



REPORT

Fire analysis of the events at Waco, Texas, 19 April 1993

Prepared for

The Office of Special Counsel

By

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Executive Summary

This report describes the fire development in the Branch Davidian complex on April 19, 1993. The fire analysis is based on information made available to me by the Office of Special Counsel (“OSC”). I have been in close contact with the OSC FLIR experts Lena Klasén and Sten Madsen, Linköping, Sweden, who have assisted me with interpretation of the imagery on the April 19, 1993, FLIR tapes. I have also been in contact with OSC expert Walter Wetherington, who examined the physical evidence relating to the cause and origins of the fire.

Based on my review of all the available evidence, analysis of the fire, and after consideration of the final reports and opinions of Drs. Quintiere and Mowrer¹, Mr. Kennedy⁷, and others, I conclude that fires were started by means of accelerants at many locations throughout the building. The fires commenced within a very short time interval, evidencing that occupants of the Branch Davidian complex deliberately started the fires. Many of the fires went out by themselves when the combustible liquid was consumed. Fires did, however, continue to develop in three separate locations, which can be concluded with certainty with or without support of the FLIR tape imagery.

The first fire, denoted *Fire A*, started at the stage in the rear of the chapel. The first visible heat image on the FLIR occurs at 12:04:23 on the catwalk over the stage. This fire spread quickly in the debris of the crushed building. When the fire spread to the asphalt felt roof a lot of black smoke developed. This fire spread slowly against the wind direction towards the chapel and merged at a rather late stage with the fire that started in the southeast corner Red/White tower, i.e. *Fire C*.

The second fire, denoted *Fire B*, started in the cafeteria/kitchen area of the Branch Davidian complex. This fire was very dangerous, as most of the Davidians seem to have taken shelter and were found dead near this part of the complex. Fire B was first discovered on the FLIR as a heat image at 12:08:10. TV footage of Fire B shows smoke streaming out from the north side of the cafeteria at 12:08:11. Ground photos of the cafeteria taken between 12:08:10 and 12:08:58 also show flames penetrating through the north wall of the cafeteria at the same position as the heat images on the FLIR.

The third fire, denoted *Fire C*, started on the second floor of the southeast tower of the Branch Davidian complex. This fire was first observed on the FLIR as a heat image at 12:07:41, and the first flames were seen on TV footage at 12:09:42. This fire developed quickly as mainly accelerants and other easily ignitable items burnt. The wind, however, cooled this fire thereby delaying its burn through of the structure and its spread into the complex.

Although the fire developed rapidly and started at three different locations, the occupants could all have escaped the fire if they so wanted except possibly those residing in the center bunker, who may have been trapped by a fire started near its only door.

The fire could only have been fought if the risks of being shot at and being killed could be neglected. If so, I believe the fire could have been successfully fought with adequate equipment and personal being on site, adjacent to the complex, and on alert when the fire started. The Office of Special Counsel has advised me, however, that fire fighters could not safely approach the complex until after 12:30 p.m. Under these circumstances the fire could not have been controlled or stopped.



Finally I conclude, that the hole in concrete bunker roof was created by the heat from the fire. It was not made by a demolition charge as claimed by some experts.

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1 Introduction

1.1 Assignment

The Office of Special Counsel retained me on January 21, 2000, to evaluate the U.S. Government's and Plaintiffs' Expert Fire Analyses and review evidence related to the fire that destroyed the Branch Davidian complex on April 19, 1993. The Office of Special Counsel specifically tasked me to:

- 1) Determine whether agents of the United States started or contributed to the spread of the fire that killed members of the Branch Davidian group on April 19, 1993;
- 2) Determine whether additional information can be developed concerning the cause and/or point(s) of origin of the fire;
- 3) Determine time of ignition for individual fires;
- 4) Determine whether fire fighters could have controlled or stopped the spread of the fire;
- 5) Determine whether the Branch Davidians had the opportunity to escape the fire;
- 6) Determine whether the analyses of Dr. James Quintiere, the U.S. Government's Fire Dynamics Expert and Patrick Kennedy, a Fire Dynamics Expert retained by the Branch Davidians, accurately and completely defined the cause of the fire and its point(s) of origin; and
- 7) Determine whether heat from the fire affected the structural integrity of the concrete bunker roof.

1.2 Personal Qualifications

The Swedish National Testing and Research Institute (SP) is a Swedish Organization headquartered in Borås, Sweden. The Swedish government owns the institute. The Fire Technology Department, which I have led since 1986, is one of the world's leading authorities in projects concerning materials reaction to fire, structural response to fire, media and equipment for extinguishing fires and fire dynamics. The SP primarily supports the Swedish Government and private companies based in Sweden and



throughout the European Union. Prior to being retained by the Office of the Special Counsel neither the Fire Technology Department of the SP nor myself had ever been under a direct contract to the U.S. Government. Executive and operational control of the SP is under its Board of Directors, all of whom are Swedish nationals.

The Office of Special Counsel selected me on the basis of my unique and extensive background in heat transfer and structural fire analysis. Internationally I have made contributions in the analysis of in-door structural fires. Prior to my engagement with the Office of Special Counsel I had no involvement with any investigation into the events occurring at Waco, Texas on April 19, 1993. Moreover, in advance of commencing work, I signed a statement promising my complete impartiality throughout the investigation and guaranteeing that I would not make public any information relating to the investigation. For my CV, see Annex E.

1.3 Source of data

All material for carrying out this assignment and writing this Report was obtained from the OSC. Table 1.1 contains a detailed list of the materials obtained.

Table 1.1 Material obtained from the OSC.

No.	Date	Item
1	01/03/00	Paul Gray: Fire Investigation Report
2	01/03/00	Patrick Kennedy: Fire Investigation Report
3	01/03/00	Frederick Mowrer: Fire Investigation Report
4	01/03/00	Dr. James Quintiere: Fire Investigation Report
5	01/03/00	Richard Sherrow: Fire Investigation Reports
6	01/03/00	Attorney General Briefing Book: 4-12-93. (Bates numbered SCSL001-0001 to SCSL 001-0104)
7	01/03/00	Attorney General Briefing Book: 8-1-95. (Bates numbered SCSL003-0002 to SCSL 003-0321)
8	01/03/00	Thirteenth Report by the Committee on Government Reform and Oversight August 2, 1996
9	01/1300	Photographs from FBI of Branch Davidian Compound on April 19, 1993
10	01/20/00	Photographs of the fire at Waco compound (CDs and zip drive – each containing different photographs)
11	01/20/00	Waco – Major Network News Footage – Tape No.1
12	01/20/00	Waco – Fire Footage Mt. Carmel – Tape No 2
13	01/2700	John Ricketts – Summary of Activities and Personal Observation, Fire Report
14	01/27/00	John Kaus Fire Marshal Report
15	01/27/00	Thomas Hitchings Fire Scene Origin and Cause Examination
16	01/27/00	Bill Cass Fire Investigation Team Report
17	02/08/00	FBI Lab Reports File NO. 89B-SA-38851, Dated August 4, 1993 (FBI10360351-FBI0360048)
18	02/08/00	FBI Lab Reports File NO.89B-SA-38851, Dated October 4, 1993 (USA WDTX 007-01667)
19	02/08/00	FBI Lab Reports File NO.89B-SA-38851, Dated December 6, 1993 (Page 1-49)
20	02/08/00	OSC Group I, Packet A: Mt Carmel Floor Plan, Floors 1-4
21	02/08/00	OSC Group I, Packet B: Branch Davidian Cause of Death Color Coding Grid/Bunker Recovery Grid
22	02/08/00	OSC Group I, Packet C: Mt Carmel Side Views
23	02/08/00	OSC Group I, Packet D: First and Second Floor Plans

**Table 1.1** **Continue**

Nr.	Date	Item
24	02/08/00	OSC Group I, Packet E: Maps and Diagrams of Mt. Carmel and Surrounding Area
25	02/08/00	OSC Group I, Packet F: Mt. Carmel Side Views
26	03/08/00	Final report of Patrick Kennedy (Plaintiff's expert)
27	03/08/00	Final report of System Engineering & Lab Corp. (Plaintiff's expert)
28	03/08/00	Final report of Andrew Armstrong (DOJ expert)
29	03/08/00	Final report of William Cass (DOJ expert)
30	03/08/00	Final report of Thomas Hitchings (DOJ expert)
31	03/08/00	Final report of Dr. James G. Quintiere (DOJ expert) <ol style="list-style-type: none">1. VHS Branch Davidian Fire2. VHS Methylene Chloride (MC)
32	03/08/00	Final report of John Ricketts (DOJ expert)
33	03/08/00	Final report of Michael McNamee (DOJ expert)
34	03/08/00	Final report of Construction Technology Lab (DOJ expert)
35	03/16/00	4 CDs with additional fire photos
36	03/27/00	Two (2) levers and caps from expended hand delivered flash bang grenade (Evidence label No.A00811749)
37	03/27/00	Two (2) forty millimeter Ferret casings, wadding and projectiles of the type used by the FBI at the Branch Davidian complex in 1993 (Evidence label No.A00811108)
38	03/27/00	Two (2) forty millimeter XM651E1 casings (military rounds) with spent projectiles of the type used by the FBI at the Branch Davidian complex in 1993 (Evidence label No.A00811102)
39	03/27/00	Two (2) forty millimeter Flash Bangs casings and projectiles fired from a M-79 Grenade Launcher
40	03/30/00	Six (6) CDs containing high resolution photos of the fire at the Branch Davidian complex
41	04/13/00	Two Coleman Model 290 A700 lanterns
42	04/13/00	One Coleman Model 220 lantern
43	04/13/00	One hurricane style glass antique lantern
44	04/13/00	One American Camper RK-12 kerosene style lantern
45	04/27/00	One (1) gallon of Coleman Lantern Fuel
46	05/11/00	Vector Data Systems (U.K.) LTD. Final Report
47	05/17/00	K-6 VHS Video tape with compiled fire footage
48	05/18/00	Four 2'x4' sections of 3/8" plywood
49	05/18/00	1 roll of asphalt roofing materials
50	05/18/00	1 packet of asphalt roofing shingles
51	05/18/00	1 roll of 15 STD roofing felt
52	05/18/00	T-1-11 (exterior)/2x4 Wooden Supports
53	05/18/00	T-1-11 (exterior)/2x4 Wooden Supports/1/2 Sheetrock (interior)
54	05/18/00	1/2 Masonite (exterior)/2x4 Wooden Supports
55	05/18/00	1/2 Masonite (exterior)/2x4 Wooden Supports/ 1/2 Sheetrock (interior)
56	09/15/00	Final report of Walter Wetherington

I made a very detailed examination of all the above materials and evidence. Photographs and evidence were examined and then re-examined several times. Many of the videotapes were replayed one frame at a time for detail and referred to many times before any determinations were made. Crosschecks were made between photographs, videotapes, and other reported information for comparisons.

In particular the FBI video coverage sensitive to infrared radiation, FLIR (Forward Looking InfraRed), the Canadian Broadcast Corporation (CBC) television coverage and FBI aerial and ground color photos have been important sources for this investigation.



1.4 Work Performed

In addition to my detailed review of photographic and documentary evidence, analysis, and preparation of my Final Report, I participated in following meetings:

- Participated in a conference of experts at the Office of Special Counsel in Washington, D.C., addressing the Waco fire investigation.
- Traveled to Peterborough, England and met with and participated in a meeting with Vector Data Systems experts' (U.K.) David Oxlee, Nick Evans and Robert Scully and with Walter Wetherington, fire investigator. These are all experts for the Office of Special Counsel. We discussed all aspects of the FLIR tapes as they related to the fire locations, time sequence of the individual fires and comparisons with other photographs and videos.
- Participated in a conference call on the bunker damages with OSC explosive experts, Dr. Gerry Murray and Mr. David Green.
- Conducted three lengthy and comprehensive meetings with OSC experts Lena Klasén and Sten Madsen to analyze the FLIR tape of the Waco fire.

SP, at my direction, also conducted three types of scientific tests to provide additional data for the analysis of the Branch Davidian fire. These tests included:

- Bonfire Tests. A M651 military teargas round, a 40 mm teargas Ferret and a Flash Bang grenade were placed in a controlled bonfire of wooden cribs to analyze the deterioration of these items under extreme temperatures and to determine what could remain after a severe heating exposure. See Annex A.
- Heat penetration tests of roof structure materials. Reconstructed samples of the Branch Davidians complex roof were exposed to fire on their underside. These tests were carried out in a small furnace to determine how long it takes until the temperature starts to rise on the unexposed side of the roof. See Annex B.
- Cone Calorimeter tests. Heat release test were carried out on sheets of wooden products believed to have made up the exterior walls of the Branch Davidian complex. The purpose of these tests was to determine the ignition and burning properties of the wood product, and the length of time to burn through the test materials. See Annex C.

1.5 Photos

Photos and other figures have been used extensively in this report for illustration purposes. They have been placed in the body of the text for clarity and convenience. The pictures have been cut to highlight certain details but have not been manipulated in any other way. The FLIR imagery frames have been obtained on CDs from OSC experts Klasén and Madsen.

1.6 Nomenclature

1.6.1 Directions

The front side (the south side) of the Branch Davidian complex is herein called the White Side. The backside (north side) is called the Black Side, while the right side (east side) and the left side (west side) are called the Red Side and the Green Side, respectively. See the aerial photo of the Branch Davidian complex in Figure 1.1 reproduced from the report of Wetherington³.

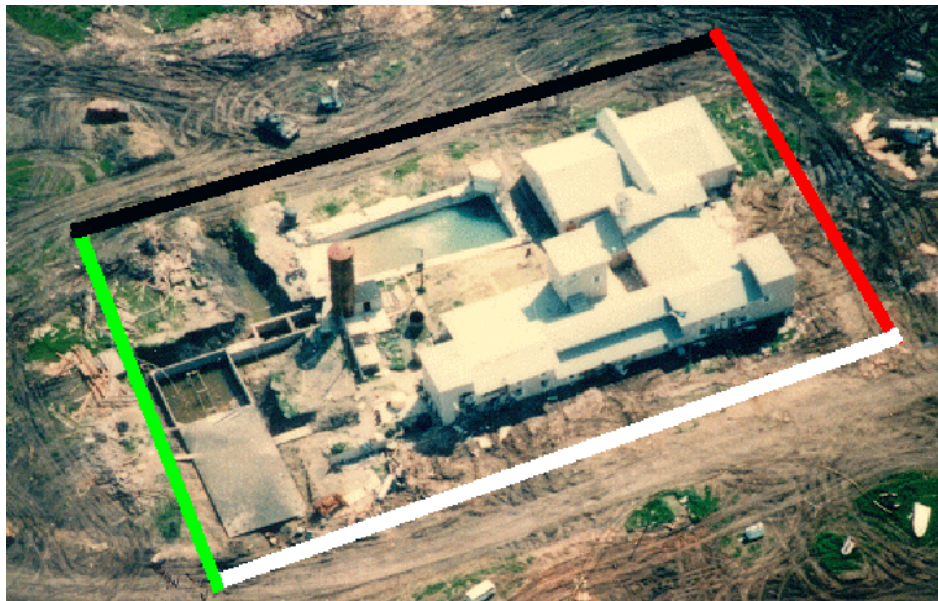


Figure 1.1 The Branch Davidian complex color-coding. Reproduced from Wetherington³.

1.6.2 Flashover/full fire involvement

The term flashover is used in several places in this report. It denotes the transfer of a fire from a small event limited by the amount of combustible gases available in a fire compartment, to being much hotter and limited by the amount of oxygen available. This rapid transfer occurs when the supply of combustible gases is high enough to consume the available oxygen. Thus, all things being equal, it takes longer for a fire to go from fuel controlled to ventilation control, i.e. to reach flashover, in a well-ventilated compartment. A well-ventilated compartment has, in general, large openings or is exposed to external wind pressures.

At flashover, the overall temperature in the entire fire compartment rises and all surfaces exposed to the fire start to give off combustible fumes, i.e. full fire involvement. All the fumes do not burn inside the compartment, but instead emerge through the compartment openings and burn in flames outside. If the openings lead to other internal spaces, the flames may travel along the ceiling and rapidly spread the fire. Before flashover the fire is localized to a room and there is no immediate risk for fire spread to adjacent rooms. After flashover, flames emerge out of the room of origin and can spread the fire rapidly inside or along facades of the building. Smoke is also produced in large quantities and

is, in this stage of a fire, very toxic as the combustion occurs with limited supply of oxygen.

2 Fire development

2.1 Building structure

My assessment of the Branch Davidian complex structure is based on the work of OSC expert Walt Wetherington who has reviewed the physical evidence related to the fire. I have also independently reviewed photos and videos of the fire to confirm his findings.

Below is a summary of Wetherington's³ findings, which are relevant to my analysis.

The roof was constructed with 3/8" plywood laid over home made trusses. The roof was covered with roofing felt # 15 STD. The roofing felt was then covered with two types of material, each on a different part of the roof. One section was covered with roll asphalt composition material and the other with fiberglass shingles with an asphalt base.

With the exceptions of the cafeteria and the second and third floors of the towers, the interior wall surfaces were of 1/2" non-combustible drywall, also referred to as sheet-rock (gypsum plasterboard). Drywall interior claddings on the first and second floors can be seen in FBI photographs taken from ground level on the White Side of the Green/White tower, see e.g. Figure 2.1.



Figure 2.1 FBI ground photo of Green/White tower. The front wall was covered on the external side with wood panels and on the inside of first two floors with drywall (gypsum boards). The tower second and third floor walls had no internal claddings.

There were no doors to the rooms on the second floor.

The exterior walls were covered with two types of material, each on a different part of the exterior wall. The first type T1-11 panels (1/2" plywood) covered the entire structure except the walls of the cafeteria Black Side and the tower over the concrete



bunker. These were covered only with thin wooden exterior boards, approximately 3/8” to 1/2” thick. They had no interior linings.

In summary, the building did not comply with building codes for facilities accommodating many people, as many of the known interior wall linings were combustible. However, the building structure, in itself, was no worse in terms of fire safety than many single-dwelling houses. No building code fire regulations apply in most countries for such buildings. The Branch Davidian complex had in principal only two stories and the distances to escape routes were short given that windows could be opened from the inside and used for escape, and large parts of the interior wall surfaces had non-combustible linings of drywall. The structural surfaces of the rest of the building, including the towers and the cafeteria, had combustible linings of wood panels, which are acceptable according to most building fire codes in single-dwelling houses.

Wetherington also agrees with the Government’s 1993 fire investigators² who concluded that the Branch Davidian complex was a multi-storied, wood-framed building in an irregular shape, with a ground floor area of approximately 12,500 square feet (=1125 m²) and that the building appeared to have been constructed haphazardly over a period of time, with no attention to existing building codes or fire codes. Used lumber had been employed in construction.

2.2 Fuel load

Evidence of flammable liquids of various kinds were found at many places throughout the building and on clothes of the people who escaped the fire. Wetherington³ reports that heavy petroleum was found in the Red/White corner, kerosene, mixed kerosene/gasoline, and gasoline in the chapel area, and finally a sample containing gasoline was found in the kitchen/cafeteria area. Empty fuel containers have also been found at numerous locations. The remains of combustible and easily ignitable materials such as hay and mattresses etc. were also retrieved from the fire debris.

Where fires developed, the building internal surfaces, walls, ceilings and floor coverings were of wood products with fire properties similar to soft wood panels. These types of products ignite within a few minutes when exposed to flames, and release large amounts of energy. See Annex C for detailed information. Thus, any fire started in places of the Branch Davidian complex with combustible surface linings could develop rapidly and spread throughout the structure.

2.3 Chronology of pictorial evidence

Time is based on the FLIR video camera time, which was calibrated with official time (ref. 1). The CBC video tape is given in Eastern Daylight Time and is corrected to the official time by subtracting 1 hr and adding 19 s for Central time.

The FBI aerial photos were taken from an airplane circling the Branch Davidian complex¹. Several series of photos were taken. In this report only series 7 have been used. These photos are 7-1 through 7-36. Figure 2.2 shows the airplane

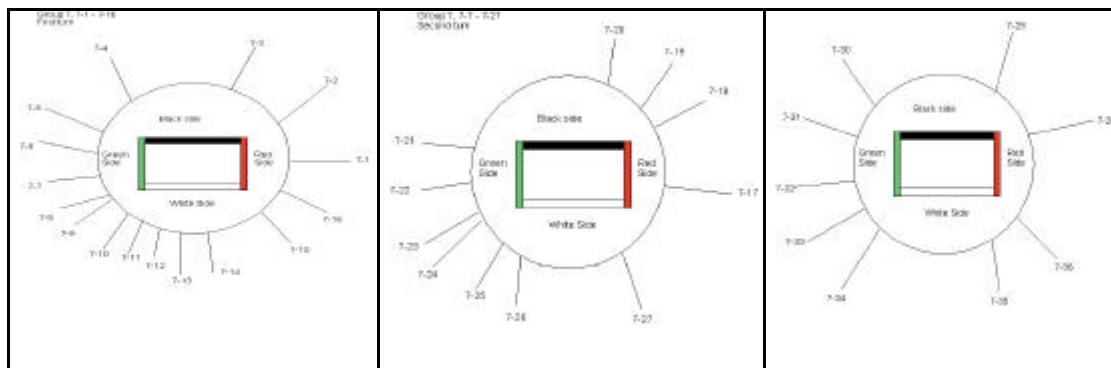


Figure 2.2 Position of airplane in relation to the Branch Davidian complex when taking the aerial photos numbered 7-1 to 7-36.

positions in three circles when the photos were taken. The positions are obtained by observing the visual angles of the photos. There are no times recorded on the FBI photos. Estimates of time are obtained by comparisons with events shown on the FLIR tapes.

The FBI ground photos are, when possible, timed based on observed CEV positions on the FLIR tapes or on CBC broadcasting sequences.

2.4 Fire events

Fires were initially started in at least three locations. Events of these three fires are reported in separate sections below. Figure 2.3 taken from the Final Report of Walter Wetherington³ shows the positions of these fires. I agree with Mr. Wetherington's conclusions concerning the points of origin of the Branch Davidian fire and use his diagram here for illustration purposes.

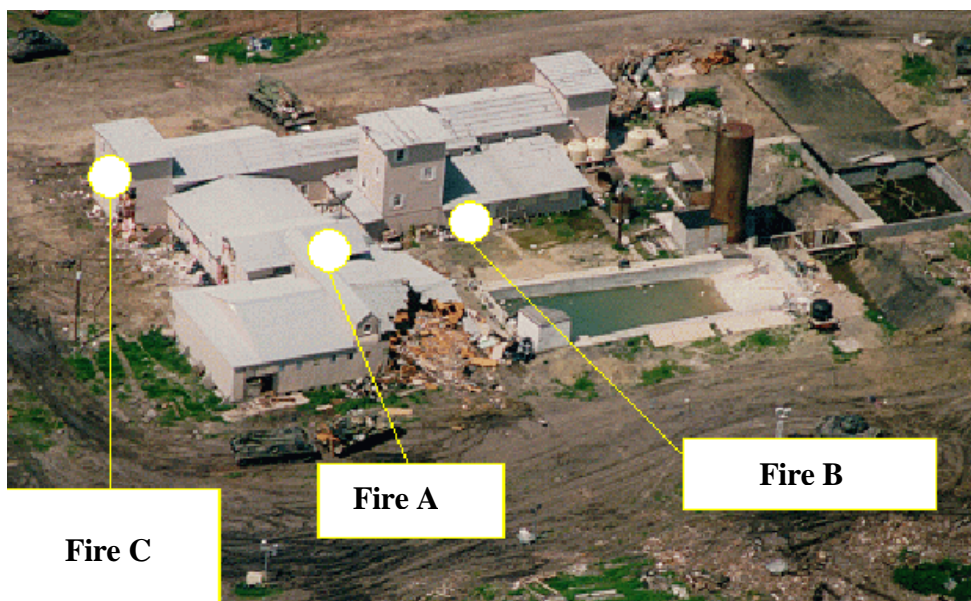


Figure 2.3 The fire started at three separate locations denoted Fire A, B and C, respectively.

In Figure 2.4 FLIR images and aerial photos are shown side by side at approximately equal times for comparison. The images and the photos are taken from two separate airplanes circling independently above the Branch Davidian complex. With the FLIR, hot surfaces can be detected through the smoke. Hot smoke can also be detected when it leaves the building but before it has been diluted with cool fresh air and adjusted to ambient temperature.



Figure 2.4 FLIR images and aerial photos taken at approximately the same times.

Fires started and continued in at least three locations. Presented below are events observed from recordings of the FLIR tapes, Canadian Broadcast Company, Waco

television stations, aerial photos, and ground photos. These events are in chronicle order for each of the three fires, A, B, and C.

2.4.1 Fire A The stage at the rear of the chapel

Fire A started under the catwalk near the stage at the rear of the chapel. The OSC experts Klasén and Madsen⁴ detected a faint heat image on the original FLIR tape at 12:04:23 at the eave of the collapsed catwalk roof. An indication of a temperature rise at the same location was derived by a detailed numerical analysis of pixels of the FLIR imagery by Klasén and Madsen⁴. This temperature rise on the catwalk roof occurs at 12:04:51. The third (blue) curve in Figure 2.5 plotted at 12:04:51 shows a slight temperature rise at a position where the temperature rise later on at 12:07:02 (cyan line) becomes evident, while the curve plotted before at 12:02:43 (green line) shows no heat increase.

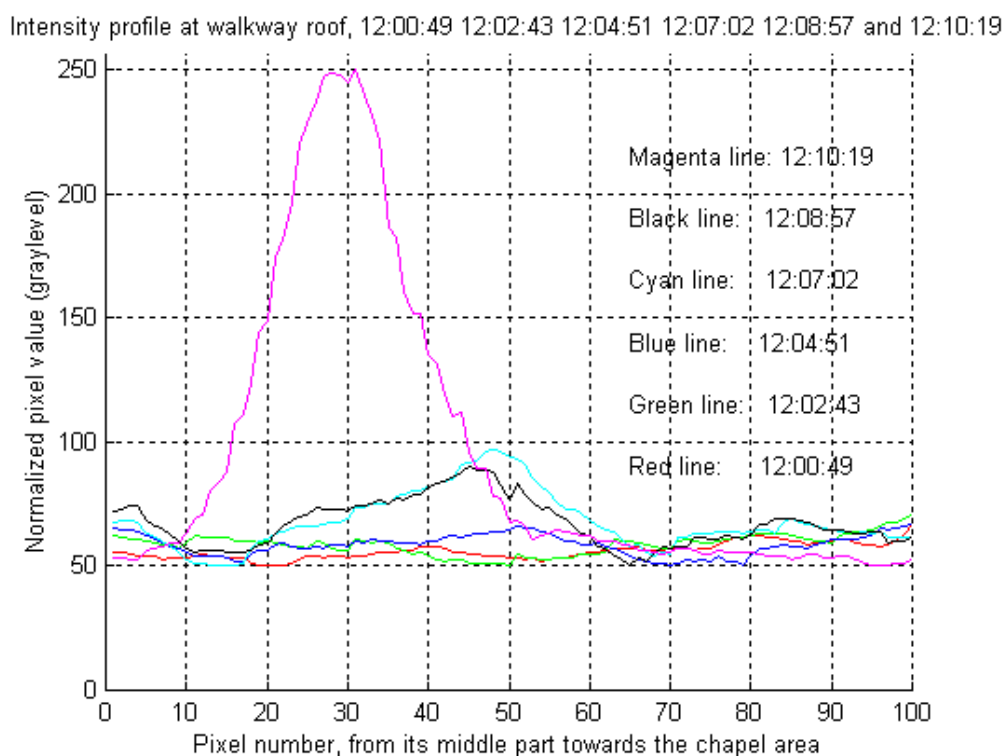


Figure 2.5 Temperature along the eave of the damage catwalk above the gym and stage, cf. Figure 2.7 plotted at various times. The temperatures are obtained by numerical analysis of the FLIR tape. The blue curve shows the first indication of an onset of a temperature rise.

A second heat image was discovered at the eave of the collapsed catwalk roof on the FLIR tape at 12:06:13⁴.

An FBI agent took a ground photo from the Black Side, Figure 2.6 between 12:09:10 and 12:10:21 showing the fire developing in the damaged building under the collapsed catwalk roof. The time range was determined by comparisons with FLIR recordings. A CEV, which left the gym area at about 12:09:10, cannot be detected on the photo and a heated plume emerging outside the gym occurs on the FLIR at 12:10:21. The fire

started further into the building, in the stage area, and was driven by the wind towards the Black Side.



E-12

Figure 2.6 FBI Ground photo between 12:09:10 and 12:10:21. Early phase of fire under the collapsed catwalk roof near the stage area.

Heat images in the area of the fallen catwalk quickly develop into intense flaming and were also detected on the FLIR imagery at 12:10:21, see Figure 2.7.



Figure 2.7 FLIR image from 12:10:22. A strong heat image started to appear at the eaves of the collapsed catwalk at 12:10:21. It developed quickly into intense flaming.

The aerial photo where flames are seen was taken about 12:11 p.m., see Figure 2.8.

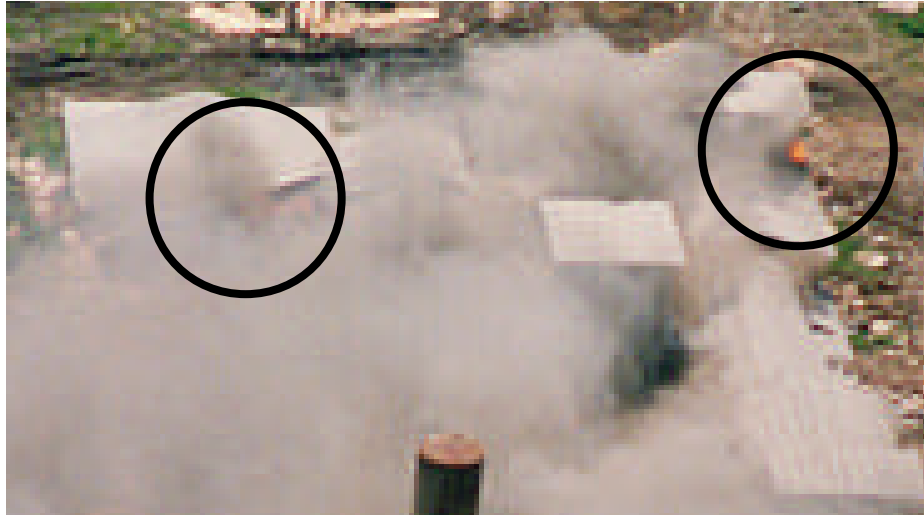


Photo 7-6

Figure 2.8 Aerial photo from approximately 12:11 p.m. First sighting of flames on aerial photos at collapsed catwalk roof. Flames are also seen at the Red/White corner.

Fire A then burnt intensively and generated large amounts of black smoke when the asphalt of the roof covering got involved. The wind, however, hampered the fire from spreading to the rest of the complex, and not until a rather later stage did it merge with fire C, which started in the Red/White tower, see Figure 2.9.



Photo 7-36

Figure 2.9 Aerial photo from approximately 12:16 p.m. Fire A merges with fire B.

Table 2.1 summarizes the main events of Fire A.

Table 2.1 Summary of observations of Fire A at the chapel/stage area

Time	Media	Event
12:04:23	FLIR	A first faint image of heating is detected on the FLIR tape, see Ref. 4.
12:04:51	FLIR	Heating starts of catwalk roof eave according to numerical analysis of FLIR images (Ref. 4), see diagram in Figure 2.5.
12:06:13	FLIR	A second faint image of heating is detected on the FLIR tape, see Ref. 4.
12:09:10 to 12:10:21	Ground photo	Fires in debris under catwalk, see Figure 2.6.
12:10:21	FLIR	Intense flaming starts to develop at the collapsed gym roof, see Figure 2.7.
12:11	Aerial photo	First aerial photo sighting of flames at catwalk roof, see Figure 2.8.
12:16	Aerial photo	Fire merges with the fire which started in the Red/White tower, see Figure 2.9.

2.4.2 Fire B The cafeteria/kitchen

Fire B started in the cafeteria/kitchen. It was first detected by the FLIR at 12:08:10, see Figure 2.10.



Figure 2.10 FLIR at 12:08:10. The first sighting of fire on the cafeteria wall.

Shortly afterwards at 12:08:11 white smoke over the cafeteria roof came in sight in the CBC TV sequence. The smoke peaked after about a minute and then the intensity seems to go down, see Figure 2.11.



Figure 2.11 CBC at 12:08:24 and at 12:09:13. White smoke coming out from the rear of cafeteria. (For correction of time, see Section 2.3.)

A series of ground photos were taken by the FBI some time between 12:08:10 and 12:08:58, see Figure 2.12. These photos show flames penetrating through the Black Side wall of the cafeteria due to a pressure rise in the early stage of the fire, see Section 3.1.2 and Appendix D. On the right photo of Figure 2.12, flames are seen on both sides of the cafeteria Black Side outer door.



Figure 2.12 FBI ground photos from the Black Side at 12:08:10 to 12:08:58. Flames penetrating through the Black Side wall of cafeteria are circled.

The first aerial photo showing flames of the cafeteria fire was taken at about 12:10:40, see Figure 2.13.



Photo 7-4

Figure 2.13 Aerial photo 12:10:40. First aerial sighting of flames outside the building at the cafeteria Black Side wall.

The flaming on the Black Side of the cafeteria increases and shortly before 12:12:25 black smoke starts to develop as the cafeteria roof ignites at the Black Side eave near the center tower, see Figure 2.14.



Photo 7-18

Figure 2.14 Aerial photo 12:12:25. The cafeteria roof has ignited and the smoke turns black.

At about 12:14 p.m the cafeteria roof burns through, see the two consecutive photos of Figure 2.15.



Photo 7-26



Photo 7-27

Figure 2.15 Aerial photos at about 12:14 p.m. The cafeteria roof burns intensively on the left photo. On the right photo the roof has burnt through and the roof rafters are visible.

Table 2.2 summarizes the main events of Fire B.

Table 2.2 Summary of observations of Fire B at the cafeteria/kitchen area.

Time	Media	Event
12:08:10	FLIR	First heat image on Black Side wall, see Figure 2.10.
12:08:10 to 12:08:58	Ground photos	Flames coming through Black Side wall, see Figure 2.12.
12:08:11	CBC	First sighting of white smoke streaming out from rear of cafeteria, see Figure 2.11.
12:08:26	FLIR	Two heat images on Black Side wall.
12:10:40	Aerial photo	First sighting of flames on aerial photo, see Figure 2.13.
App. 12:12:00	Aerial photo	Red Side of cafeteria roof starts to burn, see Figure 2.14.
App. 12:13:55	Aerial photos	Red Side of cafeteria roof burns through, see Figure 2.15.

2.4.3 Fire C in the Red/White tower

Fire C started on the second floor of the Red/White tower. It was first seen by the FLIR tape at 12:07:41, in the window of the White Side and then ten seconds later on the Red Side at 12:07:51. See Figure 2.16 and Figure 2.17, respectively.

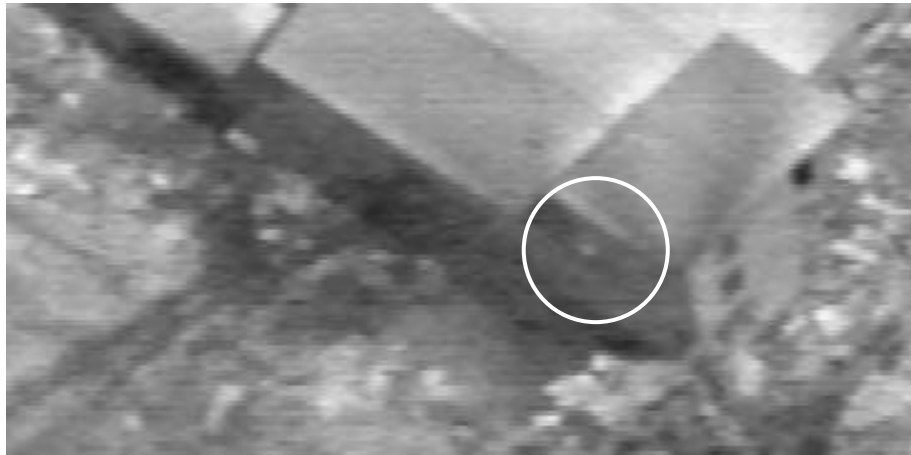


Figure 2.16 FLIR image 12:07:41. The first image of hot air is coming from the Red/White tower (circled).



Figure 2.17 FLIR image 12:07:51. The first heat image in the second floor Red Side window of the Red/White tower (circled).

Heat images caused by conduction through the outer wall appear on the FLIR imagery at 12:09:09. Shortly thereafter at 12:09:25, see Figure 2.18, heat images are discovered in the second floor window to the left of the tower.



Figure 2.18 FLIR image 12:09:25. A bright heat image in the second floor window immediately to the left of the tower. Heat images also due to heat conducted through second floor tower wall. The wood studs appear as cooler (darker) than the fields between.

The first flames are seen on the CBC TV-footage at 12:09:42, see Figure 2.19. These flames appear intermittently depending on the gusty wind and appear alternatively from the White Side and the Red Side of the tower.

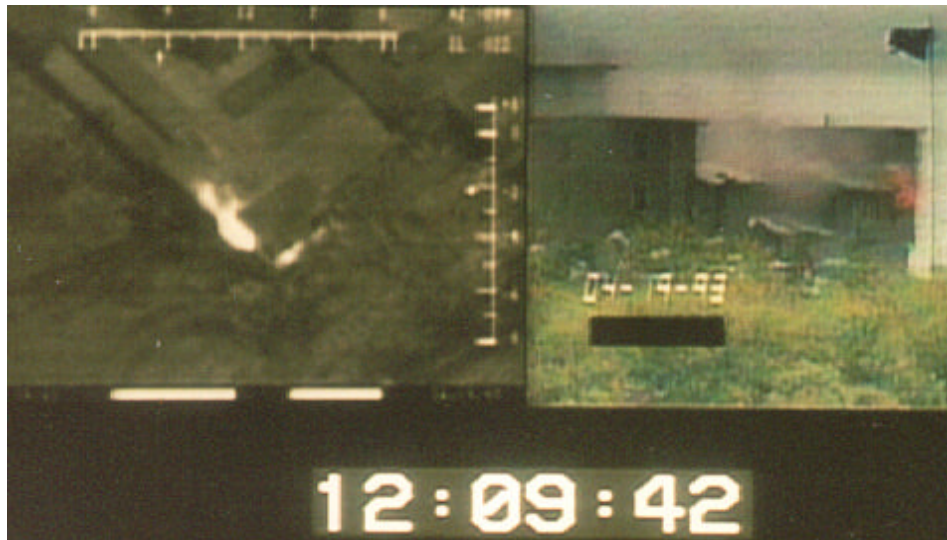


Figure 2.19 Simultaneous FLIR and TV-footage at 12:09:42. First flames emerging from the Red/White tower.

The first aerial photo showing flames in the Red/White tower was taken around 12:10:20, see Figure 2.20. The time estimate is based on the position of the CEV seen in lower left corner of the picture.



Photo 7-1

Figure 2.20 Aerial photo around 12:10:20. The first sighting of flames in the Red/White on aerial photos are seen in the second floor window.

Smoke starts to emerge at 12:13:49 from the first floor on the White Side. The intense flow continues for about three minutes, as shown in Figure 2.21.



Figure 2.21 TV-footage at 12:13:49. Smoke belches out at the White Side of the between 12:13:49 and 12:16:50. (For correction of time, see Section 2.3).

At about 12:16 p.m. the Red/White tower walls start to burn through, see Figure 2.9.

Table 2.3 summarizes the main events of Fire C.

Table 2.3 Summary of observations of Fire C in the Red/White tower

Time	Media	Event
12:07:41	FLIR	A heat image is first seen in the front second floor window of the right tower. No increase in pixel intensity could be detected on the White Side wall on the Red/White tower previous to this time. See Figure 2.16.
12:07:51	FLIR	A heat image is seen in the Red Side window of the second floor of the Red/White tower. See Figure 2.17.
12:09:09	FLIR	Heat images on the outside White Side tower wall.
12:09:25	FLIR	Heat images in the second floor window immediately to the left of the tower. See Figure 2.18.
12:09:42	CBC	Flames begin to emerge at second floor White Side, see Figure 2.19. Flames continue at a slowly increasing intensity to emerge alternatively on the White and Red Sides depending on the wind direction, see Figure 3.8
12:10:20	Aerial photo	First aerial photo sighting of flames on White Side of the tower, see Figure 2.20.
12:13:49 to 12:16:50	CBC	Smoke belches out on the White Side, see Figure 2.21.
12:16	Aerial photo	Red/White tower walls burn through, see Figure 2.9.
12:25:00	CBC	Red/White tower collapses.

3 Analysis of the fire development

3.1 General

Fires were started at several positions in the complex. Three separate fires developed into large fires that eventually burnt down the whole Branch Davidian complex. The remaining fires extinguished themselves when the liquid ignition sources were consumed. As can be seen in Figure 3.1 hot gases leave the building at many places, indicating that separate fires have been started at several locations. There are many heat images on the second floor green end of the main building. These fires did not develop and did not get involved again until very late in the fire, around 12:20 p.m. when fire spread from the cafeteria.

Large parts of the building, including the chapel and two stories of the main building, had interior linings of non-combustible drywall (gypsum boards). That is an important reason why the fire did not spread faster than it actually did. Drywall resists intensive fire exposure for 15 to 20 minutes. As a matter of fact the fire spread to a very large extent via facades and roof constructions. The roof coverings contained asphalt, which ignited easily and burnt intensively.



Figure 3.1 FLIR image 12:10:19. Hot gases are indicated in several places of the second floor and along the Black Side of the cafeteria.

3.1.1 Fire A at the stage in the rear of the chapel

The first faintly visible heat image of the fire at the stage in the rear of the chapel was discovered on the FLIR at 12:04:23, and the first indication of fire derived from an numerical analysis of the FLIR pixels occurred at 12:04:51, see Section 2.4.1. The heat signatures are from smoke and heat that had traveled in the wind direction from the stage area. In order to be detected by the FLIR, the fire in the stage area must have reached certain intensity yielding smoke at the eave of the catwalk roof that was sufficiently hot and dense to be detected by the FLIR. However, as the rate of development in the early stage of a fire can vary, estimates of when this fire may have started are difficult to make. Given the fire was started with accelerants, it is reasonable to assume that this fire started shortly before 12:04 p.m.

The fire at that early phase developed in the debris of the damaged gymnasium. At about 12:10 p.m. the roof covering on the catwalk ignited and burnt vigorously producing a large amount of black smoke, see Figure 3.2 and Figure 3.3.



Photo 7-7

Figure 3.2 Aerial photo at about 12:10 p.m. The fire in the debris of the damaged gym developed quickly and ignited the roof covering which burnt and produced large amounts of black smoke.



Figure 3.3 FBI ground photo from the Red/Black corner. The fire in the Red/White tower and the fire at the stage at the rear of the chapel are two separate fires.

The fire spread slowly against the wind towards the chapel and did not merge with the fire, which started at the Red/White tower (Fire C) until about 12:16 p.m., see Figure 2.9.

3.1.2 Fire B in the cafeteria/kitchen area

The first indications of a fire in the cafeteria/kitchen are the hot spots (flames) detected by the FLIR at 12:08:10 (Figure 2.10) and 12:08:26 on the Black Side wall. Heat penetration tests, c.f. Annex B, indicate that it takes about 3 minutes for heat to

penetrate by conduction 1/2" of plywood and create a temperature rise of 10°C on the side unexposed to fire. The cafeteria wall was only 3/8" to 1/2" thick, see Section 2.1.

The FLIR image at 12:08:10 (Figure 2.10) shows no sign of a temperature rise in the wall surface. It shows only flames penetrating through the wall, cf. Figure 2.12. This indicates that the heating of the larger parts cafeteria Black Side wall must have started later than 12:05. On the other hand, the FLIR imagery of 12:10:22 (Figure 2.7) shows heat images on all the boarded windows on the Black Side wall of the cafeteria. This indicates that flashover or full fire involvement has occurred two to three minutes earlier, i.e. about 12:08 p.m. or at the same time as flames were seen penetrating through the Black Side wall.

The large amounts liquid fuel ignited inside the cafeteria caused the flames evident in the FBI ground photos of Figure 2.12. The intense burning that followed the ignition of accelerants and other easily ignitable combustibles raised the pressure inside the cafeteria and pressed fuel vapor out through the thin and poor wall construction, see Annex D. No flames occurred around the door presumably because it was blocked to prevent the FBI from coming in.

The cafeteria was more or less a closed space. As a result an overpressure was generated in the cafeteria when the temperature of the internal gas mass rose due to the fire. The windows were boarded and only two doors existed internally. To be clear there was no explosion. However, the pressure rose by approximately the same magnitude as the wind pressure or more, which was enough to force fuel vapor through the poor wall construction. At the time the photos of Figure 2.12 were taken, the Black Side wall of the cafeteria had already been exposed to fire for some time and had become damaged and more permeable. Figure 3.4 shows the White Side



Figure 3.4 FBI ground photo. The Green/White tower on fire. Similar holes as shown here on the third floor allowed flames to emerge out of the cafeteria Black Side wall in the very early stage of the fire, cf. Figure 2.12.

of tower in a late stage of the fire. Like the cafeteria wall, the third floor of the Green/White tower have no interior sheet covering. This is evident as the flames are

seen through the poor construction. If the wind pressure had been in the other direction flames would have emerged out these holes as they did at the cafeteria wall in the beginning of the fire at around 12:08 p.m. For a detailed analysis of the pressure rise see Appendix D.

After the expansion of the gas mass inside the cafeteria (lasting 30 seconds or less), the fire intensity inside the cafeteria went down as the liquid accelerants were consumed and the oxygen concentration was reduced. The fire, however, continued to burn inside the cafeteria and at the eave of the roof. It appears that the board covering the window to the left of the cafeteria door fell down or was opened by the gas pressure allowing the hot fire gases to come out. This had a profound effect on the fire conditions in the cafeteria. Note in Figure 3.5 that the boarding of the window to the left of the door is weaker than the boarding of the window to right of the door. The patch in at the upper right corner of that boarding is not fastened in its lower left corner.



Figure 3.5 FBI ground photo from the Black Side of the cafeteria. The board covering of the window to the left of the door appears weak and may have fallen when liquid fuel was ignited and the interior pressure increased.

At around 12:12 p.m. the fire spreads to the roof and the smoke turns black from the cafeteria roof area, see behind the center tower in Figure 3.6. See also Figure 2.14. The black smoke comes from the burning asphalt of the roof covering.



Photo 7-16



Photo 7-17

Figure 3.6 Aerial photos at around 12:12 p.m. The smoke from the cafeteria area turns black when the roof covering starts to burn.

The cafeteria roof consisted of 3/8" plywood sheets covered with roof felt and rolled asphalt or asphalt shingles, which did not burn through during 15 minutes of intense fire exposure, cf. Annex B. However, Cone Calorimeter tests with the 3/8" plywood showed that the specimens were consumed after about 7 minutes, cf. Annex C. The mounting of the specimen with a backing material and better access to air and oxygen in the Cone Calorimeter test, in comparison to the furnace tests explains this discrepancy in time between the two tests methods. In the Branch Davidian fire the roof burnt from two sides from about 12:12 p.m., which of course reduces the burn through time. Thus, the burn through time would indicate that a ceiling fire was developed in the cafeteria already at about 7 to 15 minutes before the roof burnt through at 12:14 p.m., i.e. between 11:59 and 12:07 p.m. These estimates are of course very rough and uncertain, as they depend on the actual quality of the plywood. It is just noted that the time of ignition maybe put further back in time than the conservative time concluded below.

3.1.3 Fire C in the Red/White tower

Fire C is first seen on the FLIR imagery at 12:07:41 in the second floor window of the White Side of the Red/White tower. During the aircraft's immediately preceding circle of the compound, the FLIR captured the Red Side of the tower until 12:06:14 and the Black Side of the tower until 12:06:41. The Black Side of the tower is downwind and even a relatively small fire in the tower at 12:06:41 would have been discovered by the FLIR by its hot smoke. From this time and the quick development that subsequently occurs, I conclude that the fire in the Red/White tower must have started sometime between 12:06:30 and 12:07:30.

Flames were first seen from the second floor window of the Red/White tower, White Side at 12:09:42. This was captured by the news media, see Figure 2.19. The ignition source was powerful and flames emerged out of the second floor windows both on the Red and the White Sides. The wind, however, cooled the fire, and temperatures therefore did not become as high as they otherwise would have been.

It has been claimed that the fire may have started by lanterns, tipped over when a CEV hit the Red/White corner of the complex shortly before the fire started. The lanterns in question contain at most about one liter of liquid fuel. They are of a robust construction and are unlikely, even if they fall to the floor, to quickly let the fuel out and start an intense fire in the Red/White tower.

The tower walls were made of wood studs covered only with 3/8" to 1/2" thick external wood boards. These burn through in about 10 to 15 minutes at the relatively low irradiance level of 25 kW/m², see the Cone Calorimeter tests reported in Annex C. The first hole in the exterior walls, limited to an area near a presumable ignition source, is observed at around 12:15 pm. A total collapse did not occur until 12:25.

The wind cooled the fire in the early stage and therefore it took a rather long time for high temperatures to develop and full involvement or flashover to occur. In general after flashover, the fire becomes very hot and so much combustible gas is produced inside the compartment in relation to the ventilation, that these gases cannot burn inside the compartment, see also Section 1.6.2. Thus, as the time to flashover was extended due to the wind, the fire development was delayed and the fire did not spread into the second floor corridor in the center of the building until a relatively late stage. Ultimately, the fire spread with the wind moving towards the chapel and igniting its roof at about 12:14 p.m. Note in Figure 3.7 how the smoke at the Red/White tower has turned black, as the asphalt of the chapel roof covering has started to burn.



Photo 7-28

Figure 3.7 Aerial photo at 12:14:10. The fire in the Red/White tower spreads with the wind and ignites the chapel roof.

The fire inside the chapel developed slowly. Even by 12:16 p.m. there are no flames from the Red Side windows, and the roof at that end has not yet ignited, see Figure 2.9.

3.2 Conclusion

The occupants of the Branch Davidian complex started numerous fires using liquid fuels and other easily ignitable combustibles. Three of those fires developed into sustained burning fires and each started within a short period of time, i.e.

- Fire A in the stage area shortly before 12:04 p.m.
- Fire B in the cafeteria between 12:05 and 12:06 p.m.
- Fire C in the Red/White tower between 12:06:30 and 12:07:30 p.m.

The above ignition times are supported by the FLIR tapes, photos, videos and testing performed by SP, and are my best estimate given that fires in the early stage can develop very differently depending type of fuel, fuel configuration and ventilation.

It is beyond credibility that the three fires could have started in a similar fashion, yet independent of one another. These fires must therefore have been started deliberately and I have seen no evidence or indications that they could have been started by anyone but the occupants.

3.3 Wind effects

The wind can have a dramatic effect on the development of a fire and may even extinguish a fire. Depending upon the circumstances, the wind can either speed up or delay fire development. In theory, the highest temperatures in a fire, or any combustion process, are obtained when the relation between the amounts of fuel and oxygen (or air) is optimal. This is called stoichiometric combustion. In general, too much air cools a fire, as the excess air cannot participate in the combustion process. In practice roof vents are often installed in industrial buildings to permit hot fire gases to leave a building and be replaced by cool fresh air. It is also common practice for fire fighters to punch holes in roofs to cool off a fire and facilitate extinguishments.

However, after flashover, when not enough air is available inside the fire compartment to maintain combustion of the gases, additional ventilation will increase the combustion rate inside the room and the temperature will continue to increase. Winds can also speed wood fires when surface glowing has developed or on fires situated deep inside a fuel bed where fresh air otherwise does not reach.

Another basic fire principal is that fires spread with the flames, i.e. upwards or with the wind. A bushfire spreads rapidly with the wind because the flames bend over allowing the fire to spread horizontally. In general, a room fire spreads slowly until the flames hit the ceiling and start to travel horizontally along the ceiling, often along a wall. If the ceiling or the wall is combustible it will contribute to the burning and the intensity of the fire can increase rapidly.

In the case of the Branch Davidian fire, the wind both sped up and retarded the fire development as discussed below. On April 19, 1993, the wind was strong coming from the direction of the Red/White corner. At 6.02 a.m. the wind speed was reported to be 20 kt (10 m/s) with gusts up to 28 kt (14 m/s)⁴.

Fire A at the stage at the rear of the chapel was influenced by the wind as the fire in the debris of the damaged building was accelerated by the wind. However, the wind retarded the spread of the fire towards the chapel and the rest of the complex.

Fire B in the cafeteria/kitchen area was not as sensitive to the wind in the early stage of the fire as there was no large opening on the leeward side of the building in the very beginning of the fire. The wind, however, did cause an under-pressure on the leeward side, i.e. the outside of Black Side wall of the cafeteria. The under-pressure in combination with the inside overpressure due to rapid fire development, see Section 2.4.2, caused the fire gases and flames to penetrate through the Black Side wall, see Figure 2.12.

In a later stage of the fire between 12:08 and 12:45 p.m., when an opening was established on the Black Side wall of the cafeteria, the wind created a draft through the building from the White Side to the Black Side. This forced flames and heat towards the Black Side of the complex, and kept the White Side relatively free from smoke and hot gases.

Fire C in the Red/White tower was started using large amounts of liquid fuels. Flames emerged at 12:09:42 from the second floor White Side window of the tower. At this early stage of the fire the wind forced the flames of the mainly liquid fire out the tower windows. Flames then continued to emerge out the windows alternatively from the White Side and the Red Side, see Figure 3.8. Without the wind, the flames would have stayed at one position heating and igniting the ceiling and the walls within a couple of minutes.



7-16



7-17

Figure 3.8 Aerial photos at 12:12:30. Two consecutive photos. The flames appear alternatively from the white and the Red Side tower windows. Intensive flames in the chapel.

We know from Cone Calorimeter tests, see annex C, that it takes 30 seconds to two minutes of continuous heating to ignite wooden linings similar to those in the Branch Davidian complex. The wind caused the flame inside the second floor room of the Red/White tower to move around heating some parts of the room for a short time and then allowing them to cool. The wind therefore cooled the room and slowed the development of a hot gas layer under the ceiling. Without the wind, the walls and ceilings of this room would have ignited much earlier and the fire intensity would have increased more rapidly than actually occurred. Note that the walls and ceilings have a very large surface that can burn. Wood does not burn at the same rate as liquid fuels, but the wooden structure constitutes the major part of the fuel load of this fire.

In conclusion, the Red/White tower would have burnt down faster without the strong wind. Other fires were also started in the complex, which were extinguished by themselves. The strong wind may have contributed to this as well.

4 Possibilities of escape

Fire B in the cafeteria/kitchen area is definitely the most critical for the safety of the occupants of the Branch Davidian complex. Most of the victims were found in the concrete bunker and immediately in front of it. From that position there are four ways to escape, through the cafeteria, up the stairs through the second floor, through the

windows on the first floor White Side, and through the holes made by a CEV on the White Side.

One or more fires were started in the cafeteria and quickly filled that space with smoke blocking any escape. The staircase was involved early in the fire by 12:10:19. See the FLIR image shown in Figure 4.1. Thus this route may have been blocked in an early stage as well. Two cans of fuel with holes were found in this area after the fire.



Figure 4.1 FLIR image 12:10:19. Hot gases or flames are indicated in the windows of the staircase and of the adjacent room.

Whether escape was possible through the White Side windows and the CEV holes depends on where fires were started in relation to the positions of the occupants. No fire was likely started immediately in front of the bunker opening or towards the White Side of that opening, as it took a very long time before the roof above the kitchen to burn through, see Figure 2.9. This may, however, been driven by the fact that the ceiling in that part of the building was covered with noncombustible sheetrock boards.

A fully developed fire did not probably develop in the bunker itself in an early stage. This would have caused flames and hot gases to leave out through its only opening which would have ignited the ceiling outside the bunker opening. This seems not to have occurred, as no heat sources on the roof at the White Side of the bunker were detected on the FLIR imagery, nor did it burn through in an early stage. A minor fire may, however, have been started in the bunker, which could have blocked the entrance and released enough toxic gases to cause lethal conditions in the confined area of the bunker. The hole in the bunker ceiling created by spalling, see chapter 6, could not have been an escape point for fire gases, as spalling does not occur until late in a fire when very high temperatures have developed.

Those who were outside the bunker must have been aware of the fire burning in the cafeteria and could have exited through the many holes on the White Side. In fact, nobody left the building from the first floor of the White Side. Those four who escaped the fire from the White Side did so at a rather late stage from the second floor of the complex. The staircase from the cafeteria was blocked by fire very early so these people must have either been on the second floor when the fire started or entered via another

staircase. Figure 4.2 from the final report of Walter Wetherington³ shows generally where nine Davidians escaped the fire.

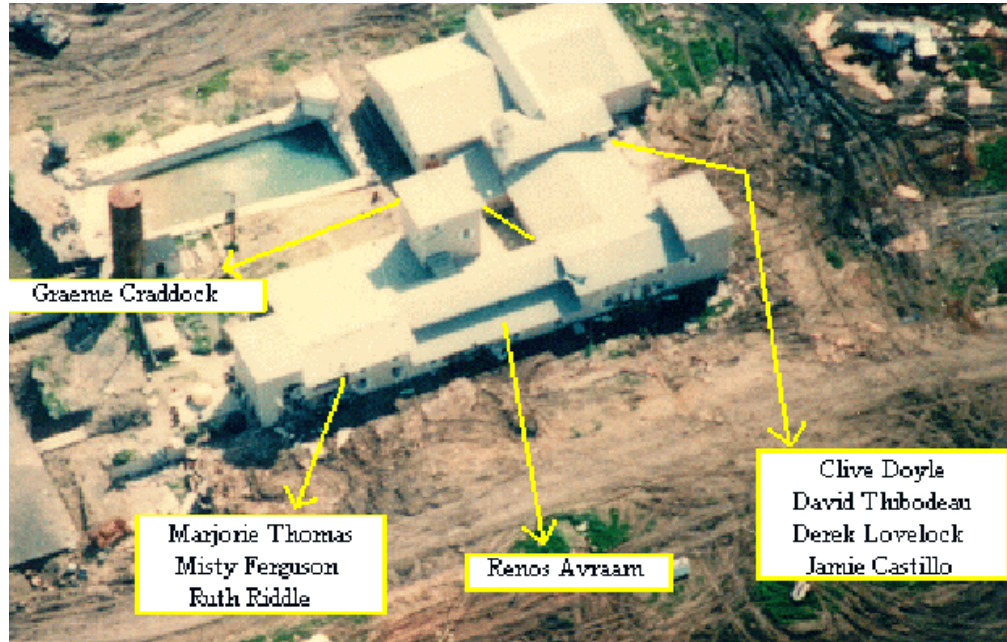


Figure 4.2 Davidians' escape routes from fire. This drawing is reproduced from the final report of Walter Wetherington³.

4.1 Conclusion

In summary, I believe that all the occupants could have left the building if they so wanted, except possibly those residing in the bunker or those being forced to stay.

5 Possibilities of fire fighting and rescuing

The discussion below assumes that fire fighters could respond without risk of being killed or repelled by Branch Davidian gunfire. My knowledge and experience of fire extinguishment is based on the activities I follow at the Department of Fire Technology of SP, where we daily conduct extinguishing tests and where we have several experts on fire extinguishment procedures, which I have consulted. My opinion in this regard is based on theoretical knowledge and not on practical experience of fire fighting.

Although the fire was started with lots of accelerants, there are circumstances that would facilitate fire fighting in an early stage. The building was easy to access as it had, in principal only two stories and no long internal access routes. Moreover, fire gases could efficiently be evacuated due to the wind and the many openings, including those created by the CEVs. Therefore, the fire would have been relatively easy to knock down and control in an early stage, when the combustible structure and solid items are still cool except for thin burning surface layers, and no glowing, deep-seated, fire pockets have yet formed. I want to stress that to fight the fire successfully it has to be in very early stage requiring equipment and personal on site, adjacent to the building, when the fire broke out.



In particular if the rescue operation were directed towards the central area and the bunker, additional time could have been given for the people to escape. Even those in the bunker could have been helped unless a fire had been started inside the bunker as well.

Fire A at the stage at the rear of the chapel would be difficult to fight, but it is, on the other hand, of rather limited importance for the safety of the occupants. It could have been attacked with success from the Black Side when it was very small and before the smoke became too dense. It could of course also have been attacked via the chapel, but the fire was not directly accessible that way.

Fire B in the cafeteria/kitchen area is relatively difficult to fight, as it is situated inside the building and not directly accessible from the windward direction. However, I still believe a successful fire fighting and rescuing operation could have been carried out if started early enough, that is, before the wooden structure and other solid combustible items had ignited and before the heat had penetrated deeply into the burning objects and no glowing was formed. I would roughly estimate the available time for a successful rescue operation is up until 12:09 p.m. That is about two and a half minutes after flames were photographed on the back side (Black Side) of the cafeteria. The amount of high quality modern dry powder needed to knock down the fire in the cafeteria in an early stage is in the order of 50 kg (110 lb). This would give about 140 g/m^3 , as the volume of the cafeteria is 370 m^3 (4000 ft^2). This value is well on the safe side to knock down the fire and if followed by limited amounts of water from a fire truck the fire could probably have been extinguished. Dry powders are in general not toxic.

I believe that Fire C in the white/red corner could have been extinguished with about the same amount of dry chemical powder if applied within a one or two minutes after flames were seen outside the compartment, i.e. around 12:11 p.m, when the fire had not yet spread to the interior of the building. The extinguishing media could have been applied from the outside with suitable equipment mounted on a specialized vehicles, e.g. airport fire service trucks using mixtures of dry chemical powder and gaseous extinguishing media like halon 1211. Halon 1211 is an agent often used in e.g. portable fire extinguishers.

5.1 Conclusion

At least theoretically the fire could have been successfully fought if conducted within a few minutes after the fires were ignited and discovered. The response, however, would have to be direct and immediate, that is, equipment and personnel ready on scene, adjacent to the complex, and with knowledge of the layout of the Branch Davidian complex and the location of people. The Office of Special Counsel has advised me that during the early stages of the fire Davidians were shooting at and repelling outsiders. As a result, firefighters could not safely approach the complex until after 12:30 p.m. Under these circumstances the fire would have progressed too far by 12:30 p.m. to have been controlled or stopped by any means.

6 Comments on center bunker damages

I understand that some experts claim that the hole discovered in the center bunker was made by a "demolition charge" that went off on the ceiling. See Figure 6.1



Figure 6.1 FBI photo. The hole in the concrete ceiling slab of the bunker. Note the poor concrete quality.

I have carefully studied pictures that I have received from the OSC and I have made the following observations.

1. From the TV footage of the final demolition of the center bunker and from Figure 6.2 it is evident that the bunker had brick or cinder block walls covered in a thin coat of plaster or cement. This type of wall is very brittle, which is obvious from the TV footage of the demolition. This type of wall can carry gravity loading, but is sensitive to impact loading, for example, from an earthquake or an explosion.



Figure 6.2 FBI photo. Bunker walls were made of plastered cinder blocks.

2. The bunker was constructed in the 1930's and was subject to a fire in 1980. Concrete does in principal not deteriorate over time, but the qualities of cement from the 1930's are inferior to modern qualities. The fire exposure from 1980

may well have given the concrete irrecoverable internal damages that influenced its strength. On April 19, 1993, the bunker was exposed to fire for a long time and the concrete was exposed to intensive heating from above and from below. The temperature in the concrete therefore varied substantially over the thickness, as well as over the plane of the slab. Thus, internal stresses developed when the concrete expanded due to the temperature rise. Stresses also developed due to water steam pressure when the concrete temperature passed the boiling point of water of 100 °C. When the total stresses passed the strength of the concrete, it spalled off smaller or larger pieces. In this case the concrete was of low quality and had been exposed to a previous fire, cf. Figure 6.1 and Figure 6.3.



Figure 6.3 Spalling occurred at several places of the bunker slab due to intense fire exposure from below and from above.

3. Spalling is generally a random phenomenon, but is quite common. Figure 6.4 shows two examples from the literature of spalling of fire exposed concrete structures.

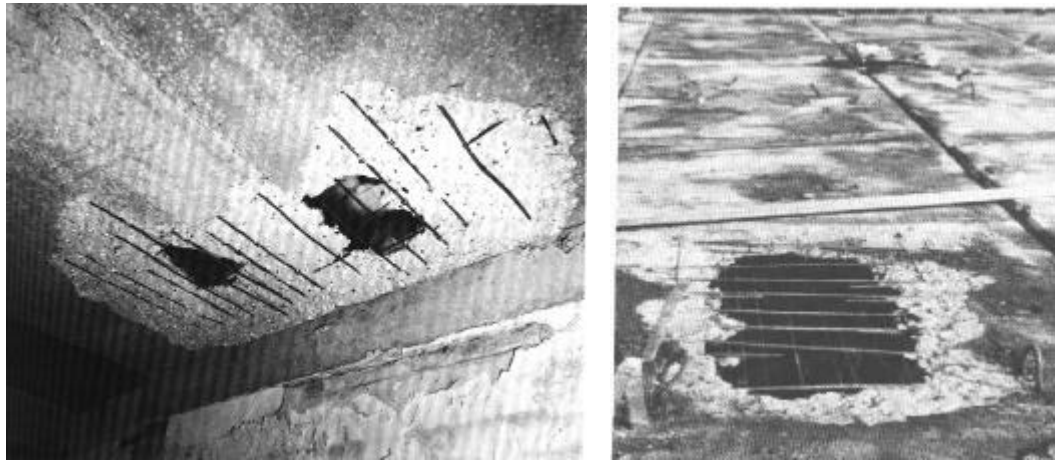


Figure 6.4 Example of spalling of concrete structures exposed to fire found in the literature⁵.

4. As can be seen in Figure 6.3 the hole developed near one of the beams. That is a weak point of the slab as it is only reinforced for sagging. The concrete therefore cracked under load at the top surface along the beam while compression developed at the bottom surface.
5. The visually shallow concrete coverage of the reinforcement bars, sometimes in a diagonal direction, gives an impression of a non-professional building technique.

6.1 Conclusion

Based on the photos I have seen and the knowledge of the fire that the bunker top slab has been exposed to, I conclude that the hole was caused by spalling which resulted from the intensive heat of the fire.

7 Comments on reports of other investigators

In preparing this report the OSC provided me with several reports by other experts on this same subject matter. In particular I have been asked to consider the reports of the Drs. James G. Quintiere and Fredrick Mowrer, of September 1993¹, and the briefing conducted by Patrick M. Kennedy, October 1999⁶ and his report and declaration of February 2000⁷.

7.1 Quintiere and Mowrer

Quintiere and Mowrer¹ have made a very comprehensive and accurate compilation of the fire events observed mainly from the FLIR video, the CBC television broadcasting, channel 10 of Waco live coverage and 7 rolls of 36 color prints. Most importantly, I do agree with Drs. Quintiere and Mowrer that three separate fires cannot start accidentally at the same time. I agree that the fires inside the Branch Davidian complex were intentionally started.

Quintiere and Mowrer have analyzed these fires using theories that are developed for room fires with “normal” fuel loads and with no wind effects. I do not think such theories apply in this case. The early stage of the Branch Davidian complex fire is

controlled by the accelerants. As a result, the fire develops very quickly in the beginning and then goes down when the liquid fuel is consumed. Contrary to Quintiere and Mowrer's analysis I do not believe it is reasonable to assume that the fires double in a given time.

Moreover, it is not reasonable to apply conventional rules for calculating ventilation rates. The wind effects dominate the buoyancy effect developed by the fire. Therefore, I believe the theoretical base of their considerations of the fire development is weak. Drs. Quintiere and Mowrer contend that the wind had a profound effect on the external fire, but that it did not appear to have had a significant effect on the fire growth within the complex. I do not agree. I believe the strong wind in combination with open windows had a strong effect on the fire development in three ways: several fires were extinguished by the wind, the wind cooled the fires and delayed flashover, and finally the wind prevented the fire to spread against its direction. The wind also had a significant effect on the possibilities for escape and to fight the fire. The wind actually kept the White Side of the building relatively unaffected by the fire for a long time.

7.2 Patrick Kennedy

Patrick Kennedy⁷ claims that the U.S. Government expert investigation of the fire was "fatally flawed." Below I have commented on his key observations relevant to my investigation as outlined in his report under "Overview of Report and Declaration."

A *"The government's fire investigation was fatally flawed."*

I have reviewed several reports of the government's experts, see Table 1.1, and I have not noticed any important information that has been misused or left out in coming to the main conclusion that the fire was simultaneously and intentionally started at at least three places in the Branch Davidian Complex.

B *"The government's fire experts opinions that there were three separate, simultaneous fires and Davidian arson are unreliable."*

Based on the FLIR video and photos like the one in Figure 7.1, I am strongly convinced that fires started in at least three separate locations. Mr. Kennedy expressed doubt in using the FLIR recordings as evidence for the fire development. Even without the FLIR imagery it is clear that the fire started in at least three locations.



Photo 7-7



Photo 7-11

Figure 7.1 Aerial photos approximately 12:10:30 and 12:11:45, respectively.

A fundamental fact is that the first flames were observed on the TV footage at 12:09:42 and the photos in Figure 7.1 were taken only a minute or two afterwards. This cannot happen unless more than one fire was started. Given the wind direction and its strength, a fire could spread neither from the cafeteria nor from the gym area to the Red/White tower in such a short time. If started in the Red/White tower second floor, on the other hand, the fire could not spread to the cafeteria (first floor), as fires do not easily or quickly spread downwards.

Other possibilities could of course be considered, but I cannot see any credible explanation for the fire development other than there has been multiple ignition sources. In particular, none of the means (a) to (h) listed by Kennedy⁷ on page 13 in his report are relevant.

C. *“The government’s fire experts’ opinion that there was Davidian arson ignores potential ignition of the fire by government actions.”*

Three fires developed very fast in the first phase. That excludes the possibility of small ignition sources. The Branch Davidian complex was carefully surveyed when the fire started and observations were recorded by both conventional means, aerial and ground photos and TV sequences, and video sensitive to infrared radiation (FLIR). The observations from the first indication of a fire until full fire involvement is so short that it could not have happened without the use of accelerants. Moreover, based on the tests reported in Annex A, I concluded that the tested projectiles and the Flash Bang grenade left remains after exposure to the severe fire conditions. Thus had an M651 military round been responsible for a fire inside the compound, it would have been found amidst the fire debris.

D. *“The government’s fire experts’ opinion that flammable liquids were intentionally used to accelerate the fire is unreliable.”*

See above. Also see analysis of physical evidence in Wetherington’s report³.

E. *“Though not relied on by the government’s fire experts, purported Davidian statements are unreliable and inconclusive.”*

No comments. See Davidians statements related in Wetherington’s report³.

F. *“The government’s destruction of the fire scene made it impossible to answer the questions left open by the government’s inadequate fire investigation.”*

For my analysis of the fire development, little would probably have been gained by a visit to the fire scene. My analysis is based on pictorial evidence.

G. *“The government’s position that it had no role in the fire-related deaths is erroneous.”*

As outlined in Chapter 5, I believe the fire could have been fought in an early stage under certain circumstances. Not necessarily by airborne extinguishment with water, but probably more efficiently with dry chemical powder possibly mixed with gaseous extinguishing media. These extinguishing media are very efficient on liquid fires and also on wood fires in an early stage when the heat has not yet penetrated into the wood and no glowing wood fires have yet developed. However, as stated earlier, because the

fire fighters could not safely approach the complex until after 12:30 p.m., it was not possible for them to extinguish this fire.

The demolition of the building had an effect on the fire, in particular fire A, which started at the stage at the rear of the chapel. This fire, however, spread very slowly towards the wind and never became a direct threat to the occupants. Whether the demolition at the center of the building had any influence on the fire in that area is hard to exactly know. No doubt the opening provided a way for escape and it cleared the way from smoke. On the other hand, it could make the circumstances worse for the occupants situated in the wind direction and make the building easier to ignite. The fact is, however, there was no fire near the CEV holes on the White Side until a very stage late of the fire, i.e. after 12:22 p.m.

8 Final conclusions

The assignment of this work is outlined in Section 1.1 and repeated in *italics* below. After having completed this investigation I have come to the following conclusions concerning the listed questions at issue:

- 1) *Determine whether agents of the United States started or contributed to the spread of the fire that killed members of the Branch Davidian group on April 19, 1993;*

I see no evidence that agents of the United States started or contributed to the spread of the fire that killed members of the Branch Davidian group on April 19, 1993.

- 2) *Determine whether additional information can be developed concerning the cause and/or point(s) of origin of the fire;*

By carefully studying the material provided to me, I have in cooperation with OSC experts Klasén and Madsen⁴, and Wetherington³ improved and widened the information about the fire development. In particular the times and origins of the various fires have been thoroughly investigated.

- 3) *Determine time of ignition for individual fires;*

The fire was started in at least three separate locations. The early parts of the fires have been thoroughly investigated and the best possible estimates of the time of initiations of the fires have been determined.

- 4) *Determine whether fire fighters could have controlled or stopped the spread of the fire;*

At least theoretically, the fire could have been successfully fought if conducted within a few minutes after the fires were ignited and discovered. The response, however, would have to be direct and immediate, that is, equipment and personnel ready on scene, adjacent to the complex, and with knowledge of the layout of the Branch Davidian complex and the location of people. If applied early enough dry chemical powder backed up with water would be effective to knock down the fires before the heat had penetrated far into the solid combustible items. However, because fire fighters could not safely approach the complex until after 12:30 p.m. due to Davidian gunfire, it was not possible for them to extinguish the fire.

- 5) *Determine whether the Branch Davidians had the opportunity to escape the fire;*

The Branch Davidian Complex was a relatively small and low building. Escape routes were short and all the Davidians could therefore have walked away from the fire if they so wanted, except possibly those who were residing in the bunker who could have been trapped by fires started outside the bunker entrance.

- 6) *Determine whether the analyses of Dr. James Quintiere, the U.S. Government's Fire Dynamics Expert and Patrick Kennedy, a Fire Dynamics Expert retained by the Branch Davidians, accurately and completely defined the cause of the fire and its point(s) of origin;*

Drs. Quintiere and Mowrer, the U.S. Government's Fire Dynamics experts, reported thoroughly and accurately about the fire. Their theoretical analyses are in some aspects, however, based on wrong assumptions. Patrick Kennedy, a Fire Dynamics expert retained by the Branch Davidians, accused the government of having flawed the fire investigation. I have commented his statements and expressed my deviating opinions.

- 7) *Determine whether heat from the fire affected the structural integrity of the concrete bunker roof;*

Based on the photos I have seen and the knowledge of the heat and fire that the bunker top slab has been exposed to, I conclude that the hole was caused by spalling which resulted from the intensive heat of the fire.

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10 References

- ¹ Quintiere, J., and Mowrer, F., Fire Development Analysis, Mount Carmel Branch Davidian Compound, Waco, Texas, April 19, 1993, submitted September 1993.
- ² The Government's 1993 Fire Investigation
- ³ Wetherington, W., Final Report concerning the Fire at the Branch Davidian Complex, Waco, Texas, 19 April 1993, prepared for the Office of Special Council Waco Investigation, August 2000.
- ⁴ Klasén, L., and Madsen, S., Waco Investigation: Image Analysis and Video Authentication, prepared for the Office of Special Council Waco Investigation, September 2000.
- ⁵ Kordina and Meyer-Ottens, "Beton Brandschutz Handbuch", Beton-Verlag, 1981, ISBN 3-7640-0136-4
- ⁶ Briefing conducted by Patrick Kennedy, CFEI, October 5, 1999.
- ⁷ Patrick M. Kennedy, Report and declaration, February 29, 2000.



Annex A – Testing of ferret rounds – Bonfire melt testing

1 Purpose of test

To determine what debris, if any, could be recovered of the test specimens after being exposed to severe fire conditions.

2 Customer

The test was performed for Office of Special Counsel (“OSC ”), John C. Danforth, St Louis, Missouri, USA.

3 Date of test

The test was carried out on April 26, 2000.

4 Test specimens

4.1 Identification and source of test specimens

The following test specimens were delivered to SP by the OSC on March 31, 2000. Four types of objects, two items of each, were received:

Item no	Evidence Label No	Description
1	A00811749	Two (2) levers and caps from expended hand delivered flash bang grenades.
2	A00811748	Two (2) forty millimeter flash bang casings and projectiles fired from a M-79 Grenade Launcher.
3	A00811108	Two (2) forty millimeter Ferret casings, wadding and projectiles of the type used by the FBI at the Branch Davidian complex on April 19, 1993.
4	A00811102	Two (2) forty millimeter XM651E1 casings (military rounds) with spent projectiles of the type used by the FBI at the Branch Davidian complex on April 19, 1993.

4.2 Measured data

No dimensions were measured on the test specimens. Weight before and after test is given under test results.

4.3 Conditioning

No conditioning was performed on the test specimens prior to test.

5 Test specifications

The specimens were placed in a wood crib as shown in figure 1.

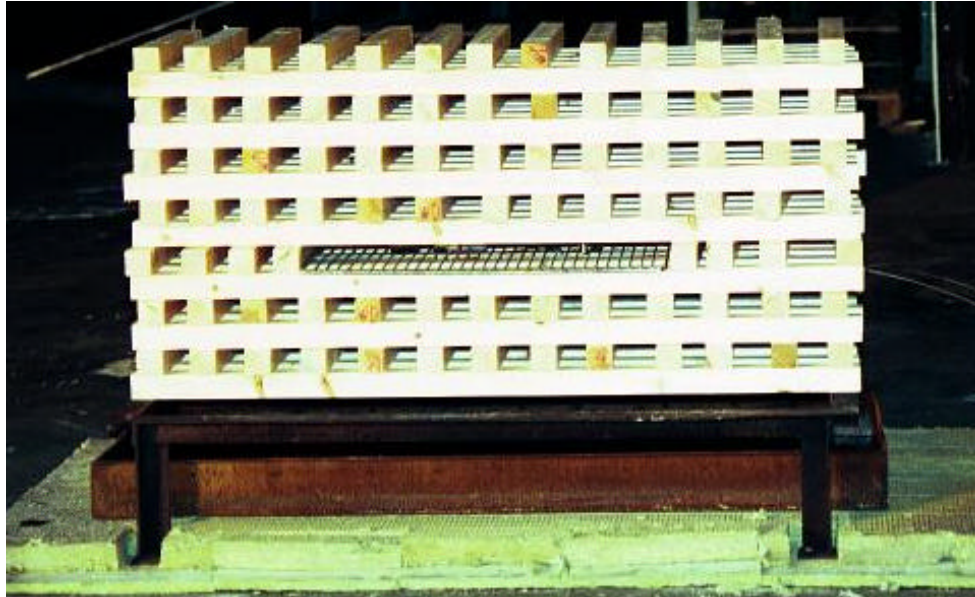


Figure 1 Wood crib on steel grid and container for ignition fuel underneath. The entire set up is placed on a sheet of mineral wool for protection of the floor.

The cribs had the dimensions 45 mm by 45 mm. (The crib used is similar to the crib of size 13A as specified in EN 3-1:1996, enclosure B). One sample of each the four types of products was placed on a metal grid, which was then placed on top of the 3rd layer of 7, see figures 1 and 2.



Figure 2 The specimens were placed inside the wood crib. Item 1 lower/right, item 2 upper/right, item 3 upper/left and item 4 lower/left. (The bags at the sides contain the duplicates of the test samples. The duplicates were removed prior to completion of the wood crib.)

The crib was placed on a steel frame. Under the crib was a container that was filled with 3 litres of heptane (gasoline) to ignite the fire. A thermocouple was placed inside the crib to record temperature.

6 Test procedure

The data logging was started. The heptane in the container was ignited one minute later. The test was terminated one hour after the heptane was ignited.

The temperature near the specimens inside the crib was recorded during the whole test period.

The remains of each test specimen were compared to the duplicates of the test specimens after test.

7 Observations

The wood crib had access to air from all sides including from below and burnt intensively at high temperatures for about one hour.

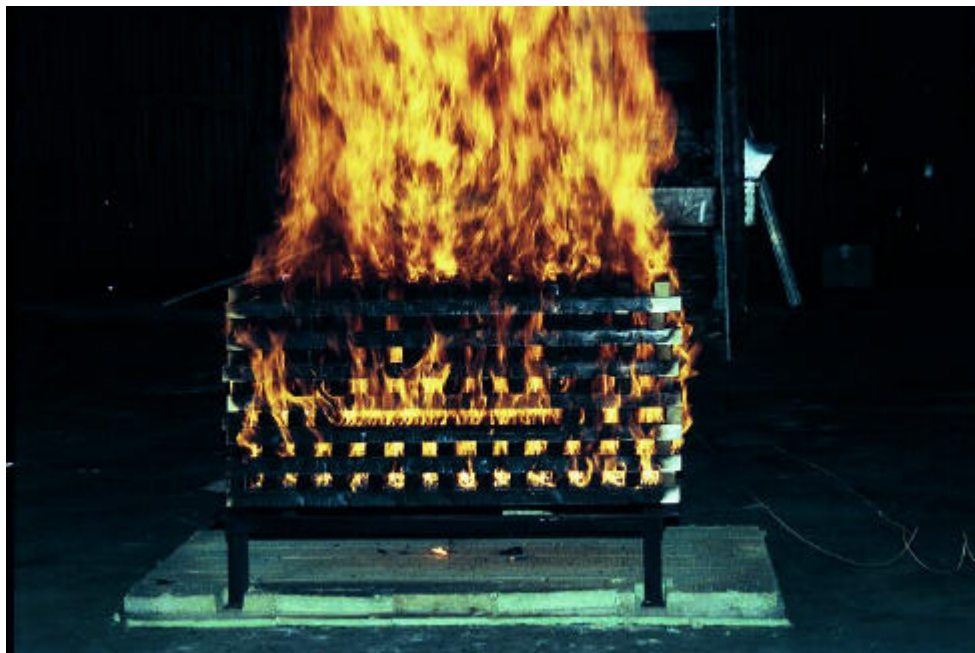


Figure 3 The crib burnt intensively at high temperatures. The specimens were placed inside the crib.

Time (min:s)	Observations
0:00	Start of test
1:00	Ignition of heptane
2:45	Heptane consumed
3:00	Melting plastic dropped down
18:00	The crib collapsed
61:00	The test was terminated

Temperatures above 1000 °C were recorded for a period of 35 minutes, see figure 4.

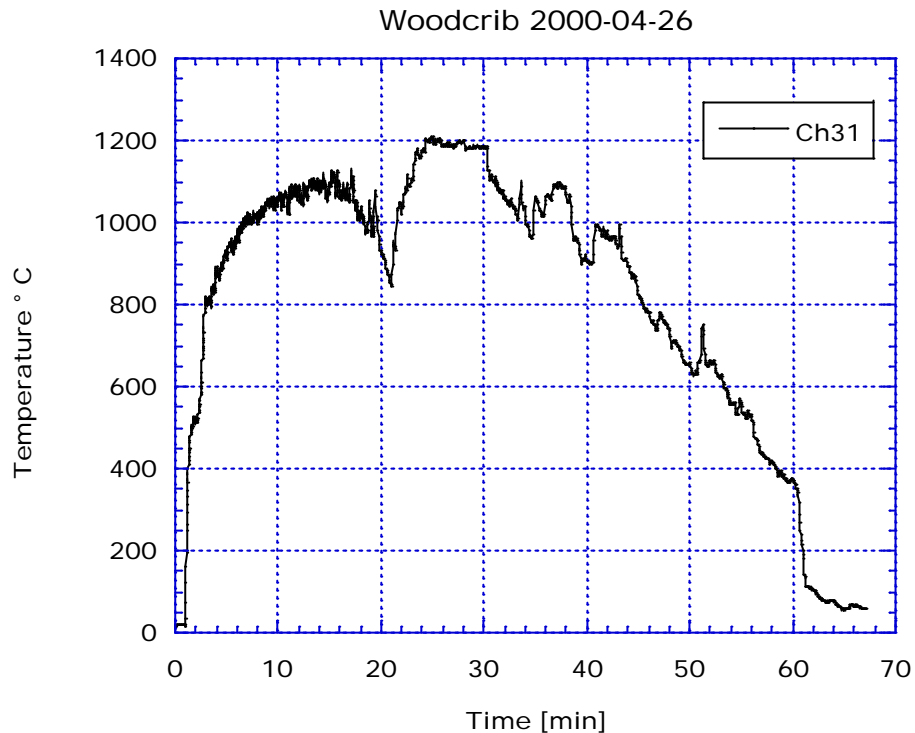


Figure 4 Temperature recorded in the wood crib near the specimen.

If ferret rounds had been shot into the Branch Davidian complex, they would have fallen to the floor. At such a location the temperature during the Branch Davidian complex fire is not likely to have exceeded 1000 °C.

8 Test results

After the test, the ashes were searched to recover all remaining pieces of the fire-exposed items. Figure 5 to 8 below show pictures of tested and not tested parts. Plastics (organic materials) were completely consumed by the fire. Pieces of aluminum melted, while the handle of item 1 remained more or less in shape, see Figure 5.

Item No	Description	Weight (gram)	
		Before test	After test
1	Lever and cap from expended hand delivered flash bang grenade (<i>Figure 5</i>).	24	26
2 (whole item)	Forty mm flash bang casings and projectiles fired from a M-79 Grenade Launcher (<i>Figure 6</i>).	201	97
2 (casing only)		50	¹⁾
3	Forty mm Ferret casing, wadding and projectile of the type used by the FBI at the Branch Davidian complex on April 19, 1993 (<i>Figure 7</i>).	51	28 ²⁾
4 (casing)	Forty mm XM651E1 casing (military rounds) with spent projectiles of the type used by the FBI at the Branch Davidian complex on April 19, 1993 (<i>Figure 8</i>).	75	69
4 (projectile only)		170	73

¹⁾ Not possible to separate casing and projectile after test.

²⁾ Piece of casing only



Figure 5 Item 1, Evidence Label No. A00811749 - Lever and cap from expended hand delivered flash bang grenade, not tested and tested, respectively.



Figure 6 *Item 2 Evidence Label No. A00811748 - Forty millimeter flash Bang casing and projectile fired from a M-79 Grenade Launcher, not tested and tested, respectively.*



Figure 7 *Item 3 Evidence Label No. A00811108 - Forty millimeter Ferret casing, wadding and projectile, not tested and tested, respectively. The remainder is a piece from the casing.*



Figure 8 Item 4 Evidence Label No. A00811102 - Forty millimeter XM651E1 casing (military rounds) and spent projectile, not tested and tested, respectively. The lower picture shows the projectile only.

9 Conclusion

Item 1 Evidence Label No. A00811749, Item 2 Evidence Label No. A00811748 and Item 4 Evidence Label No. A00811102 left remains after exposure to the severe fire conditions, see figures 4, 5 and 7. These remains could have been found amidst the fire debris after the Branch Davidian complex fire. The plastic ferret round and casing of Item 3 Evidence Label No. A00811108 was completely consumed by the fire. Only a piece of the casing remained.



10 References

- EN 3-1:1996 "Portable fire extinguishers part 1: Description, duration of operation, class A and B fire test", European Committee for Standardization, Brussels, 1996



Annex B – Heat Penetration Tests

(3 enclosures)

1 Purpose of test

To measure how fast heat would penetrate a sample of the Branch Davidian complex roof construction and cause a temperature rise on the unexposed surface.

2 Customer

The test was performed for Office of Special Counsel (“OSC”), John C. Danforth, St Louis, Missouri, USA.

3 Date of test

The tests were carried out between June 15 – 19, 2000.

4 Test specimens

4.1 Identification and source of test specimens

The following test specimens to be tested in a small fire resistance furnace were delivered to SP by the OSC on May 25, 2000. Double tests were carried out. Photos of the tested products are given in enclosure 1 – 3.

No	Board	Covering	Comments
1	Plywood 3/8”	#15 standard roof felt + asphalt shingles	Delivered by client
2	Plywood 3/8”	#15 standard roof felt + rolled asphalt	Delivered by client
3	Plywood 1/2”	#15 standard roof felt	Plywood purchased by SP Roof felt delivered by client

The roof of the Branch Davidian Complex was made of plywood boards with a thickness of 3/8” or 1/2” covered with roof felt and shingles or rolled asphalt. Some areas were covered with roof felt only.

4.2 Measured data

The following data were measured on the roof-covering products.

	#15 std roof felt	Asphalt shingles	Rolled asphalt
Thickness, mm	0.5 – 0.6	3.8 – 4.5	2.5 – 2.7
Area weight, kg/m ² (app.)	0.42	4.0	3.7

4.3 Conditioning

The test specimens were conditioned at a temperature of (23 ± 2) °C and a relative humidity of (50 ± 5) %.

5 Test specifications

Furnace orifice size: 500 mm by 600 mm.
 Orientation: Horizontal.
 Specimen size: 500 mm by 600 mm.
 Fastening: The roof coverings were stapled to the underlying plywood.

6 Test procedure

The specimen was placed on top of a small fire resistance furnace. The temperature in the furnace was increased according to ISO 834. The temperature at the unexposed surface and between the plywood and the roof covering was measured with thermocouples. Visual observations were also taken during the test. The tests were terminated when the fire broke through or when the asphalt covering started to melt.

7 Test results

Test results are given in enclosure 1 – 3 in form of time temperature diagrams and tables of observations.

8 Conclusions

These tests were carried out to determine the time it takes for heat to penetrate through roof constructions. The tests lasted at least 15 minutes. In reality, failure may occur earlier due to gravity loads and longer spans between supports. The times to reach temperature rises of 10°C at the plywood/cover interface and at the top surface, respectively, are summarized in the table below.

No.	Board	Covering	Time to reach a temperature rise of 10°C (min:s)	
			At plywood/cover interface	At top surface
1	Plywood 3/8"	#15 standard roof felt + asphalt shingles	1:50	4:10
2	Plywood 3/8"	#15 standard roof felt + rolled asphalt	2:20	3:30
3	Plywood 1/2"	#15 standard roof felt	3:00	3:40

Smoke started to appear from the unexposed upper side after about 13 minutes for the specimens with top coverings containing asphalt. For the specimens with only #15 standard roof felt smoke appeared much later.

9 References

ISO 834:1975 "Fire resistance tests: Elements of building construction", International Organisation for Standardisation, Geneva, 1975.

Enclosure 1 of Annex B - Plywood 3/8" with #15 standard roof felt and asphalt shingles

Test specimen

Plywood 3/8" with #15 standard roof felt and asphalt shingles, see Figure 1.

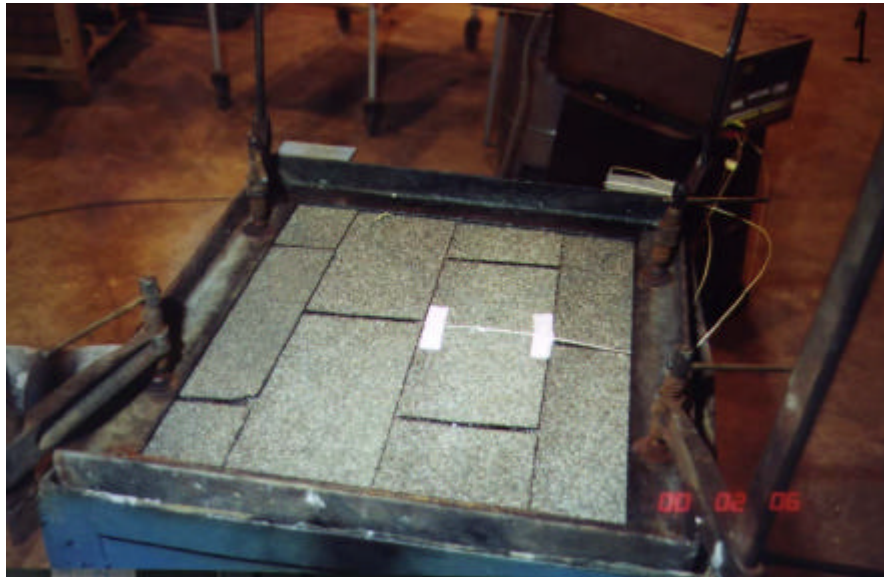


Figure 1 Specimen on top of the small fire resistance furnace, specimen size 500 mm by 600 mm.

Visual observations during test

Observations	Time, (min:s)	
	No. 1:1	No. 1:2
Start of test	0:00	0:00
A pressure increase under the roof covering forced the surface to bend.	9:30	8:00
The pressure disappeared and the surface was flat again.	12:30	11:00
Small blisters occurred on the surface.	13:00	12:00
Small amounts of smoke started to appear.	13:00	14:00
The asphalt started to melt. Smoke production was evident. The test was terminated.	17:30	18:00

Temperature graphs

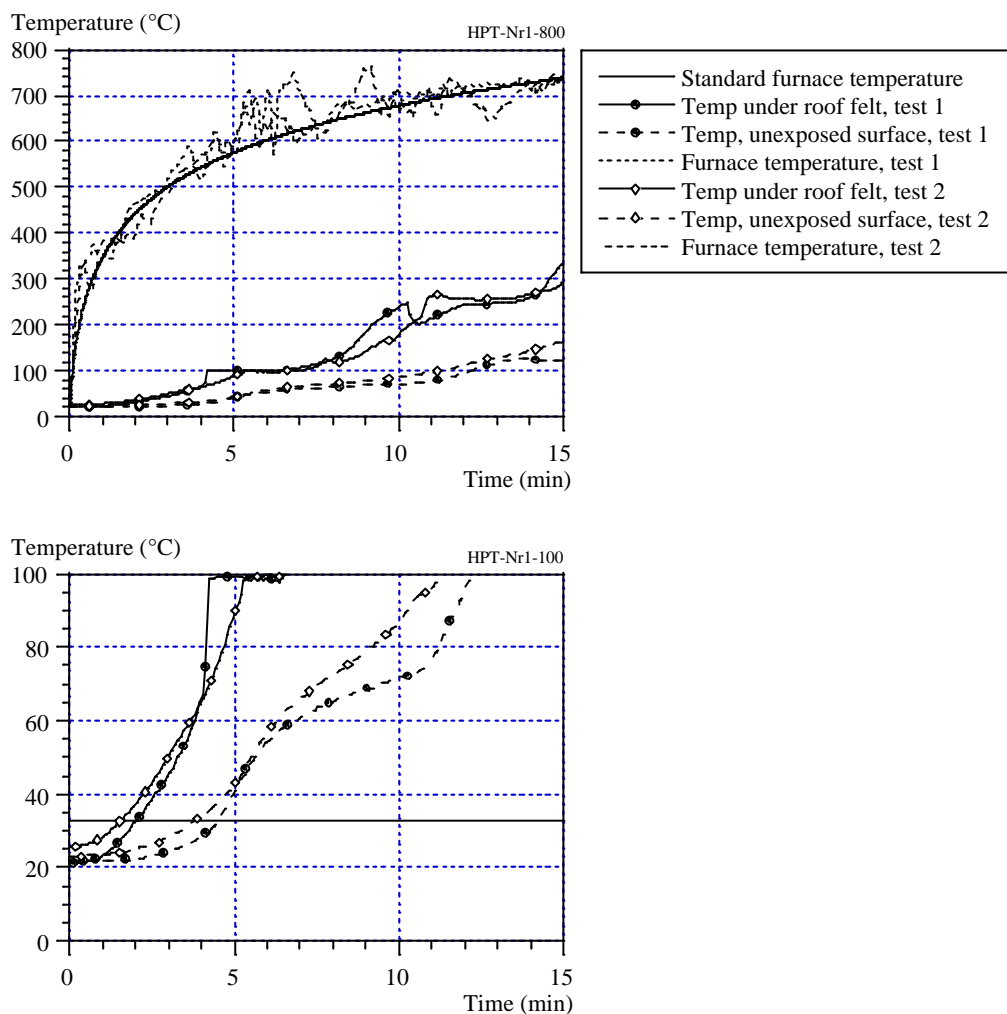


Figure 2 Temperature development of roof construction when exposed to standard furnace temperature according to ISO 834. Two temperature scales. A temperature rise of 10°C above the average of the initial temperatures of all four thermocouples is indicated in the higher resolution diagram at the very bottom.

The diagrams in Figure 2 show the recorded temperature of the duplicate tests as a function of time in the furnace: at the interface between the plywood and the roof covering (under the roof felt), and at the top of the covering (unexposed surface). For clarity the 10°C temperature rise is in the bottom diagram, which has magnified temperature scale.

Enclosure 2 of Annex B – Plywood 3/8” with #15 standard roof felt and rolled asphalt

Test specimen

Plywood 3/8” with #15 standard roof felt and rolled asphalt, Figure 1.

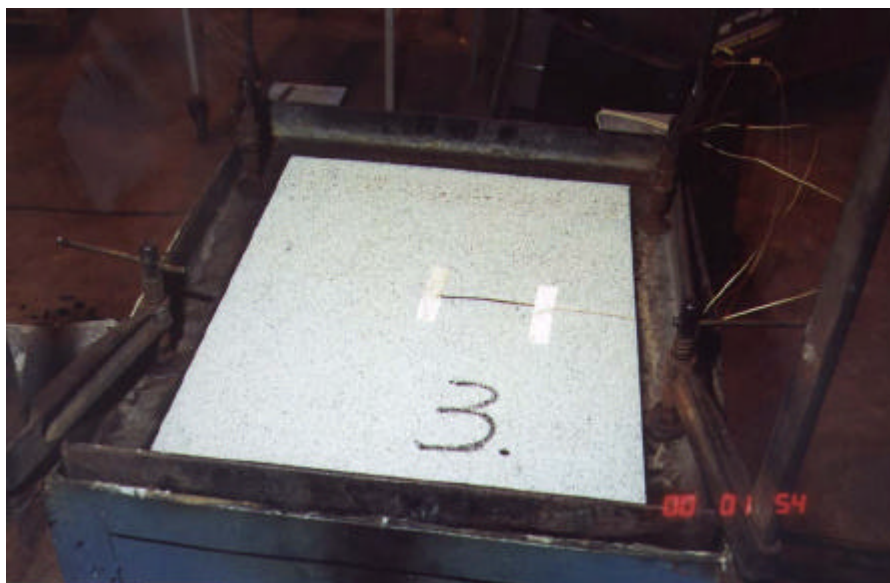


Figure 1 Specimen on top of the small fire resistance furnace, specimen size 500 mm by 600 mm. (The number “3” refers to the third test in the row of six tests.)

Visual observations during test

Observations	Time, (min:s)	
	No. 2:1	No. 2:2
Start of test	0:00	0:00
A pressure increase under the roof covering forced the surface to bend.	8:00	7:10
Small blisters occurred on the surface.	-	10:00
The pressure disappeared and the surface was flat again.	10:10	10:30
Small blisters occurred on the surface.	10:30	-
The thermocouple on the surface of the roof covering lost contact with roof felt. It rose about ½”.	11:00	-
The asphalt started to melt. Small amounts of smoke started to appear.	13:00	13:30
Most of the asphalt on the surface had melted. Smoke production was evident. The test was terminated.	15:30	16:00

Temperature graphs

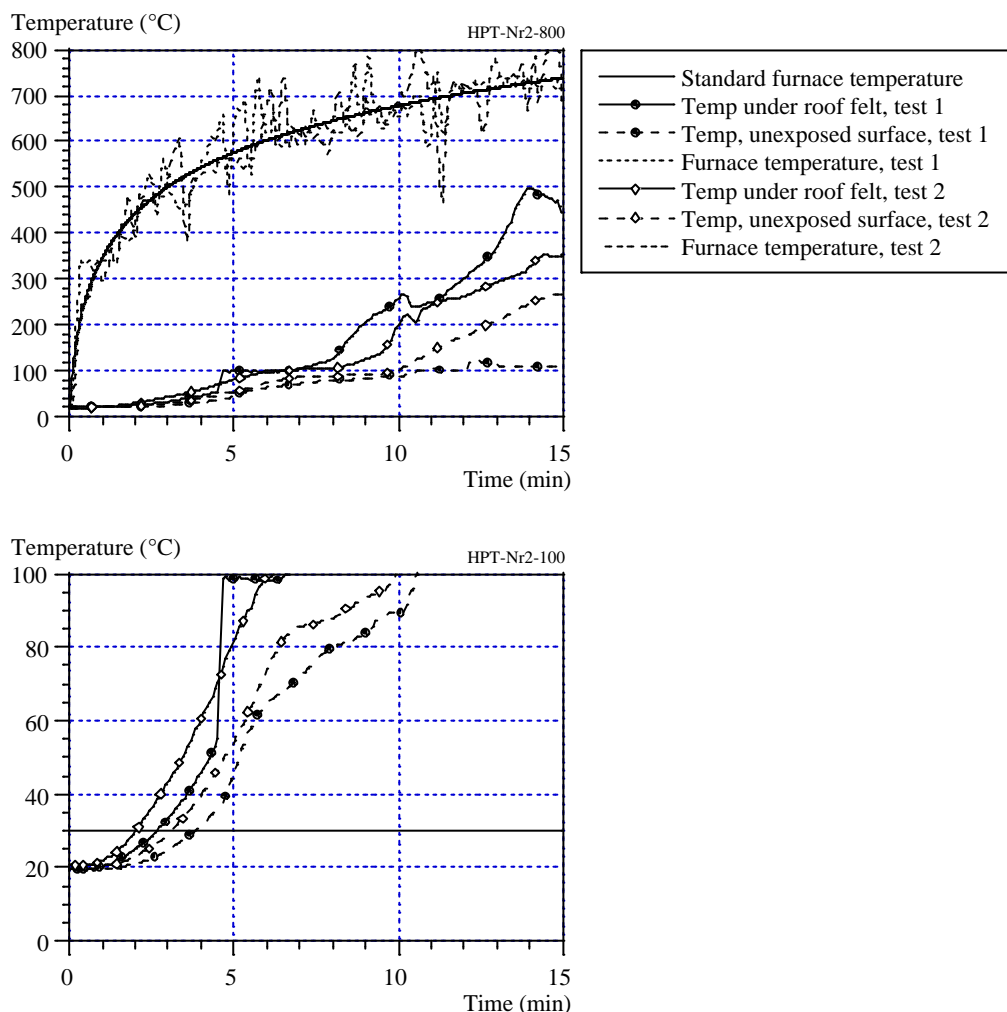


Figure 2 Temperature development of roof construction when exposed to standard furnace temperature according to ISO 834. Two temperature scales. A temperature rise of 10°C above the average of the initial temperatures of all four thermocouples is indicated in the higher resolution diagram at the very bottom.

The diagrams in Figure 2 show the recorded temperature of the duplicate tests as a function of time in the furnace: at the interface between the plywood and the roof covering (under the roof felt), and at the top of the covering (unexposed surface). For clarity the 10°C temperature rise is in the bottom diagram, which has magnified temperature scale.

Enclosure 3 of Annex B - Plywood 1/2" with #15 standard roof felt

Test specimen

Plywood 1/2" with #15 standard roof felt. Plywood purchased by SP, see Figure 1.

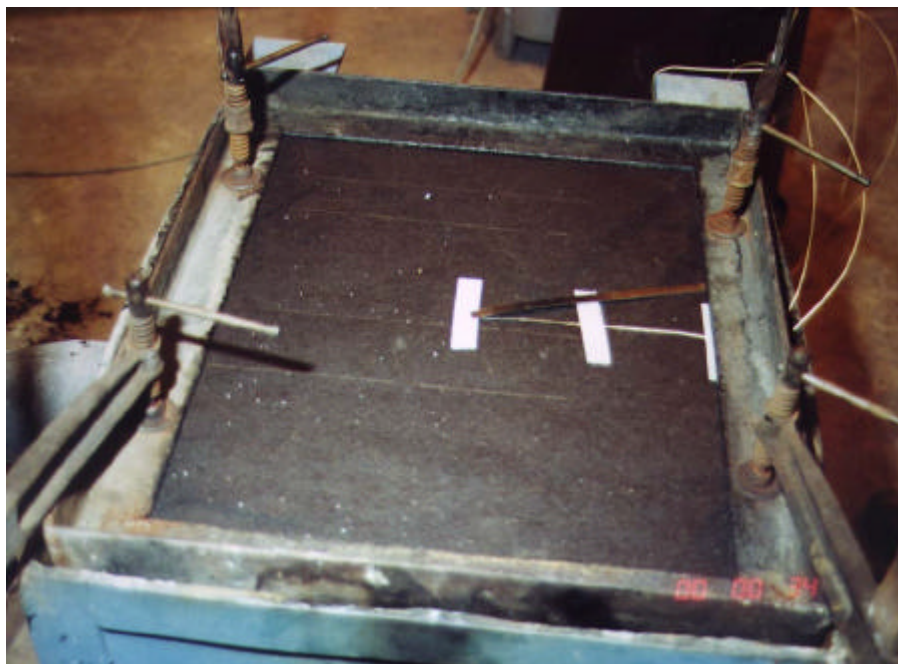


Figure 1 Specimen on top of the small fire resistance furnace, specimen size 500 mm by 600 mm.

Visual observations during test

Observations	Time, (min:s)	
	No. 1:1	No. 1:2
Start of test	0:00	0:00
A pressure increase under the roof covering forced the surface to bend.	10:00	13:00
The asphalt started to melt.	13:30	11:00
Small amounts of smoke started to appear.	17:30	-
Small amounts of smoke started to appear.	-	19:00
The smoke production was evident.	-	21:00
Fire broke through the surface and the smoke production was evident. The test was terminated.	21:00	-
Fire broke through the surface. The test was terminated.	-	23:00

Temperature graphs

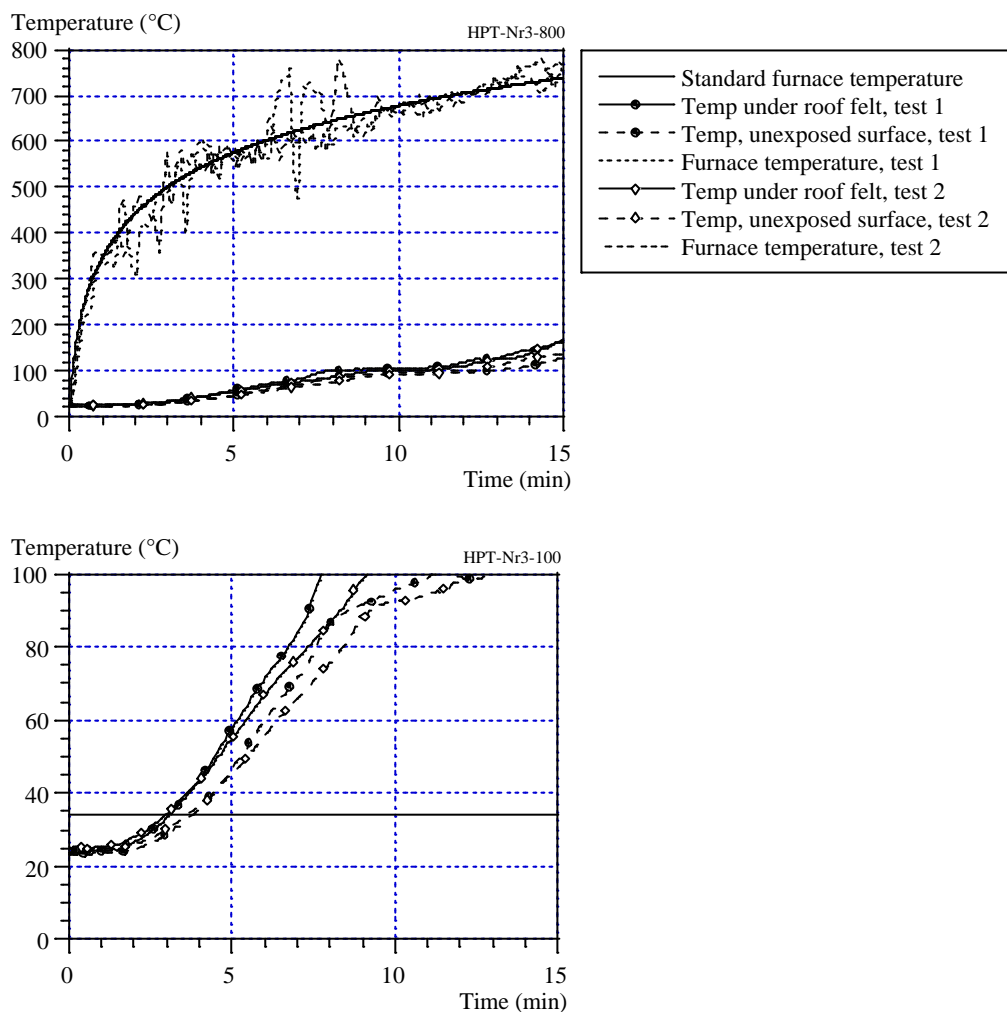


Figure 2 Temperature development of roof construction when exposed to standard furnace temperature according to ISO 834. Two temperature scales. A temperature rise of 10°C above the average of the initial temperatures of all four thermocouples is indicated in the higher resolution diagram at the very bottom.

The diagrams in Figure 2 show the recorded temperature of the duplicate tests as a function of time in the furnace: at the interface between the plywood and the roof covering (under the roof felt), and at the top of the covering (unexposed surface). For clarity the 10°C temperature rise is in the bottom diagram, which has magnified temperature scale.

Annex C – Cone Calorimeter testing and prediction of the burning behaviour in the Room/Corner Test

(6 enclosures)

1 Purpose of test

The purpose of the small-scale fire tests reported here was to obtain information about the burning properties of the interior wall and ceiling surfaces of the Branch Davidian complex. The best available small-scale test method for this purpose is the Cone Calorimeter, see figure 1. It is an international standard ISO 5660-1 as well as an American standard ASTM E 1354. The method was developed in the USA by the National Institute of Standards and Technology (NIST).

To get a better understanding of what the small scale test results mean in a real fire situation, the results obtained in the Cone Colorimeter were used to predict time to flashover (flames coming out of the doorway) in a small room according to ISO 9705, the Room/Corner Test.

2 Customer

The test and prediction were performed for Office of Special Counsel (“OSC”), John C. Danforth, St Louis, Missouri, USA.

3 Date of test

The tests were carried out on June 7, 2000.

4 Test specimens

4.1 Identification and source of test specimens

The following test specimens to be tested in ISO 5660-1 were delivered to SP by OSC on May 25, 2000. Where enough material was available double tests were carried out. Photos of the tested products are given in enclosures 1 – 4.

No.	Product	No. of tests
1	Plywood 3/8” without any surface treatment	2
2	Plywood 5/8” with external side grooves	1
3	Masonite 1/2” with external side treatment 1	2
4	Masonite 3/8” with external side treatment 2	1

The roof of the Branch Davidian complex was made of plywood boards with a thickness of 3/8” or 1/2” covered with roof felt and shingles or rolled asphalt. The 3/8” plywood was tested in order to assume a fire from underneath. The 5/8” plywood, which presumably had been a part of the wall, had grooves on the facade side, the outside. It was tested from the un-grooved inside. The same applies to the masonites. They were treated on the outside and the tests were carried out from the inside.

4.2 Measured data

Measured data of the test specimens are given in enclosures 1 – 4.

4.3 Conditioning

The test specimens were conditioned at a temperature of $(23 \pm 2) ^\circ\text{C}$ and a relative humidity of $(50 \pm 5) \%$.

5 Test specifications

Irradiance level:	25 kW/ m ² .
Orientation:	Horizontal.
Backing:	No other than the non-combustible required in the standard.
Fastening:	The product was cut in sheets of 100 mm x 100 mm, enclosed in al-foil on back and sides and loosely put on the backing.
Note:	The retainer frame was used.

Single or duplicate tests were performed. In addition to ISO 5660-1 smoke production rate was measured with a laser light system.

6 Test procedure

In the Cone Calorimeter, ISO 5660-1, specimens of 10 cm by 10 cm are exposed to controlled levels of radiant heating. The specimen surface is thereby heated and an external spark igniter ignites the pyrolysis gases from the specimen. The combustion gases are collected by a hood and extracted through a duct. The heat release rate (HRR) is determined by measurements of the oxygen consumption derived from the oxygen concentration and the mass flow rate in the exhaust duct. The specimen weight loss is measured during testing.

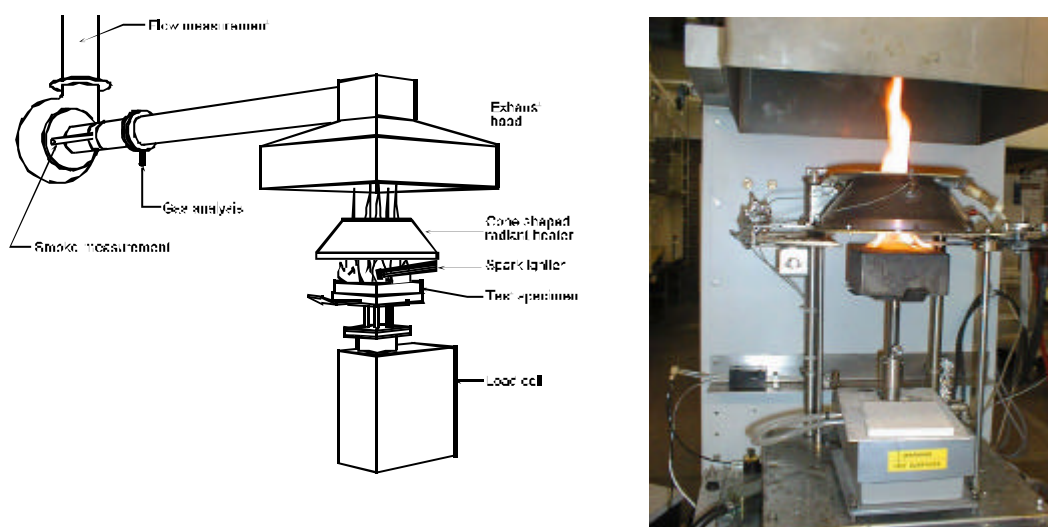


Figure 1 The Cone Calorimeter according to the international standard ISO 5660

7 Cone Calorimeter test results

Test results according to ISO 5660-1 are given in enclosure 1 - 6. All tests were carried out with an external irradiations level of 25 kW/m² produced by the cone heater. The test results comprise derived standard data from the Cone Calorimeter tests.

8 Full scale predictions

The predicted results for the ISO 9705 Room/Corner Test based on the results of ISO 5660-1 Cone Calorimeter tests are given in the table below and in enclosure 6. The Room/Corner Test equipment is shown in figure 2.

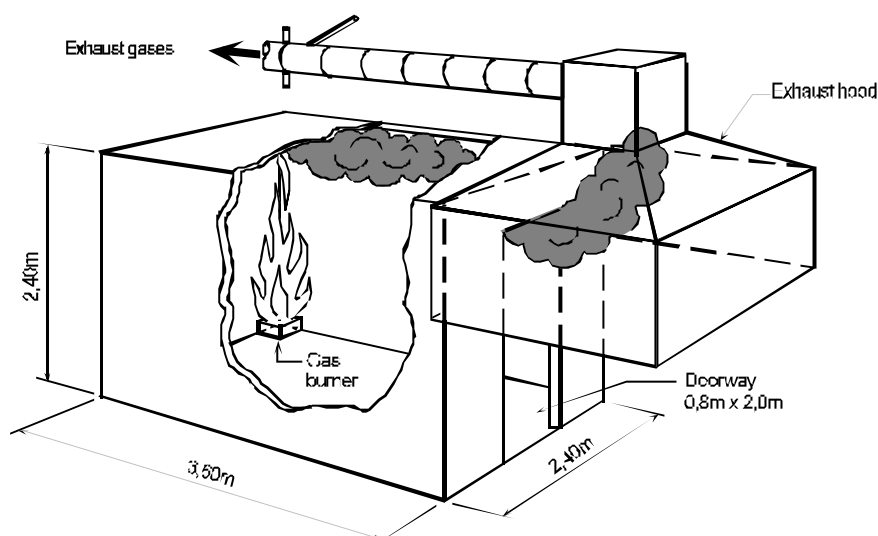


Figure 2 The ISO 9705 Room/Corner Test equipment. The test specimen is mounted on the walls and in the ceiling

9 Summary of results

The table below contains times to ignition and times to second peak of the heat release curve from the Cone Calorimeter tests as well as predicted average times to flashover in the Room/Corner Test. It must be noted that the ignition time depends very much on the irradiance level. At higher irradiance levels the ignition time may be considerably reduced.

Products tested	Time to ignition (min:sec)	Time to second peak (min:sec)	Predicted time to f/o(min:sec)*
Plywood 3/8" w/o. any surf. treatm.	1:53	7 :00	2:47
Plywood 5/8" w. ext. side grooves	2:43	15:00	4:29
Masonite 1/2" w. ext. side treatm. 1	1:58	10:00	3:09
Masonite 3/8" w. ext. side treatm. 2	1:59	11:00	3:00

*See enclosure 6 and discussion of predicted results below

10 Discussions

10.1 Discussion of Cone Calorimeter results

The results indicate that the products have fire technical properties similar to wood panels and will therefore behave similar in a fire. The time to consume the specimen varied between 7 and 15 minutes (time to second peak). The second peak of heat release arose when the product was about to burn through. Note that the burning rates drop due to the creation of a protective char layer by a factor of 3 for the plywoods and a factor 2 for the masonites after the first peak.

The irradiance level chosen, 25 kW/m², is relatively low. In real fires, two or three times as high levels can occur. In general, time to ignition decreases with the irradiance level squared. The burning rate, however, increases only marginally for wooden products.

10.2 Discussion of predicted results

In the Room/Corner Test the test specimen is mounted on the walls and in the ceiling and a gas diffusion burner is placed in a corner. Igniting the burner, which runs at 100 kW yielding flames that just reach the ceiling, starts the test. The time it takes for the fire to develop so much that flames come out of the doorway, i.e. time to flashover, is the most important parameter measured. This test as well as the Cone Calorimeter test originates from USA.

The prediction is based on the model developed at SP by Ulf Wickström and Ulf Göransson (see Wickström and Göransson, "Full-scale/Bench-scale Correlations of Wall and Ceiling linings" Journal of Fire and Materials, Vol. 16,1992). The model has proven to yield reliable predictions particularly for cellulosic materials like wood and derivatives thereof like particleboard. The prediction model takes into account the ignition time as well as the heat release rate as a function of time to predict the heat release rate in the Room/Corner Test.

11 Conclusions

The tested products have fire properties normal for wood products. They are not likely to ignite easily unless exposed directly to flames. Time to reach flashover in a small room when a burning item is placed in a corner yielding flames that reach the ceiling is in the order of a few minutes.

In a larger or more ventilated room it would take a longer time. Flames emerging out of the room of the fire origin generally means that not enough air (oxygen) is available inside the room for the combustion process. Excessive ventilation due to large openings or effects of external winds before flashover cools the fire and reduces the length of the flames. That increases the time to flashover or may even prevent flashover to occur. Do also note the burning characteristics of wooden products in the Cone Calorimeter tests. After a couple of minutes of heat exposure, a first peak of heat release rate develops. Then the burning rate reduces substantially as char develops on the wooden surface. Thus, a surface that has burnt and then re-ignites, will burn at a lower rate a second time.



12 References

- ISO 5660-1:1993 “Fire tests: Reaction to fire – Rate of heat release from building products (Cone Calorimeter method)”, International Organisation for Standardisation, Geneva, 1993.
- ASTM E 1354:1997 “Test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter”, USA, 1997.
- ISO 9705:1993 “Fire tests: Full scale room test for surface products”, International Organisation for Standardisation, Geneva, 1993.

Enclosure 1 of Annex C – Cone Calorimeter tests of plywood 3/8” without any surface treatment

Test specimen

Plywood 3/8” without any surface treatment see figure 1.



Figure 1 The received sample of plywood 3/8” without any surface treatment.

Measured data

Thickness 8.6 – 8.8 mm. Density 590 – 600 kg/m³.

Test results

Property	Name of variable	No. 1:1	No. 1:2	Average
Flashing (min:s)	t_{flash}			
Ignition (min:s)	t_{ign}	01:44	02:02	01:53
All flaming ceased (min:s)	t_{ext}	09:09	09:48	09:29
Test time (min:s)	t_{test}	11:19	11:48	11:34
Heat release rate (kW/m ²)	q	See figure 2		
Peak heat release rate (kW/m ²)	q_{max}	176	193	184
Average heat release, 3 min (kW/m ²)	q_{180}	111	102	106
Average heat release, 5 min (kW/m ²)	q_{300}	110	118	114
Total heat produced (MJ/m ²)	THR	50.9	58.3	54.6
Smoke production rate (m ² /m ² s)	SPR	See figure 3		
Peak smoke production (m ² /m ² s)	SPR_{max}	1.24	1.03	1.14
Total smoke produced (m ² /m ²)	TSP	218	247	232
Sample mass before test (g)	Mass ₀	46.8	48.0	47.4
Average mass loss rate (g/m ² s)	MLR _{ave}	6.86	7.07	6.96
Total mass loss (g)	TML	34.7	36.4	35.6
Effective heat of combustion (MJ/kg)	ΔH_c	12.9	14.0	13.5

Specific smoke production (m ² /kg)	SEA	55	60	57
Volume flow in exhaust duct (l/s)	V	24	24	24

Graphs of heat release rate and smoke production rate

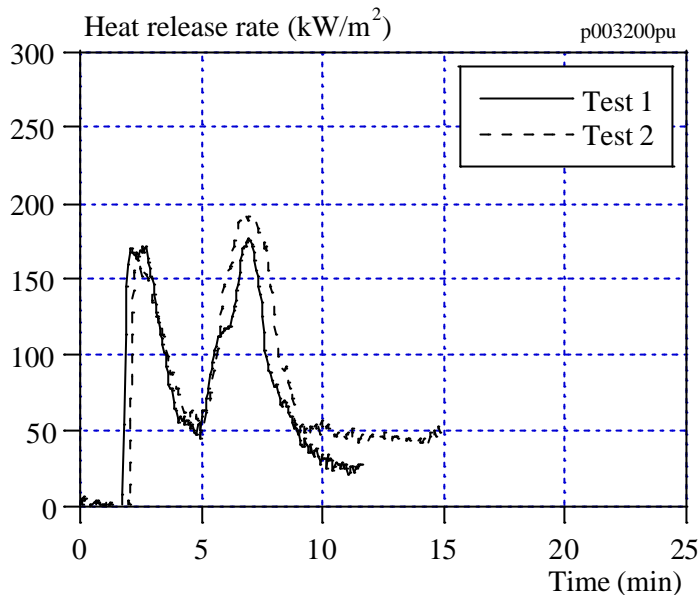


Figure 2 Heat release rate for plywood 3/8" without any surface treatment, double tests at an irradiance of 25 kW/m².

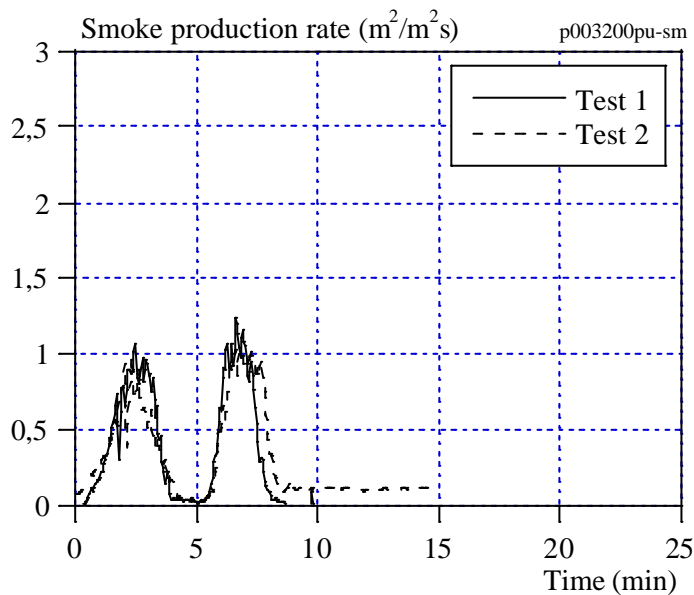


Figure 3 Smoke production rate for plywood 3/8" without any surface treatment, double tests at an irradiance of 25 kW/m².

Enclosure 2 of Annex C – Cone Calorimeter tests of plywood 5/8” with external side grooves

Test specimen

Plywood 5/8” with external side grooves, see figure 1.



Figure 1 The received sample of plywood 5/8” with external side grooves. The left photo shows the external side. The un-grooved side was exposed to the radiant heat.

Measured data

Thickness 14.6 – 14.7 mm. Density 600 kg/m³ approximately.

Test results

Property	Name of variable	No. 2
Flashing (min:s)	t_{flash}	
Ignition (min:s)	t_{ign}	02:43
All flaming ceased (min:s)	t_{ext}	21:19
Test time (min:s)	t_{test}	23:19
Heat release rate (kW/m ²)	q	See figure 2
Peak heat release rate (kW/m ²)	q_{max}	174
Average heat release, 3 min (kW/m ²)	q_{180}	100
Average heat release, 5 min (kW/m ²)	q_{300}	81
Total heat produced (MJ/m ²)	THR	96.8
Smoke production rate (m ² /m ² s)	SPR	See figure 3
Peak smoke production (m ² /m ² s)	SPR_{max}	1.23
Total smoke produced (m ² /m ²)	TSP	395
Sample mass before test (g)	$Mass_0$	96.3
Average mass loss rate (g/m ² s)	MLR_{ave}	6.59
Total mass loss (g)	TML	71.7
Effective heat of combustion (MJ/kg)	ΔH_c	11.8
Specific smoke production (m ² /kg)	SEA	48
Volume flow in exhaust duct (l/s)	V	24

Graphs of heat release rate and smoke production rate

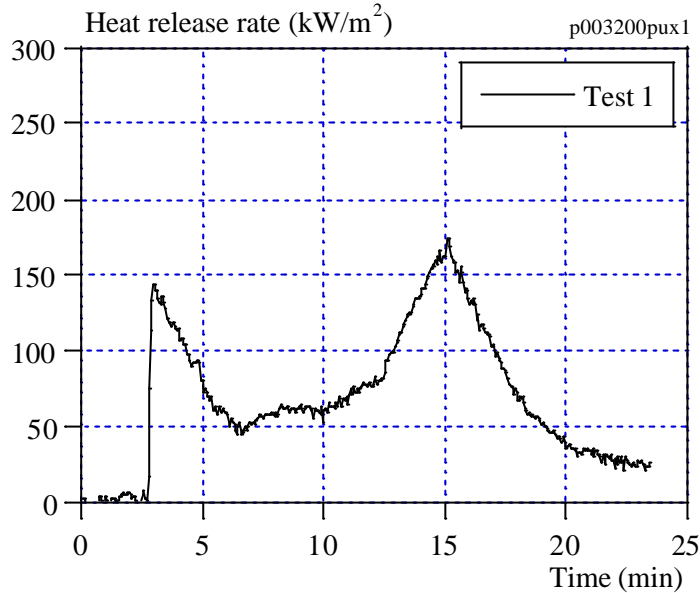


Figure 2 Heat release rate for plywood 5/8" with external side grooves, single test at an irradiance of 25 kW/m².

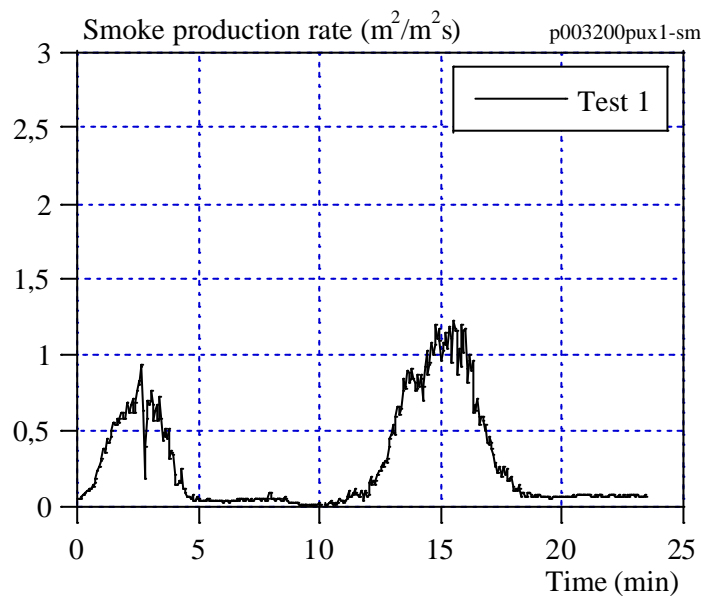


Figure 3 Smoke production rate for plywood 5/8" with external side grooves, single test at an irradiance of 25 kW/m².

Enclosure 3 of Annex C – Cone Calorimeter tests of Masonite 1/2” with external side treatment 1

Test specimen

Masonite 1/2” with external side treatment 1, see figure 1.

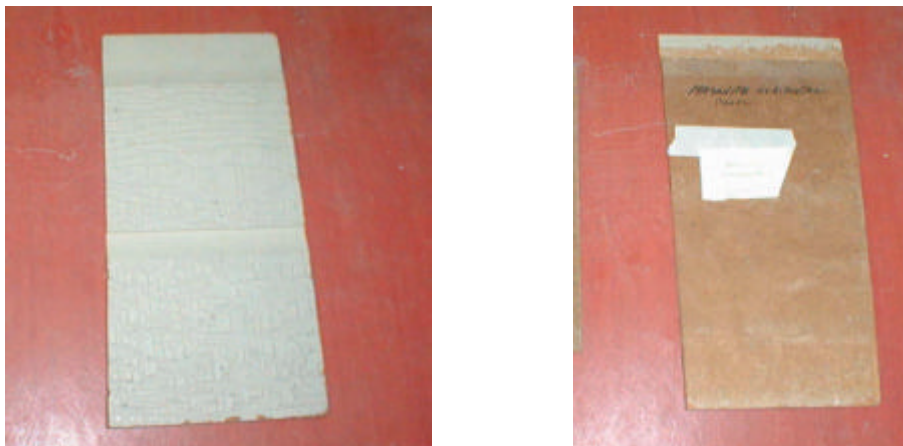


Figure 1 The sample of masonite 1/2” with external side treatment 1. The left photo shows the external side. The inside was exposed to the radiant heat.

Measured data

Thickness 11.4 – 11.9 mm. Density 750 kg/m³ approximately.

Test results

Property	Name of variable	No. 3:1	No. 3:2	Average
Flashing (min:s)	t _{flash}			
Ignition (min:s)	t _{ign}	01:57	01:59	01:58
All flaming ceased (min:s)	t _{ext}	16:04	18:24	17:14
Test time (min:s)	t _{test}	18:04	20:24	19:14
Heat release rate (kW/m ²)	q	See figure 2		
Peak heat release rate (kW/m ²)	q _{max}	204	286	245
Average heat release, 3 min (kW/m ²)	q ₁₈₀	104	104	104
Average heat release, 5 min (kW/m ²)	q ₃₀₀	91	90	91
Total heat produced (MJ/m ²)	THR	86.8	105.4	96.1
Smoke production rate (m ² /m ² s)	SPR	See figure 3		
Peak smoke production (m ² /m ² s)	SPR _{max}	2.14	2.62	2.38
Total smoke produced (m ² /m ²)	TSP	415	466	440
Sample mass before test (g)	Mass ₀	88.8	92.5	90.6
Average mass loss rate (g/m ² s)	MLR _{ave}	7.68	7.35	7.52
Total mass loss (g)	TML	65.4	71.5	68.4
Effective heat of combustion (MJ/kg)	ΔH _c	11.7	13.0	12.3
Specific smoke production (m ² /kg)	SEA	56	57	57
Volume flow in exhaust duct (l/s)	V	24	24	24

Graphs of heat release rate and smoke production rate

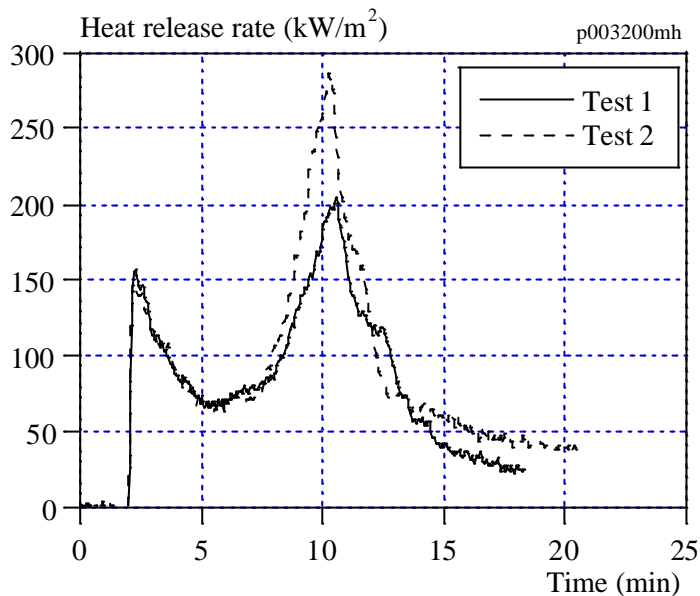


Figure 2 Heat release rate for masonite 1/2" with external side treatment 1, double tests at an irradiance of 25 kW/m².

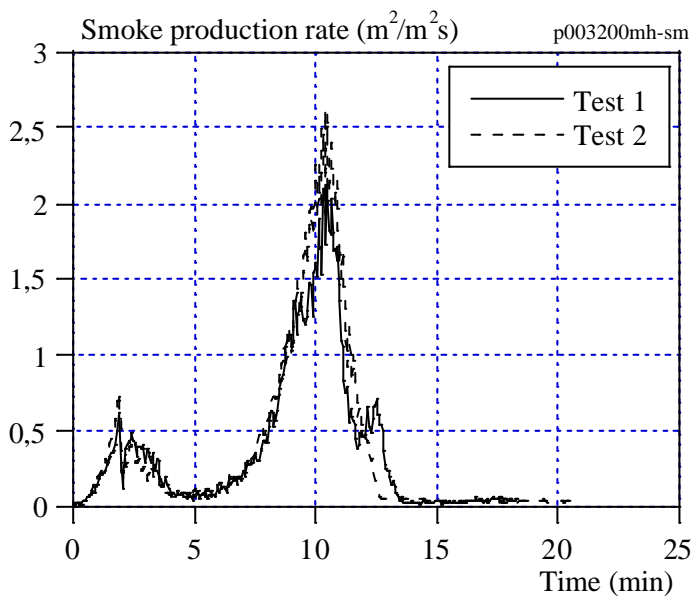


Figure 3 Smoke production rate for masonite 1/2" with external side treatment 1, double tests at an irradiance of 25 kW/m².

Enclosure 4 of Annex C – Cone Calorimeter tests of Masonite 3/8” with external side treatment 2

Test specimen

Masonite 3/8” with external side treatment 2, see figure 1.

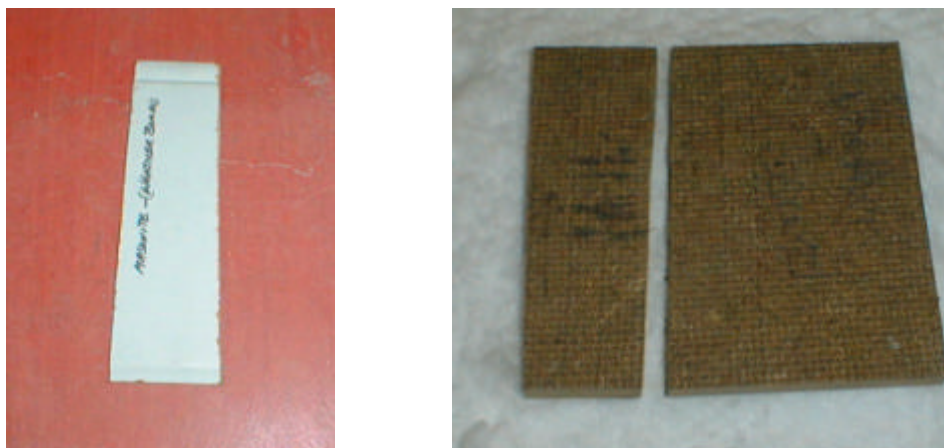


Figure 1 The received sample of masonite 3/8” with external side treatment 2. The left photo shows the external side. The photo to the right shows the side of the test specimen, which was exposed to radiant heat. The specimen had to be comprised of two pieces due to the insufficient width of the sample.

Measured data

Thickness 9.5 – 9.7 mm. Density 800 kg/m³ approximately.

Test results

Property	Name of variable	No. 1:1
Flashing (min:s)	t_{flash}	
Ignition (min:s)	t_{ign}	01:59
All flaming ceased (min:s)	t_{ext}	15:27
Test time (min:s)	t_{test}	17:27
Heat release rate (kW/m ²)	q	See figure 2
Peak heat release rate (kW/m ²)	q_{max}	164
Average heat release, 3 min (kW/m ²)	q_{180}	126
Average heat release, 5 min (kW/m ²)	q_{300}	113
Total heat produced (MJ/m ²)	THR	98.4
Smoke production rate (m ² /m ² s)	SPR	See figure 3
Peak smoke production (m ² /m ² s)	SPR_{max}	1.31
Total smoke produced (m ² /m ²)	TSP	468
Sample mass before test (g)	$Mass_0$	75.9
Average mass loss rate (g/m ² s)	MLR_{ave}	7.47
Total mass loss (g)	TML	61.0

Effective heat of combustion (MJ/kg)	ΔH_c	14.2
Specific smoke production (m ² /kg)	SEA	56
Volume flow in exhaust duct (l/s)	V	24

Graphs of heat release rate and smoke production rate

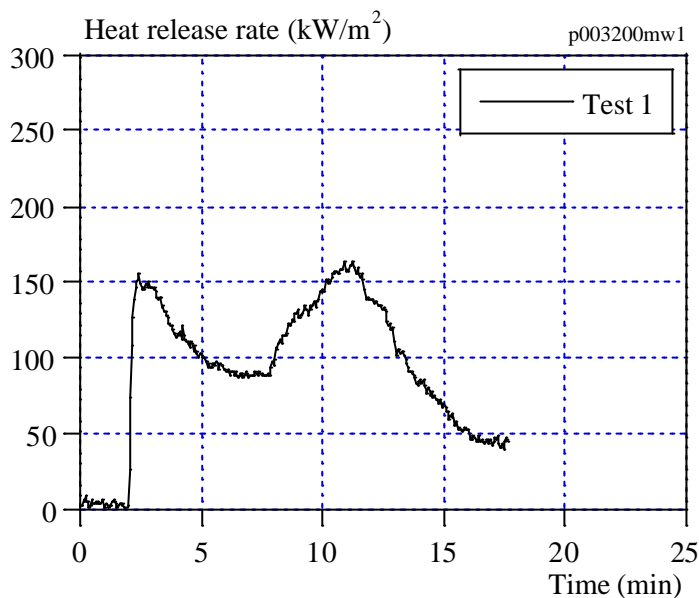


Figure 2 Heat release rate for masonite 3/8" with external side treatment 2, single test at an irradiance of 25 kW/m².

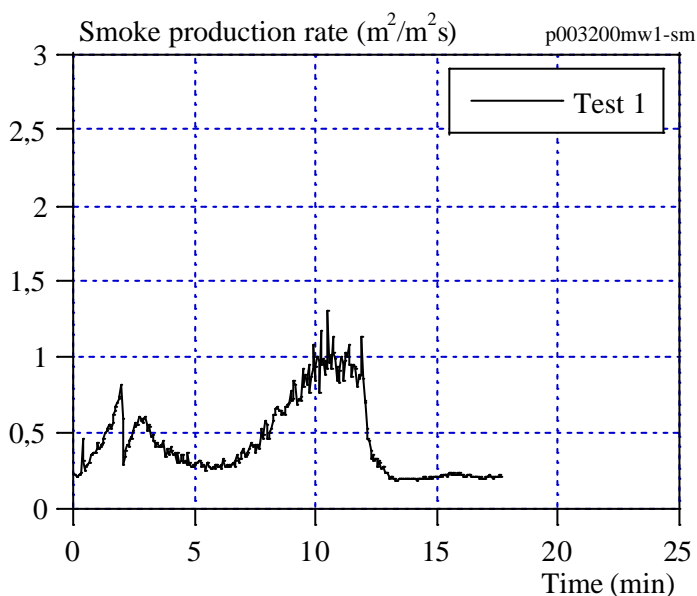


Figure 3 Smoke production rate for masonite 3/8" with external side treatment 2, single test at an irradiance of 25 kW/m².

Enclosure 5 of Annex C – Cone Calorimeter test results explanation according to ISO 5660

Parameter	Explanation
Test start	The test specimen is subjected to the irradiance and the clock is started.
t_{flash}	Time from test start until flames with shorter duration than 1 s.
t_{ign}	Time from test start until sustained flaming.
t_{ext}	Time from test start until the flames have died out.
End of test	Defined as the time when both, the product has been extinguished for 2 minutes, and the mass loss is less than 150 g/m^2 during 1 minute.
t_{test}	Test time. From test start until end of test.
q_{max}	Peak heat release rate during the entire test.
q_{180}	Average heat release rate during 3 minutes from ignition. If the test is terminated before, the heat release rate is taken as 0 from the end of test.
q_{300}	Average heat release rate during 5 minutes from ignition. If the test is terminated before, the heat release rate is taken as 0 from the end of test.
THR	Total Heat Released from test start until end of test.
SPR_{max}	Peak Smoke Production Rate from test start until end of test.
TSP	Total Smoke Produced from test start until end of test.
MLR_{ave}	Mass Loss Rate. Average mass loss rate from ignition until end of test.
TML	Total mass loss from ignition until end of test.
ΔH_c	Effective heat of combustion calculated as the ratio between total energy released and total mass loss calculated from test start until end of test.
SEA	Specific Extinction Area defined as the ratio between total smoke released and total mass loss calculated from test start until end of test.
V	Volume flow rate in exhaust duct. Average during the test.

Enclosure 6 of Annex C – Prediction of Room/Corner Test results based on Cone Calorimeter test results

Input data for the prediction

The model uses heat release rate and time to ignition measured in the Cone Calorimeter from tests at an irradiance of 25 kW/m².

The results of the prediction of flashover time and heat release rate are given the tables below and in the figures 1 - 4. Flashover as defined here is deemed to occur when the heat release rate reaches 1000 kW. In all cases the peak heat release rate is more than 1000 kW.

Prediction results

Plywood 3/8” without any surface treatment

Property	Test 1	Test 2
Ignition time used (min:s)	1:44	2:02
Predicted flashover time (based on a heat release rate of 1000 kW) (min:s)	2:29	3:06

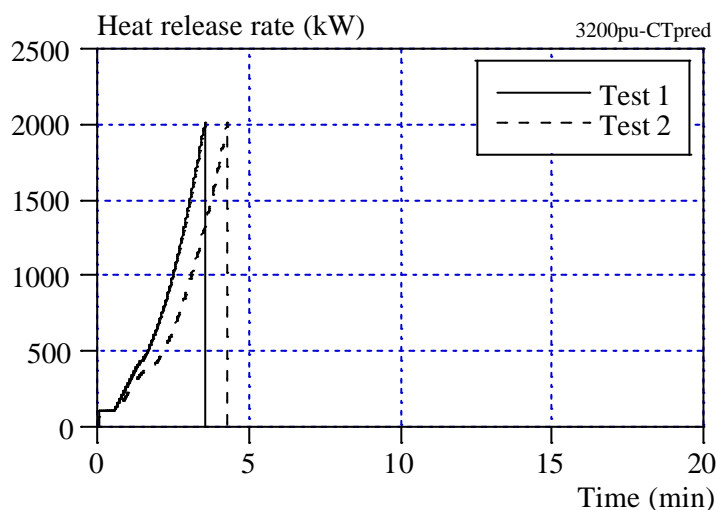


Figure 1 Predicted heat release rate in the Room/Corner Test (ISO 9705) based on Cone Calorimeter tests for plywood 3/8” without any surface treatment.

Plywood 5/8" with external side grooves

Property	Test 1
Ignition time used (min:s)	2:43
Predicted flashover time (based on a heat release rate of 1000 kW) (min:s)	4:29

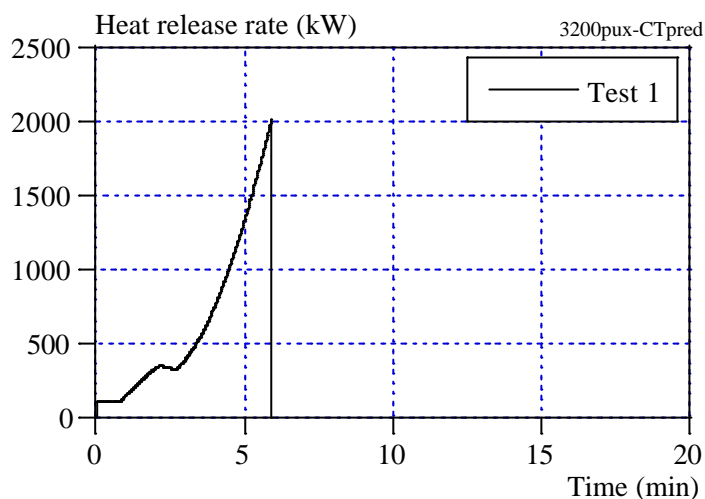


Figure 2 Predicted heat release rate in the Room/Corner Test (ISO 9705) based on Cone Calorimeter tests for plywood 5/8" with external side grooves.

Masonite 1/2" with external side treatment 1

Property	Test 1	Test 2
Ignition time used (min:s)	1:57	1:59
Predicted flashover time (based on a heat release rate of 1000 kW) (min:s)	3:06	3:12

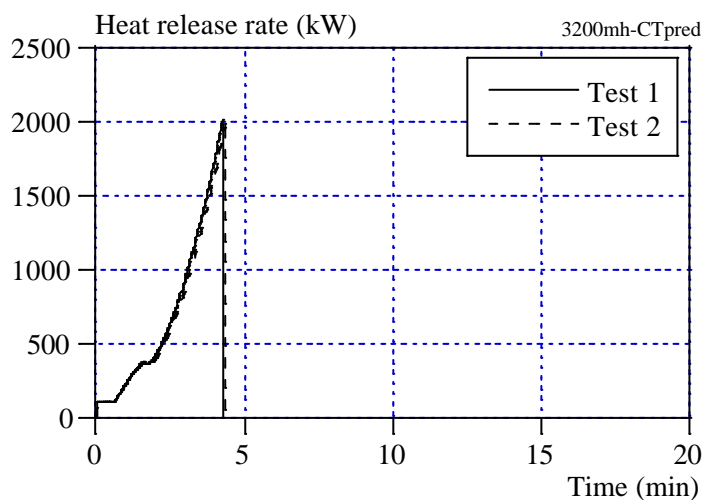


Figure 3 Predicted heat release rate in the Room/Corner Test (ISO 9705) based on Cone Calorimeter tests for masonite 1/2" with external side treatment 1.

Masonite 3/8” with external side treatment 2

Property	Test 1
Ignition time used (min:s)	1:59
Predicted flashover time (based on a heat release rate of 1000 kW) (min:s)	3:00

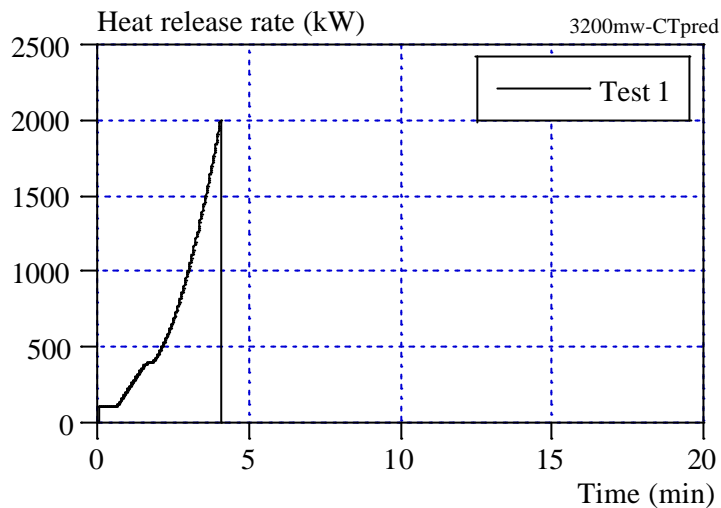


Figure 4 Predicted heat release rate in the Room/Corner Test (ISO 9705) based on Cone Calorimeter tests for masonite 3/8” with external side treatment 2.



Annex D – Estimation of pressure rise in the cafeteria

At the outbreak of the fire, the cafeteria had only two internal openings, i.e. two doorways leading out to the kitchen the reception area. All the windows were boarded. Under these conditions and in room of this size, a pressure will occur when an intensive fire starts due to accelerants and the gas temperature rises. This pressure is highly dependent on fire intensity and opening sizes, which are not very well known. Therefore the estimates and calculations below are very approximate. They are just meant to give an understanding of what levels of pressure can occur in the cafeteria when liquid fuel is ignited and burns at a high rate.

The total volume of the cafeteria ¹ :	$51.5' * 31' * 8.2' = 370 \text{ m}^3$
Density of air:	1.2 kg/m^3
The total mass oxygen, 23% by mass:	$0.23 * 1.2 * 370 \text{ kg}$
Amount of oxygen available for combustion, 50%:	$0.5 * 0.23 * 370 = 51 \text{ kg}$
Energy release:	$13 \text{ MJ/kg of oxygen}$
Total heat release without ventilation:	664 MJ
Assumed peak burning rate:	10 MW

The volume increase is proportional to the total heat release when assuming no heat loss of the gas mass to the surroundings. For this crude estimate and short time of analysis this is deemed reasonable. Thus at constant pressure and a density and specific heat capacity of air 1.2 kg/m^3 and 1.0 kJ/kg , respectively, each MJ of heat release yields a volume increase of three m^3 at room temperature 300 K. Therefore according to the ideal gas law:

Volume rise at room temperature:	$10^6 / (1.2 * 10^3 * 300) = 2.8 \text{ m}^3/\text{MJ}$
Rate of volume rise at a heat release rate of 10MJ/s:	$2.8 * 10 \text{ MJ/s} = 28 \text{ m}^3/\text{s}$
Assumed opening size, (two alternatives):	$2 \text{ or } 4 \text{ m}^2$
Gas velocity in opening:	$28/2 = 14 \text{ m/s or } 7 \text{ m/s}$

The pressure drop for gas flow through a rectangular opening is proportional to the gas density and the velocity squared. The proportionality factor depends on the opening geometry but is always larger than unity. Thus the pressure difference between the inside and outside of the cafeteria is larger than as calculated below:

Pressure at 7.5 m/s:	$0.6 * (7)^2 = 29 \text{ N/m}^2$
Pressure at 15 m/s:	$0.6 * (14)^2 = 118 \text{ N/m}^2$

These estimates are very rough, but they indicate that relatively high pressures can develop when the heat release is high. As a comparison the pressure due to winds at the day of the fire was in the order of 36 N/m^2 , see Quintiere and Mowrer². Pressures developed at high temperatures of a room fire at quasi-steady conditions (slow temperature rise, large openings) are in the order of 10 to 20 N/m^2 .

For a fuel having a typical heat of combustion of 40 MJ/kg , a total heat release of 520 MJ corresponds to 13 kg of fuel or about 25 litres (= 6 gallons). This amount is in the same order of magnitude as could be held in the empty containers found in the area after the fire according to the report by Wetherington³, i.e. four one-gallon fuel cans at one location and two fuel cans with punctured holes and gasoline at another in the vicinity of the cafeteria.



References

- ¹ Vector Data System, Imagery Analysis Report, The Events at Waco Texas 19 April 1993, prepared for the US District Court for the Western District of Texas and the Office of Special Counsel
- ² Quintiere, J., and Mowrer, F., Fire Development Analysis, Mount Carmel Branch Davidian Compound, Waco, Texas, April 19, 1993, submitted September 1993.
- ³ Wetherington, W., Final Report concerning the Fire at the Branch Davidian Complex, Waco, Texas, 19 April 1993, prepared for the Office of Special Counsel Waco Investigation, August 2000.

Annex E - CV for Ulf Wickström

Professor Ulf Wickström heads the department of fire technology at the Swedish National Testing and Research Institute (SP). The department has a staff of more than 50 individuals involved in fire testing and research.

Professor Wickström has a PhD from the Lund University of Technology (1979) in fire technology, a masters of science from University of California (1977), Berkeley, and Master of Science in civil engineering from the above Lund University of Technology (1974).

Professor Wickström was given the name "professor" in 1988 by the Department of Industry of the Swedish Government. His special scientific interest lies heat transfer analysis of structures exposed to fire where he has published several scientific papers.

Professor Wickström joined the Department of Fire Technology of SP in 1979 and has been leading it since 1986. The laboratory is one of the leading of its kind in the world. It is active in international research as well as direct services to industry in the field of fire safety testing and evaluation. The staff of specialists from various engineering fields are experienced and well educated; over ten have obtained academic PhDs.

Professor Wickström has been active during his entire career in international research and standardisation committees and working groups and is internationally well known in the field. For more than ten years he leads the Swedish delegation in the European standardisation committee on fire safety.