KM Tesh, RA Graveling,
P Ritchie, PA Hutchison, GZ Wetherill

FINAL REPORT ON HOME OFFICE CONTRACT SC/89 42/247/1

Duration of Project: May 1990 to April 1993

Institute of Occupational Medicine
8 Roxburgh Place
Edinburgh
EH8 9SU

Tel: 031 667 5131
Fax: 031 667 0136

November 1994

CONTENTS

Page

Report No. TM/94/05

INSTITUTE OF OCCUPATIONAL MEDICINE

STUDY OF THE PHYSIOLOGICAL EFFECTS OF WEARING BREATHING APPARATUS

by

RG Love, JBG Johnstone, J Crawford, KM Tesh, RA Graveling, P Ritchie, PA Hutchison, GZ Wetherill

SUMMARY

1. A two stage study of the use of breathing apparatus (BA) in the fire service has: (i) identified areas of task and those particular protective equipment combinations, common to fire brigades, likely to cause problems to firefighters and to require more detailed investigation; (ii) quantified the degree of the effects of different tasks/protective equipment in relation to safe working practice by measuring physiological and subjective performance under conditions simulating severe physical and thermal conditions, as a means of assessing both the physiological effects on firefighters of wearing BA and the adequacy of existing apparatus.

2. The first stage consisted of a questionnaire study of brigades and operational firefighters. An initial set of questions was drawn up and six stations in three brigades were visited (Lothian and Borders, Humberside and Greater Manchester). Structured interviews with senior personnel, including BA training officers, and firefighters were carried out, in order to obtain more detailed information about some of the likely problems associated with particular task/equipment combinations identified by firefighters. These were intended to allow the research team to devise a comprehensive questionnaire on problems associated with donning and using BA during training and operational duties. Every local authority brigade in the UK and over one thousand wholetime operational firefighters were sent questionnaires. Factual information about BA usage and problems associated with use of BA in relation to tasks and other protective equipment was obtained. All brigades responded to their questionnaire and 76.3% of firefighters from one in six stations, selected randomly from all stations in the country, responded to the firefighters' questionnaire.

3. Most (95%) firefighters used BA less than once per week, 31% had worn BA for a toxic substance spillage at least once during the last year and 23% had attended a flammable substance leak, none more frequently than once per week. Only 6% of firefighters had needed to change their BA cylinder on more than twelve occasions in the last year. The most widely used open circuit sets (OCBA) were Draeger P112 (30%), Interspiro Spiromatic (23%), Sabre Centurion (14%) and Siebe Gorman Firefighter 1 and 2 (10% each).

4. Problems with donning and using the sets were reported by users of all types of BA. On average about a quarter of all users reported problems related to the weight and size of the set, difficulty with the facemask seal and visibility and interactions with other protective clothing, such as gastight suits. Problems were also caused by interactions with clothing and other personal items, such as helmets (37%) and gloves (57%). Users of Sabre Centurion sets reported the least number of problems, whereas users of Siebe Gorman Firefighter 1 were most dissatisfied. No information was obtained about the only closed circuit BA (CCBA) in use in the fire service, as none of the stations using it were included in the random selection process.

5. Following discussions with the Fire Research and Development Group of the Home Office, twelve brigades were selected for subsequent physiological studies from those using the four OCBA types in most widespread use. Brigades were asked to supply a list of at least twelve volunteers (firefighters or leading firefighters) in age bands: less than 25; 25 to 35; and over 35 years. One team of four firefighters, in the ratio of 1:2:1, according to these age bands, was selected by the IOM from each brigade. Additional teams were selected from Kent (two extra teams using Sabre SEFA CCBA), London (four teams, including two each with 50% female firefighters) and Essex (two teams). A long duration (lightweight) BA was not available in operational use at the time of this phase of the study and could not therefore be included.

6. In total 72 firefighters (eighteen teams) participated during nine different weeks in the physiological studies, which took place over four days at the Fire Service College, Moreton-in-Marsh. On each morning at the same time subjects undertook a series of five minute walks at 5km h^{-1} on an inclined treadmill (average room temperature 22°C), while wearing either tee shirt and shorts (PE kit), full firefighter's turn out gear (firekit), firekit and own BA, or firekit and own BA with lightweight cylinder. Details were obtained on height (mean = 1.79m), age (mean = 31 years), skin fold thicknesses at four body sites (for body fat determination [mean = 17%]), smoking habit (26% smokers) and length of fire service employment (mean = 8 years). During each exercise heart rate (HR), inspired air volume, % oxygen and % carbon dioxide in expired air were recorded at minute intervals: the oxygen uptake (Vo_2), (the volume of oxygen consumed per minute) and volume of air expired per minute (V_E) were subsequently derived. HR and Vo_2 were examined in relation to factors, such as workload, presence of firekit and BA and type of BA.

7. Firekit and BA in combination increased Vo_2 from 2.0 to 2.7*l* min^{-1} (35%) and HR from 124 to 158 beat min^{-1} (27%) at the steepest treadmill gradient used (7.5%), each factor contributing almost equally to the increased response. Replacement of the standard 11kg air cylinder used in OCBA by a lightweight (6.5kg) cylinder reduced Vo_2 slightly (0.1*l* min^{-1}) and HR significantly (6 beat min^{-1}). Vo_2 was significantly lower (by about 0.1*l* min^{-1}) among users of Sabre Centurion, compared to other types of BA. HR was also lower, by 6 beats min^{-1}, but this difference was not statistically significant.

It was not possible to obtain reliable estimates of maximum aerobic capacity (maximum oxygen uptake, Vo_2 max) from all the participants in this study. This was principally because it was necessary to set relatively low workloads on the treadmill, in order to examine the additional physiological response to wearing clothing and BA. If the workloads had been set too high for the no BA/clothing tests, many participants would have been unable to complete the tests when BA and clothing were worn. However, from the limited range of measurements available, the estimated average indirect Vo_2 max in this study group was 3.71*l* min^{-1} (equivalent to 46.4m*l* min^{-1}, when corrected for average body weight). This is slightly greater than the fitness level (3.45 [43.7]) observed in a recent nationwide survey of firefighters with similar average age and body weight to those in the present study, indicating that more fitter individuals may have volunteered than the less fit or that the general fitness level of firefighters has improved during recent years.

8. On consecutive afternoons the participating teams carried out three exercises designed to simulate different aspects of firefighters' duties requiring BA and exposure to combinations of heat and physical workloads. These scenarios were devised in conjunction with fire officers/instructors from the BA Training School at the Fire Service College. They consisted of a short duration (20-30 minutes) search and rescue exercise in a two storey building, containing an intense live fire; removal of heavy chemical containers following a toxic substance spillage, for example, at a road accident and requiring use of a gastight suit; and a longer duration (approximately 1 hour) search through an industrial complex containing a live fire requiring re-entry after the replacement of the BA air cylinder, all under trained supervision.

9. The first exercise led to very high heart rates (over 200 beats min^{-1} in at least one member of 50% of the teams), body temperatures (over 40°C in at least one member of two thirds of the teams) and sweat rates (averaging 2.5*l* per hour). The chemical spillage exercise lasted 20 minutes and led to a modest rise in body temperature, which only occasionally rose above 38°C, but a more substantial increase in heart rate (five over 200 beats min^{-1}). The long duration exercise caused high heart rates (40% of firefighters greater than 200 beats min^{-1}) and body temperatures which rose to unacceptably high levels (> 39.5°C) in members of one team only (Sabre SEFA). Air consumption, expressed as volume of air used per minute (minute volume), averaged 43, 57 and 42*l* min^{-1} respectively for the three exercises. No clear differences in physiological responses were observed between users of different BA during these exercises. However, although Sabre Centurion users included the team with the highest average heart rate and increase in body temperature during the short duration exercise, this group also had a lower minute volume, 43*l* min^{-1}, compared to the other teams, whose average minute volumes ranged from 48 to 51*l* min^{-1}.

10. Ergonomic assessment of the four sets in most common use suggested that the Sabre Centurion, by virtue of the position of its centre of gravity in relation to the wearer, was biomechanically more efficient during dynamic movements typical of training exercises or operational incidents. The Draeger P112 was almost as good in this respect but the Interspiro and Siebe Gorman sets had second moments of inertia (a measure of the energy needed to move the BA when worn) twice as great as the other two sets and they would therefore require greater muscular effort by the firefighter to control his body during movement. The backplates of these four sets in current use tend to be too long for the range of wearers. A newer Draeger model (P90) has a considerably shorter backplate which would conform to the 99th percentile male back length but would still be too long for the 95th percentile female user.

11. In conclusion, about a quarter of all UK firefighters experience minor or major problems related to their BA, mainly associated with the weight or size of the set and adverse interactions with other personal equipment. Some types of BA are much more acceptable to their users than others. To a limited extent we have found that the additional physiological response caused by wearing BA is less amongst firefighters wearing the BA reported in the questionnaire as giving the least problems in use. The physiological response of firefighters to realistic training exercises requiring BA leads to unacceptably high heart rates, and body and skin temperatures

in many cases. Consideration should therefore be given to providing physiological monitoring in such exercises. Manufacturers of BA for fire service use should continue to develop equipment that minimises additional physiological, including musculoskeletal, strain. This can be achieved by reducing cylinder weights and designing sets that allow the BA's and the body's centres of gravity to be as close together as possible. Making the size of BA, particularly the length of the backplate, more appropriate to the users' dimensions should then reduce the amount of complaints from firefighters. However, design of BA must be considered in the context of other essential clothing and equipment used by the firefighter.

1. INTRODUCTION

1.1 Background to the Study

The widespread use of open-circuit breathing apparatus (OCBA) by Local Authority Fire Brigades in the UK during the last 10-15 years has raised concern about the additional load that firefighters' tasks now impose on them. Such equipment, while providing an essential life support system for firefighters carrying out many of their operational duties, imposes an extra physiological load, which could affect their performance and safety under certain adverse conditions.

Typical protective equipment for the firefighter, in addition to BA, includes head and body protection, gloves and boots. The function of these items has been to protect the wearer from radiant heat and to a lesser degree, contact with hot sources and minor contact injury. This level of protection can result in the build up of heat within the garments and helmet during exertion, especially in hot or humid environments. The result of such heat build up increases the load on the individual.

These considerations were amongst those which led to the Operational Study on Breathing Apparatus held at the Fire Service College in 1985. One outcome of the study was the identification of a need to clarify the influence on operating efficiency of wearing BA.

Although the Operational Study was useful in highlighting aspects of the design of existing respiratory protection, it was not clear to what degree there were operational problems in various fire brigades. Although, as a general principle, it is useful to improve existing protective systems, there would be cost benefits in having some means of systematically identifying areas of potential concern and assigning priorities for research on the basis of such objective information.

Very few studies of the performance of firefighters under actual or simulated firefighting conditions have been carried out in the UK.

Therefore, with the general concern being voiced about the potential effects of personal protection on health, safety and performance of firefighters, it was considered advisable to obtain an understanding of which tasks or task/equipment combinations are a source of potential problems and then to carry out a study of the physiological effects of wearing BA under real or simulated conditions. Having established objectively whether there are potential effects on performance, then priorities for evaluations of, and solutions to, these could be recommended to brigades.

1.2 Overview of Relevant Literature

This summary is based on available literature concerning the use of breathing apparatus by firefighters. It covers topics such as physiological responses to firefighting and work performance during simulated work tasks.

The work performance of firefighters wearing breathing apparatus in different climates was studied by Sköldstrom (1987). Subjects walked on a treadmill at a workload of 20% of maximal oxygen uptake (Vo_2 max) without protective equipment (protective clothing and breathing apparatus) and at 30% Vo_2 max wearing such equipment. The weight of the breathing apparatus was found to increase oxygen consumption by 0.4*l* min^{-1}. The combined effect of the clothing and weight of the breathing apparatus had a significant limiting effect on the endurance level, reducing the firefighters' ability to carry out strenuous work. Both the environmental temperature and the weight of the equipment caused additionally elevated heart rates.

Smolander *et al* (1984) assessed the cardiorespiratory effects of subjects working at 21% and 41% of Vo_2 max for 25-30 minutes while wearing gas protective clothing consisting of an impermeable suit over a self contained breathing apparatus (SCBA). Increased heart rates, mean skin temperature and sweat rates, measured when protective clothing was worn, indicated a high cardiovascular and thermoregulatory strain, which did not decrease when the suit was ventilated. As a result of the increased physiological load caused by the protective clothing, the author suggested that the work-rest regimens, physical fitness level, cardiovascular health and heat tolerance should be assessed for those expected to wear the protective clothing.

Epstein *et al* (1982) measured the aerobic work capacity of the subjects, who ran on a treadmill, set to give rise to a workload of 80% of Vo_2 max, with and without respiratory protective equipment (RPE), until the point of exhaustion. They subsequently filled in questionnaires on physical and general performance. It was concluded that subjects using respiratory protection near their maximum work capacity rapidly adapted to the test conditions.

The cardiovascular responses of firefighters wearing protective clothing and SCBA was studied by Davis and Santa Maria (1975). Physiological measurements were taken while the subjects walked on a treadmill. The heart rate, blood pressure and oxygen consumption increased by one third as a result of wearing protective equipment in comparison to walking on the treadmill wearing duty uniforms only. Firefighters were one third less efficient before carrying out any work, as a result of the equipment required for protection. The authors suggested that the breathing apparatus was responsible for the largest decrease in performance.

Faff and Tutak (1989) studied the physiological responses of firefighters wearing protective equipment in heat. The subjects cycled on a bicycle ergometer for 30 minutes, while lactic acid concentration and anaerobic threshold were determined. They wore either standard firefighting uniform or firefighter's aluminized protective clothing and SCBA. They terminated the exercise when fatigue and overheating would have caused them to stop work in a real situation. The working time in the firefighting clothing was considerably lower than that for the standard uniform. The heart rate and rectal temperature rose continuously throughout the exercise and showed no sign of reaching a plateau.

White and Hodous (1987) looked at the reduced work tolerance of firefighters wearing different types of protective clothing and respiratory protective equipment (RPE). Subjects walked on a motor driven treadmill at 30% and 60% Vo_2 max. Four types of protective clothing were used; light clothing with a low resistance mask, light clothing with SCBA, turnout gear with SCBA and chemical protective clothing with SCBA. Heart rates rose slowly and remained 15 beats min^{-1} higher when wearing SCBA than when wearing the light ensemble. It rose sharply and did not reach a plateau during tests in which SCBA was worn. It was concluded that the protective clothing and RPE caused significant stress to both the cardiorespiratory and thermoregulatory systems, even at low work levels in a neutral environment.

O'Connel *et al* (1986) studied the physiological costs of stair climbing. Firefighters carried out the exercise with and without firefighting uniform and equipment. Stair climbing while wearing protective clothing and equipment required the consumption of at least 2.7 litres of oxygen per minute (39m*l* kg body weight min^{-1}).

The effects of impermeable protective clothing on firefighters was further studied by Paull and Rosenthal (1987). The protective clothing consisted of a laminated PVC-type chemical resistant hooded suit with rubber boots, elbow length gloves, a full facepiece, dual cartridge respirator and hard hat. A comparison of the heart rate between men working with or without suits showed that wearing the protective suit imposed a heat stress equivalent to adding 6-11°C to the ambient WBGT (wet bulb globe temperature) index. As heat exhaustion collapse can occur at core temperatures as low as 38°C under conditions of convergence of skin and core temperature, the authors suggested that monitoring skin temperature as well as heart rate and core temperature should be used in order to provide an additional criterion for terminating work in heat.

In a further study on protective clothing and equipment, White *et al* (1989) assessed work tolerance and subjective responses to wearing protective clothing and BA during physical work. The four protective clothing ensembles were used, as described above for White and Hodous (1987). The subjects walked on a treadmill until either the experiment was finished or the subject was exhausted. Fatigue was the main reason given for stopping when wearing the control clothing or SCBA. Whilst wearing turnout gear with SCBA all the subjects stopped because of exceeding the upper heart rate criterion. The reasons given for stopping when wearing the chemical protective suit and SCBA were mainly high heart rate and rectal temperature.

Louhevaara *et al* (1984) studied the effects of RPE, including SCBA, on the cardiorespiratory system. The subjects initially walked on a treadmill at 5% gradient, subsequently increased to 20%; the speed was also increased by 1mph per minute. It was found that all the devices caused hyperventilation since a large dead space increases the concentration of CO_2 at rest and during exercise. The authors concluded that the increased cardiorespiratory strain caused by the RPE was due to the interaction of increased breathing resistance, equipment, dead space, the weight of the device or subjective stress factors.

The cardiovascular strain in jobs requiring respiratory protection was studied by Louhevaara *et al* (1985). Some subjects carried out smog diving (exercises in dense smoke) with simulated fires aboard a ship while wearing protective clothing and SCBA. Other subjects simulated repair and rescue tasks outdoors, while wearing impermeable gas protective suits. The protective clothing and SCBA used during the study were found to be suitable only for individuals in good physical condition. It was recommended that the use of SCBA and protective clothing should be limited and that users should have adequate rest periods.

These studies indicate that BA, when worn with protective clothing, imposes a considerable physiological strain particularly under adverse environmental conditions. Consequently, it was felt that a study of the physiological response of UK firefighters, wearing BA and protective clothing under severe physical and thermal conditions, was needed.

1.3 Aims and Project Plan

The study consisted of two phases:

Phase 1: the identification of those tasks in which protective equipment is worn and where particular task/equipment combinations are likely to cause firefighters problems; and

Phase 2: the measurement of physiological and subjective performance under conditions simulating a range of typical work practices, as a means of assessing both the physiological effects on firefighters of wearing BA and the adequacy of existing apparatus in these conditions.

The principal objectives of the study were therefore:

i) to identify those particular areas of task and protective equipment combinations common to Fire Brigades requiring more detailed investigations; and

ii) to quantify the degree of the effects of different task/protective equipment combinations in relation to safe work practice.

The first objective was to be achieved by carrying out a survey using a representative sample of fire brigades, including both male and female firefighters, by means of structured interviews and questionnaires. Such a survey would aim to obtain assessments of activities during and associated with firefighting; non-firefighting activities, such as chemical spillage and training; and activities involving the wearing of BA and protective clothing (fire and chemical) during physically demanding tasks, in order to identify those which could be considered as examples of extreme activity.

The second objective was to be achieved by simulating some of the firefighters' tasks, identified in phase one, and measuring firefighters' physiological and subjective performance either under controlled conditions or in the field, depending on the task. This part of the study was also to involve an ergonomic assessment of existing BA sets, including identification of where redesign was necessary; measurement of physiological parameters of firefighters performing defined tasks while wearing BA and normal fire and chemical protective clothing; determination of volumes of air and consumption rates required by BA wearers during a range of tasks; and measurement of maximal oxygen consumption of participating firefighters to enable heart rates to be related to oxygen consumption.

2. METHODS

2.1 Identification of BA/Protective Equipment and Task Problem Areas

2.1.1 Introduction

In response to concern expressed by some brigades relating to breathing apparatus (BA) this study undertook to assess BA by both subjective and objective measures. In addition, in order for objective testing of the sets to be carried out, information needed to be collated on the different sets in use within brigades, how the sets differed and what, if any, problems were caused by them. Apart from the sets themselves, there was also concern regarding any problems arising from possible interactions between the set and the clothing and/or equipment worn.

Once an initial framework of questions had been drawn up, six fire stations were visited in a total of three brigades: Humberside, Lothian and Borders and Greater Manchester. The visits provided an insight into the range and variety of problems encountered in different stations. Information was collected from both operational firefighters and officers by means of structured interviews and questionnaires thereby providing a broad range of comments and experiences.

The visits gave an indication of the breadth and variety of problems likely to be encountered by firefighters. However, it was not always possible to separate concerns over BA issues from other factors. For example, in one brigade, some stations were concerned about the difficulties in manipulating BA controls with gloved hands whereas at another station in the same brigade, concern over gloves centred around them not being considered adequate to provide protection from infected "sharps" in premises used by drug users. Experience also differed between urban and rural stations; rural stations being more likely to attend incidents of long duration, eg. heath fires, while urban stations reported more short duration incidents, such as house fires.

During the interviews the firefighters were encouraged to comment on any aspects of their work with BA that caused problems. As the use of BA during training was mentioned on several occasions during the interviews, it was considered important to include training aspects in the brigade questionnaire, in order to obtain information on the amount of BA training individual firefighters received at each brigade.

2.1.2 Development of Questionnaires

Two questionnaires were required. The first (brigade questionnaire) was designed to cover all the factual information relating to the sets used by a brigade (eg. the manufacturer and model of the BA), as well as information relating to the personal equipment and clothing issued to the firefighter to be worn with the BA. This questionnaire was intended to be completed at brigade headquarters level. The second questionnaire was directed towards the operational firefighter and was aimed at collating the individual firefighter's perception of their own set and other equipment (firefighter questionnaire).

2.1.3 Questionnaire 1 - The Brigade Questionnaire

As can be seen from the sample questionnaire in Appendix A, the brigade questionnaire consisted of 7 sections. The first section was concerned with background information, such as the number of firefighters and stations in the brigade and the proportion of callouts requiring BA in relation to the total. The questionnaire then asked about the BA set itself and the criteria used to select the set, eg. what, if any, wearer trials were used during a brigade's assessment of sets and what approved modifications were requested by the brigade? Sections C and D asked in some detail about the basis of selection for the protective clothing and personal equipment used with the BA. Section E asked about the criteria used to assess the fitness of firefighters and Section F followed on with questions on training and retraining, eg. the conditions in which training was undertaken and whether any physiological measurements were taken. The final section of the questionnaire dealt with the provision of clothing and equipment for female firefighters.

2.1.4 Questionnaire 2 - The Firefighter Questionnaire

As can be seen in Appendix B, the firefighter questionnaire asks for background information in Sections A, B and C; such as general brigade information, personal issue clothing and the use of the BA set incidents involving toxic, flammable substance leaks and spillages.

The format of the remaining sections was based on the information collected during the visits to the brigades. Numerous problems mentioned by the operational firefighters during preliminary visits related solely to the donning of the BA, but with no subsequent problems. The questionnaire was therefore divided into sections on the weight and size of the BA, donning and using the BA. Some of the problems encountered when using the BA relate specifically to the interactions between the BA and the clothing and/or equipment. As a result of this the section covering the use of BA was further sub-divided into sections on standard issue clothing, special protective clothing and personal equipment. The questions in each of the sections were based on those points consistently raised during the interviews.

A pilot study of the first draft of both questionnaires was carried out at Lothian and Borders Fire Brigade. The brigade questionnaire was evaluated by fire officers at the headquarters and the firefighter questionnaire was assessed by firefighters on a station. A number of comments were made by the participants, particularly on the operational questionnaire, mainly to clarify the meaning of specific questions. The questionnaires were then redrafted, taking account of the brigade comments, and sent out to all brigades.

2.1.5 Distribution of Questionnaires

All sixty-six brigades were sent copies of both questionnaires with the request that the brigade questionnaire was to be completed by an appropriate person at brigade Headquarters. The number of operational firefighter questionnaires sent to brigades was dependant upon the number of stations within the brigade, rather than the number of firefighters. Approximately one thousand questionnaires were distributed nationwide, using a random sample of one station in six, each receiving three questionnaires. Of the three questionnaires sent to each station it was requested that one was completed by a leading firefighter. All the questionnaires sent to the brigades were individually coded. The liaison officer from each brigade was provided with a list of the stations selected and requested to distribute the coded questionnaires. In total 342 stations received 1026 questionnaires. Replacement questionnaires were sent out one month later to brigades, if the first questionnaire had not been returned. The selection provided a representative sample of the BA sets used throughout the UK.

2.2 Physiological Responses to Wearing BA and Protective Clothing

2.2.1 Selection of brigades and firefighters

In consultation with Home Office (Fire Research and Development Group) personnel, sufficient numbers of fire brigades were selected that used the four main types of open circuit BA in service: namely, Sabre Centurion, Draeger P112, Interspiro Spiromatic (single cylinder) and Siebe Gorman Firefighter 2. (The original intention had been to include a long duration lightweight open circuit set but such a set had not come into operational use at the time these studies began and could not therefore be included). At the time of the project planning two brigades were using a closed circuit oxygen set, the Sabre SEFA (Selected Elevated Flow Apparatus). However, only one brigade, Kent, used this set at the time the selection was being made. The chief fire officer or firemaster of each selected brigade was approached through the Fire Service Inspectorate to participate in this part of the study and, following their agreement, a meeting of all the designated brigade liaison officers was held at the Fire Service College, Moreton in Marsh for a full briefing by the IOM, Home Office and Fire Service College staff so that any potential difficulties could be sorted out at an early stage.

Subsequently a list of wholetime firefighters was provided by the liaison officers (in three age groups: less than 25, 25-35 and over 35 years), from which the IOM made a random selection of four people for each team in order to minimise selection bias. The names of at least four people under 25, eight between 25 and 35 and four over 35 were requested to allow a selection to be made. Reserves were nominated to replace any volunteers who could not attend through prior duties, holidays, illness, etc. Some of the smaller brigades had difficulty in providing as many names of wholetime personnel as requested. One brigade (Essex) provided two teams and another (Kent) provided three. London provided four teams, because one aim of the study was to examine the physiological responses of female firefighters, who were only employed in substantial numbers by the London Fire Brigade. Consequently, two additional teams from London contained two male and two female firefighters and a fourth team, which we had originally hoped would be operating with an extended duration BA (see below). Table 2.1 lists all the brigades and types of BA used in the experimental part of the study.

2.2.2 Physiological studies

All physiological studies were performed using facilities provided at the Fire Service College. Six BA sets were originally selected for inclusion in these studies. Four of the sets were standard open circuit self contained breathing apparatus, one was an extended duration open circuit set and one was a closed circuit oxygen set. However, as already noted, prior to these studies commencing the extended duration set was withdrawn from the study because it had not yet been certified for operational use by the brigade intending to use it.

The study was carried out during nine weeks between January and April 1992. Each week four firefighters from each of two brigades undertook a series of exercises involving the use of BA over a four day period. During the four morning sessions the firefighters carried out a series of exercises on a treadmill and during the three afternoon sessions three different fire and rescue exercises requiring use of BA, devised in conjunction with the College staff, were carried out. At the start of the week the selected firefighters, Fire Service College staff and IOM personnel met for an informal briefing on the aims of the study.

2.2.3 Treadmill tests

On the first day of the study information on age, fire service experience and smoking habits was obtained. Anthropometric data, such as height, weight and skin fold measurements (as described by Durnin and Womersley, 1974) were also obtained.

The treadmill exercises were carried out in the Fire Service College Occupational Health Unit from Monday to Thursday mornings inclusive. Each subject was allocated the same time period during the morning in which to carry out his or her tests in order to minimise the effects of circadian rhythms on performance. The firefighters carried out four different exercises (workloads varied according to treadmill gradient) during the week; one baseline assessment of physiological response to exercise at four five minute workloads and three shorter tests which assessed the physiological effects of firefighters' clothing and BA with light and standard weight cylinders, at two of the same workloads. The baseline fitness assessment allowed the physiological response (heart rate and oxygen uptake) to be measured on firefighters wearing tee shirt, shorts and training shoes from which it was intended that the indirect maximal aerobic capacity could be derived. This test involved initially walking at a speed of 5km hr^{-1}, the gradient of the treadmill increasing by 2.5% after each 5 minute walk, up to a final gradient of 7.5%. For the three exercises requiring firefighters' clothing, both with and without BA, gradients of 2.5% and 7.5% were used. The firefighters wore standard A26 Bristol Uniforms Nomex tunics and overtrousers for these exercises, except for seven firefighters who wore slightly lighter weight Bristol Delta T tunics. An empty lightweight (6.5kg) cylinder fitted to the firefighter's own BA harness was used to simulate a lightweight BA. Each firefighter wore the BA set used by their own brigades for these treadmill exercises but did not wear the facemask during the tests, because they were required to wear a mouth piece for physiological monitoring. The subjects were fitted with a heart rate transmitter on a chest strap before the start of the exercises (Polar Sport Tester). They rested for five minutes before commencing the treadmill tests to allow the heart rate at rest to be measured. After 4½ minutes of rest the heart rate was recorded during the next half minute. The subject then stood on the treadmill, the treadmill was started and adjusted to 5km hr^{-1} at which point the start of the exercise was recorded.

The firefighters walked for five minutes at each workload and then rested for five minutes between workloads or until the heart rate had returned close to resting values. At the end of each minute of the exercise the volume of air inspired, the percentage of CO_2 and O_2 in the mixed expired air and the heart rate were recorded. The heart rate and inspired air volume are indices measuring the response of the circulatory and respiratory systems to additional physical loading. The percentage of CO_2 and O_2 in expired air allow the volumes of CO_2 produced and O_2 consumed during these exercises to be derived. The CO_2 and O_2 concentrations were measured using PK Morgan Gas Analysers. These were both calibrated immediately before testing using oxygen free nitrogen and a calibrated CO_2 in air supply. The inspired air volume was measured using a dry gas meter (Parkinson Cowan) connected to a digital counter which measured air consumption in litres. The general experimental layout is shown diagrammatically in Figure 2.1. Minute volume (lung ventilation), O_2 consumption and CO_2 production were subsequently derived from the average of the third to fifth minutes of exercise, ie. when a steady state had been achieved.

2.2.4 Simulated fire and rescue exercises

The "Sir Henry" training facility at the Fire Service College was used for these exercises (Figure 2.2). It is designed to simulate a medium sized ship and contains holds, an engine room, accommodation block, gangways and staircases. The exercises were devised by IOM and Fire Service College staff to ensure they represented use of BA in typical training situations. On day 1 the firefighters, wearing full firekit (Bristol Uniforms tunic and overtrousers) undertook a short fire/rescue exercise designed to last approximately 20 minutes; on day 2 another exercise was carried out in overalls and gastight suits (referred to airtight suits in the questionnaire) to simulate a clear up after a chemical spillage on a hot summer day. The third exercise, again in full firekit, simulated a longer search exercise in a burning industrial building; this required an air cylinder change and was intended to last approximately 45 minutes.

Before and after each exercise the subjects were weighed (in disposable suits) to allow weight loss due to sweating to be calculated. Between these two weighing sessions the firefighters were requested not to drink unmonitored liquids, urinate or defecate. Note was taken of all the fluids that were drunk after the exercise and before reweighing. The cylinder weights were also measured before and after each exercise. Firefighters were fitted with a heart rate monitor and temperature sensors. The skin sensors were attached to the back, chest and left inner thigh with micropore tape. In addition, an aural temperature sensor was placed in the outer ear canal (either left or right) to allow a core body temperature to be measured. This sensor was insulated against the effects of radiant heat by covering it with cotton wool (and a fire hood in the two "live fire" exercises).

Short fire exercise: Immediately before this exercise began a standard wooden pallet fire was ignited in a crib in the lower hold 1 area (Figure 2.2). The firefighters entered the forward part of "Sir Henry" as a team via the top hatch and descended a vertical ladder to the first floor level (tween deck). A full right hand search of the tween deck and lower hold was carried out using a pre-set guideline before the firefighters reached two dummies (casualties) on the ground floor (lower hold). Two pairs of firefighters then attempted to remove the "casualties" along the reverse of the entry route. The exercise ended when the casualty was removed via the inspection hatch on the top of the "Sir Henry" (see Figure 2.2) or earlier if the firefighters were withdrawn for safety reasons.

The firefighters' body and skin temperatures were measured immediately before and after the exercise. The heart rates were monitored continuously and subsequently down loaded to a portable computer to give tabular and graphical presentations. Air consumption was calculated from the change in cylinder pressure readings.

Gastight suit exercise: This took place in the lower hold 1 area, used in the previous exercise, heated to about 28-30°C by gas fired space heaters. Firefighters wore helmet, boiler suits and BA under gastight suits and operated in teams of four. The exercise involved lifting partially filled 50 litre containers (weighing 25-30Kg) from one platform to another round a short circuit. This pattern was repeated for five minutes at a steady pace dictated by the observers and Fire Service College staff. The teams of four were then stopped so that body and skin temperatures could be measured. The subjects continued the exercise for twenty minutes stopping for temperature measurements after 5, 10, 15 and 20 minutes. At each restart each firefighter walked in the reverse direction and carried the container in their other hand.

Long duration exercise: This exercise was carried out in the engine room (where a fire had been lit) and rear hold 2 area of the "Sir Henry" (Figure 2.2) The exercise involved following a guideline down through the accommodation block, around the tween deck 2 area and up to the deck house and onto the deck (where body temperatures were measured). The firefighters then re-entered the deckhouse and climbed down a vertical ladder, through a shaft tunnel and round the engine block (where a fire was burning). They then climbed a metal stairway and walked along metal gantries over the site of the fire. Their route continued through the accommodation block again exiting onto the deck. At this point temperatures and cylinder pressures were recorded and the firefighters using open circuit BA had their empty cylinders replaced with full ones. To complete the exercise the firefighters then returned through the ship following the previous route in reverse. Temperatures were again monitored at the deckhouse, halfway round the circuit. On re-entry the firefighters picked up a 50 litres container and carried it from the tween decks area to the exit point on the top deck. Immediately on exit temperatures and cylinder pressures were again monitored before the firefighters removed their BA masks.

The start and finish times of all three exercises were recorded. As soon as any exercise was finished and BA removed, cold drinks (water, squash, etc) were offered and the number of 200ml cups of liquid consumed by each person was recorded.

Safety procedures: During the exercise in the "Sir Henry" one or more Fire Service College safety officers were present at all times. During the short duration fire/rescue exercise, which required exposure to very hot conditions, the normal safety procedures operated by the Fire Service College were followed. If one of the officers observed any of the firefighters to be in difficulty (eg. stumbling gait, glazed eyes, unable to comprehend simple instructions) he led that person (or the whole team if necessary) to the nearest exit. However, if, in the opinion of the senior IOM physiologist present, the team of firefighters was highly unlikely to complete the exercise within 30-35 minutes, at which time body temperatures were expected to be reaching physiologically unacceptable levels, instructions were given by radio to withdraw the team.

The IOM scientists and safety officers were in contact by radio throughout the short and long duration exercise, first aid kit and resuscitators were always available and the occupational health centre was alerted, if any incident required medical attention.

2.2.5 Environmental temperature monitoring

Environmental monitoring was carried out during each of these exercises. Thermocouples were positioned at 22 points throughout the "Sir Henry" and connected to an Orion Data Logger. The information was then transferred on computer disc to Lotus 1-2-3 where graphs were constructed of temperature against real time.

The short duration exercise: During the short duration exercise temperature was monitored in 9 positions; four positions in the tween deck and five positions in the forward lower hold all at shoulder height (1.5m).

The gastight suit exercise: This exercise was carried out in the forward hold of the "Sir Henry". Temperatures were monitored in 5 positions during the exercise and the average temperature in the hold was calculated at each 5 minute period.

The long duration exercise: This exercise was carried out in the rear holds of the "Sir Henry". Temperatures were monitored at 10 locations along the route followed. After several weeks of the study it was decided to reduce the number of thermocouples used to 3. This still enabled a temperature profile to be recorded. During the last two weeks of the study it was impossible to monitor temperature as the wiring connecting the thermocouples to the data loggers had been burnt out.

2.3 Ergonomic Assessment of BA

In order to make a detailed assessment of the different BA sets, visits to several fire brigades were undertaken by another ergonomist who had not been involved with the other parts of the study. Initial contacts were made through the liaison officer at each fire headquarters. All discussions were held with ex-operational firefighters at either station or sub-officer level. Discussions at Grampian and Fife were with the assistant divisional and divisional officer respectively.

The locations which were visited are shown in Table 2.2

Discussions were held around a brigade's BA set in the brigade's BA workshop. The purpose of these discussions was to gather information on both good and bad features of the sets in operational use. Problems encountered during routine maintenance procedures were also briefly discussed. If staff had experience with other BA makes or models, comparisons were drawn between the sets.

Prior to these visits a discussion took place with the other project ergonomists, so that comments received on BA sets during the physiological phase of the study could be identified and explored during the ergonomic assessments.

2.4 Data Processing and Statistical Analysis

2.4.1 Data preparation and transcription

Responses to the firefighters' questionnaires and most of the physiological and other data gathered during the treadmill and the fire rescue exercises were entered onto paper data forms. The forms were designed to be compatible with the computer data entry that subsequently took place. The exception to this method was the heart rate data collected during the fire rescue exercises. These were recorded directly using the Polar Heart Rate Monitor system which is described in section 2.4.4.

Following any necessary coding and manual checking the data forms were punched to computer using the Key Entry III data entry package (version 5.1.v) on an IBM compatible personal computer. During data entry programmed checks were carried out to validate the data by screening for erroneous and implausible data. Checks were also carried out on the ranges of the data and to test that related data were consistent with each other.

2.4.2 The study database

Following entry the data were transferred to the IOM's Prime 2850 minicomputer running the Primos operating system (version 23.3.0a). The SIR (Scientific Information Retrieval) database management system (version 2.2.18) was used to construct a secure database to contain the data from the questionnaires and the physiological trials. Related record types were implemented which reflect the related sets of information produced in the study. An outline data model showing the structure of the database is shown in Figure 2.3.

During and immediately following the uploading of data to the database further data checking and consistency procedures were carried out. These checks and other programs used to process the study data are preserved in a procedure file which is integral to the database. The final count of verified data records in the database is shown in Table 2.3. A full description of the contents of the database is contained in the database schema. This document describes the variables in each record in detail including the names, the order in which they are held, valid values, ranges and labels for each of the values.

2.4.3 Firefighter questionnaire comments

The comments made on the firefighter questionnaires were entered along with the quantitative questionnaire data. However, due to their volume and qualitative nature they were not incorporated into the SIR database itself and instead were made available as text files for scrutiny by researchers. The comments were identified in a way that allowed comments on any particular question or group of questions to be picked out and linked to other questionnaire responses made by the same respondent or group of respondents.

2.4.4 Heart rate data

Heart rate data were gathered from participants during the course of the fire rescue exercises. Heart rates were sampled at five second intervals using Polar Sports Tester recording watches carried by each subject. The data were downloaded and preliminary analysis carried out by the Polar Heart Rate Analysis Software (version 3.20a) on IBM compatible PCs. Further analysis was carried out using programs written in the PQL language of the SIR Database, and data were transferred to the Quattro Pro spreadsheet package for graphical presentation. Due to the bulk of the raw data files they have not been uploaded to the SIR database and only summary information (maximum, minimum and average) has been stored for each exercise.

2.4.5 Statistical analysis

The SIR database constitutes the master repository for experimental data arising from this study. For statistical analyses by other packages subsets of the data were written out into flat files suitable for use by the package. Data files for each of the basic record types were produced as well as several incorporating data from two or more record types. These were made available to the project statistician for analysis.

The physiological data from the treadmill studies were tabulated and analysed using multiple linear regression methods to investigate the effects of age, workload, clothing, BA, BA type and other relevant personal and experimental factors, eg. test order, day of week. Analyses of variance were performed on these data to identify the statistical significance of the additional effects of BA, cylinder type and clothing on physiological response to the standard work loads.

The physiological data from the fire rescue simulation exercises were examined in a similar but less detailed manner, in particular, to identify any differences between teams using different types of BA. Results were summarised in tabular form according to brigade team and BA type for each test. Maximum heart rate during each test, changes in and maximum levels of aural and skin temperatures were investigated for the influence of BA type; air consumption and sweat loss were also examined as additional indicators of physiological response. (However, in this part of the study there was generally a lack of statistical significance when differences between BA sets were examined).

2.4.6 Data archiving

The paper based forms generated by this project will be held in dry, secure archive storage by the IOM.

Following completion of the project archiving of the computerised data took place. This included the project database, the database schema, additional data files (questionnaire comments and heart rate readings) and any other related project files. This has been accomplished by the following procedure:-

a) The Prime project directory has been purged of any working, backup or scratch files, so that only the database, master data, documentation and final program files remained in the project directory. A full annotated list of these has been constructed and stored both on computer and as hard copy.

b) A portable (exported) version of the SIR database has been made, and resides in the database directory with the native (Prime) database files.

c) Two copies of the project directory have been made and stored on 8 mm cartridge tapes. One copy is stored as standard, adjacent to the secure IOM computing facilities. The second, backup copy, is stored in secure facilities in a separate building.

d) PC based files arising have been backed-up and stored in secure facilities in a separate building.

3. RESULTS

3.1 Fire Brigade Questionnaire Responses

Questionnaires were returned from all 66 brigades. Much of the information obtained from this questionnaire provided the basic factual background about all the UK brigades, such as number of stations, size of workforce, number of callouts, etc. Information about BA was used mainly to confirm the opinions expressed in the firefighter questionnaire about the type of BA used by their brigade.

Twelve different BA sets were in use by brigades at the time of the survey namely:

Draeger P112 (19 brigades), P212 (2), A202 (2);
Interspiro Spiromatic 219 (4), Spiromatic 211 (10);
Siebe Gorman Firefighter 1 (9), Firefighter 2 (8), Airmaster 2 (5);
Sabre Brigade (3), Centurion (10), SEFA (1); and
Racal Panorama (1)

Eleven brigades used two different sets/models and the remainder used only one.

3.1.1 Environmental conditions during training

Nearly two thirds of brigades gave some indication of the environmental temperatures and humidities measured or estimated during live fire and/or hot and humid exercises used for BA training. Some of these were carried out in the brigade's training facilities or in training facilities outside the fire service. Maximum temperatures during live fire exercises were reported by one third of brigades to range from less than 100°C to 800°C. Some of the wide variation is accounted for by the location of measurement (eg. shoulder height, head height, ceiling level). Twenty one brigades provided information on hot and humid exercises. Twelve operated to a maximum temperature of 38°C, six operated to temperatures higher than this and three below this level. Relative humidities where known were reported to range from 75-100%.

Typically the hot and humid exercises lasted for twenty minutes (5 brigades) or were based on the temperature/humidity chart of safety limits (1 brigade). The live fire exercises were stated to be limited by time to between 15 and 35 minutes (5 brigades), the duration of one cylinder (13 brigades), duration of two cylinders (2 brigades), or relied on the guidance of the BA instructors (13 brigades).

3.1.2 Physiological monitoring during training exercises

Just over one third of brigades said they carried out some physiological monitoring to assess the condition of firefighters during training, most often during heat and humidity tests. Twenty brigades used pulse counts, either by manual counting (15 brigades) or by pulse meters (9 brigades). Some used both methods. However, the peak values most frequently occurring during tests ranged from 100-109 beats min^{-1} to over 180 beats min^{-1}. The most often quoted range was 150-159 beats min^{-1}.

Fifteen brigades measured body temperature either by mouth (12 brigades) or other methods (4 brigades). Of the eleven brigades that indicated the range of peak temperatures most often encountered during tests, the temperatures reported ranged from 37.0 to 38.1°C. Eleven brigades stated that they carried out other forms of monitoring of the firefighters' condition, including breathing rate, consumption of air, blood pressure (before and after), general visual check, pupil dilation, cramps or speech coherence/writing legibility.

3.2 Firefighter Questionnaire Responses

3.2.1 General differences between BA types

The number of completed questionnaires received from the firefighters was 783 out of the 1026 distributed, a response rate of 76.3%. Of these, ten different breathing apparatus sets were represented as shown in Table 3.1

The distribution of BA type indicated in Table 3.1 was generally representative of the number of sets used by the fire service, ie. Draeger P112 has the most widespread usage within the brigades. The only anomaly was the number of returns from Sabre Centurion users, which was lower than expected. As Sabre SEFA and Racal Panorama were so poorly represented they were not included in the analysis as the very small sample would give unreliable results. These sets were known to be of limited use so this response was not unexpected. One of these sets has subsequently been withdrawn from operational use and was not considered further. The other set was used in other parts of the study. The sets have also been classified into "newer" and "older" sets: Draeger P112, Interspiro Spiromatic, Sabre Centurion and Siebe Gorman FF2 being newer and the other four being older sets.

BA usage

The vast majority (95.2%) of firefighters stated that they wore BA less than once per week. Only one person wore BA at least once per day. When asked about the use of BA, during the last 12 months, for toxic substance leaks and spillages, only 30.8% of the respondents said they had worn BA for this purpose. Of these only 0.3% had used BA regularly, ie. about once per week.

None of the firefighters questioned had regularly attended a flammable substance leak. All of the 22.9% of firefighters who had attended such incidents had attended them less than once per week.

Few of the firefighters questioned had needed to use more than one cylinder during an operational incident. Only 6.1% had needed a further cylinder at more than 12 incidents in 12 months, 53.1% had never needed to change cylinders, 28.9% had only needed to replace a cylinder at one or two incidents in 12 months.

Weight and size of BA

Table 3.2 shows that 19.9% of respondents commented that the weight of the sets caused problems during donning. Within this total there were large variations in the perceived weight problems for the different sets. Both Siebe Gorman FF1 and Siebe Gorman Airmaster were perceived as causing the most problems due to weight, 31.1% and 31.6% of wearers respectively finding problems. Sabre Centurion caused noticeably fewer problems than the other sets (8.3%).

Table 3.2 also shows that 14.9% of all the firefighters surveyed commented that they had difficulty in adjusting the BA to fit because of the weight of the set. Again, certain sets appeared to cause more problems than others. Both Siebe Gorman FF1 and Siebe Gorman Airmaster caused many more wearers to encounter problems due to weight, 24.1% and 26.2% respectively of wearers finding problems in adjusting the set. Two sets in particular caused very few problems for wearers, Sabre Centurion and Brigade respectively caused only 2.8% and 4.3% of wearers to report problems.

12.1% of the firefighters questioned found the size of their sets caused them difficulties during donning. The size of Siebe Gorman FF1 caused markedly more problems for firefighters with 22.8% encountering difficulties. Three sets, Sabre Centurion, Sabre Brigade and Draeger A202 caused no problems for their wearers.

Table 3.2 also indicates that 6.9% of the respondents considered that the size of their sets caused problems of adjustment. The Siebe Gorman FF1 again caused the greatest number of difficulties due to the size of the set with 15.2% of wearers finding the set difficult to adjust. None of the wearers of either Sabre Brigade or Draeger A202 had any difficulty in adjusting their sets to fit.

Putting on and adjusting BA

Mask straps - The results in Table 3.3 show that none of the firefighters questioned considered the mask straps caused any major problems, eg. because of twisting or small size. Two of the newer models caused the greatest number of minor problems for firefighters, 28.8% of Draeger P112 wearers and 27.8% of Siebe Gorman FF2 wearers encountering problems with the mask straps. In comparison the older sets gave fewer problems with the mask straps, Siebe Gorman Airmaster causing 13.1% of firefighters problems, Sabre Brigade 13.0% and Draeger A202 12.5%.

Harness straps - Table 3.3 shows that more firefighters appeared to have problems, such as twisting or tangling, with their harness straps than with mask straps. 24.5% of all firefighters had minor problems and 1.8% had major problems. Two of the older sets caused the greatest number of major problems, Siebe Gorman FF1 and Siebe Gorman Airmaster causing 6.3% and 5.0% of wearers major problems respectively. The most minor problems were caused to wearers of a new set (Siebe Gorman FF2), which was reported to cause problems for 40.5% of wearers. Overall, the best performance was achieved by Sabre Centurion, which caused 11.1% of its wearers to comment on minor problems and none to report major problems.

Mask adjusters - In general the mask adjusters were perceived to cause fewer problems than the mask straps as can be seen in Table 3.3. A new set, Siebe Gorman FF2, caused the most difficulties with 20.3% of firefighters mentioning minor problems and 2.5% commenting on major problems. Three of the older sets, Siebe Gorman Airmaster, A202 and Sabre Brigade, caused few problems. Siebe Gorman Airmaster caused 6.6% of firefighters minor problems, 4.3% of Sabre Brigade wearers and 6.2% of Draeger A202 wearers also found minor problems with the mask adjusters.

Harness adjusters - As with the mask adjusters the harness adjusters were perceived to be less problematic than the harness straps (Table 3.3). A new set, Interspiro Spiromatic was found to produce the most problems with 23.5% commenting on minor problems caused by the adjusters. Sabre Centurion caused fewest problems with only 2.8% mentioning that they incurred minor problems with the harness adjusters.

Helmet - Table 3.3 also shows that a large proportion of the firefighters commented that their helmets caused problems when putting on and adjusting their BA sets, eg. interference from the face mask. The interactions between helmets and sets were most problematic for Siebe Gorman FF2 wearers, 48.1% of wearers commenting on minor problems and 3.8% on major problems. The best overall performance was found to be for Sabre Centurion, although there was still a large number reporting problems (26.2%).

Tunic - The tunic was perceived to cause far fewer problems than the helmet with 13.5% of the firefighters stating that the tunic caused minor problems and 2.1% major problems mainly due to its bulk and size (Table 3.3). Two of the older sets, Siebe Gorman Airmaster and Draeger A202 caused wearers noticeably fewer problems than the others. 6.6% of Siebe Gorman Airmaster users and 6.2% of A202 users mentioned minor problems resulting from the interactions between the sets and the tunics. However, wearers of another older set (Siebe Gorman FF1) encountered the most problems, 20.3% of the wearers commenting on minor and 2.5% on major problems.

Using the BA

Weight of set - 25.4% of all the respondents in Table 3.4 answered that when using, as opposed to donning and adjusting their sets, the set's weight caused them difficulties. Siebe Gorman FF1 caused its wearers the most problems, (39.2%) and Sabre Brigade was evaluated as causing the least number of problems, although this was still a significant proportion (17.4%).

Size of set - The results in Table 3.4 also indicated that the size of the sets showed a similar trend to that caused by their weight. In total 23.7% of the respondents felt that the size caused problems. Siebe Gorman FF1 caused the most problems for wearers (38%). The least number of problems were encountered by Sabre Centurion users (12.1%).

Controls - Overall, 7.9% of the firefighters found that the controls were difficult to operate (Table 3.4). One of the newer sets, Interspiro Spiromatic, caused wearers to have noticeably more problems than use of the other sets, 21.3% of its wearers commenting on this point. Sabre Brigade, one of the older sets, was found to cause none of its wearers any difficulty in operating the controls.

Facemasks - Table 3.4 also shows that 16.3% of the firefighters found minor discomfort caused by their facemasks while 0.5% felt major discomfort. 31.6% of Siebe Gorman FF2 wearers and 26.6% of Siebe Gorman FF1 wearers encountered minor discomfort with the facemask and 1.3% of Siebe Gorman FF1 wearers also felt major discomfort with the mask. The least discomfort caused by a facemask was found to be produced by Interspiro Spiromatic (7.3%).

Backplate - 15.3% of the firefighters surveyed found that the backplate caused them discomfort, eg. because of lack of padding (Table 3.4). A further 1.3% felt that the backplate caused major discomfort. In general, the older sets caused their wearers the most discomfort. Draeger A202 caused the greatest level of discomfort for wearers, 43.7% commenting on minor discomfort. Siebe Gorman FF1 users reported major discomfort more frequently than other firefighters (6.3% of users). This set also caused 26.6% of wearers to have minor problems. The least discomfort was experienced by wearers of Sabre Centurion, only 7.4% of users having minor discomfort.

Straps - 17.6% of the firefighters shown in Table 3.4 found that their straps caused them minor discomfort, usually due to weight of the set. Two of the older sets caused the most discomfort for wearers. Siebe Gorman Airmaster caused 37.7% minor discomfort and Draeger A202 37.5%. The most comfortable straps were those of Sabre Centurion, 9.3% of users encountering only minor discomfort with them.

Buckles - Few firefighters commented that the buckles caused discomfort (Table 3.4). The buckles of three of the older sets, Siebe Gorman Airmaster, Sabre Brigade and Draeger A202, caused no discomfort. The greatest level of minor discomfort caused by buckles was 3.3% for Interspiro Spiromatic.

Seal of facemask - Table 3.5 shows that 26.1% of respondents felt that the facemask did not always seal properly, because of its size or lack of padding. Both Siebe Gorman FF1 and 2 were the least acceptable, as 36.7% of wearers said the facemask did not fit properly. The best performance of a facemask was judged to be that of Sabre Centurion with only 7.4% of wearers finding that it was not always properly sealed.

Correct adjustment of mask straps - Table 3.5 also shows that 7.2% of the firefighters found that the mask straps did not always remain correctly adjusted. One of the newer sets, Siebe Gorman FF2, was assessed as loosening during use by 17.7% of wearers compared to 12.7% for Siebe Gorman FF1, which is the older version of Siebe Gorman FF2. All of the wearers of Sabre Brigade felt that the mask straps remained correctly adjusted.

Visor - There was a large variation in the responses to this question (Table 3.5). On average 25.2% of firefighters felt that the facemask visor did not provide clear vision. Two new sets, Interspiro Spiromatic and Sabre Centurion were perceived by wearers to provide the clearest vision with only 14.8% of Centurion wearers and 17.8% of Spiromatic wearers reporting that the visor did not provide clear vision. Draeger A202 was considered to provide the poorest vision, 46.7% of wearers commenting that the visor did not provide clear vision.

Using BA with standard issue clothing

Gloves - Table 3.6 shows that 56.5% of all the firefighters felt that their gloves caused problems in using their sets. Siebe Gorman FF2 wearers in particular found their gloves problematic, 73.4% reporting problems. Siebe Gorman Airmaster was found to cause the least number of problems when using the gloves (44.3%).

Tunic - 15.9% of respondents found that their tunics caused problems in using the BA (Table 3.6). The wearers of two of the older sets, Sabre Brigade and Draeger A202 found their tunics caused few problems, whereas both Siebe Gorman FF1 and FF2 were found to cause the most problems, 19% of wearers commenting on the interactions between the sets and the tunics, for example, the backplate causing the lower part of the tunic to ride up the back.

Helmet - 37.1% of the respondents shown in Table 3.6 found that their helmets caused problems during BA use, usually snagging the top of the cylinder. One of the older sets, Sabre Brigade, was found to cause the least problems for wearers when worn with a helmet, but there were still 21.7% of the wearers reporting problems. The most problems (51.9%) arising from the interactions between set and helmet were found for one of the new sets, Siebe Gorman FF2.

Other standard issue clothing - Table 3.6 also shows that 9.5% of all the firefighters surveyed found that other items of standard issue clothing, eg. PVC leggings, caused problems during BA use. The wearers of two of the older sets, Sabre Brigade and Draeger

A202, found no interference between the sets and such items and Interspiro Spiromatic gave rise to the poorest response (13.9%).

BA with special protective clothing.

Splash suits - Table 3.7 shows that 22.3% of the firefighters incurred minor problems when putting on BA in combination with a splash suit, a further 4.7% of firefighters felt that they had major problems in putting on BA with a splash suit. These problems often related to the bulk of the suits. The wearers of one of the new sets, Siebe Gorman FF2, encountered the most major problems (10.4%). Sabre Brigade was found to produce the greatest number of minor problems (47.8%). The best result overall was found to be for Siebe Gorman Airmaster which caused 13.6% of wearers minor discomfort, none of the wearers having any major problems.

Use of gastight suits - 46.9% of the firefighters surveyed had worn a gastight suit in combination with a BA set. Only one Draeger A202 user had used his set with a gastight suit, whereas at least 40% of users of the other seven sets had done so. This set has therefore been excluded from Table 3.7.

On average 17.8% of firefighters found minor difficulties in putting on the BA set in combination with the gastight suit. 1.9% of users found major problems. Siebe Gorman FF1 caused the most major problems (6.5%). One of the new sets, Draeger P112, caused the greatest number of minor problems (21.4%).

Of the wearers who specified that they used BA in combination with a gastight suit, 22.2% felt that they encountered minor problems and 2.8% major problems in using BA with the gastight suit. Siebe Gorman FF1 and FF2 caused the greatest percentage of problems for their wearers. Siebe Gorman FF2 caused 26.2% minor and 4.8% major problems for users, while Siebe Gorman FF1 caused 35.5% minor and 9.7% major problems.

When using BA in combination with other special protective clothing, 6.1% of the firefighters felt that they had problems (Table 3.7). Users of Draeger A202, in particular, encountered many problems with 37.5% of wearers commenting on problems. The wearers of Sabre Centurion and Brigade sets found no problems with other special clothing.

Using BA with personal equipment.

Main guideline - 14.4% of the firefighters found minor problems in using BA while using a main guideline often because of the lack of attachment points on the straps of the set for users of most types of BA, as can be seen in Table 3.8. The set that resulted in the most minor problems was Siebe Gorman FF2 (26.9%). Wearers of one of the older sets, Sabre Brigade, found that the main guideline caused no problems.

Radio - Table 3.8 also shows that 18.4% of the respondents felt that they had problems in using BA while wearing a radio. These divided into comments about hand held as well as integrated radios. Siebe Gorman FF1 was found to produce the most problems (34.2%), whereas Siebe Gorman Airmaster gave the best performance (5.2%) with Interspiro Spiromatic (9.1%) not far behind.

Other personal equipment - 3.9% of the firefighters shown in Table 3.8 encountered minor problems in using the BA set with other equipment, a further 0.5% finding major problems.

None of the firefighters commented on any problems for Sabre Brigade. Wearers of Interspiro Spiromatic encountered the most difficulties, 5.6% of wearers experiencing minor and 0.6% major problems.

Using personal equipment with BA.

Main guideline - Table 3.9, which is complementary to Table 3.8, shows that 17.9% of the firefighters found minor difficulties in using a main guideline whilst wearing BA; a further 3.0% of firefighters remarked that they had major problems. Siebe Gorman FF1 and FF2 gave the poorest rating (31.2% and 28.6% respectively). Siebe Gorman FF1 also caused 2.6% of wearers major problems. The best overall performance was for one of the older sets, Draeger A202, only one wearer reporting on minor problems.

Radio - Table 3.9 also shows that 24.6% of the respondents found minor problems and 3.5% major problems in using a radio while wearing BA. Siebe Gorman FF2 and Sabre Brigade were considered to interfere the most with the use of radios. Siebe Gorman FF2 caused 35.5% minor problems and 5.3% major problems for wearers and Sabre Brigade caused 34.8% minor problems and 8.7% major problems. The best performance overall was for Siebe Gorman Airmaster, one of the older sets, 13.8% of wearers commenting on minor problems and a further 1.7% on major problems.

Other personal equipment - Only 3.8% of the firefighters incurred minor problems when using other personal equipment while wearing a BA set. 0.5% of the respondents commented on major problems. Two of the older sets, Sabre Brigade and Draeger A202, were found to cause no problems. Siebe Gorman FF2 caused the most problems, 7.9% commenting on minor problems and a further 2.6% mentioning major problems.

3.2.2 Comments on specific problems related to BA types

Weight and Size of BA.

Sabre Centurion was found to cause the fewest problems for wearers in terms of its weight, although it was not the lightest set (Draeger P112 was 1.5kg lighter). The better acceptance of Sabre Centurion may have been due to the weight distribution of the cylinder on the back, ie. the cylinder sits low on the wearer's back causing the majority of the weight to be carried on the hips. In comparison, the poor assessment of Siebe Gorman FF1 may be attributed to the cylinder sitting high on the back of the firefighter causing the weight to be carried on the shoulders rather than on the hips. This set was also found to cause the greatest number of problems due to its size both during donning and adjusting it to fit correctly.

The size of the sets was perceived by all the firefighters to produce fewer problems than the weight. The wearers of three sets, Sabre Centurion, Brigade and Draeger A202, found that the size of their sets caused them no problems during donning. Draeger P112 was found to cause more problems than average, which was unexpected as the backplate of the set is contoured to the shape of the back and its weight is carried mainly on the hips, thereby allowing the cylinder to sit lower on the back. The centre of gravity of this set was also found to lie in the line of the waist straps while the other sets had their centre of gravity higher up on the wearer's backs, which in theory should have caused fewer problems for wearers of this set.

In relation to the adjustment of the set during donning the older, heavier sets caused the most problems to wearers. Again, this is due, in part, to the weight and positioning of the cylinder but also to the ease with which the harness straps could run in the adjusters. Many firefighters commented that the straps were not easily adjusted as the weight of the cylinder pulled the harness up at the front which caused problems in adjusting the harness straps.

Putting on and adjusting BA.

Straps - The main reported problems were caused by the mask straps twisting around each other and becoming entangled with the helmet strap. Several comments were made about the flimsy material and construction of the straps and the ease with which they are broken. When the firefighters were required to tighten the straps during an incident a number of them found difficulty in locating and gripping the small end tabs when wearing gloves.

The results show that the mask straps on many of the newer sets caused problems. These mainly related to the central forehead strap which on all of the mask straps catches the wearer's hair as it is being adjusted. In order to release the hair the strap has to be loosened and readjusted resulting in a prolonged period for donning the set. Many firefighters requested that the forehead strap should be removed and the design returned to the old style.

The problems of the straps twisting and breaking could be reduced by widening and thickening the straps. Larger thicker tabs on the end of the straps would allow easier location of the tabs and reduce the chances of breakage.

The major problems with the harness straps were found to be similar to those of the mask straps, ie. twisting and tangling with other protective equipment. In the case of the harness straps, they became entangled with the torch, DSU (Distress Signal Unit) and pressure gauge which are attached either to the straps or the tunic. Some wearers found that the straps jammed in the adjusters when being tightened. A number of other problems were also similar to those reported for the mask straps. For example, the end tabs of the harness straps are difficult to locate when gloves are worn and the straps loosen during use owing to the weight of the cylinder pulling on the straps.

A possible solution to the problem of the straps loosening could be to use deeper grooves in the straps to lock the adjusters into position more effectively thereby reducing slippage. Insufficient adjustment of the straps was also found to be a problem for smaller firefighters, ie. when the straps were adjusted to their maximum they were still loose on certain individuals. The shoulder straps were found to cut into the neck of some firefighters at the point where they attach to the backplate. The abrasions caused by the straps could be reduced by padding the straps at the back of the neck or repositioning them further apart on the backplate.

In relation to the waist strap, firefighters felt that this was not as secure as it could have been as it sat around the hips rather than the waist of some wearers. This point identified the need for adjustable backplates which would allow wearers to have backplates that fitted their needs.

Two of the newer sets, Siebe Gorman FF2 and Interspiro Spiromatic, caused the most problems for wearers. Both of these sets are heavier than average which could have contributed to the problems of straps loosening. Siebe Gorman FF2 was targeted specifically by respondents on the use of its chest strap which caused restricted breathing when arduous tasks were undertaken.

Adjusters - The mask adjusters caused fewer problems for the firefighters than the mask straps. The adjusters were found to be awkward to use because of their rather small size. Some of the metal adjusters were found to distort during use as the metal was not sufficiently rigid. Some of the problems attributed to the adjusters related to the interaction between the adjusters and the straps, in particular the straps working loose and/or disconnecting from the adjuster. Some wearers also found that the adjusters did not release the straps easily.

The newer sets were found to cause more problems for their users than the older sets, the main reasons being the addition of the extra strap and adjuster sitting over the forehead. The helmet of some wearers sits directly on top of the adjuster causing it to press into their scalp. This interaction could easily be designed out if the helmet was taken into consideration during the design stage. The adjusters could be located to sit over the head rather than the forehead so that the helmet does not press the adjuster into the scalp. This problem could also be reduced by thickening the forehead strap so that there is increased padding between the adjusters and the scalp.

The harness adjusters caused fewer problems for wearers than did the straps. Not surprisingly the problems caused by the harness adjusters were very similar to those of the mask adjusters, the respondents finding that the straps were particularly inefficient when wet or soiled. The other problem mentioned was caused by equipment covering or sliding down over the adjusters, so that it was difficult for users to locate them. The easiest method of preventing equipment obscuring the end of straps is to design in specific anchor points, either on the straps or on the tunic, at locations where the equipment will not cover or slip over the strap adjusters.

Problems caused by the helmet. The interactions between the helmets and the BA sets were found to be a major source of problems for firefighters. The most frequently mentioned problem related to interaction between the facemask and helmet. It is not possible for both the helmet and the facemask to sit in the correct position when worn in combination. If the facemask is positioned correctly on the face, then the helmet is pushed up at the front; conversely if the helmet is positioned correctly, then the facemask is pushed downwards. A further interaction problem was caused by the adjustment of the neck strap of the helmet. If this strap was fully adjusted it pulled the helmet down on to the forehead, thereby displacing the facemask and causing the seal to be broken. However, if the helmet was not properly adjusted the helmet fell off when the firefighters bent forwards/downwards. These problems could be alleviated completely by taking into consideration at the design stage that the equipment will be worn in combination with another piece of equipment and that they need to be compatible, in order to function as effectively in combination as they would on their own. The issue of compatibility is now covered in Regulation 5 of the European Directive on Personal Protective Equipment at Work. Regulation 5 states that: "every employer shall ensure that where the presence of more than one risk to health or safety makes it necessary for his employee to wear or use simultaneously more than one item of personal protective equipment, such equipment is compatible and continues to be effective against the risk or risks in question".

Problems caused by the tunic. The bulk and size of the tunics were found to cause problems. The tunics bunched up when the BA waist straps were adjusted. The bulk and number of layers of material in the tunics caused metabolic heat produced by the wearers to be trapped within the tunic. This caused the firefighters to heat up relatively quickly, giving rise to discomfort, especially during the summer months.

The firefighters felt that the problems caused by the tunic, when putting on and adjusting the BA, could have been reduced by taking into account the personal protective equipment (PPE) used in combination with the tunic when the garment was being designed. Currently the straps of the BA sit over the inner pockets of the tunic resulting in the contents of the pockets being pressed into the chest of the wearer. These inner pockets are also difficult to access after the BA set has been donned. The inner pockets in particular could be relocated to the bottom of the tunic so that they can easily be accessed even when the chest and waist straps have been secured.

Using the BA.

Discomfort caused by the set - The seal of the facemask was found to cause a number of problems for wearers. The facemasks are of one size only which causes problems for people with slim faces. Several firefighters commented that a good seal was difficult to attain unless the mask straps were pulled tight which was uncomfortable for the wearer. The greatest leakage from a facemask was due to the build up of sweat on the skin causing the mask to slip. In order to overcome this problem the firefighters again had to have the straps pulled very tightly. The seal between the mask and the wearer's face caused discomfort because of the lack of padding around the seal. This was commented on in particular by Draeger P112 users. The oro-nasal mask of the various facemasks caused discomfort for firefighters with large noses as the mask cut into the bridge of the nose.

The discomfort caused by the oro-nasal mask and the seal of the facemask could be reduced by the use of a more pliable, softer rubber than is currently used. The leakage of the facemask could be overcome to an extent by the use of a range of sizes of masks particularly for those who have masks that are currently too large for them. The problem of the seal slipping when sweat builds up on the skin may be reduced by applying a non-allergenic hydrophobic solution to the seal prior to donning.

The main comments made about the backplates of the sets related to the lack of contouring and padding, which caused users to feel discomfort when wearing the sets for prolonged periods. A number of the sets had straight backplates that were not contoured to the natural curves of the spine. Such backplates tended to cause discomfort particularly when wearers were bending. As the backplates were of one size only, any firefighter who was not of "average" dimensions found the backplate uncomfortable as it was either too long or too short and dug into the back.

As previously mentioned, many of the problems associated with the backplate could be reduced by the introduction of adjustable and more flexible backplates that contour to the shape of the back. The backplate was considered to be too wide by some firefighters but this factor was dependent upon which BA set was worn; for example, Interspiro Spiromatic was found to have a wider backplate than the other sets. In terms of the position of the cylinder on the backplate, Siebe Gorman FF1 and FF2 held the cylinder high on the back thus increasing the weight carried by the upper torso, which in part explains the reason for the high levels of minor problems reported by the wearers of these sets, such as the top of the cylinder catching on overhead obstructions.

The problems caused by the straps when the set was being used were due mainly to the weight of the set and have been mentioned previously. The buckles of the BA sets were found to cause few problems for the firefighters.

Most of the comments that related to other parts of the set referred to the high pressure hose to the facemask. The hose tends to push the facemask out of position when the wearers move their heads to the side where the hose attaches to the mask. Because of the inflexibility of the hose it tends not to move when the wearers move their heads, which results in the facemask being displaced.

Using BA with standard issue clothing. Of all the standard issue clothing the gloves caused the most problems for firefighters: more than 50% experienced problems in using the BA set whilst wearing them. However, the problems identified relate more to the gloves themselves than to the interactions between the sets and the gloves. The one problem that did occur when the set was being used was that of trying to operate the controls of the set when bulky gloves were worn.

The main concern of the wearers was that the size and bulk of the gloves reduced the sense of touch, movement and grip. The inability to identify small objects and differences in materials caused the firefighters concern. The inner lining of the gloves was found to gather in the fingertips making it difficult for firefighters to fit their hands in properly.

As the gloves are not water resistant they get wet very quickly which further reduces the tactile sense, particularly if the wearer's hands are cold. After wetting, the gloves become very stiff when dried out.

There is no one solution to the problems caused by the gloves as firefighters work in a variety of situations which have different requirements for hand protection. For example, when firefighters are working in an area where there is a large amount of metal work present, heavy leather gloves would be used to prevent wearers burning their hands. However, if a firefighter was trying to find a casualty, thinner gloves would be preferable to allow the firefighters to distinguish the body from other objects. One solution to this problem is to issue firefighters with a range of gloves which could be kept on the appliance and selected upon reaching the incident.

Most of the problems caused by the tunic, that the firefighters encountered, have already been mentioned in the preceding section. The only remaining problem that firefighters found with the tunics was their tendency to ride up the back during crawling whilst wearing BA. However, since the introduction of the new A26 specification tunics, this problem has been reduced, but another has developed to a lesser extent. The longer length A26 tunic has been known to get caught under the knees of wearers when crawling.

The most common complaint caused by the helmet interacting with the BA was the back of the helmet catching on the top of the cylinder during work in confined spaces. All the other problems with the helmet relate to the design of the helmet itself. For example, a number of firefighters found that the comb of the helmet caught on overhead projections. However, the new generation of helmets no longer have the comb, thus reducing this problem, although some of the helmets still tend to sit high on the head. The new visors have been found to impair vision when worn over a BA facemask.

Putting on BA with special protective clothing. The first problem that firefighters encounter with splash suits is putting them on, which is difficult to do without assistance. Once the suits are donned firefighters find it difficult to put on BA sets due to the bulkiness of the suits. Problems were also found in positioning the mask under the hood and obtaining an air tight seal.

Gastight suits were found to cause fewer problems than the splash suits probably because the BA set and facemask is encapsulated within the suit, so there is no chance of contamination or leakage around the facemask. As for the splash suit, the wearers of the gastight suits have to be given help in putting them on, particularly over the cylinder of the set. The older suits are difficult to put on as the material becomes very stiff. A major problem with these suits is that they and the integral rubber boots are of one size only. For firefighters who are either particularly tall or small the suits are uncomfortable to wear.

The main problem resulting from interactions between the set and the suit was caused by the weight of the suit pulling the helmet down over the head. The helmet in turn displaced the facemask causing leakage into the suit. This is particularly awkward for the wearer as it is difficult to reposition the mask once they are fully kitted up in the suit.

Using BA in combination with gastight suits. Some firefighters consider the gastight suits to cause greater restriction of movement than splash suits. These suits do cause greater problems for communication as the firefighter has to talk through both a facemask and also the suit itself, making communication difficult. Firefighters found it difficult to read the gauge unless they removed their arms from the sleeves of the suit and twisted the gauge around. The remaining comments referred to the problems caused by the body heat and cylinder air trapped within the garment for the duration of an incident. In combination these two factors caused both the facemask and the visor to steam up, resulting in the firefighter having to stop work and wipe the mask and visor, thus reducing the effective time available during an incident.

Interactions between the BA and personal issue equipment

Main guidelines - The problem identified with the main guidelines is the lack of attachment points for the guideline on the straps of the set. Currently the line is attached to the waist strap where it slides around the waist of the wearer making it difficult to pay out the line.

Radio - Two types of radio are currently used in the fire service, the hand held radio and integrated radios in facemasks. The main problems faced by users of the hand held radios are trying to use the controls when wearing gloves and the inability to hear/speak into the radio above the sound of the demand valve. The hand held radios have a neck strap that can be used. However, during crawling the radio swings forward and causes obstruction. Many of the problems caused by the hand held radio could be eliminated by using an integrated radio, although these radios caused other problems (see below).

The integrated radios have several wires that tend to catch on projections and become entangled during donning of the set. The position of the communication unit on the waist band was found to cause problems to some users. Comments were also made about the wires of the throat microphone transmitting heat and causing burns to the neck in hot environments. The microphone was also found to cause discomfort. A general point made was that at times it was difficult to hear the radio over the noise of the set during breathing.

3.3 Treadmill Test Results

3.3.1 Characteristics of participating firefighters.

The firefighters selected for physiological testing were drawn from twelve UK fire brigades:

nine from England, two from Scotland and one from Wales. One was a metropolitan brigade (London) and the remainder were shire brigades (Gloucestershire, Hereford and Worcester, Fife, Lothian and Borders, Humberside, West Yorkshire, Mid Glamorgan, Essex, Leicestershire, Oxfordshire and Kent).

Seventy two firefighters participated, all except four (from London) being male. Their average age was 31 years and the average number of years in the fire service was eight. Twenty six per cent of the participants smoked, their average height was 1.79m and average weight was 80kg. Further details, subdivided by type of BA, are given in Table 3.10.

3.3.2 Physiological responses to treadmill exercises

All firefighters participated in these exercises. Occasionally tests had to be cancelled, postponed or repeated owing to factors such as equipment failure, temporary unavailability and in one case blistered skin on the shoulders (from a fire simulation exercise) preventing the wearing of BA. There were 709 sets of data (test runs) out of the planned 720 five minute tests (ten per subject).

The firefighters achieved a steady state by the third (occasionally the fourth) minute of exercise (Table 3.11). The inspired air volumes, which were recorded cumulatively, were averaged over the third to the fifth minutes: this improved the accuracy compared to using the readings from the fourth or fifth minutes alone. Similarly, because of small variations in heart rate, which resulted from 5 second averages at the end of each minute, the averages of the heart rates at the ends of the third, fourth and fifth minute readings of heart rate were used in the subsequent analysis. The respiratory exchange ratio (volume of CO_2 expired to volume of O_2 absorbed) reached the expected 0.85 at the fourth minute on average and continued to increase to 0.88 (range 0.67 - 1.35) by the fifth minute, indicating that a steady state of exercise had been achieved.

Physical fitness of selected firefighters. The four test runs on the treadmill in which the subjects wore only tee shirts, shorts and training shoes (PE kit) were intended to provide enough information for an indirect maximum oxygen uptake (Vo_2 max) to be derived. This technique, which relies on the relationship between heart rate and Vo_2 over the linear range of the HR/Vo_2 relationship being extrapolated to an assumed maximal heart rate, avoids exercising subjects to their actual Vo_2 max. However, because all subjects exercised at the same treadmill speeds and gradients, the higher workloads were often well within the fitter firefighters' aerobic capacity, thus rendering less reliable an extrapolation to maximum values. Nevertheless, calculation of indirect Vo_2 max gave an average of 3.7*l* min^{-1} or 46.4ml kg min^{-1}, when corrected for body weight. This latter figure compares to the 45ml kg min^{-1} recommended for firefighters who are tested according to the current guidelines (Home Office, 1988).

During the treadmill tests, particularly at the steepest gradients (7.5%) when clothing and BA were being worn, the heart rates were compared by the observer to the expected age related maximum (based on the equation Max HR = 220 - age). If the measured heart rate approached or exceeded 85% predicted maximum during a test, the subsequent test would be carried out at a less steep gradient (5%). On a few occasions it was possible to do this but on several other occasions, when the gradient was increased from 2.5% to 7.5% during clothing and BA tests, it was difficult to estimate whether the heart rate would exceed the 85% predicted value. In these cases the tests continued, if the participant appeared otherwise in good order and was willing to continue. Although these tests were not intended to take individuals to their maximum heart rates, three subjects all did exceed their predicted maximum at the highest workload.

Oxygen uptake. Effects of wearing firekit and BA.

Table 3.12 shows the oxygen uptakes (Vo_2) of all participating firefighters according to their brigade and the type of BA they were wearing.

Firekit - There was very strong evidence of an increase in oxygen uptake when firekit was worn (compared to PE kit). There was no significant interaction between firekit and treadmill gradient nor was there any significant difference between the standard Nomex and lighter weight firekit. On average, Vo_2 increased by 0.34l min^{-1}, with a 20% rise from 1.5 to 1.8l min^{-1} at the 2.5% gradient, and a 15% rise (from 2.0 to 2.3l min^{-1}) at 7.5%, not significantly different. Overalls, worn by the two Kent Sabre SEFA teams, increased Vo_2 by about half that of other fire kit (table not shown) and, after adjusting for effects of BA, there was found to be a significant difference between overalls and firekit on Vo_2 (t ratio = 4.4). Statistically significant variations in the effect of firekit from person to person were also observed ($P < 0.1\%$), although these were small relative to the average effect of firekit.

Breathing apparatus - The effect of wearing BA was to increase Vo_2 by an additional 0.3l min^{-1} at a gradient of 2.5% to 2.1l min^{-1}, giving a total rise of 40% from the no kit condition. At a 7.5% gradient the total increase was 0.7l min^{-1} to 2.7l min^{-1}, a rise of 35%. The additional physiological response caused by wearing BA with a lightweight cylinder instead of the standard cylinder was slightly less: increases to 1.9 and 2.6l min^{-1} respectively.

Overall, the Vo_2 increase caused by wearing BA additional to that related to firekit, averaged 0.33l min^{-1}. This increase was highly significant (at 0.1%). When the lightweight cylinder was worn the increased Vo_2 was 0.21l min^{-1}, a significantly smaller increase. However, there was no difference in Vo_2 between those wearing 1800l and 2250l cylinders. There was very strong evidence of a larger increase in Vo_2 caused by BA at the steepest slope (7.5%) compared to the increase at the lower slope of 2.5% indicating that the physiological cost of carrying additional loads increases disproportionately as the vertical component of the exercise increases.

Type of breathing apparatus - There was a highly significant effect of type of BA on Vo_2, Sabre Centurion wearers requiring about 0.1l min^{-1} less Vo_2 than those using the other OCBA types. Although not apparent in Table 3.12, after allowance for other factors had been made, the Sabre SEFA required a slightly higher O_2 demand (Vo_2 was 0.01 to 0.10l min^{-1} greater depending on the set compared) than the four OC types but these differences were only statistically significant when comparing with Sabre Centurion or with the lightweight cylinder tests.

There was also strong evidence of slightly different effects of BA from person to person and also variations in the effect of the lightweight cylinder from person to person.

Additional effects - There was strong evidence of a lower Vo_2 (about 0.07l min^{-1}) for the first exercise in a session, having adjusted for the effects of treadmill gradient; an effect which was absent on Mondays, the first session of the week. These effects and other day to day differences were allowed for before the investigation of differences related to firekit and BA described above.

Heart rate. Effects of firekit and BA.

Table 3.13 shows the heart rates for each brigade sub-divided by BA type for exercises with and without firekit and BA.

Firekit - At a gradient of 2.5% the overall effect of wearing firekit was to increase the heart rate from 107 to 118 beats min^{-1}, just over 10%. At the steeper gradient of 7.5% the heart rate increased from 124 to 140 beats min^{-1}, about 13%. Adjusting for other effects the statistical analysis showed a highly significant effect ($P<0.1\%$) of firekit, which caused an average increase of 17 beats min^{-1}. As for Vo_2, there was no significant difference between standard Nomex firekit and lighter weight firekit, and wearing overalls gave rise to a heart rate increase about halfway between PE kit and firekit. There were also highly significant ($P<0.1\%$) but small variations in the effect of firekit from person to person.

Breathing apparatus - The effect of wearing BA as well as firekit at a gradient of 2.5% was to increase the heart rate by 26 beats min^{-1} to 133 beats min^{-1}, a rise of 24% from the no firekit/no BA condition. At 7.5% the equivalent increase was 34 beats min^{-1} to 158 beats min^{-1}, a rise of 27%. When the lightweight cylinder was attached to the BA the heart rate rose slightly less, to 128 beats min^{-1} at 2.5% and 152 beats min^{-1} at 7.5% respectively. The statistical analysis showed a highly significant effect (at 0.1%) of BA, compared to wearing firekit alone. The increase in heart rate resulting from the wearing of the BA was 17 beats min^{-1}. The increase when the lightweight cylinder was used (12 beats min^{-1}) was significantly smaller. There was again no difference between 1800*l* and 2250*l* cylinder wearers. There was a greater increase in heart rate (statistically significant at the 0.1% level) at the 7.5% compared to the 2.5% gradient. However, there was no significant effect of type of BA on heart rate.

There was a significant person by BA and person by cylinder type interaction, indicating evidence of slight variations in the effects of BA and lightweight cylinders from person to person.

Additional effects - As for oxygen uptake there was again strong evidence that heart rates were lower (by 8 beats min^{-1}) for the first exercise in a session than for subsequent ones, following adjustment for gradient. Account has been taken of the first exercise and other day to day effects when analysing the data.

Summary - BA and full firekit contributed equally to significant increases in heart rate and Vo_2 during standardised treadmill exercises. Overall Vo_2 rose by 35 to 40% and heart rate by 24 to 27% when BA was worn with firekit. Sabre Centurion wearers expended 0.1*l* min^{-1} less Vo_2 than those wearing the other types of OCBA.

3.4 Fire/Rescue Simulation Tests: physiological response

3.4.1 Short duration fire/rescue exercise

Environmental conditions during tests. Although the same size of fire, using the standard crib, was set prior to each exercise the evidence from the 12 temperature monitoring points around the circuit indicated that there were considerable variations in temperature at the same monitoring points during the course of the combustion process. Figure 3.1 shows several different temperature profiles during different exercises demonstrating not only different temperatures achieved at the same points but also the variation in the pattern of temperature build up and decline.

It is assumed that this was caused by wood having different moisture content, fuel being set in the fire cradle in different ways, draught (related to door and hatch openings and wind direction) and whether a previous fire had just been extinguished from an exercise earlier in the afternoon. However, even if the temperature patterns had been identical each team would have experienced a different set of temperature conditions because they would have arrived at these monitoring points at different times in the combustion process.

An attempt was made, therefore, to classify the environmental conditions during each exercise using information from these temperature profiles in the following way: **1)** The average temperature during the first five minutes of measurement in the upper hold area was taken to represent the conditions experienced by the team in this area. **2)** The temperature at the top of the vertical shaft between the two holds at 15 minutes was considered to represent the conditions experienced by the teams as they descended to the lower hold. **3)** The average temperature during the five minute period before the end of the exercise was taken to represent the conditions experienced in the lower hold.

Temperature profiles were sufficiently complete or reliable for thirteen of the eighteen teams tested, which allowed the environmental conditions, estimated to be experienced by these teams, to be quantified. The upper hold temperatures were on average 48°C (range 40-60°C), the shaft average temperature was 100°C (range 60-130°C) and the lower hold temperature average 116°C (range 75-175°C) at the times specified above. Because the shaft and lower hold temperatures were so variable, the teams were subdivided into three groups, assessed as being exposed to relatively high or low temperatures. This subdivision was made as follows:

Lower hold temperature in last 5 minutes	**Brigade teams**
< 100°C	Kent 1, 2 and 3, Essex 2
100-150°C	Essex 1, Mid Glamorgan, London 2 and 4, Gloucestershire and Lothian & Borders
> 150°C	Oxfordshire, Leicestershire and London 1
Unknown (insufficient information)	Humberside, Hereford & Worcester, Fife, London 3 and West Yorkshire

These figures are shown in order to demonstrate the difficulty of reproducing identical conditions for even a nominally well controlled simulation of a fire/rescue exercise.

Duration of exercise. When this exercise was being planned, it was believed that the teams would be able to complete the course in 20-30 minutes, based on trial runs using college staff traversing the route slowly and deliberately. However, following the first two exercises using brigade teams of firefighters, it became clear that this time was likely to be an underestimate, owing to unfamiliarity and the variable experience of the team members. Furthermore, the temperature conditions were sufficiently severe, given the longer period of exposure, to cause one or more team members to be withdrawn for safety reasons by the attending safety officers in these early exercises. Hence, a decision was taken after the first week's experience that the IOM scientist in charge would give instructions to terminate the exercise on safety grounds, if it appeared that the team was unlikely to complete the exercise within 30-35 minutes. The safety officers present in the firehouse also continued to have overriding control to withdraw any firefighter from the building if he or she was in difficulty. Therefore the duration of the exercise for each team was influenced by a number of factors and none of the teams completed the exercise as originally planned and described.

The duration of the exercise (ie. time from entering upper hatch to emerging at any exit) is shown for each team in Table 3.14. The times ranged from 19 minutes, for the Humberside team wearing Siebe Gorman FF2, to 40 minutes, for the Kent No. 2 team wearing the Sabre SEFA closed circuit set. On average the teams were in the firehouse for 29 minutes and the times also varied according to the type of BA being worn. The six teams wearing Siebe Gorman FF2 sets averaged 25.5 minutes (range 19-30 minutes), whereas the two Kent Sabre SEFA teams averaged 35 minutes, the other BA teams being intermediate.

Aural and skin temperatures. The average initial and final aural and skin temperatures for each team are shown in Table 3.14, subdivided by type of BA worn during the exercise. It can be seen quite clearly that the aural temperatures, representing deep body temperatures, reached very high levels in some cases. Overall the aural temperature averaged 39.7°C; ranging from 39.3°C, the average for wearers of Draeger P112, to 40.0°C for wearers of Sabre Centurion and Interspiro Spiromatic sets. The team with the highest final aural temperature (40.3°C) was Essex No. 2 wearing Interspiro Spiromatic and the highest individual value (41.5°C) was a member of the Kent 2 team wearing Sabre SEFA. The differences between the BA sets are, however, not statistically significant.

The increase in aural temperature during this exercise averaged 3.0°C, ranging from 1.7°C to 4.0°C for individual teams. Sabre Centurion wearers experienced the highest average increase of 3.4°C. It is therefore not surprising that some of these firefighters were very close to physical collapse when they were withdrawn, although it should be emphasised that normal safety procedures drawn up by the college were followed throughout these exercises. Again these differences between BA sets are not statistically significant.

Skin temperatures, particularly those on the back, also rose to high levels. Back temperatures averaged 41.4°C at the end of the exercise; chest and thigh temperatures were somewhat lower, averaging 39.6°C and 39.1°C respectively. Three teams had back temperatures equal to or higher than 43°C and two members of one of these teams (London No. 2) experienced burns (raised blisters) under the shoulder straps of the BA during the test. One of these men was not able to carry out subsequent tests (treadmill or firehouse) involving use of BA.

Wearers of Draeger P112 on average experienced skin temperatures at all three sites about 2°C lower than wearers of other open circuit sets, whereas their aural temperatures were very similar. In other respects there did not appear to be any obvious differences in skin temperatures between wearers of different BA. Kent No. 1 team had lower aural and skin temperatures principally because they did not reach the lower hold where the environmental temperatures were much higher.

Heart rate. The heart rates of participants in the short duration exercise are shown in Table 3.15 for each team subdivided by type of BA. Figures 3.2 to 3.4 show selected continuous heart rate recordings (averaged over 30 second periods from successive 5 second averages) for individual firefighters. These figures show generally steady and continuously increasing heart rates as the exercise progressed. It was not possible to indicate at which point particular activities incurred. However, the declining heart rates at the end indicate emergence from the ship.

Very high heart rates were achieved by most of the firefighters, 147 beats min^{-1} on average. Thirty three (50% of those with available readings) had maximum heart rates greater than 200 beats min^{-1}. Furthermore, the highest team average heart rate was 161 beats min^{-1} (Gloucestershire using Sabre Centurion). The heart rates before entry through the hatch leading to the building, during which minimum heart rates were observed, were themselves often very high, up to 137 beats min^{-1}; the average minimum being 101 beats min^{-1}.

The two Kent teams, wearing Sabre SEFA closed circuit sets, tended to have lower heart rates (average HR = 134 beats min^{-1}, average maximum HR = 178 beats min^{-1}). This was principally due to their much slower, deliberate pace consistent with their normal training: consequently, they did not progress as far as the other teams. Kent 1 did not even reach the lower hold where the fire was burning and were not exposed to the much hotter conditions experienced by the other firefighters.

Air consumption. The volume of air consumed by firefighters, based on the change in pressure of the air cylinder during the exercise, was 1250 litres on average for users of open circuit sets. This is equivalent to a minute volume of 43*l* min^{-1} at 20°C (or 47*l* min^{-1} at normal body temperature (37°C), the condition at which minute volume is usually expressed). Comparison of the volumes derived from changes in cylinder pressure with volumes derived from changes in cylinder weight gave the same air consumptions on average. Figure 3.5 shows the generally expected relationship between air consumption and duration.

When these air consumptions are expressed as minute volumes at body temperature (total volume divided by duration of test) the teams wearing Sabre Centurion had a lower minute volume on average (42.8*l* min^{-1}) than wearers of the other types of BA (Table 3.16), whose average minute volumes ranged from 48 to 50*l* min^{-1}, although again these differences were not statistically significant.

Sweat rate. The change in body weight during the exercise was assumed to be entirely due to the loss of sweat. When allowance had been made for any liquids drunk immediately after the exercise, sweat losses ranged from 0.3kg to 2.3kg, equivalent to approximately 300-2300ml (Table 3.16). On average 1.22kg of sweat was lost during the exercise, equivalent to a sweat rate of 2.5 litres per hour, which is a very high rate indeed.

Although there was large variation in the sweat loss within each BA type, only the Sabre Centurion and Sabre SEFA groups had higher than average sweat losses (rates). Interestingly, the Kent No. 2 team's sweat rate averaged 3.50 litres per hour compared to the rate (2.18 litres per hour) of the Kent No. 1 team, who did not reach the much hotter lower hold area.

3.4.2 Gastight suit/chemical spillage exercise

Environmental conditions during tests. The temperature in the lower hold area was controlled to approximately 30°C throughout the exercise (Figure 3.6) by means of gas fired space heaters. Occasionally the gas supply ran out during the test or the background temperature was slightly higher or lower than usual, resulting in a variation in environmental temperature within the range 23°C to 38°C. This did not appear to have a significant physiological effect on the body temperatures.

Aural and skin temperatures. The temperatures immediately before and at the end of this exercise are shown in Table 3.17. It can be seen that aural (body) temperatures only rose to modest levels, on average to 37.6°C and did not vary significantly according to the type of BA being worn. The average increase in aural temperature during the 20 minute exercise was 1.2°C and only the Siebe Gorman FF2 group were noticeably lower than this.

The temperature of the skin measured on the back increased on average by nearly 3°C to 35.7°C. In this case there was slightly more variation between BA groups, the Siebe Gorman FF2 group showing a much smaller increase (2.0°C) compared with SEFA wearers (4.7°C). The SEFA set, which generates considerable heat via the exothermic reaction of the CO_2 absorbent, would be expected to increase the temperature in the back region under these conditions. The skin temperatures measured on the chest and thigh (35.8°C and 35.3°C respectively) were very similar to those on the back and did not vary significantly from one BA type to another: only thigh temperature for Draeger P112 wearers averaged lower than 35°C (Table 3.17).

Overall this exercise gave rise to a relatively small increase in body temperature during the intentionally limited period of measurement recommended by FSC staff. However, there is a clear indication that body temperature would have continued to increase at an accelerating rate (Figure 3.6) and the gradual convergence of skin temperatures at all three sites suggested an increasing difficulty for heat loss to occur under the conditions of this exercise.

One of the SEFA teams (Kent No. 1) experienced the most marked physiological response, because either the final temperature or the change in temperature was the highest of all the teams at each of the four measurement sites. Within the groups wearing the open-circuit type of BA the Spiromatic group tended to have slightly higher aural and skin temperatures than the other three groups, although these differences were not of statistical significance.

Heart rates. The heart rates during this exercise were on average considerably lower than in the previous exercise (Table 3.18). The average maximum heart rate of all the teams was 173 beats min^{-1} and five firefighters reached levels as high as 200 beats min^{-1}. The differences between the teams wearing different types of BA were not great: the average maximum heart rate ranging from 170 beats min^{-1} for Sabre Centurion to 178 beats min^{-1} for Spiromatic sets.

The heart rates continued to increase during successive stages of this exercise, ie. following each (approximately one minute) rest period, during which aural and skin temperatures were monitored. Figures 3.7 to 3.9 show some examples of the heart rate pattern during the course of the exercise, demonstrating both the nature of the intermittent work regime (5 minutes work, 1 minute rest) and the individual variations in physiological response to the exercise, even during the same test.

Air consumption. The average air consumption derived from pressure readings during this exercises was 1360 litres (Table 3.19) which is equivalent to a minute volume of 67*l* min^{-1} at room temperature over the 20 minutes of the exercise. However, the air supply had to be connected to the wearer and switched on before the gastight suit was sealed and the firefighter was taken to the test area; at the completion of the exercise firefighters had to be removed from their suits before the air supply could be switched off. Allowing ten minutes for these actions at an assumed minute volume of 20*l* min^{-1} would leave approximately 1130 litres to be used in 20 minutes equivalent to a minute volume of 57*l* min^{-1} (63*l* min^{-1} corrected to 37°C).

There was a somewhat lower air consumption among Siebe Gorman FF2 wearers (1210*l*) than among the other groups of open circuit BA wearers (1360, 1360 and 1520*l* respectively for Draeger P112, Centurion and Spiromatic).

Sweat rate. The change in body weight during this exercise was 0.63kg on average, equivalent to an approximate sweat loss of 630ml and a sweat rate of about 1.9 litres per hour. Although some of the data were unavailable for two teams in the first week, the Spiromatic group showed the highest values compared with the other groups of open circuit BA wearers (Table 3.19).

In summary, there was some indication that the SEFA wearers had slightly greater increases in body and skin temperatures. Among wearers of open circuit sets the Spiromatic group tended to experience a greater physiological strain than the other groups during the gastight suit exercise, although none of these differences reached a level of statistical significance.

3.4.3 Long duration fire/rescue exercise

Environmental conditions during tests. As described in section 3.4.1 for the short duration tests, there were similar difficulties in reproducing identical environmental conditions for each team in the areas of the Ship used during this exercise. Temperatures were monitored throughout the exercise from 10 fixed points as described in section 2.2.5 but, owing to the malfunction of thermocouples on several occasions (damage by fire or contact; broken connections), environmental temperature data were unavailable for some teams altogether and from other teams the data were sparse. It was not practicable to repair the damaged thermocouples during these exercises, because of other college activities in the area.

However, during seven of the nine exercises at least some temperature readings were available; these have been averaged for each of the four phases of this exercise. Figure 3.10 shows temperature profiles from six monitoring points, two very close to the fire, four further away.

In general, the temperature in the area of the fire rose to about 260°C during the first stage and fell fairly rapidly to about 60°C during the final stage. The temperatures measured during each stage partly depended on the speed at which the participating teams traversed the route.

Duration of exercise. Although the two teams carried out this exercise at the same time, they entered a few minutes apart and to all intents were operating independently of each other. On no occasion did one team catch up with the other team or affect its performance but one team did sometimes emerge at the deckhouse monitoring point at the same time as the other team emerged for a cylinder change, which itself took several minutes. Table 3.20 shows the times each team took to complete each stage, the cylinder change (except for SEFA teams who were given a nominal change over time) and the total time of the exercise.

The total time taken to complete the exercise was 65 minutes on average and ranged from 52 to 89 minutes; the cylinder change-over averaged 6 (3 to 12) minutes and the total time less the change-over time was 59 (46-86) minutes. The duration of the change-over depended on the ease of replacing the air cylinder and the availability of trained personnel: it was also relevant because the cylinder change took place in the open air and allowed the firefighters to cool down to a variable extent dependant on the external temperature, wind speed and rainfall. Such variability was unexpected and could not have been allowed for by the research team, as it depended largely on the requirements of other courses taking place at the Fire Service College at the time of these exercises.

Having allowed for the change-over time the total duration of the exercise differed from one BA group to another. The quickest on average were the Siebe Gorman and Spiromatic groups (53 and 50 minutes respectively), followed by the Sabre and Draeger groups (61 and 62 minutes). The first and second SEFA groups were very different from each other, taking respectively 56* and 86 minutes. (* - this team were withdrawn at 47 minutes [see below] and the time to completion has been estimated).

Aural and skin temperatures. The aural temperatures rose steadily during this exercise from 36.5°C at the start to 37.1°C at the first check point after 12 minutes, 38.0°C at the change-over (30 minutes), 38.1°C after 52 minutes and 38.2°C at the end (Table 3.21a). The highest individual temperature reached was by a SEFA user (39.7°C). Clearly the body temperature increased most rapidly by 1.5°C on average during the first complete circuit of the course (stages 1 and 2) when environmental conditions were most severe. During the second circuit, when the firefighters had partially cooled down and the environmental temperatures were much cooler, the aural temperatures only rose by another 0.1°C. Because of the high aural temperatures (average 39.5°C) experienced by the Kent No. 1 team the whole team were withdrawn before the final stage of the exercise for safety reasons.

The final aural temperature reached by the different OCBA groups was lowest in Siebe Gorman wearers (37.8°C). The SEFA group's final temperature averaged 38.7°C. Because these final temperatures might have been affected differentially by the change-over duration and conditions, comparison has also been made between aural temperatures after the first complete circuit. The same relative pattern is shown again: Siebe Gorman users having the lowest temperature (37.8°C), Spiromatic and SEFA users having the highest (38.2°C). These latter two groups also had the largest temperature increases (2.2°C) compared to the other groups (Table 3.21a).

The skin temperature showed a similar pattern to the aural temperatures during the first two stages, increasing by 3.5°C to 38.1°C on the back, for example (Table 3.21b-d). However, following the change-over skin temperatures fell by just over 1°C, indicating that additional evaporative cooling was taking place. This pattern of steady cooling of skin surfaces was observed for all BA groups except for the Spiromatic group whose back and chest temperatures continued to increase slightly during the second (return) circuit.

Heart rate. Heart rates during this exercise were intermediate between those of the previous two exercises reflecting the balance between its less intense physical workload and intermittent exposure to very hot conditions over a longer timescale (Table 3.22). The average maximum heart rate was 186 beats min^{-1} and ranged from 170 beats min^{-1} for Humberside using Siebe Gorman FF2 to 199 beats min^{-1} recorded by both London No. 2 (Siebe Gorman) and Lothian and Borders (Draeger P112). The average heart rate for all teams was 141 beats min^{-1}, ranging from 124 beats min^{-1} for Humberside and Kent No. 2 (Sabre SEFA) to 157 beats min^{-1} for London No. 2.

The pattern of heart rate change in relation to the course of the exercise is shown in Figures 3.11 and 3.13, which demonstrate that the heart rates increase steadily during the course of the exercise, sometimes to very high levels at the finish, over 190 beats min^{-1} in some cases. The low points coincide with intervals during which the teams emerged on deck for temperature and cylinder pressure measurements to be made: the decreasing heart rates at the end of the recordings represent varying periods of recovery.

Air consumption. Approximately 1180 litres of air were used during both the outward and return circuits of this exercise (Table 3.23). Individual teams' air consumptions ranged from 670 litres for Humberside (Siebe Gorman FF2) to 1920 litres for Lothian and Borders (Draeger P112) during the outward circuit. On the return circuit the air consumptions were less variable, ranging from 830 to 1500 litres. Over the two circuits the air consumptions ranged from 1750 litres to 3000 litres.

Although the highest and lowest air consumptions coincided with the second longest and the shortest exercise durations there was not a very close relationship overall between consumption and duration (Figure 3.14). In relation to the type of BA worn the two Draeger P112 teams with complete data had the highest air consumption (2610 litres on average in 68 minutes) and the six Siebe Gorman FF2 teams had the lowest (2070 litres in 53 minutes on average). Overall, the air consumptions are equivalent to average minute volumes of about $42l$ min^{-1}, close to the nominal consumption rate of $40l$ min^{-1} used by the fire service to limit the duration of an operation. (This is equivalent to about $46l$ min^{-1} at normal body temperature). Spiromatic users had higher minute volumes on average.

Sweat rate. On average body weight fell by 1.4kg during the complete exercise, approximately equivalent to 1.4 litres of sweat production (Table 3.23). The highest sweat loss was observed among the Kent No. 2 team (SEFA), which lost 2.1 litres on average, and the lowest value was found in the Humberside team (0.9 litres). These teams also had respectively the longest (86 minutes) and shortest (43 minutes) times for the exercise and the equivalent sweat rates are therefore 1.46 and 1.26 litres per hour respectively. The BA group which had the highest sweat loss is the SEFA group at 1.9 litres, followed by the Spiromatic group at 1.5 litres, the other three teams being about 1.2 litres each.

Summary - The short duration and, to a less extent, the long duration fire/rescue exercises caused these volunteer firefighters to experience extreme physiological responses: many individuals having heart rates over 200 beats min^{-1} and body temperature greater than 40°C. Perhaps because of the severe conditions, the relatively small differences in physiological response between wearers of different types of BA were not of statistical significance.

3.5 Ergonomic Assessments of BA

The main factors investigated focused on the weight, bulk and weight distribution of the BA. In addition, harness configuration, shape and weight of the back plates were also evaluated.

3.5.1 BA weights

In order to make a true comparison between BA set weights, the same number of optional items of equipment extras were attached to the BA before the set was weighed. As there were many different types of cylinders compatible with each BA, in terms of charging capacity and duration, the weight of the BA sets was considered without the compressed air cylinders. For the comparisons of weight, sets included the standard personal line, distress signal unit (DSU), back plate with BA harness and face mask. Weights for each set (ie, excluding the air cylinder) are shown in Table 3.24.

Draeger P90, the new BA set intended to replace the P112, was not included in this study as it only became available on the market after the initial study had commenced.

Table 3.24 shows that the heaviest set was almost 30% heavier than the lightest set. Although this additional weight is carried close to the firefighter's own centre of gravity, thereby minimising the load on the back, it will still have a significant additional effect on the overall physiological workload of the operator.

3.5.2 BA weight distribution

In order to establish the weight distribution of the different BA sets, measurements were taken of the cylinder location relative to the waist strap position. The waist/hip strap was chosen as the datum point, as its location along the spine falls close to the fulcrum point of the back. Consequently, the effect of the BA set weight on the operator could be expressed from the same pivotal point as the back muscles have to act to provide support and stability in different postures.

Because of the wide range of cylinder sizes and weights a standard cylinder dimension was used to compare the layout of the different sets. A 300 bar, 6 litre water capacity cylinder was selected with an overall length and diameter of 550mm and 140mm respectively. This cylinder weighed 10.8kg when fully charged. In the case of the BA set which operated with twin cylinders (Interspiro Spiromatic) the manufacturer's own cylinder dimensions were used in the comparison study. The twin cylinder weighed 16.5kg.

In order to describe the weight distribution pattern, two figures were derived. The first, called the first moment of inertia considers the effect of the cylinder weight on the user's (firefighter's) back while in the static position. In the upright position the weight acts behind the user's centre of gravity causing an extensor moment on the back (a tendency to arch the back rearwards). To counteract this force the user adjusts his posture by leaning forward so that the centre of gravity of the cylinder lies more directly over the weight fulcrum point [see Figure 3.15(i)]. The extent of the extensor moment depends on the weight and distance the cylinder acts from the user's own centre of gravity. (The resultant extensor moments are shown in Table 3.24).

The first moment of inertia can act on the back in different directions depending on the posture of the firefighter. If, as is likely, the firefighter is flexed forward then the cylinder weight will act in front of the operator's centre of gravity causing a flexor moment, ie. tendency to bend the back further forward.

Table 3.24 shows that the bending moments on the spine are very similar despite the twin bottle set being fitted with smaller diameter cylinders that are positioned closer to the user's centre of gravity. The advantage of having the set closer to the body (shorter length *l* in Figure 3.15(i)) was offset by the additional weight of the twin cylinders.

The second figure derived is a measure of the cylinder's location on the user during dynamic manoeuvres. This figure, called the second moment of inertia (I), is more representative of the types of activities a firefighter would encounter while attending an incident and/or undertaking training exercises. I is expressed as:

$$I = Mr^2$$

where M is the mass of the object being manoeuvred, in this case the BA set, and r is the distance between gravity centres (see figure 3.15(ii)). The second moment of inertia is a measure of the energy required to move the BA set while worn on the user's back, assuming constant angular speeds. Table 3.24 shows the value of I for the different BA sets.

This table can be conveniently separated into two groups; Draeger P112 and Sabre Centurion with low second moments and Interspiro Spiromatic, Siebe Gorman FF2 and Draeger P90, which have high values. For standard cylinder weight Draeger P112 and Sabre Centurion are located close to the operator's centre of gravity; therefore less muscular effort is required to move the firefighter's body compared to Interspiro Spiromatic, Siebe Gorman FF2 and Draeger P90, assuming all other factors are the same, ie. backplate design, harness configuration, padding and retention capabilities.

3.5.3 Backplate design

The shape, contour and flexibility of the backplate will influence the comfort and hence the perceived weight distribution of the BA sets. A poorly contoured and hard backplate will result in adverse comments on the set, even though its weight distribution may be well designed for the user. During measurement of the BA sets, specific observations were made on the shape, contour and backplate material.

Draeger P112 (Figure 3.16i)

1. Shape. When viewed from the rear the backplate is diamond shaped, closely matching the soft tissue areas of the human back. The lower edges of the backplate follow the bony prominence of the posterior region of the iliac crest (rear portion of pelvis) while the upper curved edges fits inside the raised scapular over the shoulder joints. This backplate is manufactured to fit comfortably onto the user as well as housing the cylinder.

2. Contour. From the side the backplate appears fairly flat in profile except at the ends. At the head end the plate is angled forward by 30° to account for the kyphosis in the thoracic region of the back. At the tail end the plate is bent rearwards by approximately 20° from the vertical to cater for the rearward protruding coccyx. In the lumbar region the plate is flat although at the edges it is slightly convex in shape to help align the belts around the waist. The waist belts are anchored at the edge of the backplate and do not slide across the small of the back.

3. Material. The shell of the backplate is made of stainless steel but its anterior surface is covered with a hard neoprene rubber material.

Interspiro Spiromatic (Figure 3.16ii)

1. Shape. This set offers a more rectangular shaped backplate when viewed from the rear. The width of the backplate is much wider compared to the Draeger P112 throughout its length.

2. Contour. In side profile the backplate is better shaped than the Draeger P112 with

the change in shape at the head and tail of the plate being smoother producing a better overall profile of the user's back.

3. Material. The backplate is made of "Vistaflex", a fairly flexible plastic material.

Sabre Centurion (Figure 3.16iii)

1. Shape. This backplate is shaped like a light bulb with the bulbous part of the plate covering the lower part of the back. The lower part of the plate is the widest of all the sets assessed although the width of the top part was similar to the Siebe Gorman FF2.

2. Contour. The side profile of the backplate is very flat along its entire length except at the ends where the plate is angled forward at the top end and angled rearward at the bottom. Towards its lateral edges in the lower part of the plate it is slightly convex to follow the waist profile. Along the flat part of the plate a square channel is moulded into the plate which gradually emerges from the front surface of the backplate. While this provides some support in the small of the back when upright, it tends to dig into the back when the user bends forward, as the lumbar lordosis flattens out. However, the waist belt crosses the width of the plate in the lumbar region to give some padding to the metal backplate protrusion.

3. Material. The entire backplate is manufactured from stainless steel.

Siebe Gorman FF2 (Figure 3.16iv)

1. Shape. The backplate is shaped like an inverted cross. The arms of the cross do not constitute part of the backplate but act as the hinged anchorage points for the waist and shoulder straps. Consequently the area of the backplate is relatively narrow compared with the other BA sets.

2. Contour. The backplate is very flat throughout its length except at each end of the plate. In the lumbar region the waist band loops across the front of the backplate.

3. Material. Like the Sabre Centurion it is also manufactured from stainless steel.

Draeger P90 (Figure 3.16v)

1. Shape. The shape is similar to that of the backplate of the Draeger P112. The backplate has been reduced in length but is provided with extra width.

2. Contour. A more lordotic curve was observed in the lumbar region but the contour is similar to the Draeger P112.

3. Material. Unlike the Draeger P112 all of the backplate is manufactured in rubber with the tail of the plate finished with a protective cover consisting of a softer type of rubber.

Sabre SEFA (Figure 3.16vi)

Unlike the other sets the SEFA set has no separate backplate. The back cover of the metal casing acts as the backplate. Consequently, it lies flat across the back in the lumbar region.

3.5.4 Backplate length

It was reported earlier in section 3.2.2 that the waist straps were in a poor position once the backplate had been comfortably located and the shoulder straps tightened. The waist strap tended to lie at hip level rather than higher on the wearer's waist.

Straps positioned at waist level can sit on the pelvic bone due to the narrowing of the torso in this region. This anatomical "ledge" allows the strap to hold its position without slippage. On the other hand, if the strap is positioned around the hips it is unable to hold its position unless excessively tightened. Even if the strap were tightened it would tend to work loose as the wearer's hips move even during walking. Subsequent slippage will cause the shoulder straps to support more of the BA set load.

An examination of the backplate dimensions and the anthropometric dimensions of a typical BA set user highlighted discrepancies which may explain the poor location of the harness straps. The evaluation enabled a more suitably sized backplate to be suggested with appropriate adjustment to meet the requirements of the majority of users.

The stature requirements for a firefighter are between 1.70m and 1.93m which covers approximately half the male (upper 50 percentile) and 1 in 20 (top 5 percentile) of the female population. Back lengths for the range of firefighter statures have been extrapolated from anthropometric tables of British Men and Women (Pheasant 1986) and are shown in Table 3.25. Backplate lengths measured for different BA sets are shown in Table 3.26.

BA set dimensions were measured from the top of the backplate, where shoulder harness straps are attached, to a level adjacent to the waist strap location. This dimension, as the usable length, would come into contrast with the user's back when the set was donned.

A comparison between the two tables shows that the current set of backplates are too long for the range of individuals using the equipment. Consequently the waist straps tend to fall over the hip region when the backplate is correctly positioned and the shoulder straps are tightened. The updated Draeger P90, which was not used in the initial study had the shortest backplate length which would suit the largest user (99th percentile male) but would still be too large for the smallest user (95th percentile female). In order to accommodate the largest percentage of users the distance between the shoulder and waist strap should be around 380mm with 20mm adjustment each side of this length. Designing the backplate to match the user would also have the benefit of reducing the weight of the BA set.

3.5.5 Harness design

All the sets had similar harness configurations, although there were some slight variations. Draeger P90 had independent anchorage points for the shoulder and waist straps, while the other sets had the shoulder strap branching off the main waist strap. The distance of the branch point from the centre line of the sets varied between sets but ranged between 200-240mm. The shoulder strap on the anchorage point on Draeger P90 was only 90mm from the midline and was inserted into the backplate. The branch angle again varied with different sets. Sabre Centurion was at 90° to the waist strap while Draeger P112, Spiromatic and Siebe Gorman FF2 subtended an angle of 45° to 60° with the waist strap.

The advantage of separate anchorage points for the shoulder and waist straps is that tension or slack in one belt will not affect the retention capabilities in the other strap. However, the disadvantage of this strap arrangement is that, being close to the centre line of the set, it is not as effective in controlling backplate movement about its long axis during manoeuvres involving twisting, for example. During observation of the donning procedures at fire stations, the consensus method was first to pull down on the shoulder straps and then to secure the waist belt. These instructions, if followed, would tend to lead to a shift in the weight of the BA set onto the shoulders rather than onto the hips. It was interesting to note that the instructions given for Draeger P90, the revised P112, were the reverse; ie. to secure the waist belt and then pull down to secure the shoulder straps. This revised donning procedure will cause the weight of the set to be shifted onto the hips, which is biomechanically correct, rather than the shoulders.

The only set fitted with a chest strap was the Siebe Gorman FF2. The possible reason for this is that the set produced the highest second moment of inertia (see Table 3.24) which indicates that it had the greatest tendency to pull on the shoulder straps during usage due to its distance from the firefighter's own centre of gravity. The horizontal chest strap would provide additional support by bracing the two vertical shoulder straps together.

All sets except the Draeger P90 offered strap widths of 1½ - 2" (35 - 50mm) whereas Draeger P90 straps were 3" in width (75mm). Consequently the load was spread over a larger area thereby reducing the contact pressure across the firefighter's shoulders and waist.

4. DISCUSSION

This study consisted of several different assessments of firefighters' responses to breathing apparatus. (1) Their own subjective opinions about BA from training and operational experience were collected by means of a nationwide questionnaire; (2) the physiological effects of BA, additional to those related to standard turnout gear, were examined in controlled laboratory conditions; (3) different models of BA were studied both on and off the wearer to assess the ergonomic, and specifically biomechanical, aspects of the sets to help explain any differences in firefighters' response; and (4) the physiological response of selected firefighters was investigated during the severe physical and thermal conditions imposed during simulated fire and rescue operations. As a result of these studies it is possible to make recommendations concerning various improvements in training, fitness, safe working times and design of BA which would be of benefit to the fire service and manufacturers of BA for firefighters in local authority brigades.

The separate aspects of each part of the study are discussed in this chapter before the information is drawn together and the implications for the fire service discussed.

4.1 Responses to the Firefighter Questionnaire

The findings from the questionnaire on firefighters' responses to the use of BA during training and operational duties have already been discussed in some detail in section 3.2, and in some cases in relation to the known design features identified during the ergonomic assessments. Several points are clear from the results of this nationwide study.

1. Only a few types of open circuit BA are in widespread use in the UK, principally Draeger P112, followed by the Interspiro Spiromatic single or twin cylinder set. Two other types of OCBA are also widely used; the Sabre Centurion and Siebe Gorman Firefighter 2, which is gradually replacing the older Firefighter 1 model, itself still in widespread use. These four sets make up about 77% of all BA used in the fire service (based on our survey) and, being supplied by the four main manufacturers, provided a convenient basis for undertaking the subsequent physiological/ergonomics studies.

2. Although the majority of BA users appear to be satisfied with their sets a substantial minority have identified problems, of greater or lesser importance, relating to the weight and size of the set; comfort, fit, seal and adjustment of the facemask; comfort and ease of adjustment of the body harness; and interactions with many other items of personal clothing and equipment used during fire and rescue situations.

   These comments, important though they are, should be considered in the context that most (95%) firefighters completing the questionnaire used BA less than once a week and most of them have had limited experience of any other type of set with which to make a comparison. Therefore, firefighters in brigades which had recently changed over from one type of BA to another could have based their assessments on different criteria, if their previous set had been substantially more or less comfortable, for example. It was apparent that, when a brigade had changed to a newer model of BA from the same manufacturer, some of the firefighters favoured the older models more than the new ones, eg. Siebe Gorman FF1 and FF2, Draeger P112 and P202. Such comments need further investigation but could be a factor of familiarity with the older set leading to more active comparison and criticism of the replacement set. However, if a brigade had just changed to a new BA the respondents were asked to refer their comments to the latest model, as this would be more relevant for future needs.

3. There are substantial and generally consistent differences in the levels of satisfaction between the different BA. Overall, Sabre Centurion was rated as the best set by its users in terms of weight, size, comfort of backplate, straps and facemask, as well as interactions with other items of clothing and equipment such as the helmet and gastight suit. Conversely Siebe Gorman FF1, which is in the process of being replaced by FF2, scored worst on several aspects, relating to weight and size during use, face seal, and use with a gastight suit. Occasionally other sets gave rise to as many adverse comments as FF1, notably FF2 (facemask seal and interactions with the helmet) and Siebe Gorman Airmaster (problems with harness straps during use). In general the interaction between the helmet and the BA gave rise to the highest adverse response (30-52% of users).

   It would seem that, if firefighters are generally satisfied with their sets, their comments will tend to be more favourable towards all aspects of the set. However, the aspects that were considered of particular importance to the second phase of the study, such as weight and its distribution on the body, will be discussed in more detail later.

4. The results from this questionnaire are believed to be fully representative of brigades in the UK. Every brigade in England, Scotland and Wales was sampled and the number of questionnaires distributed was in proportion to the number of stations within each brigade. Although the forms were completed by (usually) named firefighters selected by the brigade's liaison officer, it is unlikely that they would have systematically selected men who were known to have opinions about their BA that were either particularly unfavourable or complimentary. It is possible that the opinions of the selected firefighter were influenced by comments from other members of their watch (shift). However, this should not detract from the representativeness of the results, which are based on a relatively high response rate of over 75% of those selected.

   Female firefighters were under-represented in the returns, as they are only employed in any number by one or two brigades, predominantly London. Therefore an additional batch of questionnaires was sent for distribution to about thirty female firefighters only: their responses are included within the overall responses to the questionnaire and have not been treated separately.

4.2 Results of Treadmill Tests

Laboratory trials of BA, which is normally used in adverse physical and thermal conditions, can only examine limited aspects of the performance of the user and the set. However, because of the opportunity such trials give to study different sets under planned and controlled conditions, it was considered essential to include treadmill tests in an attempt to isolate specific aspects of physiological responses, which would be very difficult to study under the far less controlled conditions of the fire and rescue scenarios.

It was considered particularly important to distinguish the relative contributions to physiological strain made by both turnout gear (including helmet, boots and gloves) and BA, because in practice BA is always worn with some kind of protective clothing, usually tunic and overtrousers based on the Home Office A26 specification. The majority of the treadmill tests were therefore conducted using a standard issue uniform supplied new for the study (and laundered between weekly trials). It is clear that heart rate, oxygen uptake (by measurement) and sweat rate (by observation) increased significantly from the control tests when such clothing was worn, because of the additional weight and thermal insulation provided. This aspect is, however, being examined in more detail as part of a separate Home Office funded study still in progress.

The increases in heart rate and oxygen uptake, when BA was worn in addition to full turnout gear, are consistent with the observations from previous studies in other countries (Davis and Santa Maria, 1975; O'Connel *et al*, 1986; Skoldstrom, 1987; White and Hodous, 1987). These authors observed that heart rate and oxygen uptake could increase by up to a third (Davis and Santa Maria, 1975) when BA and protective clothing were worn, compared to duty uniforms: this increase was mostly due to the BA. White and Hodous (1987) concluded that exercise in turnout gear and BA led to significant cardiovascular and thermoregulatory strain, even at low work levels in a neutral environment.

The present study has identified that light to moderate exercise, walking at 5km hr^{-1} at a gradient of 7.5% which, in lightweight clothing is equivalent to an average oxygen uptake of $2.0l$ min^{-1}, becomes a severe test for some firefighters in full turnout gear and BA. Their heart rates exceeded 80% of their predicted maximum in several cases and the average oxygen uptake of all firefighters tested rose by 35% to $2.7l$ min^{-1}. This would eventually lead to exhaustion and would severely limit their endurance level. White *et al* (1989) noted that exceeding the upper heart rate criterion was the usual reason given for stopping firefighters exercising in turnout gear and BA.

Overall, our results confirm that wearing BA with normal firefighter turnout gear leads to a significant increase in physiological strain, represented by an increase of 35% in oxygen uptake and 27% in heart rate at the highest workload undertaken in the present study. Lightweight cylinders, instead of the conventional steel type, led to a (significant) reduction in these physiological parameters, confirming some recent observations (Sykes *et al*, 1993. Private communication) on new lightweight cylinders.

Since the weights of the different types of BA included in this investigation did not differ by more than 1kg (total weight 17-18kg fully charged) we did not expect to observe significant differences in the physiological response due solely to weight. It was therefore interesting that Sabre Centurion users had significantly lower oxygen uptakes during the BA wearing tests compared to the other groups. This was consistent with the observations from the questionnaire study but was not due to this set being lighter than the others; it was actually one of the heavier sets.

It is not possible solely from our laboratory trials to indicate the fitness level, in terms of maximum aerobic capacity, required by firefighters to do their job (see earlier discussion). O'Connel *et al* (1986) observed that firefighters climbing stairs in BA and protective clothing required an oxygen uptake of $2.7l$ min^{-1} (equivalent to $39ml$ kg min^{-1} for a 70kg person). The extensive study of the fitness of UK firefighters (Scott *et al*, 1988) indicated that on average their aerobic capacity was $3.45l$ min^{-1} ($43.7ml$ kg min^{-1}), which was considered to be no better than the average male of the same age group. As a result, recruits to the fire service are now required to undergo a step test for the assessment of aerobic fitness and to have an aerobic capacity of at least 45m*l* kg min^{-1}, which is equivalent to 3.6*l* min^{-1} for an 80kg firefighter.

Because of the design of these treadmill tests, in which three test conditions were compared to a control condition at the same speed and gradient, the control workloads (four in total) were at the lower end of the range of heart rate and oxygen uptake for most of the fitter firefighters. It was therefore unreliable to extrapolate this relationship to the maximal oxygen uptake (Vo_2 max) estimated from where the best fit line coincides with the predicted maximum heart rate, assuming a linear relationship between HR and Vo_2. For the fitter firefighters this procedure overestimated the Vo_2 max considerably, whereas for most firefighters of average fitness the estimates of Vo_2 max were likely to be more reliable. It is clearly essential that those wearing BA and any kind of impermeable or insulated protective clothing are in good physical condition as also observed by Louhevaara *et al* (1985). The additional physiological strain imposed on firefighters by BA and protective clothing should therefore be taken into account when assessing the suitability of firefighters based on a fitness test.

4.3 Fire/Rescue Scenarios

In order to simulate as closely as possible the conditions likely to be experienced by firefighters at an incident, it was decided to include a psychological component, as well as the physical and thermal components, in the scenarios. The Fire Service College at Moreton-in-Marsh offers an advantage for such a study, as it runs courses for fire officers. Hence, most of the teams of firefighters in this study who were at a rank of leading firefighter or below, would not have been familiar with the facilities. Other than a short safety briefing before each exercise the teams were given no more than the essential details to undertake the tasks. This psychological component was particularly important for the short and long duration fire/rescue exercises, in which visibility was very poor because of natural and artificial smoke. Observation of the participating firefighters immediately before entry to the first (short duration, very hot) exercise confirmed that many of them were already very anxious. Figures 3.2 - 3.4 indicate how high some of the heart rates were at the commencement of this exercise.

4.3.1 Short duration fire rescue exercise

The penalty for trying to simulate realism, particularly for the short duration fire/rescue exercise, was that most of the teams came nowhere near completing the exercise as originally planned, because of their unfamiliarity with the training facility. Owing to the tight schedule required to carry out the planned tests (in order to fit in with the College training timetable), it was not possible to run sufficient pilot trials to duplicate all of the possible conditions expected using naive firefighters. However, having embarked on the procedure planned in conjunction with the College's BA School, it was thought to be more important to be consistent and to leave the exercise unchanged. Although several teams reached the "casualties" in this first exercise and had begun to remove them, the participants were already close to their own physiological limits and had to be withdrawn.

Further difficulties were encountered because of the inconsistency of the environmental temperatures, resulting from combustion of standard quantities of wooden pallets and the different rates at which the teams progressed. Consequently it is unlikely that one team experienced the same conditions as any other team. It is fair to assume, however, that these inconsistencies were randomly distributed across the teams and did not affect one BA type more than another. Damage to thermocouples by fire or physical contact during the course of these trials led progressively to less environmental temperature data being obtained, but the availability of such data was not considered essential to the study. Another variable factor which could not be quantified was the "carry-over" or heat storage effect of an earlier fire in the forward hold area, caused either by a College training exercise previous to our first exercise or by our first exercise on the second exercise.

As a consequence of the above factors and the inevitably inconsistent means for terminating the short duration exercise, the duration of this exercise as an outcome variable should be treated with caution. Furthermore, the body and skin temperatures, air consumption and sweat loss will all to some extent be dependent on the time at which the individuals, or more usually the whole teams, were withdrawn.

It is quite clear, however, that almost without exception the firefighters were under extreme physiological strain during this exercise. Body and skin temperatures close to 40°C and heart rates close to or above 200 beats min^{-1} represent the upper limits of endurance for most people, however physically fit they might be. The convergence of core and skin temperatures suggests that the body is unable to lose heat effectively through the principal channel of sweat evaporation, because of complete enclosure in protective equipment.

In such a situation heat will be gained from radiation, conduction and convection as well as via metabolic activity and it was noticeable that the few firefighters who had been issued with the lighter weight Delta T firekit tended to have higher skin temperatures and sweat loss than those wearing standard Bristol Uniforms fire kit. In the conditions of this test the heavier conventional uniform seems to provide greater protection from the effects of external heat.

Although there were no clear and significant differences in the physiological responses between different BA types, Sabre Centurion wearers tended to have a lower air consumption rate (minute volume) on average (43*l* min^{-1}) than the other groups, whose average minute volume ranged from 48 to 51*l* min^{-1}. Therefore even under these severe physical and thermal conditions, the BA, which had emerged as the most subjectively acceptable, and had given rise to the least physiological strain during treadmill tests, seems to have evoked a lesser physiological response in this respect.

The two Kent teams who wore Sabre SEFA sets had undergone different training from the other teams, because their set was intended for long duration use (over two hours) for reaching fires or other hazardous incidents in the Channel Tunnel. In this exercise these two CCBA teams progressed more slowly than the OCBA wearers. Consequently one of the teams in particular experienced much less severe environmental conditions than the remainder. However, the temperature of the inspired air from the SEFA is about 45°C saturated with water vapour, which will not only prevent any loss of heat from the lungs but will lead to further heat gain. Users of such sets should therefore be given a shorter safe working time in equivalent temperature and humidity conditions compared with OCBA users. This is already recognised by the Mines Rescue Service (MRS), who have issued separate tables of safe working times for CCBA and OCBA wearers based on the early work of Lind *et al* (1957) and recently reviewed and revised by Graveling and Miller (1989) following the introduction of SEFA into the MRS.

A further point to emerge during this part of the study was the additional physiological strain imposed on the first firefighter in the team, ie. the one making the initial decisions about progress along the guideline. Of the nine teams where the leaders were clearly identified, the leaders' average heart rates were the highest in the team in six cases and second highest in another two: on average they were nine beats min^{-1} higher (157 beats min^{-1}) than the average for the whole team (148 beats min^{-1}). There was also some evidence that their body temperatures were higher than average at the end of the exercise.

4.3.2 Chemical spillage exercise using gastight suits

Tolerance of physical activity, such as exercising on a treadmill, is severely limited, even in relatively cool or neutral environments, by the wearing of impermeable chemical protective clothing (CPC) which fully envelopes the body. For example, White *et al* (1991) reported a 50% reduction in total working time in a hot environment (34°C, 55% RH) for subjects wearing CPC compared to other clothing ensembles. Therefore, when the present study was planned care was taken to limit both the exposure time (to a 20 minute exercise) and environmental temperature. The latter was initially planned to be about 27°C but in practice averaged about 30°C.

Consequently, the exercise did not lead to very high body temperatures (the highest was 38.8°C) and all firefighters successfully completed it without undue physiological strain. Compared with the previous exercise this was easier to control, because the observers as well as the safety officers could be present throughout the exercise. However, this exercise was far more artificial and did allow regular monitoring of the physical and physiological condition of the participants. As there was less psychological stress during the exercise, the heart rate in particular should reflect more completely the physiological response to the workload imposed by carrying heavy canisters in impermeable clothing.

The physical workload was almost continuous and gave rise to a higher air consumption rate, as far as it could be estimated, than the other two exercises: yet, in spite of the more standardised nature of the work, no clear differences between types of BA were observed for any of the physiological parameters. If the exercise had continued further the body temperatures would have continued rising ultimately to unacceptable levels. However, before then, either the heart rate would have reached near maximum level or local muscle fatigue would have prevented the firefighter lifting the canisters onto the platforms. In practice, the BA's low pressure warning whistle would have sounded within a few minutes necessitating a change of air cylinder. One or two of the whistles did sound before the 20 minute exercise had finished, although in these cases the firefighters were allowed to complete their exercise.

4.3.3 Long duration fire/rescue exercise

This exercise, like the short duration exercise, was conducted at the team's own pace and gave rise to a realistic fire search and rescue operation. Consequently its duration varied considerably, on some occasions influenced by the care which the teams took to follow the recommended procedure of clipping on and off the guideline. Because of the length of the exercise and the greater frequency of monitoring, it was possible to examine the pattern of rise in body temperature more closely.

This indicated that the aural (and skin) temperatures rose rapidly during the first circuit of the course when the environmental temperatures in the vicinity of the fire were very high. During the second circuit the fire had begun to subside and the environmental temperatures at parts of the route were not much greater than room temperature on some occasions.

Consequently the body temperatures of the firefighters did not rise more than a fraction of a degree during the second half of the exercise. Most teams were therefore able to complete the planned route without undue physiological strain: only a few aural temperatures were greater than 39.5°C and a similarly small number of maximum heart rates greater than 200 beats min^{-1}.

This suggests that a training exercise, involving search and removal of (in this case) a heavy water filled canister, lasting 1-1½ hours and requiring a cylinder change is within the physiological capacity of most firefighters using open circuit BA under these conditions. Because we were not able to identify any significant differences between the performance of the teams using different types of BA during this exercise, these results could apply equally to all types of sets.

4.4 Ergonomic Factors Related to Wearing BA

The major ergonomic concern related to BA sets was their weight. Significant advances in material technology has meant that lightweight cylinders made of carbon/glass fibre composites, although not available for the present study, are now available on the market at less than one third the weight of the conventional steel type. Any weight reduction in the cylinder will be an advantage as it will reduce both the biomechanical load on the firefighter's body and the energy required to do the task.

Although the majority of the BA weight is attributed to the cylinder the remainder of the equipment, including the protective clothing, can still contribute significantly towards the total weight. Table 4.1 shows the percentage breakdown of the different components worn by the firefighter.

Approximately half the weight of the BA set is due to the cylinder and the other half to the remainder of the set and the protective clothing. Unlike the cylinder the other component weights are distributed over the body and located close to its surface. The backplate, however, is concentrated behind the body's centre of gravity, although if properly profiled is located as near to the centre as possible. The lightest backplate (Interspiro Spiromatic), made of Vistaflex, a plastic material, was a third lighter than that of Draeger P112, a composite backplate of stainless steel wrapped in a neoprene rubber. Reductions in backplate weights of this order would still have a significant benefit on the overall physiological workload of the user even though its load acts close to the user's centre of gravity.

The biomechanical analysis carried out on the BA sets demonstrated that it is not only the weight of the set that is important but also its position relative to the fulcrum point of the user, in this case the base of the lumbar spine. In an upright static posture all BA sets produced similar extensor movements on the back as the load acted behind the back tending to extend it (see Figure 3.15(i) and Table 3.24) whereas a measure of the second moment of inertia (I) in Figure 3.15(ii) and Table 3.24 showed a different picture. I is a more realistic and comprehensive measure of the biomechanical loading on the body as it reflects the operator's effort to manoeuvre in the BA set during different task activities.

It is interesting to compare the I values with the responses in Table 3.4, summarising the subjective comments from firefighters across the whole of the UK. When asked whether their BA set caused problems during use because of the weight, Sabre Centurion along with Sabre Brigade users reported the least problems while Siebe Gorman FF2 and FF1 produced the most problems. A similar pattern emerged with the I rankings in Table 3.24, Sabre Centurion emerging the best and Siebe Gorman FF1 the worst from the five sets selected in the ergonomic assessment study.

For comparison a preliminary examination of the long duration SEFA set shows a second moment of inertia value of approximately 1.3Nm^2. This low and beneficial I value is accomplished because the compressed oxygen cylinder, which accounts for the main weight of the BA, is positioned low in the set and also sits horizontally across the small of the back, thereby reducing the moment arm (ie. shorter length l in Figure 3.15(i)) offset from the base of the lumbar spine.

4.5 Implications for Design of BA

It was noted in Section 4.1 that for some features the firefighters gave worse assessments of the new models of BA compared to the older models. This could have resulted from changes to the BA set itself or indirectly via changes to other equipment used with the BA. Incompatibility of the equipment is fairly prevalent when the firefighters' comments from the questionnaire data are viewed together with the results of ergonomic assessments. Designing apparatus in isolation without considering its interaction with other equipment, will lead to considerable user dissatisfaction and ultimately lack of confidence in the BA set itself. Attempts to address this problem have been covered in the recently introduced Personal Protective Equipment at Work Regulations (1992).

One major area of concern among firefighters was the incompatibility between the BA and helmet (see Section 3.2.2). One major problem was caused by the central forehead strap not allowing the helmet or facemask to sit correctly on the head. The West Midlands Fire Service has overcome this problem by instructing the helmet manufacturers (Cromwell 500) to fit a "drop-down" inner piece so that the face mask and helmet can interface correctly.

Related to compatibility is the issue of designing the equipment to fit the size and shape of the majority of users. There were a number of aspects both of the BA sets and the clothing that did not cater for those users whose sizes were at either end of the height range. For example, the following items were identified as not providing enough adjustment:

Feature of BA/Clothing	Design Constraint
Backplate length	too long for shorter users
Harness straps	insufficient adjustment for shorter users
Wrist cuff	more adjustment required for larger users
Length of intermediate pressure hose	too short for tall users

Obviously the BA set cannot be designed with all potential users in mind because even within a height criterion, which covers the majority of operators, there will be extreme anthropometric dimensions not catered for. However, the fact that the above design constraints were fairly common indicated that the BA sets and clothing in no way cater for all users. It is possible that, although the individual pieces of equipment are designed for the correct range of users, when used in combination the usable sizes shift into a different range. For example, the wrist cuffs could fit the large operator not wearing protective gloves but when gloves were worn and tucked inside the cuff the velcro adjustment strap became too short.

On designing equipment to fit the majority of users, in particular straps, attention should be paid to the location of surplus strap when a small user is wearing the standard BA set. A velcro strip in addition to the standard rucksack buckle was incorporated on one helmet strap observed (Cromwell F500). A similar arrangement could be employed on the harness straps to avoid the surplus strap hanging loose. Alternatively a fixed loop on the harness straps could be considered in order to retain the surplus strap.

Problems caused by the harness straps during donning, adjusting and wearing BA were very common. For example, straps worked loose during use, some straps lacked padding and a chest strap, fitted on one set, was necessary to provide additional stability. All sets involved in the biomechanical analysis (see section 3.5) had instructions for the operator firstly to pull down on the shoulder straps and then to secure the waist belt. This procedure requires amendment as it will result in the shoulders taking most of the load of the BA set via the shoulder harness. From a biomechanical point of view this will increase the bending moment on the spine compared to a set that was supported closer to the base of the back such as on the coccyx. The Draeger P90 was issued with instructions to position the set on the coccyx, to secure the waist belt and then to pull down to secure the shoulder straps. This latter procedure would reduce the muscular effort required to support the BA set. The tendency for the straps to work loose during use would also be reduced as the weight would be concentrated nearer the fulcrum point of the back. Loading in the shoulder straps would also be reduced as the weight would then be supported across the base of the spine (coccyx) and around the waist via the waist straps. A more realistic set of instructions for all sets, such as those outlined for Draeger P90, may require the configuration and position of the harness straps to be altered to accommodate the different loading pattern.

Because of the observations made during the fire/rescue exercises, it is pertinent to mention problems associated with the design of personal lines. Many firefighters mentioned that under operational circumstances the line was cumbersome, and tended to snag on obstructions, thereby becoming a trip hazard. Further consideration needs to be given to the possibility of using a retractable personal line similar to a retractable dog walking lead in order to eliminate these potential hazards. The securing device was also heavily criticised as it was difficult to clip and unclip the dog lead style of clip from the main guideline when gloves were worn. Even without gloves the dog clip is difficult to unclip with one hand, because one hand is needed to hold it tightly while the other depresses it. When thick gloves are worn the effective gripping strength is reduced such that a small clip cannot be held firmly; consequently the operator has difficulty in releasing the dog clip. A climber's caribiner type hook with a hinged joint should be investigated as it requires less finger force to unclip and is more easily manipulated with a gloved hand. This style would also provide a larger aperture, which would be beneficial as firefighters also complained that the current hook was too small to run smoothly over the tallies and other obstructions on the main guideline.

4.6 Implications for Training and Operational Procedures

The first and major implication arising from the physiological studies, at least in the scenarios reported here, is the severity of the physiological strain imposed on firefighters. We cannot say how reliably these observations would apply to operational firefighting duties but clearly there must be concern that firefighters are being exposed to combinations of environmental conditions and workloads during BA training which bring them close to the limits of physiological endurance.

While it is possible to define safe working (exposure) times in stable hot and humid conditions, such as those encountered in underground mining environments, the rapidly changing thermal environment of a burning building makes it very difficult to define such limits for firefighters. However, based on the physiological data obtained during the exercise involving intense heat exposure, it is clear such training exercises should be scheduled to last not longer than 30 minutes and preferably 20 minutes. All OCBA teams, except one, whose time for the short duration exercise was between 20 and 30 minutes, had average aural temperatures greater than 39.5°C at the end of the exercise. During a controlled laboratory exercise such a temperature would justify terminating the exercise. Any excessively high heart rate (say, greater than 180 beats min^{-1}) would be another reason for withdrawing a subject from an exercise.

It is worth noting that, on at least one occasion, the experimenters were made aware that the operational team had reached their turn-round time (the point at which they should return to fresh air) as indicated by cylinder pressures. However, because of the nature of the exercise and the extent of safety cover, the firefighters were assured that the usual BA procedure need not be applied and they were instructed to continue. Nevertheless, within a few minutes they were withdrawn from the exercise because of the concern of the safety officer, a concern corroborated by their physiological measures. It was apparent that, in an operational incident, had they turned round when indicated they would not have been in a sufficient state to retrace their steps. This suggests that the use of remaining cylinder air as the main operational criterion for withdrawal should be re-evaluated.

It could be argued that the current fire service practice of using trained officers to observe the participants in such training exercises for signs of distress (eg. staggering, unco-ordinated movement, glazed eyes, inability to answer simple questions) has provided adequate protection during training in the past. All the same, such subjective monitoring may be inadequate to protect all firefighters in all circumstances. Therefore, consideration should be given to issuing BA safety officers with body temperature (or less importantly heart rate) monitors to enable them to take regular observations of those participating in such hot conditions.

The practice of using oral (sub-lingual) temperature for monitoring purposes has been observed, but it is important to recognise that, when wearing OCBA, the supply of breathing air at a temperature considerably below body temperature will give erroneous oral temperatures. A more reliable measurement site, such as aural (ear canal) temperature, should be considered. Furthermore, incorrect wearing of aural sensors can also lead to erroneous readings; a potential hazard if not recognised and corrected.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Results and Conclusions

i) Firefighters in the UK currently use a range of different open circuit breathing apparatus (OCBA), ten types according to the results of our nationwide questionnaire. Four of these are in widespread use (87% of the total): Draeger P112; Interspiro Spiromatic (single or twin cylinder); Sabre Centurion; and Siebe Gorman Firefighter Mk 1 and Mk 2. These sets (excluding Firefighter Mk 1) were, therefore, examined further as part of the physiological studies.

ii) Use of BA was not frequent amongst respondents to the questionnaire. During the previous year, only 5% used BA more than once per week, 31% had used BA in a chemical spillage incident and 53% had never had to change their air cylinder during incidents.

iii) Users of all types of set reported some problems during donning or use of their BA. About a quarter of all users experienced problems related to the weight or size of the set and a similar proportion had difficulty with the seal and visibility through their face mask. Problems were also reported when BA was worn with other protective clothing, such as gastight suits (25%). Interactions with other clothing or personal equipment were also reported, most frequently (37% on average) with the helmet.

Users of Sabre Centurion sets generally tended to regard them as the most problem-free, whereas users of Siebe Gorman Firefighter 1 sets were most dissatisfied. Stations using the only closed circuit BA (Sabre SEFA) in current fire service use were not selected in the random selection process for this questionnaire study and their comments are, therefore, not included.

iv) Ergonomic assessment of the four sets in most common use suggested that the Sabre Centurion, by virtue of the position of its centre of gravity in relation to the wearer, was biomechanically more efficient during dynamic movements typical of training exercises or operational incidents. The Draeger P112 was almost as good in this respect but the Interspiro and Siebe Gorman sets had second moments of inertia twice as great as the other two sets and they would, therefore, require greater muscular effort by the firefighter to move and control his body.

v) The backplates of these four sets tend to be too long for the range of wearers. A newer Draeger model (P90) has a considerably shorter backplate which, although conforming to the 99th percentile male back length, would still be too long for the 95th percentile female user.

vi) Laboratory based tests identified that both clothing (firefighter's full turnout gear) and BA significantly increased the heart rate and oxygen consumption required to carry out a 5km hr^{-1} inclined treadmill walk. Replacement of a standard (11kg) cylinder with a lightweight cylinder (6.5kg) gave rise to a significantly lower heart rate. In combination, firekit and BA increased heart rate by 27% and oxygen uptake by 35% at the steepest treadmill gradient used; the clothing and BA contributing almost equally to the increased physiological strain.

vii) The Sabre Centurion set gave rise to a significantly lower oxygen uptake than any of the other sets, by about 0.1l min^{-1} on average probably because of its design features leading to greater comfort. However, heart rates were not significantly different between BA types.

viii) It was not possible to measure reliably the maximum oxygen uptake of all participating firefighters, because by necessity the design of the treadmill test precluded the setting of a range of workloads to suit every firefighter's fitness level. However, the average maximum oxygen uptake, based on the limited range of measurements taken, is estimated to be 3.7l min^{-1} (46.4ml kg^{-1} min^{-1}), slightly greater than that found in a nationwide study of firefighters. This group of firefighters is, therefore, either slightly fitter than previous studies have indicated, possibly due to recent fitness programmes, or more fitter individuals may have volunteered.

ix) Based on information derived from the questionnaires and advice from BA training officers from the Fire Service College, three fire, search and rescue scenarios were devised to provide combinations of severe physical and thermal loads to participating firefighters. Each of these exercises led to different degrees of physiological strain. The shorter duration intense fire, search and rescue exercise led to unacceptably high heart rates (over 200 beats min^{-1}) in at least one member of half of the teams, body temperatures (over 40°C) in at least one member of two thirds of the teams, and sweat rates averaging 2.5l hr^{-1}. During the simulated chemical spillage the firefighters' body temperatures only occasionally rose above 38°C, partly because of the intentional time limit imposed, and only five firefighters had maximum heart rates higher than 200 beats min^{-1}. In the long duration search/rescue exercise body temperatures rose to unacceptable levels (>39.5°C) in only one team and reached 38.5°C on average in seven teams. Heart rates again reached very high levels, over 200 beats min^{-1} in more than 40% of the firefighters, during this exercise.

We can conclude that some, and in the case of the live fire exercises, many firefighters were experiencing severe physiological strain as indicated by their heart rate and body temperature measurements.

x) Air consumption rates during the three exercises averaged 1250l (average minute volume 43l min^{-1}) for the short fire/rescue exercise; 1345l (57l min^{-1}) for the gastight suit exercise; and 2360l (40l min^{-1}) for the two stage longer fire/rescue exercise. Other than the gastight suit exercise, which consisted of almost continuous heavy work, these exercises gave rise to average air consumption rates close to the rate of 40l min^{-1} used by the fire service to estimate the nominal duration of a BA set.

xi) In general no differences in physiological response between different BA users were observed in these three exercises, principally because the firefighters were at or close to their physiological limits in many cases. In the short fire/rescue exercise the Sabre Centurion teams, while registering the largest increase in body temperature and the highest team average heart rate (Gloucestershire), had a minute volume which was considerably lower than the other BA users. This would be consistent with the observations from the questionnaire and treadmill studies and may relate to the better ergonomic design features of the Centurion set.

5.2 Recommendations

The studies carried out and reported here have led to the following recommendations.

i) If the findings in this study are representative of training activities elsewhere in the fire service, it is now clear that BA training can produce extreme physiological responses in participating firefighters. Consequently firefighters must be shown to have excellent physical, especially cardiovascular, fitness in order to respond to the extreme demands placed upon them by hot environments. The current recommended minimum fitness levels in the fire service (maximum aerobic capacity of 45ml kg^{-1} min^{-1}) should continue to be a requirement for all wholetime firefighters. Regular testing would be necessary to ensure that the requisite level of fitness is maintained. Annual assessments are carried out in the Mines Rescue Service, for example.

ii) When training exercises, such as those described in this study, are undertaken, it is recommended that additional objective measures of physiological response be provided for supervising safety officers. Consideration should therefore be given to monitoring aural (body) temperature of at least one member of a team undertaking BA (and other) exercises in hot environments. Where conditions are more stable (eg. hot and humid exercises), a modified version of the tables, used by the Mines Rescue Service to set safe working times, should be considered for fire service use.

iii) If such monitoring is not provided, exercises requiring relatively short exposure to intense heat using live fires should be limited to 20 minutes, in order to provide a greater element of safety. [BA instructors and safety officers also spend considerable periods of time in hot conditions. A study to monitor their physiological condition (body temperature and heart rate) is also recommended].

iv) These recommendations do not apply to operational conditions where the experience of the officer in charge and the local circumstances would govern the decisions concerning duration of exposure to hot conditions, re-entry to a fire, etc. However, the experience gained from training situations should be used to help minimise the risk of firefighters becoming overheated. For example, the use of remaining cylinder air as the main operational criterion for withdrawal of firefighters should be re-evaluated.

v) Efficacy of additional body cooling aids, such as hand cooling in water (as currently being introduced by the Royal Navy), and ventilation of clothing by cool air, in order to reduce the safe time to re-entry, should also be considered by the fire service.

vi) When local authority brigades are planning to replace their BA, consideration should be given to those sets which are most comfortable to wear, easy to put on, and conform to good ergonomic principles. Of the open circuit sets examined in this study the Sabre Centurion set achieved widest acceptance by its users, gave rise to less additional energy expenditure during laboratory trials (and, possibly, during simulated operational use), and its design is the most biomechanically efficient of all sets examined. This set and others designed on similar principles would, therefore, give rise to less physiological strain (energy expenditure) than other currently available sets.

vii) Although it was not possible to include an operational BA set fitted with lightweight cylinders in this study, it is clear from this and other studies that replacement of the standard steel cylinder with a much lighter composite (fibre-wrapped) type can considerably reduce the energy expenditure required to carry out a standard task. The introduction of such cylinders from a physiological point of view should therefore be encouraged. However, care should be taken to ensure that this new technology is not used to increase the working times in thermal conditions which already impose severe physiological strain on firefighters. Lighter cylinders in these circumstances should be used in order to reduce physiological strain. In circumstances where access to more distant objectives is required, eg. in tunnels, it is acceptable for this technology to be used to increase the capacity and hence duration of cylinders, as long as the thermal load on the firefighter is within the recommended safety limits.

viii) The ergonomic principles examined here, particularly as they apply to the dynamic aspects of BA during operational and training use, should be applied by manufacturers, if not already doing so, to the design of future equipment. Brigades should take such factors into account when selecting new equipment. Note should also be taken by brigades of the number of firefighters who report problems using BA with their normal clothing and equipment, particularly helmets and gloves as well as with other equipment worn with BA less frequently, such as splash suits and gastight suits. It is a requirement under the PPE at Work Regulations (1992) that the selection of BA, and in fact any equipment, should take into account any adverse interactions with other essential items.

ix) Sizing of equipment to conform to the bodily dimensions of firefighters, including an increasing numbers of female recruits, should be given greater consideration by manufacturers. Lightweight cylinder design should allow backplate lengths to be reduced, for example, to conform to the range of back length of firefighters and to minimise interaction with the rear of the traditional firefighter's helmet.

x) Calculations to describe the dynamic aspects of carrying a cylinder, ie. the second moment of inertia, were derived from static measurements and weights of the backplate in isolation. As a suggestion for further study, it would be informative to evaluate and measure the dynamic effects of the BA set on the user's back during simulated use by means of a model torso that could be adjusted to move in different planes. Sensors in the harness straps could also record the amount and distribution of the loading during this manoeuvre to ascertain a more acceptable strap configuration.

xi) In general, consideration should be given as to whether any of the above recommendations can be used to define optimum designs for BA and other PPE used in the fire service. For example, further studies (ergonomic assessments and user responses) could be carried out to provide more specific design criteria for future BA appropriate to fire service use.

6. ACKNOWLEDGEMENTS

We thank the following people and organisations for their assistance and co-operation during the course of this study:

The Home Office, for funding the study as part of their ongoing fire research programme.

Mr R Dunn, Occupational Health Unit, Fire Service College, Moreton-in-Marsh for allowing us to use the FSC Medical Centre.

ADO RS Nichol and other staff at the BA School, FSC, for helping to devise fire/rescue exercises and for supervising during the trials.

Mr I Hill, Managing Director, Bristol Uniforms Limited, for supplying free all the tunics and overtrousers used during the study.

All the brigade liaison officers who helped distribute and complete questionnaires; liaison officers from the 12 brigades who attended and assisted with the trials at the FSC; all the firefighters who participated so willingly in the physiological exercises.

Senior personnel, especially BA officers, at the brigades who took part in structured interviews and helped with ergonomic assessments of BA.

Dr GE Scott, Project Officer, Home Office, Fire Research and Development Group, for his constant concern and interest in the study and for smoothing the path to the many fire service personnel needed for this project.

Finally, Ms L Rae for typing the manuscript.

7. REFERENCES

Davis PO, Santa Maria DL. (1978). Heart rate responses to firefighting activities. International Fire Chief; 41: 10-11.

Durnin UV, Womersley J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. British Journal of Nutrition; 32: 77-97.

Epstein Y, Keren G, Lerman Y, Shefer A. (1982). Physiological and psychological adaptation to respiratory protective devices. Aviation, space and environmental medicine; 53: 663-665.

Faff J, Tutak T. (1989). Physiological responses to working with firefighting equipment in the heat in relation to subjective fatigue. Ergonomics; 32: 629-638.

Graveling RA, Miller BG. (1989). Permissible wearing times for rescue personnel using a new self-contained breathing apparatus. Final report on CEC Contract 7258-04/146/08. Edinburgh: Institute of Occupational Medicine, (IOM Report TM/89/04).

Health and Safety Executive. (1992). Personal Protective Equipment at Work Regulations, 1992. Guidance on Regulations L25. London: HMSO.

Home Office. (1988). The Fire Service (Appointments and Promotion) (Amendment) (No. 3) Regulations, 1988. London: HMSO.

Louhevaara V, Tuomi T, Korhonen O, Jaakkola J. (1984). Cardiorespiratory effects of respiratory protective devices during exercise in well-trained men. European Journal of Applied Physiology; 52: 340-345.

Louhevaara V, Tuomi T, Smolander J, Korhonen O, Tossavainen A, Jaakkola J. (1985). Cardiorespiratory strain in jobs that require respiratory protection. International Archives of Occupational and Environmental Health; 55: 195-206.

O'Connel ER, Thomas PC, Cady LD, Karwasky RJ. (1986). Energy costs of simulated stair climbing as a job-related task in firefighting. Journal of Occupational Medicine; 28: 282-284.

Paull JM, Rosenthal FS. (1987). Heat strain and heat stress for workers wearing protective suits at a hazardous waste site. American Industrial Hygiene Association Journal; 48: 458-463.

Pheasant ST. (1986). Bodyspace. Anthropometry, ergonomics and design. London: Taylor and Francis.

Scott GE, Barham P, Ellam L, Fordham M, Garlick J, Goldsmith R, Pateman C. (1989). The physical fitness of firemen. Joint Committee on Fire Research, Report No. 33. London: Home Office, Scientific Research and Development Branch.

Sköldström B. (1987). Physiological responses of firefighters to workload and thermal stress. Ergonomics; 30: 1589-1597.

Smolander J, Louhevaara V. Tuomi J, Korhonen O, Jaakkola J. (1984). Cardiorespiratory and thermal effects of wearing gas protective clothing. International Archives of Occupational and Environmental Health; 54: 261-270.

White MK, Hodous TK. (1987). Reduced work tolerance associated with wearing protective clothing and respirators. American Industrial Hygiene Association Journal; 48: 304-310.

White MK, Vercruyssen M, Hodous TK. (1989). Work tolerance and subjective responses to wearing protective clothing and respirators during physical work. Ergonomics; 32: 111-1123.

Table 2.1 Brigades and types of BA used in the experimental part of this study

Type of BA/ Manufacturer/Model	Brigade	Number of Teams	Male/Female Firefighters
Siebe Gorman FF Mk 2	London	4	12/4
	Humberside	1	4/0
	Fife	1	4/0
		6	**20/4**
Interspiro Spiromatic	Essex	2	8/0
	Mid Glamorgan	1	4/0
	Kent	1	4/0
		4	**16/0**
Draeger P112	Leicestershire	1	4/0
	West Yorkshire	1	4/0
	Lothian & Borders	1	4/0
		3	**12/0**
Sabre Centurion	Oxfordshire	1	4/0
	Hereford & Worcester	1	4/0
	Gloucestershire	1	4/0
		3	**12/0**
Closed Circuit			
Sabre SEFA	Kent	2	8/0
Total		**18**	**68/4**

Table 2.2 Sites chosen for BA ergonomic assessments

Location	Fire Region	BA Set(s)
Edinburgh	Lothian & Borders	Draeger P112A/P90[1]
Kirkcaldy	Fife	Siebe Gorman: Firefighter II
Hamilton	Strathclyde	Interspiro: Spiromatic/Sabre Centurion[2]
Aberdeen	Grampian	Sabre Centurion
Maidstone	Kent	Long duration SEFA
Birmingham	West Midlands	Siebe Gorman: Firefighter II[3]
Crossgates	Fife (Mines Rescue)	Long duration SEFA (British Coal)[4]

Notes:

[1] - Although the P90 set was not included in the physiological phase of the study as it was not available on the market at the commencement of the research it was assessed to compare the ergonomic design of future generation sets to those of current models.

[2] - The Sabre Centurion set was being evaluated at the time of visit for the retained firefighters. Observation of the additional set and feedback from firefighter staff allowed a comparison of the two sets on site.

[3] - This visit allowed a comparison between the same Siebe Gorman sets but within different regions, ie. Metropolitan (West Midlands) -vs- Shire (Fife). The heavier demands on the BA set in an urban environment compared to a rural one may highlight different user concerns with the sets.

[4] - As the SEFA set was originally designed for mines rescue work a visit to Crossgates gave the ergonomist an opportunity to see if British Coal had experienced any previous problems and effective solutions that could be adapted for the fire brigade's long duration set.

Table 2.3 Contents of the study database

Record Type	No. of records of type in database	No. of variables in record type
Firefighter's basic information	855	3
Operational firefighters questionnaire data	783	50
Moreton trial subjects personal information	72	16
20 minute treadmill test basic information	215	8
40 minute treadmill test basic information	72	4
20 and 40 minute treadmill test results	715	24
Gastight suit exercise results	71	39
Short duration exercise results	72	24
Long duration exercise basic information	71	13
Long duration exercise results	418	7

Glossary for Tables 3.1 to 3.9

Set A Draeger P112
Set B Interspiro Spiromatic
Set C Sabre Centurion
Set D Siebe Gorman Firefighter 2
Set E Siebe Gorman Firefighter 1
Set F Siebe Gorman Airmaster
Set G Sabre Brigade
Set H Draeger A202
Set I Sabre SEFA
Set J Racal Panorama

Table 3.1 Number (%) of completed questionnaires returned for each type of BA in use

Set	Questionnaires Returned (%)
A	233 (29.8)
B	180 (23.0)
C	108 (13.8)
D	79 (10.1)
E	79 (10.1)
F	61 (7.8)
G	23 (2.9)
H	16 (2.0)
I	2 (0.3)
J	2 (0.3)

Table 3.2 Percentages (to nearest whole number) of users of each BA experiencing difficulties (i) due to weight of the set (Weight), (ii) in adjustment to fit due to weight of set (Weight Adjustment), (iii) due to size of set (Size) and (iv) in adjustment to fit due to its size (Size Adjustment)

Set Code	No. of Users	Weight	Weight Adjustment	Size	Size Adjustment
A	233	23	17	14	6
B	180	15	13	12	8
C	108	8	3	0	2
D	79	20	15	17	13
E	79	32	24	23	15
F	61	31	26	15	5
G	23	17	4	0	0
H	16	20	13	0	0
Total	779	19.9	14.9	12.1	6.9

Table 3.3 Percentages of BA users experiencing minor or major problems during donning/adjustment of BA caused by (i) mask straps, (ii) harness straps, (iii) mask adjusters, (iv) harness adjusters, (v) helmet and (vi) tunic

Set Code	% Reporting Problems											
	Mask Straps		Harness Straps		Mask Adjusters		Harness Adjusters		Helmet		Tunic	
	Minor	Major	Minor	Major	Minor	Major	Minor	Major	Minor	Major	Minor	Major
A	29	0	14	1	20	0	7	1	34	5	12	2
B	24	0	38	1	17	0	24	0	29	3	15	2
C	23	0	11	0	11	0	3	0	26	1	13	1
D	28	0	41	4	20	3	11	0	48	4	17	4
E	18	0	25	6	14	0	15	3	39	6	20	3
F	13	0	30	5	7	0	17	0	30	2	7	0
G	13	0	22	0	4	0	9	0	39	0	13	0
H	13	0	19	0	6	0	6	0	44	0	6	0
Total	23.7	0	24.5	1.8	15.8	0.3	12.1	0.5	33.6	3.6	13.5	2.1

Table 3.4 Percentage of BA users experiencing problems or discomfort during use of BA caused by (i) weight of set, (ii) size of set, (iii) operating controls, (iv) facemask, (v) backplate, (vi) straps and (vii) buckles

Set	% Reporting Problems/Discomfort										
	Weight	Size	Controls	Facemask		Backplate		Straps		Buckles	
				Minor	Major	Minor	Major	Minor	Major	Minor	Major
A	26	25	2	19	1	11	1	12	1	3	0
B	22	25	21	7	0	11	0	15	1	3	0
C	18	12	7	9	1	7	0	9	0	1	0
D	33	30	6	32	0	20	4	33	1	3	0
E	39	38	3	27	1	27	6	18	1	3	0
F	22	13	7	12	0	31	0	38	0	0	0
G	17	17	0	17	0	13	0	17	0	0	0
H	19	13	6	13	0	44	0	38	0	0	0
Total	25.3	23.7	7.9	16.3	0.5	15.3	1.3	17.6	0.8	2.3	0

Table 3.5 Percentage of BA users reporting (i) inadequate sealing of the facemask, (ii) inadequate mask straps adjustment, and (iii) lack of clear vision through the visor during use

Set Code	% with Problems		
	Facemask Seal	Mask Strap Adjustment	Clarity of Visor
A	35	7	28
B	17	4	18
C	7	3	15
D	37	18	33
E	37	13	35
F	28	7	25
G	17	0	30
H	19	13	47
Total	26.1	7.2	25.2

Table 3.6 Percentage of BA users reporting problems using BA with standard issue clothing

Set Code	% with Problems			
	Gloves	Tunic	Helmet	Other
A	59	15	41	10
B	53	19	34	14
C	49	16	29	7
D	73	19	52	8
E	61	19	37	9
F	44	13	33	12
G	57	4	22	0
H	50	0	44	0
Total	56.5	15.9	37.1	9.5

Table 3.7 Percentages of BA users reporting problems putting on BA with (i) a splash suit, (ii) a gastight suit (GTS); and using BA with (iii) a gastight suit or (iv) any other (unspecified) special protective clothing

Set Code	% with Problems						
	Splash Suit		GTS Donning		Using with GTS		Use with other Special Clothing
	Minor	Major	Minor	Major	Minor	Major	
A	23	3	21	1	21	3	3
B	24	8	20	1	20	1	5
C	17	1	8	0	20	2	0
D	29	10	21	5	26	5	13
E	17	8	16	7	36	10	9
F	14	0	12	0	19	0	7
G	48	0	18	0	27	0	0
H	31	6	N.A	N.A	N.A	N.A	38
Total	22.3	4.7	17.8	1.9	22.2	2.8	6.1

N.A - Not applicable owing to lack of use of GTS with this set

Table 3.8 Percentages of BA users reporting problems using BA with other equipment (i) main guidelines, (ii) wearing a radio, (iii) other (unspecified) personal equipment

Set Code	% with Problems				
	Main Guidelines		Radio	Other Personal Equipment	
	Minor	Major		Minor	Major
A	12	2	18	4	0
B	11	2	9	6	1
C	18	0	17	3	0
D	27	0	30	4	0
E	18	1	34	4	1
F	15	0	5	2	2
G	0	0	30	0	0
H	13	0	27	6	0
Total	14.4	1.3	18.4	3.9	0.5

Table 3.9 Percentages of BA users reporting problems in using (i) main guidelines, (ii) a radio, and (iii) other personal equipment while wearing BA

Set Code	% with Problems					
	Main Guidelines		Radio		Other Personal Equipment	
	Minor	Major	Minor	Major	Minor	Major
A	10	3	22	3	2	0
B	20	5	23	4	3	0
C	20	3	26	1	8	0
D	31	0	36	5	8	3
E	29	3	28	5	3	1
F	13	5	14	2	3	0
G	13	0	35	9	0	0
H	6	0	20	7	0	0
Total	17.9	3.0	24.6	3.6	3.8	0.5

Table 3.10 Characteristics of participating firefighters

BA Type	No.	Age (yr)	Length of Service (yr)	Female (%)	Height (m)	Weight (kg)	Body Fat (%)	Smokers (%)
Draeger P112	12	32 (25-45)*	8 (1-17)*	0	1.81 (1.75-1.90)*	81 (70-93)*	17 (11-22)*	0
Aga Spiromatic	16	30 (22-38)	8 (2-18)	0	1.82 (1.70-1.98)	84 (70-96)	17 (11-22)	37
Sabre Centurion	12	31 (22-45)	8 (1-18)	0	1.78 (1.71-1.82)	83 (70-110)	17 (11-27)	17
Siebe Gorman FF2	24	32 (21-48)	8 (1-25)	17	1.77 (1.68-1.88)	76 (61-92)	18 (10-27)	37
Sabre SEFA	8	33 (23-41)	11 (2-21)	0	1.77 (1.71-1.80)	78 (73-89)	17 (10-20)	25
Total	72	31 (21-48)	8 (1-25)	6	1.79 (1.68-1.98)	80	17	26

*** - Mean (range)**

Table 3.11 Mean values (ranges) of all 709 measured and derived physiological response variables during treadmill testing minute by minute

Time From Start of Test (min)	Inspired Air Volume (l_{STP})	Expired Air		Heart Rate (bpm)
		O_2 (%)	CO_2 (%)	
1	27 (12-57)	16.4 (15-19)	4.3 (0.6* - 6.1)	120 (54 - 186)
2	35 (14-67)	15.6 (14-18)	4.3 (1.0 - 5.9)	124 (76 - 191)
3	37 (14-90)	15.6 (14-18)	4.5 (1.6 - 5.9)	126 (72 - 192)
4	37 (15-82)	15.7 (14-18)	4.6 (1.6 - 6.2)	128 (70 - 195)
5	38 (16-81)	15.8 (14-18)	4.7 (3.3 - 6.4)	129 (74 - 194)

(* % O_2 and % CO_2 in expired air were measured in a 25*l* mixing box. Subjects with very low breathing rates and expired minute volumes will take longer to flush out the residual gas from the previous test or room air, if it was the first test of the session)

Table 3.12 Mean oxygen uptake (V_{O_2} in $l\,min^{-1}$), at treadmill gradients of 0%, 2.5% and 7.5% subdivided by brigade and type of BA (uncorrected for body weight, responses without clothing and BA)

BA/Brigade	No Firekit or BA			Firekit Only - No BA		Firekit and BA		Firekit, BA with Light Cylinder	
	0%	2.5%	7.5%	2.5%	7.5%	2.5%	7.5%	2.5%	7.5%
Siebe Gorman FF2									
London 1	1.2	1.3	1.8	1.6	2.1	1.8	2.3	1.8	2.4
London 2	1.0	1.2	1.6	1.5	2.0	1.8	2.4	1.8	2.4
London 3	1.2	1.5	2.0	1.7	2.3	2.0	2.7	1.8	2.5
London 4	1.3	1.5	2.0	1.8	2.3	2.1	2.7	2.1	2.7
Humberside	1.4	1.5	2.0	1.8	2.4	2.1	2.7	1.9	2.6
Fife	1.3	1.5	2.0	1.9	2.4	2.2	2.8	2.1	2.8
Mean	**1.2**	**1.4**	**1.9**	**1.7**	**2.3**	**2.0**	**2.7**	**1.9**	**2.6**
Interspiro Spiromatic									
Essex 1	1.3	1.4	2.0	1.8	2.4	2.0	2.6	2.0	2.7
Essex 2	1.4	1.6	2.0	1.9	2.3	2.1	2.8	2.1	2.6
Mid Glamorgan	1.5	1.6	2.2	2.0	2.6	2.2	3.0	2.1	2.8
Kent 3	1.3	1.5	2.0	1.8	2.3	2.1	2.8	2.1	2.6
Mean	**1.4**	**1.5**	**2.1**	**1.9**	**2.4**	**2.1**	**2.8**	**2.1**	**2.7**
Draeger P112									
Leicestershire	1.3	1.6	2.0	1.8	2.2	2.2	2.8	2.0	2.5
West Yorkshire	1.5	1.6	2.2	2.0	2.6	2.3	2.9	2.2	2.9
Lothian & Borders	1.3	1.6	2.1	1.8	2.2	2.1	2.8	2.0	2.5
Mean	**1.3**	**1.6**	**2.1**	**1.8**	**2.4**	**2.2**	**2.8**	**2.0**	**2.6**
Sabre Centurion									
Oxfordshire	1.3	1.4	1.9	1.8	2.4	2.0	2.7	1.8	2.5
Hereford & Worcester	1.3	1.4	2.1	1.8	2.3	2.0	2.7	1.9	2.6
Gloucestershire	1.3	1.5	1.9	1.7	2.1	2.0	2.4	1.8	2.2
Mean	**1.3**	**1.4**	**1.9**	**1.8**	**2.3**	**2.0**	**2.6**	**1.8**	**2.4**
Sabre SEFA									
Kent 1	1.1	1.5	1.9	1.9	2.3	2.2	2.8	2.0	2.6
Kent 2	1.1	1.2	1.7	1.5	2.0	1.8	2.3	1.6	2.2
Mean	**1.1**	**1.3**	**1.8**	**1.7**	**2.1**	**2.0**	**2.6**	**1.8**	**2.4**
Overall Mean	1.3	1.5	2.0	1.8	2.3	2.1	2.7	1.9	2.6

Table 3.13 Mean heart rates (beats min^{-1}) at treadmill gradients of 0%, 2.5% and 7.5% subdivided by brigade and type of BA under different combinations of firekit and BA

BA/Brigade	No Firekit or BA			Firekit Only - No BA		Firekit and BA		Firekit, BA with Light Cylinder	
	0%	2.5%	7.5%	2.5%	7.5%	2.5%	7.5%	2.5%	7.5%
Siebe Groman FF2									
London 1	97	101	116	117	141	126	154	130	157
London 2	104	112	113	124	148	145	156	136	158
London 3	105	114	131	125	143	139	162	132	154
Lonond 4	104	110	127	119	141	144	159	128	154
Humberside	96	101	118	109	132	120	144	119	141
Fife	108	114	131	126	150	140	168	138	166
Mean	**102**	**109**	**126**	**120**	**143**	**135**	**158**	**131**	**155**
Interspiro Spiromatic									
Essex 1	91	99	120	109	135	127	155	123	147
Essex 2	114	117	132	135	149	140	165	138	151
Mid Glamorgan	99	105	118	118	136	133	156	125	147
Kent 3	106	110	129	122	145	139	169	136	161
Mean	**103**	**108**	**126**	**120**	**141**	**135**	**161**	**131**	**152**
Draeger P112									
Leicestershire	91	104	119	116	134	127	158	130	151
West Yorkshire	95	103	121	110	135	134	157	124	153
Lothian & Borders	100	110	136	123	150	135	166	134	160
Mean	**96**	**106**	**135**	**117**	**140**	**132**	**160**	**129**	**147**
Sabre Centurion									
Oxfordshire	99	104	120	105	131	126	153	120	146
Hereford & Worcester	101	103	115	114	128	119	145	122	143
Gloucestershire	103	109	121	118	136	132	158	121	152
Mean	**101**	**105**	**118**	**112**	**132**	**126**	**152**	**121**	**147**
Sabre SEFA									
Kent 1	95	101	124	128	147	142	166	134	158
Kent 2	99	101	117	112	129	125	139	116	140
Mean	97	**101**	**120**	**119**	**138**	**134**	**154**	**125**	**149**
Overall Mean	**101**	**107**	**124**	**118**	**140**	**133**	**158**	**128**	**152**

Table 3.14 Mean aural and skin temperatures (°C) at start and finish of short duration fire/rescue exercise

BA/Brigade	Duration (mins)	Aural Temperature			Back Temperature			Chest Temperature			Thigh Temperature		
		Start	End	Diff	Start	End	Diff	Start	End	Diff	Start	End	Diff
Siebe Gorman FF2													
London 1	30	36.0	39.8	4.0	33.9	40.8	6.8	34.0	39.9	6.0	31.9	39.0	7.1
London 2	28	36.2	39.6	3.4	34.1	43.5	9.4	33.4	40.9	4.7	30.5	40.5	9.9
London 3	25	36.2	39.6	3.4	35.3	41.5	6.2	33.9	39.6	5.7	31.5	38.5	7.0
London 4	25	36.8	39.6	2.8	34.6	42.3	7.7	34.2	40.3	6.1	32.4	39.7	7.3
Humberside	19	36.3	38.8	2.6	34.0	41.9	7.6	34.1	40.8	6.7	32.5	39.8	7.2
Fife	27	36.6	40.2	3.6	34.2	41.0	6.7	33.9	40.0	6.1	33.5	39.4	5.9
Mean	**26**	**36.4**	**39.6**	**3.2**	**34.4**	**41.8**	**7.4**	**33.9**	**40.3**	**6.4**	**32.1**	**39.5**	**7.4**
Interspiro Spiromatic													
Essex 1	38	36.1	40.0	3.9	34.0	41.7	7.7	33.4	41.0	7.6	31.2	40.2	9.0
Essex 2	32	37.5	40.3	3.1	35.6	42.2	6.6	34.1	40.5	6.4	34.4	39.5	5.2
Mid Glamorgan	31	37.1	40.1	3.0	35.7	43.0	7.3	34.2	40.5	6.3	32.8	39.2	6.4
Kent 3	35	36.5	39.6	3.0	34.4	41.7	7.3	33.8	39.6	5.8	31.5	39.3	7.9
Mean	**34**	**36.8**	**40.0**	**3.2**	**34.9**	**42.2**	**7.2**	**33.9**	**40.4**	**6.5**	**32.5**	**39.6**	**7.1**
Draeger P112													
Leicestershire	32	36.9	39.4	2.7	33.5	37.6	4.2	31.7	34.5	2.5	29.8	35.1	5.3
West Yorkshire	22	36.8	39.7	2.9	34.6	41.2	6.6	34.5	39.9	5.3	32.3	32.3	6.6
Lothian & Borders	26	37.1	38.8	1.7	34.4	39.6	5.2	32.7	38.9	6.2	32.2	32.2	6.7
Mean	**27**	**36.9**	**39.3**	**2.4**	**34.2**	**39.7**	**5.4**	**33.0**	**37.7**	**4.7**	**31.4**	**37.6**	**6.2**
Sabre Centurion													
Oxfordshire	22	37.0	39.9	3.6	34.7	40.2	5.5	31.8	36.8	5.0	33.1	37.7	4.6
Hereford & Worcester	35	36.2	39.7	3.5	34.3	41.1	6.8	33.4	40.7	7.3	31.0	39.9	8.8
Gloucestershire	24	37.0	40.2	3.2	35.3	43.4	8.1	35.0	41.3	6.3	33.0	41.1	8.1
Mean	**27**	**36.7**	**40.0**	**3.4**	**34.8**	**41.6**	**6.8**	**33.4**	**39.6**	**6.2**	**32.4**	**39.6**	**7.2**
SEFA													
Kent 1	30	36.9	38.7	1.8	34.7	39.3	4.6	34.1	38.2	4.0	32.4	37.3	4.8
Kent 2	40	36.7	40.1	3.4	35.2	41.8	6.6	34.7	40.0	5.3	33.5	39.1	5.6
Mean	**35**	**36.8**	**39.4**	**2.6**	**34.9**	**40.5**	**5.6**	**34.4**	**39.1**	**4.7**	**33.0**	**33.0**	**5.2**
Overall Mean	**29**	**36.7**	**39.7**	**3.0**	**34.6**	**41.4**	**6.8**	**33.7**	**39.6**	**5.9**	**32.2**	**39.1**	**6.9**

Table 3.15 Heart rates of teams of firefighters participating in short duration fire/rescue exercise

BA Type	Brigade	Heart Rate (beats min^{-1})		
		Mean	Minimum	Maximum
Siebe Gorman FF2	London 1	154.0	107.3	209.0
	London 2	146.5	113.0	201.0
	London 3	148.5	116.0	188.5
	London 4	156.7	105.2	203.2
	Humberside	125.0	82.2	182.7
	Fife	153.7	105.7	208.0
	Group Mean	**147.4**	**104.9**	**198.7**
Interspiro Spiromatic	Essex 1	144.2	95.2	195.7
	Essex 2	149.0	105.7	211.0
	Mid Glamorgan	145.2	115.7	196.2
	Kent 3	141.0	92.5	201.0
	Group Mean	**144.9**	**102.3**	**201.0**
Draeger P112	Leicestershire	N.A	N.A	N.A
	West Yorkshire	144.7	102.5	202.0
	Lothian and Borders	144.7	83.5	209.5
	Group Mean	**144.7**	**93.5**	**205.7**
Sabre Centurion	Oxford	151.7	103.2	198.0
	Hereford & Worcester	135.2	103.7	199.2
	Gloucestershire	161.0	116.7	200.0
	Group Mean	**149.3**	**107.9**	**199.1**
Sabre SEFA	Kent 1	139.5	104.5	182.2
	Kent 2*	122.5	88.5	169.5
	Group Mean	**133.8**	**99.2**	**178.0**
Overall Mean		**145.2**	**102.3**	**198.1**

N.A - Not available
*** - Data available for two subjects only**

Table 3.16 Total air consumption (derived from changes in cylinder pressure using Boyle's Law), minute volumes and sweat losses during short duration fire/rescue exercise

BA/Brigade	Air Consumption (*l*)	Minute Volume (l min^{-1})	Sweat Loss (*l*)
Siebe Gorman FF2			
London 1	1830	61	0.90
London 2	750	27	0.29
London 3	1330	53	1.82
London 4	1170	47	1.23
Humberside	670	35	0.75
Fife	1330	49	1.09
Mean	**1180**	**45.4 (49.9)***	**1.01**
Interspiro Spiromatic			
Essex 1	1330	35	0.76
Essex 2	1420	44	1.40
Mid Glamorgan	1670	54	1.63
Kent 3	1500	43	1.18
Mean	**1480**	**43.5 (47.9)**	**1.24**
Draeger P112			
Leicestershire	1250	39	N.M
West Yorkshire	1170	53	0.94
Lothian and Borders	1250	48	0.98
Mean	**1220**	**45.2 (49.7)**	**0.96**
Sabre Centurion			
Oxfordshire	830	38	N.M
Hereford & Worcester	1250	36	1.30
Gloucestershire	1080	45	1.88
Mean	**1050**	**38.9 (42.8)**	**1.59**
Sabre SEFA			
Kent 1	N.A	N.A	1.09
Kent 2	N.A	N.A	2.33
Mean	-	-	**1.71**
Overall Mean	**1250**	**43.1 (47.4)**	**1.22**

*** - Minute volume converted to normal body temperature conditions (37°)**
N.M - Not Measured
N.A - Not Applicable

Table 3.17 Mean aural and skin temperatures (°C) at start and finish of the gastight suit exercise (20 minutes duration)

BA/Brigade	Aural Temperature			Back Temperature			Chest Temperature			Thigh Temperature		
	Start	End	Diff	Start	End	Diff	Start	End	Diff	Start	End	Diff
Siebe Gorman FF2												
London 1	36.5	37.1	0.6	33.2	35.8	2.6	32.6	35.4	2.7	29.0	34.5	5.4
London 2	36.4	37.7	1.3	32.0	34.3	2.3	32.9	35.8	2.8	29.4	34.1	4.7
London 3	36.4	37.6	1.2	33.0	35.3	2.4	32.7	36.0	3.2	29.6	35.5	4.9
London 4	36.6	37.9	1.3	34.0	35.9	1.9	33.0	36.3	3.3	30.3	36.1	5.8
Humberside	36.3	37.5	1.2	33.4	35.4	2.0	32.8	36.3	3.5	31.8	36.3	4.5
Fife	36.7	37.6	0.9	32.2	32.8	0.6	33.6	35.6	2.0	30.4	35.0	4.6
Mean	**36.5**	**37.6**	**1.1**	**33.0**	**35.0**	**2.0**	**33.0**	**35.9**	**3.0**	**30.4**	**35.3**	**5.2**
Interspiro Spiromatic												
Essex 1	36.8	38.0	1.2	32.9	36.6	3.7	32.7	36.0	3.3	31.6	35.9	4.3
Essex 2	36.5	38.2	1.8	34.6	36.9	2.3	34.3	37.1	2.7	32.9	36.6	3.7
Mid Glamorgan	36.3	37.3	1.0	32.9	36.0	3.1	31.8	35.6	3.8	29.6	35.4	5.8
Kent 3	36.0	37.6	1.6	32.7	35.8	3.1	31.3	35.4	4.1	29.1	35.4	6.3
Mean	**36.4**	**37.8**	**1.4**	**33.3**	**36.3**	**3.0**	**32.6**	**36.0**	**3.5**	**30.8**	**35.9**	**5.0**
Draeger P112												
Leicestershire	36.2	37.7	1.5	30.8	34.0	3.2	31.1	34.2	3.6	28.9	33.5	4.6
West Yorkshire	-	37.4	-	-	35.0	-	-	36.0	-	-	34.6	-
Lothian & Borders	36.1	37.2	1.1	32.7	36.6	3.9	32.4	35.8	3.4	30.6	34.8	4.2
Mean	**36.2**	**37.4**	**1.3**	**31.8**	**35.2**	**3.6**	**31.8**	**35.4**	**3.5**	**29.8**	**34.3**	**4.4**
Sabre Centurion												
Oxfordshire	36.1	36.9	0.8	31.5	34.4	2.9	30.1	34.1	3.9	28.9	33.8	5.0
Hereford & Worcester	36.1	37.8	1.7	32.7	36.3	3.6	32.1	35.6	3.5	29.8	35.4	5.6
Gloucestershire	36.3	38.0	1.7	35.9	37.5	2.0	34.4	37.2	2.6	31.3	36.4	5.1
Mean	**36.2**	**37.5**	**1.4**	**33.4**	**36.0**	**2.9**	**32.2**	**35.5**	**3.4**	**30.0**	**35.1**	**5.2**
SEFA												
Kent 1	36.9	38.5	1.6	31.4	37.2	5.8	30.8	36.6	5.8	32.0	36.8	4.8
Kent 2	35.9	36.9	1.0	32.3	35.9	3.6	31.6	35.3	3.7	31.0	34.9	3.9
Mean	**36.4**	**37.7**	**1.3**	**31.8**	**36.5**	**4.7**	**31.2**	**36.0**	**4.8**	**31.5**	**35.8**	**4.3**
Overall Mean	**36.3**	**37.6**	**1.2**	**32.9**	**35.7**	**2.9**	**32.4**	**35.8**	**3.5**	**30.4**	**35.3**	**5.0**

Table 3.18 Mean heart rates of teams of firefighters participating in gastight suit/chemical spillage exercise

BA Type	Brigade	Heart Rate (bpm)		
		Mean	Minimum	Maximum
Siebe Gorman FF2	London 1	124.3	86.3	164.0
	London 2	144.3	93.0	175.3
	London 3	140.0	98.0	166.0
	London 4	139.7	87.7	187.7
	Humberside	124.5	83.2	163.5
	Fife	144.7	100.2	178.5
	Mean	**136.3**	**91.4**	**172.5**
Interspiro Spiromatic	Essex 1	145.7	96.7	179.5
	Essex 2	141.3	91.0	200.3
	Mid Glamorgan	116.7	73.2	149.2
	Kent 3	136.2	82.5	182.0
	Mean	**135.0**	**85.9**	**177.7**
Draeger P112	Leicestershire	125.2	74.5	171.0
	West Yorkshire	131.7	71.2	169.2
	Lothian and Borders	139.0	85.2	183.7
	Mean	**132.0**	**77.0**	**174.7**
Sabre Centurion	Oxford	109.5	70.0	145.0
	Hereford & Worcester	138.7	90.2	172.0
	Gloucestershire	147.0	94.2	193.0
	Mean	**131.7**	**84.8**	**170.0**
Sabre SEFA	Kent 1	152.2	89.7	189.5
	Kent 2	119.2	82.0	152.0
	Mean	**135.7**	**85.9**	**170.7**
	Overall Mean	**134.4**	**86.0**	**173.4**

Table 3.19 Mean total air consumption (derived from changes in cylinder pressure) and sweat loss during gastight suit exercise

BA/Brigade	Air Consumption (*l*)	Sweat Loss (*l*)
Siebe Gorman FF2		
London 1	1085	0.64
London 2	1165	0.36
London 3	1250	0.72
London 4	1335	0.55
Humberside	1000	0.51
Fife	1415	0.66
Mean	**1210**	**0.58**
Interspiro Spiromatic		
Essex 1	1665	0.99
Essex 2	1665	0.49
Mid Glamorgan	1335	0.82
Kent 3	1415	0.63
Mean	**1520**	**0.73**
Draeger P112		
Leicestershire	1335	N.M
West Yorkshire	1165	0.56
Lothian and Borders	1585	0.82
Mean	**1360**	**0.69**
Sabre Centurion		
Oxfordshire	1085	N.M
Hereford & Worcester	1415	0.69
Gloucestershire	1585	0.65
Mean	**1360**	**0.67**
Sabre SEFA		
Kent 1	N.A	0.63
Kent 2	N.A	0.25
Mean		**0.44**
Overall (Weighted) Mean	**1345**	**0.63**

N.M - Not Measured
N.A - Not Applicable

Table 3.20 Mean cumulative times (in minutes) to complete each stage of the long duration fire simulation exercise

BA/Brigade	Cumulative time at end of designated stage					Total time minus time to change cylinders
	1	2	Change	3	4	
Siebe Gorman FF2						
London 1	12	33	41	66	78	70
London 2	8	23	33	45	58	48
London 3	14	29	39	54	63	43
London 4	14	31	43	57	66	54
Humberside	12	24	(33)*	44	52	(43)
Fife	8	26	31	45	54	49
Mean	**11**	**28**	**37**	**52**	**61**	**53**
Interspiro Spiromatic						
Essex 1	11	28	32	44	(58)	(54)
Essex 2	11	26	35	46	55	46
Mid Glamorgan	9	25	30	53	54	46
Kent 3	11	29	37	54	65	57
Mean	**11**	**27**	**34**	**47**	**57**	**50**
Draeger P112						
Leicestershire	14	34	38	61	76	72
West Yorkshire	10	32	38	50	61	55
Lothian and Borders	15	32	41	57	68	59
Mean	**13**	**33**	**39**	**56**	**68**	**62**
Sabre Centurion						
Oxfordshire	16	37	43	67	82	75
Hereford & Worcester	10	27	-	-	53	(48)
Gloucestershire	12	31	35	53	63	60
Mean	**13**	**32**	**39**	**60**	**66**	**61**
Sabre SEFA						
Kent 1	12	30	34	47	(62)	(56)
Kent 2	18	46	49	62	89	86
Mean	**15**	**38**	**41**	**54**	**76**	**71**
Overall Mean	12	30	37	52	65	59

* - ( ) indicates estimated time

Table 3.21(a) Mean (maximum) aural temperature at the start and after each stage of the long duration fire simulation exercise

BA/Brigade	Start	Stage 1	Stage 2	Stage 3	Stage 4
Siebe Gorman FF2					
London 1	36.6 (36.9)	37.4 (37.8)	38.2 (38.7)	37.9 (38.5)	37.7 (38.2)
London 2	36.5 (36.8)	36.7 (37.0)	38.0 (38.2)	38.0 (38.4)	38.8 (39.2)
London 3	35.9 (36.7)	37.2 (37.3)	38.0 (38.2)	37.6 (37.7)	37.9 (38.0)
London 4	36.5 (36.8)	37.1 (37.6)	37.8 (38.1)	37.2 (37.8)	37.6 (38.1)
Humberside	36.3 (36.9)	36.3 (36.9)	37.2 (37.9)	37.2 (37.7)	37.5 (38.2)
Fife	36.7 (36.8)	36.6 (36.9)	37.4 (37.6)	37.2 (37.3)	37.6 (37.7)
Mean	**36.4 (36.9)**	**36.9 (37.8)**	**37.8 (38.7)**	**37.5 (38.5)**	**37.8 (39.2)**
Interspiro Spiromatic					
Essex 1	36.4 (36.8)	37.5 (37.7)	37.9 (38.5)	38.7 (38.8)	39.1 (39.4)
Essex 2	35.9 (36.3)	37.3 (37.6)	38.3 (38.6)	38.0 (38.5)	38.3 (38.7)
Mid Glamorgan	36.8 (37.0)	37.3 (37.8)	38.4 (38.9)	38.6 (38.9)	39.0 (39.2)
Kent 3	36.6 (36.9)	37.3 (37.5)	38.1 (38.6)	37.9 (38.1)	37.9 (38.1)
Mean	**36.4 (37.0)**	**37.4 (37.8)**	**38.2 (38.9)**	**38.3 (38.9)**	**38.6 (39.4)**
Draeger P112					
Leicestershire	36.7 (37.0)	37.3 (37.8)	38.1 (38.3)	38.5 (38.8)	38.3 (38.4)
West Yorkshire	36.6 (36.8)	37.0 (37.7)	38.2 (38.7)	38.1 (38.3)	38.4 (38.6)
Lothian and Borders	36.8 (37.2)	36.9 (37.2)	37.7 (37.9)	37.9 (38.2)	38.1 (38.1)
Mean	**36.7 (37.2)**	**37.1 (37.8)**	**37.9 (38.7)**	**38.2 (38.8)**	**38.3 (38.6)**
Sabre Centurion					
Oxfordshire	36.8 (37.2)	37.5 (37.7)	38.0 (38.7)	38.5 (38.8)	38.3 (38.4)
Hereford & Worcester	36.6 (37.1)	37.2 (37.5)	37.8 (38.2)	38.1 (38.3)	38.4 (38.6)
Gloucestershire	35.9 (36.6)	36.8 (37.0)	37.7 (37.9)	37.9 (38.2)	38.1 (38.4)
Mean	**36.4 (37.2)**	**37.2 (37.7)**	**37.9 (38.7)**	**38.2 (38.8)**	**38.3 (38.6)**
Sabre SEFA					
Kent 1	37.0 (37.3)	37.5 (37.7)	38.4 (38.5)	39.5 (39.7)	* *
Kent 2	36.7 (36.9)	37.2 (37.4)	37.9 (38.3)	38.4 (38.9)	38.7 (39.2)
Mean	**36.8 (37.3)**	**37.3 (37.7)**	**38.2 (38.5)**	**39.0 (39.7)**	**38.7 (39.2)**
Overall Mean	**36.5 (37.3)**	**37.1 (37.8)**	**38.0 (38.9)**	**38.1 (39.7)**	**38.2 (39.4)**

* - Did not undertake this stage
All figures in brackets are the maxima not the means of the group to which they refer

Table 3.21(b) Mean (maximum) back tempertaure at the start and after each stage of the long duration fire simulation exercise

BA/Brigade	Start	Stage 1	Stage 2	Stage 3	Stage 4
Siebe Gorman FF2					
London 1	34.8 (35.9)	37.5 (38.0)	38.2 (38.9)	36.9 (37.7)	36.7 (37.7)
London 2	34.5 (35.2)	37.1 (37.7)	38.3 (38.9)	37.7 (38.8)	36.8 (37.5)
London 3	34.6 (35.3)	38.0 (38.7)	38.0 (39.4)	36.4 (36.6)	36.3 (37.2)
London 4	34.2 (34.9)	37.6 (38.6)	37.7 (38.9)	36.1 (36.8)	36.4 (36.9)
Humberside	33.8 (35.1)	36.9 (37.5)	37.4 (38.0)	36.6 (37.6)	36.4 (37.2)
Fife	34.6 (35.5)	36.9 (37.6)	37.1 (37.7)	35.7 (36.2)	34.6 (36.1)
Mean	**34.4 (35.9)**	**37.3 (38.7)**	**37.8 (39.4)**	**36.5 (38.8)**	**36.2 (37.7)**
Interspiro Spiromatic					
Essex 1	34.2 (34.9)	37.7 (38.4)	38.8 (39.4)	38.2 (38.5)	38.2 (38.5)
Essex 2	34.4 (35.7)	38.3 (39.2)	39.2 (39.6)	36.6 (37.0)	36.6 (36.9)
Mid Glamorgan	35.3 (35.8)	37.8 (38.8)	38.5 (39.7)	38.3 (38.5)	38.2 (38.7)
Kent 3	35.0 (35.4)	37.3 (38.4)	37.2 (38.3)	36.1 (37.2)	36.6 (38.9)
Mean	**34.8 (35.8)**	**37.8 (39.2)**	**38.4 (39.7)**	**37.3 (38.5)**	**37.4 (38.9)**
Draeger P112					
Leicestershire	35.0 (36.1)	37.8 (38.5)	38.5 (38.8)	38.1 (38.3)	37.2 (37.4)
West Yorkshire	34.6 (35.7)	37.4 (37.6)	38.0 (38.6)	36.4 (36.6)	36.0 (36.4)
Lothian and Borders	34.9 (35.7)	37.3 (37.7)	37.5 (38.5)	36.8 (37.8)	36.5 (37.4)
Mean	**34.8 (36.1)**	**37.5 (38.5)**	**38.0 (38.8)**	**37.1 (38.3)**	**36.6 (37.4)**
Sabre Centurion					
Oxfordshire	34.5 (35.5)	38.1 (38.3)	38.4 (39.1)	37.7 (38.0)	36.9 (37.4)
Hereford & Worcester	34.5 (35.5)	38.6 (38.9)	38.7 (39.2)	37.8 (38.1)	37.6 (37.9)
Gloucestershire	34.1 (34.9)	37.1 (37.6)	37.6 (38.0)	37.0 (37.6)	36.7 (37.2)
Mean	**34.3 (35.5)**	**38.0 (38.9)**	**38.2 (39.2)**	**37.5 (38.1)**	**37.1 (37.9)**
Sabre SEFA					
Kent 1	35.0 (36.0)	37.5 (38.4)	39.2 (39.4)	39.4 (39.8)	* *
Kent 2	34.1 (35.1)	37.2 (37.5)	37.9 (38.7)	37.7 (38.6)	38.0 (39.1)
Mean	**34.6 (36.0)**	**37.3 (38.4)**	**38.5 (39.4)**	**38.6 (39.8)**	**38.0 (39.1)**
Overall Mean	**34.6 (36.1)**	**37.6 (39.2)**	**38.1 (39.7)**	**37.2 (39.8)**	**36.8 (39.1)**

*** - Did not undertake this stage**

Table 3.21(c) Mean (maximum) chest temperature at the start and after each stage of the long duration fire simulation exercise

BA/Brigade	Start	Stage 1	Stage 2	Stage 3	Stage 4
Siebe Gorman FF2					
London 1	34.1 (34.7)	37.0 (37.4)	37.5 (38.0)	36.5 (37.5)	35.6 (36.3)
London 2	34.1 (34.6)	36.0 (36.3)	37.8 (37.8)	36.5 (36.7)	36.8 (37.3)
London 3	32.4 (33.7)	36.7 (37.4)	36.9 (37.6)	36.1 (36.9)	35.8 (36.9)
London 4	33.4 (35.0)	36.9 (38.1)	37.2 (37.9)	35.4 (36.4)	35.8 (36.7)
Humberside	34.0 (35.0)	36.0 (36.9)	37.2 (37.6)	35.9 (36.3)	36.3 (36.7)
Fife	33.7 (34.3)	35.8 (36.4)	36.5 (37.0)	35.5 (36.0)	33.4 (35.5)
Mean	**33.6 (35.0)**	**36.4 (38.1)**	**37.2 (38.0)**	**36.5 (37.5)**	**35.5 (37.3)**
Interspiro Spiromatic					
Essex 1	34.9 (35.3)	37.0 (37.7)	38.1 (38.4)	37.6 (37.9)	37.7 (37.9)
Essex 2	33.9 (35.3)	37.2 (37.5)	37.8 (38.1)	36.6 (37.2)	36.6 (37.4)
Mid Glamorgan	34.3 (35.4)	36.2 (36.6)	38.6 (38.8)	37.4 (37.6)	37.8 (38.3)
Kent 3	34.9 (35.2)	36.8 (37.5)	37.5 (37.8)	36.6 (37.1)	36.6 (37.2)
Mean	**34.5 (35.4)**	**36.8 (37.7)**	**38.0 (38.8)**	**37.0 (37.9)**	**37.2 (38.3)**
Draeger P112					
Leicestershire	32.9 (34.4)	36.8 (37.2)	37.6 (37.8)	37.2 (37.5)	36.9 (37.4)
West Yorkshire	34.3 (34.5)	36.9 (37.2)	37.1 (37.4)	36.3 (36.9)	35.9 (37.0)
Lothian and Borders	34.0 (35.1)	36.3 (37.1)	36.8 (37.2)	36.3 (37.0)	36.2 (36.9)
Mean	**33.7 (35.1)**	**36.7 (37.2)**	**37.2 (37.8)**	**36.6 (37.5)**	**36.3 (37.4)**
Sabre Centurion					
Oxfordshire	33.6 (34.9)	36.9 (37.6)	37.6 (38.1)	36.9 (37.8)	36.3 (37.5)
Hereford & Worcester	33.4 (35.2)	36.5 (37.5)	37.7 (38.3)	36.4 (37.1)	36.4 (37.0)
Gloucestershire	34.5 (35.4)	36.6 (37.1)	37.1 (37.6)	36.5 (37.2)	36.6 (37.1)
Mean	**33.8 (35.4)**	**36.7 (37.6)**	**37.4 (38.3)**	**36.6 (37.8)**	**36.4 (37.5)**
Sabre SEFA					
Kent 1	33.4 (34.5)	36.8 (37.0)	37.9 (38.3)	37.8 (38.3)	* *
Kent 2	34.4 (35.1)	36.6 (37.0)	37.2 (37.5)	36.9 (37.5)	37.4 (38.1)
Mean	**33.9 (35.1)**	**36.7 (37.0)**	**37.6 (38.3)**	**37.4 (38.3)**	**37.4 (38.1)**
Overall Mean	**33.9 (35.4)**	**36.6 (38.1)**	**37.5 (38.8)**	**36.6 (38.3)**	**36.4 (38.3)**

* - Did not undertake this stage

Table 3.21(d) Mean (maximum) thigh temperature at the start and after each stage of the long duration fire simulation exercise

BA/Brigade	Start	Stage 1	Stage 2	Stage 3	Stage 4
Siebe Gorman FF2					
London 1	33.1 (34.3)	36.0 (36.5)	36.7 (37.8)	34.3 (35.3)	34.1 (35.0)
London 2	31.7 (33.0)	34.4 (34.9)	37.1 (38.1)	35.6 (36.6)	35.6 (37.0)
London 3	30.7 (31.8)	35.2 (37.0)	35.6 (37.2)	34.1 (35.3)	33.8 (35.6)
London 4	31.3 (33.5)	35.7 (36.6)	36.7 (37.5)	34.5 (35.2)	34.8 (35.6)
Humberside	32.2 (33.1)	35.1 (35.7)	36.5 (37.1)	35.3 (36.0)	35.1 (36.0)
Fife	32.1 (32.9)	34.9 (35.8)	36.4 (37.1)	34.8 (35.0)	35.2 (36.2)
Mean	**31.9 (34.3)**	**35.2 (37.0)**	**36.5 (38.1)**	**36.5 (36.6)**	**34.8 (37.0)**
Interspiro Spiromatic					
Essex 1	32.4 (33.7)	35.4 (36.0)	36.3 (38.4)	36.7 (37.6)	36.5 (37.6)
Essex 2	31.4 (32.3)	35.7 (36.3)	36.8 (37.5)	35.4 (36.1)	35.4 (36.6)
Mid Glamorgan	32.9 (34.6)	35.3 (36.5)	38.6 (39.0)	36.9 (37.2)	36.3 (37.7)
Kent 3	31.1 (31.8)	34.7 (35.6)	35.7 (36.4)	34.7 (35.1)	34.7 (35.1)
Mean	**32.0 (34.6)**	**35.3 (36.5)**	**36.9 (39.0)**	**35.9 (37.6)**	**35.7 (37.7)**
Draeger P112					
Leicestershire	32.1 (33.6)	36.1 (36.6)	36.5 (37.3)	35.9 (36.6)	35.2 (36.6)
West Yorkshire	32.4 (32.8)	35.3 (35.7)	36.1 (37.5)	34.9 (36.2)	34.3 (35.2)
Lothian and Borders	31.9 (33.7)	35.2 (37.0)	36.3 (37.8)	35.7 (36.2)	35.4 (36.2)
Mean	**32.1 (33.7)**	**35.5 (37.0)**	**36.3 (37.8)**	**35.5 (36.6)**	**35.0 (36.6)**
Sabre Centurion					
Oxfordshire	32.6 (34.0)	36.2 (37.2)	36.7 (37.6)	36.1 (37.4)	36.0 (36.9)
Hereford & Worcester	31.0 (32.2)	36.0 (36.7)	37.1 (37.2)	36.1 (36.9)	36.4 (36.9)
Gloucestershire	30.8 (31.3)	34.7 (35.5)	36.7 (37.6)	35.8 (36.4)	35.3 (36.4)
Mean	**31.5 (34.0)**	**35.6 (37.2)**	**36.8 (37.6)**	**36.0 (37.4)**	**35.9 (36.9)**
Sabre SEFA					
Kent 1	34.0 (34.5)	35.1 (36.9)	37.1 (38.4)	37.0 (38.4)	* *
Kent 2	34.2 (35.6)	35.7 (36.1)	36.4 (36.8)	36.1 (36.5)	36.5 (37.0)
Mean	**34.1 (35.6)**	**35.4 (36.9)**	**36.8 (38.4)**	**36.6 (38.4)**	**36.5 (37.0)**
Overall Mean	**32.1 (35.6)**	**35.4 (37.2)**	**36.6 (39.0)**	**35.6 (38.4)**	**35.4 (37.7)**

* - Did not undertake this stage

Table 3.22 Mean heart rates of teams of firefighters participating in long duration fire/rescue exercise

BA Type	Brigade	Heart Rate (beats min^{-1})		
		Mean	Minimum	Maximum
Siebe Gorman FF2	London 1	148.7	96.2	195.0
	London 2	157.0	97.7	199.2
	London 3	141.0	96.7	176.7
	London 4	128.2	91.0	180.5
	Humberside	123.7	80.0	170.2
	Fife	135.2	99.2	175.2
	Mean	**139.0**	**93.5**	**182.8**
Interspiro Spiromatic	Essex 1	153.2	95.2	190.5
	Essex 2	155.7	112.2	191.5
	Mid Glamorgan	142.0	89.7	187.1
	Kent 3	140.0	99.0	182.7
	Mean	**147.7**	**99.1**	**188.0**
Draeger P112	Leicestershire	150.0	93.0	194.3
	West Yorkshire	137.5	85.5	183.5
	Lothian and Borders	141.7	91.7	199.0
	Mean	**143.1**	**90.1**	**192.3**
Sabre Centurion	Oxford	142.2	87.7	185.0
	Hereford & Worcester	141.5	90.5	180.0
	Gloucestershire	143.2	101.2	187.0
	Mean	**142.3**	**93.2**	**184.0**
Sabre SEFA	Kent 1	140.0	89.3	193.7
	Kent 2	123.7	73.0	179.7
	Mean	**131.8**	**81.1**	**186.7**
Overall Mean		**141.4**	**92.8**	**186.2**

Table 3.23 Air consumption (derived from changes in cylinder pressure), minute volume and sweat loss during long duration fire simulation exercise

BA/Brigade	Air Consumption (*l*)	Duration (Mins)*	Minute Volume (*l*)	Sweat Loss (*l*)
Siebe Gorman FF2				
London 1	2750	70	39	1.3
London 2	2000	48	42	1.2
London 3	2170	53	41	1.7
London 4	2000	54	37	1.0
Humberside	1750	(43)	41	0.9
Fife	1750	49	36	1.1
Mean	**2070**	**53**	**39**	**1.20**
Interspiro Spiromatic				
Essex 1	2420	(54)	45	1.7
Essex 2	2250	46	49	1.1
Mid Glamorgan	2500	46	54	1.7
Kent 3	2580	57	45	1.4
Mean	**2440**	**51**	**48**	**1.48**
Draeger P112				
Leicestershire	3000	72	42	N.M
West Yorkshire	2000	55	36	1.3
Lothian and Borders	2830	77	37	1.2
Mean	**2610**	**68**	**38**	**1.25**
Sabre Centurion				
Oxfordshire	3000	75	40	N.M
Hereford & Worcester	2000	48	42	1.2
Gloucestershire	2750	60	46	1.3
Mean	**2580**	**61**	**43**	**1.25**
Sabre SEFA				
Kent 1	N.M	(56)	N.M	1.7
Kent 2	N.M	86	N.M	2.1
Mean	**N.M**	**71**	**N.M**	**1.90**
Overall Mean	**2360 +**	**58**	**41.8 +**	**1.37**

*** - Total time minus cylinder changeover time (estimated times in brackets)**
N.M - Not Measured
+ - Open circuit BA only

Table 3.24 Characteristics of BA sets: weight, excluding cylinder; extensor moment on the firefighter in the upright position; and second moment of inertia

BA set	Weight (without cylinder) (kg)	Extensor Moment (with cylinder) (Nm)	Second moment of inertia (with cylinder) (Nm^2)
Draeger P112	3.7	11.1	3.52 (2)*
Interspiro Spiromatic (twin cylinder)	2.9	9.9	6.92 (4)
Sabre Centurion	3.4	10.2	3.42 (1)
Siebe Gorman FF2	3.1	9.5	7.01 (5)
Draeger P90	3.2	10.6	6.28 (3)

*** - Ranking of BA sets. (1) = set with lowest second moment of inertia**

Table 3.25 Back length measurements for selected percentiles of British male and female populations covering height criteria for firefighters

Gender	Percentile	Back Length (mm)
Male	50	370
Male	99	385
Female	95	365

(Back length has been measured between shoulder height and mid lumbar height).

Table 3.26 Usable length of backplate on different BA sets

BA Set	Backplate length (mm)
Draeger P112	457
Interspiro Spiromatic	434
Sabre Centurion	426
Siebe Gorman FF2	408
Draeger P90	386

Table 4.1 Weights and percentage breakdown of BA components and other protective equipment worn by a firefighter

Component	Wt (Kg)	%
Cylinder +	10.8	51.9
Clothing *	3.6	17.3
Helmet (av) $	1.1	5.3
Backplate (av) $	3.3	15.9
Boots (rubber)	2.0	9.6
Total	20.8	100.0

+ - Based on standard 300 bar, 6 litre water capacity cylinder
*** - Separate leggings and jackets (GD Protective Products)**
$ - Averages of several different models

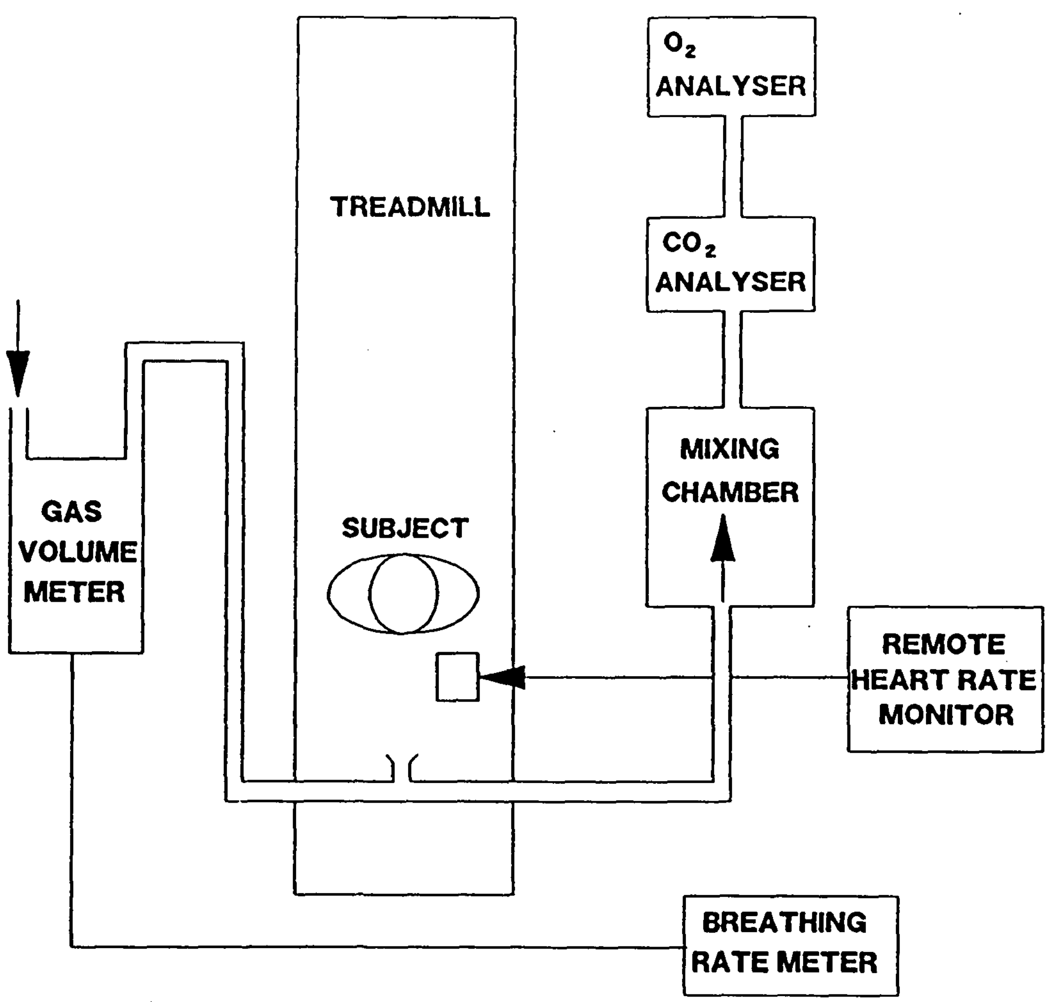


Figure 2.1 **Diagrammatic layout of treadmill test**

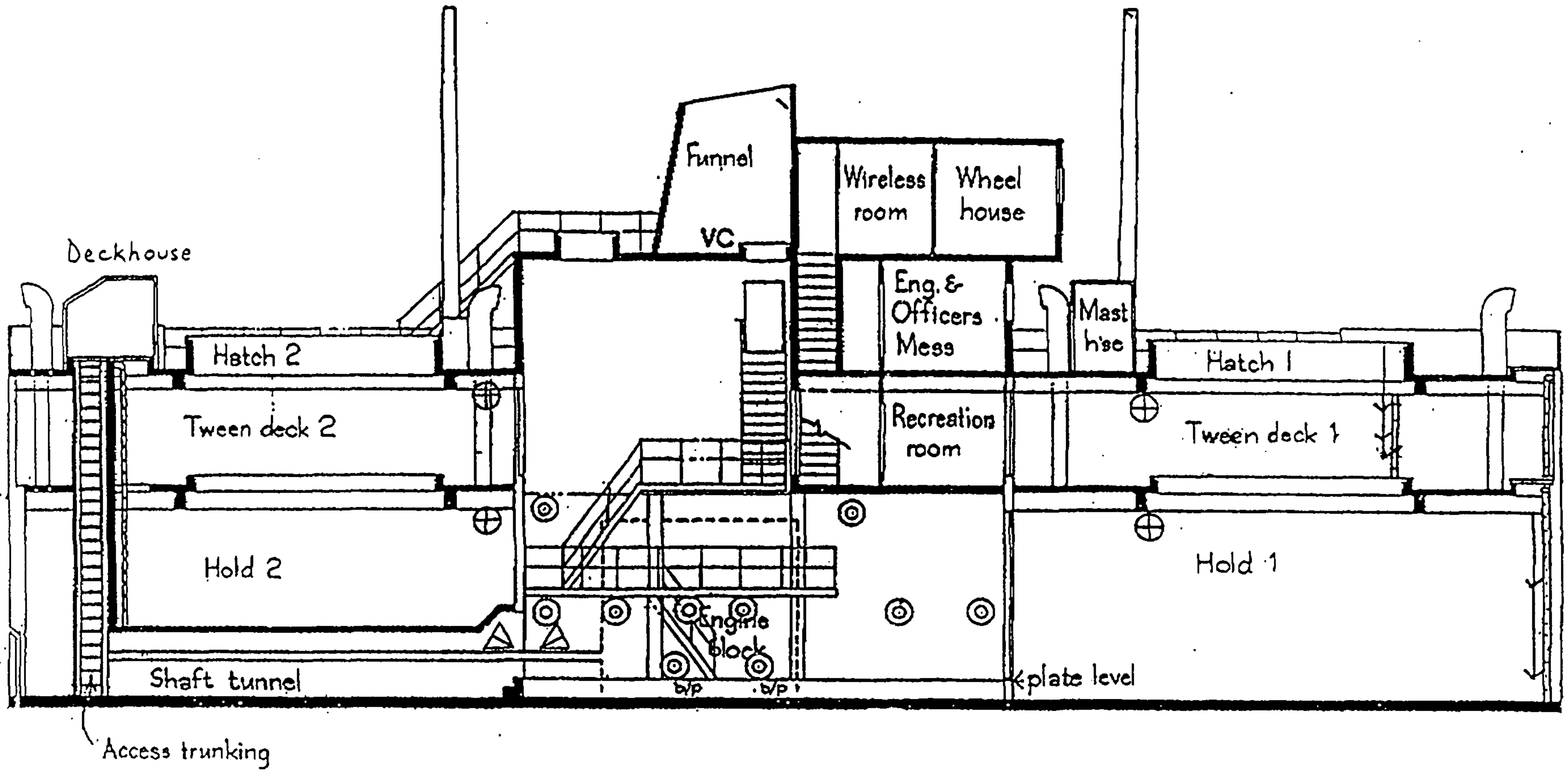


Figure 2.2 Cross-sectional view of the "Sir Henry" training facility used for all fire/rescue simulations. The forward area of the ship is on the right

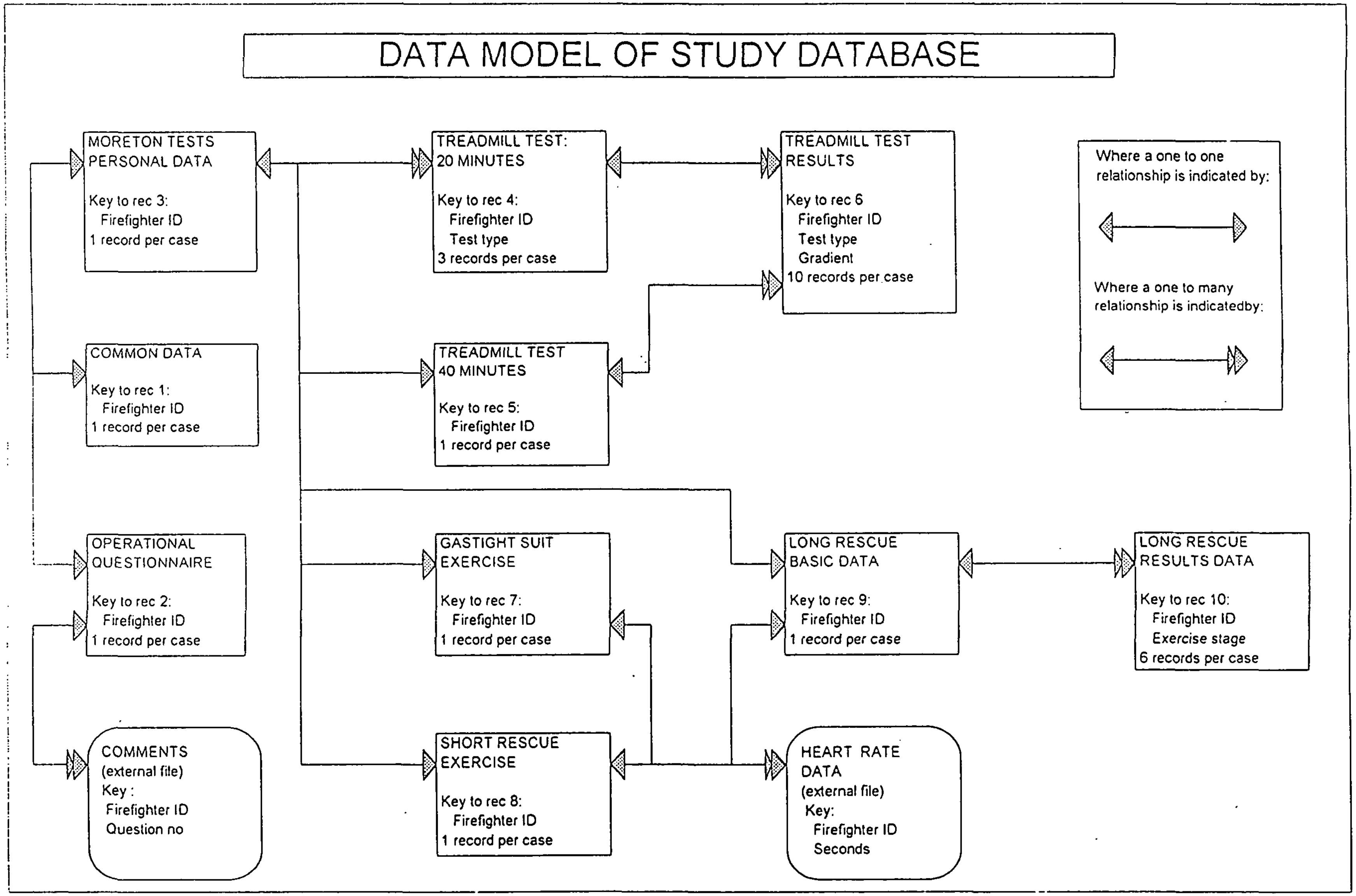


Figure 2.3 Outline data model showing the database structure

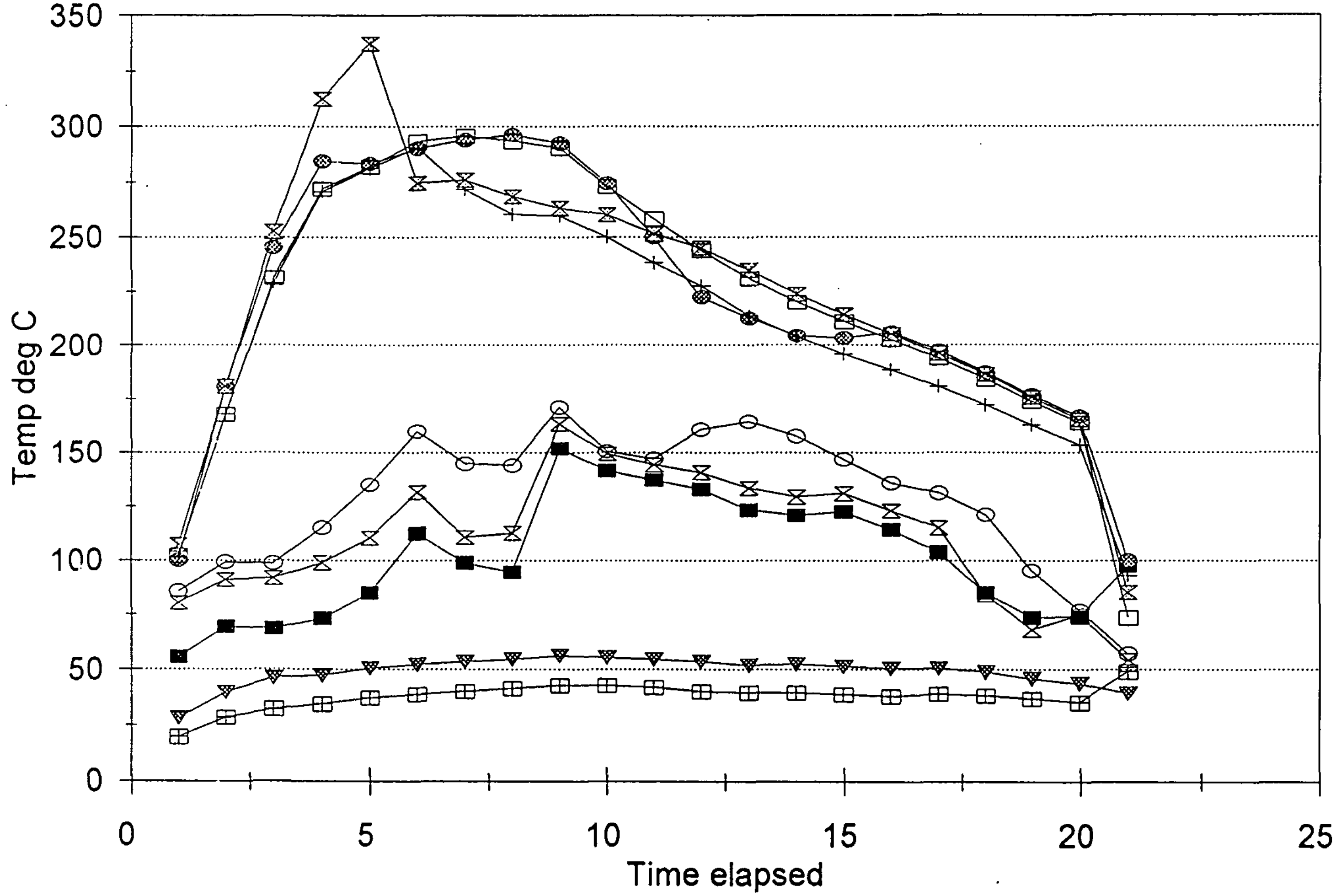


Figure 3.1 Profile of environmental temperatures against elapsed time (in minutes) during a short duration fire/rescue exercise (Oxford FB). Each symbol represents temperatures at a different monitoring point in the circuit

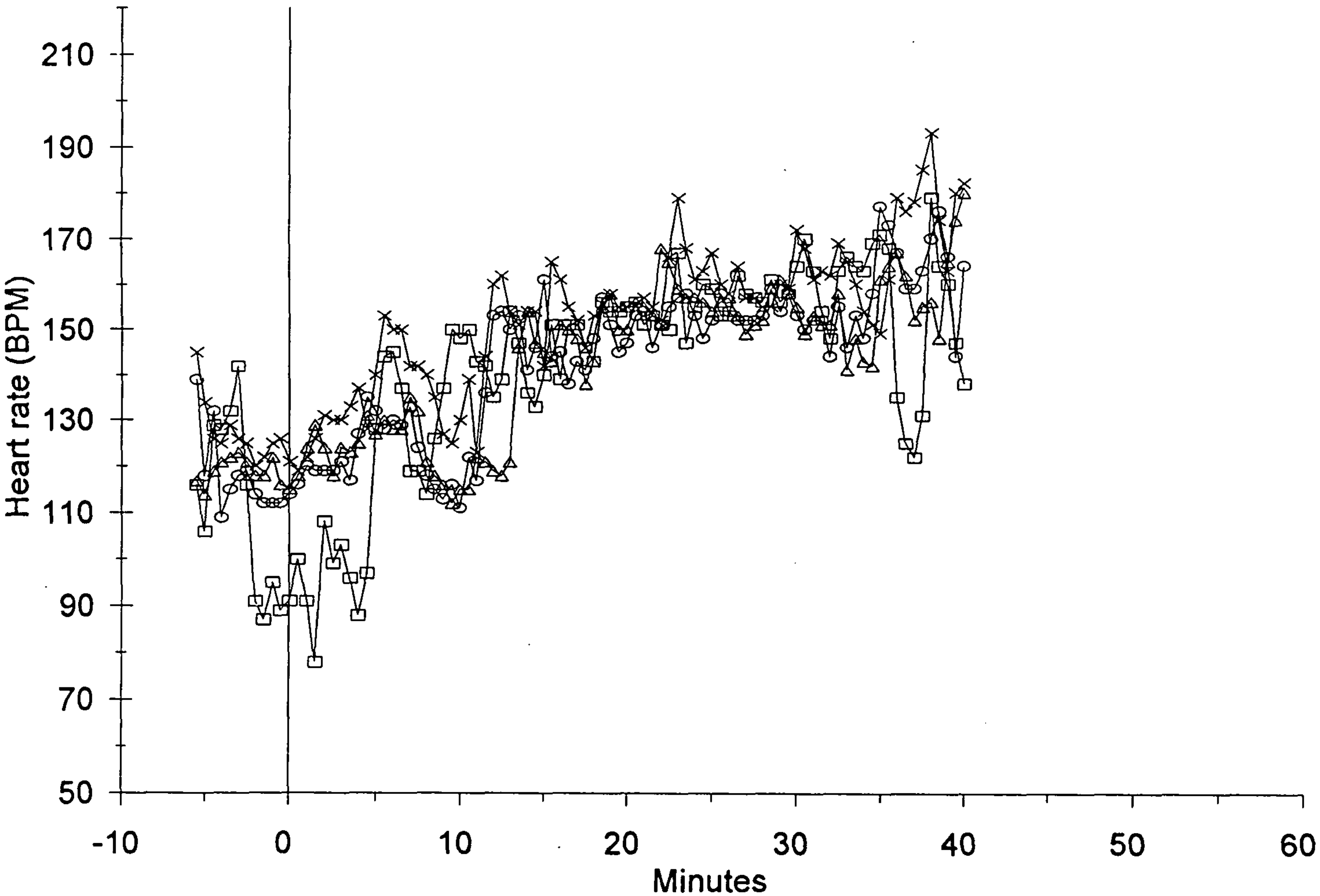


Figure 3.2 **Heart rates (beats per minute - beats min^{-1}) recorded every 30 seconds on 4 Kent firefighters wearing Sabre SEFA CCBA during the short duration fire/rescue exercise**

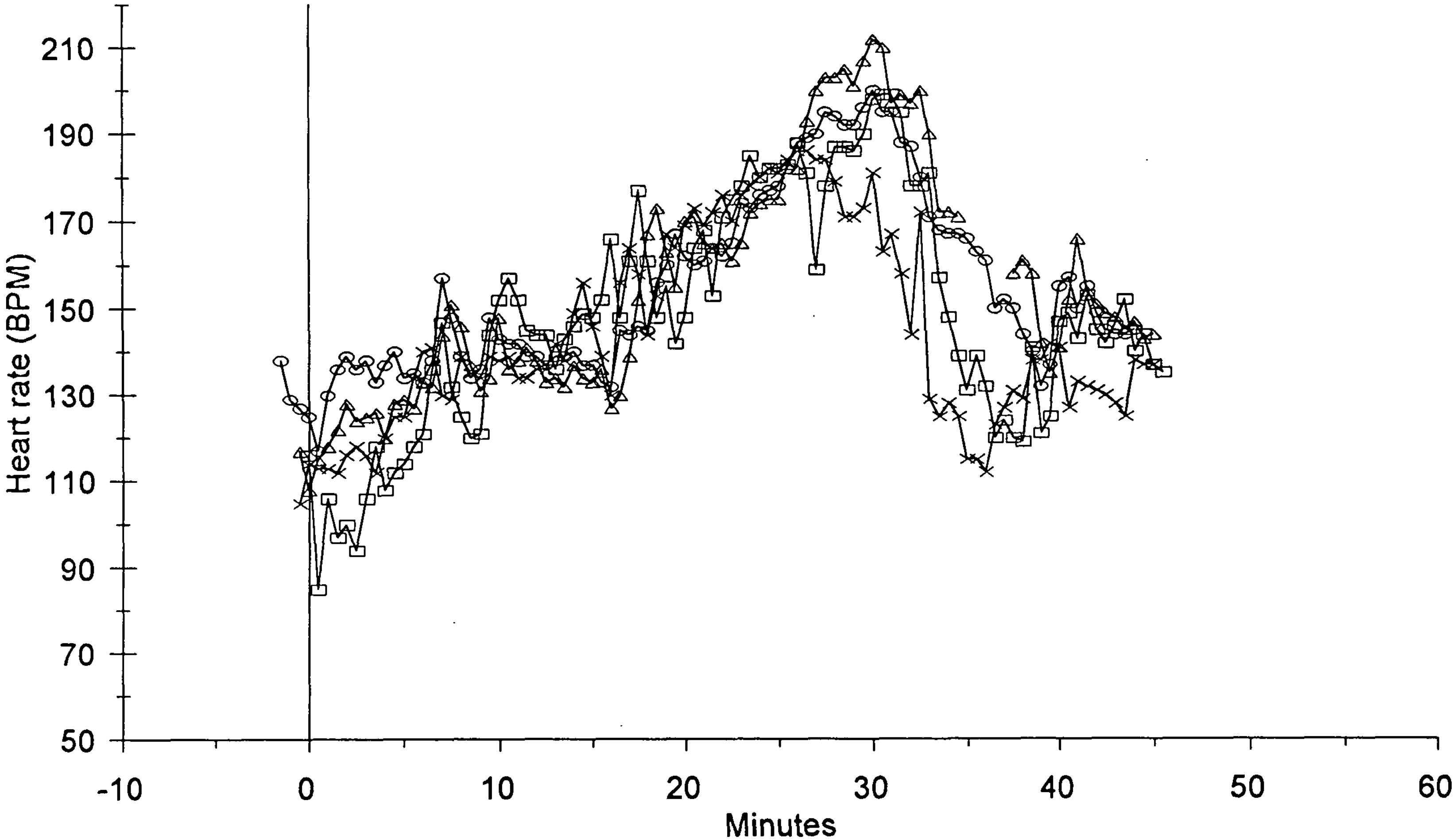


Figure 3.3 **Heart rates recorded every 30 seconds on 4 Hereford & Worcester firefighters wearing Sabre Centurion OCBA during the short duration fire/rescue exercise**

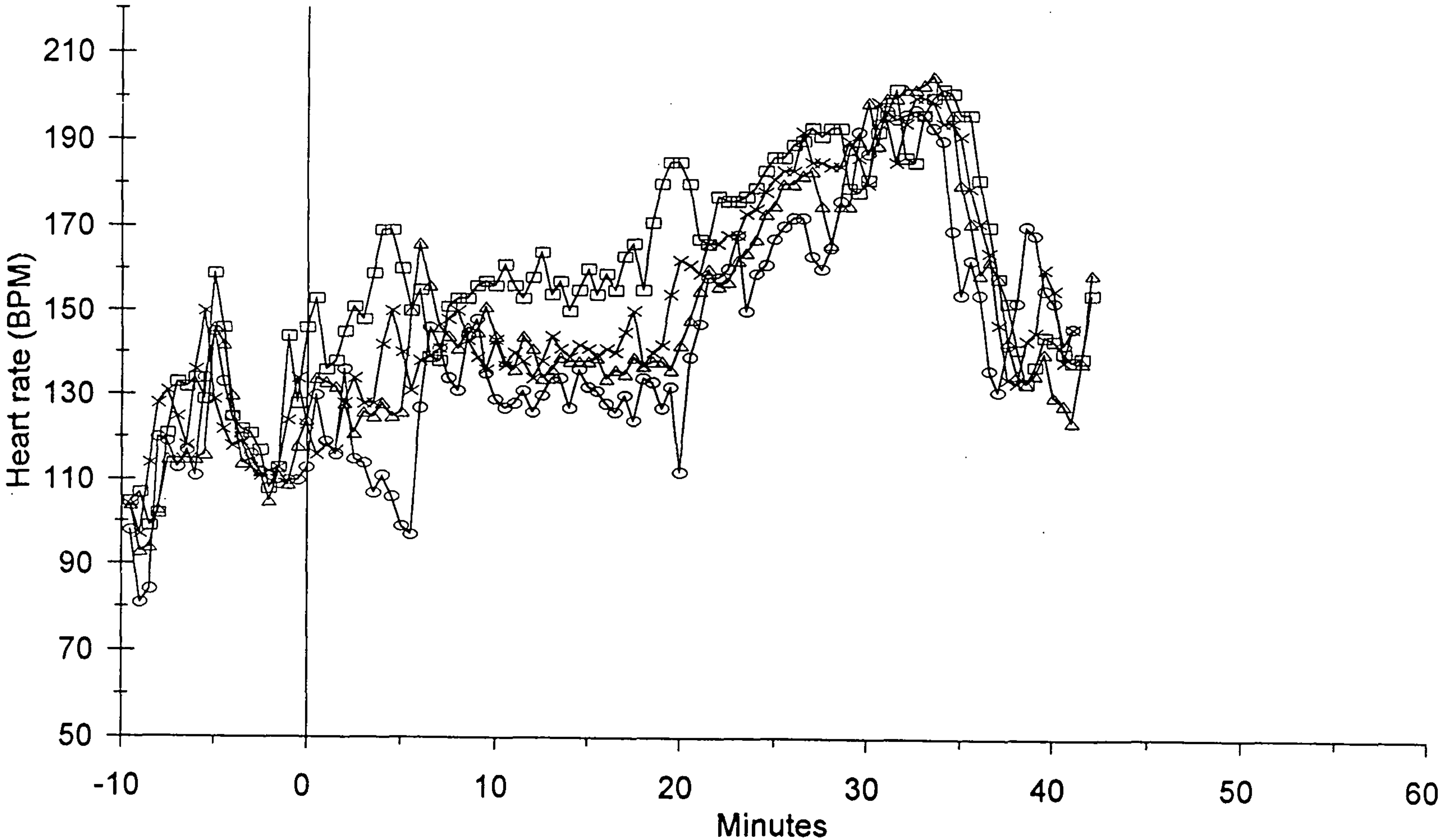


Figure 3.4 Heart rates recorded every 30 seconds on 4 Kent firefighters wearing Interspiro Spiromatic OCBA during the short duration fire/rescue exercise

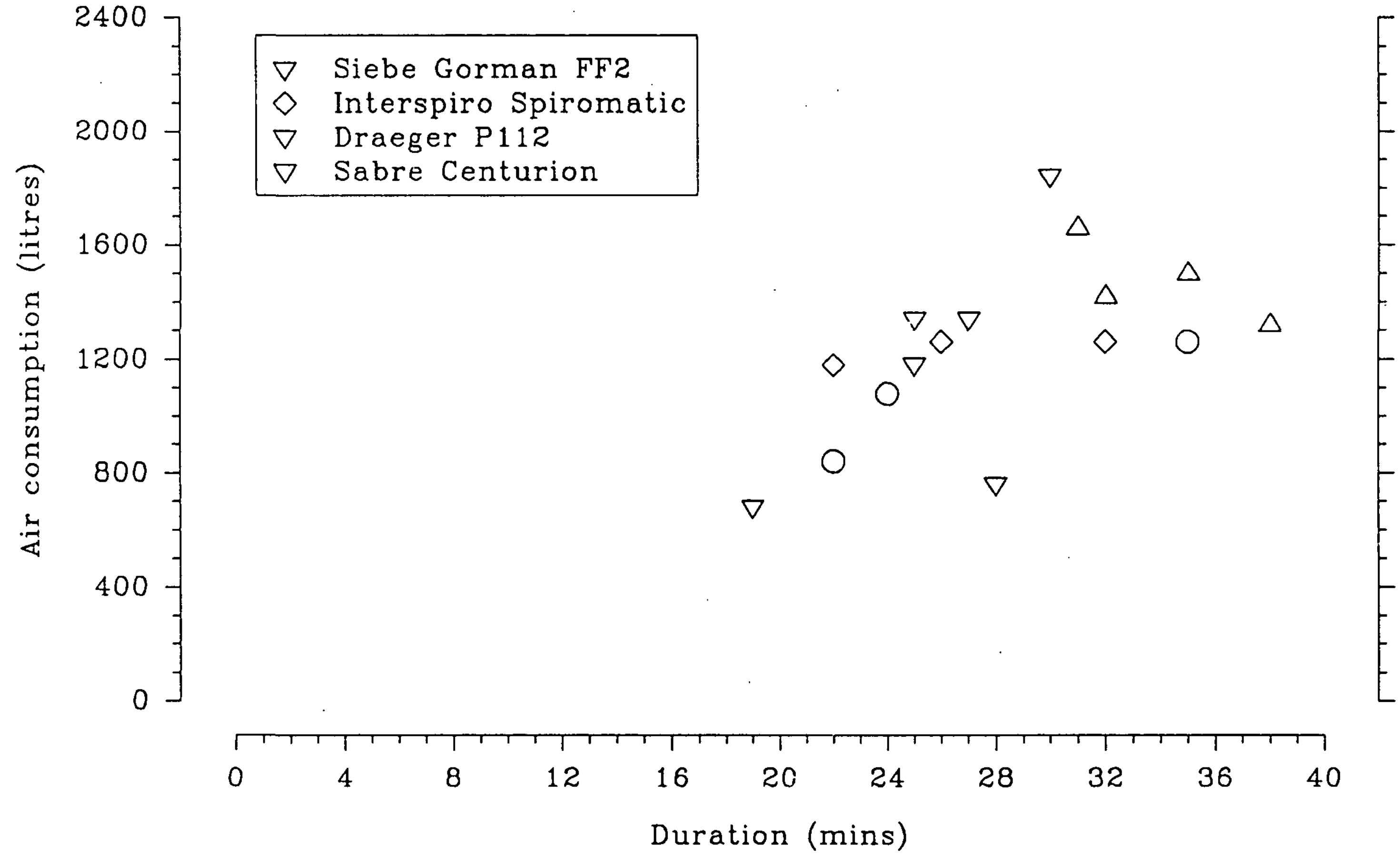


Fig 3.5 Air consumption (derived from change in cylinder pressure) of 16 brigade teams wearing open circuit BA.

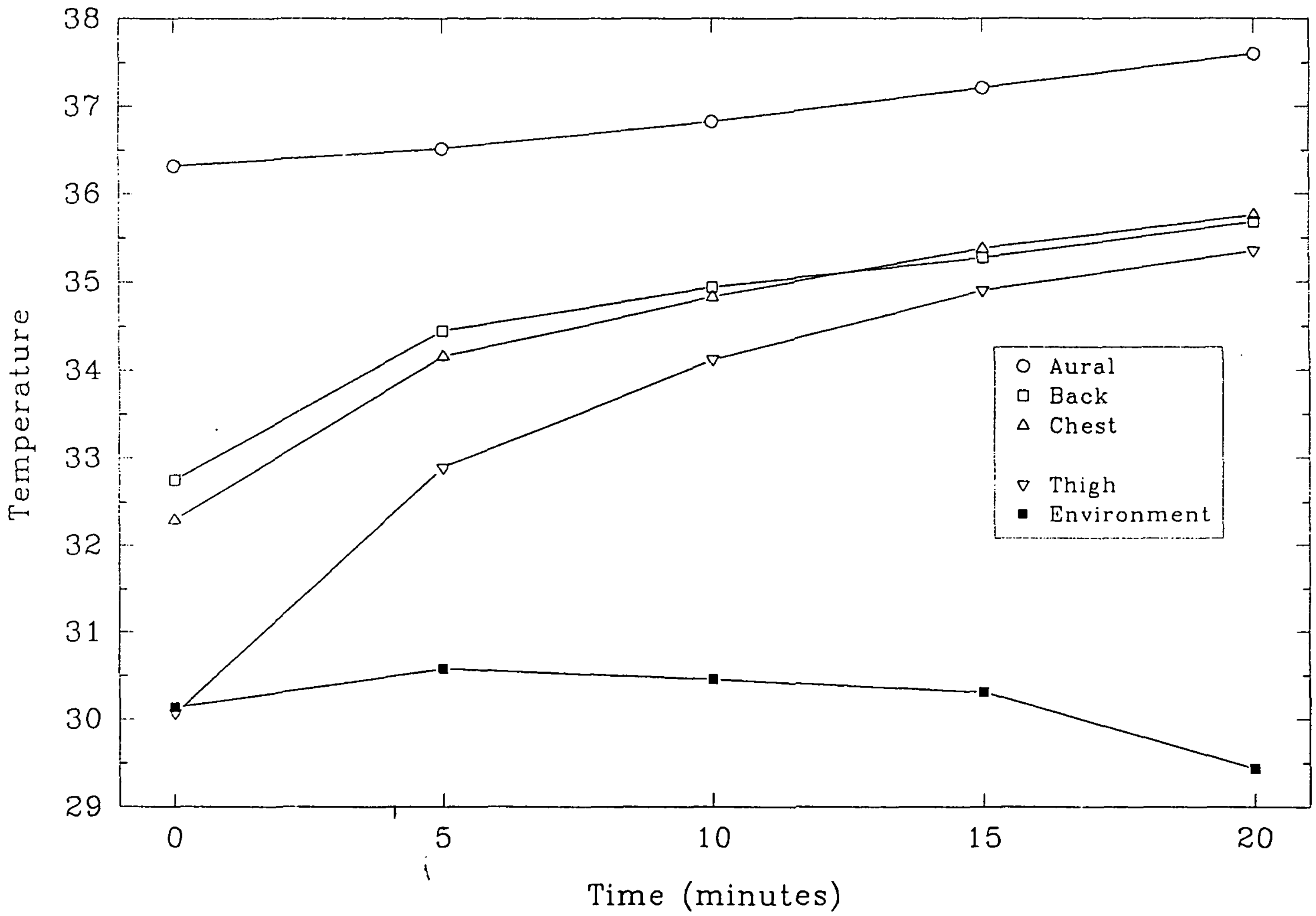


Figure 3.6 **Average environmental, aural and skin temperatures taken at 5 minute intervals during the gastight suit exercise**

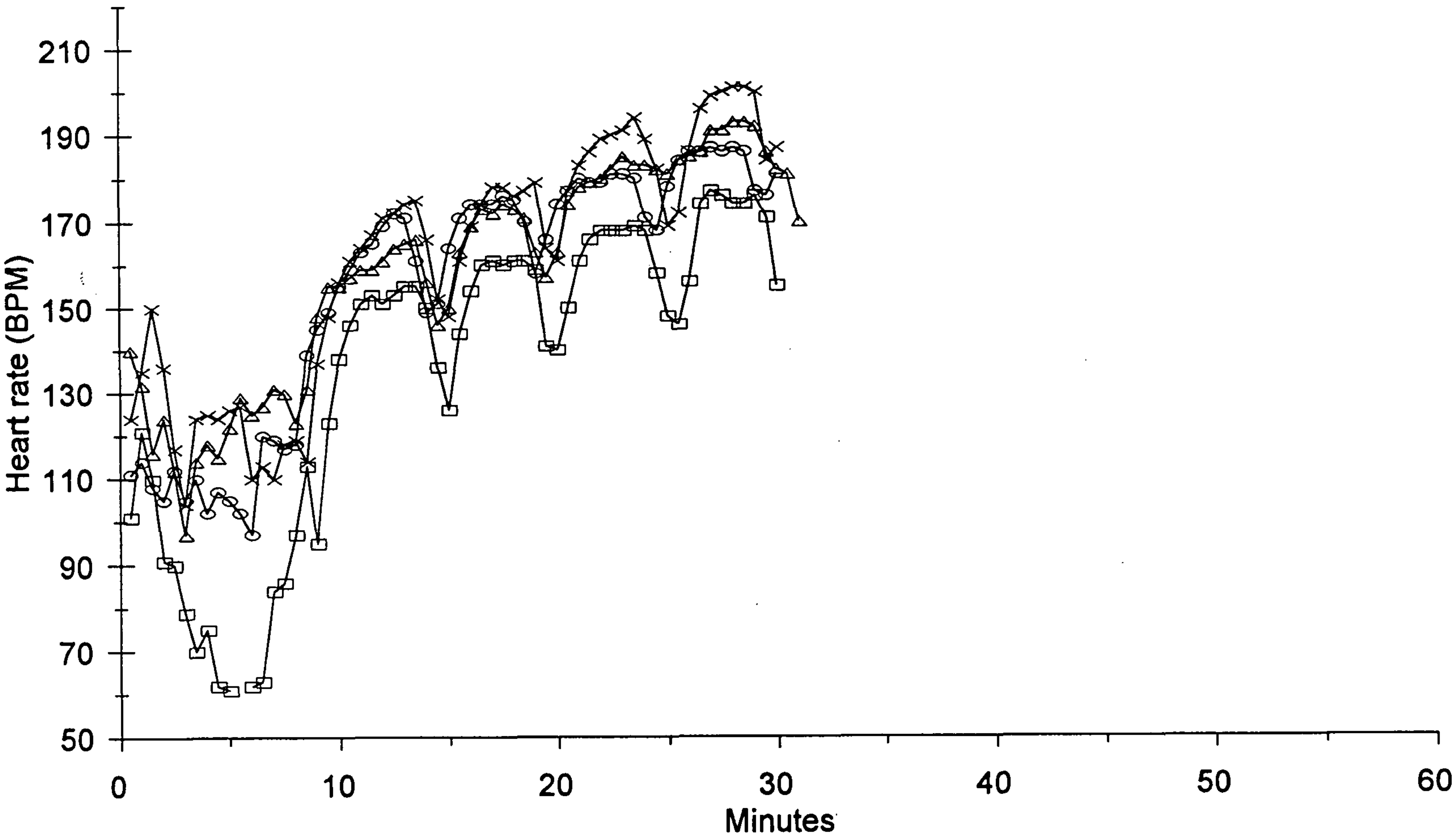


Figure 3.7 Heart rates recorded every 30 seconds on 4 Kent firefighters wearing Sabre SEFA CCBA during the gastight suit exercise

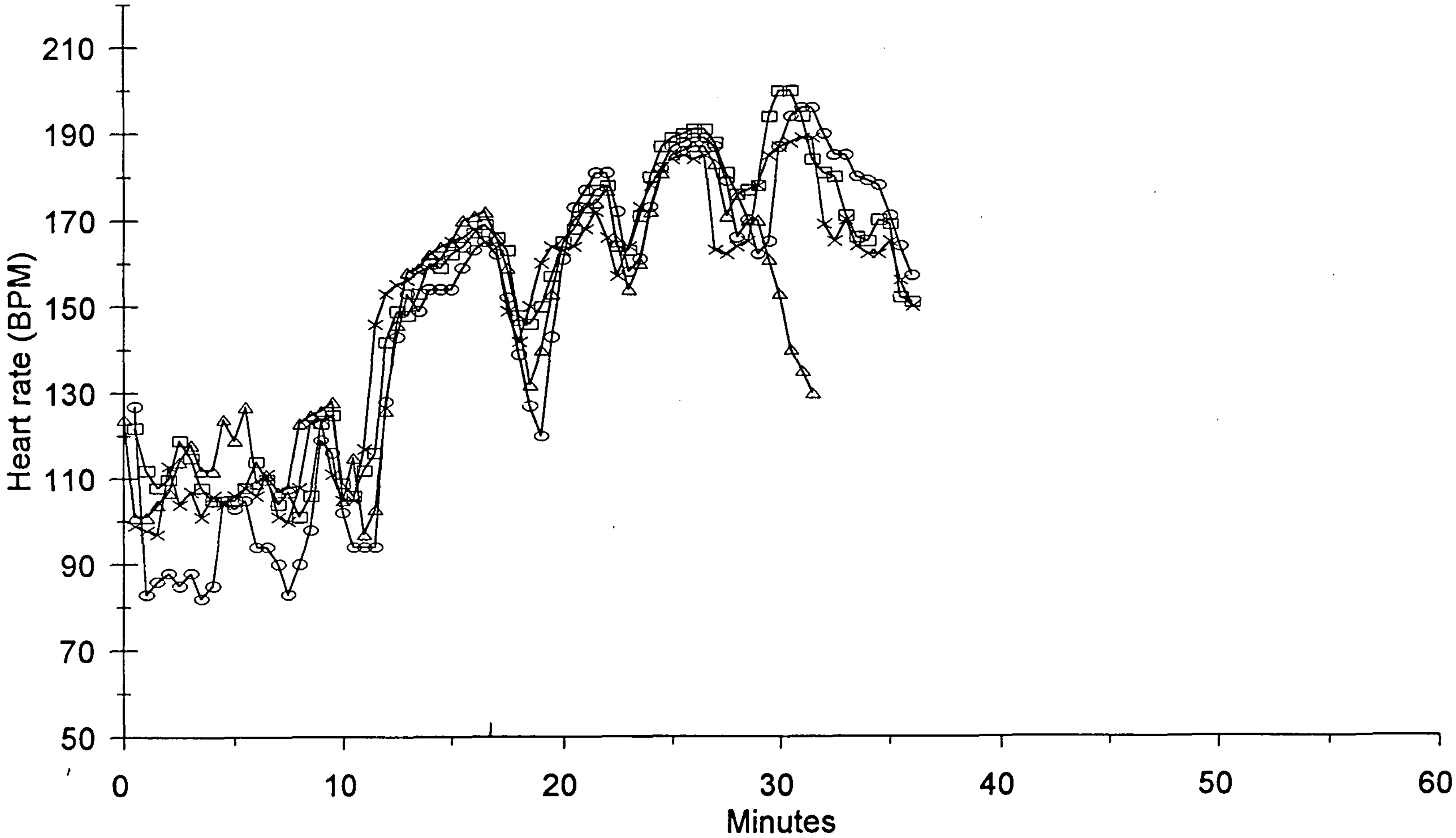


Figure 3.8 **Heart rates recorded every 30 seconds on 4 Gloucestershire firefighters wearing Sabre Centurion OCBA during the gastight suit exercise**

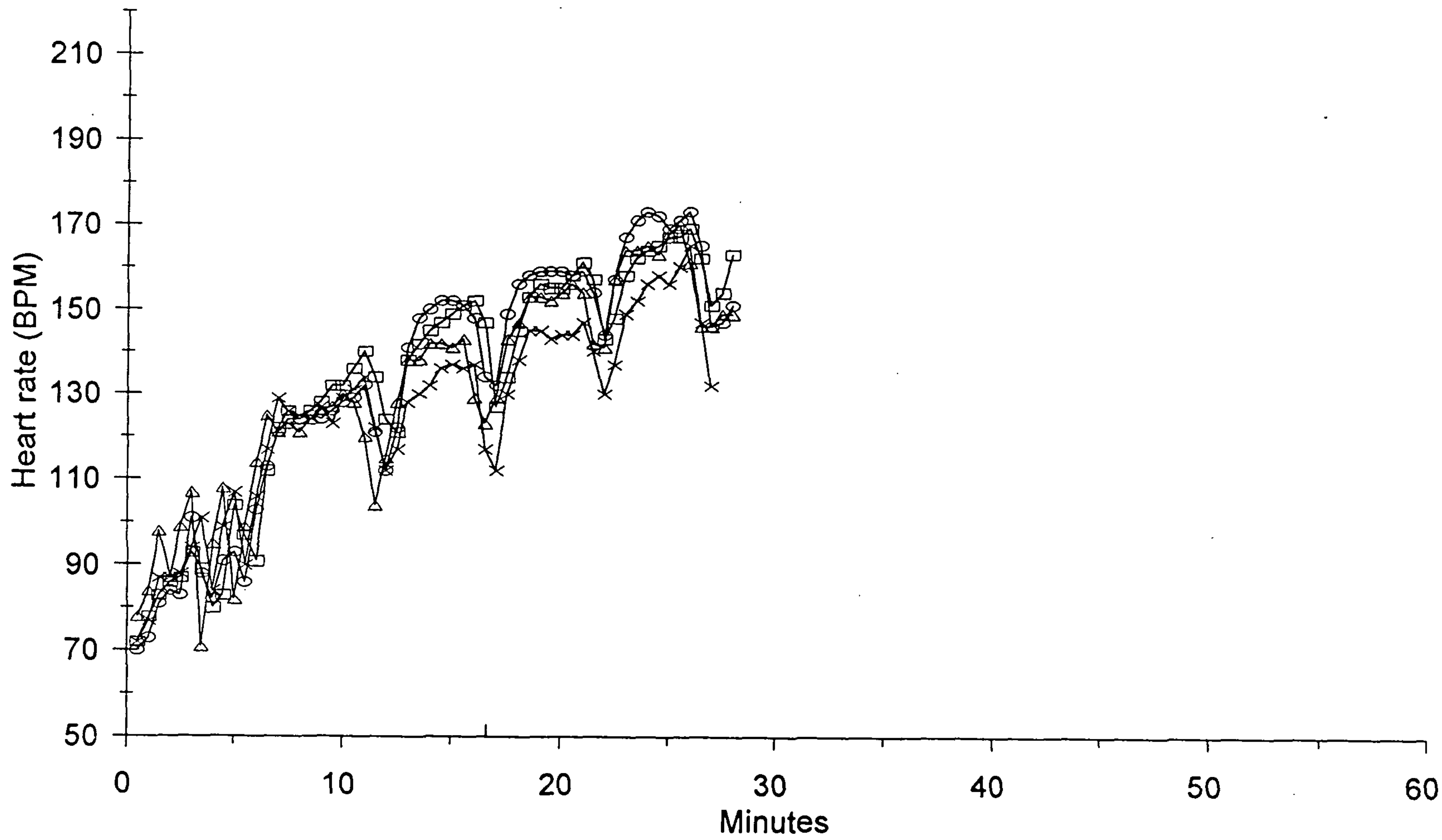


Figure 3.9 Heart rates recorded every 30 seconds on 4 West Yorkshire firefighters wearing Draeger Premier OCBA during the gastight suit exercise

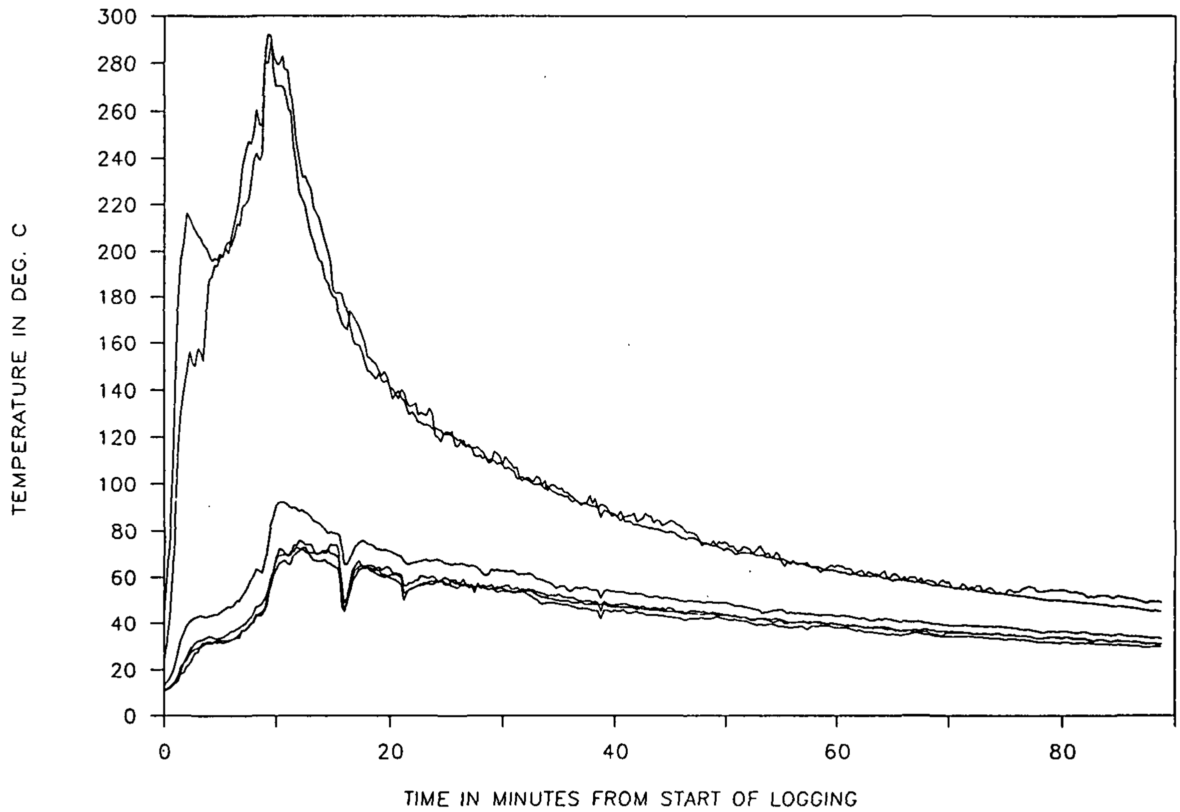


Figure 3.10 Temperature profiles from six different monitoring points in the rear hold and engine room areas of the "Sir Henry". The two upper curves are the temperatures recorded at points close to the fire

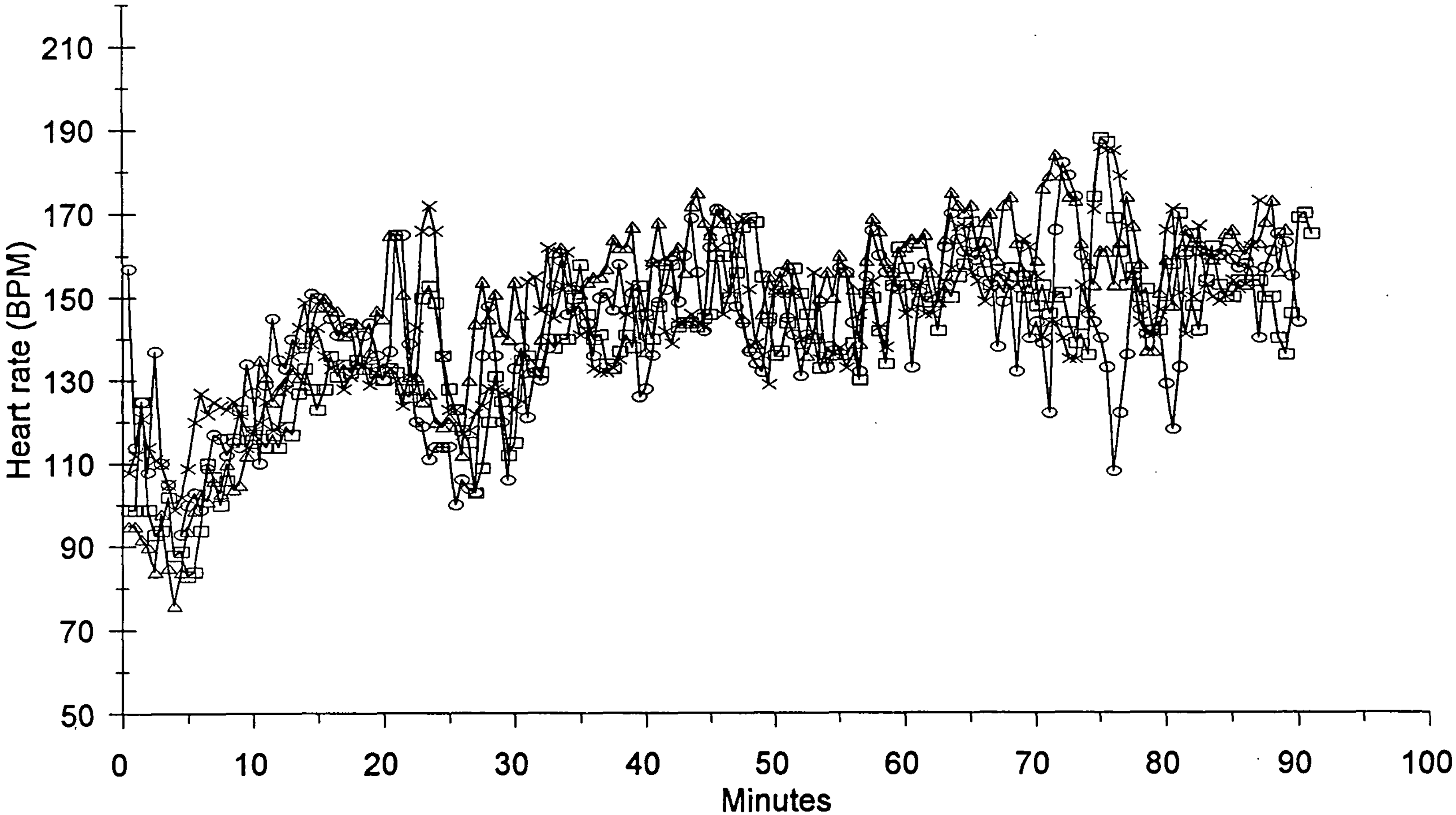


Figure 3.11 **Heart rates recorded every 30 seconds on 4 Oxfordshire firefighters wearing Sabre Centurion OCBA during the long duration fire/rescue exercise**

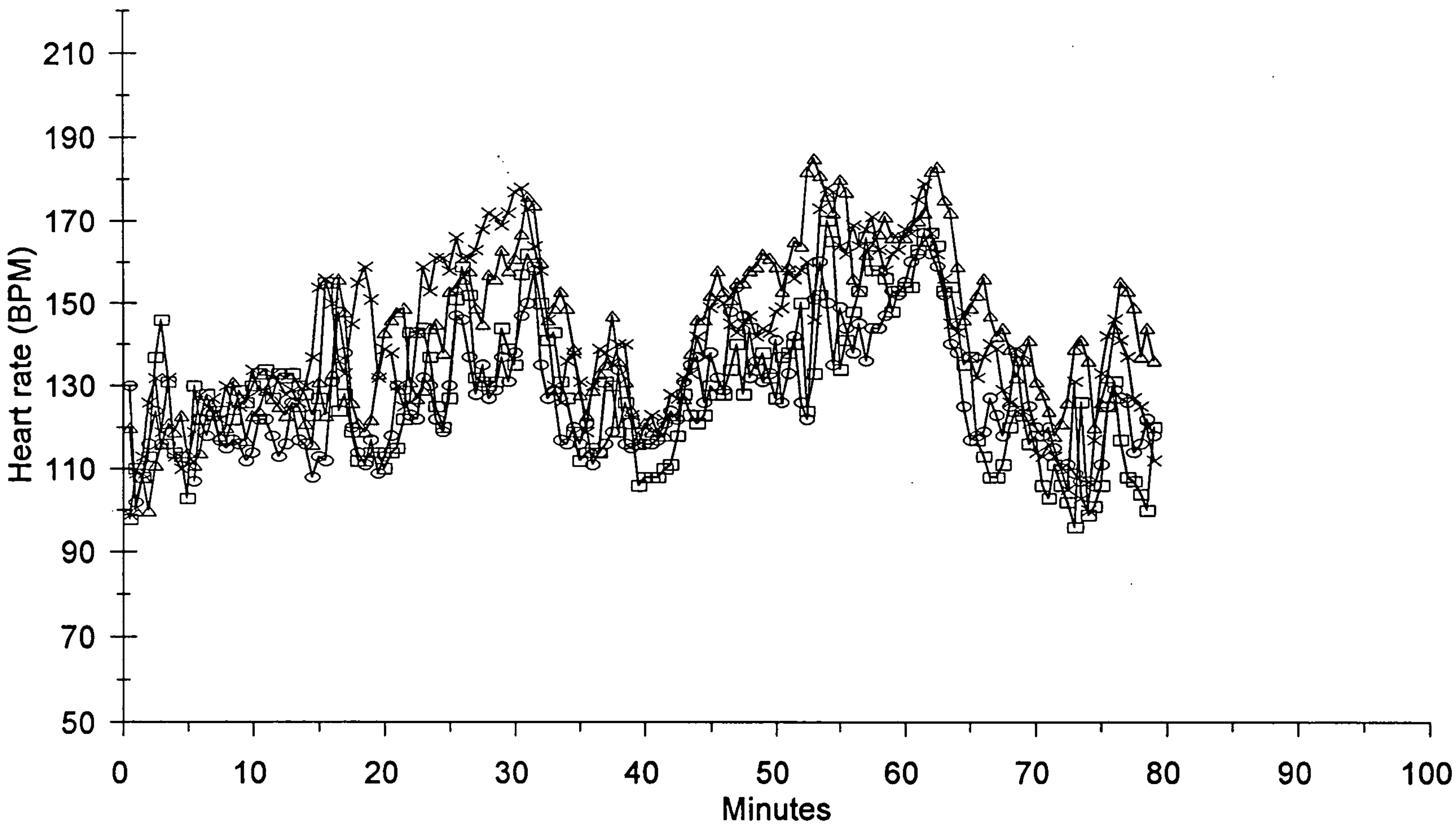


Figure 3.12 Heart rates recorded every 30 seconds on 4 Fife firefighters wearing Siebe Gorman OCBA during the long duration fire/rescue exercise

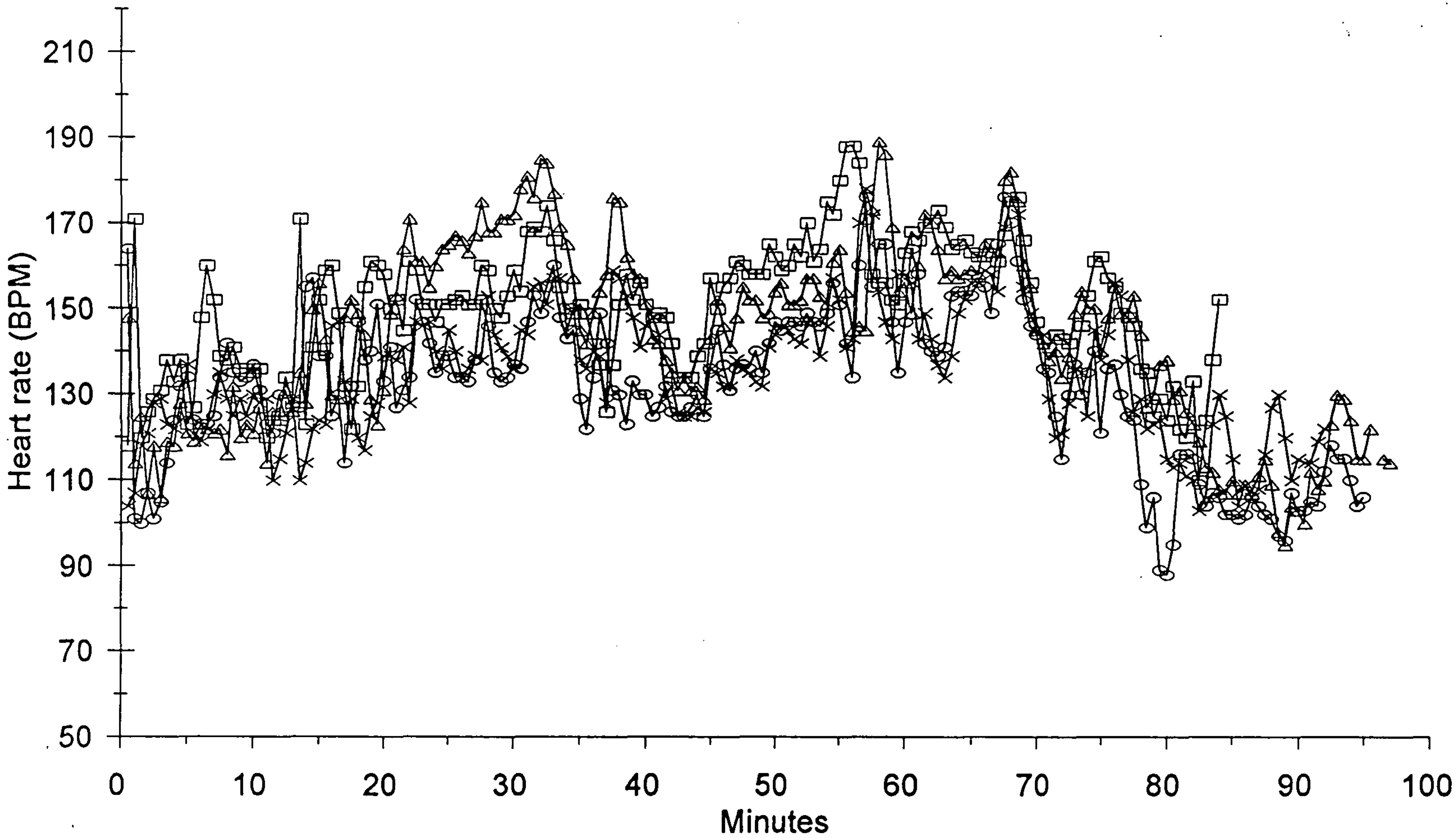


Figure 3.13 **Heart rates recorded every 30 seconds on 4 Kent firefighters wearing Interspiro Spiromatic OCBA during the long duration fire/rescue exercise**

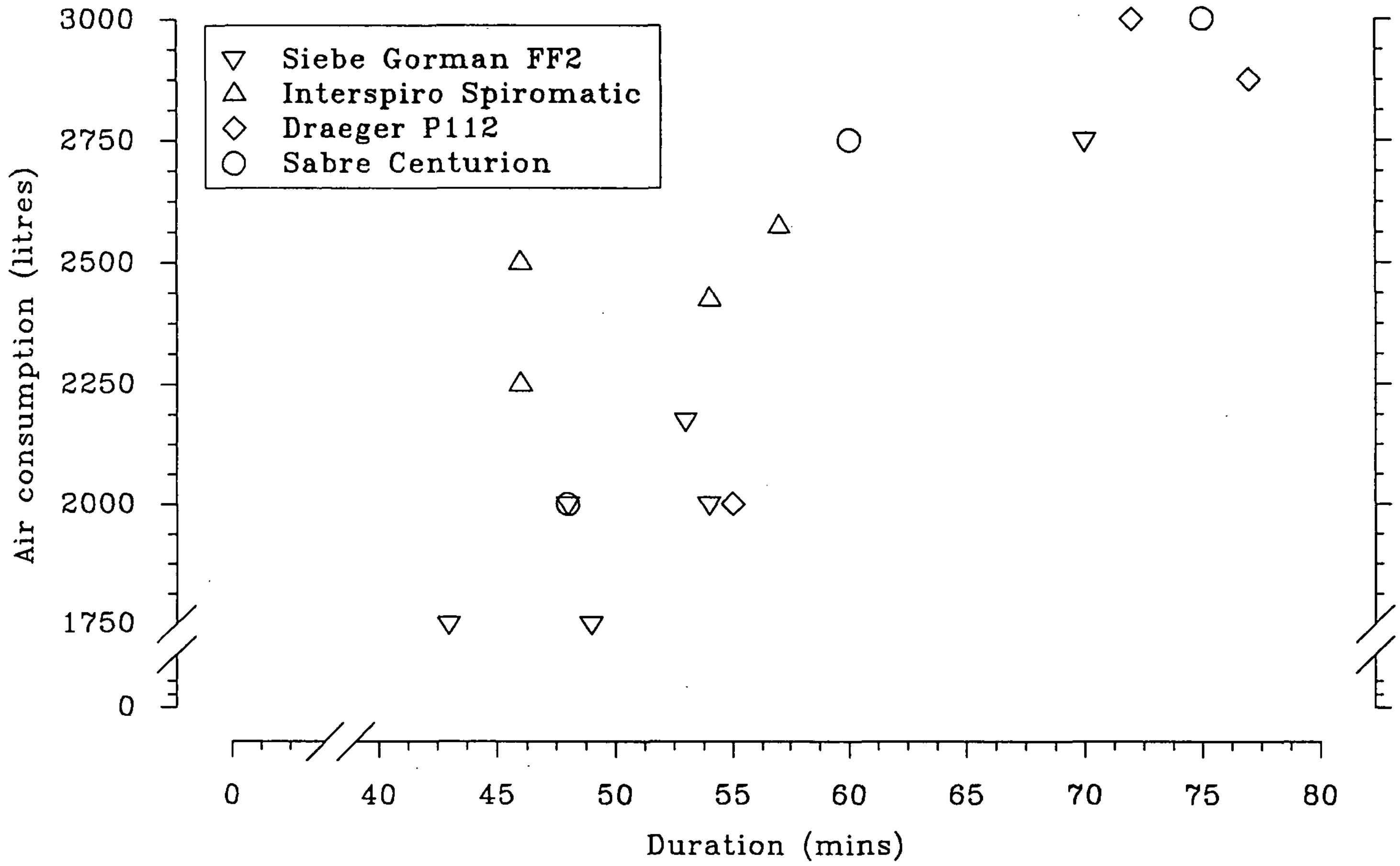


Figure 3.14 Total air consumption (derived from cylinder pressure readings) in relation to duration of long duration fire simulation exercise

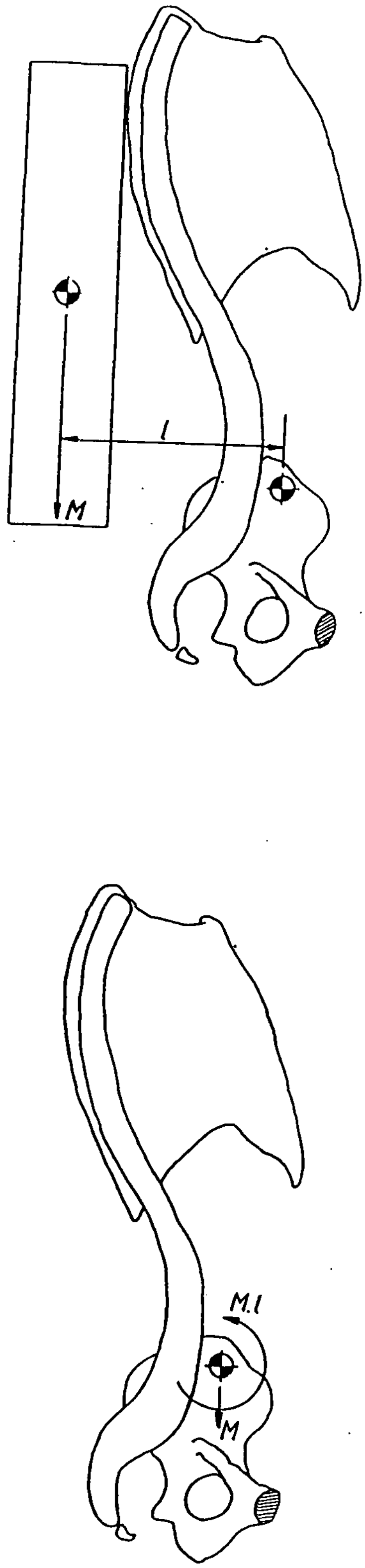


Figure 3.15(i) The extensor moment (M*l*) on the firefighter's back caused by the weight of the cylinder (M) acting a distance *l* behind the operator's centre of gravity

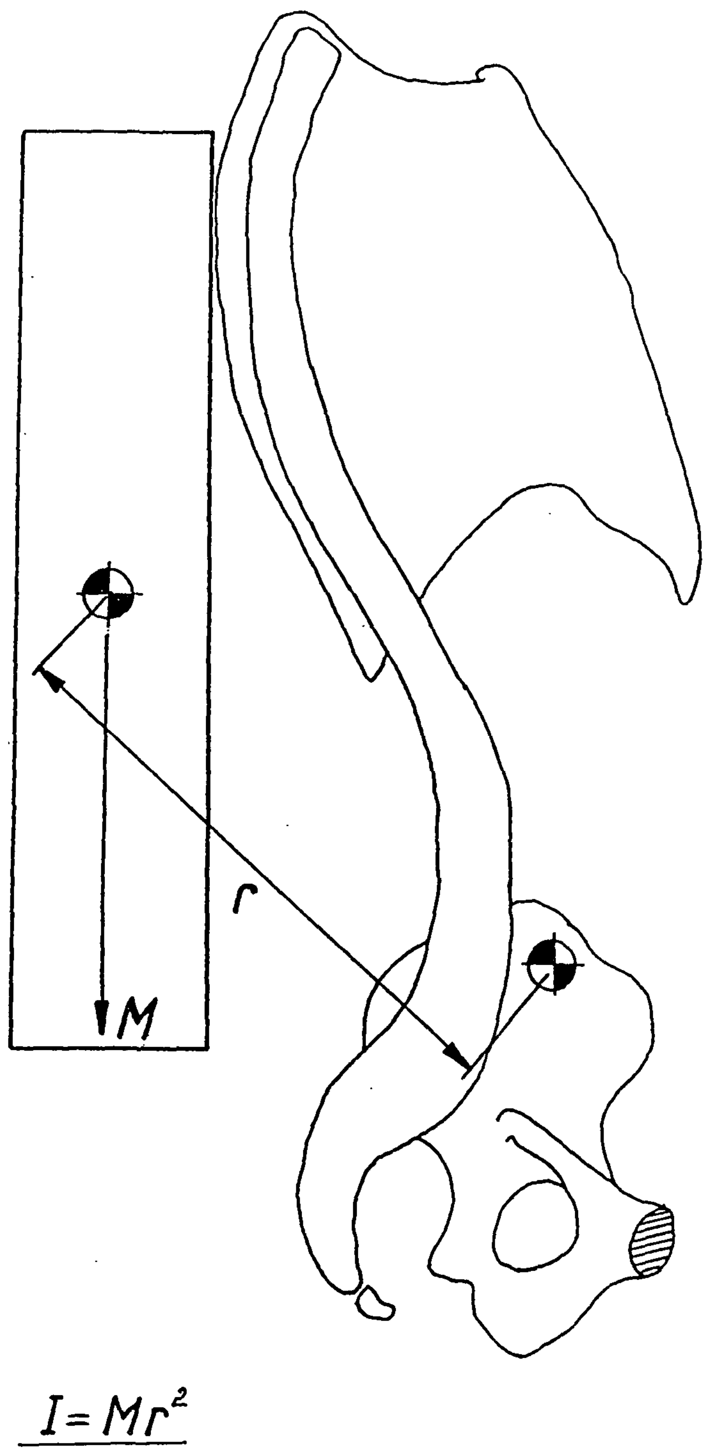
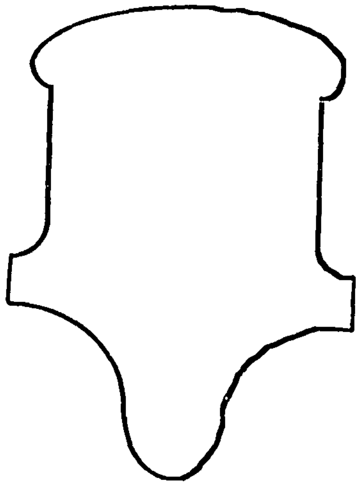
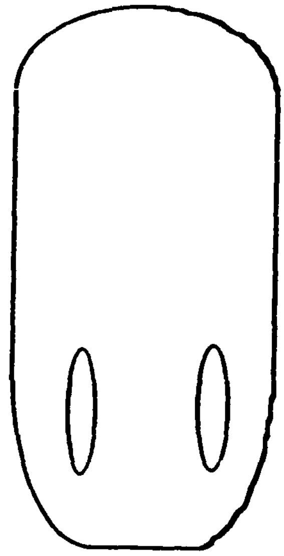


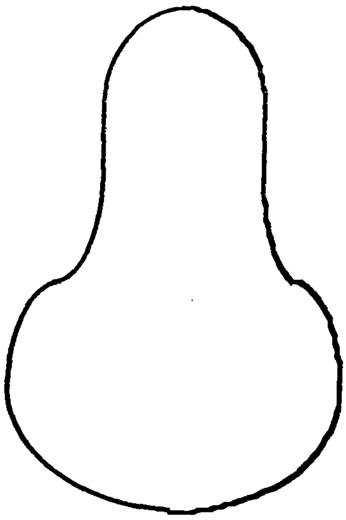
Figure 3.15(ii) The second moment of inertia (I) figure as a rèsult of the cylinder weight (M) acting a distance r between gravity centres



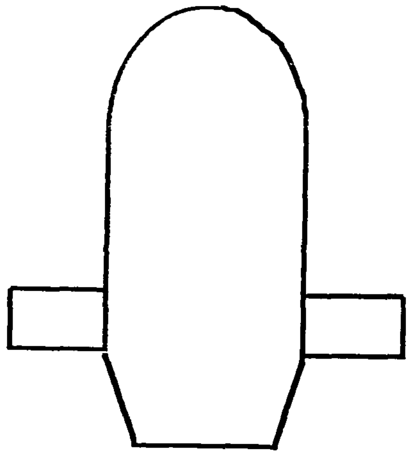
(i) Draeger P112



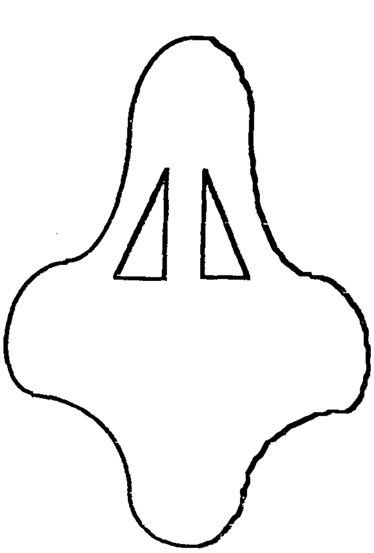
(ii) Interspiro Spiromatic



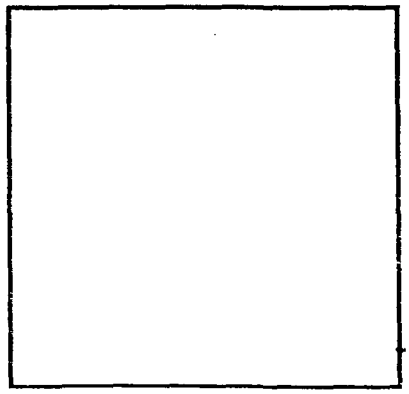
(iii) Sabre Centurion



(iv) Siebe Gorman (FEII)



(v) Draeger P90



(vi) Sabre SEFA

Figure 3.16 Shapes of the different BA backplates (not to scale)

APPENDICES A & B

I (Ltd) M

Questionnaire on Breathing Apparatus Provision Within Brigades

INSTRUCTIONS

This questionnaire is part of a 3 year study commissioned by the Home Office on the physiological stress of breathing apparatus on the firefighter. This questionnaire will provide factual information on the type of breathing apparatus (BA) and clothing which firefighters use, and on the training in BA use which they receive.

Section A asks for some background information on the manpower of your brigade, and on the frequency with which they use BA.

Sections B-G then ask various specific questions about the selection and use of BA and other equipment. Depending on the nature of the question, provision has been made for your answer to be recorded in one of four ways.

1. Factual information about e.g. manufacturer and model of equipment should be entered into the relevant tables.
2. In some questions, you are asked to select your answer from a list of possible alternatives and place the corresponding number in the adjacent box.
3. For some questions, e.g. B5 on which criteria are used to select BA, there may be several answers which are all relevant to your brigade; here we have given each possible answer a separate box, and you should tick as many as are appropriate.
4. Where it is necessary to provide additional information or to expand on a previous answer, please write in the designated space (and continue on a separate sheet of paper if desired).

If you have any queries regarding the questionnaire or the questions asked, please contact, Miss Julia Johnstone at the Institute of Occupational Medicine Limited in Edinburgh on (031) 667 5131 Ex. 2120.

Thank you for your co-operation.

When completed please return in the prepaid envelope to The Institute of Occupational Medicine Ltd, 8 Roxburgh Place, Edinburgh EH8 0LL by Friday 22nd February 1991.

SECTION A :

The Brigade : ______________________

Number of firefighters

Males	: ______
Females	: ______
Total	: ______

Number of stations

Whole-time	: ______
Part-time	: ______
Day-manned	: ______
Retained	: ______
Total	: ______

Total number of callouts and the number of incidents where BA was used per calender year

	BA callouts	Total callouts
(1989)	______	______
(1988)	______	______
(1987)	______	______

SECTION B : BA AND ITS SELECTION

B1. Please specify the manufacturer, model and number stocked of all types of Breathing Apparatus used (including compressed oxygen sets)

TYPE OF BA SET	MANUFACTURER	MODEL	NUMBER STOCKED

B2. Please specify the manufacturer, model, number and capacity of cylinders stocked.

MANUFACTURER	MODEL	CAPACITY	NUMBER STOCKED

B3. What makes and sizes of full or orinasal facemasks are used ?

MANUFACTURER	MODEL	SIZES	NUMBER STOCKED

B4. Please describe any special risks within your catchment area that would require extended duration BA sets.

SECTION B : BA AND ITS SELECTION

B5. Which criteria are used for selecting standard issue BA sets ?

Tick if used

* Manufacturer of current BA used ☐
* reports from other brigades ☐
* wearer trials ☐
* cost ☐
* other (if other, please specify) ☐

IF WEARER TRIALS ARE USED

B6. What assessments are carried out during wearer trials ?

Tick if used

* **equipment effectiveness** ☐
* **equipment reliability** ☐
* **wearer acceptance** ☐
* **other (if other, please specify)** ☐

B7. When do you expect the present standard issue BA set to be replaced ?

Please write the appropriate number in the box ☐

1 = in less than one year

2 = one-three years

3 = more than three years

4 = don't know

SECTION B : BA AND ITS SELECTION

B8. What approved modifications are made to the standard model BA, eg. second man attachment ?

B9. Please describe any problems that arise during routine servicing of the standard issue BA.

SECTION C : PROTECTIVE CLOTHING

C1. What are the standard issue helmet, tunic and gloves used by your brigade. Please specify the manufacturer, model and number stocked of each.

STANDARD ISSUE	MANUFACTURER	MODEL	NUMBER STOCKED
Helmet			
Tunic			
Gloves			

C2. Please specify any changes to the standard issue clothing when BA is worn (eg. gloves)

SECTION C : PROTECTIVE CLOTHING

C3. What special purpose clothing is available for use with BA ?
Please specify manufacturer, model and number stocked.

PROTECTIVE CLOTHING	MANUFACTURER	MODEL	NUMBER STOCKED
Splash Suit			
Air tight suit			
Coveralls			
Cooled garments			
E9 anti-flash hood			
Close fitting anti-flash balaclavas			
General purpose balaclavas			
Others (please specify)			

C4. What other special issue personal protective equipment is likely to be used in conjunction with BA ? Please give details of manufacturer and model.

C5. Please describe any planned changes to the protective clothing or equipment.

IF NO CHANGES ARE PLANNED, GO TO QUESTION D1.

SECTION C : PROTECTIVE CLOTHING

C5.1 When do you expect to introduce the changes.

Please write the appropriate number in the box

1 = in less than one year

2 = one-three years

3 = more than three years

4 = don't know

SECTION D : OPERATIONAL FACTORS

D1. What equipment is carried on the individual while wearing BA ?
Please specify, manufacturer and model.

PERSONAL EQUIPMENT	MANUFACTURER	MODEL
Hand-held lamp		
Hand-held radio		
Distress Signal Unit		
Guidelines		
Others - please specify		

D2. Please specify what separate respiratory protection, if any, is provided for other risks, eg. underwater, asbestos or other fibres and dusts ?

D3. Please specify any guidelines given on repeated wearings of BA at a single incident.

SECTION D : OPERATIONAL FACTORS

D4. Please specify any criteria which are used on a day to day basis to determine whether a firefighter is fit enough to wear BA eg. heavy cold, recent return to work.

SECTION E : THE FIREFIGHTERS

E1. Please specify what factors, if any, are used to decide whether a firefighter should be submitted for fitness retesting eg. reaching a certain age.

IF THE FITNESS OF FIREFIGHTERS IS NOT RETESTED, GO TO QUESTION F1.

E2. Please specify the pass criteria used for any retesting of fitness if different from the standard entry requirements, eg. age adjusted fitness levels.

SECTION F : BA TRAINING

F1. Where is initial BA training carried out ?

Tick if used

* ★ on station ☐
* ★ at a variety of stations ☐
* ★ at brigade training centre ☐
* ★ others, ☐

if other, please specify

F2. Does initial BA training involve

Tick if used

* ★ heat and humidity ? ☐
* ★ smoke ? ☐
* ★ simulated fire situations ? ☐
* ★ working in restricted access area ? ☐
* ★ adverse conditions requiring the use of splash suits, gas tight suits etc. ? ☐
* ★ other ? ☐

if other, please specify

F2.1 Please give an outline of training scenarios.

SECTION F : BA TRAINING

F3. After the initial training, is any BA re-training carried out ?

Y = Yes
N = No

IF YES

F3.1 How frequently is re-training carried out?

F3.2 Where is BA re-training carried out ?

Tick if used

* on station
* at a variety of stations
* at brigade training centre
* other

- if other please specify :

F3.3 Does BA re-training involve

Tick if used

* heat and humidity ?
* smoke ?
* simulated fire situations ?
* working in restricted access areas ?
* adverse conditions requiring the use of splash suits etc. ?
* other ?

- if other please specify :

SECTION F : BA TRAINING

F4. Please specify any guidelines on the period between BA wearings during training.

F5. Please specify any guidelines on how long a firefighter can be exposed to different temperatures and humidities during BA training.

F6. What is the maximum temperature and humidity that a firefighter would be subjected to during BA training, (if known) ?

F7. Please specify which if any of these physiological measurements are obtained during heat and humidity exercises.

Tick if used

* heart rate from pulse ☐
* heart rate from specialized equipment ☐
* mouth temperature ☐
* ear temperature ☐
* other body temperature ☐
* other ☐

- if other, please specify

IF NO MEASUREMENTS ARE OBTAINED GO TO QUESTION F8

SECTION F : BA TRAINING

F7.1 If you take physiological measurements during heat and humidity exercises, please indicate the range(s) in which most of the peak values obtained occur.

Heart Rate

Beats/minute	Tick appropriate box(es)
100 - 109	☐
110 - 119	☐
120 - 129	☐
130 - 139	☐
140 - 149	☐
150 - 159	☐
160 - 169	☐
170 - 179	☐
180 +	☐

Body Temp

°C	°F	
37.0 - 37.3	98.6 - 99.2	☐
37.4 - 37.7	99.3 - 99.9	☐
37.8 - 38.1	100.0 - 100.6	☐
38.2 - 38.5	100.7 - 101.3	☐
38.6+	101.4	☐

F8. Please specify which, if any of these physiological measurements are obtained during exercises other than heat and humidity.

Tick if used

- ★ heart rate from pulse ☐
- ★ heart rate from specialized equipment ☐
- ★ mouth temperature ☐
- ★ ear temperature ☐
- ★ other body temperature ☐
- ★ other ☐

- if other, please specify

IF NO MEASUREMENTS ARE OBTAINED GO TO QUESTION F9

SECTION F : BA TRAINING

F8.1 *If you take physiological measurements during exercises other than heat and humidity, please indicate the range(s) in which most of the peak values obtained occur.*

	Beats/minute	Tick appropriate box(es)
Heart Rate	100 - 109	☐
	110 - 119	☐
	120 - 129	☐
	130 - 139	☐
	140 - 149	☐
	150 - 159	☐
	160 - 169	☐
	170 - 179	☐
	180 +	☐

	°C	°F	
Body Temp	37.0 - 37.3	98.6 - 99.2	☐
	37.4 - 37.7	99.3 - 99.9	☐
	37.8 - 38.1	100.0 - 100.6	☐
	38.2 - 38.5	100.7 - 101.3	☐
	38.6+	101.4	☐

F9. Other than progressive updating, please specify any major changes planned to the BA training eg. the introduction of foam ?

IF NO CHANGES ARE PLANNED, GO TO QUESTION G1

F9.1 When will the changes in BA training be introduced.
Please write the appropriate number in the box.

1 = in less than one year
2 = one to three years
3 = more than three years
4 = don't know

☐

SECTION G : FEMALE FIREFIGHTERS (if appropriate)

G1. Are female firefighters accommodated in your brigade by (please write the appropriate number in the box)

1 = purchasing clothing and equipment on an individual basis
2 = extending the standard clothing size range to include female sizes
3 = no separate provision

☐

G1.1 If individual clothing and equipment is provided, does it include

Tick appropriate box(es)

★ personal issue ? ☐

★ special personal equipment eg. splash suits ? ☐

★ BA facemask ? ☐

★ other equipment ? ☐

- if other, please specify

ANY FURTHER COMMENTS :

if necessary, continue overleaf

ANY FURTHER COMMENTS (Cont) :

IOM Ltd

Questionnaire on the operational use of

breathing apparatus

When completed please return in the prepaid envelope to the Institute of Occupational Medicine Limited, 8 Roxburgh Place, Edinburgh EH8 0LL

INSTRUCTIONS

This questionnaire is part of a three year study commissioned by the Home Office on the physiological effects of Breathing Apparatus (BA) on the firefighter. The questionnaire asks about the operational use of BA and is interested in the opinions of individual firefighters on their own BA. The results will be used to assess how BA could be improved in order to reduce the physiological stress on the firefighter.

Section A asks for your background details. The information collected in the questionnaire is confidential and will not be reported back to your brigade or the Home Office.

Section B asks about the BA and clothing you use. If the BA/clothing has been changed within the last six months please write down the previous BA set and/or clothing used as well as the current set. Please indicate when the set/clothing was replaced and which of the two you are more familiar with. You should complete the questionnaire with reference to the equipment which you are more familiar with.

There are three types of question in this questionnaire, an example of each is shown below :

1. For questions with yes/no answers please write a Y or an N in the box provided

   eg. D1. when you are putting on the BA, does its WEIGHT cause difficulty ? Y = Yes N = No ☐

   - if you have difficulties with the weight of the BA. "Y" would be written in the box, as shown - Y

2. Questions with several different answers to the question require one of the numbers, allocated to the answers, to be written in the box provided.

   eg. C2. during the last twelve months how often have you worn BA in Fires ?

   1 = Never
   2 = Less than once per week
   3 = About once per week
   4 = About once per day
   5 = More than once per day ☐

   - if you have worn BA in fires less than once per week a "2" would be written in the box, as shown - 2

3. Questions that have a box below them require written answers.

   eg. C1. does your station cover any special risks which require extended duration BA sets ? Y = Yes N = No ☐

   C1.1 IF YOU ANSWERED "YES", please give details :

   - if your station does cover special risks a "Y" is written in the box, Y , and the special risk is described in the space provided eg.

   The Channel Tunnel.

If you have any queries about the questionnaire or the questions asked, please contact Miss Julia Johnstone, at the Institute of Occupational Medicine in Edinburgh on (031) 667 5131 Ext. 2120.

SECTION A : BACKGROUND INFORMATION

NAME :	
BRIGADE :	
STATION :	
WATCH :	
TODAY'S DATE :	

SECTION B : CLOTHING & EQUIPMENT

B1. Please specify the manufacturer and model no. of your standard issue :

	Manufacturer & Model No.
- Breathing Apparatus (BA)	
- Helmet	
- Tunic	
- Gloves	
- Splash suit (if used)	
- Coverall (if used)	
- Airtight suit (if used)	

SECTION C : BA USAGE

C1. Does your station cover any special risks which require extended duration BA sets ?

Y = Yes
N = No

c1.1 IF YOU ANSWERED "YES", please give details

C2. During the last twelve months, how often have you worn BA in FIRES ?

1 = Never
2 = Less than once per week
3 = About once per week
4 = 2-3 times per week
5 = About once per day day
6 = More than once per day

C3. During the last twelve months, how often have you worn BA in TOXIC SUBSTANCE LEAKS OR SPILLAGES ?

1 = Never
2 = Less than once per week
3 = About once per week
4 = 2-3 times per week
5 = About once per day day
6 = More than once per day

C4. During the last twelve months, how often have you worn BA in FLAMMABLE SUBSTANCE LEAKS OR SPILLAGES ?

1 = Never
2 = Less than once per week
3 = About once per week
4 = 2-3 times per week
5 = About once per day day
6 = More than once per day

C5. Other than the above, in what situations during the last twelve months have you used BA MORE THAN ONCE A DAY ?

C6. During the last twelve months, on how many occasions did the operational use of BA require REPLACEMENT OF THE CYLINDER ?

1 = Never
2 = Once or twice
3 = Three to 12 times
4 = More than 12 times

SECTION D : WEIGHT & SIZE OF BA

D1. When you are putting on the BA, does its WEIGHT cause difficulty ?

Y = Yes
N = No

D2. When you are adjusting the BA to fit, does its WEIGHT cause difficulty ?

Y = Yes
N = No

D3. When you are putting on the BA, does its SIZE cause difficulty ?

Y = Yes
N = No

D4. When you are adjusting the BA to fit does its SIZE cause difficulty ?

Y = Yes
N = No

SECTION E : PUTTING ON & ADJUSTING BA

When you are putting on the BA and/or adjusting it to fit,

E1. do the MASK STRAPS cause problems ?

1 = No problems
2 = Minor problems
3 = Major problems

E1.1 IF THE MASK STRAPS CAUSE PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

E2. do the HARNESS STRAPS cause problems ?

1 = No problems
2 = Minor problems
3 = Major problems

E2.2 IF THE HARNESS STRAPS CAUSE PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

E3. do the MASK ADJUSTERS cause problems ?

1 = No problems
2 = Minor problems
3 = Major problems

E3.1 IF THE MASK ADJUSTERS CAUSE PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

E4. do the HARNESS ADJUSTERS cause problems ?

1 = No problems
2 = Minor problems
3 = Major problems

E4.1 IF THE HARNESS ADJUSTERS CAUSE PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

SECTION E : PUTTING ON & ADJUSTING BA

When you are putting on the BA and/or adjusting it to fit -

E5. does your HELMET cause problems ?

1 = No problems
2 = Minor problems
3 = Major problems

E5.2 IF YOUR HELMET CAUSES PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

E6. does your TUNIC cause problems ?

1 = No problems
2 = Minor problems
3 = Major problems

E6.1 IF YOUR TUNIC CAUSES PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

E7. Do you have ANY OTHER PROBLEMS ? Please describe them; and, if possible, suggest how they could be eliminated :

SECTION F : USING THE BA

F1. Does the WEIGHT of the set cause difficulty ?

Y = Yes
N = No

F2. Does the SIZE of the set cause difficulty ?

Y = Yes
N = No

F3. Do you have any problems operating the CONTROLS ?

Y = Yes
N = No

F4. How comfortable is the FACEMASK ?

1 = No discomfort
2 = Minor discomfort
3 = Major discomfort

F4.1 IF THE FACEMASK CAUSES DISCOMFORT please describe the discomfort, and, if possible, suggest how it could be eliminated :

SECTION F : USING THE BA

F5. How comfortable is the BACKPLATE ?

1 = No discomfort
2 = Minor discomfort
3 = Major discomfort

F5.1 IF THE BACKPLATE CAUSES DISCOMFORT please describe the discomfort; and if possible, suggest how it could be eliminated :

F6. How comfortable are the STRAPS ?

1 = No discomfort
2 = Minor discomfort
3 = Major discomfort

F6.1 IF THE STRAPS CAUSE DISCOMFORT please describe the discomfort; and, if possible, suggest how it could be eliminated :

F7. How comfortable are the BUCKLES ?

1 = No discomfort
2 = Minor discomfort
3 = Major discomfort

F7.1 IF THE BUCKLES CAUSE DISCOMFORT please describe the discomfort; and, if possible, suggest how it could be eliminated :

F8. Does ANY OTHER PART of the BA cause discomfort ? Please describe the part and the discomfort caused; and, if possible, suggest how it could be eliminated :

F9. Is the FACEMASK always properly sealed ?

Y = Yes
N = No

F10. Do the MASK STRAPS remain correctly adjusted ?

Y = Yes
N = No

F11. Does the VISOR provide clear vision ?

Y = Yes
N = No

SECTION G : USING BA WITH STANDARD ISSUE CLOTHING

G1. Do your GLOVES cause any problems in using BA ?

Y = Yes
N = No

G1.1 If your GLOVES CAUSE PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

G2. Does your TUNIC cause any problems in using BA ?

Y = Yes
N = No

G2.1 IF YOUR TUNIC CAUSES PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

G3. Does your HELMET cause any problems in using BA ?

Y = Yes
N = No

G3.1 IF YOUR HELMET CAUSES PROBLEMS, please describe the problems; and, if possible, suggest how they could be eliminated :

G4. While the set is in use, do you have any other problems with your standard issue clothing ?

Y = Yes
N = No

G4.1 IF YOU HAVE OTHER PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

SECTION H : BA WITH SPECIAL PROTECTIVE CLOTHING

H6. Do you have any problems PUTTING ON BA in combination with the SPLASH SUIT ?

1 = No problems
2 = Minor problems
3 = Major problems

H6.1 IF YOU HAVE ANY PROBLEMS please describe them; and, if possible, suggest how they could be eliminated :

H7. Do you ever use an AIRTIGHT SUIT in combination with BA ?

Y = Yes
N = No

IF YES :

H8. Do you have any problems PUTTING ON BA in combination with the AIRTIGHT SUIT ?

1 = No problems
2 = Minor problems
3 = Major problems

H8.1 IF YOU HAVE PROBLEMS, please describe them and, if possible, suggest how they could be eliminated :

H9. Do you have any problems USING BA in combination with the AIRTIGHT SUIT ?

1 = No problems
2 = Minor problems
3 = Major problems

H9.1 IF YOU HAVE PROBLEMS, please describe them; and if possible, suggest how they could be eliminated.

SECTION H : BA WITH SPECIAL PROTECTIVE CLOTHING

H10. Please specify the manufacturer & model of any other protective clothing used with BA ?

IF NO OTHER SPECIAL PROTECTIVE CLOTHING IS USED, GO TO QUESTION I.1

H11. Do you have any problems using BA in combination with any other special protective clothing ?

Y = Yes
N = No

H11.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

SECTION I : USING BA WITH PERSONAL EQUIPMENT

I.1 Do you have any problems in using BA while wearing a MAIN GUIDELINE ?

1 = No problems
2 = Minor problems
3 = Major problems

I1.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

I2. Do you have any problems in using BA while wearing a PERSONAL LINE POUCH ?

1 = No problems
2 = Minor problems
3 = Major problems

I2.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

I3. Do you have any problems in using BA while wearing a HAND-HELD LAMP ?

1 = No problems
2 = Minor problems
3 = Major problems

I3.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

SECTION I : USING BA WITH SPECIAL PROTECTIVE CLOTHING

I4. Do you have any problems in USING BA while wearing a RADIO ?

Y = Yes
N = No

I4.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible suggest how they could be eliminated ;

I5. Do you have any problems USING BA while wearing any other personal equipment ?

1 = No problems
2 = Minor problems
3 = Major problems

I5.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

SECTION J : USING PERSONAL EQUIPMENT WITH BA

J1. Do you have any problems in using a MAIN GUIDELINE while wearing BA ?

1 = No problems
2 = Minor problems
3 = Major problems

J1.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

J2. Do you have any problems in using a PERSONAL LINE POUCH while wearing BA ?

1 = No problems
2 = Minor problems
3 = Major problems

J2.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

SECTION J : USING PERSONAL EQUIPMENT WITH BA

J3. Do you have any problems in using a HAND-HELD LAMP while wearing BA ?

1 = No problems
2 = Minor problems
3 = Major problems

J3.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

J4. Do you have any problems in using a RADIO while wearing BA ?

1 = No problems
2 = Minor problems
3 = Major problems

J4.1 IF YOU HAVE PROBLEMS, please describe them; and if possible, suggest how they could be eliminated :

J5. Does your BA cause problems in using ANY OTHER PART of your personal equipment ?

1 = No problems
2 = Minor problems
3 = Major problems

J5.1 IF YOU HAVE PROBLEMS, please describe them; and, if possible, suggest how they could be eliminated :

SECTION K : PHYSICALLY DEMANDING TASKS

K1. Which one task you have performed in an OPERATIONAL SITUATION have you found most physically demanding ? Please describe the task, situation and conditions.

SECTION K : PHYSICALLY DEMANDING TASKS

K2. Which one task you have performed during BA TRAINING have you found most physically demanding ? Please describe the task, situation and conditions :

K3. Comparing your answers to questions K1 and K2, please state which task was more physically demanding, and why :

SECTION L : DURATION OF SETS

L1. Are you equipped with extended duration BA sets eg. closed circuit sets ? Y = Yes N = No

L1.1 IF YOU ARE NOT, would you like to have an extended duration set available ? Y = Yes N = No

L1.2 IF YOU WOULD LIKE EXTENDED DURATION SETS, please give examples of situations in which a extended duration set would be useful :

L2. Would you like to have a shorter duration set available ? Y = Yes N = No

L2.1 IF YOU WOULD LIKE SHORTER DURATION SETS, please give examples of situations in which a shorter duration set would be useful :

If you have any queries regarding the questionnaire or the questions asked, please contact, Miss Julia Johnstone at the Institute of Occupational Medicine Limited in Edinburgh on (031) 667 5131 Ex. 2120.

Thank you for your co-operation.

ANY FURTHER COMMENTS :

If necessary, continue overleaf