

# Investigating the Impact if Using Personal Protective Equipment for Hazardous Materials amongst Firefighters in the City of Johannesburg

Butiki Johannes Tenyane\*<sup></sup>, Botshelo Brenda Mokaleng<sup></sup>, Nthai Freddy Monnye

Department of Physics, Tshwane University of Technology, Acadia Campus, Pretoria, South Africa  
Email: \*Butijoha@gmail.com, MokalengBB@tut.za, Simunye13@yahoo.com

**How to cite this paper:** Tenyane, B.J., Mokaleng, B.B. and Monnye, N.F. (2025) Investigating the Impact if Using Personal Protective Equipment for Hazardous Materials amongst Firefighters in the City of Johannesburg. *Materials Sciences and Applications*, 16, 348-366.

<https://doi.org/10.4236/msa.2025.166020>

**Received:** January 30, 2025

**Accepted:** June 16, 2025

**Published:** June 19, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

## Abstract

Firefighters respond to various types of emergencies in the emergency services, including incidents involving hazardous materials. Four levels of chemical protective suits are identified by the Environmental Protection Agency (EPA): Level A is a fully encapsulating suit that envelops both the wearer and the breathing apparatus. Level B can be encapsulating or non-encapsulating. Level C is a coverall with a canister respiratory device, and Level D is the normal work uniform. Level A and Level B generate high temperatures. Prolonged exposure causes some firefighters to suffer heat exhaustion, heat stress, heat cramps, heat stroke, and heart attack. The study aimed to investigate the challenges of using chemical protective suits among firefighters in the City of Johannesburg in South Africa. The study simulated a spillage incident with 30 subjects to measure the temperature generated by Level A and B suits while performing three hazardous materials operational activities: damming, dyking, and diverting. Screening of vital signs was implemented using BP and pulse machine, thermometer and Glasgow coma scale before and after exercises. Questionnaires were distributed to the fire personnel within the region on the current practice of the chemical suit's use. The results show elevated temperatures, which increase the risk of subjects while wearing Level A suits compared to those wearing Level B suits, which generate less. The results were analysed and interpreted using Cronbach and Pearson test tools to provide a solution to the identified problems. Short-term exposure reduces the risk to subjects. However, this requires more resources.

---

## Keywords

City of Johannesburg, Emergency, Chemicals, Firefighters, Levels, Protection

---

## 1. Introduction

The City of Johannesburg is situated in Gauteng Province of South Africa. The city was established as a small village controlled by a health committee in 1886 after the discovery of gold on an outcrop of a reef on the farm of Langlaagte. The population of the city grew rapidly, becoming the largest city in South Africa [1].

According to Tuholske *et al.* [1], the spatial change in Johannesburg has been rapid since 1994, with the emergence of new suburban nodes and edge cities, the development of gated communities in sprawling settlements, the growth of publicly provided housing and informal settlements on the periphery, and racial change and densification in the inner city.

In order to deal with emergencies within the jurisdiction, the City of Johannesburg Metropolitan Municipality has a Public Safety department responsible for emergency services as stipulated by the Constitution of South Africa Act [2] supported by the Fire Brigade Act [3].

In South Africa, there are about 257 municipalities made up of metropolitan, district, and local municipalities, all of which are legally obliged to provide fire services to the community as per Municipal Structures Act No. 117/1998 [4].

Emergency services personnel in South Africa are estimated to be over 80,000 personnel, including firefighters and emergency medical services [5]. The City of Johannesburg has 31 fire stations and an estimated 600 emergency services workers covering 1620 km<sup>2</sup> [6].

Although fire departments have special teams responsible for chemical incidents, the challenges of hazardous materials posed to personal protective equipment (PPE) are not eliminated. Whenever a hazardous material incident occurs, emergency personnel are vulnerable to health risks due to the danger posed by chemicals. SANS [7] in *The Standard for Community Safety Protection against Fire* states, “It is the responsibility of the Emergency Services Department to respond to a variety of incidents within the municipality”. Whenever accidents occur, firefighters must put on PPE to mitigate the hazards involved in chemical incidents [5].

Chemicals are transported every day on regional, provincial, and national roads passing through the jurisdiction of the City of Johannesburg and other provinces. Shah *et al.* [8] define a chemical substance as “any material with a definite chemical composition that exists as either solids, liquids, gases, or plasma, and may change between these phases of matter with changes in temperature or pressure”.

Firefighters are exposed to hot, toxic gases and weather conditions that contribute to the overall workload encountered during emergency operations. Due to the

nature of the hazardous material incidents, during an emergency, firefighters are obliged to wear either structural firefighting garments, coveralls with canisters, proximity suits, fire entry suits, or non-encapsulated or fully encapsulated chemical protective suits [9].

The Environmental Protection Agency (EPA) [10] further states that vapours, gases, and particulates from hazardous substance response activities place response personnel at risk. For this reason, response personnel must wear appropriate personal protective clothing (PPC) and equipment whenever they are near the site. According to the EPA [10], there are four levels of PPE for hazardous materials. This study will focus on Level A and Level B suits used commonly by various fire departments to manage hazardous materials incidents.

Level A protection is required when there is a high risk of deadly chemical exposure and when the greatest level of skin, respiratory, and eye protection is required. Level A clothing and equipment include positive pressure, full face-piece self-contained breathing apparatus (SCBA) or positive pressure supplied air respirator with escape SCBA, totally encapsulated chemical-and-vapour-protective suit, inner and outer chemical-resistant gloves, and disposable protective suit, gloves, and boots.

Level B protection is required when the circumstances need the highest level of respiratory protection, with a lesser level of skin protection. Level B protection includes positive pressure, full face-piece SCBA or positive pressure supplied air respirator with escape SCBA, inner and outer chemical-resistant gloves, face shield, hooded chemical-resistant clothing, coveralls, and outer chemical-resistant boots.

Level C protection is required when the concentration and type of airborne substances are known, and the criteria for using air-purifying respirators are met. Typical Level C components include full-face air-purifying respirators, inner and outer chemical-resistant gloves, hard hats, escape masks, and disposable chemical-resistant outer boots.

Level D protection may be sufficient when no contaminants are present, or work operations preclude splashes, immersion, or the potential for unexpected inhalation or contact with hazardous levels of chemicals. Appropriate Level D protective equipment may include gloves, coveralls, safety glasses, face shields, and chemical-resistant, steel-toe boots or shoes.

The nature of these suits, combined with workload and environmental conditions, pose a potential heat stress problem for firefighters. Firefighters within the City of Johannesburg respond to various types of emergencies in line with the National Fire Protection Association's (NFPA) standards. NFPA [11] and NFPA [12] cover both the firefighter's professional competence and hazardous material exposure of first responders.

The use of these protective garments may lead to massive heat production, which may lead to heat stress, heat stroke, heat cramps, and injuries such as heart-related diseases, suffocation, fainting, and death.

## 2. Literature Review

The following literature review focuses on addressing research question 1. Research question 2 and Research question 3.

The problem with the current practices regarding PPE and PPC is that some firefighters collapse while wearing the garments, and the probability of death in the situation cannot be ruled out [13].

Based on the challenges that are identified, the following questions can be raised:

- 1) What is the temperature increase that the personal protective suits generate?
- 2) What is the impact of personal protective suits on the wellness of the firefighters during an emergency?
- 3) How can firefighter's best protect themselves against the increase in temperature during hazardous materials operations?

## 3. Aims and Objectives

This study aims to evaluate the challenges that emanate from wearing four types of PPE while performing simulated hazardous material operational activities. Furthermore, the study seeks to compare the temperature difference when wearing two types of PPE.

The objectives of this study are to evaluate how various types of chemical suits impact the health and performance of firefighters. The study will investigate how Level A and B PPE contribute to various health issues while performing simulated hazardous material operational activities and will compare the amount of heat production when wearing the PPE. Furthermore, the study will explore alternative ways to manage the heat produced by the wearing of protective suits and identify critical programmes that could enhance the safety of firefighters.

The following objectives were established.

- To measure the temperature increment during operations.
- To assess the impact of PPE to the wellness of fire fighters.
- To enhance safety of fire fighters during fire operations.

## 4. Hypothesis

The solution is to implement strategies that reduce exposure time, adopt programmes to enhance physical fitness and skills, adopt maintenance programmes, and conduct medical programmes as per international codes. These strategies will further help the City of Johannesburg and South Africa to develop policies to support the process.

## 5. Materials and Methods

### 5.1. Study Design

A mixed-method approach was followed. A mixed method is usually used to combine quantitative and qualitative research methods in the same research project

[14]. The multi-method used was relevant for this study because it is the philosophical underpinning of pragmatism, which allows and guides mixed methods researchers to use a variety of approaches to answer research questions that cannot be addressed using a singular method. The research design for the study was a descriptive survey.

A descriptive survey was selected because it provides an accurate portrayal or account of the characteristics, for example, behaviour, opinions, abilities, beliefs, and knowledge of a particular individual, situation, or group. This design was chosen to meet the study's objectives, namely, to evaluate the challenges that emanate from wearing two types of PPE while performing simulated hazardous material operational activities.

The descriptive research design involves using a range of qualitative and quantitative research methods to collect data that aids in accurately describing a research problem [15].

Descriptive research allows researchers to thoroughly investigate the background of a research problem before further research can be carried out. Descriptive research can prove to be a useful tool when trying to test the validity of an existing condition, as descriptive research involves conducting an in-depth analysis of every variable before concluding [16]. The study incorporated the survey into its research design because, in survey research, questionnaires are used to collect information on a specific topic from respondents. The survey in the study involved a mix of closed-ended and open-ended questions, as both have their own advantages [17].

The process of selecting a portion of the population to represent the entire population is known as sampling. A population is an entire group that the researcher wants to conclude about, while a sample is a specific group from whom the researcher will collect data. The sample size is always less than the size of the population [18]. Neuman [19] sees sampling as "a representative sample of a larger population". Sampling is usually done because it is impossible to test every individual in the population. It also saves time, money, and effort while conducting the research.

The study population comprised firefighters in the City of Johannesburg working across 30 fire stations. The number of firefighters working within the City of Johannesburg is 1243. All the ranks of firefighters within the City of Johannesburg are on the same level and only differ in terms of experience. The participants' names were anonymised and replaced with study identity numbers. A sample of 360 randomly selected firefighters participated in the study.

The sample size was determined at a 95% confidence interval with a margin of error of 5%, an expected response of 50%, and a standard normal z-statistic of 1.96 with a targeted population size of 1243 firefighters. The minimum size includes a 20% non-response adjustment, which was rounded off at 360 firefighters. Probability simple random selection was used to select participants at various fire stations across the City of Johannesburg. There were six crews of six people per

group, simulating the number of people who responded to emergencies and the backup team. The number of crews is enough to give the research adequate data to identify the challenges of using the PPE when performing HAZMAT operations activities for a maximum of 40 minutes, the average time spent while wearing PPE.

## 5.2. Data Collection

Data collection is collecting data to gain insights regarding the research topic [20]. The data collection sequence in the study was qualitative first, followed by quantitative. In this study, data were collected through the following instruments: For the qualitative approach, simulation was conducted with firefighters, and for quantitative research, the participants filled in questionnaires.

Before collecting data, the researcher obtained an Ethical Clearance Certificate from the Ethics Committee of Tshwane University of Technology. The researcher visited all the fire stations in the City of Johannesburg and held a debriefing session with the commanders of the stations to introduce the study to them, including its aim and its purpose. The researcher further explained the benefits of the study, which will be beneficial to all firefighters in South Africa, and then requested a meeting with the firefighters as they were the sample population in the study. The permission was granted to address all firefighters, and the meeting went well because they fully understood the study's problem statement.

The 30 firefighters who were selected randomly were notified, and they all signed a consent form indicating their willingness to participate in the study. Ethical issues like privacy, confidentiality, and the use of pseudonyms were fully explained to them. Firefighters were assured that medical practitioners would be available on-site during the simulation to assuage their fears. I explained that they could leave the study if a need arose.

Simulation exercises were conducted at Turfontein Fire Station. Only participants who were screened were allowed to take part. All firefighters were off duty, and the simulation exercise was done over two weeks.

Each exercise session was conducted as presented in **Table 1**.

**Table 1.** Structure of the proposed exercise session for firefighters.

Group	PPE	Activity	Duration
Crew A	Level A	Damming	10 minutes
Crew B	Level B	Damming	10 minutes
Crew C	Level A	Diking	10 minutes
Crew D	Level B	Diking	10 minutes
Crew E	Level A	Diverting	10 minutes
Crew F	Level B	Diverting	10 minutes

The information obtained through a questionnaire is similar to that obtained

by an interview, but the questions tend to have less depth [21]. Questionnaires were also administered to the participants to collect data. A questionnaire is a printed self-report form designed to elicit information that can be obtained through the written responses of the subjects. The questionnaires consisted of open-ended and closed-ended questions. The questionnaires were written in English only. A questionnaire about the chemical protective suits and the processes involved was administered to the firefighters online. The communication department within the City of Johannesburg EMS was approached to provide a survey link to all the firefighters within the city.

### 5.3. Questionnaire

The following was the scope of the questionnaire used to collect data from the participants:

- 1) Biographical information.
- 2) Current practices regarding PPE.
- 3) Advantages of using PPE.
- 4) Disadvantages of using PPE.
- 5) Reasons that prevent firefighters from using PPE.
- 6) State of policies regarding PPE use.

The scope enabled the researcher to obtain the crucial information necessary to make conclusions about PPE [22].

## 6. Results of the Questionnaire

The results of the questionnaire gave a picture of the views, opinions, and on-the-ground experience regarding a variety of issues pertaining to the use of PPE for various types of incidents.

### 6.1. Participants per Gender

**Figure 1** shows that most (70%) of the participants were men and few (30%) were women. This skewed gender prevalence of the participants confirms that firefighting careers are still as male-dominated as in the 1970s [23] when the profession was still new. Amongst other reasons, the skewed gender prevalence is because of the nature of the job, which is dangerous and physical.

### 6.2. Participants per Age

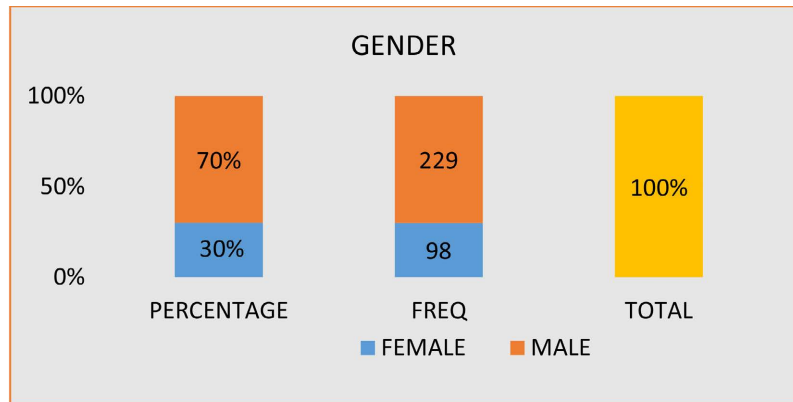
**Figure 2** illustrates that a total of (72%) firefighters fall in the matured age groups, followed by 23% youth and 5% veterans.

One of the reasons there are more matured age groups is that many fire departments in South Africa delays in their annual recruitment programmes.

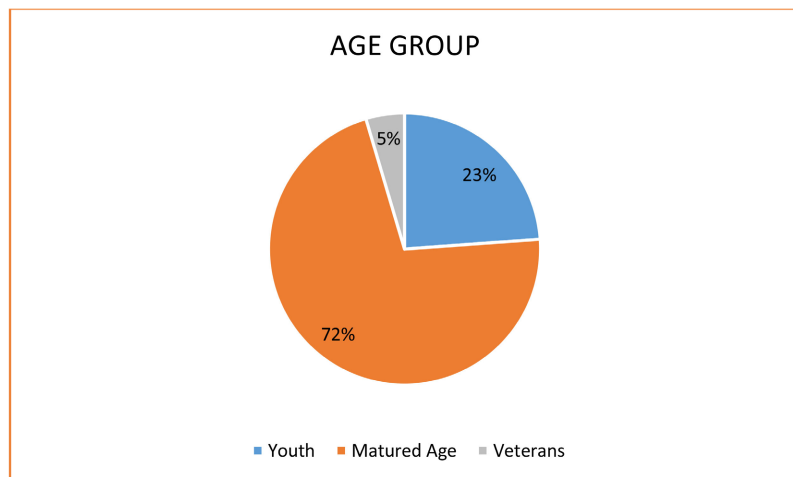
### 6.3. Advantages of Wearing PPE

Participants were asked to select the advantages of using PPE to establish their level of knowledge regarding the wearing of such garments. **Figure 3** shows that

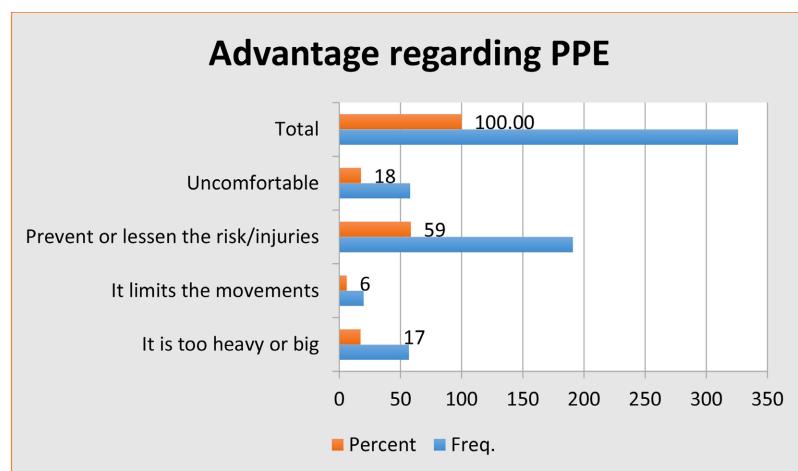
of the 326 participants, 18% think that the PPE is too uncomfortable, and 17% think that PPE is too big, 6% said PPE limits movements, and 59% agreed that PPE lessens or prevents injuries.



**Figure 1.** Gender.



**Figure 2.** Participants per age.



**Figure 3.** Advantages regarding PPE.

Many participants (59%) agree that PPE can prevent injuries and protect firefighters from harmful hazards associated with their jobs, compared to 41% who complained about the limitations. Thus, PPE is the first safety tool in any emergency.

## 7. Reliability Study

The Cronbach's alpha for this scale is 0.8661, which indicates good internal consistency. Therefore, the items in this scale measure the underlying construct (attitudes towards chemical protective suits) reliably. The item-test correlations range from 0.6634 to 0.7296, indicating a moderate to strong relationship between the individual items and the overall scale. The item-rest correlations range from 0.5575 to 0.6392, also suggesting a moderate to strong relationship between the items and the scale after controlling for the item.

### 7.1. Policies and SOPs regarding the Use of Chemical Protective Suits

The Cronbach's alpha for this scale is 0.8674, also indicating good internal consistency. The item-test correlations range from 0.5421 to 0.7111, suggesting a moderate to strong relationship between the individual items and the overall scale. The item-rest correlations range from 0.4244 to 0.6250, also indicating a moderate to strong relationship between the items and the scale after controlling for the item.

### 7.2. Statistical Data Showing Policies and Sops regarding the Use of Chemical Protective Suits

. alpha Statement20Thedepartmenttha-Statement29Thedepartmenttha, item std

Test scale = mean(standardized items)

Item	Obs	Sign	item-test correlation	item-rest correlation	average interitem correlation	alpha
S~0Thedepa~a	320	+	0.5421	0.4244	0.4202	0.8671
S~1Thedepa~a	325	+	0.6397	0.5381	0.4026	0.8584
S~2Thedepa~a	324	+	0.6855	0.5931	0.3938	0.8540
S~3Thedepa~s	324	+	0.6941	0.6038	0.3921	0.8531
S~4Thedepa~s	325	+	0.7070	0.6193	0.3895	0.8517
S~5Thedepa~a	325	+	0.6701	0.5748	0.3966	0.8554
S~6Thedepa~a	324	+	0.7111	0.6250	0.3887	0.8512
S~7Thedepa~a	321	+	0.7070	0.6191	0.3899	0.8519
S~8Thedepa~a	327	+	0.6930	0.6019	0.3920	0.8530
S~9Thedepa~a	327	+	0.7034	0.6140	0.3900	0.8520
Test scale					0.3956	0.8674

The average inter-item correlation is 0.3956, which is within the recommended range, further supporting the internal consistency of the scale.

### 7.3. Relationship between Attitudes and Challenges

The Pearson correlation analysis shows a significant negative relationship be-

tween attitudes towards chemical protective suits and perceived disadvantages of using PPE, with a correlation coefficient of  $-0.2269$  and a p-value of  $0.0001$ . This correlation suggests that negative attitudes towards chemical protective suits are associated with higher perceived disadvantages of using PPE. The overall relationship between attitudes and challenges has a correlation coefficient of  $-0.2051$  and a p-value of  $0.0002$ , indicating a significant negative relationship.

In summary, the reliability analysis suggests that the scales used to measure attitudes towards chemical protective suits and policies/SOPs regarding their use have good internal consistency. The analysis also reveals a significant negative relationship between attitudes towards chemical protective suits and perceived challenges or disadvantages associated with using them.

#### 7.4. Statistical Data Showing Attitudes towards Chemical Protective Suits

```
. alpha Statement11Isitnecessaryt-Statement19Safetybootsprot, item std
Test scale = mean(standardized items)
```

Item	Obs	Sign	item-test correlation	item-rest correlation	average interitem correlation	alpha
Statement~yt	323	+	0.6634	0.5575	0.4251	0.8554
S~2Chemica~i	325	+	0.7002	0.6020	0.4170	0.8512
S~3Earprot~r	326	+	0.6733	0.5694	0.4231	0.8544
S~4Eyeprot~r	325	+	0.7104	0.6155	0.4147	0.8500
Statement~ts	324	+	0.7291	0.6392	0.4103	0.8477
Statement~ks	325	+	0.7094	0.6141	0.4147	0.8500
Statement~es	324	+	0.6684	0.5638	0.4237	0.8547
S~8Chemica~i	327	+	0.6656	0.5601	0.4250	0.8553
Statement~ot	326	+	0.7296	0.6390	0.4102	0.8477
Test scale					0.4182	0.8661

The average inter-item correlation is  $0.4182$ , which is within the recommended range of  $0.15 - 0.50$ , further supporting the internal consistency of the scale.

## 8. Comparative Results

**Table 2** highlights the activities with various crews wearing different suits.

**Table 2.** Comparative results activities.

Crew A Level A suits vs Crew B Level A suit	Damming
Crew A Level B suits vs Crew B Level B suit	Damming
Crew B Level A suits vs Crew B Level A suit	Diking
Crew B Level B suits vs Crew B Level B suit	Diking
Crew C Level A suits vs Crew C Level A suit	Diverting
Crew C Level B suits vs Crew C Level B suit	Diverting

### 8.1. Simulation Results

Variables: Glasgow coma scale, BP, pulse, temperature before and after.

#### Results of Crew A performing a damming activity with Level A suit

**Table 3** shows Crew A participants' results of the screening before performing damming of the water spillage, the time taken to wear the garment, the travel time to the hot zone, working time of ten minutes, undressing time, and vital signs after the performance of damming. For all the participants, temperatures increased, as did pulse and blood pressure. However, the level of consciousness remained the same. The participants were allocated a maximum of two minutes to wear their garments (suits) and to doff (undress) after the activity.

**Table 3.** Results of Crew A performing damming with Level A suit.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37.0°C	67	125/83	15/15	37.4°C	90	145/94	15/15
B	37.2°C	64	120/85	15/15	37.5°C	84	139/75	15/15
C	36.6°C	70	125/92	15/15	38.7°C	82	154/124	15/15
D	37.4°C	65	124/85	15/15	38.5°C	70	149/70	15/15
E	36.8°C	72	130/95	15/15	38.4°C	86	143/94	15/15
F	37.2°C	68	121/80	15/15	38.5°C	80	147/104	15/15

The increase in temperature, pulse and blood pressure affirms that firefighting is physical and requires an acceptable level of physical fitness. The steady Glasgow coma scale (levels of consciousness) affirms that the participants have adapted to the firefighting tasks. Therefore, their levels of consciousness are still 15/15 (100%).

### 8.1.1. Results of Crew B Performing a Damming Activity with Level B Suit

**Table 4** shows Crew B participants' results of the screening before performing damming of the water spillage while wearing Level B suits. **Table 4** further shows the allocated time to wear the garment, the travel time to the hot zone, a working time of ten minutes, doffing time, and screening after the performance of damming. For all the participants, temperatures increased, as did pulse and blood pressure. However, their level of consciousness remained the same. The participants were allocated a maximum of two minutes to wear their garments (suits) and to doff (undress) after the activity.

**Table 4.** Results of Crew B Damming with Level B suits.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37.3°C	68	120/86	15/15	37.5°C	70	124/90	15/15
B	36.5°C	62	120/85	15/15	37.2°C	74	137/85	15/15
C	37.2°C	69	122/84	15/15	37.5°C	73	130/94	15/15
D	37.4°C	70	125/85	15/15	37.9°C	79	129/92	15/15
E	37.1°C	72	117/85	15/15	37.4°C	102	137/87	15/15
F	36.2°C	84	122/97	15/15	37.2°C	105	132/98	15/15

The increase in temperature, pulse and blood pressure affirms that the fire-

fighting job is physical and requires an acceptable level of physical fitness. However, the increment is steady, showing that the suit allows the wearer space for fresh air. The steady Glasgow coma scale (levels of consciousness) affirms that the participants have adapted to the firefighting tasks. Therefore, their levels of consciousness are still the same.

### 8.1.2. Comparative Results of Crew A and Crew B Performing Damming

**Table 5** shows that the average temperature produced by Crew A is 1.1°C higher than 0.5°C for Crew B. On average, the heart rate produced by Crew A is 14.4 higher compared to 13.0 by Crew B. On average, the BP produced by Crew A is 22/7 higher compared to 11/4 of Crew B. The Glasgow coma scale score is 15/15, which means the participants were all fully alert and orientated.

One of the common reasons for the temperature difference might be the level of physical fitness or underlying medical conditions. Nonetheless, Level A suits are fully encapsulated compared to Level B suits.

**Table 5.** Comparative results for Crew A and Crew B.

Variable	Crew A	Crew B
Temp (Before)	37.0°C	36.9°C
Pulse (Before)	67.6	70.8
BP (Before)	124/87	121/87
GCS	15/15	15/15
Hazmat Activity	Damming	Damming
Travel Time	avg = 2 min	avg = 2 min
Work Time	10 min	10 min
Temp (After)	38.1°C	37.4°C
Pulse (After)	82.0	83.8
BP (After)	146/94	132/91
GCS (After)	15/15	15/15

### 8.1.3. Results of Crew C Performing Diking with Level a Suit

**Table 6** shows Crew C participants' results of the screening before performing diking of the water spillage, the time taken to wear the garment, the travel time to the hot zone, working time of ten minutes, doffing time, and vital signs after the performance of damming. For all the participants, temperatures increased, as did pulse and blood pressure. However, their level of consciousness remained the same. The participants were allocated a maximum of two minutes to wear their garments (suits) and to doff (undress) after the activity.

**Table 6.** Results of Crew C performing diking with Level A suits.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS (Before)	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37	67	125/83	15/15	37.4	90	145/94	15/15

## Continued

B	37.2	64	120/85	15/15	37.5	84	139/75	15/15
C	36.6	70	125/92	15/15	38.7	82	154/124	15/15
D	37.4	65	124/85	15/15	38.5	70	149/70	15/15
E	36.8	72	130/95	15/15	38.4	86	143/94	15/15
F	37.2	68	121/80	15/15	38.5	80	147/104	15/15

#### 8.1.4. Results of Crew D Performing Diking with Level B Suit

**Table 7** shows Crew D participants' results of the screening before performing diking of the water spillage, the time taken to wear the garment, the travel time to the hot zone, working time of ten minutes, doffing time and vital signs after the performance of damming. For all the participants, temperatures increased, as did pulse and blood pressure. However, their level of consciousness remained the same. The participants were allocated a maximum of two minutes to wear their garments (suits) and to doff (undress) after the activity.

**Table 7.** Results of Crew D performing diking with Level B suits.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS (Before)	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37	67	125/83	15/15	37.4	90	145/94	15/15
B	37.2	64	120/85	15/15	37.5	84	139/75	15/15
C	36.6	70	125/92	15/15	38.7	82	154/124	15/15
D	37.4	65	124/85	15/15	38.5	70	149/70	15/15
E	36.8	72	130/95	15/15	38.4	86	143/94	15/15
F	37.2	68	121/80	15/15	38.5	80	147/104	15/15

#### 8.1.5. Comparative Results of Crew C vs Crew D Performing Diking

**Table 8** shows that on average, the amount of temperature produced by Crew C is 1.7°C higher than 0.6°C of Crew D. On average, the pulse rate produced by Crew C is 15 times higher compared to 14 times for Crew D. On average, the BP produced by Crew C is 20/7 higher compared to 10/8 of Crew D. The Glasgow coma scale score is 15/15, which means the participants were all fully alert and orientated.

**Table 8.** Comparative results of Crew C and Crew D.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS (Before)	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37	67	125/83	15/15	37.4	90	145/94	15/15
B	37.2	64	120/85	15/15	37.5	84	139/75	15/15
C	36.6	70	125/92	15/15	38.7	82	154/124	15/15
D	37.4	65	124/85	15/15	38.5	70	149/70	15/15
E	36.8	72	130/95	15/15	38.4	86	143/94	15/15
F	37.2	68	121/80	15/15	38.5	80	147/104	15/15

One of the common reasons for temperature differences might be the level of physical fitness or underlying medical conditions. Level A suits are fully encapsulated compared to Level B suits.

### 8.1.6. Results of Crew E Diverting Spillage Using Level A Suit

**Table 9** shows Crew E participants' results of the screening before performing diverting of the water spillage, the time taken to wear the garment, the travel time to the hot zone, working time of ten minutes, doffing time, and vital signs after the performance of damming. For all the participants, temperatures increased, as did pulse and blood pressure. However, their level of consciousness remained the same. The participants were allocated a maximum of two minutes to wear their garments (suits) and to doff (undress) after the activity.

**Table 9.** Results of Crew E diverting spillage while wearing Level A suits.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS (Before)	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37	67	125/83	15/15	37.4	90	145/94	15/15
B	37.2	64	120/85	15/15	37.5	84	139/75	15/15
C	36.6	70	125/92	15/15	38.7	82	154/124	15/15
D	37.4	65	124/85	15/15	38.5	70	149/70	15/15
E	36.8	72	130/95	15/15	38.4	86	143/94	15/15
F	37.2	68	121/80	15/15	38.5	80	147/104	15/15

### 8.1.7. Results of Crew F Diverting Spillage Wearing Level B Suits

**Table 10** shows Crew F participants' results of the screening before performing diverting of the water spillage, the time taken to wear the garment, the travel time to the hot zone, working time of ten minutes, doffing time, and vital signs after the performance of damming. For all the participants, temperatures increased, as did pulse and blood pressure. However, their level of consciousness remained the same. The participants were allocated a maximum of two minutes to wear their garments (suits) and to doff (undress) after the activity.

**Table 10.** Results of Crew F diverting spillage wearing Level B suits.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS (Before)	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37	67	125/83	15/15	37.4	90	145/94	15/15
B	37.2	64	120/85	15/15	37.5	84	139/75	15/15
C	36.6	70	125/92	15/15	38.7	82	154/124	15/15
D	37.4	65	124/85	15/15	38.5	70	149/70	15/15
E	36.8	72	130/95	15/15	38.4	86	143/94	15/15
F	37.2	68	121/80	15/15	38.5	80	147/104	15/15

### 8.1.8. Comparative Results of Crew E and Crew F Results

**Table 11** shows that the on-average temperature increase for Crew E is 1.3°C

higher compared to 0.5°C for Crew F. On average, the pulse rate produced by Crew E is 13 times higher compared to the nine times of Crew F. On average, the BP produced by Crew E is 17/2 higher compared to 6/4 of Crew F. The Glasgow coma scale score is 15/15, which means the participants were all fully alert and orientated.

One of the common reasons for the temperature difference might be the levels of physical fitness or underlying medical conditions.

**Table 11.** Comparative results for Crew E and Crew F while diverting.

Participant	Temp (Before)	Pulse (Before)	BP (Before)	GCS (Before)	Temp (After)	Pulse (After)	BP (After)	GCS (After)
A	37	67	125/83	15/15	37.4	90	145/94	15/15
B	37.2	64	120/85	15/15	37.5	84	139/75	15/15
C	36.6	70	125/92	15/15	38.7	82	154/124	15/15
D	37.4	65	124/85	15/15	38.5	70	149/70	15/15
E	36.8	72	130/95	15/15	38.4	86	143/94	15/15
F	37.2	68	121/80	15/15	38.5	80	147/104	15/15

## 9. Summary of the Results

The cumulative average temperature increase produced by Level A suits is 4.1°C higher compared to 1.6°C for Level B suits. The cumulative average heartbeat rate produced by Level A suits is 42.4 higher compared to 36.0°C of Level B suits.

The cumulative average of BP produced by Level A suits is 59/16 higher than that of 27/16 of Level B suits. The Glasgow coma scale score is 15/15, which means all participants were fully alert and orientated before and after the simulation activities.

One of the common reasons for temperature deference might be the level of physical fitness or underlying medical conditions. Level A suits are fully encapsulating and are compared to Level B suits.

## Policies and SOPs regarding the Use of PPE during Emergencies

Most (70%) of the participants agree that the department has systems and personnel in place for hazardous materials incidents, including a SOP, a policy, a response team, a rapid intervention team, and an incident management system to manage hazardous materials incidents supported by the NFPA [12] international safety code.

Strategically, the department is successful in managing hazardous materials incidents. These efforts are important towards a safe work environment.

## 10. Outcomes

The following outcomes were drawn from the findings.

An average of 50% of the respondents demonstrated that they are aware of the

importance of PPE in hazardous incidents. More than half (57%) agreed that the PPE for hazardous materials restricts movement, causes suffocation, and can elevate the risk of stress.

Simulation exercise results showed that an average of 70% of participants' temperatures increased, pulse and blood pressure also increased while the Glasgow coma scale score was stable. Short-term exposure for firefighters reduces the risk of heat stroke, heat stress, and heat exhaustion.

As shown in **Table 12**, a total of (80%) participants agree that PPE prevents injuries on duty, 13% affirm that PPE increases the risk of respiratory illnesses, 4% believe that PPE does not protect against hazards, and 3% say PPE gives no protection against falling hazards, and 20% of the views affirm the limitations of PPE in various accidents. However, there are still more benefits to using PPE.

**Table 12.** Policies and SOPs regarding the use of PPE.

Statement	A: Strongly Agree	B: Agree	C: Do Not Know	D: Disagree	E: Strongly Disagree
The department has a SOP for using chemical protective suit	30%	44%	22%	4%	0%
The department has a chemical response team	35%	50%	9%	3%	2%
The department has a rapid intervention team in every chemical incident	34%	54%	9%	3%	0%
The department uses incident management system	35%	54%	8%	2%	1%
The department uses NFPA 1500 on chemical incidents	27%	45%	24%	3%	1%
The department has a health safety policy	35%	58%	5%	1%	1%
The department has a SOP on cleaning and maintenance of suits	31%	57%	10%	1%	1%
The department has implemented a policy for chemical incidents	37%	55%	6%	1%	1%

## 11. Gender Distribution

Most (70%) of the participants were men and few (30%) were women. This skewed gender prevalence confirms that firefighting careers are still as male-dominated as in the 1970s when the profession was still new. Amongst other reasons, the skewed gender parity is because of the nature of the job, which is dangerous and physical. Therefore, there is a need for discussion in terms of how fire departments can increase the number of women in this physically demanding occupation. On the other hand, despite women being perceived as unable to do hard labour, they play a significant role in rescuing lives during suicide incidents and also succeed in conducting incident stress debriefing. Therefore, the fire departments should further discuss the role of women in modern emergency services.

## 12. Different Age Groupings

Most (45%) of the participants were in the middle age groups (mature adults),

followed by 31% veterans (46 to 60 years), and 24% youth (18 to 35 years). A reason that there are more mature adults is that many fire departments in South Africa do not have annual recruitment programmes. The departments wait for people to apply and for firefighters going on pension to retire before appointing new firefighters.

The fire departments need to create a balance to reduce the risk of heart attack and at the same time ensure that there is knowledge transfer from the seasoned firefighters to the new firefighters. As to how the department should create this balance, it is a discussion that top management and stakeholders should pursue in consideration of the required physical strength, funding, and other factors.

### **13. Permanent Personnel versus Volunteers**

The City of Johannesburg has 1243 firefighters, and most (99%) are permanent firefighters, and only 1% are volunteers. The responses affirm that 99% of the participants are those responsible for responding to various emergencies in the city.

### **14. Challenges of Using PPE for Hazardous Materials**

More than half (57%) of the participants agree that all factors listed on the questionnaire are the disadvantages of wearing PPE, 19% complain that PPE restricts, 16% say it can elevate the risk of stress, and 8% restrict vision and movement. Therefore, firefighters believe that the use of PPE presents more challenges than protection. This researcher recommends that further research should explore the best ways to make PPE more comfortable.

### **15. Further Discussions**

The main focus of the study is the effect of short-term exposure on the overall efficacy of operations. Although the short-term exposure strategy improves safety, it is time-consuming and requires a larger workforce. However, some participants still find the strategy to be the best option.

The problems of excessive heat production in Level A suits raise the question of whether firefighters should not wear the Level A suit or opt for less safe Level B suits. Most (70%) of the participants still prefer Level A suits irrespective of the identified shortcomings that may put their lives at risk. More than half (57%) of the participants believe that the risk of exposure to chemicals is more detrimental than that of heat generation. The risks depend on the nature of the activity, the level of physical fitness, and the duration of the activity.

This researcher recommends that further research should investigate a possible alternative to these two suits. For instance, a safer suit that generates less heat but gives maximum protection.

### **16. Contribution of the Study**

The City of Johannesburg Emergency Management Services will benefit positively by reducing injuries and fatalities and improving standard working procedures,

training programmes, awareness activations, and quality assurance.

The study will help the City of Johannesburg address the identified policy shortcomings, help personnel with behavioural challenges, close knowledge gaps, and adopt maintenance programmes to enhance overall safety.

## 17. Conclusions

Level A suits generate more heat than Level B suits. More than half (57%) of the participants agreed that the PPE for hazardous materials restricts movement, causes suffocation, and can elevate the risk of stress. The simulation exercise results showed that an average of 70% of participants' temperatures increased, pulse and blood pressure also increased, and the Glasgow coma scale score was stable.

Most (70%) of the participants agree that the department has an SOP and policy for hazardous materials, a response team, and a rapid intervention team. The SOP uses an incident management system to manage hazardous materials incidents supported by the NFPA [12] international safety code. Strategically, the department is doing well in managing hazardous materials incidents.

Shortening the exposure time to hazardous material incidents reduces the risk of heat stroke, heat stress, and heat exhaustion. However, shortening exposure times requires a larger workforce to service the incidents.

The study has given emergency services personnel the opportunity to learn about the shortcomings of PPE, policies, strategies, and resources. Although the City of Johannesburg has policies and SOP, adopting the NFPA [13] standard (health-related fitness programmes for fire department members) will enhance the efficacy and overall wellness and safety during operations.

In order to achieve a balanced, safe environment, the management needs to create a balance on a variety of factors not limited to the workforce, PPE, supervision, and good tactics and strategies for every emergency supported by policies, standard operating procedures, and directives.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Tuholske, C., Caylor, K., Funk, C., Verdin, A., Sweeney, S., Grace, K., *et al.* (2021) Global Urban Population Exposure to Extreme Heat. *Proceedings of the National Academy of Sciences*, **118**, e2024792118. <https://doi.org/10.1073/pnas.2024792118>
- [2] Republic of South Africa (1996) The Constitution of the Republic of South Africa, Act 108 of 1996. Government Printer.
- [3] Republic of South Africa (1987) Fire Brigade Services Act 99 of 1987. Government Printer.
- [4] Republic of South Africa (1998) Local Government: Municipal Structures Act 117 of 1998. Government Printer.
- [5] Monnye, N.F. (2017) Physical Fitness Status of Gauteng Fire Fighters and Its Impact on the Job Performance. Doctoral Dissertation, Tshwane University of Technology.

- [6] Radebe Khiba, N. (2018) Overview—City of Johannesburg Emergency Management Services. <http://www.joburg.org.za/>
- [7] South African Bureau of Standards (SABS) (2003) SANS 10400: The Application of the National Building Regulations. SABS Standards Division.
- [8] Shah, P.S., Link, N., Jang, G.M., *et al.* (2018) Comparative Flavivirus-Host Protein Interaction Mapping Reveals Mechanisms of Dengue and Zika Virus Pathogenesis. *Cell*, **175**, 1931-1945.
- [9] Ayikoru, M. and Park, H.Y. (2019) Films and Critical Pedagogy in Management Education: A Tourism Studies Context. *Journal Academy of Management Learning & Education*, **18**, 414-432.
- [10] Burke, I.J. (2020) Personal Protective Equipment: Selection and Use in Hazardous Environments.
- [11] Environmental Protection Agency (EPA) (2017) Multi-Model Framework for Quantitative Sectoral Impacts Analysis: A Technical Report for the Fourth National Climate Assessment. United States Environmental Protection Agency.
- [12] National Fire Protection Association (NFPA) (2017) NFPA 1500: Standard on Fire Department Occupational Safety, Health, and Wellness Program. National Fire Protection Association.
- [13] National Fire Protection Association (NFPA) (2015) NFPA 1583: Standard on Health-Related Fitness Programs for Fire Department Members. National Fire Protection Association.
- [14] National Fire Protection Association (NFPA) (2019) NFPA 1500: Standard on Fire Department Occupational Safety, Health, and Wellness Program. NFPA.
- [15] Brown, A.H. and Green, T.D. (2021) The Essentials of Instructional Design. Routledge.
- [16] Maxwell, J.A. and Loomis, D.M. (2013) Mixed Methods Design: An Alternative Approach. In: Teddlie, C. and Tashakkori, A., Eds., *Sage Handbook of Mixed Methods in Social & Behavioral Research*, Sage Publications, 257-272.
- [17] Ranganathan, P. and Aggarwal, R. (2018) Study Designs: Part 1—An Overview and Classification. *Perspectives in Clinical Research*, **9**, 184-186. [https://doi.org/10.4103/picr.picr\\_124\\_18](https://doi.org/10.4103/picr.picr_124_18)
- [18] LoBiondo-Wood, G. and Haber, J. (2019) Nursing Research: Methods and Critical Appraisal for Evidence-Based Practice. Elsevier.
- [19] Neuman, W.L. (2010) Social Research Methods: Qualitative and Quantitative Approaches. Pearson Education.
- [20] Polit, D.F. and Beck, C.T. (2021) Nursing Research: Generating and Assessing Evidence for Nursing Practice. Wolters Kluwer.
- [21] Oliveira, A.M., Powell, S. and Feitosa, R.M. (2021) A Taxonomic Study of the Brazilian Turtle Ants (Formicidae: Myrmicinae: Cephalotes). *Revista Brasileira de Entomologia*, **65**, e20210028. <https://doi.org/10.1590/1806-9665-rbent-2021-0028>
- [22] Taherdoost, H. (2021) Data Collection Methods and Tools for Research: A Step-by-Step Guide to Choose Data Collection Technique for Academic and Business Research Projects. *International Journal of Academic Research in Management*, **10**, 10-38.
- [23] Jung, A.M. (2021) Adverse Reproductive Outcomes in the US Fire Service: Results from a Survey of Women Firefighters. Doctoral Dissertation, The University of Arizona.