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M. K. Donnelly
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Building and Fire Research Laboratory
建物與消防研究實驗室

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U.S. Department of Commerce
Carlos M. Gutierrez, Secretary
美國商務部
部長Carlos M. Gutierrez

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技術管理
技術副部長Robert Cresanti

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ABSTRACT

摘要

Handheld portable radios are one of the critical electronic devices that firefighters and other first responders use during emergency response. These radios must operate in severe environmental conditions while maintaining acceptable radio communication. This paper focuses on the thermal environment that radios would be expected to withstand while being used in building firefighting operations. The thermal classes for electronic equipment defined in an earlier paper (Donnelly, *et al*, 2006) are applied to investigate the performance of emergency responder radios. Current National Fire Protection Association (NFPA) standards for radios are reviewed and recommendations for establishing performance standards are presented. The need for providing additional protection from the thermal environment is documented.

在緊急應變情境下，手持可攜式無線電對消防員及其他初期緊急應變人員來說是相當重要的電子裝置。無線電必須要在嚴峻環境條件下運作，而且還要保持可接受的無線電通訊功能。本文側重於無線電用於建物消防任務時可能會遭遇到的溫度環境。我們使用電子設備熱等級相關文獻（Donnelly, *et al*, 2006）研究緊急應變人員所用無線電之性能。我們在本文中檢視美國消防協會（NFPA）目前針對無線電的標準，並提出建立性能標準建議。我們亦針對在溫度環境下提供額外防護措施之需求做成文件。

INTRODUCTION
引言

The National Fire Protection Association (NFPA) standards for portable radios and other two-way mobile communication equipment are not specific as to temperature, heat flux and other environmental conditions. The devices are included in the NFPA 1221 standard for Installation, Maintenance and Use of Emergency Services Communications Systems (NFPA 1221, 2002 Ed.). Sections 8.3.5 and 8.3.6 summarize general equipment usage. The only requirements pertaining to the fire environment are section 8.3.5.4, which states "Mobile radios and associated equipment shall be manufactured for the environment in which they are to be used", and section 8.3.6.2 which states "Portable radios shall be manufactured for the environment in which they are to be used and shall be of a size and construction to allow their operation with the use of one hand." The NFPA standard is not specific with regards to the details of the "environment" in which the radios are to be used. No testing procedures or performance criteria are outlined.
美國消防協會（NFPA）針對無線電與其他雙向行動通訊設備的標準對於溫度、熱流與其他環境條件並無著墨。這些裝置包含在NFPA 1221標準下的緊急服務通訊系統之安裝、維護與使用（NFPA 1221，2002年版）內。第8.3.5與8.3.6內容為一般設備使用做結。唯一與消防環境有關的僅有第8.3.5.4節，其內文寫道：「製造移動式無線電與相關設備時應考量其使用環境」，以及第8.3.6.2，其內文寫道：「製造可攜式無線電與相關設備時應考量其使用環境，且其大小與結構應適合單手操作。」NFPA標準對無線電的使用「環境」的細節不夠精確。NFPA標準對測試程序或性能標準也毫無描述。

This paper applies the Thermal Classes, see Table 1, that were developed in an earlier study (Donnelly, *et al*, 2006) to define the environment and performance criteria for portable handheld radios. Radios currently in use by firefighters were tested using the Fire Equipment Evaluator (FEE) to determine their current capability to withstand conditions as severe as Thermal Class III. The results will be used to develop test methods and recommendations that will be submitted to NFPA 1221 for standards development for portable radios.
本文使用之熱等級（見表1）係由Donnelly, *et al*, 2006於研究中提出，用來定義環境與可攜式手持無線電性能標準。消防員目前使用無線電都經過消防設備評估器（FEE）測試，以決定其耐受條件（最嚴峻條件為等級III）的能力。測試結果可用來開發測試方法與建議，並提交給NFPA 1221做為開發可攜式無線電標準之用。

Table 1 Thermal Classes
表1 熱等級

Thermal Class 熱等級	Maximum Time (min) 最長時間（分鐘）	Maximum Temperature (℃)/(℉) 最高溫度（℃）/（℉）	Maximum Flux (kW/m^2) 最大流量（kW/m^2）
I	25	100/212	1
II	15	160/320	2
III	5	260/500	10
IV	<1	>260/500	>10

Radio Testing

無線電測試

Three models of radios from three different manufacturers were selected for this study. They will be identified in this report as Radio A, Radio B and Radio C. The radios were marketed for use by firefighters and other first responders. The radios ranged in price from approximately $800 each to $2500 each. The radios tested for this project were a sampling of the many makes and models that are available to first responders. The selected radios are commonly used and represent a variety of price ranges. The goal of this study was not to compare and rank the performance of individual radios, but rather to evaluate the general performance of portable radios at elevated thermal conditions and to identify shortcomings and suggest standards for the radios.

本研究選用三組製造商提供的三種無線電型號。我們在本報告中用無線電A、B與C指稱這三種無線電。這些無線電專門銷售給消防員及其他初期緊急應變人員使用。價格區間約為800美元到2500美元（每隻）。用於本計畫的測試無線電為目前市面上可買到的初期應變人員用無線電樣本。被選中的無線電皆為常用的型號，涵蓋價格範圍也較廣。本研究目的並非在於比較並評比各無線電的性能，而是評估可攜式無線電在高溫條件下的整體性能，並找出缺點，為無線電標準提出建議。

All of the radios tested for this investigation listed their maximum operating temperatures at 60 ℃ (140 ℉). The frequency stability for the radio signal was guaranteed to 60 ℃ (140 ℉) as well. The radios, however, are marketed to and used by firefighters in firefighting situations, so it is reasonable to expect that they may be used at temperatures above 60 ℃ (140 ℉).
本研究中所有受測無線電的登記最高操作溫度為60 ℃ (140 ℉)。無線電信號頻率穩定性的表定保證溫度也是60 ℃ (140 ℉)。但這些無線電其實是要販售給消防員於消防現場使用，因此我們預期的合理使用溫度是高於60 ℃ (140 ℉)的。

Firefighters routinely spend time at temperatures up to 100 ℃ (212℉), and often encounter much higher temperatures such as the peak conditions of Thermal Class III. Radio operation may be most crucial when the firefighter is experiencing an emergency situation, possibly trapped at elevated temperatures, and the radio would be instrumental in calling for assistance. As shown in Table 1, which lists the thermal classes, electronic equipment should be able to withstand a minimum of 100 ℃ (212℉) for up to 25 minutes in order to survive Thermal Class I conditions while Thermal Class III conditions would require the electronic equipment to survive 260 ℃ (500 ℉) for five minutes.
消防員固定會在溫度達100 ℃ (212℉)的場所工作，有時還會面臨到更高的溫度（如熱等級III的極端條件）。當消防員面臨緊急情況（如被困在高溫電梯）時，無線電操作便至關重要，因為無線電可用來請求支援。如熱等級表1所示，要通過熱等級I條件，電子設備的最低耐熱度為100 ℃ (212℉)，持續時間為25分鐘，而熱等級III的條件則為耐熱度為260 ℃ (500 ℉)，持續時間為5分鐘。

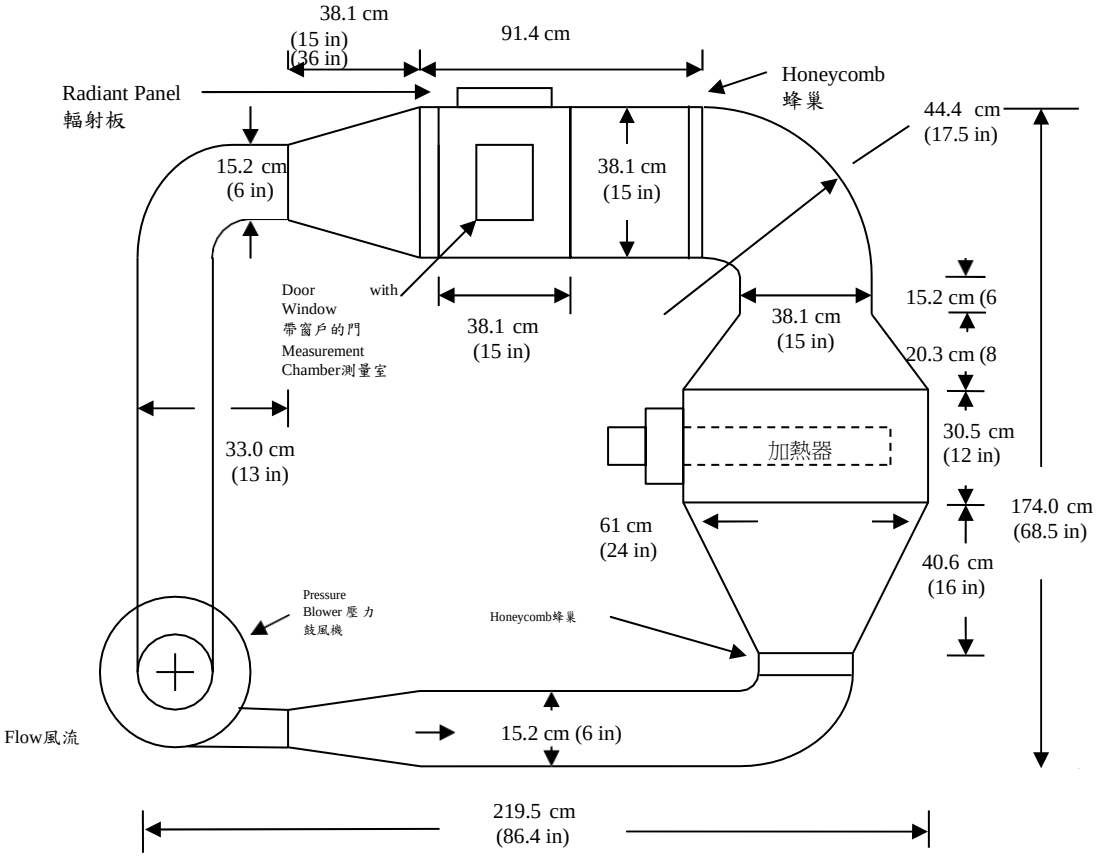


Figure 1 Diagram of Fire Equipment Evaluator (FEE)

圖 1 消 防 設 備 評 估 器 （ FEE ） 圖

Testing Procedures

測試程序

Testing of the radios was performed using the Fire Equipment Evaluator (FEE). The FEE is a closed-loop, recirculating wind tunnel designed to simulate thermal conditions up to Thermal Class III. A diagram of the FEE is shown in Figure 1. It consists of a stainless steel enclosed, fan driven, air flow loop 219.5 cm (86.4 in) long by 174 cm (68.5 in) high. The testing section is 910 mm (36 in) long with a cross section of 380 mm^2 (15 in^2). It is capable of reaching temperatures up to 300 ℃ (572 ℉) and velocities from 0.5 m/s to 2.0 m/s. Temperature measurements inside the FEE were made using type K (Chromel-Alumel) thermocouples, each with a bead diameter of 1.0 mm ± 0.2mm. A bidirectional probe was used for the velocity measurement. Details of the FEE can be found in Donnelly, *et al*, 2006.

我們使用消防設備評估器（FEE）來測試無線電。FEE為一封閉迴路、再循環風洞，可以模擬熱等級III的熱條件。圖一即為FEE。FEE由長219.5 cm（86.4 in）、高174 cm（68.5 in）的氣流迴路，兩端由不銹鋼封口，氣流由風扇製造。測試段長度為910 mm（36 in），橫截面面積為380 mm^2（15 in^2）。FEE的最高溫度可達300 ℃（572 ℉），風速範圍為0.5 m/s至2.0 m/s。我們使用K型（鎳鉻-鎳鋁）熱電偶測量FEE溫度，珠直徑為1.0 mm ± 0.2mm。我們使用雙向探針測量風速。讀者可在Donnelly, *et al*, 2006中查詢FEE細節。

For the elevated temperature tests, the radio was placed into the test tunnel at ambient temperature, subjected to a heat-up time reaching the target temperature for the particular thermal class and then maintained at this temperature for the time period specified for that thermal class. The radio performance was also monitored during the cool down period. Heating of the radio at constant temperature for a prescribed time period will be referred to as “soak” throughout the remainder of the paper. This would simulate a firefighter entering a structure and encountering progressively higher temperatures before reaching the maximum temperature, performing firefighter tasks at this maximum temperature for a period of time, and then exiting the high temperature region. Actual times encountered by a firefighter would depend on the building geometry and conditions within the building. The heat-up time varied depending on the soak temperature, but was held constant for all tests at the same soak temperature. See Figure 2 for a temperature profile displaying a typical heat-up time for Thermal Class III conditions.

進行高溫測試時，我們將無線電放進測試室溫風洞中，溫度會隨時間上升，直到達到特定熱等級溫度為止，接著我們會按照熱等級上所列的時間維持溫度。我們也會在降溫的時候監測無線電性能。將無線電加熱並維持溫度一段時間的動作稱為「持溫」，以下全用持溫一詞。持溫可以用來模擬消防員進入建築物後，面臨逐步上生高溫，一直到溫度達到最高，接著在最高溫狀況下展開消防作業，接著離開高溫區的情境。消防員實際面對此類情境的次數取決於建築物幾幾何結構及建築物內的條件。加熱時間會隨持溫溫度變化，但會我們在所有測試中都會使用恆定的持溫溫度。圖2為溫度曲線圖，顯示的是熱等級III條件的典型加熱時間。

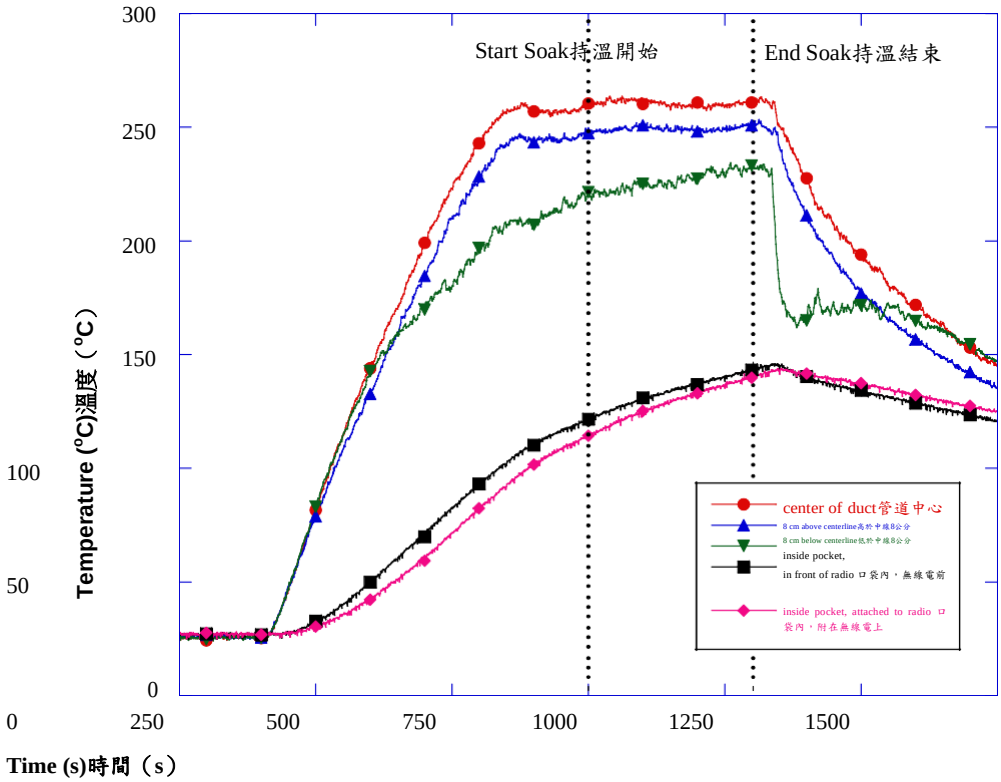


Figure 2 Plot of Temperatures inside and outside of pocket.

圖2　　口袋內外溫度圖

Radios tested inside the FEE were placed in the test section where they were visible through the access door window. The radios were suspended by the radio belt clip from a 50 mm wide Kevlar strap with the front of the radio (speaker and microphone) facing the airflow. They were placed with the long side along the vertical at a height such that the center of the radio was centered, 190 mm from the walls of the test section. The radio hung at a slight angle of approximately 20 degrees from vertical, with the top tilted towards the airflow.
我們將無線電放在FEE測試段內，我們可以進出門口的窗戶看到無線電。我們將無線電懸掛在皮帶扣上，皮帶（克維拉材質）寬度為50 mm，無線電正面（喇叭與麥克風面）朝向氣流。無線電的長邊側延垂直面放置，高度必須使無線電中心居中，須距離測試段牆面190 mm。無線電需微微傾斜，大約與垂直面呈20度角。頂部朝氣流傾斜。

Testing was also performed with the radios protected inside of a turnout gear style pocket. When portable radios are carried into firefighting environments, the radios are often worn clipped close to the body underneath the turnout gear coat, or placed in pockets located on the outside of the turnout gear coat where they are protected from direct heating by the pocket as displayed on a mannequin in Figure 3.
我們也將無線電放在消防衣口袋中進行測試。消防員將可攜式無線電入消防環境時，通常會把無線電貼身緊扣在消防衣內側，或是放在消防衣外部的口袋中，口袋可以保護無線電不受溫度直接破壞，詳情請見圖3。

Figure 3 Radio inside turnout coat pocket with speaker/microphone
圖3 消防衣口袋內無線電（附喇叭與麥克風）

To investigate the operation of these protected radios, a pocket was constructed and used for testing. The pocket was fabricated by a company that produces firefighter turnout gear. It was made from 2.5 x 10^{-2} kg/m^2 (7.5 oz/yd^2) PBI Gold, material that is a blend of 40 % polybenzimidizole and 60 % Kevlar. The pocket measures 100 mm wide by 90 mm deep and is 220 mm tall. It is open at the top for radio insertion, with a flap to cover the top of the radio. Figure 3 shows the pocket suspended from the Kevlar strap inside the FEE. The radio was placed inside the pocket for testing.

為研究受保護無線電的運作，我們設計了一個測試用口袋。口袋由專門生產消防衣的公司製造。口袋由2.5 x 10^{-2} kg/m^2（7.5 oz/yd^2）PBI黃金製成，材料成份為40 %聚苯並咪唑與60 %克維拉。口袋寬度為100 mm，深度為90 mm，高度為220 mm。口袋上方有開口，方便裝入無線電，開口帶覆片，可包住無線店頂部。圖3為即為置於FEE中並以克維拉皮帶懸吊的口袋。我們將無線電放在口袋內進行測試。

Figure 4 Pocket inside FEE for testing. Radio is inside with insulated cable attached. The speaker/microphone cable is the front cable with the aluminum foil at the top while the coax cable connecting the radio output to the spectrum analyzer is the back cable. A thermocouple tree is attached to the ring stand in front of the pocket and the airflow is from the left.

圖4 FEE 內測試用口袋。將無線電放在口袋內，並連接上絕緣纜線。喇叭/麥克風纜線即為前方頂部以鋁箔包住的纜線，而後方的纜線則是將無線電輸出連接到頻譜分析儀的同軸電線。我們將熱電偶樹附在口袋前方的環型架上。氣流來自左側。

For the majority of the tests, the radio antenna was removed and the antenna jack was connected to a coaxial cable leading to a Tektronix RSA3303A Spectrum Analyzer. This permitted the radio transmission signal to be observed and recorded during testing, and degradation of the signal to be identified and measured. The coaxial cable was well insulated to insure that any decrease in the signal was due to heating of the radio, and not to heating of the cable. During the temperature soaks, the transmissions from the radios were tested by keying the "Push to talk" (PTT) button and recording the resulting output signal using the spectrum analyzer. The PTT button on the radio was activated manually through an access hole in the bottom of the tunnel.
For some tests, an external speaker/microphone was connected to the radio and its PTT button was used to trigger the radio. In these cases, the cable to the external speaker/microphone was well insulated. A small number of tests were performed with the radio antenna in place. For tests with the antenna in place, the signal analyzer was not used to measure radio transmission.
我們在大多數測試中將無線電天線移除，用同軸電線插入天線插孔插，連結到Tektronix RSA3303A頻譜分析儀上。如此便可以在測試過程中觀察並記錄無線電發送信號，同時識別與測量信號劣化。同軸電線已經過絕緣處理，以確保信號減弱是由無線電變熱引起，而不是由於電線變熱的緣故。在持溫期間內，我們使用鍵控「按鈕通話（PTT）」鍵來測試無線電發送，並使用頻譜分析儀記錄輸出信號結果。我們透過風洞底部的進出口手動壓按PTT鍵來啟動功能。在進行某些測試時，我們將外部喇叭/麥克風連接到無線電上，並使用PTT鍵觸發無線電。進行這些測試時，連結到外部喇叭/麥克風的纜線都經過絕緣處理。還有少數測試會在無線電天線維持原狀的狀態下進行。這些測試不須使用信號分析儀測量無線電發送。

In addition to the portable radios, thermal exposure testing was also performed on the radio's external speaker/microphones. Firefighters often use external speaker/microphones that are connected to their portable radios by a cord. These external speaker/microphones are usually worn near the firefighter's neck or mouth so that voice may be transmitted easily. This also provides the additional benefit of having a speaker close to the ears so that radio transmissions can be more easily heard. The external speaker/microphone allows the body of the radio to be worn in a harness, coat pocket or otherwise secured, possibly underneath their turnout gear to protect the radio. Often it is only the external speaker/microphone that is exposed to the extreme thermal environment, making this the part most vulnerable to malfunction.
除了可攜式無線電以外，我們也對無線電的外部喇叭/麥克風進行熱暴露測試。消防員常用的外部喇叭/麥克風透過發送線連接到他們的可攜式無線電上。消防員通常會將外部喇叭/麥克風安裝在頸部附近或嘴部，方便語音發送。這樣也可以使喇叭離耳朵較近，方便消防員聽到無線電發送。使用外部喇叭/麥克風可以讓無線電本體受護套、消防衣口袋保護，或是緊貼在消防衣內側。外部喇叭/麥克風通常是直接暴露在極端熱環境下的部位，因此容易故障。

To investigate the possible problems, tests were conducted using the FEE. Each speaker/microphone was placed in the test section, with a cord connecting it to a radio located in ambient conditions outside of the FEE. Each radio was tested with its own proprietary speaker/microphone designed for use with the radio. The cords connecting the speaker/microphones to the radios were not thermally insulated, which provided a realistic test of the speaker/microphone/cord system. The ruggedized version of the speaker/microphone was used when available. The speaker/microphones were suspended from the same Kevlar strap used to support the radios. The strap was lowered so that the center of the speaker was located at the center of the test chamber cross section. The portable radio was located outside of the test chamber, and the cable connecting the radio to the speaker/microphone was well insulated.

Transmission from the speaker/microphones was initiated the same way as it was for the radios, by keying the PTT button on the microphone, using the access hole in the bottom of the tunnel.

為研究可能存在的問題，我們使用FEE進行測試。我們將喇叭/麥克風放在測試段內，並用發送線將喇叭/麥克風連接到無線電上，無線電位於FEE外部，溫度條件為室溫。我們測試了每款無線電的原廠周邊喇叭/麥克風。用來連接喇叭/麥克風與無線電的發送線並未經過絕緣處理，以提供喇叭/麥克風/電線系統真實測試。如果可取得強化版喇叭/麥克風，便使用強化版喇叭/麥克風。我們使用懸吊無線電的克維拉皮帶來懸吊喇叭/麥克風。我們將皮帶放低，讓喇叭/麥克風的重心落於測試室剖面的中心位置。可攜式無線電位於測試室外部，連接無線電與喇叭/麥克風的電線經絕緣處理。我們透過風洞底部進出孔鍵控麥克風上的PTT鍵來啟動喇叭/麥克風發送，和啟動無線電發送的方式一樣。

The radios and speaker/microphones tested were subjected to thermal exposures consistent with the maximum time and temperature for the Thermal Classes shown in Table 1. Testing was performed with the radios both inside a turnout gear pocket and exposed to the airflow. Testing of the external speaker/microphones was conducted with the speaker/microphones exposed to the airflow. Radios and speaker/microphones that did not suffer permanent damage were reused for repeat tests. The majority of the tests were performed at an air flow velocity of 0.9 m/s. This velocity was chosen to represent a typical human walking speed or a flow velocity that might be experienced with Thermal Class III exposure.

受測無線電與喇叭/麥克風的熱暴露最長時間與最高溫度與表1熱等級相符。我們進行兩種測試：無線電在消防衣口袋內測試與無線電暴露在氣流下測試。外部喇叭/麥克風測試條件為喇叭/麥克風暴露在氣流下。受測無線電與喇叭/麥克風在測試後若無出現永久損害，便會接受重覆測試。大多數測試所使用的風速為0.9 m/s，因為這個速度可代表一般人暴露在熱等級III條件下時的行走速度。

RESULTS
結果

Testing with Radio in Turnout Coat Pocket
將無線電放在消防衣口袋內測試

Elevated temperature tests were performed using the FEE with the portable radios placed inside the turnout gear pocket. Two thermocouples were located inside the pocket. One monitored the air temperature directly in front of the radio, and the other was attached to the body of the radio. The pocket was able to provide significant thermal protection to the radio, with the air inside the pocket remaining more than 75 ℃ cooler than the air inside the rest of the tunnel, when the flow rate was 0.9 m/s. Figure 2 is an example of the thermal difference between the pocket air and the tunnel air for a 260 ℃ temperature soak with airflow 0.9 m/s. When the FEE air speed was increased to 2 m/s, the air inside the pocket still remained at least 57 ℃ cooler. The air temperature inside the pocket was continually increasing during the temperature soaks, so the difference between the pocket air temperature and the tunnel temperature was even greater at the start of the soaks.

我們使用FEE進行高溫測試，並將可攜式無線電放在消防衣口袋內。口袋內裝有兩個熱電偶。其中一個用來監測無線電正前方的空氣溫度，另一個則固定在無線電本體上。口袋可提供絕佳熱防護，在風速為0.9 m/s時，口袋內的溫度會比風洞內其他地方的空氣溫度低75 ℃，並可維持溫差。圖2為口袋空氣與風洞空氣的熱差範例圖，持溫溫度為260 ℃，風速為0.9 m/s。將FEE風速上調至2 m/s時，口袋內空氣依然比外部空氣低57 ℃。因為口袋內空氣溫度隨隨持溫時長逐步上升，因此口袋空氣溫度與風洞溫度的熱差在持溫初始時呈最大值。

The test results are listed in Table 2. The protection provided by the turnout gear pocket kept the radio temperatures low enough for the radios to survive even the severity of the class III tests.

Radio A worked well throughout the class II tests and did not have any evident damage. Radio A also received and transmitted during the class III testing, suffering only some slight melting deformation to the outer casing and buttons. Radio B was able to survive all of the temperature soaks attempted during the pocket testing. Transmission and reception of the signals were clear. There was no damage evident to the body of radio B during the pocket tests. Radio C was also able to transmit and receive at the test conditions when located inside the pocket.

Some variations on the basic testing conditions were performed and the results are shown in Table 3. Tests were performed at the Thermal Class III condition using radios A and B with the regular antenna connected, instead of the shielded cable connected to the analyzer. The antenna was sticking up out of the pocket and was directly exposed to the elevated temperatures. For these tests, no signal was recorded using the analyzer. Transmission and reception were measured qualitatively by the FEE operator. For both Radio A and Radio B, transmission and reception were considered to be the same as when not exposed to elevated temperature conditions for the duration of the soak. Some damage did occur to the antennas as a result of their exposure to the heat outside of the pocket. For Radio A, there was some slight melting and deformation of the antenna. The antenna for Radio B was very deformed curving approximately 90 degrees and remained permanently bent over after the test. However, even with the bending of the antenna, transmission and reception worked in the laboratory setting.

無線電A可順利通過等級II測試，且沒有明顯損毀。無線電A在等級III測試中依然可以接收並發送信號，僅外殼與按鍵有些許熔化變形。無線電B通過所有持溫口袋測試。信號傳送與接收皆相當清晰。無線電B在進行口袋測試時沒有出現明顯本體損毀。無線電C在口袋內測試條件下也可以傳送與接收信號。我們在基礎測試條件上加上一些變動，並將結果記錄在表3內。我們使用無線電A與B進行測試，熱等級條件為第III級，我們將無線電天線維持原狀，不用防護電線連結到分析儀上。天線突出於口袋外部，直接暴露在高溫下。我們在進行這些測試時不用分析儀記錄信號。FEE操作員以質化方式測量信號傳送與接收性能。我們認為無線電A與B在持溫過程中的信號傳送與接收性能應該會和未暴露在高溫條件下一樣。結果顯示無線電天線因為暴露在口袋外高溫下，所以發生損毀。無線電A的天線出現熔化變形狀況。無線電B變形情況相當嚴重，幾乎扭曲成直角，並在測試結束前都維持彎曲狀態。雖然天線彎曲，但信號傳送與接收性能在實驗室條件下仍然正常。

Table 2 Testing inside turnout coat pocket, air velocity 0.9 m/s
表2 消防衣口袋內測試（風速0.9m/s）

Radio 無線電	Temp (℃) 溫度(℃)	Time Soak (min) 持溫時間(min)	Survive Soak 通過持溫	Notes 備註
A	160	15	Yes 是	No damage to radio evident 無線電無明顯損毀
A	160	15	Yes 是	No damage to radio evident 無線電無明顯損毀
A	260	5	Yes 是	Some melting, deformation of PTT button and display
B	100	25	Yes 是	No damage to radio evident 無線電無明顯損毀
B	100	25	Yes 是	No damage to radio evident 無線電無明顯損毀
B	160	15	Yes 是	No damage to radio evident 無線電無明顯損毀
B	160	15	Yes 是	No damage to radio evident 無線電無明顯損毀
B	260	5	Yes 是	No damage to radio evident 無線電無明顯損毀
B	260	5	Yes 是	No damage to radio evident 無線電無明顯損毀
C	100	25	Yes 是	No damage to radio evident 無線電無明顯損毀
C	160	15	Yes 是	No damage to radio evident 無線電無明顯損毀
C	160	15	Yes 是	No damage to radio evident 無線電無明顯損毀
C	260	5	Yes 是	No damage to radio evident 無線電無明顯損毀
C	260	5	Yes 是	No damage to radio evident 無線電無明顯損毀

Table 3 Testing inside Turnout Coat Pocket, Variations

表3 消防衣口袋內測試（變動）

Test 測試	Radio 無線電	Temp (℃) 溫度 (℃)	Time Soak (min) 持溫時間 (min)	Survive Soak 通過持溫	Notes 備註
Antenna 天線	A	260	5	Yes* 是*	Slight melting on antenna 天線稍微熔化
Antenna 天線	B	260	5	Yes* 是*	Antenna bent over 天線彎曲
Increased velocity 增加風速	B	260	5	Yes 是	Air velocity at 2 m/s for this test 測試風速2 m/s
Rotated 90 degrees 旋轉90度角	B	260	5	Yes 是	No damage to radio evident 無線電無明顯損毀
Speaker/ Microphone 喇叭/麥克風	C	260	5	No 否	Speaker/mic failure – standard mic 喇叭/麥克風失效-標準麥克風
	C	260	5	No 否	Speaker/mic failure – rugged mic 喇叭/麥克風失效-強化麥克風

Yes* – Qualitative measurement by operator. The change in the orientation of the antenna may impact the ability to transmit but this change in transmission capability was not quantified.
是*—由操作員以質化方式測量。改變天線方向可能會影響傳送能力，但我們沒有量化傳送能力量改變。

An additional pocket test was performed on Radio B with the flow rate doubled to 2 m/s in order to increase the heat transfer into the pocket. As noted above, the air temperature inside the pocket increased to within 57 ℃ of the air outside the pocket. However, even with the increased temperature, radio B continued to transmit and receive during the 5 minute soak with the FEE air at the Thermal Class III temperature of 260 ℃. Another test was performed on Radio B with the pocket rotated 90 degrees so that the radio was horizontal inside the tunnel. This modified geometry had no affect on the results, the radio operated successfully inside the pocket.
我們對無線電B實施了另一場口袋測試，風速上調至2 m/s，增強口袋內的熱傳遞。如前述，口袋內空氣溫度開始上升，與口袋外空氣的熱差變為57 ℃內。雖然溫度上升，無線電B在持溫期間（5分鐘）內仍可以持續傳送與接收信號，而FEE內的空氣溫度此時為熱等級III，即260 ℃。在另一場無線電B測試中，我們將口袋旋轉90度角，使無線電與風洞底部呈水平關係。改變方向對測試結果沒有影響，無線電在口袋內仍正常運作。

The only problems that occurred with the radio inside the pocket were for Radio C when the external speaker/microphone was connected. For these tests, the external speaker/microphone was located outside the FEE and connected to the radio by a well insulated cable. Two different speaker/microphones were tried, a standard one first, followed by a ruggedized one. For both tests at Thermal Class III conditions, with the external speaker/microphone connected, the radios malfunctioned. They became stuck in the transmit mode and could not receive. Although the cables were insulated, inspection of the cables after the test found that they had experienced melting and shorting of the wires inside. A test performed with just the ruggedized cable inside the FEE tunnel, and the radio and speaker/microphone outside also produced melting and shorting of the wires inside as well as signal failure. See the section on Speaker/Microphone testing for additional information.

在口袋中出現問題的無線電僅有連接上外部喇叭/麥克風的無線電C。進行測試時，我們將外部喇叭/麥克風置於FEE外部，並用絕緣電線將喇叭/麥克風連接到無線電上。我們試了兩種不同的喇叭/麥克風，第一種是標準組合，接著是強化組合。在兩次熱等級III測試中，連接外部喇叭/麥克風的無線電都發生故障。無線電變成只能傳送信號，無法接收信號。雖然電線經過絕緣處理，但在測試後檢查中我們發現電線已熔化，內部線路也出現短路。我們又進行一次測試，這次將強化電線放在FEE風洞內，結果放在外部的無線電與喇叭/麥克風內部也出現熔化與短路情況，信號也出現問題。詳情請見喇叭/麥克風測試章節。

Testing of Radios without Turnout Coat Pocket Protection
測試無消防衣口袋保護的無線電

In some cases, the portable radios used in a fire fighting situation would be protected from direct exposure either inside a pocket or worn under the turnout gear. However, testing of the radios exposed directly to the heat was performed as a “worst case scenario” for thermal conditions the radios may encounter. The tables below show the results of testing the radios directly exposed to the heated airflow. Unlike the radios inside the pocket, the unprotected radios could not withstand the higher temperatures. This emphasizes the protection provided by the pocket.

在某些案例中，可攜式無線電在消防情境中會被放在口袋內或置於消防衣內部受保護。但我們仍會對無線電進行直接熱暴露測試，作為無線電可能會遭遇到的熱暴露「最差情境。」下列幾張表格的內容為無線電直接熱氣流暴露測試的結果。與口袋內無線電截然相反，未受保護的無線電完全無法耐受高溫。測試結果更突顯口袋保護的重要性。

The results of the radios tested fully exposed at the Thermal Class I conditions of 100 ℃ for 25 minutes are given in Table 4. Both Radio B and Radio C had no trouble maintaining performance at this temperature for the designated time. Inspection of these radios showed no damage evident after the Thermal Class I temperature soak. The results for Radio A were mixed. Radio A was tested three times and it worked properly throughout two of the three tests. However, during the second test, the radio stopped working and would not transmit or receive after 25 minutes at 100 ℃. This radio did recover on cool down.

表4顯示將無線電完全暴露在熱等級I條件下（100 ℃，25分鐘）的測試結果。無線電B與無線電C在指定時間內皆可維持正常性能。在經過熱等級I持溫後檢查無線電，亦無發現明顯損毀。無線電A的結果較為複雜。我們對無線電A進行三次測試，在三次測試中，無線電共出現一次故障。但在第二次測試時，無線電在100 ℃環境下停留25分鐘後突然停止運作，完全無法傳送或接收信號，並在降溫後才恢復正常。

Table 4 Thermal Class I – 100 ℃ for 25 min soak, velocity 0.9 m/s
表4 熱等級I – 100 ℃ 下 持溫25分（風速0.9m/s）

Radio 無線電	Survive Soak 通過持溫	Notes 備註
A	Yes 是	No damage to radio evident 無線電無明顯損毀
A	No	At 25 minutes – no transmit or receive 第25分鐘一無法傳送或接收信號
A	Yes 是	No damage to radio evident 無線電無明顯損毀
B	Yes 是	No damage to radio evident 無線電無明顯損毀
B	Yes 是	No damage to radio evident 無線電無明顯損毀
C	Yes 是	No damage to radio evident 無線電無明顯損毀
C	Yes 是	No damage to radio evident 無線電無明顯損毀

Tests performed at the Thermal Class II conditions of 160 ℃ for 15 minutes exposed the vulnerabilities of the unprotected radios at higher thermal conditions. As Table 5 shows, all of the radios experienced some degradation of operation at these test conditions. Radio A went completely dead 8.5 to 9.5 minutes into the soak, ceasing to either transmit or receive. For Radio B, there was increased noise on transmission, and the signal shifted off target frequency before the end of the soak. For one of the tests there was also power loss of 2.4 dBm on cool down. Radio C also had performance problems during the Thermal Class II conditions. Its transmission frequency shifted just 5 minutes into the soak in both tests. The signal continued to degrade, before completely stopping at 6 minutes into cool down for the first test, and 4 minutes for the second test. During the repeat test the radio also lost reception on cool down. Figure 5 shows the progression of the signal for Radio C from normal transmission at ambient temperature through the shifted transmission during heating to the degraded signal on cool down. At the end of the 15 minute soak at 160 ℃, the centerline frequency had shifted approximately 0.5 kHz lower with and peak intensity drop of approximately 7%. At 5 minutes after the soak, the peak intensity has dropped by a factor of 10 with the centerline frequency shifting by another 0.1 kHz.

進行熱等級II條件（160 ℃，維持15分鐘）測試可看出未受保護的無線電在高溫條件下的缺點。從表5中可看出所有無線電在此測試條件下都出現運作劣化情況。無線電A在進入持溫後的8.5到9.5分鐘後便完全停擺，無法傳送或接收信號。無線電B在持溫結束前發送的信號都帶有噪音，且信號也偏離目標頻率。在其中一場測試內，降溫過程甚至出現功率損失（2.4 dBm）。無線電C在熱等級II條件下依然出現問題。無線電C的發送頻率僅在進入持溫測試的5分鐘後便出現偏移。信號持續劣化，直到進入降溫後的第6分鐘時完全停擺（第一次測試），在第二次測試時則為4分鐘。在重複測試中，無線電在降溫時亦喪失接收信號能力。圖5所示為無線電C的信號進程，從室溫下的正常傳送，到加熱時的信號偏移，一直到降溫時的信號劣化。在160 ℃的15分鐘持溫期間結束時，中線頻率偏移約0.5 kHz，尖峰強度則下降了7%左右。持溫結束後5分鐘，尖峰強度下降量以十倍計，中線頻率偏移量再增加0.1 kHz。

Table 5 Thermal Class II – 160 ℃ for 15 min soak, velocity 0.9 m/s

表5 熱等級II –160 ℃ 下持溫15分鐘（風速0.9m/s）

Radio 無線電	Survive Soak 通過持溫	Notes 備註
A	No 否	9 ½ min – no transmit or receive 9 ½ 分鐘─無法傳送或接收信號
A	No 否	8 ½ min – no transmit or receive 8 ½ 分鐘─無法傳送或接收信號
B	No 否	Transmission signal shift, increased noise 傳送信號偏移、噪音增加
B	No 否	Transmission signal shift, power loss and increased noise 傳送信號偏移、功率損失、噪音增加
C	No 否	Transmission signal shift, no transmission on cool down 傳送信號偏移、降溫時無法傳送信號
C	No 否	Transmission signal shift, no transmit or receive on cool down 傳送信號偏移、降溫無法傳送或接收信號

Because none of the radios survived at the Thermal Class II conditions, testing did not immediately progress to Thermal Class III conditions The radios were tested at high temperatures for the relatively short 5 minute time period, but were subjected to temperatures lower than the Thermal Class III temperature of 260 ℃, with the air velocity remaining at nominally 0.9 m/s. Because Radio C had shown transmission signal irregularity after only 5 minutes at the Thermal Class II temperature of 160 ℃, it was not tested at a higher temperature. Table 6 shows the results for the 5 minutes soaks at temperatures beyond 160 ℃. The transmission signal for Radio A did not maintain frequency when the temperature was at 190 ℃ and 200 ℃. Radio B was able to transmit and receive for 5 minutes at the temperature of 220 ℃; however there was some melting of the radio casing, especially around the speaker, the display area and the top switches. When radio B was tested at 230 ℃, the radio reception was not successful during either trial.

因為所有無線電都無法通過熱等級II條件，因此我們便沒有立即進行熱等級II條件測試。我們對無線電進行高溫測試，持續的期間較短，僅5分鐘，溫度比熱等級III的260 ℃稍低，風速依然維持為0.9 m/s。因為無線電C僅在進入熱等級II條件溫度（160 ℃）後的5分鐘後便出現傳送信號不規則性，因此我們便不對其進行更高溫的測試。表6所示為160 ℃以上的5分鐘持溫測試結果。當溫度達190 ℃與200 ℃時，無線電A的傳送信號便無法維持頻率。無線電B在220 ℃時仍可持續傳送與接收信號達5分鐘，但外殼、顯示器周圍與頂部開關已開始熔化，熔化情況在喇叭周圍最為明顯。用230 ℃測試無線電B時，無線電信號接收皆無法通過測試。

Table 6 Temperatures beyond 160 ℃, for 5 min soak velocity 0.9 m /s
表6 溫度高於160 ℃持溫5分鐘（風速0.9m/s）

Radio 無線電	Temp (℃) 溫度 (℃)	Time Soak (min) 持溫時間 (min)	Survive Soak 通過持溫	Notes 備註
A	190	5	No 否	transmission signal shift, melting of casing 傳送信號偏移，外殼熔化
A	200	5	No 否	Reception quality and volume degrades, transmission signal shift 接收品質與音量劣化，傳送信號偏移
B	220	5	Yes 是	Some melting of casing 外殼局部熔化
B	230	5	No 否	Reception loss at 150s into soak (analog) 進入持溫後150s出現接收損失（類比）
B	230	5	No 否	Reception loss at 150s into soak (digital) 進入持溫後150s出現接收損失（數位）

Speaker/Microphone testing
喇叭/麥克風測試

The results of the speaker/microphone testing are summarized in Table 7. The flow velocity was set at nominally 0.9 m/s for all tests. In general, the speaker/microphones for all radios remained fully functional and did not have any damage during the tests at Thermal Class I and Class II conditions. The only problem occurred for Radio C, where during a Thermal Class I test, the reception volume of the speaker decreased. For two subsequent tests at this Thermal Class I condition, the speaker/microphone operated normally without any decrease in volume. None of the speaker/microphones were able to operate normally during the soak at the Thermal Class III conditions of 260 ℃ for 5 minutes. For radio A, the PTT button melted and no transmission could be made. Additionally for radio A, the sound level on the speaker/microphone decreased, and then the speaker began making a humming sound, preventing clear reception over the speaker. For radio B, the speaker worked and messages could be received clearly throughout the Thermal Class III tests, but the PTT button melted and no transmission could be sent from the microphone. For radio C, the transmission worked, but the reception volume of the speaker decreased significantly. Melting and deformation of the casing occurred for all three speaker/microphones.

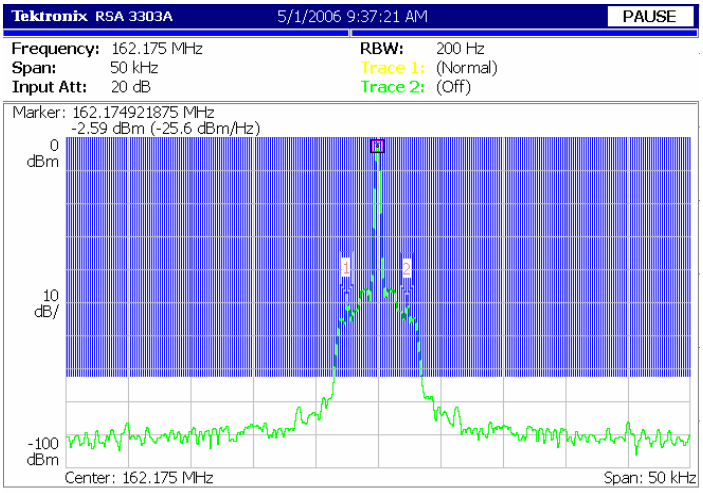
喇叭/麥克風測試結果列於表7。所有測試所用風速皆為0.9 m/s。整體來說，在熱等級I與熱等級II條件測試下，所有無線電的喇叭/麥克風都可正常運作，也沒有出現任何損毀。唯一出現的問題無線電為無線電C，測試條件為熱等級I，無線電C的喇叭接收音量減弱。但在接下來的兩次熱等級I條件測試中，喇叭/麥克風運作正常，音量也沒有減弱。所有喇叭/麥克風都無法在熱等級III條件（260 ℃，維持5分鐘）下正常運作。無線電A的PTT按鍵熔化，無法傳送信號。無線電A的喇叭/麥克風音量減弱，喇叭開始出現哈姆聲，影響信號接收。無線電B的喇叭在熱等級III條件測試中可正常運作並清楚接收訊息，但PTT按鍵熔化，因此無法透過麥克風發送信號。無線電C的傳送功能正常，但喇叭的接收音量大幅減弱。三款喇叭/麥克風的外殼都出現熔化與變形狀況。

Tests at an intermediate temperature of 210 ℃ for 5 minutes were performed in order to determine if the speaker/microphones could handle a temperature halfway between Thermal Class II and Thermal Class III. The speaker/microphone for Radio A did not maintain normal operation at this temperature. The speaker volume became increasingly lower during the soak. Melting of the cord was also observed. The speaker/microphone for Radio B could receive messages, but transmission was impeded due to difficulty operating the PTT button and melting of the cord. The speaker/microphone for Radio C was able to successfully transmit and receive throughout the 5 minute soak. The speaker/microphone for Radio C was also tested at 220 ℃ and survived at this temperature as well.

為判定喇叭/麥克風可耐受熱等級II與熱等級III的中間溫度，我們使用中等溫度（210 ℃，持續5分鐘）進行測試。無線電A的喇叭/麥克風在此溫度下無法維持正常運作。喇叭音量在持溫期間逐漸變小，電線也開始熔化。無線電B的喇叭/麥克風可以接收訊息，但無法發送信號，因為PTT按鍵操作困難與電線熔化。無線電C的喇叭/麥克風在進入持溫期間的5分鐘內可順利傳送與接收信號。我們用220 ℃對無線電C的喇叭/麥克風進行測試，而無線電C也順利通過測試。

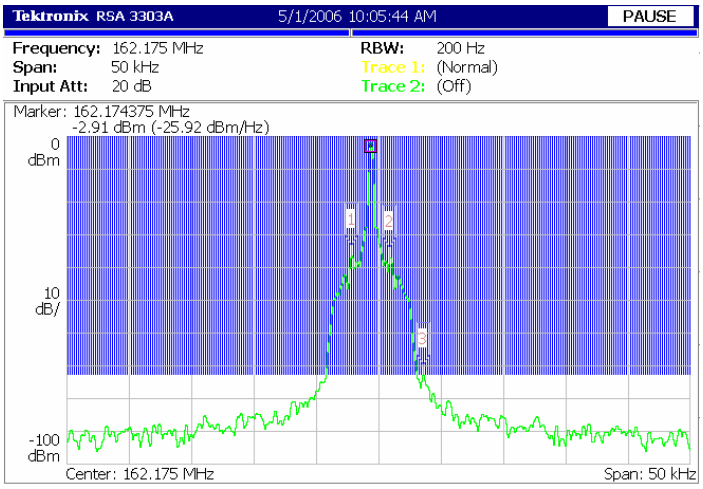
a. Signal at ambient temperature

a. 常溫下的信號



b. Signal at 160 ℃ for 15 minutes

b. 160 ℃持續15分鐘後的信號



c. Signal on cool down, 5 minutes after Soak

c. 持溫結束5分鐘後的降溫信號

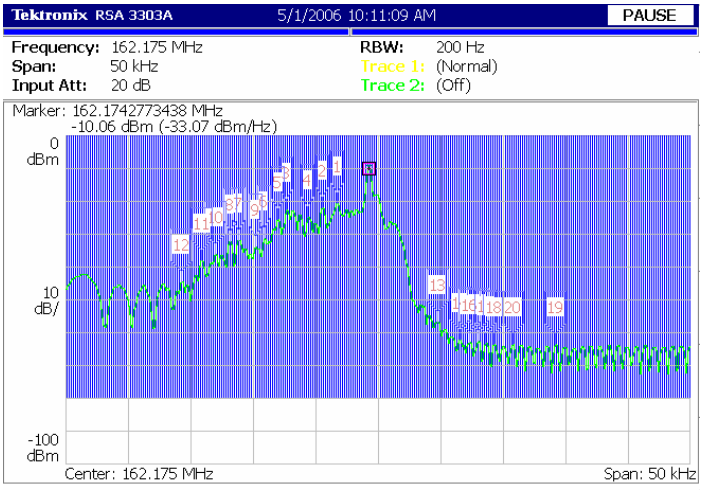


Figure 5 Radio Transmission Signal for Radio C during Thermal Class II Soak

圖 5 無線電 C 在熱等級 II 持溫狀況下之無線電發送信號

Table 7 External Speaker/Microphone Testing, velocity 0.9 m/s

表7 外部喇叭/麥克風測試（風速0.9m/s）

Radio 無線電	Temp (℃) 溫度 (℃)	Time Soak (min) 持溫時間 (min)	Survive Soak 通過持溫	Notes 備註
A	100	25	Yes 是	No damage 無損毀
A	160	15	Yes 是	No damage 無損毀
A	210	5	No 否	Reception volume decreased, cord and case melted 接收音量減弱、電線與外殼熔化
A	260	5	No 否	No transmit or receive, Push to talk button (PTT) melted-does not work, cord melted, case deformed 無法發送或接收信號、按鈕通話（PTT）按鍵熔化（失效），電線熔化、外殼變形
B	100	25	Yes 是	No damage 無損毀
B	160	15	Yes 是	No damage 無損毀
B	210	5	No 否	PTT difficult to press, cord melted PTT按鍵壓按困難、電線熔化
B	260	5	No 否	No transmission, PTT melted, cord melted 無法傳送信號，PTT按鍵熔化、電線熔化
C	100	25	No 否	Reception volume decreased 接收音量減弱
C	100	25	Yes 是	No damage 無損毀
C	100	25	Yes 是	No damage 無損毀
C	160	15	Yes 是	No damage 無損毀
C	160	15	Yes 是	No damage 無損毀
C	210	5	Yes 是	No damage 無損毀
C	220	5	Yes 是	No damage 無損毀
C	260	5	No 否	Volume decreased, some melting and deformation 音量減弱，出現熔化與變形

DISCUSSION
討論

The results of these tests exposed the vulnerability of the portable radios to elevated temperature conditions, and emphasized the need to protect the radios when used in firefighting situations. Radios tested inside the turnout gear pocket showed that the turnout gear pocket was able to protect the radios and allow them to operate at the Thermal Class III temperature of 260 ℃. This contrasts with tests where the radios were exposed directly to the airflow, in which the radios did not survive at Thermal Class II conditions and beyond. In all but one test, the exposed radios were able to operate properly at the Thermal Class I temperature of 100 ℃, above the listed maximum operating temperature of 60 ℃.
測試結果顯示可攜式無線電在高溫環境下的弱點，同時也強調在消防情境下保護無線電的必要性。消防衣口袋內測試顯示消防衣口袋可以保護無線電，讓在熱等級III溫度（260 ℃）條件下也能運作。與消防衣口袋內測試相對的是氣流直接暴露測試，在此測試中所有無線電都無法通過熱等級II（及以上）條件。幾乎所有無線電都能在熱等級I（100 ℃）條件的直接暴露測試中正常運作（僅有一次測試失敗），結果優於無線電表定的最高運作溫度（60 ℃）。

Failure of the electronics due to heating was not permanent for the radios. In all cases where the radio casing was not damaged, the radios regained normal operating function once they had sufficiently cooled. Permanent damage to the casing, such as difficulty turning knobs or pressing buttons did occur for some radios whose casings experienced melting. Permanent damage also occurred to the external speaker/microphones, especially due to the melting of the connecting cables.
電子元件因高溫失效並不會對無線電產生永久影響。在所有無線電外殼無損的測試案例中，無線電性能會在充份降溫後回復。但如果無線電外殼熔化，無線電便會出現永久性毀損（如無法旋轉按鈕或壓按按鍵）。如果連接電線熔化，外部喇叭/麥克風便會出現永久性毀損。

The radio transmission signal was measured using the signal analyzer. Each radio was programmed to Very High Frequency (VHF) frequency 162.175 MHz assigned for testing purposes. Baseline transmissions were recorded with the radio at ambient room temperatures. When the radio was heated, a deviation of the transmission signal from the programmed frequency of greater than 0.1 kHz signaled the start of degradation of the transmission signal, and indicated that further problems were imminent.
我們用信號分析儀測量無線電傳送信號。我們將無線電設定為極高頻（VHF）162.175 MHz，專門供測試用。我們記錄無線電在室溫條件下的基線傳送（baseline transmissions）。在加熱無線電的過程中，如傳送信號偏離設定頻率超過0.1 kHz，代表傳送信號開始劣化，且很快就會出現其他問題。

It should be noted that in most tests when the radio was heated above 160 ℃ the liquid crystal display (LCD) display became darkened and in some cases it became unreadable. The impaired display was not considered a communication malfunction because the display was not needed for radio communication; it was used for radio programming and other setup functions that would not be used in the emergency situation. Not all of the radios had an LCD displays.
另外，在絕大多數測試中，當無線電加熱達160 ℃以上時，液晶顯示器（LCD）便會變暗，在某些測試中，用戶甚至無法讀取內容。我們不將顯示器故障歸類為通訊異常，因為通訊過程中並不需要顯示器，顯示器僅用於無線電調整與其他設定功能，不用於消防情境中。也不是所有無線電都有液晶顯示器。

Testing of the external speaker/microphones fully exposed to the heated airflows showed that these parts were better able to perform at the elevated temperatures than the radios themselves. While none of the speaker/microphones survived the Thermal Class III conditions of 260 ℃ for 5 minutes, they were able to operate during most of the tests at lower temperatures. Since this is the part of the radio system most likely to be directly exposed to harsh environments, it is crucial for this part to be able to withstand thermal stress without protection.
根據外部喇叭/麥克風氣流直接暴露測試結果顯示，外部喇叭/麥克風在高溫條件下的運行能力優於無線電本身。雖然所有外部喇叭/麥克風都無法通過熱等級III條件（260 ℃，維持5分鐘），但卻在絕大多數較低溫測試中表現良好。外部喇叭/麥克風是無線電系統中最有可能直接暴露在嚴苛環境下的部位，所以外部喇叭/麥克風一定要能夠在無保護的狀態下耐受高溫。

Connecting the external speaker/microphones required that the connector cord be screwed into place on the side of the radio. Some of the radios operated such that when the external speaker/microphone was connected, it disabled the PTT and speaker on the radio itself, diverting all transmission and reception to the external speaker/microphone. If the external speaker/microphone or its cord were to fail, in an emergency situation it would be extremely difficult (if not impossible) to disconnect the speaker/microphone and operate the radio by itself. Thus failure of the external speaker/microphone, the part most likely to be exposed to extreme conditions, could mean loss of the radio operation entirely.
連接外部喇叭/麥克風時須將連接線旋入無線電側邊。有些無線電會在接上外部喇叭/麥克風的時候停用本體PTT與喇叭，並將信號傳送與接收直接轉移到外部喇叭/麥克風。如果外部喇叭/麥克風或其電線故障，消防員便必須在緊急現場將喇叭/麥克風移除，轉而操作無線電本體，但此程序相當困難，在某些狀況下甚至是完全不可能達成的。若最有可能暴露在極端條件下的外部喇叭/麥克風出現故障，即代表消防員完全失去通訊能力。

CONCLUSION
結論

The performance of handheld radios in thermal environments encountered by firefighters based on the experimental data in this paper suggests the following recommendations.

1. Handheld radios without additional thermal protection should be treated as Thermal Class I electronics.
2. Radios protected in turnout gear pockets may be treated as Thermal Class II electronics.
3. Standards for the thermal protection afforded by turnout gear pockets need to be developed to support recommendation 2.
4. While pocket protected radios withstood Thermal Class III conditions, the cord and speaker/microphone limited their performance to Thermal Class II conditions. Improving the thermal performance of the speaker/microphone and cord could move pocket protected radios to Thermal Class III electronics.

Since firefighter turnout gear is designed to protect firefighters exposed to Thermal Class III conditions, handheld radios should be constructed to handle these conditions. One of the radios tested, Radio C, had a speaker/microphone and cord that almost survived Thermal Class III conditions which suggests that small design changes may be all that are necessary to reach the Thermal Class III rating.

The next step for this project is to work with the NFPA to develop a radio standard that would include requirements for the thermal testing of handheld radios.

根據本文實驗資料，我們提出下列手持無線電在消防人員可能遭遇的熱環境下性能之建議：

1. 可將無熱保護機制的手持無線電視為熱等級I電子裝置。
2. 可將置於消防衣口袋內的手持無線電視為熱等級II電子裝置。
3. 應針對消防衣口袋所提供的熱保護機制制定標準，以便滿足第2點。
4. 雖然受口袋保護的無線電可以承受熱等級III條件，但喇叭/麥克風卻只能承受熱等級II條件。只要改善喇叭/麥克風與電線的熱性能，便可將受保護無線電的等級提升為熱等級III電子裝置。

消防衣的設計目的是為了使消防員能夠暴露在熱等級III條件下，因此手持無線電也應該要能夠耐受同等級條件。接受我們測試的無線電C的喇叭/麥克風與電線僅差一點便可通過熱等級III條件，代表只要稍微修改無線電設計即能達到熱等級III級別。

本計畫接下來將與NFPA合作設定無線電標準（包含手持無線電熱測試需求）。

REFERENCES

參考

1. Donnelly M. K., Davis W. D., Lawson, J. R., and Selepak, M. S., “Thermal Environment for Electronic Equipment used by First Responders,” National Institute of Standards and Technology, Gaithersburg, MD, NIST Technical Note 1474; January 2006.

2. National Fire Protection Association, NFPA 1221 Standard on Installation, Maintenance and Use of Emergency Services Communications Systems, 2002 Edition, Volume 11. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101.

1. Donnelly M.K.，Davis W.D.，Lawson，J.R。和Selepak，M.S。，「初期應變人員使用的電子設備的熱環境」，美國國家標準與技術研究所，Gaithersburg，MD，NIST技術說明1474; 2006年1月。
2. 美國國家消防協會，NFPA 1221緊急服務通訊系統之安裝，維護和使用標準，2002年版，第11卷。美國國家消防協會，1 Batterymarch Park，P.O。 Box 9101，Quincy，MA 02269-9101。

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