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Prepared at the request of counsel for the purposes of the Grenfell Tower Public Inquiry

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Preliminary Fire Investigation Status Report to the Grenfell Tower Public Inquiry

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Prepared for

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1 Introduction

The Grenfell Tower fire was reported to the London Fire Brigade (LFB) at 00:54 on 14 June 2017.[1] The Grenfell Tower is a 24-story residential apartment building located in the Royal Borough of Kensington and Chelsea in London, England. The fire area of origin was reported to be in the kitchen in one of the flats in the building, and it has been suggested that the cause of the fire was a Hotpoint FF175BP fridge freezer in the kitchen. The fire spread to exterior building cladding through the kitchen window, eventually spreading throughout the structure. The fire grew to involve most of the tower leading to significant damage and numerous injuries and fatalities. Exponent is aware that public agencies are undertaking separate, independent investigations including an Independent Public Inquiry.

Exponent was originally instructed by Cooley (UK) LLP, on behalf of Whirlpool Corporation, to investigate and analyze the origin and cause of the fire. Exponent's investigation is in process. Cooley has subsequently requested that Exponent provide a preliminary fire investigation report to the Grenfell Tower Public Inquiry (Inquiry) based on our limited investigations carried out to date. This report serves as a preliminary summary of our observations, findings as to potential points of origin for the fire, and evaluation of the Hotpoint Model FF175BP fridge freezer (hereinafter referred to as the fridge freezer) and associated evidence retained by the Metropolitan Police Service (MPS). The intent of this preliminary fire investigation report is to assist the Inquiry team in their investigations. It is anticipated that Exponent's findings will be updated as the investigation progresses and new information becomes available. Further report(s) will be issued if thought to be helpful to the Inquiry team.

1.1 Exponent Investigators

Exponent's investigation has been led by Dr. Delmar "Trey" Morrison, P.E., CFEI, and Dr. John Martens, P.E., M.B.A., CFEI. Dr. Morrison is a Chemical Engineer by training and has spent nearly two decades investigating fire incidents involving appliances, working with manufacturers on failure analysis and risk management of the fire safety of appliances, and studying the dynamics of compartment fires involving appliances, spontaneous combustion, and other types of fires. Dr. Martens is an Electrical Engineer by training. Dr. Martens has over twenty-five years of experience specifying, designing, constructing, and analyzing digital and analog electronic circuits for a variety of applications. Additionally, Dr. Martens has spent the last decade investigating the causes of failures and fires involving electrical systems including appliances, electronics, and residential electrical distribution systems. Dr. Morrison and Dr. Martens have led numerous complex fire investigations, presented their works to both non-technical and technical audiences, and have published extensively. A more thorough summary of their qualifications is provided in their curriculum vitae, which are attached to this report for reference as Appendices A and B.

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1 http://www.london-fire.gov.uk/LatestIncidentsContainer_grenfell-tower-fire-update-15-june-2017.asp.

Exponent is available to support and assist the Inquiry and the experts that the Inquiry has instructed, and we hope to be able to advance our own investigations as the necessary evidence becomes available.

1.2 Summary of Investigation to Date

This report is intended to convey Exponent's current findings in the fire investigation in relation to the point of origin of the fire and preliminary analysis of the subject FF175BP fridge freezer and associated evidence made available to Exponent so far. The following key points will be expanded upon in the report:

- An objective and systematic fire investigation must follow the scientific method.
- In a fire investigation, the investigation process identifies the area where the fire originated (fire origin), potential points of exact origin within the area of origin, and potential causes of the fire. Each of these is evaluated in the context of the scientific method.
- The information and evidence available to Exponent is very limited, which in turn limits the extent of the conclusions that can be drawn at this stage.
- Based on media reports and discussions with public agency representatives, the fire area of origin is assumed for the purposes of this report to be in the kitchen of Flat 16 in Grenfell Tower.
- The available information and evidence available to Exponent to date are ambiguous and do not support a reliable determination regarding the point of origin of the fire within the kitchen. For example, the witness précis statement (see Section 3.4) initially noted visible smoke and then later evidence of a fire in the kitchen but did not identify the point where the fire ignited.
- Based on the limited evidence that has been reviewed to date, five potential points of origin for the fire in the kitchen have been identified, and those are still under investigation. When further evidence is made available, other potential points of origin may become apparent.
- The evidence reviewed to date does not uniquely support a point of origin for the fire in any particular location or specifically at the fridge freezer.
- The fridge freezer was heavily damaged, making it possible that the fridge freezer was attacked either by a fire originating outside the fridge freezer or by one originating within the fridge freezer.
- Since the point of origin of the fire is undetermined, the cause of the fire cannot be determined at this time.
- The analysis and findings in this report are preliminary and subject to change, when or if additional information and evidence become available.

2 Fire Investigation Process

After a fire incident has occurred, a systematic and objective fire investigation is necessary to attempt to determine where the fire started, why it started, and how it could have been prevented. An authoritative resource for this process is the National Fire Protection Association (NFPA®) 921 *Guide for Fire and Explosion Investigations*, 2017 Edition. NFPA® 921 is internationally accepted, and several UK organizations, including the United Kingdom Association of Fire Investigators, the Institution of Fire Engineers, and the Fire Protection Association, have promoted its use for objective, systematic fire investigations.[2,3,4] The Code of Practice for Investigators of Fires and Explosions for the Criminal Justice Systems in the UK (Code of Practice) provides similar guidance. NFPA® 921 incorporates best practices from throughout the international fire service community, including from the London Fire Brigade (LFB), which has a member on the current technical committee for NFPA® 921.[5]

NFPA® 921 details the application of the scientific method to fire investigation. The scientific method requires a systematic approach to problem solving that starts with the identification and definition of a problem to be solved. Due to the destructive nature of fire, the direct evidence of the fire's cause is often obliterated or obscured; thus, the cause of the fire may not be readily discernable. Therefore, an iterative process is followed whereby data is collected and analyzed to objectively develop hypotheses, test the hypotheses, and, if possible, identify a hypothesis that is uniquely consistent with the facts, evidence, and the principles of science. The probability of reaching sound conclusions is improved by applying the scientific method. Because fires can be such destructive events, the distinct cause of an individual fire incident may not always be capable of being determined regardless of the scientific rigor of the investigation.

A scientific fire investigation follows a process of identifying and evaluating the following aspects: (1) an area where the fire originated (referred to as the area of origin), (2) potential points of origin within that area, and (3) potential causes associated with those points of origin. NFPA® 921 provides helpful definitions for these technical terms as applied to fire investigation:[6]

> ***Origin.*** *The general location where a fire or explosion began.*

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2 "Fire Investigation," Journal of the United Kingdom Association of Fire Investigators, Vol. 1, No. 1, 2015, p. 2.

3 "IFE Level 5 Award in Fire Investigation: Qualification Handbook," The Institution of Fire Engineers, August 2017, p. 7.

4 "FPA Member Event," Fire Protection Association, April 2015, http://www.thefpa.co.uk/about/news/news_detail.fpa-member-event.html.

5 "NFPA 921 Pre-First Draft Meeting Minutes," NFPA Technical Committee on Fire Investigations, October 2017.

6 Chapter 3 Definitions, NFPA® 921 Guide for Fire and Explosion Investigations, 2017 edition.

> ***Area of Origin.*** *A structure, part of a structure, or general geographic location within a fire scene, in which the "point of origin" of a fire or explosion is reasonably believed to be located.*
>
> ***Point of Origin.*** *The exact physical location within the area of origin where a heat source and a fuel first interact, resulting in a fire or explosion.*
>
> ***Cause.*** *The circumstances, conditions, or agencies that brought about or resulted in the fire or explosion incident, damage to property resulting from the fire or explosion incident, or bodily injury or loss of life resulting from the fire or explosion incident.*

The diagram from NFPA® 921 (see Figure 1 below) illustrates example steps in applying the scientific method to determine the area of origin and the point of origin. A similar flow diagram is available illustrating the scientific method as applied to fire cause determination.

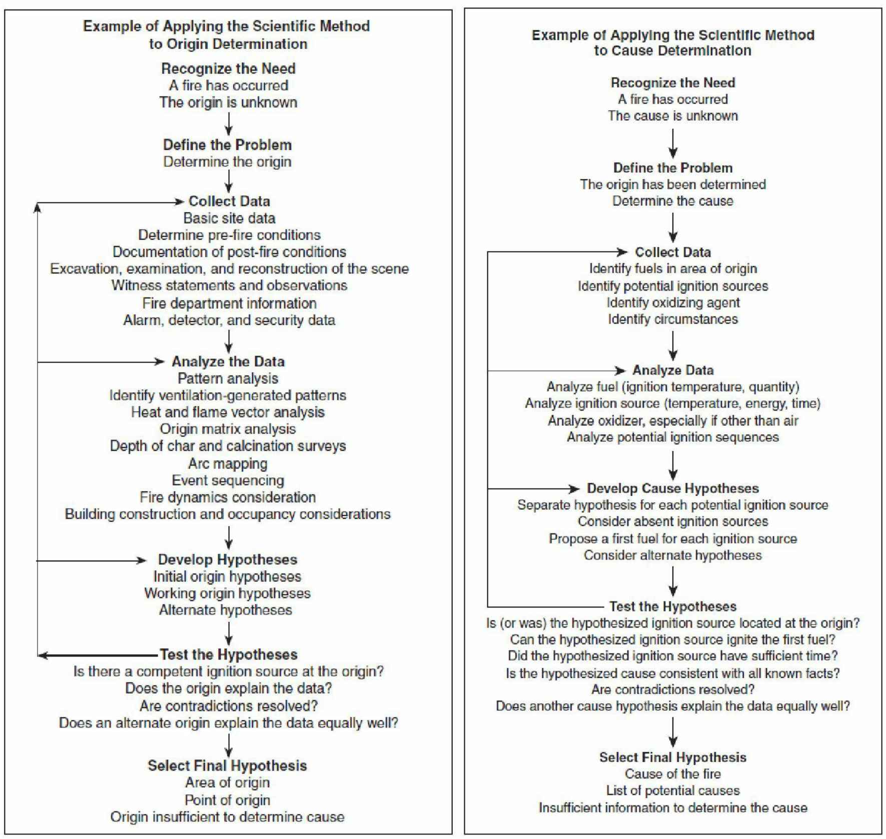

Figure 1. NFPA® 921 Figure 18.2 "An Example of Applying the Scientific Method to Origin Determination," and Figure 19.2 "An Example of Applying the Scientific Method to Cause Determination."

All credible hypotheses are examined during this process to determine the point of origin for the fire, if possible, and then the cause of the fire, if possible. The Code of Practice also endorses that "all realistic hypotheses for the origin, cause, and if required, development of the fire…should be stated," and "each hypothesis must be evaluated and the conclusions reached must be justified in light of the case circumstances and interpretation of physical evidence…"[7] In terms of the investigation, finding the point of origin may lead directly to identification and evaluation of potential causes for the fire. Thus, the final hypothesis explaining the point of origin must be uniquely consistent with the available data in order to reliably identify a point of origin. In accordance with the scientific method and accepted fire investigation practices, if the point of origin is not determined reliably in an investigation, then the cause cannot be assigned (i.e., if one does not know where precisely the fire started, one cannot determine the cause of ignition of that fire).

7 Section 9. Review of Critical Findings, The Code of Practice for Investigators of Fires and Explosions for the Criminal Justice Systems in the UK, April 2017.

3 Data Collected

It is Exponent's understanding that there is an ongoing criminal investigation into this matter; thus, to date, Exponent has either received or been given access to very limited information from the LFB and MPS regarding the fire scene, evidence at the scene, witness observations, fire discovery, and other pertinent facts. The information received has come in various forms, including informal discussions with these agencies' investigators and consultants during evidence examinations. Exponent has also gathered some information from informal discussions with representatives from the Department for Business, Energy & Industrial Strategy (BEIS). Our analysis is subject to update as new information is made available during the ongoing investigation. The entirety of the physical evidence and information surrounding the fire has yet to be examined by Exponent.

Limited evidence has been made available by the MPS for non-destructive examination under their supervision. Whirlpool representatives had the opportunity to conduct a preliminary examination of some of the retained evidence from the kitchen associated with the fridge freezer on 23 June 2017 at an MPS facility. Exponent, Whirlpool representatives, and BEIS representatives examined an exemplar Hotpoint model FF175BP fridge freezer on 28 June 2017. Subsequently, while under the supervision of the MPS, Exponent conducted examinations of evidence associated with the fridge freezer and some wiring on 30 June, 8 August, and 9 August 2017 at a Bureau Veritas facility.

3.1 Information and Evidence

To date, Exponent has had access to the following information and evidence from the fire. A list of the individual evidence items and dates of examination is provided below in Table 1.

- Hotpoint model FF175BP fridge freezer evidence
- Wiring collected from behind the fridge freezer
- Flooring from under the fridge freezer
- Viewing of 137 photographs from the area of origin[8]
- Précis of a key witness statement
- Informal conversations with public agency representatives during the evidence examinations

Additionally, Exponent has obtained and reviewed information pertaining to the following:

- Fire Incident statistics from the United Kingdom

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8 Exponent was afforded the opportunity to view 137 photographs from the fire scene during the evidence examinations; however, the contents of these photographs could not be thoroughly analyzed due to limitations of the viewing process, and no copies have been provided.

- Publicly-available information from multiple sources, such as online media reports and product manuals available online
- Planning documents from The Royal Borough of Kensington and Chelsea

3.1.1 Fridge Freezer Evidence Examinations

The fridge freezer and associated evidence have been examined by the MPS, LFB, and their consultants prior to Whirlpool or Exponent's examinations. The extent of those examinations is unknown to Exponent at this time. Whirlpool and Exponent subsequently examined evidence in June and August 2017. Table 1 below lists those pieces of evidence along with their identifier code, a short description, and the date that the material was examined by Exponent and/or Whirlpool.

Table 1. List of evidence examined by Exponent

Identifier Code	MPS Evidence Description	Examination Status
BPS1 / N00001790	Fridge freezer only. Compressor unit sampled separately. Seized 14/6/17	Viewed by Whirlpool - 23 June 2017 Viewed by Exponent - 30 June 2017
SLW/5 / MPSZ012613113	Control board taken from within BPS1 – Fridge Freezer on 30/6/17	Viewed by Whirlpool - 23 June 2017 Viewed by Exponent - 30 June 2017
SLW/6	Original packaging from BPS1	Viewed by Exponent - 30 June 2017
BPS2 / N00001788	Fridge freezer door. Seized 14/6/17	Viewed by Whirlpool - 23 June 2017 Viewed by Exponent - 30 June 2017
BPS3 / N00001789	Conductors from fridge base. Seized 14/6/17	Viewed by Whirlpool - 23 June 2017 Viewed by Exponent - 30 June 2017
SLW/111	Stranded conductor wire from BPS3, diameter = 1.05-1.10 mm, strand = 0.18-0.19 mm	Viewed by Exponent - 08-09 August 2017
SLW/112	Used in x-ray of SLW/111	Viewed by Exponent - 08-09 August 2017
SLW/113	Stranded conductor wire from BPS3, diameter = 0.92-1.07 mm, strand = 0.18-0.19 mm	Viewed by Exponent - 08-09 August 2017
SLW/114	Stranded conductor wire from BPS3, diameter = 0.95-1.05 mm	Viewed by Exponent - 08-09 August 2017
SLW/115	Solid core conductor from BPS3, diameter = 0.48-0.49 mm	Viewed by Exponent - 08-09 August 2017
SLW/116	Stranded conductor wire from BPS3, diameter = 0.90-1.08 mm	Viewed by Exponent - 08-09 August 2017
BPS4 / P00010363	Compressor unit for fridge freezer. Seized 14/6/17	Viewed by Whirlpool - 23 June 2017 Viewed by Exponent - 30 June 2017
SLW/7	Original packaging from BPS4	Viewed by Exponent - 30 June 2017

Table 1. continued… List of evidence examined by Exponent

Identifier Code	MPS Evidence Description	Examination Status
SLW/110	Section of wire taken from within compressor (BPS4), diameter = 1.3-1.55 mm, strand = 0.16-0.20 mm	Viewed by Exponent - 08-09 August 2017
MCL-06-076029-14062017 / MPSE53166732	Remains of mains supply flex associated with fridge freezer. Seized 15/6/17. Note that this was collected the day following the other fridge evidence.	Not provided for Whirlpool's 23 June 2017 examination Viewed by Exponent - 08-09 August 2017
SLW/117	Solid core conductor from MCL-06, diameter = 0.61-0.65 mm	Viewed by Exponent - 08-09 August 2017
SLW/118	Section of flex core and stranded flex (diameter = 0.99-1.08 mm, strand = 0.20-0.21 mm, marked with red cable tie) from MCL-06	Viewed by Exponent - 08-09 August 2017
SLW/119	Section of stranded conductor wire from MCL-06, diameter = 0.99-1.16, strand = 0.21-0.26	Viewed by Exponent - 08-09 August 2017
BPS5 / P02839036	Assorted wiring. Seized 14/6/17	Unclear if provided for Whirlpool's 23 June 2017 examination Viewed by Exponent - 08-09 August 2017
SLW/120	Section of seven stranded wire from BPS5, strand = 1.00-1.16 mm	Viewed by Exponent - 08-09 August 2017
SLW/121	Section of seven stranded wire from BPS5, diameter = 2.85-3.02 mm	Viewed by Exponent - 08-09 August 2017
SLW/122	Interconnected wiring of assorted sizes from BPS5, diameter = 1.39-1.85 mm, strand = 0.61-0.76 mm	Viewed by Exponent - 08-09 August 2017
MCL/7	Vinyl flooring from underneath the fridge freezer	Viewed by Exponent - 08-09 August 2017
MCL/8-12	Flooring from under the fridge, Parts 1-5	Viewed by Exponent - 08-09 August 2017
SLW/123	Blue craft paper under BPS3, BPS5, and MCL-06 during examination	Viewed by Exponent - 08-09 August 2017

3.2 Information and Evidence not yet Available

As the investigation proceeds, Exponent anticipates that additional evidence and information will become available. Several items of information and evidence were identified in Annex 1 of a Memorandum of Understanding (MOU) between the Inquiry and the MPS as transcribed in the list below:

(i) All audio recordings of 999 calls between the start of the fire and 8 p.m. on 14 June 2017.

(ii) All transcripts of the same so far as yet created.

(iii) All digital and other photographic and video recordings (including CCTV recordings) of and around Grenfell Tower between midnight on 13 June and 8 p.m. on 14 June 2017 taken by residents, neighbours, volunteers, firefighters, and other emergency services.

(iv) All contemporaneous records made by the London Fire Brigade, including fireman logbooks, thermal imaging and other measurements and electronically recorded data relating to the fire, commander records or logs, data from each fire engine, up to 8 p.m. on 14 June 2017.

(v) All formal witness statements taken from any witness to the fire, including in particular residents, families, neighbours, fire-fighters and other emergency services who attended the fire up to 8 p.m. on 14 June 2017.

(vi) In respect of the flat of origin only, all contemporaneous scene notes from police including SIO, crime scene manager's decision logs, cordon logs, and notes relating to access and discussion throughout the period that the fire scene investigation in the flat of origin was underway.

(vii) All contemporaneous scene notes from the London Fire Brigade and any other fire investigators involved in the fire scene investigation including of any electrical appliances in the flat of origin.

(viii) Copies of all fire service response/incident logs relating to the initial call received and all fire-fighting activities relating to the initial fire in the flat of origin and time line for such activities.

(ix) Copies of all plans and drawings of the building layout and specifically including the flat of origin (if possible).

(x) Copies of all witness statements from first responders, fire-fighters who attended the initial fire, witnesses relating to the initial fire and initial fire spread, and any statements of the owners of the flat of origin and neighbours.

(xi) Copies of all reports and draft reports relating to the fire scene investigation from London Fire Brigade, BRE, Key Forensics, and any other investigators.

(xii) Copies of all investigations, notes and photographs from all parties relating to the appliance(s) and any other electrical material (e.g. wiring) which were examined.

(xiii) Copies of all actions and messages relating to the fire scene investigation including correspondence with appliance manufacturers.

We anticipate that in addition to the Inquiry's list above, the information and evidence such as that listed below will aid our investigation:

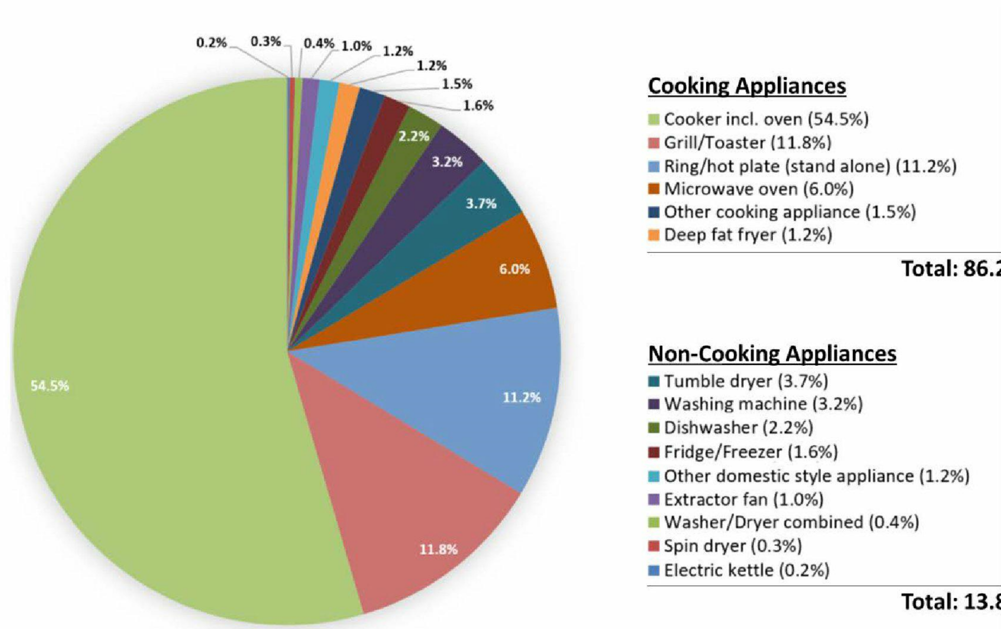
- MPS evidence list for items associated with Flat 16.
- Physical examination of the following items of evidence:
  - Kitchen extractor fan and its wiring,
  - Glen electric cooker (range),
  - Extension lead and associated wiring,
  - Two small fridges in kitchen,
  - Portable electric cooker,
  - Consumer unit for Flat 16, including the electrical distribution system, and
  - All other physical evidence and fire debris visible in the kitchen photographs (e.g., debris on cooktop, debris between fridge freezer and window, and debris behind small fridge), including debris collected from the kitchen and surrounding area.
- Fire scene examination including examination of similar flats.
- Information on the history of the index Hotpoint FF175BP and other appliances in the kitchen.
- Smoke detector(s) from Flat 16 and example units with other pertinent information.
- Information regarding past power surges/outages.
- All scene photographs.
- All laboratory examination photographs of evidence including radiography.
- Any forensic laboratory analysis or investigation reports pertaining to the origin or cause of the fire.

3.3 Background Statistics on Residential Kitchen Fires

Exponent analyzed fire statistics for residential dwellings to assist in identifying potential types of items in Flat 16 that have been reported to have caused kitchen fires in other incidents. The UK Home Office provides a detailed database[9] of fire incidents attended by the Fire and Rescue Services (FRS), which is similar to the NFIRS database used by the National Fire Protection

[9] Fire statistics data tables, Incident level datasets. https://www.gov.uk/government/statistical-data-sets/fire-statistics-data-tables. Accessed 30 June 2017.

Association in the United States.[10] The dwelling fire datasets include data from FRS-attended incidents that occurred in England at occupied primary dwellings during fiscal years 2010 through 2015.[11] Fires may be caused for many reasons in a dwelling, and 55% of the fires originated in kitchens. From within the fire cause datasets, the data indicated that cooking appliances accounted for 86% of the fire causes. A breakdown of the appliances that may be located in a kitchen and their relative percentage of incidents is provided in Figure 2.



Analysis of the Domestic Appliance Fires Dataset, Home Office, Government of the United Kingdom, Published April 27, 2017.

Figure 2. Chart of fires caused by appliances in kitchens in England.

[10] The NFIRS database in the United States catalogs data on fire response incidents and is made available to the public as a means to analyze, track, and appropriately address the problem of fire.

[11] Each financial year runs from April 1 to March 31 of the following year.

3.4 Witness Statements

Exponent understands that many witnesses have been interviewed by the MPS in regards to the fire incident. We do not know the extent of those interviews, and we have not been provided with transcripts or written statements with one exception. An occupant of Flat 16 provided information to the authorities regarding discovery of smoke in the kitchen, and a précis of the witness statement has been provided to Exponent. The "Précis of a key witness statement" is copied in its entirety below:

> The sliding doors to the kitchen were closed. At around 00.55 I was woken up by the sound of the fire alarm, which I think was the one in the kitchen. I couldn't smell anything but went straight into the kitchen via the main door which was open. I could see light coloured smoke in the area next to the fridge/freezer and window. It was in the general area there, I cannot be more specific about exactly where it was coming from. The window was open by about 10 inches. The window has two central panels that open inwards with a flip up pane running along the top. The smoke was rising up from floor level and coming towards me. I thought it was coming from the floor below but I did not go to investigate.
>
> I had left the door open so while I was in the communal corridor I could see that the smoke had changed colour and become darker.
>
> The smoke did not enter the communal corridor, it stayed in the kitchen and I never smelt anything.
>
> When I saw the smoke in the kitchen it was coming from the area of the fridge-freezer between the cooker and window. This is a Hotpoint fridge-freezer which I bought about five years ago new from somewhere in Brent Cross. It wouldn't have been more that £270.
>
> I've never had any problems with it except when it got iced over about a year ago and I had to defrost it for a couple of days. It's never been faulty. It is plugged into a double socket behind it halfway up the wall and is kept constantly plugged in and on. The socket was marked "fridge" by the council. The other socket is unused.

The précis indicates that the occupant was alerted to the incipient fire by an audible smoke alarm in the flat. The occupant observed a "light coloured smoke in the area next to the fridge/freezer and window." The précis provides insufficient detail to distinguish between numerous potential points of origin. The précis does not indicate an observation of flames or a visible fire involving anything in the kitchen; thus, the statement is ambiguous in and of itself as to the fire's point of origin within the kitchen. The fire in the kitchen caused significant damage to the appliances and other contents, which also precluded a specific identification of the point

of origin of the fire from viewing the photographs. The fridge freezer was heavily damaged like other items in the kitchen, and it is possible that the fridge freezer was attacked either by a fire originating outside the fridge freezer or by one originating within the fridge freezer.

Our preliminary work and consideration of the précis provides sufficient information for the basis of this report to assume that the fire likely originated in the kitchen of Flat 16. However, the précis does not provide clarity as to the following elements of the fire scenario:

- Ignition source,
- First fuel ignited in the fire,
- Point of origin of the fire, or
- Cause of the fire.

Exponent's fire investigation is focused on evaluating these elements in an effort to reliably determine the point of origin and cause of the fire.

3.5 Layout of the Flat

Given the ongoing criminal investigation, Exponent has not yet been given access to the fire scene or provided with copies of diagrams or photographs of the fire scene. Thus, we evaluated the layout of the flat and its kitchen from a combination of external examination of the building, online news reports, planning agency documents, review of physical evidence, and viewing of a limited number of scene photographs. Exponent extracted a typical residential floorplan for the 4^{th} story of Grenfell Tower from planning documents obtained at the Royal Borough of Kensington and Chelsea website.[12] As shown in Figure 3, Flat 16 is a two bedroom flat including a living room separated from the kitchen by sliding doors.[13] This layout is consistent with the 137 photographs viewed by Exponent.

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[12] Planning search: Documents related to case PP/12/04097, Drawing-952258.pdf, 6 November 2012, The Royal Borough of Kensington and Chelsea, www.rbkc.gov.uk.

[13] Note that the sliding doors detail has been modified by Exponent based on review of online and scene photographs.

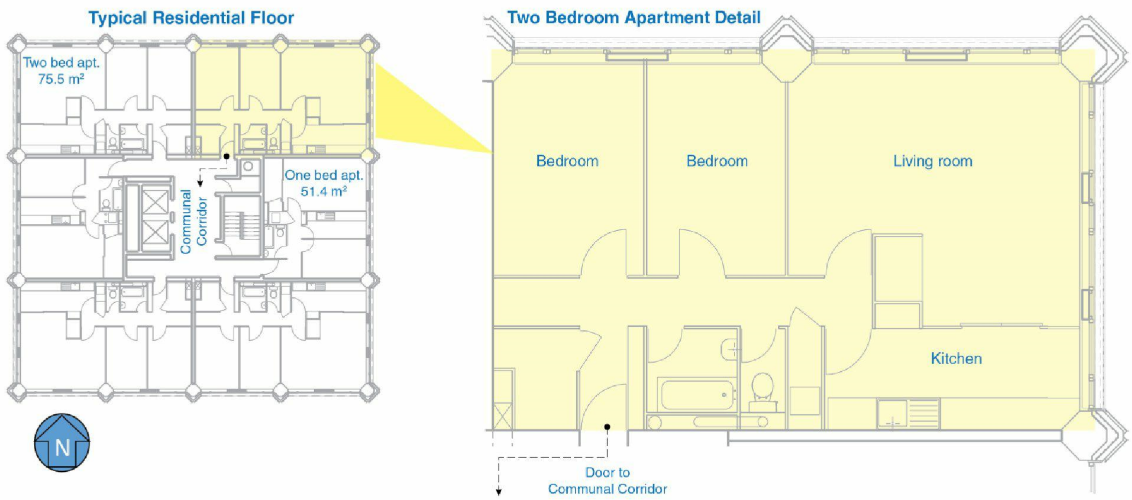

Figure 3. Floorplan believed to correspond to Flat 16.

3.6 Fire Scene Reconstruction

Fire scene reconstruction is a useful tool in fire investigation where the investigators recreate "the physical scene during fire scene analysis investigation or through the removal of debris and the placement of contents or structural elements in their pre-fire positions."[14] We have not been made aware of any reconstruction of the fire scene having been undertaken. Thus, Exponent created diagrams to reconstruct the pre-fire layout of the kitchen and many items in the kitchen. The diagrams were developed from examination of the retained evidence, viewing the available scene photographs, viewing representative images of other unburned flats in the building available online, and reviewing appliance information available online.[15] The two diagrams below (Figure 4) depict the layout of the kitchen and major appliances. The first (top) figure is an elevation view, as though the reader is standing in front of the appliances in the kitchen. The second (bottom) figure is a plan view, looking down onto the floor of the kitchen.

From the photographs, Exponent was unable to determine whether or not the kitchen contained wall cabinets above the counter before the fire, but those cabinets would be expected in typical kitchen construction. The kitchen was observed to contain several appliances including a dishwasher, an electric cooker (a Glen branded unit), a Hotpoint FF175BP fridge freezer, a window-mounted extractor fan, two small fridges (only one is depicted because the other was either to the right or on top of the one depicted at the time of the fire), and an extension lead positioned behind the small fridge and in front of the window. The corner between the FF175BP fridge freezer and the window also contained burned debris (possibly from a cabinet or shelf

[14] Section 3.3.76, NFPA® 921 Guide for Fire and Explosion Investigations, 2017 edition, p. 15.

[15] These diagrams are preliminary and subject to revision as new information becomes available or if Exponent is permitted to perform a scene examination.

unit), a burned portable electric cooker, and other materials. The kitchen was accessible through a traditional door to the west end of the kitchen or through the sliding doors on the north wall.

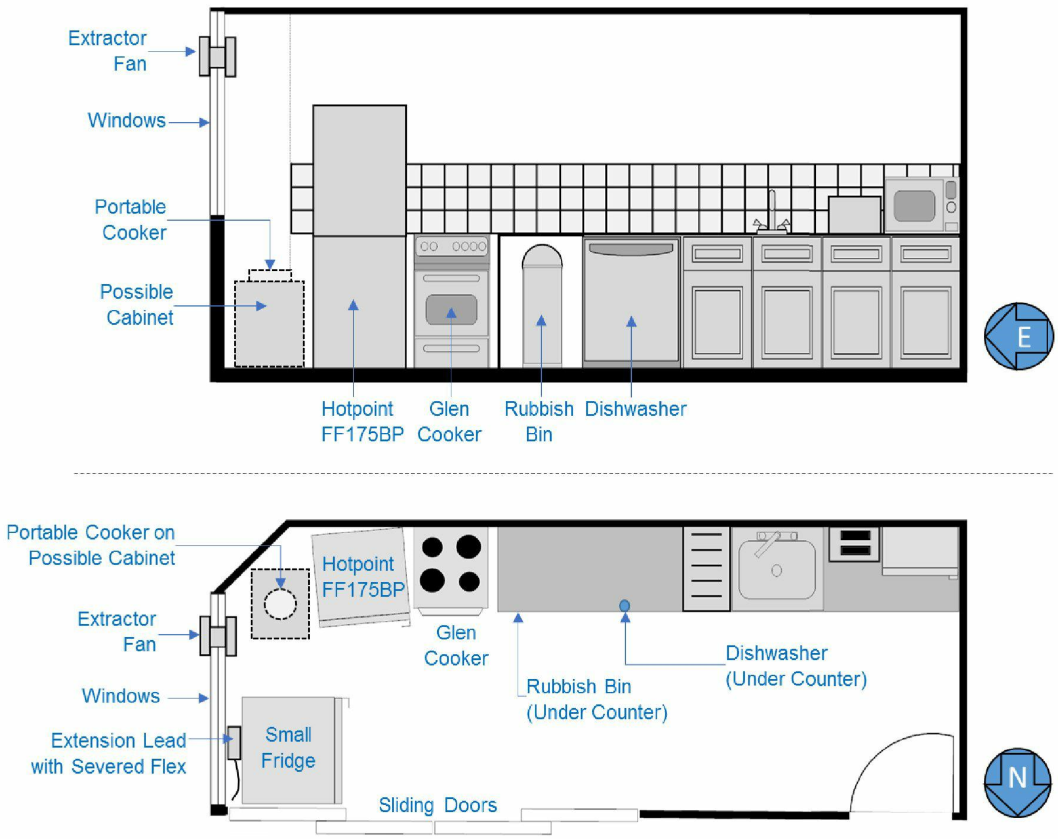

Figure 4. Diagrams showing Exponent's reconstruction of the Flat 16 kitchen: elevation view (top) and plan view (bottom).

4 Fire Point of Origin

4.1 Area of Origin

In accordance with the scientific method, the initial focus of a fire investigation is to define the origin where the fire started so that potential points of origin can be evaluated within that area. The fire reportedly originated in the kitchen of Flat 16 on the 4th story of the building, and Exponent's report has been prepared based upon that assumption. Exponent understands that the first responding fire units extinguished a fire confined to the kitchen area of Flat 16 and that smoke was first witnessed in the kitchen. We believe that the area of origin was placed within the kitchen of the flat by the LFB and MPS based on this information.

4.2 Potential Points of Origin for the Kitchen Fire

Applying the scientific method requires development and evaluation of realistic hypothetical points of origin and potential causes. As noted above, the point of origin for a fire is the exact physical location within the area of origin where the fire started. Statistically, kitchens are the most common areas of origin for residential fires, and these fires are often attributed to cooking appliances (86% of residential kitchen fires in England) as well as other kitchen appliances.[16] These realistic potential fire causes should be considered during the investigation.

Fire damage patterns provide objective evidence that may support potential points of origin for a fire. Fire damage patterns can reveal useful information about the progression of a fire from the initial fuel to other items in the area of origin, the effects of ventilation on fire growth, and the effects of the intensity of combustion of individual items on the growth and spread of the fire. Analysis of fire damage patterns is an inherent aspect of a fire investigation. By analyzing the fire damage patterns to the kitchen and items within the kitchen from viewing photographs and examining the fridge freezer evidence, we identified five potential points of origin (see Figure 5) that are consistent with the currently available physical evidence. Given the limited available information and evidence, we cannot conclude that we have yet identified all potential points of origin in the kitchen. Thus, this list may change as new information is provided. Our analysis of the limited available information is insufficient to investigate all other credible potential points of origin in the kitchen in a manner consistent with the scientific method.

[16] Fire statistics data tables, Incident level datasets. https://www.gov.uk/government/statistical-data-sets/fire-statistics-data-tables. Accessed 30 June 2017.

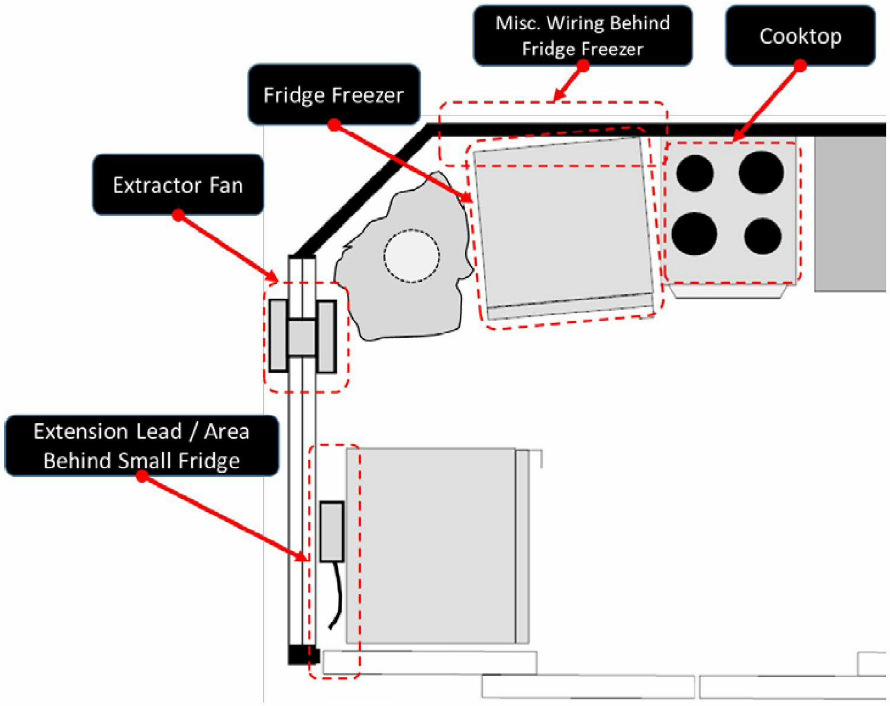

Figure 5. Diagram showing potential points of origin for the fire within the kitchen.

The potential points of origin in the figure are discussed below in counterclockwise order from the figure starting with the Cooktop.

1. Cooktop: Burned debris was visible on the left rear element of the electric cooker's cooktop surface adjacent to the fridge freezer. The content of this burned debris could not be determined from viewing only the photographs and warrants further investigation and analysis. Ceramic backsplash tiles had fallen from the wall behind and above the cooker and were observed on top of the debris on the left rear-heating element on the cooktop. This observation may be consistent with a fire originating on the cooktop and then spreading to the fridge freezer. The précis statement does not mention the cooktop surface, and the activities of the occupant(s) during the time leading up to fire have not been reported to date. This possible fire scenario should be analyzed further. The plastic control knobs for the heating elements were melted away; thus, their position could not be determined from viewing the photographs. A laboratory examination may reveal their position at the time of the fire. Furthermore, to date, no information has been reviewed that explains the source of the debris or whether combustible items were located on or near the cooktop. As a result, it is possible that the cooktop is the point of origin for the fire.

2. Miscellaneous wiring: The electrical wiring in the kitchen that provides power to the AC sockets, power switches, and the appliances may provide useful information about the point of

origin for the fire, for example through arc map analysis. However, a full accounting of the wiring for the fridge freezer, extractor fan, building wiring, and other electrical items cannot be performed effectively based on Exponent's review of the limited fire scene photographs or Exponent's preliminary nondestructive laboratory examination of the evidence.

For example, the copper wires from a fire-damaged flex cord believed to be part of the fridge freezer do not appear to match the expected length of a flex cord for a model FF175BP fridge freezer. Thus, we cannot confirm that this is the fridge freezer's flex cord, that it is all of the flex cord, or that this flex cord was originally supplied with the fridge freezer. Additionally, a segment of unidentified electrical wire was examined that was partially melted, which may be consistent with fire attack while being energized, which could relate to the flex cord, fridge freezer wiring, or something else. A thorough examination of all of the wiring and electrical components from this area is necessary to evaluate potential points of origin at the wiring or nearby electrical items. The extent of the limited examination to date is discussed below. It is possible that the electrical wiring in the area of the fridge freezer is the point of origin of the fire.

3. FF175BP fridge freezer: Currently no fire patterns or other evidence has been identified that uniquely indicate a point of fire origin at the fridge freezer. Preliminary analysis of the fridge freezer evidence will be presented in a subsequent section of this report, but the damage patterns to the fridge freezer and its immediate surroundings could be the result of either a fire originating within the fridge freezer or from an external fire starting at a point of origin remote from the fridge freezer subsequently attacking the fridge freezer. The severity of damage to the fridge freezer and to the floor directly under the fridge freezer may be attributed to the nature of the materials that burned and the confinement afforded by the steel casing of the fridge freezer. A fire originating elsewhere in the kitchen could create similar fire damage patterns to the fridge freezer and the flooring underneath it. It is possible that the fridge freezer is the point of origin of the fire.

4. Extractor fan: An extractor fan was mounted in a panel in the window adjacent to the fridge freezer. An electrical fault in the fan or its wiring could cause a fire in the kitchen. The fan, wiring for the fan, and controls were not identified in the photographs viewed by Exponent or in the evidence provided for examination. As with any electrical appliance, several potential failure modes can lead to a fire. Given the lack of information, photographs, and physical evidence, these potential failure modes cannot be ruled out by Exponent, and this is a possible point of origin.

5. Extension lead and area behind the small fridge: A power extension lead with multiple sockets was present in the debris between the small fridge and the window. While it was conveyed to us that nothing was plugged into the extension lead, the device itself was believed to be powered by a socket in the living room with its flex cord running through a sliding door into the kitchen. The extension lead's flex cord was burned and severed near the sliding door. The fire scene photographs depicted a local fire pattern on the wall behind the small fridge and above the extension lead and its flex cord, and this pattern appeared to emanate from the severed section of the cord by the sliding door to the north. A failure involving the extension lead or

damage to its flex cord that caused the fire cannot be ruled out, thus this is a possible point of origin.

4.2.1 Other Factors Related to Potential Points of Origin

Currently, there are a number of potential points of origin that are possible but cannot be adequately investigated until further evidence becomes available. For example, the role, if any, of the two small fridges or the portable cooker in the kitchen cannot be evaluated. While Exponent heard unconfirmed reports that these items were not plugged in at the time of the fire, we cannot currently verify their electrical connection status at the time of the fire.

Reports in the news media identified a history of power surge events at Grenfell Tower in 2013 that damaged appliances.[17] Failures in damaged appliances can lead to fires. News reports have also called into question whether power surges had been occurring in the Grenfell Tower flats even up to or at the time of the 14 June 2017 fire.[18] A power surge can cause electrical components to fail in many ways depending upon the nature of the surge and the component in question. It is unclear whether power surge incidents were related to all flats in the building or localized to individual flats, but it is possible that an electrical power surge could be manifested in a single flat if the cause is related to that flat's supply of power or interior power distribution.[19] However, other than the unverified news reports, Exponent does not have access to sufficient information to reliably evaluate power surges as factors in potential fire causes in Flat 16.

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17 https://grenfellactiongroup.wordpress.com/2017/06/19/grenfell-tower-the-kctmo-culture-of-negligence/, downloaded 18 July 2017.

18 http://www.bbc.com/news/uk-40632705, downloaded 18 July 2017.

19 As of the writing of this update, Exponent has insufficient information on the power system and power distribution in the tower.

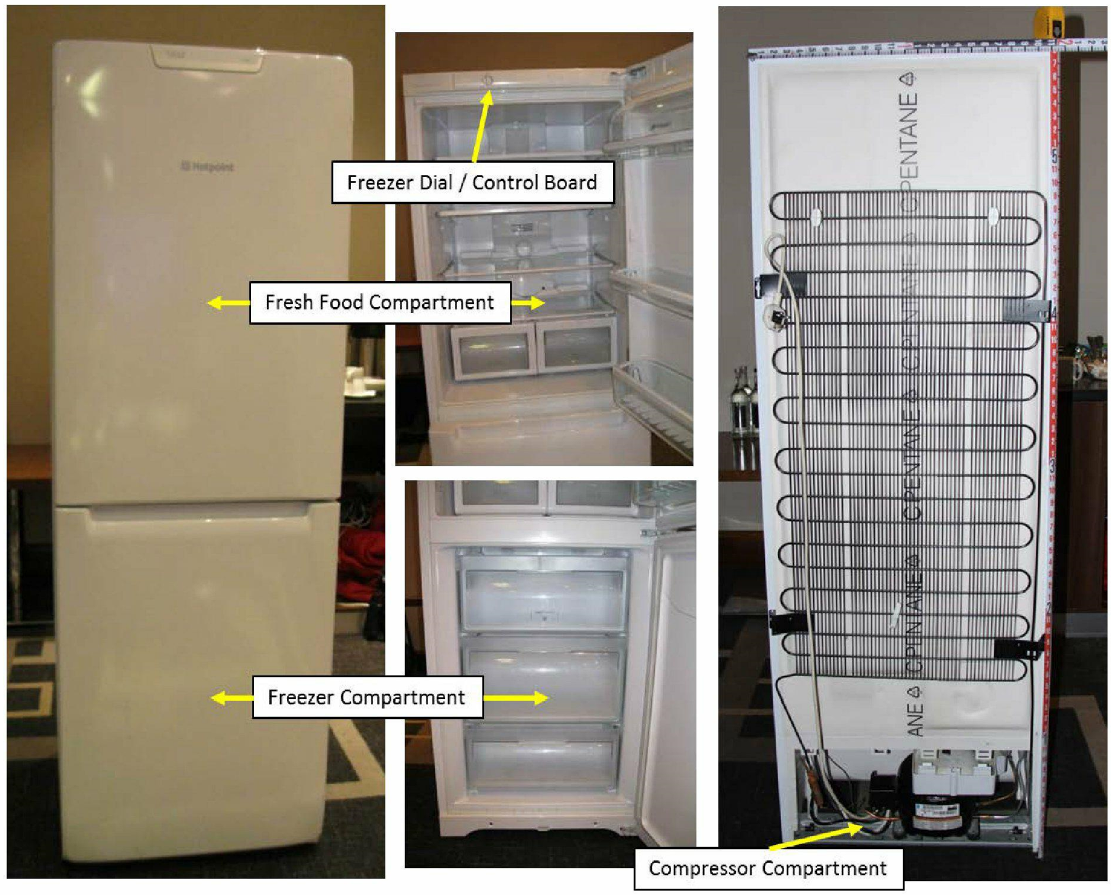
5 Analysis of Physical Evidence

Consideration of all relevant information and evidence is necessary to complete a thorough scientific investigation. This section is focused on the fridge freezer and associated evidence because these were the primary items of evidence made available for Exponent's examination up to this point. We anticipate thorough examination of other evidence items from the kitchen will also be subject to engineering analysis as potential causes of the fire. This section first starts with a discussion of the FF175BP fridge freezer model line and then transitions into discussion of the potential relevance of damage patterns to the fridge freezer evidence. Hypothetical fire causes for a fire originating at the fridge freezer are then evaluated in light of the evidence.

5.1 Overview of the FF175BP Fridge Freezer Model

The Hotpoint model FF175BP fridge freezer used a common design to the industry. Photographs of a similar (i.e., exemplar) unit examined jointly with representatives from BEIS on 28 June 2017 are shown in Figure 6.[20] This fridge freezer model has two food compartments: an upper fresh food refrigeration compartment and a lower freezer compartment. The unit was insulated with polyurethane foam on the side walls and enclosed by a corrugated polyethylene panel on the back wall, a polypropylene compressor enclosure on the bottom and bottom rear, steel sheet panel walls on the sides and top, and insulated doors on the front. The inner liner for the compartments was manufactured from high-impact polystyrene, and the compartments contained drawers and shelves.

[20] There are a few minor differences between this exemplar and the FF175BP involved in the fire, which will be identified where appropriate.

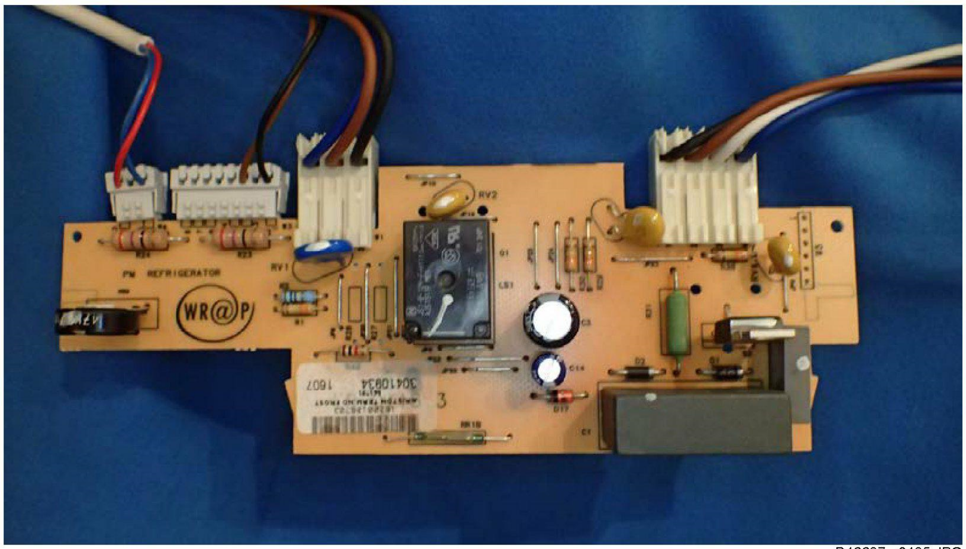


D16695 - 0033.JPG, D16695 - 0035.JPG, D16695 - 0042.JPG, D16697 - 0009.JPG

Figure 6. Exemplar FF175BP (S/N 705263184, manufactured in 2007) examined with representatives from BEIS on 28 June 2017. There are slight differences in the condenser coil and compressor between the exemplar and the subject unit.

The model FF175BP fridge freezer utilizes an R600a (refrigerant) closed-loop refrigeration system to cool the appliance. This system compresses the vapor refrigerant using a compressor mounted underneath the unit, condenses the refrigerant to a liquid, and then expands the condensed liquid refrigerant to cool the air inside of the food compartments. The compression process heats the refrigerant, and this heat is dissipated from the condenser cooling coils on the back wall outside the unit making the vapor refrigerant condense to a liquid. Evaporation of that liquid refrigerant as it flows through the evaporator coils mounted in the wall behind the freezer compartment absorbs heat and cools the air inside the unit. Air is circulated inside the unit within the freezer compartment and between the freezer compartment and the fresh food compartment by means of a small fan mounted near the evaporator behind the freezer compartment wall. Temperature of the air is controlled automatically by a control board mounted at the top front of the fresh food compartment (see exemplar control board in Figure 7). The air temperature of the freezer can be set by adjusting a dial at this location, and the air temperature of the fresh food compartment is controlled by adjusting a mechanical baffle that

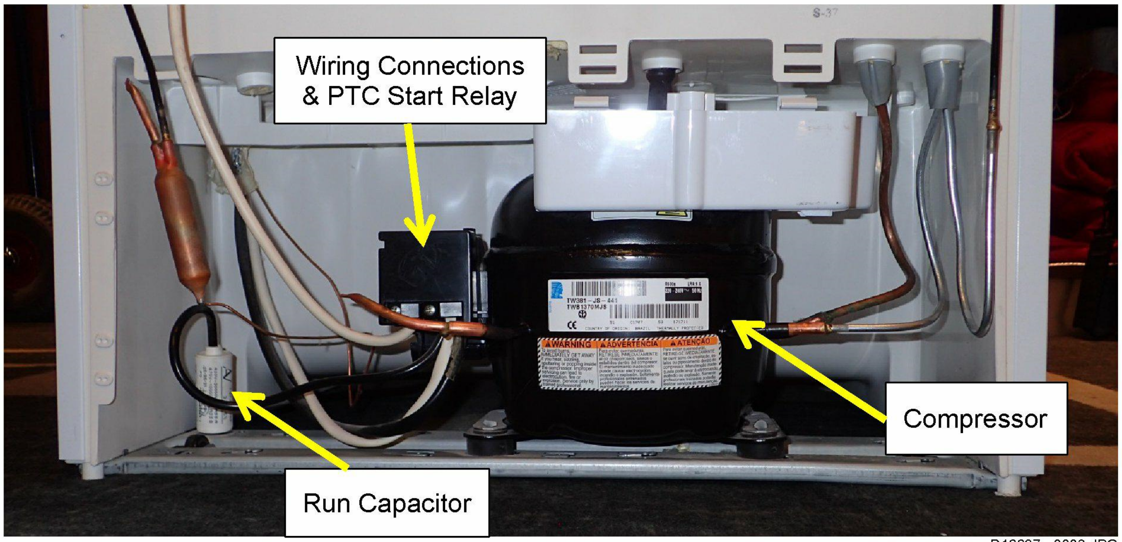
controls air circulation between the freezer and the fresh food compartment. The refrigerator contains electrical resistance heaters that are intended to defrost the evaporator and prevent ice accumulation in other areas of the unit. The fridge freezer is automated to maintain the desired level of cooling in the freezer and fresh food compartment and defrost as necessary.



D16697 - 0195.JPG

Figure 7. Control board from the exemplar FF175BP (S/N 705263184) examined on 28 June 2017. There are slight differences in this control board from the one in the subject FF175BP.

The closed loop refrigeration system contains approximately 36 grams of R600a (isobutane) refrigerant, which is approximately 20 mL of liquid. The refrigeration cycle is driven by a mechanical compressor that pressurizes the refrigerant vapor to drive the flow of the vapor and condensed liquid through the tubing that comprises the refrigeration cooling system. The compressor is controlled by the control board according to temperature demands. The exemplar compressor was a Tecumseh-manufactured unit, which is similar to the Embraco-manufactured compressor in the subject FF175BP. A photograph of the exemplar fridge freezer's compressor compartment is shown in Figure 8. The compressor is powered through electrical connections in a terminal enclosure mounted to the compressor, which also includes a Positive Temperature Coefficient (PTC) start relay device. To increase operational efficiency, a run capacitor is wired to the compressor and mounted inside the compressor compartment.



D16697 - 0083.JPG

Figure 8. Compressor compartment from the exemplar FF175BP (S/N 705263184) examined on 28 June 2017. The exemplar contained a Tecumseh-manufactured compressor that is similar to the Embraco-manufactured compressor in the subject unit. The exemplar was equipped with a class P0 run capacitor, but was mounted in the same location as the class P2 run capacitor would be in the subject fridge freezer.

5.1.1 P2 Run Capacitors

During the joint examinations with representatives of BEIS, there was considerable discussion about run capacitors as a potential cause of the fire. Exponent has been informed by Whirlpool that the date of manufacture of the subject fridge freezer (October 2008) indicates that the fridge was equipped with a run capacitor of class P2. This has implications on the likelihood of a fire-causing failure in the capacitor. The standard EN 60252-1:2001 (IEC 60252-1:2001) defines designations for capacitors of class P0, P1, and P2, which are relevant to the date of manufacture of the fridge freezer.[21] In particular, P2 class of safety protection is defined in the standard as:

> *(P2) indicates that the capacitor type has been designed to fail in the open-circuit mode only and is protected against fire or shock hazard. Compliance is verified by the test described in 2.16.*

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[21] IEC 60252-1:2001 "AC Motor Capacitors – Part 1: General – Performance, Testing and Rating – Safety Requirements – Guidance for Installation and Operation". Version 1.0 is dated February 15, 2001 and is the applicable version for the given time product date of the index unit. (The next version is 2.0 and includes the dates September 29, 2010 and August 29, 2013.)

By design and by verification through testing, class P2 safety capacitors are less likely to fail in a way that leads to fires than class P0 safety capacitors.[22]

Although construction of P2 capacitors varies from manufacturer to manufacturer, some common features of construction may include the following elements: self-healing design, segmented construction, and inclusion of a pressure-sensitive interrupter (circuit-opening). These features are intended to provide for extended life, tolerance to surges, and a fail open circuit design. Through these mechanisms, P2 capacitors have a higher safety rating as evidenced by the IEC 60252-1:2001 labeling.

5.2 Fridge Freezer Fire Damage Patterns

The fire damage to the appliances and contents of the kitchen was extensive. Exponent only had access to examine the fridge freezer after it had been removed from the scene and examined by others. The fire damage to the fridge freezer and its components was analyzed by Exponent in order to identify and evaluate potential fire cause hypotheses involving the unit as it was one of the five potential points of origin identified to date. The following discussion provides an overview of fire damage patterns to the fridge freezer and primary components.

The fridge freezer has the most damage at the top in the refrigerator compartment, which decreased towards the bottom of the appliance and the front of the appliance. This damage is consistent with the anticipated effects of fire exposure with the greatest extent of damage toward the top (i.e., from exposure to the hot gases in the upper level of the room) and rear (i.e., combustible rear wall versus steel side walls affects fire penetration into the interior of the appliance). Images of the four sides of the fridge freezer starting at the front and moving in a clockwise direction around the appliance are provided in Figure 9.

Most of the polyurethane foam insulation, the inner liner, and likely the contents were consumed by the fire in the upper half (fresh food compartment) of the unit. The entire rear wall of insulation and rear panel were consumed. The compressor compartment wall and foam insulation were consumed around the compressor compartment as shown in Figure 10. The fire damage to the bottom of the fridge freezer is consistent with fire involvement of the polypropylene compressor compartment wall, which subsequently melted and created a pool fire under the fridge freezer. This fire damage pattern alone does not indicate that the fire started in the fridge freezer because similar damage will occur if an external fire spreads to the fridge freezer and ignites these materials.

[22] P0 “indicates that the capacitor type has no specific failure protection.”

D16695 - 0190.JPG, D16695 - 0096.JPG, D16695 - 0350.JPG, D16695 - 0098.JPG

Figure 9. Fridge freezer exterior fire damage patterns.

D16695 - 0659.JPG

Figure 10. View of the underside of the fridge freezer showing damage to the compressor compartment and the insulation.

A view of the lower (freezer) compartment from the front indicates that fire breached the rear wall of the freezer compartment with slightly more damage to the right side (Glen cooker side). Views from the front and back of the freezer compartment are provided in Figure 11 to illustrate the extent of damage. This damage is consistent with the effects anticipated by the configuration of the compressor compartment as depicted in Figure 12. The larger open area to the left of the compressor as viewed from the rear will allow preferential burning and more extensive fire development to the left side of the compressor compartment than on the right side of the compressor. The compressor was provided as a separate item of evidence from the fridge freezer, and scene photographs depicted that the compressor mounting plate had come loose from the fridge during the fire and/or during the investigation efforts. The refrigerant tubing was later cut by investigators in order to separate the compressor from the fridge as part of evidence collection.

D16695 - 0732.JPG, D16695 - 0366.JPG

Figure 11. View of freezer compartment with drawers re-installed (left) and compressor compartment (right, with compressor removed).

Figure 12. Compressor and mounting plate aligned with the fridge.

5.3 Fire Damage to Flooring under Fridge Freezer

Fire damage patterns to flooring and surrounding items may be useful in identifying potential points of fire origin and evaluating potential fire causes in some fire incidents. The LFB recovered the flooring located under the fridge freezer, and it was taken into evidence by the MPS. The flooring was constructed of a medium density fiberboard embossed with a faux ceramic tile surface as depicted in Figure 13. The flooring contained an approximately rectangular burn pattern directly under the fridge freezer. The fire damage patterns are consistent with the effects of burning pooled plastic on the floor while confined under the fridge freezer in the compressor compartment. The degree of charring of the flooring is most significant toward the center, open area of the compartment, which is consistent with the effects of re-radiation of heat from the pool fire that occurred in this small compartment and the location of seams between planks in the flooring.

The charred surface of the combustible flooring contains a witness mark (i.e., a protected area) that indicates the location of the compressor mounting plate during the fire. Using this witness mark, the compressor plate is oriented on the flooring in Figure 14 to illustrate the position of the fridge freezer during the fire. A hashed red box outlines the approximate orientation of the fridge freezer. This orientation also matches the fire damage to the underside of the fridge freezer shown in Figure 10. From this orientation, the fridge freezer appears to have been angled away from the wall during the fire. The flooring has a hole along the seam under the compressor. This hole does not align with the capacitor, which is typically installed to the far

right edge of the compressor plate in the image. The hole sits below the compressor electrical terminal enclosure, but there was no damage to the components in the enclosure that would indicate that this is the point of fire origin. The hole is consistent with the anticipated effects of burning at a vertical seam between planks in the flooring, which allows more intense burning than along a flat horizontal surface. This phenomenon is common for fires on combustible plank flooring. Thus, the hole does not indicate a point of origin for the fire.

D16793 - 0678.JPG

Figure 13. Fire damage to flooring under fridge freezer. The wall was located to the top of the image.

Figure 14. Compressor bracket aligned with fire damage pattern on floor. The hashed line approximates the orientation of the fridge freezer.

The fire pattern to left side of the red box (i.e., east, window side) in Figure 14 is not readily explained by the compressor compartment fire. This fire pattern extends beyond the shell of the fridge freezer, and may have been caused by external burning material or may be due to the angled orientation of the unit, which could allow flames to preferentially escape from this side. Exponent currently has insufficient information to determine the source of this fire damage pattern. A fire originating external to the fridge freezer will create the same or very similar damage patterns to those observed on the flooring under the fridge freezer if the combustible components of the fridge freezer become involved in the fire. The fire damage to the flooring does not uniquely support the fridge freezer as the point of origin or cause of the fire.

5.4 Potential Fridge Freezer Fire Causes

Exponent's preliminary analysis of the available evidence has allowed identification of several potential fire causes that may be consistent with the evidence and facts surrounding the fire. For a fridge freezer, potential causes of ignition might typically involve the control board, wiring components, the compressor PTC start relay, heaters, or the capacitor. Several of the potential causes can be ruled out, but some can be neither confirmed nor ruled out given the available information and evidence. Eight potential causes for a fire in a fridge freezer are discussed below.

1. Control Board. Exponent examined the contents of evidence bag SLW/5 labeled "Control board taken from within BPS1 – fridge freezer."[23] Although the control board and wires were damaged by fire, there was no indication of electrical activity consistent with it causing a fire. As shown in Figure 15, all of the connections of wiring to the circuit board are accounted for and have been examined. The control board is therefore not a likely cause for the fire, since this fire cause hypothesis is not supported by the evidence.

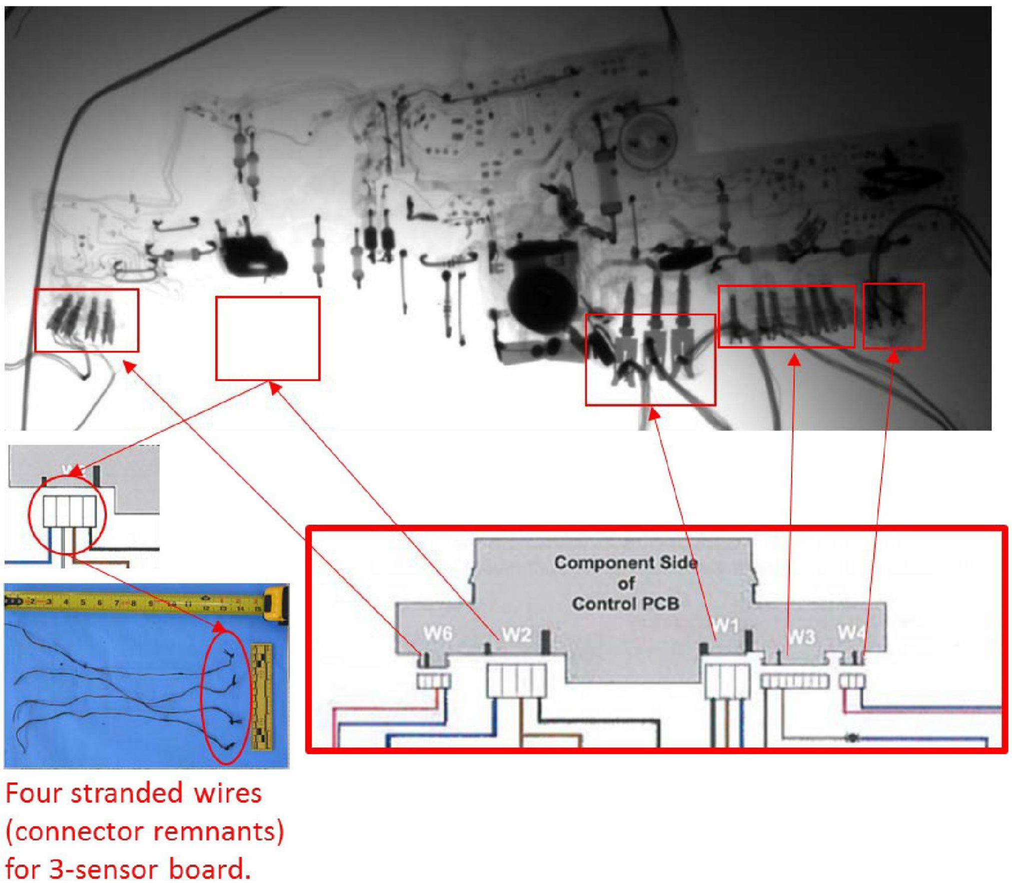

Figure 15. Image of control board from evidence that shows all connections have been identified.

[23] D16792 – 0013.JPG

2. Flex Cord Ignition. Exponent examined the contents of evidence bag MCL06 that was labeled "Remains of mains supply flex associated with fridge freezer."[24] The bag contained stranded and solid copper wire, ground buswork from a two-receptacle power socket, and a spring and section of a line or neutral bus from a power socket. From the fridge freezer parts drawings, the expected length of the flex cord wiring is 1730 to 1770 ±60 millimeters.[25] However, MCL06 contains only approximately 1625 millimeters of the flex cord wiring; therefore, the remaining length of 105 to 145 ±60 millimeters is not in that evidence bag.

It is unclear if this wiring evidence represents the original flex cord supplied with the fridge freezer or if the original flex cord has been replaced or modified at some point after original manufacture. From examination of the recovered flex cord wiring, no indication of any electrical activity on any of the flex wire or power socket remains was identified that could be the result of fire attack on an energized flex or that could be evidence of a fire cause. If a fault in the flex cord occurred, then that electrical activity may have occurred in the missing portion of the cord. Given the balance of the cord that was missing, it is possible that electrical activity in the missing section of cord played a role in the cause of the fire. This hypothetical cause cannot be confirmed or eliminated given the available evidence.

3. Compressor/PTC Start Relay/Overload/Wiring Terminal. Examination of the compressor and its electrical terminals, PTC start relay, and thermal overload device did not indicate evidence of electrical activity consistent with fire cause. Five slip-on spade terminals were identified in the evidence bag BPS4 labeled "Compressor From Fridge Freezer."[26] No electrical activity was identified on the five slip-on spade terminals. A review of the Bill of Materials and parts drawings provided by Whirlpool shows that six wires with slip-on spade terminals are expected to be installed in the compressor terminal enclosure of the FF175BP fridge freezer.[27]

Additionally, an examination of the exemplar fridge freezer showed that the exemplar terminal enclosure had six slip-on spade terminals. This indicates that one of the spade terminals is missing from the recovered evidence. Given the lack of electrical activity apparent to these components, it is unlikely that they played a role in the cause of the fire. The lack of electrical activity on the compressor components is inconsistent with any of these being the cause of ignition. As such, hypotheses involving these components in the cause of the fire were determined to be improbable.

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[24] D16792 – 0115.JPG

[25] Indesit Company Drawing No. 23000035629, Tabella Cavi Alimentazione, 09/07/10.

[26] D16695 – 0466.JPG

[27] Indesit Company Drawing No. 24000093513, Tabella Assieme Cablaggi Schiumati DD-Combi NF Meccanici, 06/02/09; Indesit Company Drawing No. 24000062453, Condensatori Di Marcia Run Capacitors, 10/9/15; Indesit Company Drawing No. 23000035629, Tabella Cavi Alimentazione, 09/07/10.

4. P2 Capacitor. According to the date of manufacture, the fridge freezer was equipped with a class P2 run capacitor. This P2 designation "indicates that the capacitor type has been designed to fail in the open-circuit mode only and is protected against fire or shock hazard."[28] Therefore, class P2 capacitors are much less likely to cause a fire than class P0 capacitors. Also, in the evidence reviewed by Exponent, there were no remains found of the run capacitor or capacitor wiring to the compressor terminal enclosure.

Additionally, five slip-on spade terminals were found (there should be six), which suggests that there was a capacitor connected to at least one tab in the enclosure. If the fridge freezer did not have a capacitor, then only four slip-on spade terminals would be present in the enclosure.[29] Given the safety rating of P2 capacitors, it is unlikely that this was the cause. However, given the absence of evidence at this time, a hypothetical fire cause involving the capacitor is possible.

5. Heater Runaway. There were three electrical resistance heaters in the fridge freezer (evaporator defrost, gutter, and freezer inlet duct). The heaters experienced damage consistent with exposure to the fire but did not show any signs of local overheating that would be consistent with a fire cause. The physical evidence is not consistent with hypothetical fire causes involving the heaters; thus, these hypotheses were determined to be improbable.

6. R600a (Isobutane) Leak. In theory, a refrigerant leak can result in more rapid spread of a fire or a flash fire. However, a leak would still require another ignition source to ignite the isobutane. Rapid fire growth from ignition of a leak of isobutane is not consistent with the initial discovery reported in the witness précis. An examination of the evidence also showed no apparent evidence of pre-fire leaks in the refrigerant tubing or compressor casing that could lead to a localized fire. Given these observations, the hypothesis of R600a participating in the cause of the fire was determined to be improbable.

7. Evaporator Fan. The evaporator fan and its wiring are located inside near the back of the fridge behind an access panel. An examination of the evaporator fan and its attached wiring did not reveal evidence of electrical activity. From the lack of electrical activity, the hypothesis of an evaporator fan fire cause was determined to be improbable.

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[28] IEC 60252-1:2001 "AC Motor Capacitors – Part 1: General – Performance, Testing and Rating – Safety Requirements – Guidance for Installation and Operation". Version 1.0 is dated February 15, 2001 and is the applicable version for the given time product date of the index unit. (The next version is 2.0 and includes the dates September 29, 2010 and August 29, 2013.)

[29] Indesit Company Drawing No. 24000093513, Tabella Assieme Cablaggi Schiumati DD-Combi NF Meccanici, 06/02/09; Indesit Company Drawing No. 24000062453, Condensatori Di Marcia Run Capacitors, 10/9/15; Indesit Company Drawing No. 23000035629, Tabella Cavi Alimentazione, 09/07/10.

8. Conductors from Fridge Base. Exponent examined evidence bag BPS3 labeled, "Conductors from fridge base."[30] The bag contained loose sections of wiring, but the source of this wiring (whether from a fridge freezer wiring harness or some other appliance in the area) could not be determined without more information from the fire scene. A melted wire from the bag is depicted in Figure 16. The appearance of the wire indicates material loss, a sharp line of demarcation, and a re-solidified metal bead. These are all indicators of electrical activity, but without further information, they do not differentiate whether the activity was either the cause or the result of fire attack. Thus, hypothetical fire causes involving this wire are possible and cannot be confirmed or eliminated given the available evidence.

D16792 - 0500.jpg

Figure 16. Section of wire from evidence bag BPS3 exhibiting evidence of electrical activity.

[30] D16792 – 0127.JPG

5.5 Summary of FF175BP Fridge Freezer Analysis

Exponent has analyzed the available fridge freezer evidence and evaluated multiple potential fire causes involving the fridge freezer. Many potential causes can be eliminated. There are several possible causes that remain under investigation, including the wiring in the fridge debris and the capacitor. Table 2 summarizes the identified potential causes relating to the fridge freezer and shows that most of them are unlikely to have caused the fire. However, the damage to all of these components cannot currently be differentiated between a fire originating in the fridge freezer versus one originating outside the fridge freezer that ultimately spreads to the unit.

Table 2. List of potential causes relating to the fridge freezer

Potential Fridge Freezer Failure	Preliminary Findings
Control Board	Not consistent with available evidence; improbable cause
Flex Cord	Missing portions of cord; possible cause
Compressor/PTC Start Relay/Overload/Wiring Terminal	Not consistent with available evidence; improbable cause
P2 Capacitor	Not likely the cause due to fail-safe design. Remains of capacitor and wiring (if such remains exist) still need to be examined. Possible cause
Heater Runaway	Not consistent with available evidence; improbable cause
R600a (isobutane) leak	Not consistent with available evidence; improbable cause
Evaporator Fan	Not consistent with available evidence; improbable cause
Conductors from fridge base	Electrical activity on wiring consistent with fire involvement while energized as either a cause or a result of the fire. Possible cause

Based upon the information and evidence examined thus far, Exponent has not observed any evidence that uniquely indicates that the cause of the fire was related to the fridge freezer and has identified several other possible fire causes that require further investigation.

6 Conclusions

This preliminary report summarizes our investigation and findings to date given the available information and evidence. Exponent's investigation has proceeded in accordance with the guidelines presented in NFPA® 921, the Code of Practice, and the scientific method. Given the destructive nature of fire incidents and the often incomplete information available afterwards, the point of origin and exact cause of a fire may not always be determined in even the most thorough investigations. Without examining the full body of evidence for the Flat 16 kitchen fire, it is unknown if the point of origin or exact cause of this fire can ultimately be determined. In the context of the investigative process, Exponent is still in the data collection stage; thus, the development and testing of hypotheses has proceeded with caution and remains incomplete.

Several potential points of origin for the fire were identified in the kitchen; currently there is insufficient data available to Exponent to test all the hypotheses regarding the point of origin of the fire and the associated hypothetical causes. When compared against the available evidence, it is apparent that among the potential points of fire origin, none can be uniquely identified as the exact point of origin. Exponent was given the opportunity to examine the fridge freezer and associated evidence, which represented two potential points of origin. From preliminary examination of that evidence, many possible fire causes were determined to be improbable, and some possible fire causes were identified that were consistent with the available evidence.

Determination of the cause of the fire in the kitchen, if possible, will require an examination of the other items present in the kitchen at the time of the fire and further analysis of the fridge freezer evidence. Exponent has not yet been given access to other evidence from the kitchen outside of a few photographs that we were briefly allowed to review. Based on Exponent's involvement to date, we understand that more information and evidence may become available to our investigation in the future. However, given the current status of our investigation, the point of origin and cause of the fire remain undetermined by Exponent.

Limitations

At the request of Whirlpool, Exponent is conducting an investigation of the origin and cause of the fire and the potential involvement of the fridge freezer in the 14 June 2017 fire in the Grenfell Tower in London, England. Exponent is investigating and analyzing specific issues relevant to this incident as requested by Whirlpool and has prepared this preliminary status report for the Grenfell Tower Public Inquiry. Exponent's scope of investigation does not currently address the fire spreading beyond the room of origin, fire protection systems in the building, occupant evacuation, firefighting efforts, or other aspects of the incident not explicitly related to the origin and cause of the fire. The scope of services performed during this investigation may not adequately address the needs of other users of this report, and any re-use of this report or its findings, conclusions, or recommendations presented herein are at the sole risk of the user. The opinions and comments formulated during this assessment are based on observations and information available at the time of the investigation. No guarantee or warranty as to future life or performance of any reviewed condition is expressed or implied.

The conclusions, observations, and recommendations presented herein are based on the preliminary work performed as described in this report. We have endeavored to accurately present all areas of concern identified during our investigation; however, we have limited information available to us as of the issuing of this summary. If there are perceived omissions or misstatements in this report regarding any aspect of our work, we ask that they be brought to our attention as soon as possible so we have the opportunity to address them fully. Exponent reserves the right to revise the discussion, conclusions, and recommendations if and when additional information becomes available and additional analysis has been completed.

This preliminary work relies on anecdotal information, such as news articles and online information, conversations with authorities and their consultants, a limited preliminary review of some of the retained evidence, and a review of a shortened summary (précis) of a single witness statement. This interim report aims to assimilate that information and outline the work that remains to be completed. Our work in this matter is ongoing, and we are collecting and analyzing data on a regular basis. As such, it is anticipated that we will refine our analyses as the work progresses and new information is obtained.

Appendix A

Curriculum Vitae of Delmar "Trey" Morrison III, Ph.D., P.E., CFEI

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Professional Profile

Within Exponent's Thermal Sciences group, Dr. Morrison's practice areas encompass product safety, product liability, and process safety through hazard and risk analysis, failure analysis, and post-incident investigation. He specializes in evaluations of origin, cause, and engineering issues related to catastrophic incidents involving fires, explosions, and chemical process technology. His expertise includes chemical engineering, fire dynamics, process safety management, and the system safety of products and industrial equipment. Dr. Morrison's practical research encompasses self-heating materials and reactive chemical hazards and evaluating scenarios such as spontaneous ignition of vegetable oil-contaminated fabrics and self-heating of reactive chemicals.

Dr. Morrison provides consulting services for a variety of industries. Beyond the wide range of consumer and industrial systems that he evaluates, he has focused on heating systems including residential and commercial clothes dryers and industrial process dryers, ovens, and furnaces. He has also focused on oil-flooded screw air compressors and other major industrial equipment failures. As a chemical engineer, his projects include analyzing the effects of chemical process design, plant operator actions, control system response, and process unit response during upset situations and operations that may lead to a hazardous loss of containment.

As part of Dr. Morrison's proactive safety consulting services, he leads hazard and risk assessments using industry-accepted process hazard analysis (PHA) methods such as HAZOP studies, What-If studies, and LOPA studies, combined with analytical techniques such as Fault Tree Analysis, Event Tree Analysis, Root Cause Analysis, Consequence Analysis, and Quantitative Risk Assessment. He routinely applies this expertise to risk analysis for natural gas, LNG, propane, and other gas processing facilities.

Dr. Morrison is an active professional in the product safety and chemical process safety communities. In addition to his technical committee memberships, international presentations, and publications, he serves in leadership roles in the field of chemical process safety through process safety conferences sponsored by the American Institute of Chemical Engineers in North America and in Latin America. Dr. Morrison has chaired many industry conferences including the 45th AIChE Loss Prevention Symposium in 2011, the 8th Global Congress on Process Safety in 2012, the 5th Process Safety Management Mentoring Forum in 2016, and the 7th Latin American Conference on Process Safety in 2016. The objectives of these activities are to aid in the prevention of major loss incidents that involve fires, explosions, runaway reactions, and hazardous material releases in the chemical, petrochemical, and related industries.

Academic Credentials & Professional Honors

Ph.D., Chemical Engineering, Illinois Institute of Technology (IIT), 2008

M.S., Chemical Engineering, Oklahoma State University, 1998

B.A., Chemistry, Knox College, 1996

Licenses and Certifications

Licensed Professional Engineer, Illinois, #062-059506

Licensed Professional Engineer, North Carolina, #037722

Licensed Professional Engineer, South Carolina, #28918

Licensed Professional Engineer, Iowa, #22945

Licensed Professional Engineer, Michigan, #6201062901

Certified Fire and Explosion Investigator, Reg. No. 12900-6508

40-Hour OSHA Certification, Hazardous Waste Operations and Emergency Response

40-Hour Training, Process Hazard Analysis (PHA) for Team Leaders

Professional Affiliations

Process Safety

- Session Chair for Fires, Explosions, and Reactive Chemicals, 2017 Loss Prevention Symposium
- Session Chair for Tutorials in Process Safety - Loss Prevention Symposium, 2017 Process Safety Management Mentoring Forum
- Conference Chair, 7th CCPS Latin American Conference on Process Safety in 2016
- Symposium Chair for 5th Process Safety Management Mentoring (PSM^2) Forum in 2016
- American Institute of Chemical Engineers (Senior Member)
- Safety & Health Division of AIChE (Member)
- Member of the American Institute of Chemical Engineers (AIChE) Loss Prevention and Process Safety Programming Committee (Area 11a of the AIChE Safety & Health Division)

Fire Safety

- National Fire Protection Association (member)
- National Association of Fire Investigators (member)
- Alternate Member: Technical Committee on Ovens and Furnaces, NFPA 86 *Standard for Ovens and Furnaces*, National Fire Protection Association

Product Safety

- Member of Underwriters Laboratories Standards Technical Panel (STP) 2157 covering the following Standards for Safety: ANSI/UL 1206 Electric Commercial Clothes-Washing Equipment, ANSI/UL 1240

Electric Commercial Clothes-Drying Equipment, ANSI/UL 2157, Electric Clothes Washing Machines and Extractors, and ANSI/UL Electric Clothes Dryers

Past Professional Affiliations/Positions

Process Safety

- Session Chair for LNG & LPG Safety, 2015 Global Congress on Process Safety
- Vice-Chair for 4th Process Safety Management Mentoring (PSM2) Forum in 2015
- Session Chair for Consequence Analysis I - Explosions, Consequence Analysis II - Toxics, and Process Safety Education, 2014 CCPS Latin American Conference on Process Safety
- Session Chair for Case Studies and Lessons Learned, 2014 Global Congress on Process Safety
- Chair of the AIChE Loss Prevention and Process Safety Programming Committee for 2012-2013
- Session Co-Chair for Consequence Analysis I & II, 2013 5th CCPS Latin American Conference on Process Safety, Cartagena, Columbia
- Session Chair for the Analysis of High Consequence Offsite Events, 2013 Loss Prevention Symposium
- Session Chair for Lessons Learned from Mentoring in the Process Safety Organization, 2013 Process Safety Management Mentoring Symposium
- Session Chair for Fires & Explosions - Fundamental Understandings for Professionals New to the Field, 2013 Process Safety Management Mentoring Symposium
- Global Congress Chair for the 2012 8th AIChE Global Congress on Process Safety, Houston, Texas
- Session Chair for Indicators and Metrics in Process Safety, 2012 4th CCPS Latin American Conference on Process Safety, Rio de Janeiro, Brazil
- Symposium Chair for the 2011 45th AIChE Loss Prevention Symposium, Chicago, Illinois
- Global Congress Vice Chair for the 2011 7th AIChE Global Congress on Process Safety, Chicago, Illinois
- Chair for Management of Change Session, 2011 3rd Latin CCPS Conference, Buenos Aires
- Symposium Vice Chair for the 2010 44th AIChE Loss Prevention Symposium, San Antonio, Texas

Product Safety

- Member of Underwriters Laboratories Task Group for Clothes Dryer Exhaust Duct Power Ventilators
- Member of Underwriters Laboratories Task Group to Address Requirements for Clothes Dryer Status Indicators

Publications

Ibarreta AF, Hart RJ, Ponchaut NF, Morrison DR, Kytömaa HK. How does concrete affect evaporation of cryogenic liquids: Evaluating liquefied natural gas plant safety. ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems Part B: Mechanical Engineering 2016; 2(1):011005-1-5.

Morrison DR. Separating anecdotes from science in low temperature ignition of wood. MDTC eNewsletter (http://www.mdtc.org/Articles/2015/June/Separating-Anecdotes-from-Science-in-Low-Tempera.aspx), posted June 2, 2015.

Ibarreta AF, Morrison DR, Kytömaa HK. Small scale and transportation: navigating the risk. LNG Industry Magazine 2014 Oct; 17-24.

Cox BL, Dee SJ, Hart RJ, Morrison DR. Development of a steel component combustion model for fires involving pure oxygen systems. Process Safety Progress 2014; 33(3):299-304.

McInerney EH, Hart RJ, Morrison DR, Kytömaa HK. New quantitative risk criteria for US LNG facilities.

Process Safety Progress 2014; 33(3):237-246.

Ibarreta AF, Ponchaut NF, Hart RJ, Morrison DR, Kytömaa HK. Using passive methods to reduce flammable release hazards at LNG facilities. FS-World Magazine "Oil & Gas Industry" edition, Spring 2014.

Kytömaa HK, Morrison DR. A moving target. LNG Industry Magazine, November/December 2013; 57-62.

Kytömaa HK, Morrison DR. The Liquefied Natural Gas (LNG) industry and fire protection regulations. Fire Protection Engineering 2013; 60: 8-24.

Ogle RA, Morrison DR, Dee SJ. Using assessments to improve process safety culture. Process Safety Progress 2014; 33(2):148-151.

Morrison DR, Fecke M, Ramirez JC. Using LOPA to understand necessary safeguards for steam boiler operation. Process Safety Progress 2012; 31(3): 248-254.

Morrison DR, Hart RJ. Guidelines for identifying and mitigating thermal hazards of sustainable materials. Process Safety Progress 2012; 31(2):174-181.

Morrison DR, Fecke M, Martens, JD. Migrating an incident reporting system to a CCPS process safety metrics model. Journal of Loss Prevention in the Process Industries 2011; 24:819-826.

Ponchaut NF, Kytömaa HK, Morrison DR, Chernovsky MK. Modeling the vapor source term associated with the spill of LNG into a sump or impoundment area. Journal of Loss Prevention in the Process Industries 2011; 24(6): 870-878.

Fecke M, Martens JD, Cowells J, Morrison DR. A guide to developing and implementing safety checklists: Plant steam utilities. Process Safety Progress 2011; 30(3):240-250.

Ogle RA, Morrison DR. Burn injury caused by mixing incompatible chemicals with sodium permanganate. Process Safety Progress 2011; 30(2):148-153.

Ogle RA, Morrison DR. Hazards of unplanned power outages: Implementing appropriate safeguards. Process Safety Progress 2011; 30(2):99-103.

Ramirez JC, Ogle RA, Carpenter AR, Morrison DR. Preventing overpressure hazards from trapped liquids. Process Safety Progress 2010; 29(4): 313-317.

Morrison DR. Fire containment and clothes dryers. Appliance Magazine 2009 Nov/Dec; 66(9):16-19.

Su YS, Morrison DR, Ogle RA. Chemical kinetics of calcium hypochlorite decomposition in aqueous solutions. Journal of Chemical Health and Safety 2009 May/Jun; 16(3):21-25.

Morrison DR, Ogle RA. Further application of the Semenov model to evaluate the possibility of spontaneous combustion in tumble dryers. Journal of Fire Science 2008; 26(2):173-190.

Ogle RA, Morrison DR, Carpenter AR. The relationship between automation complexity and operator error. Journal of Hazard Materials 2006; 159(1-3):135-141.

Morrison DR, Su YS, Fecke MJ. Spontaneous combustion tendency of household chemicals and clothes dryers - Part 2. Appliance Magazine 2006 Jul; 6:26-30.

Morrison DR, Su YS, Fecke MJ. Spontaneous combustion tendency of household chemicals and clothes dryers - Part 1. Appliance Magazine 2006 Jun; 7:26-31.

Ogle RA, Morrison DR, Carpenter AR, Su YS. Missed opportunities in reactive chemical hazard evaluations. Process Safety Progress 2006 Mar; 25(1):2-7.

Morrison DR, Ogle RA, Viz MJ, Carpenter AR, Su YS. Investigating chemical process accidents: Examples of good practices. Process Safety Progress 2006 Mar; 25(1).

Ogle RA, Morrison DR, Viz MJ. Emergency response to a noncollision hazmat release from a railcar. Process Safety Progress 2005 Jun; 24(2):81-85.

Ogle RA, Carpenter AR, Morrison DR. Lessons learned from fire and explosions involving air pollution control systems. Process Safety Progress 2005 Jun; 24(2):120-125.

Ogle RA, Carpenter AR, Morrison DR. Explosion of a railcar containing toluene diisocyanate waste. Process Safety Progress 2004 Dec; 23(4):316-320.

Ogle RA, Megerle MV, Morrison DR, Carpenter AR. Explosion caused by flashing liquid in a process vessel. J Hazard Mat 2004; 115(1-3):133-140.

Morrison DR, Carpenter AR, and Ogle RA. Common causes and corrections for explosions and fires in improperly inerted vessels. Process Safety Progress 2002 Jun; 21(2):142-150.

Ogle RA, Morrison DR. Investigation of an acid spill caused by the failure of an air-operated diaphragm pump. Process Safety Progress 2001 Mar; 20(1):41-49.

Conference Proceedings and Invited Presentations

Ibarreta AF, Hart RJ, Morrison DR, Kytömaa HK. LNG facilities- changing regulations. NFPA Conference and Expo, Boston, MA, 2017.

Morrison DR, Cox B. Investigating Chemical Process Incidents & Near Misses, Short Course. 13th Global Congress on Process Safety, San Antonio, Texas, March 26, 2017.

Morrison DR, Aiken C, Lakhiani SD, van der Graaf P. A Case Study in Human Reliability - Analysis to Support LOPA in Unloading Hazardous Liquids. 13th Global Congress on Process Safety, San Antonio, Texas, March 26-29, 2017.

Hart RJ, Morrison DR. Understanding Tolerable Risk Criteria - Considering the Growth of LNG Transportation. 13th Global Congress on Process Safety, San Antonio, Texas, March 26-29, 2017.

Morrison DR, Stern M, Osorio-Amado CH. Waste Solvents to Trash Haulers: Lessons Learned from Hazardous Waste Accidents. 13th Global Congress on Process Safety, San Antonio, Texas, March 26-29, 2017.

Morrison DR. Process Safety Management in Small- and Mid-Scale Liquefaction. GasPro Americas, Houston, Texas, September 13-14, 2016.

Morrison DR, Fecke MT. Presentation on Management of Change and Major Incident Investigation. Cargill Sponsored CCPS University Faculty Workshop in Blair, Nebraska, August 18, 2016.

Morrison DR, Dee SJ. Presentation on Major Incident Investigation and Dust Explosion Hazards. Archer Daniels Midland Sponsored CCPS University Faculty Workshop in Decatur, Illinois, July 28, 2016.

Morrison DR, Cox B. Investigating Chemical Process Incidents & Near Misses, Short Course. 12th Global Congress on Process Safety, Houston, Texas, April 10, 2016.

Dee SJ, Ogle RA, Morrison DR, Fecke MT. Becoming "Wiser" in Management of Change. 12th Global Congress on Process Safety, Houston, Texas, April 11-13, 2016.

Lakhiani SD, Morrison DR. Bridging Process and Occupational Safety Cultures for the Process Safety Professionals. 12th Global Congress on Process Safety, Houston, Texas, April 11-13, 2016.

Lakhiani SD, Morrison DR. Human Factors Considerations in 3D Model Reviews. Presentation at 12th Global Congress on Process Safety, Houston, Texas, April 11-13, 2016.

Lakhiani SD, Morrison DR. Sala JB. Addressing the Gaps between Occupational and Process Safety Cultures. Session 14P - Behavioral Safety, SPE International Conference, Stavager, Norway, April 2016.

Morrison DR, Anderson DM, Smyth SA, Hetrick TH. Understanding the fire risks of eCigarettes, Vapes, and Mods. DRI Product Liability Conference, New Orleans, LA, February 3-5, 2016.

Morrison DR. Learning from engineering disasters. Petrochemical Operations, Maintenance & Safety - Conference & Exhibition, Houston, TX, November 18-19, 2015.

Morrison DR, Hart RJ. Fire science and investigation. Invited lecture to BME 4093 - Special Topics: Forensic Engineering, Lawrence Technological University, Detroit, MI, November 11, 2015.

Morrison DR. Fire science and investigation. Invited lecture, Knox College, Chem 161, Introduction to Forensic Science. 2012, 2015.

Morrison DR. Identifying and managing the risks of LNG in rail. 3rd Annual Natural Gas for Off-Road Applications USA 2015, Houston, TX, June 2-3, 2015.

Smyth S, Morrison D, and Cox B. Application of HBSE to the fire risk of clothes dryers. Proceedings, 2015 IEEE Symposium on Product Compliance Engineering, Product Safety Engineering Society, May 2015.

Hart RJ, Morrison DR. The hazard we know: Comparing transportation risk of LPG and LNG. American Institute of Chemical Engineers, 2015 Spring National Meeting and 11th Global Congress on Process Safety, Austin, TX, April 26-30, 2015.

Morrison DR, Kumar V, Dee SJ, Cox BL, Al-Shamary M, Al-Qabandi A. Fire from the cascading failure of an oxygen supply system. American Institute of Chemical Engineers, 2015 Spring National Meeting and 11th Global Congress on Process Safety, Austin, TX, April 26-30, 2015.

Lakhiani S, Khan F, Morrison DR. Guidelines for creating a process safety culture assessment tool. American Institute of Chemical Engineers, 2015 Spring National Meeting and 11th Global Congress on Process Safety, Austin, TX, April 26-30, 2015.

Morrison DR. Fire science and investigation. Invited lecture to AA252: Techniques of Failure Analysis, Stanford University, April 10, 2015.

Ramirez JC, Morrison DR, Hart RJ, Hetrick TM. Atmospheric venting of flammable gas to a "safe area": comparing guidelines to calculations. SPE-15HSSE-P-305-SPE-MS. SPE E&P Health, Safety, Security, & Environmental Conference - Americas, Denver, CO, March 16-18, 2015.

Dee SJ, Cox BL, Hart RJ, Farina R, Morrison DR. Effects of cooking on the thermal ignition behavior of vegetable oil. Proceedings, 2015 Fire and Materials Conference, San Francisco, CA, Interscience Communications Limited, London, pp. 889-904, February 2015.

Morrison DR. Safety risk evaluations of FLNG projects. The Second FLNG & FPSO Design & Technology

Conference, Dongpu, Guangzhou, China, January 13-14, 2015.

Morrison DR. LNG risk management. LNG Bunkering North America, A technical guide to overcoming the safety, design and operational challenges of LNG bunkering, Lloyd's Maritime Academy, Miami, FL, October 29-30, 2014.

Hetrick TM, Morrison DR, Ramirez JC, Ott BA, Karneskey J. Analysis of flammable liquid ejection from a container following headspace vapor ignition. International Symposium on Fire Investigation, Hyattsville, MD, September 22-24, 2014.

Khan FS, Morrison DR. The relationship between religiosity and safety culture in the process industry. 6th CCPS Latin American Conference on Process Safety, Buenos Aires, Argentina, September 15-17, 2014.

Hart RJ, Morrison DR. Rail transportation risk assessment comparison: Ethanol versus LNG. 6th CCPS Latin American Conference on Process Safety, Buenos Aires, Argentina, September 15-17, 2014.

Morrison DR, Ramirez JC, Smyth S, Fecke MT. Understanding and managing the often-ignored fire & explosion hazards of industrial air systems. 6th CCPS Latin American Conference on Process Safety, Buenos Aires, Argentina, September 15-17, 2014.

Morrison DR. FLNG Risk Management. Post-Conference Workshop at the 8th Annual FLNG Conference, Seoul, Korea, August 28, 2014.

Morrison DR. Pick a Pillar - The role of incident investigation in process safety. Invited presentation to the Chicago Section of the American Institute of Chemical Engineers, Chicago, IL, April 9, 2014.

Ramirez JC, Morrison DR, Hart RJ, Hetrick TM. Venting flammable gas to a "safe area": An objective review of best practices and guidelines. American Institute of Chemical Engineers, 2014 Spring National Meeting, 48th Annual Loss Prevention Symposium, New Orleans, LA, March 30-April 2, 2014.

Morrison DR, Hart RJ. Utilising risk assessment for safe LNG bunker operations. LNG Bunkering North America, A technical guide to overcoming the safety, design and operational challenges of LNG bunkering, Lloyd's Maritime Academy, Miami, FL, November 18-19, 2013.

Hetrick T, Ramirez JC, and Morrison D. Ejection of flammable liquids during loading and unloading: A preliminary experimental investigation. ASME 2013 International Mechanical Engineering Conference & Exposition (IMECE 2013), San Diego, CA, November, 2013.

Ibarreta A, Hart RJ, Ponchaut NF, Morrison D, Kytömaa HK. How does concrete affect evaporation of cryogenic liquids: evaluating LNG plant safety. ASME 2013 International Mechanical Engineering Congress & Exposition (IMECE 2013), San Diego, CA, November, 2013.

Morrison DR, Smyth S. Fire science and investigation. Invited lecture to BME 4093 - Special Topics: Forensic Engineering, Lawrence Technological University, Detroit, MI, November 6, 2013.

Morrison DR, Kytömaa HK. Evaluating risk management and reliability for safe, continuous and efficient LNG operations. Workshop at the 8th Annual LNG Tech Global Summit, Barcelona, Spain, October 14-16, 2013.

Morrison DR, Fecke, M. Evaluating self-heating and ignition hazards in combustible dust handling equipment. 5th CCPS Latin American Process Safety Conference and Expo, Cartagena, Columbia, August 12-14, 2013.

Morrison DR, Marr KC. Guidelines for applying process hazard analysis techniques to combustible dust applications. 5th CCPS Latin American Process Safety Conference and Expo, Cartagena, Columbia,

August 12-14, 2013.

Cox BL, Dee SJ, Hart RJ, Morrison DR. Development of a steel component combustion model for fires involving pure oxygen systems. American Institute of Chemical Engineers, 2013 Spring National Meeting, 47th Annual Loss Prevention Symposium, San Antonio, TX, April 28-May 2, 2013.

Ogle RA, Morrison DR, Dee SJ. Using assessments to improve process safety culture. American Institute of Chemical Engineers, 2013 Spring National Meeting, 28th Center for Chemical Process Safety International Conference, San Antonio, TX, April 28-May 2, 2013.

Ibarreta AF, Hart RJ, Morrison DR, Kytömaa HK. A View of the evolving LNG regulations and associated exclusion zones from an industry perspective. American Institute of Chemical Engineers 2013 Spring National Meeting, 13th Topical Conference on Gas Utilization, San Antonio, TX, April 28-May 2, 2013.

McInerney E, Hart R, Morrison DR, Kytömaa H. New quantitative risk criteria for U.S. LNG facilities. American Institute of Chemical Engineers 2013 Spring National Meeting, 47th Loss Prevention Symposium, San Antonio, TX, April 28-May 2, 2013.

Hart RJ, Morrison DR, Ibarreta AF, Kytömaa HK. Guidelines for relative hazard ranking of refrigerants and siting considerations for LNG liquefaction units. American Institute of Chemical Engineers 2013 Spring National Meeting, 13th Topical Conference on Gas Utilization, San Antonio, TX, April 28-May 2, 2013.

Morrison DR, Lakhiani S, Khan F. Guidelines for developing site-specific human error rates and human IPLs for LOPA using a safety climate approach. Electronic Poster Presentation at the American Institute of Chemical Engineers, 2013 Spring National Meeting, San Antonio, TX, April 28-May 2, 2013.

Morrison DR, Kytömaa HK. Performing LNG hazard and consequence analysis. Workshop at the 7th Annual LNGTech Global Summit, Rotterdam, The Netherlands, December 3-5, 2012.

Lakhiani SD, Morrison DR, Arndt SR. Warning placards versus safe practices — Redefining hierarchical hazard analysis for process industries. 2012 15th International MKOPSC Symposium, October 23-25, 2012.

Dee SJ, Hart RJ, Hetrick TM, Morrison DR. Hot surface ignition of bearing grease in horizontal and vertical orientations. ISFI 2012, Maryland, October 15-18, 2012.

Morrison DR, Barrera C, Carpenter AR. Guidelines for implementing risk assessment practices in oil and gas pipelines, storage, and transportation: PHA and LOPA. 4th CCPS Latin American Process Safety Conference and Expo, Rio de Janeiro, Brazil, July 3-5, 2012.

Morrison DR, Hart RJ, Kytömaa HK. Guidelines for jetting and flashing LNG vapor exclusion zone analysis. American Institute of Chemical Engineers, 2012 Spring National Meeting, LNG Plant Safety and Protection Session, Houston, TX, April 1-5, 2012.

Hart RJ, Morrison DR. Thermal safety of ionic liquids. American Institute of Chemical Engineers, 2012 Spring National Meeting, 46th Annual Loss Prevention Symposium, Houston, TX, April 1-5, 2012.

Barrera CA, Morrison DR, Ogle RA. Using LOPA to establish SILs for power outage protection. Presentation at the American Institute of Chemical Engineers, 2012 Spring National Meeting, 14th Annual Process Plant Safety Symposium, Houston, TX, April 1-5, 2012.

Ogle RA, Morrison DR, Hart RJ. Thermodynamic models for leak detection of natural gas in salt cavern storage. American Institute of Chemical Engineers, 2011 Annual Meeting, Minneapolis, MN, October 19, 2011.

Morrison DR, Hart RJ, Heckel P. Exposing the blurry lines between personal safety and process safety education: contrasting NIOSH prevention through design (PtD) with CCPS Sache. American Institute of Chemical Engineers, 2011 Annual Meeting, Minneapolis, MN, October 18, 2011.

Vaughen BK, Spicer TO, Morrison DR, Klein JA, Rockstraw DA. Continuing our journey to bridge the process safety gaps between academia and industry. American Institute of Chemical Engineers, 2011 Annual Meeting, Minneapolis, MN, October 18, 2011.

Morrison DR, Fecke M, Ramirez JC. Using LOPA to understand necessary safeguards for steam boiler operation. 3rd CCPS Latin American Process Safety Conference and Expo, Buenos Aires, Argentina, August 8-10, 2011.

Morrison DR. Fire science and investigation. Lecture in the School of Engineering, Stanford University, April 8, 2011.

Morrison DR, Hart RJ. Guidelines for identifying and mitigating thermal hazards of sustainable materials. American Institute of Chemical Engineers, 2011 Spring National Meeting, 45th Annual Loss Prevention Symposium, Chicago, IL, March 13-15, 2011.

Morrison DR, Dillon SE, Hetrick T. A review of the hypothesis of low-temperature self-ignition of wood. Proceedings, 2011 Fire and Materials Conference, San Francisco, CA, Interscience Communications Limited, London, January 2011.

Ramirez JC, Fecke M, Morrison DR, Martens JD. Root cause analysis of an industrial boiler explosion (and how hazard analysis could have prevented it). Proceedings, ASME 2010 International Mechanical Engineering Congress & Exhibition IMECE2010, Vancouver, Canada, November 12-18, 2010.

Morrison DR, Ogle RA. Developing process safety capsules for the chemical engineering classroom. American Institute of Chemical Engineers, 2010 Annual Meeting, Salt Lake City, UT, November 9, 2010.

Morrison DR, Fecke M, Martens J. Migrating an organizational incident reporting system to a CCPS process safety metrics model. 2010 Annual Symposium, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, October 2010.

Ponchaut NF, Kytömaa HK, Morrison DR, Chernovsky MK. Modeling the vapor source associated with the spill of LNG into a sump or an impoundment area. 2010 Annual Symposium, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, October 2010.

Ogle RA, Morrison D, Carpenter AR, Ramirez JC. Process safety management of combustible and flammable liquids. The 2010 Annual Meeting of the Venezuelan Society of Safety Executives (SegurShow 2010), Caracas, Venezuela, October 19-21, 2010. (In Spanish).

Ogle RA, Morrison DR. Burn injury caused by mixing incompatible chemicals with sodium permanganate. American Institute of Chemical Engineers, 2010 Spring National Meeting, 44rd Annual Loss Prevention Symposium, San Antonio, TX, March 22-24, 2010.

Fecke M, Morrison DR, Martens J, Cowells J. A guide to developing and implementing safety checklists: Plant steam utilities. American Institute of Chemical Engineers, 2010 Spring National Meeting, 25th Center for Chemical Process Safety International Conference, San Antonio, TX, March 22-24, 2010.

Ogle RA, Morrison DR, Henriksen T. Hazards of unplanned power outages: Implementing appropriate safeguards. American Institute of Chemical Engineers, 2010 Spring National Meeting, 25th Center for Chemical Process Safety International Conference, San Antonio, TX, March 22-24, 2010.

Morrison DR, Fecke M, Dillon SE. Lessons learned from a thermal runaway incident involving an organic

peroxide intermediate during a power outage. American Institute of Chemical Engineers, 2010 Spring National Meeting, Case Histories and Lessons Learned Joint Session, San Antonio, TX, March 22-24, 2010.

Morrison DR, Ogle RA, Gidaspow D. Internal natural convection effects on the self-heating of solids. American Institute of Chemical Engineers, 2009 Annual Meeting, Nashville, TN, November 13, 2009.

Morrison DR. Analysis of a two decade old arson investigation using scientific fire investigation methods: The People vs. Madison Hobley. Invited guest lecture, Knox College Forensic Sciences Class, October 2009.

Blum A, Long RT, Ogle RA, Morrison DR, Dillon SE. Performing a high-rise life safety analysis: Lessons learned from the cook county administration building fire. 2009 NFPA America's Fire and Security Exposition, Miami Beach, FL, July 30, 2009.

Morrison DR. Industrial accident investigation. Lecture in the McCormick School of Engineering and Applied Science, Northwestern University, May 20, 2009.

Morrison DR, Martens JD, Ogle RA, Cowells JT. Root cause analysis of a cryogenic refrigeration system explosion. American Institute of Chemical Engineers, 2009 Spring National Meeting, 43rd Annual Loss Prevention Symposium, Tampa, FL, April 26-30, 2009.

Morrison DR, Martens JD, Ogle RA, Cowells JT. Accident investigation using process control event diagrams. American Institute of Chemical Engineers, 2009 Spring National Meeting, 24th Annual CCPS International Conference, Tampa, Florida, April 26-30, 2009.

Morrison DR, Ogle RA, Dillon SE, Lucas RJ. Analysis of a two decade old arson investigation using scientific fire investigation methods: The People vs. Madison Hobley. Proceedings, 2009 Fire and Materials Conference, San Francisco, CA, Interscience Communications Limited, London, January 2009.

Ogle RA, Morrison DR, Carpenter AR, Ramirez JC. Common causes and corrections for explosions and fires in improperly inerted vessels. The 2008 Annual Meeting of the Venezuelan Society of Safety Executives (SegurShow 2008), Caracas, Venezuela, October 29-31, 2008. (In Spanish).

Ogle RA, Morrison DR, Carpenter AR, Ramirez JC. The relationship between automation complexity and operator error. The 2008 Annual Meeting of the Venezuelan Society of Safety Executives (SegurShow 2008), Caracas, Venezuela, October 29-31, 2008. (In Spanish).

Morrison DR, Ogle RA, Ramirez RA. Evaporator upset investigation in a sugar processing plant. First Andean Congress on Safety and Health at Work, Lima, PerÚ, October 22-24, 2008. (In Spanish).

Morrison DR. Thermal ignition studies of wood flour. Ph.D. dissertation in Chemical Engineering, Illinois Institute of Technology, May 2008.

Morrison DR. Self-heating materials and thermal stability hazards. Lecture in the School of Engineering, Stanford University, May 5, 2008.

Morrison DR, Ogle RA. Evaluating kinetic parameters for solid substances exhibiting complex self-heating behavior. American Institute of Chemical Engineers, 2008 Spring National Meeting, 42nd Annual Loss Prevention Symposium, New Orleans, LA, April 7-9, 2008.

Dillon SE, Carpenter AR, Ogle RA. Comparative fire risk of motor vehicle fuels: Gasoline vs. ethanol. Presented at American Institute of Chemical Engineers, 2008 Spring National Meeting, 42nd Annual Loss Prevention Symposium, New Orleans, LA, April 7-9, 2008.

Morrison DR, Ogle RA, Gidaspow D. A new assessment of the finite Biot number correction to thermal ignition tests. American Institute of Chemical Engineers, 2007 Annual Meeting, Salt Lake City, UT, November 8, 2007.

Morrison DR. Transient self-heating vs. steady state theory for ignition of wood flour' and 'scientific investigation of incendiary fires.' Invited guest lectures, Knox College Chemistry Department, October 2006.

Morrison DR, Su YS, Fecke MJ. Spontaneous combustion tendency of household chemicals and clothes dryers. 2006 International Appliance Technical Conference, March 2006. This paper received the Dana Chase Memorial Award for the Best Paper presented at the conference.

Ogle RA, Morrison DR, Carpenter AR. The relationship between operator error and automation complexity. 2006 Annual Symposium, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, October 2006.

Caligiuri RD, Morrison DR. Using root cause analysis in product safety investigations. Presentation for Association of Home Appliance Manufacturers Product Liability Seminar, Washington, D.C., October 2005.

Morrison DR, Ogle RA, Viz MJ, Carpenter AR, Su YS. Investigating chemical process accidents: examples of good practices. Engineers Process Plant Safety Symposium, 2005 Spring National Meeting, American Institute of Chemical Engineers, Atlanta, GA, April 11-13, 2005.

Ogle RA, Morrison DR, Carpenter AR, Su YS. Missed opportunities in reactive chemical hazard evaluations. 39th Annual Loss Prevention Symposium, American Institute of Chemical Engineers Spring National Meeting, April 11-13, 2005.

Ogle RA, Morrison DR, Viz MJ. Emergency response to a non-collision HAZMAT release from a railcar. 19th Annual CCPS International Conference, Emergency Planning: Preparedness, Prevention and Response; Orlando, FL, June 2004.

Ogle RA, Carpenter AR, Morrison DR. Lessons learned from fires and explosions involving air pollution control systems. 38th Annual Loss Prevention Symposium, American Institute of Chemical Engineers, New Orleans, LA, April 2004.

Morrison DR, Ogle RA, MacDonald M. Analyzing lint deposition within the residential electric clothes dryer. 2004 International Appliance Technical Conference, March 2004.

Morrison DR, Ogle RA, MacDonald M. Assessing electric dryer lint fire cause scenarios. 2004 International Appliance Technical Conference, March 2004.

Ogle RA, Carpenter AR, Morrison DR. Explosion of a railcar containing toluene diisocyanate waste. 18th International CCPS Conference and Workshop: Managing Chemical Reactivity Hazards and High Energy Release Events, American Institute of Chemical Engineers, September 25, 2003.

Ogle RA, Haussmann G, Lucas RJ, Carpenter AR, Morrison DR. The scientific investigation of arson fires. 2003 DRI Fire and Casualty Seminar, Defense Research Institute, Phoenix, AZ, November 2003.

Ogle RA, Megerle MV, Morrison DR, Carpenter AR. Explosion caused by a flashing liquid in a process vessel. 2003 Annual Symposium, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, October, 2003.

Morrison DR. Basic fire origin and cause investigation. Presentation and Training Program for the Illinois Association of Special Investigation Units, March 2002.

Morrison DR, Carpenter AR, Ogle RA. Common causes and correction for explosions and fires in improperly inerted vessels. Beyond Regulatory Compliance: Making Safety Second Nature, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, 2001.

Ogle RA, Morrison DR. Evaluation of accident investigations conducted by regulatory authorities and advisory agencies. Beyond Regulatory Compliance: Making Safety Second Nature, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, October 2000.

Appendix A

Curriculum Vitae of John D. Martens, M.B.A., Ph.D., P.E., CFEI

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Engineering & Scientific Consulting

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Professional Profile

Dr. Martens applies his expertise as an electrical engineer to the scientific investigation of electrical engineering matters. He specializes in control systems and software, microprocessor-based computer systems, circuit design and analysis, electronic components failure analysis, automotive control systems, machine and process controls (including PLC, DCS and SCADA), robotics and automation, and computer vision. Dr. Martens has led complex investigations related to fires, transportation, consumer products, machine control, and industrial process control.

Prior to joining Exponent, Dr. Martens managed the embedded control systems group at Delphi Corporation, a leading global supplier of mobile electronics and transportation systems, and led an R & D team from development to commercialization of an active rear steering system for improved vehicle performance. Dr. Martens has experience developing and testing electronic stability control systems. Dr. Martens' robotic experience includes developing methods and algorithms for the automatic control of a stair-climbing mobile robot. He has experience programming PLCs and analyzing process control systems.

As a member of Delphi's Innovation Center, Dr. Martens actively supported Delphi's Intellectual Property (IP) portfolio as an inventor (8 United States patents and 1 European patent) and provided analyses related to patent prosecution, validity, and infringement questions as well as prior art research and enablement. Dr. Martens has continued his active involvement in IP matters at Exponent. His most recent IP activity has involved products such as software-controlled systems including computer hard drive control and fluid delivery systems.

Dr. Martens' facilities management experience at Delphi includes equipment specification, procurement, installation, and maintenance. His facilities experience also includes the maintenance of a mechatronics research and development laboratory containing several industrial robots and control systems.

Dr. Martens is active in the field of industrial process control, including burner management and combustion control systems for industrial boilers and furnaces. He has advised his clients regarding the appropriate level of safeguards necessary for the safe operation and control of their systems, assisted them in implementing those safeguards, and audited their installations. He draws from his accident investigation experience and his knowledge of industry standards to perform process hazard analyses.

Academic Credentials & Professional Honors

M.B.A., University of Michigan, Ann Arbor, with high distinction, 2003

Ph.D., Electrical Engineering and Computer Science, Case Western Reserve University, 2000

M.S., Electrical Engineering and Applied Physics, Case Western Reserve University, 1993

B.S., Electrical Engineering and Applied Physics, Case Western Reserve University, summa cum laude, 1993

Tau Beta Pi Engineering Honor Society

Eta Kappa Nu/IEEE's Award for Outstanding Senior in Electrical Engineering

Ohio Aerospace Institute Fellowship

Centerior Energy Fellowship

General Motors Scholarship

Case Alumni Association Scholarship

Dean's High Honors

Licenses and Certifications

Licensed Professional Engineer, Illinois, #062-058837

Licensed Professional Engineer, Michigan, #6201057824

Licensed Professional Engineer, Missouri, #2010036256

Licensed Professional Engineer, North Carolina, #037584

Licensed Professional Engineer, Ohio, #E-65142

Licensed Professional Engineer, Texas, #105276

Licensed Professional Engineer, West Virginia, #19078

Licensed Professional Engineer, District of Columbia, #PE906421

Licensed Professional Engineer, New York, #086510-1

Licensed Professional Engineer, Kansas, #PE25630

Certified Fire and Explosion Investigator (CFEI), #17603-9653

Crash Data Retrieval Technician Levels 1 & 2, Collision Safety Institute

Prior Experience

Manager, Embedded Control Systems, Delphi, Brighton, MI, 2004-2005

Project Manager, Active Chassis Systems, Delphi, Brighton, MI, 2000-2004

Research Assistant, Electrical Engineering and Applied Physics, Case Western Reserve University, Cleveland, OH, 1997-2000

Project Manager, CAM-LEM, Inc., Cleveland, OH, 1996-1997

Advanced Chassis Control Engineer, Delco Chassis, Division of General Motors, Dayton, OH, 1995-1996

Advanced Facilities Engineer, Delco Chassis, Division of General Motors, Dayton, OH, 1994-1995

Laboratory Facilities Manager, Center for Automation and Intelligent Systems Research (CAISR) Mechatronics Laboratory, Case Western Reserve University, Cleveland, OH, 1992-1993

Intern, Delco Chassis, Division of General Motors, Dayton, OH, 1991

Intern, Delco Chassis, Division of General Motors, Rochester, NY, 1990

Repair Technician, Affiliated T.V. Shops, Eastlake, OH, 1988-1989

Professional Affiliations

Institute of Electrical and Electronic Engineers — IEEE (senior member)

Subcommittee Member for Guidelines for Safe Automation of Chemical Processes, 2nd Edition. Center for Chemical Process Safety, American Institute of Chemical Engineers, Wiley, 2017

International Society of Automation — ISA (member)

National Fire Protection Association — NFPA (member)

Principal Member: Technical Committee on Single Burner Boilers, NFPA 85 Boiler and Combustion Systems Hazards Code, National Fire Protection Association, effective August 2015

Alternate Member: ASME CSD-1 Standard, Controls and Safety Devices for Automatically Fired Boilers, effective June 2017

American Society of Mechanical Engineers — ASME (member)

National Association of Fire Investigators — NAFI (member)

Society of Automotive Engineers International — SAE (member)

Patents

Patent 6,789,002 B1: Determination of Vehicle Payload Condition, September 7, 2004 (with A. Hac).

Patent 6,804,594 B1: Active Steering for Handling/Stability Enhancement, October 12, 2004 (with T. Brown, A. Chandy, H. Chen, and C. Gryczan).

Patent 6,862,506 B2: Method for Automatically Adjusting Reference Models in Vehicle Stability Enhancement (VSE) Systems, March 1, 2005 (with E. Bedner, K. Boswell, H. Chen, and B. McDonald).

Patent 6,879,896 B2: System and Method for Using Vehicle Operator Intent to Adjust Vehicle Control System Response, April 12, 2005.

Patent 6,926,114 B2, Assist Modification in Active Front Steering, August 9, 2005 (with F. Bolourchi, K. Boswell, J. Dickinson, and E. Bedner).

Patent 6,942,057 B2: Feel Control for Active Steering, September 13, 2005 (with K. Boswell and F. Bolourchi).

Patent 7,083,025 B2: Method for Implementing Vehicle Stability Enhancement Reference Models for Active Steer Systems, August 1, 2006 (with E. Bedner and K. Boswell).

Patent 7,213,675 B2: Method and System for Anti-Static Steering for Vehicle Steering Systems, May 8, 2007 (with C. Gryczan).

European Patent EP 1357013B1: System and Method for Using Vehicle Operator Intent to Adjust Vehicle Control System Response, June 6, 2007.

European Patent Application 02078139.9: Method for Automatically Adjusting Reference Models in Vehicle Stability Enhancement Systems.

European Patent Application 02079498.8: Feel Control for Active Steering.

Publications

Bobbitt B, Garner S, Cox B, Martens J, Fecke M. Manual vs. automatic boiler controls: A historical perspective from relevant codes and standards. Proceedings of the ASME 2017 Power and Energy Conference 2017. (Accepted).

Fecke M, Martens J, Cox B, Bishop J. Codes, standards, and guidelines for plant steam utilities. Exponent Electrical Engineering & Computer Science Newsletter, Volume 4, 2016.

Martens J, Sinenian N. Usage-based insurance devices. Exponent Electrical Engineering & Computer Science Newsletter, Volume 1, 2015.

Arora A, Martens JD. Energy storage for BEV's: An engineering perspective. IEEE Transportation Electrification Conference and Expo (ITEC' 13), Dearborn, MI, June 16-19, 2013. (Half-day tutorial).

Martens JD, Arora A. Understanding the role of software in product failures. IEEE Symposium on Product Compliance Engineering, Portland, OR, November 5-7, 2012.

Morrison DR, Fecke M, Martens, JD. Migrating an incident reporting system to a CCPS process safety metrics model. Journal of Loss Prevention in the Process Industries 2011.

Martens JD, Fecke, M, Ogle, RA, Bishop, JA. Functional testing for industrial control systems. Proceedings, ASME 2011 International Mechanical Engineering Congress & Exhibition IMECE2011, Denver, CO, November 11-17, 2011.

Arora A, Martens JD, Babic D. AC & DC adapters safety considerations. IEEE Symposium on Product Compliance Engineering, San Diego, CA, October 10-12, 2011.

Fecke M, Martens JD, Cowells J, Morrison DR. A guide to developing and implementing safety checklists: Plant steam utilities. Process Safety Progress 2011; 30(3):240-250.

Ramirez JC, Fecke M, Morrison DR, Martens JD. Root cause analysis of an industrial boiler explosion (and how hazard analysis could have prevented it). Proceedings, ASME 2010 International Mechanical Engineering Congress & Exhibition IMECE2010, Vancouver, Canada, November 12-18, 2010.

Morrison DR, Fecke M, Martens JD. Migrating an organizational incident reporting system to a CCPS process safety metrics model. 2010 Annual Symposium, Mary Kay O'Connor Process Safety Center, Texas A&M University, College Station, TX, October 26, 2010.

Fecke M, Morrison DR, Martens JD, Cowells JT. A guide to developing and implementing safety checklists: Plant steam utilities. American Institute of Chemical Engineers, 2010 Spring National Meeting, 25th Center for Chemical Process Safety International Conference, San Antonio, TX, March 22-24, 2010.

Morrison DR, Martens JD, Ogle RA, Cowells JT. Root cause analysis of a cryogenic refrigeration system explosion. American Institute of Chemical Engineers, 2009 Spring National Meeting, 43rd Annual Loss Prevention Symposium, Tampa, FL, April 26-30, 2009.

Morrison DR, Martens JD, Ogle RA, Cowells JT. Accident investigation using process control event diagrams. American Institute of Chemical Engineers, 2009 Spring National Meeting, 24th Annual CCPS International Conference, Tampa, FL, April 26-30, 2009.

Martens JD, Johnson G, So P. Design considerations for consumer products utilizing high voltage. Presentation, 2006 IEEE Symposium on Product Safety and Compliance Engineering, IEEE Product Safety Engineering Society, (PSES), Irvine, CA, October 23-24, 2006. Also approved for publication in the IEEE PSES 2006 Conference Proceedings.

Martens JD, Hac A, Brown T. Detection of vehicle rollover. 2004 SAE World Congress, No. 04-Annual-848, Detroit, MI, March 2004 (Book SP-1869, paper number 2004-01-1757).

Martens JD. Lyapunov-based, on-line identification for backstepping control. Department of Electrical Engineering and Computer Science, Ph.D. Dissertation, Cleveland, OH, Case Western Reserve University, 2000.

Martens JD, Newman WS. Stabilization of a mobile robot climbing stairs. 1994 IEEE Proceedings and IEEE Video Proceedings of the International Conference on Robotics and Automation, San Diego, CA, p. 2501-2507, May 1994.

Martens JD. Enhanced teleoperation of a mobile robot. CAISR Technical Report #93-111, Master's Thesis, Case Western Reserve University, 1993.

Doctoral Thesis

Martens JD. Lyapunov-based, on-line identification for backstepping control. Case Western Reserve University, Cleveland, OH, 2000.

Project Experience

Systems and Controls

Dr. Martens has over 25 years of experience specifying, designing, constructing, and analyzing control systems. A representative sampling of projects is listed below. These projects have involved control systems for products, processes, and machines ranging from office equipment to industrial processes with project scopes ranging from design and design reviews to accident investigation and failure analysis. Control systems generally consist of sensors, controllers, and actuators and Dr. Martens' work in design and analysis of control systems has ranged from detailed reviews of individual components to analysis of complex integrated systems.

Control Systems for Products

- Academic test grading system: evaluated control system for an academic test grading system (card scoring) used in schools to determine potential issues with ability to read scoring sheets.
- Automatic racquetball serving machine: designed and constructed an automatic racquetball serving machine with variable speed and pitch.

- Automatic revolving and sliding doors: analyzed control system for their potential role in various accidents related to automatic doors.
- Automotive antilock brake system: analyzed control system for antilock brakes and compared operation to industry standards and practices.
- Automotive stability control: designed, implemented, and obtained patents on several vehicle stability, rollover, and steering control methods.
- Business card scanner accuracy: analyzed accuracy of control system used to scan business cards and perform optical character recognition.
- Computer-controlled telephone answering machine: designed and constructed a computer-controlled telephone answering machine, including interface circuitry and programming.
- Computer hard disk drive control method: analyzed control algorithm for head seeking and compared to teachings of a patent.
- Electric rear steering for automotive applications: designed and implemented control algorithms for electric rear steering to improve safety and performance of automotive systems.
- Electrically-powered four-wheel recreational vehicles: analyzed control system for electrically-powered four-wheel recreational vehicles that were experiencing faults and evaluated potential solutions.
- Espresso machine temperature control system: designed and constructed an analog temperature control system for an espresso machine.
- Hand-activated liquid dispenser: analyzed electronics and control system for an automatic soap dispenser.
- Home automation and security control system: designed, constructed, and programmed a home automation and security system with internet-based access.
- Hospital-grade sterilizer accident: analyzed control system for a hospital-grade sterilizer, reviewed incident data, and performed testing to evaluate control system responses.
- Ice maker system fires: analyzed control system for commercial ice making machines that were experiencing fires.
- Microprocessor-based robotic paint nozzle controller: analyzed and redesigned a paint head controller for an automatic robotic painting machine.
- Microprocessor-based stepper motor controller: designed and constructed a stepper motor controller, including power electronics and controller logic.
- Mobile robot control: retrofitted OEM control system with multi-processor based control system for automatic stair climbing.
- Oven controls: analyzed oven control systems to determine potential mechanisms for faulty burner operation.
- Paint dispensing control method: analyzed control system method for achieving high accuracy color paint dispensing and compared to teachings of a patent.
- Paper shredder control: analyzed and tested anti-jam algorithms for commercial office paper shredder.
- Sonar sensor-based control system for mobile robotics: designed and constructed a sonar sensor hardware driver and control system to perform obstacle avoidance for a mobile robot.
- Variable low-speed feedback controller for radio control car: designed and constructed PWM-based feedback velocity controller for low-speed (crawl speed) control of radio control car and interfaced to computer control system.
- Vision-based mobile robot tracking control system: designed and constructed multi-processing control system to use real-time vision processing for object tracking.
- Waterbed temperature control system: designed and constructed an analog temperature control system with discrete over-temperature control for water bed temperature regulation.

Control Systems for Processes

- Gas burner for thermal oxidizer safety consulting: analyzed control system implementation for several thermal oxidizer burners and advised client on safety considerations.
- Grain processing facility fire: analyzed the role of the control system in an accident involving the processing of grain.
- Grain storage facility fire: analyzed the role of the control system in an accident involving the storage of grain.

- Incinerator control system safety analysis: analyzed the control system for an inert-atmosphere incinerator and developed list of considerations.
- Incinerator explosion: analyzed the control system for an inert-atmosphere incinerator that experienced an explosion.
- Laminator treating system explosion: analyzed process data and control system for an industrial, continuous processing, board laminating process.
- Natural gas and pulverized coal boiler explosion: analyzed the process data and logic for the burner management and combustion control systems for an industrial boiler that experienced an explosion.
- Nuclear control rod height control system: evaluated rod height control system in a nuclear power plant to determine potential failures.
- Phenol processing plant fire: analyzed control system response to a power outage at phenol processing plant.
- Pulverized coal, gas, and stoker boiler safety consulting: analyzed control system implementations for several pulverized coal, gas, and stoker boilers and advised clients on safety considerations.
- Sheet roll treating facility: analyzed control system for a sheet roll treating system involved in an explosion to determine sequence of operation.
- Steam-powered generator explosion: analyzed the control system response to an out-of-normal condition that led to an explosion at a power generating station.
- Steel processing plant fire: analyzed the control system used to process steel at a facility that experienced a major fire.
- Train monitoring and control system: analyzed control systems including Human Machine Interfaces (HMIs) used for monitoring and controlling a commuter rail system that experienced a collision.
- Underground salt cavern gas storage facility accident: analyzed control system and historic process data to determine storage capacity and production rate for a natural gas storage facility.
- Water treatment facility flood: analyzed control system response when a downstream valve lost communication with the control system for the main processing facility.
- Wonderware Data Analysis: evaluated historic Wonderware data to determine various operating conditions for plant operation.

Control Systems for Machines

- Airplane service lift accident: analyzed the control system for a service lift that damaged the wing of a commercial airplane.
- Amusement park ride stoppage investigation: investigated the design of a drive control system for a Ferris wheel that experienced a stoppage.
- Brick palletizing station accident: analyzed the control system for an industrial brick palletizing control system in which a worker was injured when the machine was put into motion.
- Continuous miner control system: evaluated control system and associated remote control for a continuous miner involved in an injury.
- Continuous long-wall miner: analyzed control system and available process data for a continuous long-wall miner involved in a fatal mining accident.
- Crane control system: analyzed crane control system for potential faults that could lead to unexpected motion.
- Elevator control system: evaluated control system that had experienced flooding to determine potential problems associated with water intrusion.
- Height Control Module (HCM) performance test system: designed, constructed, and programmed functional test system for automotive automatic leveling Height Control Modules (with Tech 2).
- Industrial press control system accident: analyzed control system for an industrial press in which a worker was injured.
- Lyophilizer accident: analyzed control system and Human Machine interface (HMI) and historic process data for a pharmaceutical freeze-dryer that exploded.
- Mining shuttle car drive analysis: evaluated performance of DC drive for a shuttle car.
- Remote control for construction equipment: analyzed remote control system for construction equipment to determine if potential faults could lead to unexpected motion.
- Remote control for lift system: analyzed remote control system for a lift for potential faults that could

lead to unexpected motion.

- Scissor lift accident: analyzed hard-wired control system including sensors for a lift involved in a tip accident.
- Speed detection and control system for fan clutch test system: designed and constructed a speed detection and control system for audit and performance testing for fan clutches.
- Sports lighting control system failures: analyzed control systems for remote-controlled sports lighting equipment when manufacturer was experiencing unacceptably high failure rates.
- Vision-based robotic laser cutting control system: developed control system to perform laser cutting of materials and vision-based verification of parts.
- Vertical lathe accident: evaluated control system and available data in machine to determine potential accident scenarios.
- Wiper audit and performance test stand: programmed a multi-station automotive wiper testing system to exercise wiper motors and collect data.

Electronics and Circuitry

Dr. Martens has over 25 years of experience specifying, designing, constructing, and analyzing digital and analog electronic circuits for a variety of applications including sensing, control, battery charging, radio control, electromechanical interfacing, and embedded systems. Many of the projects listed above include electronics and circuitry evaluation. An additional representative sampling of projects related to electronic circuits is listed below.

- Analog and digital interface circuitry for personal computer: designed and constructed specialized input/output interfacing circuitry to provide full optical isolation.
- Battery charging circuitry: designed, constructed, reviewed, and analyzed battery charging and battery-powered circuits for various battery chemistries and applications.
- Burn hazard analysis: analyzed various devices for potential to cause burns.
- Car audio equalizer system: designed and constructed a multi-band equalizer system for audio application.
- Custom LED-based encoder for mobile robot actuators: designed and constructed a custom encoder system for articulating mobile robot.
- dSPACE interface electronics: designed and constructed isolation and interface circuitry for automotive instrumentation.
- Failure Mode and Effects Analysis: employed FMEA and other techniques to evaluate the reliability of various circuits and systems.
- Fan clutch speed monitoring circuitry: designed and constructed an optical counting and speed detection system for measuring speed of fan clutches in test system.
- Home security system: designed and constructed a web-enabled security system for monitoring and controlling sprinkler system, lights, garage door, and security.
- Industry Standard Architecture (ISA)-based Analog-to-Digital, Digital-to-Analog, and Digital Input/Output data acquisition and control board: designed and constructed a multi-channel input/output data acquisition and control board.
- Interface circuitry for radio control car to Versa Module Europa (VME)-based multiprocessor system: designed and constructed circuitry to interface input/output boards to radio control system.
- Medical devices: analyzed various battery-operated medical devices for potential single-point failures that could create potential ignition sources during ethylene oxide sterilization.
- Optical sound transmission: designed and constructed a transmitter and receiver system for transmitting sound using light.
- Portable VME-based multiprocessor system and power electronics for autonomous mobile robot: retrofitted a teleoperated mobile robot with multi-processor-based system.
- Power electronics and electromechanical device interfaces to control audio equipment using personal computer: designed and constructed an electromechanical interfaces to control audio equipment using computer control.
- Printed Circuit Board (PCB) Failure: evaluated and tested printed circuit boards and components for failure for a variety of applications.

- Radar detection circuitry: designed and constructed a radar detection system for automotive application.
- Radio control transmitter/receiver link w/ DTMF (Dual-Tone Multi-Frequency) transmission: designed and constructed radio control transmitter and receiver system to interface to computer.
- Real-Time Damping module performance test stand: designed and constructed a customizable, multi-channel control and data logging system to test various generations of RTD control modules.
- Sixteen-channel, computer-controller nichrome heater system: designed and constructed a power amplifier/driver for computer-controlled heating system.
- Wave generator: designed and constructed a custom multi-frequency sine-wave generator and special timing circuitry for MTS test equipment.
- Wiper delay circuitry for automobile: designed and constructed an adjustable automotive wiper delay system.