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Test Report for the Internal/External Temperature Heads-Up Display

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Executive Summary

The operational field assessment of the Thermal Heads-Up Display (HUD) prototype, developed by Ultra Electronics – USSI, occurred on April 30, 2013, at the New York City Fire Academy on Randall's Island with participation from the New York City Fire Department. Four firefighters with various levels of training in hazardous materials (hazmat) were led by Hazmat Battalion Chief Edward Bergamini.

The firefighter participants executed an operational training scenario in which they were required to fix a simulated leak of a 1-ton chlorine cylinder. This task required participants to don a Level-A hazmat suit and the Thermal HUD. The task was conducted in a training shed where the inside temperature was set to 92 degrees Fahrenheit to allow the prototype and participants to experience preset alarm triggering levels.

The training scenario was conducted twice in teams of two with Hazmat Battalion Chief Bergamini acting as the incident commander. Each participant had at least 30 minutes of active use with the Thermal HUD. During the scenarios, data collectors from the National Urban Security Technology Laboratory and SAIC recorded noteworthy observations. These observations included several instances of the Thermal HUD's external temperature sensor module falling off the suit and one case where the Thermal HUD failed to report on external suit temperature even though everything appeared to be connected correctly.

Overall, participants expressed mixed opinions on the prototype system. The need for such a device was never called into question; instead, the particulars of the system's functionality were distilled into specific notional concepts of what was needed by hazmat firefighters. This was reflected in two major recommendations that resonated most with participants:

1. An ability to have information transmitted to an incident commander
2. An ability to have a greater emphasis placed on the core body temperature

Participants expressed the need to transmit information to an incident commander or medical unit because their desire to complete a mission often overrides their ability to make rational decisions about their exertion level and health during an incident. An outside decision-maker such as an incident commander is needed to direct them toward the safest actions in such situations.

Participants also found that the only indicator they were concerned with was their body temperature. Firefighters often work in hot environments and, as such, understand that everyone responds to external heat differently. Thus, it is each individual firefighter's core body temperature that provides him or her with the best information as to how he or she is coping with their environment. One participant recommended including a heart rate pulse monitor to complement the core body temperature reading, which would provide further insight into exertion levels. These recommendations do not speak to errors in or shortfalls of the prototype but to a further distillation of the needs and requirements of firefighters.

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1 Introduction

Firefighters in situations requiring Level-A hazardous materials (hazmat) suits face a host of dangers, including a reduced ability to accurately monitor the internal and external temperatures of their suits. The high temperatures in these situations pose a significant danger to firefighters, and this danger is heightened when firefighters are less capable of sensing the heat around them. The suits can be heavy, cumbersome, and provide for low dexterity. The heft of the suits provides for increased protection against high heat, but it also deprives firefighters of some of the physical sensory perception they would normally use to make decisions.

The U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T) First Responders Group (FRG), through its Responder Technologies division, funded the development of a system to solve this problem for firefighters. Ultra Electronics – USSI was the vendor chosen to develop this new technology. On April 30, 2013, members of the New York City Fire Department's (FDNY) hazmat team tested the suitability of this prototype.

1.1 Purpose

The purpose of this evaluation was to gauge the suitability of the Thermal Heads-Up Display (HUD) in its current state based on a user evaluation to determine its ability to be a marketable and viable solution for first responders who don Level-A hazmat suits.

1.2 Objectives

The objectives of this evaluation were to:

- Conduct realistic operational scenarios using trained firefighters utilizing the Thermal HUD to assess and evaluate its suitability in real-life scenarios
- Determine the Thermal HUD's level of adherence to the operational performance parameters cited in the Operational Requirements Document (ORD)
- Verify that corrective actions described in the *Statement of Work (SOW) Extension & Funding Request* have been addressed

1.3 Requirements Matrix

FRG hosted a virtual workshop on July 23, 2010. The virtual workshop consisted of 15 fire service responders primarily from the western United States. The end product of this workshop was the *Internal/External Temperature Heads-up Display Operational Requirements Document*, which was released on June 10, 2011. Table 1 is a summary of the operational performance parameters that were assigned threshold or objective designations.

Table 1 – Thermal HUD Requirements Matrix

Capability/Description	Threshold	Objective
Simple Operation	The system shall not require any pre-deployment equipment (e.g., antennas, reference nodes)	The system shall operate transparently until an alert is signaled.
Monitoring Capability		The system shall be able to effectively monitor the body[1] internal and external temperature surrounding Level-A firefighter's suit as well as the rate of rise of ambient temperature.
Display		The information regarding temperature levels and alerts shall be shown on a heads-up display, compatible with current self-contained breathing apparatus (SCBA) face piece technology that is easily read by firefighters while conducting operations.
Interoperability		The system shall be interoperable with existing environmental sensors and be able to transmit this data and warning signals (based upon pre-determined danger levels) to appropriate parties.
Compatibility with Existing Personal Protective Equipment		The system shall be compatible and able to be worn on existing firefighter personal protective equipment. The system shall not compromise the chemical protective nature, from liquids and gases, provided by a Level-A hazmat suit.
Durability		The system shall be able to operate under varying circumstances, including differing building sizes with varying wall thickness, differing team sizes, and have the ability to withstand high temperatures.
Temperature Trigger Alerts		The system shall have a baseline temperature trigger alert established at 300 degrees Fahrenheit for ambient (external) temperature and 100 degrees Fahrenheit for internal (inside the gear) temperature.

[1] The capability to monitor body temperature was not part of the original ORD but was added later.

1.4 System Description

As stated above, the prototype Thermal HUD under evaluation was designed by Ultra Electronics – USSI. The prototype, shown in Figure 1, communicates wirelessly with other components to eliminate any risk of compromising suit integrity. Specifically, radio-frequency identification technology is used between an external temperature sensor module and the internal sensor/display module. Wireless radio communications are used between the body temperature sensor and the display module. The prototype is designed to be manufacturer-agnostic in relation to the Level-A hazmat suit and self-contained breathing apparatus (SCBA) face piece used.

Figure 1 – Display Module of Thermal HUD

The system display utilizes a traffic light style for each of the three types of readings: external temperature, internal (suit) temperature, and body temperature. When temperature levels are escalated from green to yellow or yellow to red, the light of the level it is moving to will flash several times before holding steady at the new level. An audio warning accompanies this change in state. If any of the columns move to the red level, the audio alarm will continue to beep until levels decrease.

The display module connects to the interior window/shield of the Level-A hazmat suit by means of a removable adhesive dual-lock strip. The external module will connect to the outside of the mask, be aligned with the display module, and stay in place via a magnetic connection. An ambient light sensor on the internal sensor module will help regulate the luminosity of the light-emitting diodes (LEDs).

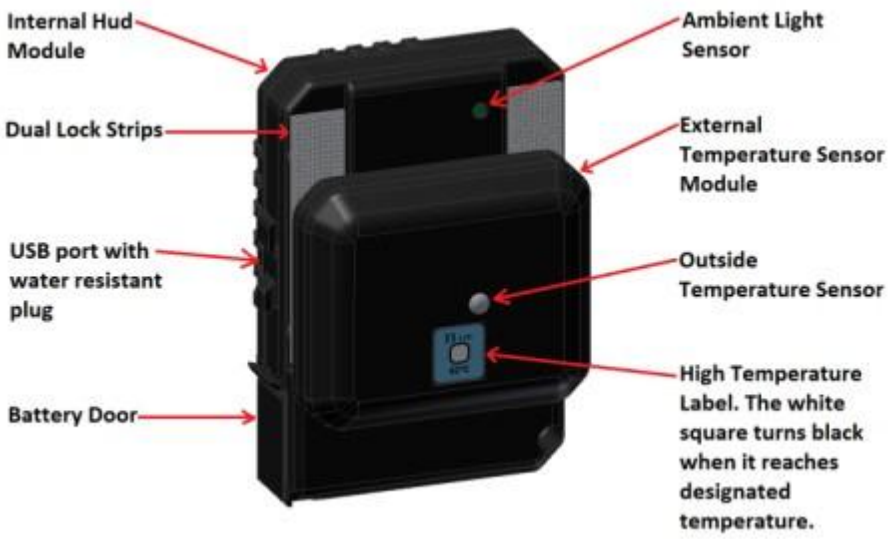


Figure 2 – External Module and Internal Module of Thermal HUD

The prototype uses two AAA batteries as a power source. A USB port resides on the side of the display module, which allows for the downloading of temperature data for post-event evaluation. Further information can be found in the *Internal/External Temperature Heads-Up Display User Manual.*

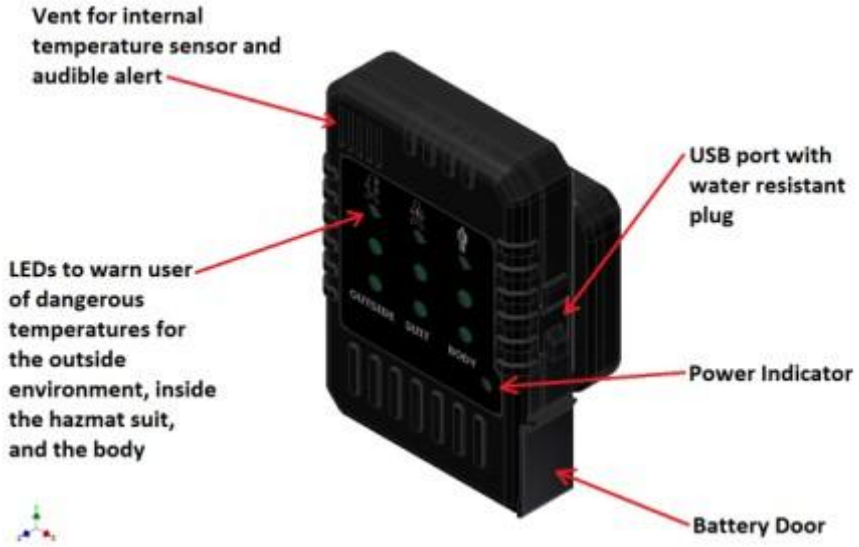


Figure 3 – Overview of Thermal HUD (Body Temperature Sensor not displayed)

2 Test Design

This section discusses the details of the test, including the overall design of and deviations from the test plan. For a full set of procedures and further detail, please see the *Operational Field Assessment Plan for the Internal/External Temperature Heads-Up Display (HUD).*

2.1 Test Design

Testing was comprised of two distinct phases. The initial phase sought to verify that the corrective actions identified in the *Statement of Work (SOW) Extension & Funding Request* (see Table 2) had been appropriately addressed. The second phase sought to validate the operational requirements and suitability of the system, as discussed in the ORD, as well as solicit additional user feedback.

2.1.1 Phase 1 – Inspection and Review

The corrective actions identified in Table 2 were verified to the extent possible through inspection and a documentation review. Several items from the table, namely 3, 9, and 10, were evaluated during operational suitability testing.

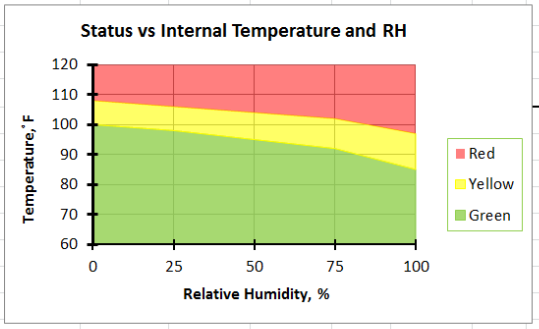
2.1.2 Phase 2 – Operational Suitability

Operational suitability of the Thermal HUD was assessed by members of the FDNY hazmat team. In teams of two, members of the FDNY hazmat team attended to the simulated leak of a 1-ton chlorine cylinder (see Figure 4). This operation required that the participants don Level-A hazmat suits while wearing a SCBA system. This training was conducted in a heated shed (92 F) and had participants actively engaged for 30 minutes, allowing for body and internal suit temperatures to more readily reach alarm triggering levels (see Figure 6).

Figure 4 – 1-ton chlorine cylinder for simulated leak scenario

Figure 5 – Firefighters sealing the leak in Level-A hazmat suits

Body Temperature		
Warning	**Body Temperature Warning Level :**	**102.0° F and above**
Alert	**Body Temperature Alert Level :**	**100.4° F to 101.9° F**
Normal	**Body Temperature Normal Level :**	**Up to 100.3° F**
Internal Temperature		
Warning	**Suit Internal Condition Warning :**	
Alert	**Suit Internal Condition Alert :**	
Normal	**Suit Internal Condition Normal :**	
External Temperature		
Warning	**External Condition Warning :**	**Temperature outside of suit greater than 165° F**
Alert	**External Condition Alert :**	**Temperature outside of suit greater than 135° F and less than 165° F**
Normal	**External Condition Normal :**	**Temperature outside of suit less than 135° F**



RH (%)	Temp Yellow	Temp Red
0	100	108
25	98	106
50	95	104
75	92	102
100	85	97

Figure 6 – Alarm trigger thresholds

2.1.3 Deviations from the Test Plan

A post-mission analysis using the HUD software was unable to be conducted with participants during the operational field assessment (OFA). There were computer device driver issues with the installation of the software that were not resolved until later that week. Participants were unable to provide feedback on their experience with this aspect of the system.

2.1.4 Summary of Events

On April 30, 2013, at 10 a.m., Bhargav Patel, Test Director (S&T); Christine Lee, Program Manager (S&T); John O'Neil, Video Production (SAIC); Matt Nakich, Data Collector (SAIC); Battalion Chief Bergamini (FDNY); and four FDNY hazmat-trained firefighters convened at the New York City Fire Academy on Randall's Island. A brief was given by Christine Lee, Hazmat Battalion Chief Bergamini, and Bhargav Patel (NUSTL) explaining the goals and objectives for the OFA. This was followed by a brief hands-on training presentation of the Ultra Electronics – USSI Thermal HUD. The participants included four firefighters with hazmat training who will be referred to as Firefighter 1, Firefighter 2, Firefighter 3, and Firefighter 4.

The first iteration of the operational scenario was carried out by Firefighters 1 and 2. During this first iteration, there were a few incidents of note. While donning the Level-A hazmat suit and gear, the external module of the Thermal HUD fell off of the visor of Firefighter 1's Level-A hazmat suit. This happened again during the scenario and Firefighter 1 opted to leave it on the floor to focus on his mission (see Figure 7). The external module was later placed back on him by Firefighter 3. Firefighter 2 was not receiving any data about his external temperature even though it was magnetically connected and in place (see Figure 8) while his internal temperature gauge was green. Both Firefighters 1 and 2 had their core body temperatures reach a red state according to the Thermal HUD, which indicates elevated levels that are unsafe; however, both reported to the incident commander that they felt fine and were capable of completing the mission without overexerting themselves. Firefighter 1 had his external and internal indicators move to the yellow state.

Figure 7 – Firefighter leaves fallen external module on the floor to carry out mission

Figure 8 – There should be a light (red, yellow, or green) in the first column to indicate some state information. However, in this instance, the HUD indicated there was no external temperature information, even though the external module was connected.

During the second iteration, similar incidents were experienced by Firefighters 3 and 4. The external module fell off the Level-A hazmat suit while Firefighter 4 was putting on his suit and twice during the operation. Firefighter 3 experienced a red body temperature state but reported feeling fine (see Figure 9).

Figure 9 – HUD indicates elevated core body temperatures

Participants were unable to use the supplied software (HUD Downloader and HUD Viewer) for post-mission analysis. While on-site, the Thermal HUD was not being detected by the computer and software via USB connection. It was later determined that the necessary computer device drivers were not installed. The drivers were supplied by the manufacturer on the CD that came with the prototypes. The drivers were successfully installed and relevant test data was downloaded after the OFA was completed.

3 Data Analysis

This section includes data collection methods, forms, and methods of analysis. Data was collected using the surveys below as well as notes taken by the data collector and test director.

3.1 Phase 1 – Inspection and Review Checklist

A checklist was created to verify that corrective changes documented in the *Statement of Work (SOW) Extension & Funding Request* were appropriately made; however, it was deemed that the checklist was an inappropriate means of verifying and discussing the changes made. Instead, Table 2 below presents a summary indication of whether corrective actions were met. The full results with explanations can be found in Section 4.

Table 2 – Summary Results of SOW Verification

	Tasks	Result
1	Reduce the latency of the external temperature sensor alarm	**Corrective action was taken**
2	Reduce the latency of the internal temperature sensor alarm	**Corrective action was taken**
3	Fix the firmware to ensure audible alerts are issued every 10 seconds on red body temperature alarms	**Corrective action was taken**
4	Improve the correlation of the body temperature sensor measurements with oral temperature readings	**Corrective action was taken; further verification is required**
5	Conformal coat the internal HUD module sensor circuit card assembly	**Corrective action was taken**
6	Revise the external temperature alarm thresholds to match the hazmat suit's environmental specifications	**No action was taken, with good cause**
7	Increase the magnetic clamping force between the internal and external HUD modules	**Corrective action was taken, but it is still insufficient**
8	Improve the HUD Downloader application	**Corrective action was taken**
9	Improve the HUD Viewer data analysis application	**Corrective action was taken**
10	Improve overall HUD reliability	**Unknown**

3.2 Phase 2 – Operational Suitability Survey

Each participant was asked to complete a survey after conducting the operational scenarios. The Operational Suitability Survey was written in the form of a Likert scale. Some questions were written in the affirmative and others in the negative. Negative statements were identified and normalized. All responses were then converted into a numerical score from 1 to 5 and an average was computed for each participant and the participants as a whole.

The following table illustrates the process described above:

Table 3 – Operational Scenario Survey Example Sheet

	Post-Mission	Strongly Agreed	Agreed	Neutral	Disagreed	Strongly Disagreed
1	The Thermal HUD posed no problem when removing my chemical protective clothing			**X**		
2	It was easy to remove the Thermal HUD and fabric fastener from my visor					**X**
3	Downloading data from the Thermal HUD was easy	**X**				
4	Using the HUD Viewer software is difficult				**X**	
5	The HUD Viewer interface made it easy for me to understand my temperature profile during the mission		**X**			
6	Storing the Thermal HUD and its accessories for later use was difficult				**X**	

We used the following scale:

1 = Strongly Disagreed
2 = Disagreed
3 = Neutral
4 = Agreed
5 = Strongly Agreed

Questions 4 and 6 were written in the negative, so we will reverse the scaling scheme for them (Strongly Disagreed = 5 and Strongly Agreed = 1). Doing so will create a uniform scale where a higher score indicates a more positive response/reaction to the product. In this example, Table 4 shows the raw score for each question, the converted score, and the average rating.

Table 4 – Operational Scenario Survey Example Score Table

Question	Raw Score	Converted Score
1	3	3
2	1	1
3	5	5
4	2	4
5	4	4
6	2	4
Average Score		3.5

In the survey provided to participants (see Appendix A) questions 9, 10, and 23 were written in the negative form and required conversions. It should also be noted that questions 20, 21, and 22 were not answered by participants or left as "not applicable" because they referred to the HUD software, which participants did not have an opportunity to use. Hazmat Battalion Chief Bergamini did not answer all questions in the survey because he did not don the HUD and run through the scenario in the same role as the other participants.

3.3 Phase 2 – Operational Suitability Debrief

After completing the mission and survey, members of the FDNY hazmat team were debriefed in a more informal method. The test director and program manager led a conversation to gain a better understanding of the suitability of the Thermal HUD, deficiencies, efficiencies, and possible improvements. Responses were recorded and are summarized in Section 4.

4 Results

This section discusses the results of testing. It includes observations made by participants and the test team, feedback from participants about the system's operational suitability, documentation provided by the vendor, and an analysis of the how the system complied to the requirements. The results of this section are not an endorsement or rejection of the product or vendor. The goal is to provide an objective understanding of how first responders interacted with the system, ways to improve the system, and other means of filling the capability gap.

4.1 Phase 1 – Inspection and Review Results

On February 5, 2013, the *Statement of Work (SOW) Extension & Funding Request* was approved and awarded to Ultra Electronics – USSI. This document highlighted several corrective tasks that S&T as well as Ultra Electronics – USSI thought might lead to an overall better and more reliable product. This section discusses what those tasks were and what was done about them in an effort to provide a better product. The bold face font sections below identify the solutions proposed by Ultra Electronics – USSI Inc. in the *Statement of Work (SOW) Extension & Funding Request.*

Task 1

<u>Reduce the latency of the external temperature sensor alarm</u> – Ultra Electronics – USSI has determined that the thermal mass under the actual temperature sensor prevents timely alarms. To correct this, the vendor has procured replacement sensors that will now be mounted on the <u>outside</u> of this module. The sensor will be mounted in a "pocket" in the front of the housing (where the metal rivet is currently) but will be fully below the plane of the housing's surface to protect it from damage. We may also change the averaging algorithm in the system's firmware to further reduce the latency of the sensor alarm.

The submitted documentation accurately reflects these changes. The following response was submitted by the vendor:

"The external sensor time constant now sits at 6.7 minutes, an improvement over the original 10.5 minutes. This was accomplished by moving the sensing element from the internal printed circuit board (PCB) to a small copper plate on the outside surface of the unit. Taking steps to thermally decouple the copper plate from the plastic enclosure may result in additional reduction of the system's response time."

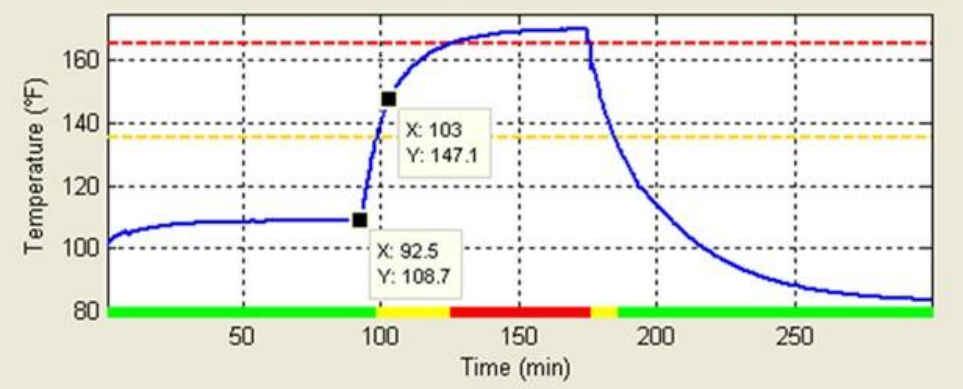


Figure 10 – Original configuration, external sensor: T= 10.5 minutes

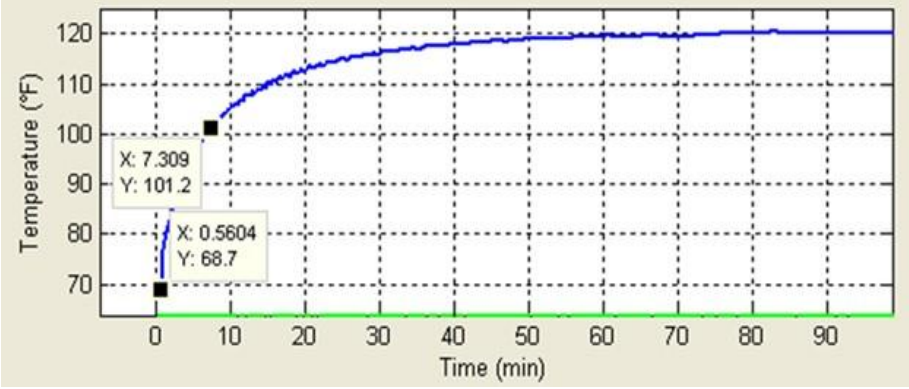


Figure 11 – Revised configuration, external sensor: T= 6.7 minutes

Task 2

<u>"Reduce the latency of the internal temperature sensor alarm</u> – Ultra Electronics – USSI will add additional holes/slots in the Internal HUD module housing to promote more airflow past the internal temperature and humidity sensors."

An inspection of the prototype reflects these changes. Additional openings were milled into the enclosure on the side and back, in addition to the five existing ones in the corner where the internal temperature sensor is located. Documentation shows that the time constant of the internal sensor was reduced from 10.5 minutes to 9.5 minutes. The following response was submitted by the vendor:

"The time constant of the suit internal temperature sensor is currently 9.5 minutes (63.2 percent response). This is only slightly improved from the original 10.5 minutes. The changes involved milling additional openings in the enclosure to encourage better airflow around the sensor. The relatively large thermal mass of the circuit board and the tight thermal coupling of the internal sensor to that assembly appear to be dominating the sensor response. Well-placed slots in the board around the sensor should help future versions to respond much more rapidly."

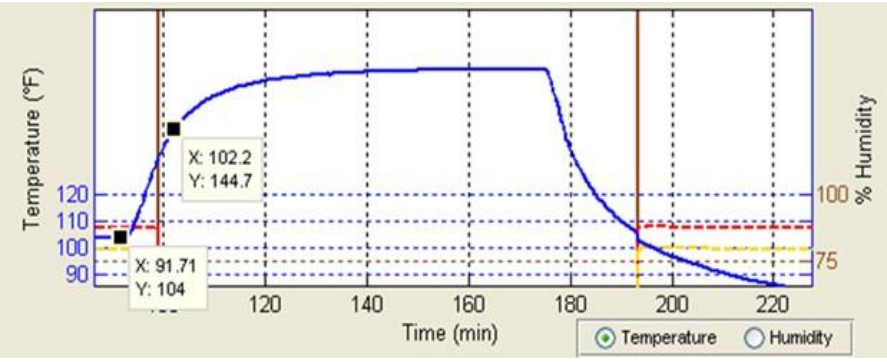


Figure 12 – Revised configuration, external sensor: T= 10.5 minutes

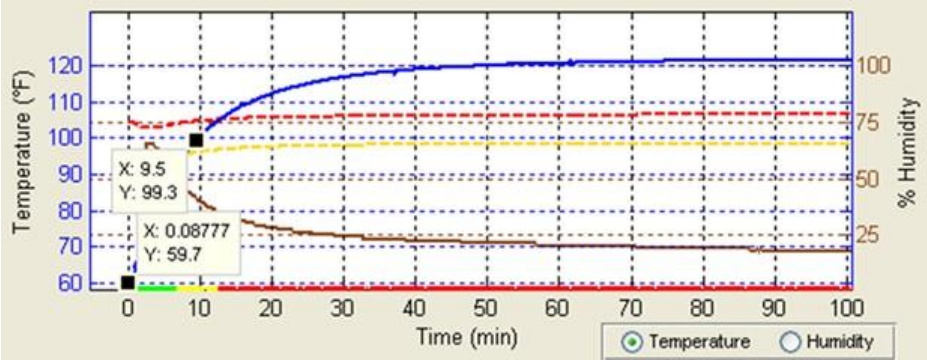


Figure 13 – Revised configuration, internal sensor: T= 9.5 minutes

Task 3

"Fix the firmware to ensure audible alerts are issued every 10 seconds on red body temperature alarms – Logikos is being tasked to make this change."

The following response was submitted by the vendor:

"The firmware was revised to ensure that audible alerts (for RED status only) are issued approximately every 10 seconds. Ultra Electronics – USSI decided we did not want to disturb the user with similar alarms for External and Internal RED status, as we believe the Body Temperature is the most critical to continue to issue such alarms."

This fix was verified during the OFA when participants exceeded the red threshold for body temperature.

Task 4

Improve the correlation of the body temperature sensor measurements with oral temperature readings – Ultra Electronics – USSI will conduct experiments to determine the offsets between oral temperature and body temperature sensor measurements on a number of people; they will then have Logikos update the firmware to better match to the user's true core temperature.

The following response was submitted by the vendor:

"A number of experiments were used to offset the Body Temperature Sensor (BTS) to approximate core temperature: Ultra Electronics – USSI staff wore the BTS, installed per the HUD User Manual, and monitored their temperatures using both Forehead and Oral measurements. The body temperature offset was determined to be +4.2 degrees F. This was based on temperature trials on three individuals. **NOTE**: The Body Temperature Sensor (BTS) does *not* provide the User's true core temperature, even after applying the offset, although it is designed to approximate it."

Operational testing found that participants were unable to accurately gauge the relationship between the body temperature sensor readings and their core body temperature. Several users were reported to have elevated core temperatures in excess of 102 F, according to the HUD, while they reported feeling completely fine. Further testing would be required to verify the correlation between the body temperature sensor and core body temperatures, particularly at high temperatures and when participants are exerting themselves. Further training might also provide participants with a better indication of the relationship between their core body temperature and physical symptoms.

Task 5

Conformal coat the Internal HUD module sensor circuit card assembly (CCA) – This will prevent condensing environments inside the Level-A hazmat suit from shorting out the sensor circuitry in the HUD, which is not sealed from the suit's environment. We may also conformal coat the other CCAs in the internal HUD module for improved reliability as well.

The following response was submitted by the vendor:

"Only the Sensor CCA was conformally coated during the assembly process. Ultra Electronics – USSI used an assembly checklist to remind the engineers responsible for HUD assembly to do so."

Task 6

Revise the external temperature alarm thresholds to match the hazmat suit's environmental specifications – Ultra Electronics – USSI will review the hazmat suit material specifications and set new alarm thresholds in the system firmware.

Ultra Electronics – USSI looked for published data on hazmat suit maximum temperatures, but did not find anything other than "recommended" temperatures. These vary among the different Level-A hazmat suit manufacturers, so Ultra Electronics – USSI decided to stay with the alarm temperatures published in the User Manual.

Task 7

Increase the magnetic clamping force between the internal and external HUD modules – During recent test, Ultra Electronics – USSI noted that the clamping force between these two modules seems weaker than expected. Ultra Electronics – USSI is replacing the magnets in the external temperature sensor module with the stronger units used in the internal HUD module.

The following response was submitted by the vendor:

"The magnetic clamping force was increased to 6.3 lb from 2.0 lb. The ETS [external temperature sensor] is now *very firmly* clamped to the Internal HUD module when installed."

Though the magnetic clamping force was increased, the team learned during the OFA that it was insufficient. The FDNY uses a Trellchem suit that contains two visor layers as opposed to the more common single-layer visor for which the mechanism was designed for. The external module had fallen off several times.

Task 8

Improve the HUD Downloader application – Ultra Electronics – USSI will task Logikos to add more identifying information to the downloaded HUD data files, such as date, time, event/location, and user name.

Features were added to the HUD Downloader application to add identifying information to the file (see Figure 14).

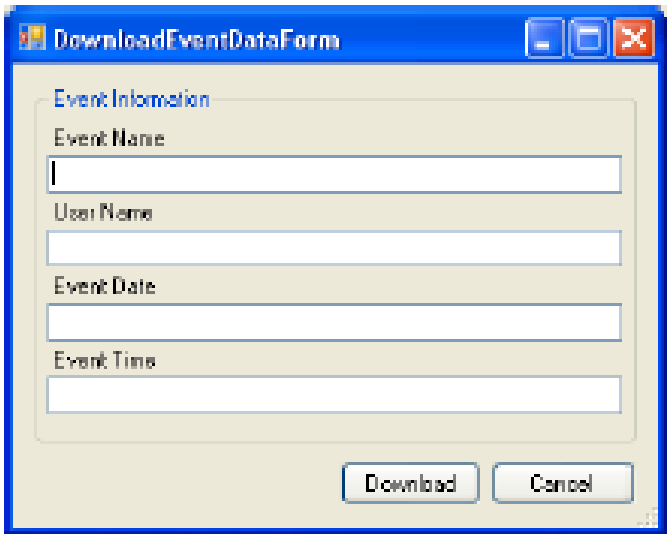


Figure 14 – Ability to add identifying information to saved files

Task 9

<u>Improve the HUD Viewer data analysis application</u> – Ultra Electronics – USSI will incorporate the additional identifying information from the HUD Downloader application into the output data screen to provide basic correlation of the graphical temperature and humidity data from the HUD to a specific hazmat event. This will help S&T and Ultra Electronics – USSI gather critical feedback on HUD performance, which will be used to improve the Thermal HUD.

It has been verified that features have been added to the HUD Viewer software that correlate identifying information from the HUD Downloader.

Task 10

<u>Improve overall HUD reliability</u> – Ultra Electronics – USSI will conduct additional HUD lab testing to identify failure modes and affect the necessary corrective action prior to shipping the Thermal HUD prototypes to S&T for user testing to ensure they perform as advertised.

The Thermal HUDs performed as expected with the exception of a few anomalies. These include the display of inaccurate information (see Figure 8). No complete failure of the system occurred at any point during testing.

4.2 Phase 2 – Operational Suitability Survey Results

A summary of results of the participants' responses to the survey can be seen in Table 5; the full responses can be found in Appendix A.

Table 5 – Summary Results of the Operational Suitability Survey

	Results Summary				
	Strongly Agreed	Agreed	Neutral	Disagreed	Strongly Disagreed
	Firefighter 1				
Raw Score	0	14	3	3	0
Corrected Score	0	14	3	3	0
Average	**3.55**				
	Firefighter 2				
Raw Score	3	10	3	4	0
Corrected Score	3	13	3	1	0
Average	**3.9**				
	Firefighter 3				
Raw Score	5	10	4	1	0
Corrected Score	4	9	4	2	1
Average	**3.65**				
	Firefighter 4				
Raw Score	13	0	4	2	2
Corrected Score	15	0	4	2	0
Average	**4.55**				
	Battalion Chief				
Raw Score	3	3	0	4	1
Corrected Score	5	3	0	4	0
Average	**4.5**				

As noted in Section 2, questions regarding the operation of HUD software for post-mission analysis were omitted from the analysis of results as participants did not have the ability to interact with the software. It should also be noted that the battalion chief only answered 11 questions that were applicable based on his role and experience with the system. Based on the survey results, the system received a positive response. The total average of all participants based on this survey was **4.03 out of 5.**

4.3 Phase 2 – Operational Suitability Debrief Results

After both iterations of the operational scenario were completed, the participants, including the battalion chief, were debriefed to gather their feedback. The conversation was informal to evoke more of a conversation, but several questions were asked to help gather responses. Here are a few examples of the questions asked:

- What did you like about the Thermal HUD?
- What did you not like about the Thermal HUD?

- What changes would you make to it?
- What would you pay for this device?
- Would you buy these for your team?
- Is it something that you would actively use if equipped with it?
- How did it affect your ability to complete this task?
- Do you foresee any issues using the Thermal HUD for other tasks or missions?

The participants provided detailed and constructive feedback that can be used to refine the prototype and/or reexamine the original requirements. Two suggestions that became resonating themes during discussions focused on:

1. An ability to have information transmitted to an incident commander
2. An ability to have a greater emphasis placed on the core body temperature

Participants unanimously agreed that when conducting missions, they will always elect to stay and attempt to work past elevated heat levels or fatigue. The information would realistically serve only as user knowledge and likely not affect user decision-making unless transmitted to an incident commander or to emergency medical services monitors.

Participants also stated that the body core temperature was the critical value of importance to them. Consensus was that the external temperature is not significant and Level-A hazmat suits would not be worn in a fire-hazard environment. Based on their experience with the device, participants felt that they did not trust the accuracy of the system as it had indicated elevated body core temperatures when they reported feeling fine. It is important to note that this user perception was not corroborated with additional testing. This disconnect could be bridged with both training and additional testing. Another point is that the device is designed to warn users before they feel the symptoms of heat exhaustion, so the disconnect between alarm thresholds could be an affirmation of its intended design; only further testing can confirm this. One participant suggested that including a heart rate or pulse monitor would be beneficial because the heart rate is a tangible number that responders are more familiar with and can relate back to their levels of physical exertion.

Another point that came out during the debrief discussion was that the pairing of multiple devices creates an issue, particularly with the body temperature sensor. Participants noted that the device was not clamped on strongly enough, and in real-life situations, they would opt to just leave the external module on the floor. The battalion chief pointed out that the body temperature sensor or charger did not provide any indication of the battery charge level.

4.4 Requirements Compliance

The operational requirements inform the vendor on how to design a tool to fulfill the identified capability gap. In addition, these requirements inform the vendor on how the OFA is designed to ensure that the system receives matches with what is desired and described. Table 6 displays the requirements and to what extent the provided prototype complied with them.

Table 6 – Requirements Compliance Matrix

Capability/Description	Threshold	Objective	Results
Simple Operation	The system shall not require any pre-deployment equipment (e.g., antennas, reference nodes).	The system shall operate transparently until an alert is signaled.	**Threshold: Passed** **Objective: Passed** No operational pre-deployment equipment is required. The system operates transparently until a sufficient change in state occurs.
Monitoring Capability		The system shall be able to effectively monitor the internal body[2] temperature and external temperature surrounding a Level-A firefighter's suit, as well as the rate of rising ambient (external) temperatures.	**Threshold: N/A** **Objective: Failed** The system did not effectively monitor external temperatures. This gauge experienced different types of issues and failures during operation.
Display		The information regarding temperature levels and alerts shall be shown on a HUD that is compatible with current SCBA face piece technologies and that can be easily read by firefighters while conducting operations.	**Threshold: Passed** **Objective: Passed** The HUD was designed to be SCBA face-piece-agnostic. So though not directly compatible with SCBA face piece technologies, the Thermal HUD does not interfere with them.
Interoperability		The system shall be interoperable with existing environmental sensors and be able to transmit sensor data and warning signals (based upon pre-determined danger levels) to appropriate parties.	**Threshold: N/A** **Objective: Failed** The system is not interoperable with existing environmental sensors. The system does not have the ability to transmit data and warning signals *in real time* to the appropriate parties.

[2] The capability to monitor body temperature was not part of the original ORD but was added later.

Capability/Description	Threshold	Objective	Results
Compatibility with Existing Personal Protective Equipment		The system shall be compatible with and be able to be worn on existing firefighter personal protective equipment. The system shall not compromise the chemical protective nature, from liquids and gases, provided by a Level-A hazmat suit.	**Threshold: N/A** **Objective: Passed** The system does not compromise the chemical protective nature of Level-A suits. The system can be worn on existing firefighter personal protective equipment.
Durability		The system shall be able to operate under varying circumstances—including differing building sizes with varying wall thickness and differing team sizes—and have the ability to withstand high temperatures.	**Threshold: N/A** **Objective: Passed** The system is able to operate in different building sizes, with varying wall thicknesses, and with differing team sizes. The system is also able to withstand high temperatures.
Temperature Trigger Alerts		The system shall have a baseline temperature trigger alert established at 300 degrees Fahrenheit for ambient (external) temperature and 100 degrees Fahrenheit for internal (inside the gear) temperature.	**Threshold: N/A** **Objective: Passed** The baseline temperature trigger alerts were altered from the original requirements. The consistency of the system's ability to alert at the correct temperatures was not isolated and tested.

5 References

- *Internal/External Temperature Heads-Up Display Operational Requirements Document* (DHS S&T, June 2011)
- *Project Plan/Statement of Work for Internal/External Temperature Heads-Up Display* (Ultra Electronics – USSI, November 2011)
- *Statement of Work (SOW) Extension & Funding Request* (Ultra Electronics – USSI, February 2013)
- *Operation Manual, DHS HUD* (Ultra Electronics – USSI, February 2013)
- *Operational Field Assessment Plan for the Internal/External Temperature Heads-Up Display (HUD)* (DHS S&T, February 2013)

Please contact Bhargav.patel@hq.dhs.gov or Christine.lee@hq.dhs.gov for access to these documents.

6 Acronym List

CPC	Chemical Protective Clothing
DHS	Department of Homeland Security
FDNY	New York City Fire Department
FRG	First Responders Group
HUD	Heads-Up Display
NUSTL	National Urban Security Technology Laboratory
OFA	Operational Field Assessment
ORD	Operational Requirements Document
PPE	Personal Protective Equipment
S&T	Science and Technology Directorate
SCBA	Self-Contained Breathing Apparatus
SOW	Statement of Work

Appendix A – Operational Suitability Survey Results

Firefighter 1						
	Questions/Response	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
	Pre-Mission					
1	I read and understood the Operational Field Assessment Plan before this exercise began		**1**			
2	I read and understood the technical manual for the Thermal HUD before this exercise began		**1**			
3	I had a thorough understanding of the Thermal HUD works before this exercise began		**1**			
4	The ancillary equipment is easy to operate, manage and store		**1**			
5	Operating the Thermal HUD was easy and intuitive		**1**			
6	Performing system checks on the prototype under test was easy to do			**1**		
	Mission Execution					
7	I had no trouble attaching the Internal Module to the visor of my Level-A Suit		**1**			
8	Donning the Thermal System did not interfere with functioning or donning of my other PPE		**1**			
9	The Thermal HUD was a visual distraction while attempting to complete my task				**1**	
10	The Thermal HUD required me to constantly interact with it to the point of distraction		**1**			
11	The alarms were noticeable and provided a clear indication of how my environment changed		**1**			

12	The Thermal HUD did not interfere with completing the task in a timely manner				**1**	
13	The Thermal HUD operated transparently until an alert was signaled		**1**			
14	The audible alarm was sufficiently loud enough to get my attention		**1**			
15	The visual indicators were sufficiently bright and visible enough to read		**1**			
16	The display of the Thermal HUD is intuitive				**1**	
17	I am confident in the Thermal HUD's ability to operate in different environments (e.g. different temperatures, indoors, outdoors, varying buildings)			**1**		
	Post-Mission					
18	The thermal HUD posed no problem when removing my CPC		**1**			
19	It was easy to remove the Thermal HUD and fabric fastener from my visor		**1**			
20	Downloading data from the Thermal HUD was easy to do					
21	Using the HUD Viewer software is difficult					
22	The HUD Viewer interface makes it easy for me to understand my temperature profile during the mission					
23	Storing the Thermal HUD and its accessories for later use was difficult			**1**		
Firefighter 2						

	Questions/Response	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
	Pre-Mission					
1	I read and understood the Operational Field Assessment Plan before this exercise began	**1**				
2	I read and understood the technical manual for the Thermal HUD before this exercise began	**1**				
3	I had a thorough understanding of the Thermal HUD works before this exercise began	**1**				
4	The ancillary equipment is easy to operate, manage and store		**1**			
5	Operating the Thermal HUD was easy and intuitive			**1**		
6	Performing system checks on the prototype under test was easy to do		**1**			
	Mission Execution					
7	I had no trouble attaching the Internal Module to the visor of my Level-A Suit		**1**			

8	Donning the Thermal System did not interfere with functioning or donning of my other PPE			**1**		
9	The Thermal HUD was a visual distraction while attempting to complete my task				**1**	
10	The Thermal HUD required me to constantly interact with it to the point of distraction				**1**	
11	The alarms were noticeable and provided a clear indication of how my environment changed				**1**	
12	The Thermal HUD did not interfere with completing the task in a timely manner		**1**			
13	The Thermal HUD operated transparently until an alert was signaled		**1**			
14	The audible alarm was sufficiently loud enough to get my attention		**1**			
15	The visual indicators were sufficiently bright and visible enough to read		**1**			
16	The display of the Thermal HUD is intuitive		**1**			
17	I am confident in the Thermal HUD's ability to operate in different environments (e.g. different temperatures, indoors, outdoors, varying buildings)			**1**		

	Post-Mission					
18	The thermal HUD posed no problem when removing my CPC		**1**			
19	It was easy to remove the Thermal HUD and fabric fastener from my visor		**1**			
20	Downloading data from the Thermal HUD was easy to do					
21	Using the HUD Viewer software is difficult					
22	The HUD Viewer interface makes it easy for me to understand my temperature profile during the mission					
23	Storing the Thermal HUD and its accessories for later use was difficult				**1**	

Firefighter 3						
	Questions/Response	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
	Pre-Mission					

1	I read and understood the Operational Field Assessment Plan before this exercise began	**1**				
2	I read and understood the technical manual for the Thermal HUD before this exercise began	**1**				
3	I had a thorough understanding of the Thermal HUD works before this exercise began	**1**				
4	The ancillary equipment is easy to operate, manage and store				**1**	
5	Operating the Thermal HUD was easy and intuitive	**1**				
6	Performing system checks on the prototype under test was easy to do	**1**				
	Mission Execution					
7	I had no trouble attaching the Internal Module to the visor of my Level-A Suit			**1**		
8	Donning the Thermal System did not interfere with functioning or donning of my other PPE	**1**				
9	The Thermal HUD was a visual distraction while attempting to complete my task	**1**				**1**

10	The Thermal HUD required me to constantly interact with it to the point of distraction			**1**		
11	The alarms were noticeable and provided a clear indication of how my environment changed	**1**				
12	The Thermal HUD did not interfere with completing the task in a timely manner			**1**		
13	The Thermal HUD operated transparently until an alert was signaled	**1**				
14	The audible alarm was sufficiently loud enough to get my attention			**1**		
15	The visual indicators were sufficiently bright and visible enough to read	**1**				
16	The display of the Thermal HUD is intuitive	**1**				
17	I am confident in the Thermal HUD's ability to operate in different environments (e.g. different temperatures, indoors, outdoors, varying buildings)				**1**	
	Post-Mission					
18	The thermal HUD posed no problem when removing my CPC	**1**				

19	It was easy to remove the Thermal HUD and fabric fastener from my visor	**1**				
20	Downloading data from the Thermal HUD was easy to do					
21	Using the HUD Viewer software is difficult					
22	The HUD Viewer interface makes it easy for me to understand my temperature profile during the mission					
23	Storing the Thermal HUD and its accessories for later use was difficult					**1**

Firefighter 4						
	Questions/Response	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
	Pre-Mission					
1	I read and understood the Operational Field Assessment Plan before this exercise began	**1**				
2	I read and understood the technical manual for the Thermal HUD before this exercise began	**1**				

3	I had a thorough understanding of the Thermal HUD works before this exercise began	**1**				
4	The ancillary equipment is easy to operate, manage and store			**1**		
5	Operating the Thermal HUD was easy and intuitive		**1**			
6	Performing system checks on the prototype under test was easy to do			**1**		
	Mission Execution					
7	I had no trouble attaching the Internal Module to the visor of my Level-A Suit		**1**			
8	Donning the Thermal System did not interfere with functioning or donning of my other PPE		**1**			
9	The Thermal HUD was a visual distraction while attempting to complete my task			**1**		
10	The Thermal HUD required me to constantly interact with it to the point of distraction	**1**				
11	The alarms were noticeable and provided a clear indication of how my environment changed	**1**				

12	The Thermal HUD did not interfere with completing the task in a timely manner				**1**	
13	The Thermal HUD operated transparently until an alert was signaled		**1**			
14	The audible alarm was sufficiently loud enough to get my attention		**1**			
15	The visual indicators were sufficiently bright and visible enough to read		**1**			
16	The display of the Thermal HUD is intuitive			**1**		
17	I am confident in the Thermal HUD's ability to operate in different environments (e.g. different temperatures, indoors, outdoors, varying buildings)		**1**			
	Post-Mission					
18	The thermal HUD posed no problem when removing my CPC		**1**			
19	It was easy to remove the Thermal HUD and fabric fastener from my visor		**1**			
20	Downloading data from the Thermal HUD was easy to do					

21	Using the HUD Viewer software is difficult					
22	The HUD Viewer interface makes it easy for me to understand my temperature profile during the mission					
23	Storing the Thermal HUD and its accessories for later use was difficult		**1**			

Battalion Chief						
	Questions/Response	**Strongly Agree**	**Agree**	**Neutral**	**Disagree**	**Strongly Disagree**
	Pre-Mission					
1	I read and understood the Operational Field Assessment Plan before this exercise began	**1**				
2	I read and understood the technical manual for the Thermal HUD before this exercise began	**1**				
3	I had a thorough understanding of the Thermal HUD works before this exercise began	**1**				
4	The ancillary equipment is easy to operate, manage and store				**1**	

5	Operating the Thermal HUD was easy and intuitive		**1**			
6	Performing system checks on the prototype under test was easy to do				**1**	
	Mission Execution					
7	I had no trouble attaching the Internal Module to the visor of my Level-A Suit					
8	Donning the Thermal System did not interfere with functioning or donning of my other PPE					
9	The Thermal HUD was a visual distraction while attempting to complete my task					**1**
10	The Thermal HUD required me to constantly interact with it to the point of distraction					
11	The alarms were noticeable and provided a clear indication of how my environment changed					
12	The Thermal HUD did not interfere with completing the task in a timely manner				**1**	
13	The Thermal HUD operated transparently until an alert was signaled					

14	The audible alarm was sufficiently loud enough to get my attention					
15	The visual indicators were sufficiently bright and visible enough to read					
16	The display of the Thermal HUD is intuitive		**1**			
17	I am confident in the Thermal HUD's ability to operate in different environments (e.g. different temperatures, indoors, outdoors, varying buildings)				**1**	
	Post-Mission					
18	The thermal HUD posed no problem when removing my CPC		**1**			
19	It was easy to remove the Thermal HUD and fabric fastener from my visor					
20	Downloading data from the Thermal HUD was easy to do					
21	Using the HUD Viewer software is difficult					
22	The HUD Viewer interface makes it easy for me to understand my temperature profile during the mission					

23	Storing the Thermal HUD and its accessories for later use was difficult					