Wednesday, 20 June 2018
(10.00 am)
SIR MARTIN MOORE-BICK: Well, good morning, everyone, and welcome to today's hearing. We are going to hear a further presentation from one of the inquiry's experts.
Yes, Mr Millett.
MR MILLETT: Good morning, Mr Chairman.
This is the final day of the experts' presentations for this week. Today, Professor Luke Bisby, who sits on your right, will be explaining certain key scientific concepts relevant to flammability and to flame spread. He will be describing the material properties of certain materials present in the facade and in the windows of Grenfell Tower. He will also set out the preliminary evidence which assists in understanding the pattern of flame spread out of flat 16 and over the exterior of the tower on the night of the fire.
Before I call Professor Bisby formally, I should give certain trigger warnings about the content of his presentation.
His presentation, and particularly this afternoon, will include a large number of images, videos and audio depicting the external flame spread on the night of the fire. That will include the playing of his composite

flame spread video, which was played during my opening, and the detailed consideration of that and other flame spread material which shows the building burning and on fire. Some of the videos include the audio of people witnessing the fire, and their distress at the unfolding events.
The presentation will also contain a number of images of the burnt-out tower after the fire and the playing of the first 999 call by Mr Kebede.
So, Mr Chairman, I will now call Professor Bisby.
SIR MARTIN MOORE-BICK: Thank you.
PROFESSOR LUKE BISBY (affirmed)
SIR MARTIN MOORE-BICK: Thank you.
MR MILLETT: Thank you.
Professor Bisby, could you please give the inquiry your flame?
PROFESSOR BISBY: Luke Alexander Bisby.
MR MILLETT: You have provided to the inquiry a written report which is dated 2 April 2018.
PROFESSOR BISBY: That's correct.
MR MILLETT: That report addresses the ignition of the facade materials and your preliminary conclusions on the fire spread to and on the exterior of the building.
PROFESSOR BISBY: Yes, it does.
MR MILLETT: As you indicate in the declaration in

section 1.6 of your report, you have provided it in the same way as you would have provided a report to a court.
PROFESSOR BISBY: That's correct.
MR MILLETT: In section 1.4 and appendix D to your report, you have outlined your background and your experience relevant to the matters in this inquiry.
PROFESSOR BISBY: Yes, I have.
MR MILLETT: I'm not going to ask you to repeat the detail of that today, we can take that as read, but in terms of key points, would you agree you are a professor of fire and structures within the school of engineering at the University of Edinburgh in Scotland?
PROFESSOR BISBY: That's correct.
MR MILLETT: And prior to taking on your expert witness role for this inquiry, you were also head of the research institute for infrastructure and environment at the University of Edinburgh?
PROFESSOR BISBY: Yes.
MR MILLETT: You are a co-editor-in-chief of the technical and scientific publication Fire Safety Journal?
PROFESSOR BISBY: That's correct.
MR MILLETT: And you are, I think, a chartered structural engineer with the Institution of Structural Engineers and a licensed professional engineer in Ontario in Canada?

PROFESSOR BISBY: That's correct.
MR MILLETT: You are also an active member of the UK Standing Committee on Structural Safety, or SCOSS, and Confidential Reporting on Structural Safety, CROSS, and a fellow of both the Institution of Fire Engineers and the Institution of Structural Engineers?
PROFESSOR BISBY: That is correct.
MR MILLETT: Are the factual matters set out in your report true to the best of your knowledge and belief?
PROFESSOR BISBY: Yes, they are.
MR MILLETT: And does your report accurately set out your opinions on matters relevant to this inquiry?
PROFESSOR BISBY: Yes, it does.
MR MILLETT: Thank you very much, Professor Bisby. Please do now go ahead and give your presentation.
PROFESSOR BISBY: Thank you and good morning.
The Grenfell Tower fire initiated in the early hours of Wednesday, 14 June 2017 and continued for many hours, with tragic effect. This catastrophic event resulted in 71 fatalities on that night and continues to cause immense trauma to the bereaved, survivors and affected community. I'd like to begin my presentation by acknowledging this central, continuing and human aspect of the fire.
During the preparation of my report, I have reviewed

harrowing evidence from victims, survivors and emergency services, and I extend my deepest sympathies to those whose lives and loved ones were and continue to be caught up in this tragic event.

As an instructed expert witness to the Grenfell Tower inquiry with a specific and technical remit, my Phase 1 report necessarily focuses on scientific and physical information and analysis related to the construction of the building and its external cladding.

It is my hope that my Phase 1 report, along with the presentation and subsequent Phase 1 evidence, will help you, sir, as well as experts and laypeople alike, to begin to understand, particularly in physical and scientific terms, how and why the Grenfell Tower fire 14 June 2017 spread so rapidly and so extensively, with devastating effect.

My Phase 1 report is intended to serve two purposes: first, to provide an initial understanding of the ignition of the cladding materials at Grenfell Tower; second, to set out preliminary conclusions on fire spread to and on the exterior of the building.

During my presentation today, I will focus on presenting the preliminary evidence that I've gathered, rather than on my hypotheses and conclusions with

respect to that evidence, although I will touch on these where necessary, at this early stage of the inquiry's hearings.

My preliminary evidence includes images and video submitted by members of the public. I am particularly grateful for these as without them my task would have been even more challenging.

My preliminary evidence also includes: evidence collected by the London Fire Brigade and the Metropolitan Police Service; information obtained from my own site investigations at Grenfell Tower; testing undertaken by various organisations, including the University of Edinburgh, on behalf of the inquiry; and information obtained by or provided to the inquiry from a range of organisations, including core participants to the inquiry.

I've also drawn on my own background knowledge and on that of a core of my specialist colleagues at the University of Edinburgh, specifically Dr Angus Law Dr Rory Hadden and Emeritus Professor Dougal Drysdale.

In addition, I've drawn on the academic literature and, in a limited number of cases, information which is publicly available via the worldwide web.

All of this information is referenced within my Phase 1 report and has been made available to the

inquiry's core participants.

For the benefit of yourself and the wider participants to the inquiry, I'd like to place my work for the inquiry within the context of the work being undertaken by the inquiry's other instructed experts. As Mr Millett has previously explained, Phase 1 of the inquiry is intended to investigate the development of the fire itself, where and how it started, how it spread from its original location to other parts of the building, and the chain of events that unfolded during the course of the hours until it was finally extinguished or burned out.

Phase 1 is also examining the response of the emergency services and the evacuation of the residents.

For Phase 1, you asked me to provide a report on a subset of these issues.

The first of these is ignition of the building's cladding materials, and if I may paraphrase: how did the fire get from inside the building out and onto the exterior cladding?

My second task is to provide preliminary evidence on fire spread to and on the exterior of the building. Again, if I may paraphrase: how and why did the fire spread so rapidly and so extensively over all four faces of the building?

My focus is therefore on the cladding materials, products and systems at Grenfell Tower and the rapid and extensive external fire spread.

I will not comment extensively on the fire's origin and cause, the emergency service response, spread of fire and smoke within the building or the building's evacuation. These are of course all critically important topics but are being addressed by the inquiry's other experts.

I will also avoid commenting on the regulatory compliance of the materials, products and systems used at Grenfell Tower as regards the applicable Building Regulations and guidance documents.

In line with your instructions, my Phase 1 work has been concerned with identifying what aspects of the building design and construction played a significant role in enabling the disaster to occur. It is only by understanding the specific make-up of the cladding and the physical processes by which the fire spread over the building that you will be able to evaluate the relative roles of materials, products and systems during the fire.

To address the relevant issues, my presentation is structured in three parts:

First, fire science. I will provide a brief overview of the fire science that is necessary to adequately understand the factors influencing fire spread to and on the cladding. This will also help to explain the potential contributions of different materials to exacerbating the speed and extent of the external fire spread.

Second, cladding materials and products. I will describe, in considerable detail, the various materials and products used within the external cladding system and briefly how each of these responds to heating from a fire.

The third and final part of my presentation will focus on fire spread to and on the cladding on the night of the fire.

I will re-visit the video shown during the opening remarks by Mr Millett, and I will use this, along with other evidence, to provide a detailed summary of both the timelines and the physical mechanisms of fire spread.

So part 1 deals with fire science.

The first part of my presentation deals with two particular aspects of fire science that are central to what occurred at Grenfell Tower: flammability and fire spread. Together, these will help us to understand how the fire spread to the cladding and on the cladding.

Both flammability and flame spread are intuitively understood by most people in general terms; however, I believe it's important to begin my presentation of my preliminary evidence by discussing their more precise technical meanings as well. Otherwise, developing a deep understanding and unpicking the causal roles associated with cladding materials products and systems is impossible.

Flammability refers to the ease of ignition of a material and the manner in which it burns. The flammability of a material is governed by the physical properties of the material, its chemical composition, and to some extent the manner in which its flammability is evaluated. A range of different flammability test are used, both in the UK and internationally. Flammability is not a yes/no proposition; there is a gradation of performance amongst materials and products.

Flame spread, however, is governed by a material's properties, its immediate environment and its geometry. As with flammability, a range of different tests can be used to assess the flame spread on different materials and products.

To interpret and understand the evidence of fire spread at Grenfell Tower, it's necessary to have a basic

understanding of the physical mechanisms that govern both flammability and flame spread.

I will avoid technical language and jargon to the extent possible; however, this is science and the subject matter is rather complex. Indeed, highlighting the complexities of the science is one of the key things that I hope to accomplish today. The topic therefore demands a certain level of technical terminology.

Fire.

We all have a sense of what fire is and a sense of which materials will burn and which will not, but fire is not, in reality, a single and simple process; rather, it is the result of a sequence of interrelated processes that may occur when fuel, oxygen and an ignition source are combined under the correct conditions.

Fire is the visible flame, smoke and heat produced by an uncontrolled combustion reaction. This results from a chemical reaction between flammable gases and oxygen, which makes up 21 per cent of air. The combustion reaction occurs rapidly and is exothermic, by which I mean that it releases energy and we perceive this as heat and light.

In the case of burning of solid materials -- such as wood, plastics or, indeed, insulating foams -- the flammable gases which enter the flame are produced by

a process of thermal decomposition. This process is referred to as pyrolysis.

Gases produced by pyrolysis of the solid are flammable when they react with oxygen in the air and form gaseous products such as carbon dioxide and water vapour. In addition, very small solid particles are generated. These form the visible component of smoke or soot.

In order for flaming to occur, the fuel must be in the form of a gas. This means that it's able to mix and react with oxygen from the surrounding air. Critically, this means that solids do not burn directly. Instead, it is the gaseous fuel produced by the thermal decomposition of the solid that is burning.

This distinction may at first seem unimportant, but I hope that my reasons for making it become clear during the course of my presentation.

The combustion of solids can be readily illustrated using the familiar example of a flame produced by the burning of a wooden matchstick, as I have shown here.

Here I should like to say, sir, that while I'm going to use a matchstick to illustrate some of the key concepts of flammability and flame spread, in reality the processes at play in the ignition and burning of a match are even more complex than I will be able to describe in my limited time today.

The solid in this case is the wood from which the matchstick is made. Wood, as we all intuitively understand, is a combustible material. When wood is heated, in this case by the flame from the match itself, the molecules that make up the solid wood thermally decompose and are released as flammable gases. By this I mean the wood undergoes pyrolysis.

These flammable gases are transported into the flame by a buoyant flow due to the fact that hot gases rise. As the flammable gases are transported into the flame, they mix with oxygen which is available from the surrounding air. We say that the surrounding air is entrained into the flame.

Provided that sufficient heat is present within the flame, and that the mixture of flammable gases and oxygen is in the correct proportions, the gases and oxygen will react. This reaction releases energy, which heats up the gases, which then radiate energy.

This reaction also produces combustion products such as carbon dioxide, water vapour and tiny soot particles, as I have already mentioned. It is the glowing, by which I mean the emission of thermal radiation and light, of these heated soot particles that produces the characteristic yellow flame that we associate with fire.

The flame can therefore heat objects by two processes of heat transfer: convection of buoyant hot gases -- typically above the flame, as I have shown here -- and by radiation to any materials that are within sight of the flame.

In the case where the match is held horizontally, as shown here, it is radiation from the flame -- shown there -- and conduction along the matchstick -- shown by that arrow -- which heats the unburned wood. Conduction refers to the transfer of heat within the solid. This heating of the wood causes further release of flammable gases and so on in a self-sustaining process that we call fire.

As I've just outlined, the process of thermal decomposition of a solid material is called pyrolysis. This process is endothermic, meaning that it requires a supply of energy from an external source in order to occur.

Pyrolysis is fundamental to determining how, or rather if, a solid material will ignite and continue to burn and the conditions under which this can occur.

Pyrolysis, like any chemical reaction, is strongly temperature-dependent, in that higher temperatures result in faster pyrolysis. This means that the rate at which a solid can be heated will depend on its rate of

pyrolysis. The rate at which pyrolysis occurs will then influence whether a flammable mixture of pyrolysis gas and air will form and sustain a flame. By this I mean that the rate at which pyrolysis occurs will dictate whether a material ignites and whether it will continue to burn.

Not all mixtures of flammable gas and oxygen can burn. The gas and oxygen have to be in the correct proportions, and in the presence of an appropriate ignition source. Those mixtures that can burn are called flammable mixtures.

Furthermore, both the thermal properties of a material and its geometry play important roles in determining both its ignition and its burning behaviour, and both are central to developing a physical understanding of what occurred at Grenfell Tower.

I would now like to discuss some particular technical concepts and terminology which relate to the heating of a solid material.

When discussing the fire behaviour of materials, it is conventional to differentiate between materials that are known as thermally thick and thermally thin materials. This distinction is based on the physical dimensions of the material, the material properties and the thermal characteristics of the surrounding

environment.

Essentially, a thermally thin fuel is one which heats uniformly and can be characterised by one temperature. In this case, the response of the material is limited by the transfer of heat from its surroundings.

A thermally thick fuel is one which heats non-uniformly and exhibits an internal temperature gradient as energy is transferred into the body of the material. By this I mean that the surface of the material gets hot but the interior stays relatively cool. In this case, the response of the material is influenced by the rate of heat transfer within the material via the process of heat conduction, as I've already mentioned.

Thermally thin fuels ignite more readily than thermally thick fuels, all other factors being equal.

A familiar example of thermal thickness can be understood by comparing the ease of ignition of wood shavings versus a solid block of wood. Both are composed of the same material: wood; however, the wood shavings are thermally thin and can be readily heated such that ignition occurs.

The large block of wood, however, is thermally thick and, when exposed to a flame, the heat is conducted into the block and away from the surface, thus making it harder to ignite.

The difference between these two cases, as regards both ignition of a material and the chances that it will continue to burn, are shown in these side-by-side videos of wood shavings and the block of wood, in both cases ignited by a match.

I'll play this now.

(Video played)

You can see, actually, multiple attempts to ignite the block of wood with subsequent matches.

You get the point, I hope.

For thermally thick fuel, when exposed to a heat source, the surface temperature of the solid material will begin to increase. The rate of increase is determined in part by the physical properties of the material.

The key parameters in this situation are:

First, the thermal conductivity of the material, this is a measure of the ability of the material to transfer thermal energy internally by conduction; second, the density of the material, and this is a measure of the material's mass per unit volume; and, third, the material's specific heat capacity, and this is a measure of the amount of energy required to

increase the temperature of 1 kilogram of the material by 1 degree Celsius.

A heat transfer analysis can show that the product of these three parameters -- thermal conductivity multiplied by the density multiplied by the specific heat -- governs the rate at which the surface temperature of a solid material increases when exposed to a heat source. This is called the thermal inertia of the material, and it represents, if you like, the ease with which the surface temperature of a material will change when exposed to heating.

Materials with a high thermal inertia -- such as metals, for example -- are comparatively slow to heat at the surface, all other factors being equal. Conversely, the surface temperature of material with low thermal inertia -- such as polymer foam insulation, for instance -- will increase rapidly when heated.

As I've already stated, pyrolysis is a temperature-dependent process. Thus, there is a strong coupling between heating of the solid and pyrolysis. Consequently, materials with a low thermal inertia, where the surface will heat more rapidly, will initially experience more rapid pyrolysis than materials with higher thermal inertia.

It's very important to understand this because it

help us to understand, and hopefully eventually to quantify, the potential roles of the various materials and products that made up the cladding at Grenfell Tower.

As a result of the factors that I've now described, it's common to assume a pyrolysis temperature at which pyrolysis will occur for a given material. All other factors being equal, materials with higher pyrolysis temperatures are more difficult to ignite than those with lower pyrolysis temperatures.

Let me now turn my attention to the issue of flammability.

On a day-to-day basis we tend to think of materials as either being flammable or not, or as being either combustible or not. Indeed, the word "combustible" has received a great deal of attention and use in the media since the Grenfell Tower fire.

In reality, for materials that have the potential to burn, by which I mean those materials that are combustible, flammability is a relative rather than absolute property.

Depending on the circumstances, therefore, combustible materials can either be more or less flammable, and this distinction is actually very important.

In a regulatory context, material flammability quantifies the degree to which a material will burn with a flame under specified conditions. Material flammability tests therefore allow different materials to be ranked as regards their suitability in certain applications based on results from tests in standardised test apparatus.

It should be noted, however, that material flammability parameters are not fundamental material properties. This is precisely because they depend on the method of evaluation.

Flammability testing outcomes may be influenced by a range of phenomena and I believe it's worth taking a bit of time now to discuss these in general terms before moving on to look at the specific materials, products and systems that were installed in the cladding at Grenfell Tower.

First, ignition.

In the context of most fire safety applications, ignition is defined as the initiation of what is known as gas phase combustion. By this I mean sustained flaming or burning of pyrolysis gases in the manner I described earlier using the photo of the wooden matchstick. Ignition is the moment that the visible flame first appears.

Whether ignition of a solid material occurs in a given situation is strongly time-dependent. This means that ignition only occurs after a period of heating of the solid such that its surface temperature reaches the pyrolysis temperature and flammable gases are produced by pyrolysis in sufficient quantities to sustain a flame.

Common ignition tests used in practice apply a radiant heating source to heat a material. The magnitude of the heating is defined in terms of what's called the incident heat flux. Heat flux is a measure of the thermal energy delivered to a surface over a given period of time. We can think of it as, if you like, the severity of heating. This is typically expressed in units of kilowatts per square metre, where one kilowatt is equivalent to 1,000 joules per second. Joules are the scientific units used to quantify energy, be it thermal, electrical or any other form of energy.

Radiation heat fluxes are called irradiances, and values of up to 50 kilowatts per square metre are typically used in materials testing to represent fire exposures in buildings, although I should note that much higher heat fluxes may actually be experienced in reality.

To put this in perspective for you, a solid block of

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wood, as I showed previously, would ignite within a matter of seconds under a heat flux of 50 kilowatts per square metre. This scenario is shown in a sequence of video clips that I will show in a moment.

Here what you can see is a thermally thick solid block of wood which is exposed to a heat flux of 50 kilowatts per square metre, as I just mentioned, from the right-hand side, as shown here. So imagine a very powerful heat lamp pointing at this block of wood from the right-hand side.

On exposure to thermal radiation from the right-hand side, as I've mentioned, the timber surface temperature increases rapidly, pyrolysis occurs and flammable gases are released, and you can see that happening here.

(Video played)

With additional heating, additional pyrolysis gases are released and this is shown in the next clip about 15 seconds later for this particular sample.

(Video played)

These gases mix with the surrounding air, which provides oxygen, as I've mentioned, and eventually, under the right conditions, ignition may occur, followed -- again, under the right conditions -- by sustained flaming combustion or fire. I'll show that here, again about 15 seconds later.

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(Video played)

For a solid block of wood like the one I've shown here, if I were to then remove the external heat source -- in this case, the radiant heater to the right of the block of wood -- the heat transfer to the wood would actually be insufficient to continue to generate the necessary pyrolysis gases and the flaming combustion would stop -- the flame would go out. Higher heat fluxes therefore lead to more rapid ignition, all other factors being equal.

As I've already discussed, the rate of heating for thermally thick fuels depends strongly on the thermal inertia of the material. The time to ignition under a given heat flux exposure is therefore also strongly dependent on the thermal inertia of the material.

Materials with low thermal inertia -- for example, polymer foams -- heat rapidly at their exposed surfaces, generally resulting in short times to ignition. Materials with higher thermal inertia -- for example, common synthetic polymers, which we more commonly call plastics -- have longer times to ignition.

It follows from the preceding discussion that there is a level of heating, by which I mean a level of heat flux, below which ignition will not occur for a given material when tested in a given configuration. This is

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called the critical heat flux for ignition. Materials with low values of critical heat flux for ignition are in general easier to ignite than those with high values of critical heat flux for ignition.

Understanding how materials ignite is essential, for instance in order to confidently suggest how the fire at Grenfell Tower spread from within the kitchen of flat 16 onto or into the cladding adjacent to the kitchen window. The ignition properties of the material are also critical in evaluating their ability to spread flame for reasons that I will discuss in a few minutes.

Before doing so, however, I'd like to discuss heat of combustion.

Once a material has ignited, the primary variable of interest is the rate at which energy continues to be released, since this is what drives the growth and spread of a fire.

The total amount of energy that is available to be released from a material is known as its heat of combustion. This is a measure of the total energy that can be released per unit mass of a material under optimal conditions for combustion. The rate at which energy is released, however, and the fraction of the total available energy that actually is released under a given set of circumstances, is a function of its

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heating conditions, its geometry and its orientation.

This distinction is critically important because, as I've already suggested, just because a material can burn under some circumstances doesn't necessarily mean that it will burn under a particular set of circumstances, and this idea will be familiar to anyone who has attempted to start a log fire without using kindling. Just because wood can burn doesn't mean it always will.

The heat of combustion of a material is measured by burning a unit mass of material in an atmosphere of pure oxygen. This increased reactivity of this atmosphere compared to air, which as I've already noted is only 21 per cent oxygen, results in complete combustion of the material and the conversion of virtually all of the stored chemical energy into thermal energy. The heat of combustion thus provides an upper limit on the amount of energy that can be released by the burning of a material.

However, the heat of combustion on its own does not give any information regarding the rate at which energy is released after a material is ignited, nor does it account for the heat transfer processes that lead to ignition, the material geometry or the physical changes that may occur, all of which also affect a material's burning behaviour.

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To give you a sense of the variability of heats of combustion amongst materials, this chart shows the heats of combustion of a number of familiar and not so familiar but relevant materials.

Materials with grey bars are common and in some senses familiar, but are not considered significant as regards my preliminary evidence relating to the Grenfell Tower fire. These are shown because these materials may be familiar to you and you may have some understanding of how they react to heating.

Whereas materials in red are less familiar -- aside from wood, of course -- but were present in significant quantities within the cladding system at Grenfell Tower.

You may note the broadly similar values for the synthetic polymer of plastic materials polyethylene and polystyrene as compared with diesel fuel, for instance. I'll return to this point later on.

Next, heat release rate.

As I have mentioned, the rate at which energy is released from a material -- by which I mean whether the available energy is released quickly or slowly in a given set of circumstances -- is described by the heat release rate. The heat release rate describes the rate of energy released per unit time as an object burns. Objects made from materials with the same heat of

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combustion may burn in very different ways once ignited.

At a material level, the heat release rate behaviour is dictated to a large extent by the pyrolysis behaviour of the solid material. If the material melts -- such as in the case of the synthetic polymer material polyethylene, for example -- then after ignition, the heat release rate will increase to an essentially steady value until virtually all of the material is consumed. This is illustrated schematically in the left-hand figure shown here.

This is a key point and I'll return to burning of polyethylene, which I abbreviate in some cases to PE, later in my presentation.

If, however, the material chars, such as in the familiar case of wood or the less familiar case of a thermosetting polymer foam insulation, which I will also return to later, then under most conditions there will be an initial period of high heat release, followed by a period of lessening heat release rate. This is due to the formation of a protective char layer on the surface of the material. This is illustrated in the right-hand figure shown here.

The formation of the char layer decreases the rate of energy transfer into the material and, hence, reduces the rate of pyrolysis and therefore the quantity of

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flammable gases produced.

The heat release rate of a material also depends, again, on its physical geometry and surrounding conditions, and on the presence of any external heat sources. The heat release rate of an object burning in the presence of an external heat source -- such as a large fire -- will be a strong function of the magnitude of the external heat source for the reasons I've already discussed.

The heat release rate is therefore important for evaluating the fire hazard associated with an object. This is because it determines the energy released from a material that is available to be transferred back to the fuel -- thinking again about my match -- thus creating a feedback loop which may sustain the flaming.

Materials with a high heat release rate therefore typically result in more rapid fire growth and/or fire spread, and, sir, the growth and spread of fire are obviously of fundamental importance to this inquiry.

So, finally, having discussed these foundational concepts of fire science, I will turn to flame spread.

Flame spread occurs when sufficient heat is transferred from a burning region to an adjacent unburnt material region. The rate at which a fire will grow depends in part on how rapidly flame can spread on the

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surface of the material.

Flame spread is strongly influenced by the physical configuration of the system, such as its material geometry and orientation. The process of flame spread is most easily thought of -- very helpfully, in my opinion -- as a series of localised ignitions, and the processes required to sustain flame spread are thus the same as those that I previously used to describe ignition.

So as already discussed for ignition, sufficient energy must be supplied to the combustible solid ahead of the flames to heat the material such that pyrolysis occurs and flammable gases can be released.

As the area where the pyrolysis is occurring advances, so too does the flame that we can visually observe. This is flame spread.

It is common to distinguish between what is known as concurrent flame spread and opposed-flow flame spread. Concurrent flame spread occurs when the flame spreads in the same direction as the flow of air. I'll show examples in a moment. Opposed-flow flame spread occurs when the flame spreads in the opposite direction to the flow of air. These two extremes are commonly observed when a flame spreads upwards -- which we call concurrent flame spread -- or downwards -- which is the case of

opposed-flow flame spread.

Because of the importance to my Phase 1 scope of work and to the preliminary evidence that I will present later today, I'm now going to describe in some detail the key processes associated with upward and downward flame spread.

I will also describe horizontal or lateral flame spread. This is in fact a special case of opposed-flow flame spread as I'll explain in a few minutes.

My discussion of flame spread draws on many of the fundamental concepts that I've already described, and hopefully you can see this is all building.

The rate of flame spread is dependent on the heat transfer to the material and the material's thermal inertia. This is because the rate of flame spread is governed by the rate at which the material adjacent to the burning region can be heated to its pyrolysis temperature.

Upward flame spread is generally faster than downward flame spread. This is because in upward flame spread, the flames and hot gases which rise due to the effect of buoyancy, as I've already mentioned, will preheat the material ahead of the advancing flames. This preheating does not occur in downward flame spread, which is therefore slower.

When considering the flame spread on synthetic polymers -- which are more commonly called plastics, as I've mentioned -- it's important to consider the effects of melting and deformations associated with their softening. Melting and dripping significantly complicate flame spread processes by removing material from the system and, with it, some of the available energy to drive flame spread. I'll demonstrate this in a moment.

In a moment I'll show a short video that shows ignition and upward flame spread on a vertically oriented matchstick. I will use this simple, familiar example again because of its intuitive value in demonstrating the relevant physics.

In upward flame spread, the heat transfer to the unburnt material ahead of the burning region increases the size of the burning zone and, hence, the flame spread rate. The flame and pyrolysis products produced by the burning of the material rise due to buoyancy and heat the surface of material, and this results in high rates of heat transfer to the surface of the material.

As the unburnt material ahead of the burning region is heated, it begins to pyrolyse and generate flammable gas. As the gas ignites, the visible flame spreads rapidly. Typically, but not always, the rate at which

the pyrolysis front advances is faster than the rate at which fuel is consumed. This is an important point. Consequently, the burning region becomes larger, producing flammable pyrolysis products at an increasing rate.

This can be seen in my video in a moment as the bottom of the match, you'll see, is still burning as the top ignites. The flame becomes larger and thereby increases the height of the heated material, which further increases the burning area. This positive feedback loop results in a self-accelerating process and rapid upward spread of flame.

The sequence of events is shown in this short video.

(Video played)

My next short video shows downward or opposed-flow flame spread on an otherwise identical vertically oriented matchstick. In the case of downward flame spread, the rate of heat transfer to the unburnt material is much less than in upward flame spread, as I have already described. Consequently the length of the preheated zone is much smaller, resulting in a smaller pyrolysis region, a smaller volume of evolved pyrolysis gases and a much slower rate of flame spread. Indeed, in this case, flame spread eventually extinguishes rather than continuing to spread downwards.

This sequence of events is shown in this short video.

(Video played)

You can just see the flame creeping down the matchstick there slowly.

(Video played)

Then you can see insufficient pyrolysis gases being released to sustain the flame.

A further special case of opposed-flow flame spread is horizontal or lateral flame spread. This is similar to downward flame spread and my next video shows the flame spreading from right to left.

In this case, the rising hot gas draws air into the flame from left to right, hence referring to this as opposed-flow flame spread, as in the case of downward flame spread. The heat transfer from the flame to the match is higher than in the downward case, as evidenced in the spread of the flame horizontally along the match.

In this case, the rate at which the pyrolysis front advances is approximately equal to the rate at which the solid fuel is consumed, as evidenced by a steady movement of the flame from right to left and a flame with a reasonably uniform size. I'll show this here.

(Video played)

That flame just continues to the left and off the screen.

Now, of course, matchsticks don't melt and drip. This is not the case, unfortunately, for all materials. Rapid downward vertical fire spread may occur due to melting and dripping, in particular for certain synthetic polymer materials.

When heated in a vertical orientation molten, possibly burning material may flow downwards. Flame spread by this mechanism is governed by the viscosity of the molten material. If heated sufficiently, the molten material may also form burning droplets which may fall downwards.

Both of these processes are clearly visible in my next video clip, and both may contribute to the formation of pool fires below and in front of the burning material, as is also clear from my next video.

This slide shows a vertically oriented sheet of a white-coloured polymer. In fact, the particular polymer used here is polyethylene. The sheet is 3 millimetres thick.

I should point out that this is a demonstration, not a scientific test.

The sheet has been ignited at its base using a butane torch. This butane torch is just barely visible as a blue flame to the bottom-left of the sample. It's quickly withdrawn out of frame.

I'll play this clip in three segments.

In the first segment, we see that a few seconds after ignition, the molten material is already beginning to fall down and burn on the floor beneath the sample. At this point, the flames on the polyethylene are relatively small.

(Video played)

In the second segment, which begins about 3 minutes later, we see that the sample is burning on both sides and that there is an almost constant flow of molten burning polyethylene falling from the sample to the floor.

(Video played)

I should point out that the vertical streaks are rivulets of melted, burning polyethylene.

In the third segment, which begins about 6 minutes later still, the sample has been significantly consumed and molten polyethylene continues to fall.

(Video played)

The fact that polyethylene burns in this manner is not at all surprising. This behaviour has been well known and documented in the scientific and technical literature for decades.

This particular issue will become very important later in my presentation when I discuss the fire spread

that was observed on the exterior of Grenfell Tower.

I've now spent considerable time discussing the most important, fundamental fire science concepts and terminology relevant to developing a physical understanding of the circumstances of external fire spread during the Grenfell Tower fire.

It is very important to note that my presentation of concepts such as ignition, burning and flame spread relate primarily to single materials rather than to composite products. By this I mean products that are composed of a combination of materials, all of which may display substantially different flammability and flame spread properties.

I should also note that very little useful fundamental experimental data are available in relation to flammability and flame spread on composite products since most of these products violate the basic assumptions of many of the existing experimental and compliance testing methods.

This issue is of particular relevance to this inquiry, not least because of the large number of other buildings in the UK and internationally that are apparently clad using similar materials and products to those used at Grenfell Tower.

Despite this disclaimer, a series of useful conclusions can be drawn on the basis of the discussion provided in this first section of my presentation today. These are as follows:

Ignition, flammability, flame spread and fire growth are all influenced by numerous factors, including material properties, chemical composition, orientation, geometry and interactions with other materials.

Upward flame spread on a solid fuel is rapid because the hot flame and gases preheat the material ahead of the burning zone.

Downward and horizontal flame spread is generally slower because preheating of the fuel ahead of the flame front is greatly reduced.

Almost all of these concepts are important in order to understand even my most basic matchstick demonstrations of some of the relevant flame spread mechanisms.

On this slide I've placed all three of the matchstick videos. I'm going to run them concurrently so you can see just how important the relevant phenomena are as regards both the rate and the extent of flame spread.

(Video played)

However, as I've just mentioned, downward flame spread may also be significantly influenced by melting

and dripping of burning material, as I showed a few moments ago with reference to polyethylene.

In all cases of upward, downward and horizontal flame spread, the spread is dominated by the heat release rate of the existing fire, how the resulting fire transfers heat to the unburnt material, and the thermal properties of the material itself.

Sir, that concludes my summary of the key fire science concepts and processes to which I'd like to draw your attention at this early stage of the inquiry.

All of these concepts must be kept clearly in mind when considering the rest of the preliminary evidence that I will present today and, indeed, during Phase 1.

SIR MARTIN MOORE-BICK: Thank you very much.

MR MILLETT: Mr Chairman, I wonder if that's a convenient moment for the break.

SIR MARTIN MOORE-BICK: I think it would be a good moment. Shall we break now and resume at 11.10, please.

Thank you.

(11.00 am)

(A short break)

(11.15 am)

SIR MARTIN MOORE-BICK: Yes, Professor Bisby, when you're ready.

PROFESSOR BISBY: Thank you.

As I have already described, the orientation, thermal properties and chemical composition are all important in understanding how materials and products may respond to fire.

During this second part of the preliminary evidence that I will present today, I'll describe the materials and products used in the refurbishment cladding system at Grenfell Tower. I will describe where they can be found on the building and how they're arranged. I will also describe how they burn.

The summary of materials and products presented in this section is based on a range of sources of evidence as follows: four post-fire inspections of Grenfell Tower that I've conducted prior to submitting my Phase 1 report; a range of documentation and photos made available to the public inquiry via formal disclosures; and materials and product samples taken from Grenfell Tower by the Metropolitan Police Service and provided to me for small-scale materials testing at the University of Edinburgh.

Before I describe the materials in detail, I'd like to ensure that I'm clear about the terminology that I will use to describe different parts of the building. I will do this by presenting a number of annotated photographs and drawings to identify the terminology for

parts of the exterior of the building that are relevant to my preliminary evidence.

This image shows a portion of the west face of the building following the fire. This photo was obtained by the Metropolitan Police Service using a drone on 25 July 2017.

During my presentation, when I refer to columns, these are the areas of the building indicated on this image.

I should like to point out that the east and west faces of the building each have four column lines, as shown here, whereas the north and south faces of the building each have five column lines, as noted by Mr Millett during his opening remarks.

When I refer to spandrels, this is a generic term that I use for the parts of the building between the windows, as indicated on this image.

I also use the terminology spandrel section to refer to the building exterior between the column lines, the sections shown here.

When I refer to rainscreen cassettes, these are the external panels as indicated on this image, for example here, here, here are spandrel section rainscreen cassettes, and here and here on the column sections of the building. It's worth noting that these are grey in

colour from level 4 upwards.
When I refer to the window sections of the building, these are the sections of the building as shown indicated on this image.
Within the window sections there are several individual components, including windows, extract fans, mounting panels and window infill panels. I'll describe these in a moment.
When I refer to window infill panels, these are as indicated here in yellow. These are unglazed sections of the window units. It's worth noting that these are white in colour from level 4 upwards.
The kitchen windows are indicated on this image. Here I'd like to draw your attention to the fact that the kitchen windows are actually made up of three separate areas, and I'll describe each of these in more detail in a few moments.
When I refer to cavity barriers, which will be very rarely, these elements are running vertically and horizontally within the cladding on the building, as indicated on this image, and visible only where the rainscreen cassettes have been damaged or removed during the fire. You can just see them as the ragged lines underneath the yellow bars.
When I refer to the floor slabs, I'm referring to

the structural reinforced concrete floors within the building, and these are at the levels approximately indicated by the yellow lines on this image.
I will now describe the cladding system and its geometry in more detail by zooming in on one specific part of the building, specifically the section shown of the building's exterior which I'm showing here.
This part of the building has the same arrangement of windows as those around the external east wall of flat 16, which is acknowledged by at least three of the inquiry's experts as the room of fire origin. The internal layout of this particular flat is also the same as that in flat 16, approximately, so the kitchen window is on the left, and the two windows to the right of the kitchen window are associated with the living room.
I'll now zoom in even further to look only at the region around the kitchen window, which is shown as highlighted there. Here I've highlighted one of the kitchen windows in the vertical line of flats in the tower ending with the number 3. These are flats positioned in the southwest corner of the building.
I will now zoom in even further to the kitchen window specifically.
The window comprises: a large glazed windowpane, which operates in both an inward tilting or inward

turning -- by which I mean swinging -- manner, and hinged on the right when observed from outside the building; an extract fan, which is mounted within an infill panel, and this infill panel appears to be made from the same materials and construction as the window infill panels that I noted previously, and I'll come back to these in a moment; and a small glazed windowpane beneath the extract fan and mounting infill panel, which operates in an inward turning manner and is hinged on the left when observed from outside the building.
I'd now like to look in some detail at the composition and geometry of the cladding in various locations around this kitchen window, which has the same design as the kitchen window of flat 16, as I mentioned. To do this, I will use my own hand-drawn sketches of the relevant sections through the building. These are based on my own post-fire investigations at Grenfell Tower, and I'll do this in the hope that my sketches will be more easily understood by you and by the other parties to the inquiry.
I will necessarily be covering some of the ground already covered by Dr Lane and Professor Nic Daeid; however, I believe that this is useful repetition and that a detailed focus on the cladding materials and

geometry is warranted under the circumstances.
It should be noted that my sketches are only indicative and are not to scale.
I should also like to note that my post-fire inspections at Grenfell Tower have confirmed that there is local variation of the refurbishment cladding geometry due to the geometry of the existing building and the presence of the original window openings. I've carefully considered this variability in examining the available evidence and drawing my preliminary conclusions.
In my sketches, I will not show the location of cavity barriers within the cladding. This point has already been discussed in some detail by Dr Lane and I don't consider it critical to my own scope of work.
So let me look now in detail at the cladding immediately above and below the kitchen window opening.
Please imagine if I were to cut through the cladding along a vertical line, as shown here, and then look inside the cladding to see the various layers that I cut through. I will look specifically at the cladding materials and geometry here above and below the kitchen window.
The following slide sequence shows the build-up of the different cladding materials, starting with the

pre-existing or original cladding construction and adding the various components of the refurbishment cladding as I go.

This slide shows a sketch of the original concrete construction at the location of the kitchen window -- and, remember, this is over a vertical slice through the building.

The left-hand side of this image shows the outside of the building and the right-hand side is inside the flat. Please note that I've removed the windowpane and brought these two sections closer together vertically in this drawing than they actually are in reality.

The original concrete structure can be seen in grey. The concrete slab that forms the ceiling is shown top-right, and the concrete wall below the windows is shown below.

There were also original timber battens and a window framing board, and purlboard foam insulation both on the ceiling in a band and on the interior wall. I'll describe these in more detail shortly.

The original windows were located approximately as shown here. Below the windows, the purlboard insulation was covered by a sheet of gypsum plasterboard as an internal finish within the flat.

During the 2012 through 2016 refurbishment

programme, the original windows were removed, and installed over the top of this original construction was the refurbishment overcladding system.

This comprised supporting aluminium rails and fixings which were anchored into the pre-existing reinforced concrete floor slabs and spandrel beams.

Polymer foam thermal insulation was applied in two layers on this section of the building, each 80 millimetres in thickness, and the aluminium composite material -- or ACM -- rainscreen cassettes were then applied.

Between the rainscreen cassettes and the foam insulation was an open, ventilated void, hence the terminology "ventilated rainscreen cladding system" to describe this particular type of cladding. I'm referring to the voids shown with the writing there.

The new aluminium framed double glazed windows, extract fan units and window infill panels were fitted into the openings and mounted on the aluminium rails, as shown here.

You can see here how I've cut and reduced the vertical size of the window.

Inside the building was placed some additional polymer foam insulation in approximately those locations, and a finishing detail of a uPVC window

board, which was bonded in place using a polymer adhesive, as shown there. Any small visible gaps were then filled with a silicone sealant.

UPVC stands for unplasticised polyvinyl chloride and is a specific type of polymer -- ie a plastic -- material that I will describe in more detail later in this presentation.

We will look at each of these materials and products in more detail in a moment, but for now I simply wanted to show their locations within the cladding.

Please note that the location of the glazing has been moved outwards as a consequence of the recladding, and that the windows themselves now sit some distance outside the original reinforced concrete construction.

I would now like to take a horizontal slice through the building and look at the cladding build-up immediately to the left of the kitchen window when viewed from outside the building at this location here.

When viewed from inside the building, this slice is across the window as shown in this image. Please note that the dark material on the windowsill in this photo is debris from the fire. This is a partially fire-damaged flat.

In this photo, the uPVC window boards are clearly visible, as are the lines of silicone sealant used to

fill the gaps between them, here.

Please also carefully note this thin strip of uPVC window board now highlighted in yellow. This has been installed in order to fill what would otherwise be a gap between the new refurbishment window frame and the pre-existing window opening within the original reinforced concrete facade, as I'll showing a moment. This appears to be held in place with a bead of silicone sealant.

Cutting through the wall of the building at this location and looking from the top down, you can see a portion of the octagonal-shaped reinforced concrete column on the left side of this sketch.

Inside the building is at the top of this slide and outside the building is at the bottom.

Again, the original construction included timber battens and timber window framing board, and the original single glazed windows within aluminium frames.

Here, the line showing the glazing fades at the right, and this is to indicate an indefinite distance in this direction in my sketch, so the window continues off to the right.

As before, the original windows were removed, and the new double glazed windows were installed on the horizontal aluminium rails which I showed previously but which are not shown in this view.

In this location, to the left of the window -- ie on the column -- the overcladding comprised the polymer foam thermal insulation, in this case a single layer 100 millimetres thick, and the ACM rainscreen cassette. As highlighted a moment ago, in this location there was a gap between the edge of the new window frame and the pre-existing reinforced concrete column. There's a void in the rainscreen and that is the gap that I'm referring to.

A weatherproofing membrane made of EPDM rubber sheet was positioned across the gap formed in this location.

Foam insulation was present both on the inside and outside of this gap, as shown there, and the uPVC window board was again applied as an internal finish, as shown there.

I should like to note at this point that the specific geometry of the small section of polymer foam insulation directly outside the kitchen window -- sorry, that's the strip of uPVC window board that I highlighted a moment ago -- which is now highlighted appears to have varied over the building. In some cases, the insulation boards were cut differently at this location, and in some cases the smaller pieces of foam insulation immediately outside the EPDM rubber membrane appear not

to have been installed at all. This is important as regards potential routes for fire spread from inside the building to the cladding.

As I will discuss later today, this is as ongoing item for investigation.

Moving lower down to the spandrel section of the exterior cladding below the kitchen window, I will now take a horizontal slice across this part of the building in this location shown here.

In this location -- again, looking down at the surface of my slice through the building -- we can see the original concrete column and spandrel beam. Here, again, the spandrel beam fades at the right to indicate that, in reality, it continues to the right.

There are one or two layers of PIR foam insulation, depending on the location on the building. On the columns, one layer was present with a thickness of 100 millimetres -- this is shown here -- whereas on the spandrel, as I've already noted, two layers each of 80 millimetres in thickness were present.

The aluminium cladding rails -- shown here -- support the spandrel ACM rainscreen cassettes, as was described in detail by Dr Lane on Monday. These were attached to the refurbishment window frames using a series of metal brackets not shown in this view.

Here are shown the connection to the ACM rainscreen cassettes on the cladding rails.

Spray foam was used liberally to fill gaps and small voids within the external cladding system. Aluminium tape also appears to have been used liberally within the cladding.

Finally, the ACM rainscreen cassettes were hung from the cladding rails and, again, please note the void within the cladding between the rainscreen cassettes and the PIR foam thermal insulation.

I'd now like to draw your attention to a particular feature of the cladding geometry that exists along the vertical line where the spandrel sections of the building meet the column sections of the building.

Remembering the two horizontal sections that I've just taken through this location and where they're positioned in the building, both through the window section and through the spandrel section -- shown here -- I've identified that a continuous vertical void exists within the cladding at the location shown in this figure.

This void is continuous on all columns from level 4 all the way to the top of the tower.

If I show the location of these voids on the column to the left of this particular kitchen window --

I should note it's the same on all columns as far as I can tell at this point -- they are as shown here.

If I show these voids on a section of the full west face of the tower, they are as shown here.

The final part of the cladding that I'd like to examine in detail is at the location that I have called the column tip in my Phase 1 report. This is highlighted in yellow in this figure. I wish to highlight this both for completeness and because of another particular feature of the cladding geometry at this location -- that location just there.

This image shows a sketch of a horizontal slice across the column tip, as shown by the dashed line in the previous slide, and again looking down at the surface of my slice.

The tip of the original concrete column's external precast concrete surface is seen in grey. The overcladding in this location comprises the aluminium fixings and rails -- shown here -- the single layer of foil-faced PIR foam insulation, 100 millimetres in thickness, and the ACM rainscreen cassettes, again with a ventilated rainscreen cavity.

Within the cladding rail, at the column tip, I've identified that there is another uninterrupted void that spans the entire height of the building. The location of this void is illustrated here.

Again, if I show these additional column tip voids on a section of the full west face of the tower, they are as shown here.

Combining these with the continuous vertical voids discussed previously -- here -- we can see that the column lines in particular provide numerous vertical voids and channels that run uninterrupted from at least level 4 right the way to the top of the building.

Sir I've now described my key preliminary evidence with respect to the geometric arrangements of the cladding.

Having dealt with the geometry, I will now describe the various materials and products that were present within the cladding system of Grenfell Tower at the time of the fire.

Before I begin, I believe it's important to make clear a distinction between materials and products. Materials are comprised of, well, a single material; products, on the other hand, can be comprised of multiple materials. For example, aluminium is a material and polyethylene is a material.

However, Reynobond PE -- shown here, for instance -- is a product consisting of two aluminium sheets separated by a gap which is filled with polyethylene.

Even at this early stage of the inquiry, Reynobond PE will no doubt be familiar to you, and I will discuss this product in more detail in a few minutes.

It has been common to refer to Reynobond PE and similar rainscreen products as aluminium composite materials, or ACMs. The use of the word "material" in this context is in some ways a misnomer; however, because the word "composite" precedes the word "material", the name tells us that this is actually a product consisting of multiple materials.

Another example of a product is Celotex RS5080, which is shown here. This product is composed of several materials: polyisocyanurate -- or PIR -- foam, which is highlighted here; a thin aluminium foil facing, which is shown here and is on both sides of this material; and a glass fibre mesh which sits within the PIR foam, as indicated by the lines shown here.

I will also return to the product Celotex RS5080, which is part of the Celotex RS5000 range of insulation products, later in my presentation.

With this distinction between materials and products made, I will now move on to describe the different cladding materials and products used on Grenfell Tower and the respective locations within the cladding system.

I apologise, this does get a bit repetitive in this

section of my presentation.

ACM rainscreen cassettes were provided on both the spandrels and columns of Grenfell Tower as highlighted here in yellow.

ACM products were also used to form the ornamental architectural crown at the top of the building, as shown here with substantial fire damage from a drone photo taken after the fire on 25 July 2017, with much of the crown now missing.

The crown elements would have been configured approximately as I've shown them here before the fire. The specific geometry and materials of the architectural crown are discussed in detail in my Phase 1 report and will be the focus of considerable additional work at Phase 2.

For my presentation today, it's sufficient to note that the architectural crown was comprised largely of closely spaced, vertically oriented, C-shaped channels formed from ACM panels. These were mounted on closely spaced aluminium rails, which were supported off the original reinforced concrete parapet beams at roof level.

As we heard on Monday, the ACMs at Grenfell Tower were a product called Reynobond PE, where the PE stands for polyethylene. This was and is manufactured and sold

by Arconic Architectural Products.

This image shows the corner of a Reynobond PE panel taken from Grenfell Tower after the fire and provided to me by the Metropolitan Police Service. It is comprised of a 0.5-millimetre thick aluminium outer surface, which is bonded to a 3-millimetre thick polyethylene filler material and a 0.5-millimetre thick aluminium inner surface.

To form the product into rainscreen cassettes, flat sheets of the material are cut and folded. This image shows various different cuts and folds in a typical ACM rainscreen cassette taken from Grenfell Tower after the fire, again provided to me by the Metropolitan Police Service.

I would like to draw your attention to the exposed edges of black polyethylene material that this image reveals. This image is showing the back of a typical rainscreen cassette, by which I mean it is showing the face of the cassette that would've been looking into the ventilated rainscreen cavity. The black areas in this image therefore present surfaces of polyethylene that would be directly exposed to any flame or heat within the cladding cavity should a fire penetrate by essentially any means into the cladding system.

Two different colours of polyethylene are present in the Reynobond PE ACMs used on Grenfell Tower: the black polyethylene that I've shown here, or a light-coloured translucent polyethylene which I've not shown. Testing will be undertaken at the University of Edinburgh to assess if there are any discernible differences between these two different colours of polyethylene in terms of their reaction to fire.

Next, I'd like to look at the PIR foam insulation products that were used at Grenfell Tower, where PIR, again, stands for polyisocyanurate.

Some of these products are also visible in this image in the locations where the ACM cassettes again have been damaged or removed by the fire. For instance, we can see some insulation here and here.

Most of the PIR foam in this photo has had its external aluminium skin removed and has been charred on its outer surface during the fire, thus having a darkened, cracked, blackened appearance. This charring behaviour is significant as regards the manner in which PIR foams may burn, and I will return to this point later in my presentation.

Just to remind you, the locations of the PIR foam on my sketches of vertical slices through the building are illustrated in yellow here, where you can see where PIR foam is located both above and below the window and

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within the window surround, and again here, around the column to the left of the window in my horizontal slice.

This image shows a piece of the PIR foam taken from one of the columns at Grenfell Tower and, again, provided to me by the Metropolitan Police Service. Visible in this photo are the PIR foam, which is yellow in colour, and one of the foil faces. I should note that the bottom surface of this product also has a foil face but it's not visible in this photo.

This insulation product is manufactured by Celotex under the generic product name RS5000. The specific product name is Celotex RS5100, where the last three digits, 100, correspond to the thickness of the product in millimetres.

This image shows a piece of PIR foam insulation that was taken from one of the spandrel sections at Grenfell Tower.

Again, visible are the PIR foam -- again, yellow in colour -- the foil faces -- again, top and bottom -- and in this particular product, a glass fibre weave within the PIR in two layers, as noted earlier.

This product is also from the Celotex RS5000 PIR insulation product range, and at Grenfell Tower this product was anchored to the concrete spandrels in two layers, each of 80 millimetres thickness, as I've

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mentioned. The specific product name is therefore Celotex RS5080, where, again, the 80 represents a product 80 millimetres thick.

Also on this photo we can see some of the polyurethane polymer spray foam that was present -- in comparatively small volumes, I should say -- in many locations within the cladding.

In addition to the PIR insulation identified during post-fire inspections at Grenfell Tower, phenolic foam -- or PF -- insulation has also been found on some areas of Grenfell Tower.

This product, the phenolic product, not shown here, has been identified as Kingspan Kooltherm K15 and, based on the available evidence, accounts for only a very small proportion of the insulation and only on a small number of spandrel sections of the building.

Two further PIR foam insulation products have been identified during my post-fire investigations of the undamaged and partially damaged sections of the building. These were located around the window framing of the refurbishment windows, as I've mentioned, and are shown in this photo -- again provided to me by the MPS -- a 25-millimetre thick foil-faced PIR polymer foam insulation board manufactured by Celotex, this is shown top-right on this slide and has yet to be definitively

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identified; and a 25-millimetre thick foil-faced polymer foam insulation board manufactured by Kingspan. This is shown bottom-left. The specific product name is yet to be confirmed, although, based on its markings, it is likely to also be PIR foam and from the Kingspan Therma product range.

I've previously mentioned an insulation product called purlboard. This appears to have been part of the original construction of Grenfell Tower and was located inside the building, both above the window on the ceiling -- as shown here -- and in a continuous band around the perimeter of all flats, and below the window on the inside face of the reinforced concrete spandrel beams. These locations are indicated here in my vertical slice through the cladding.

The purlboard insulation is a polyurethane foam board. The product is approximately 13 millimetres thick and is faced on both sides with a paper covering.

The purlboard on the internal wall of the spandrel sections was, as already noted, adhered to a layer of plasterboard, as shown in this photo, with the purlboard being the top portion of this sandwich and the plasterboard being the bottom.

I've not yet been able to determine if the purlboard on the ceiling was also faced with a layer of

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plasterboard as I've been prevented from disturbing this product due to an apparent asbestos risk associated with the Artex plaster on the ceilings.

Around the windows are uPVC window framing boards that form the final internal finish of the refurbishment cladding system. The location of these uPVC boards is indicated in this image, here, here, here, here, and, importantly, as I've already mentioned, here in a thin strip.

This image, which I've shown previously, shows a portion of a uPVC horizontal windowsill and the vertical uPVC window jamb, by which I mean the side of the window enclosure, after the fire. This is shown in my vertical slice -- again in yellow -- above and below the kitchen window, as shown here, and again here in my horizontal slice at the side of the kitchen window.

This slide shows a close-up image of one of the uPVC boards taken from Grenfell Tower. These had a smooth surface and were approximately 9.5 millimetres thick.

As already discussed, there is an EPDM rubber weatherproofing membrane that extends between the edge of the refurbishment cladding window frame and the original reinforced concrete column. This is illustrated in this photo looking up at the building during the forensic deconstruction of the cladding that

occurred following the fire, such that the rainscreen cassette and insulation boards have been removed from the column at the left-hand side of this photo.

The EPDM membrane is the material highlighted here in yellow. As you can see, this is a flexible sheet which was adhesively bonded to the existing reinforced concrete structure.

The EPDM rubber membrane is highlighted in yellow in my horizontal slice drawing to the left of the kitchen window, here.

This image shows a roll of the EPDM rubber membrane and a single sheet of the material, both taken from Grenfell Tower and provided to me again by the Metropolitan Police Service. The product used in the sections of Grenfell Tower that I've inspected is 1 millimetre thick, as shown.

The window infill panels, as I have already discussed, are the non-glazed sections of the window units and are highlighted in yellow in this image. These are comprised of two sheets of aluminium, each with a thickness of 2 millimetres, and a polystyrene foam insulation core 25 millimetres in thickness, and this is shown here.

The smaller window infill panels that house the kitchen extract fans were similar to these if not

identical in terms of materials and construction.

That concludes my presentation of preliminary evidence as regards the geometry and materials of construction of the refurbishment cladding at Grenfell Tower.

In the final section of my part 2 presentation, I'd like to briefly describe the burning behaviour of some of these materials.

In discussing specific material burning behaviour -- which includes flammability, ignition, et cetera -- I will focus on those materials which I consider to be most important with respect to the Grenfell Tower fire. Please note that I'm using the word "materials" intentionally here.

At this stage of the inquiry, I will avoid commenting on the burning behaviour of products other than to reiterate my previous statement that very little useful fundamental experimental data are available in relation to the burning behaviour of composite products, since most products, again, violate the basic assumptions of many of the existing experimental and compliance methods.

The discussion below is therefore based on samples of pure material; by this I mean a single material in the absence of coatings, protective layers or

incorporation into composite products. This is actually a very important point.

This part of my preliminary evidence gives a very brief introduction to the reaction to fire of materials that have been identified to date as being present in the refurbishment external cladding of Grenfell Tower.

I will present selected information based on data available in the scientific and technical literature rather than based on the specific materials themselves.

However, in most cases the information available in the technical literature has a strong dependence on the exact material formulations and test methods used, so at this point these properties and values are provided simply for the purposes of illustration.

I expect to study the burning behaviour of a range of relevant products in considerable detail as part of my ongoing work for the inquiry, and also to comment in some detail at some stage on compliance testing methods which are currently used to assess the burning behaviour of materials and products, both within the UK and in European regulatory environments.

Again, I will try to avoid technical language and jargon; however, again, the subject matter demands a certain level of technical terminology.

Most of the materials of interest in this discussion are polymers. Polymers are synthetic or naturally occurring compounds that have large molecules made up of many relatively simple repeated units called monomers. Polymers are created by joining together the short monomer molecules to form long molecular chains. As already mentioned, a generic term to describe synthetic polymers is plastics.

Polymers can be grouped, importantly, into two main types: thermosetting polymers and thermoplastic polymers.

The differences between these two classes of polymers are, in my opinion, very important as regards the events that occurred at Grenfell Tower.

A thermoplastic polymer will melt and can be deformed on heating, and in some cases can be returned to its original form. If heated under the correct conditions, the polymer will also undergo pyrolysis and will directly produce flammable gases.

A thermosetting polymer will not melt on heating but instead will thermally decompose, by which I mean undergo pyrolysis.

These contrasting behaviours strongly affect how these different classes of polymers burn.

Upon exposure to heat, a thermoplastic polymer will soften and melt. Once in a liquid state, the polymer

may break down into constituent monomer parts. These may evaporate or pyrolyse to generate a flammable gas mixture. It is also possible for the solid to undergo direct pyrolysis to generate flammable gases.

Thermoplastics may spread fire by burning as they flow or burning as droplets, as I've already mentioned. Since thermoplastic polymers will melt and flow, their reaction to fire is strongly dependent on their orientation. When burning in a horizontal orientation, a thermoplastic will melt and form a pool of liquid which will burn at a relatively steady rate.

In the vertical orientation, as I've already shown in part 1 of today's presentation, melting and dripping will likely dominate the burning behaviour of a thermoplastic and, as noted previously, contribute to the formation of a pool fire at the base of or in front of the material.

Conversely, thermosetting polymers do not melt, and instead chemically decompose, by which I mean pyrolyse, when exposed to heat. In this case, the pyrolysis process produces a flammable gas and leaves behind a solid char. The formation of this char means that some of the potential fuel is effectively locked up in the solid char and is therefore not available for releasing heat in the flame. The formation of the char

also reduces the rate of heat transfer into the material and, as I've already mentioned, the pyrolysis rate subsequently decreases.

Consequently, the gases may not be released at a sufficient rate to sustain a flame without some additional external source of heat. Therefore, the flame may go out.

The heat release rate of a burning thermosetting polymer is therefore typically characterised by a high initial value, as I've already mentioned, which rapidly decreases due to the formation of a char layer.

I will now describe the burning behaviour of some of the key materials found at Grenfell Tower in more detail.

Both thermoplastics and thermosetting polymers were present within the cladding system in significant quantities. As we have seen, polyethylene was present within the Reynobond PE ACM rainscreen product which was used extensively at Grenfell Tower, both in the rainscreen cassettes and in the architectural crown.

The polyethylene is highlighted here in yellow. Polyethylene is a highly flammable synthetic thermoplastic polymer. Upon exposure to heat, polyethylene will melt and drip, possibly flowing whilst burning or generating flaming droplets, as I showed in

part 1 of my presentation.

Its melting temperature is around 130 to 135 degrees Celsius, and its heat of combustion -- which, to remind you, is a measure of the total energy that a material is capable of releasing under optimum combustion conditions -- is about 46 megajoules per kilogram.

Sir, you will no doubt have noted the commentary in the media comparing the polyethylene material within the ACM rainscreen cassettes at Grenfell Tower to petrol or diesel. This is likely to be on the basis, as I've already shown, that the heats of combustion of petrol and diesel are similar to the polyethylene used in Reynobond PE ACM products.

It's perhaps worth reiterating here, however, that the heat of combustion is only one of the important parameters dictating how a material will burn, as I've already discussed in some detail.

Polyisocyanurate -- or PIR -- foam materials were also used in significant volumes within the cladding system at Grenfell Tower. This was as part of the four insulation products that I've already discussed and which are shown here. The PIR foam is again highlighted here in yellow, so makes up the bulk of these products.

PIR is a synthetic thermosetting polymer which is primarily produced as a rigid foam. It has a very low thermal inertia, which you will remember I discussed earlier. Its material properties make it extremely attractive for providing thermal insulation in buildings.

However, the very low thermal inertia of PIR, as I've discussed already, means that it tends to have a comparatively low time to ignition and will support rapid flame spread without protection from an external barrier, for instance an aluminium foil facing.

The very low thermal inertia means that PIR may also accelerate flame spread of adjacent materials by preventing the loss of energy from the system. By this I mean by insulating, for example, the rainscreen cavity and reducing losses, thus possibly accelerating flame spread.

Sorry, thus possibly accelerating fire spread -- the difference in terminology is actually quite important.

The precise formulation of PIR foams varies by manufacturer, as does the manufacturer's use of different fire retardants. As a result, comparison between products and the available technical literature is not strictly possible. Nevertheless, to give you an idea of comparative hazard, the heat of combustion of PIR is about 26 megajoules per kilogram, or about 60 per cent that of polyethylene.

But this comparison must clearly be considered in light of my previous comments noting the potential importance of other burning behaviours.

I have already noted that phenolic foam insulation has also been identified in comparatively small quantities during post-fire investigations at Grenfell Tower.

Phenolic foam is also a synthetic thermosetting polymer and is also primarily produced as a rigid foam with a cellular structure.

Like PIR, phenolic from has a very low thermal inertia and, consequently, it will have a comparatively low time to ignition and will support flame spread, again, when its surfaces are unprotected. As for PIR, the precise formulation of phenolic foams varies by manufacturer, as does the manufacturer's use of different fire retardants.

Specific properties of phenolic foam are given in my Phase 1 report, but there's limited value discussing them in this presentation due to the comparatively small quantities that appear to have been used at Grenfell Tower.

Polystyrene foam is used within the core of the window infill panels at Grenfell Tower, as highlighted here. Polystyrene foam is a low thermal inertia

thermoplastic polymer and, therefore, rapidly melts at its surface when exposed to heat or flame. Once melted, polystyrene foam typically forms burning droplets or burns as a liquid pool. Its melting temperature is about 230 degrees Celsius and its heat of combustion is about 40 megajoules per kilogram. Again, compare with polyethylene at about 46 megajoules per kilogram.

Polyvinyl chloride -- or PVC -- is a synthetic thermoplastic polymer. With relevance to Grenfell Tower, I am discussing rigid PVC, commonly referred to as uPVC or PVCu. The U simply stands for "unplasticised", meaning the PVC is rigid at room temperature.

Upon exposure to fire, uPVC may char. However, its particular chemical nature means that its heat of combustion is lower than for any other synthetic polymers. As a result, its ability to spread flame is also comparatively less than many other polymers. Its heat of combustion, for instance, is only about 18 megajoules per kilogram.

However, the temperatures at which uPVC will soften and experience significant reductions of mechanical properties are very low in comparison with other construction materials. As a result, typical day-to-day upper service temperature limits for uPVC are in the

range of about 50 degrees Celsius. Its melting temperature is between 75 and 105 degrees Celsius.

This is highly significant, in my view, in the context of Grenfell Tower because, as I've already explained, uPVC window boards form the initial barrier for flames to prevent fire spread from the kitchen of flat 16 into the cladding cavity beside the kitchen window. This issue receives considerable attention in my Phase 1 report.

Ethylene propylene diene monomer -- or EPDM -- rubber -- shown here -- is an elastomer or synthetic rubber. The chemical composition of EPDM rubber means that it will burn.

No specific details were available regarding the combustion properties of the EPDM rubber used at Grenfell Tower at the time of writing my Phase 1 report. These will be studied by laboratory-based testing on an ongoing basis.

Thus far today, I've presented quite a large volume of technical information. I'd like to summarise the key points that I think are most important when considering the evidence as regards fire spread to and on the exterior cladding of Grenfell Tower.

With regard to materials and geometry, the refurbishment external cladding system at Grenfell Tower has an extremely complex geometry and incorporates a number of different materials and products. Many of the materials and products installed within the cladding system are combustible, predominantly synthetic polymer materials.

Particular features of the cladding geometry, which I've described during my presentation, resulted in the presence of a number of vertical cavities and channels within the cladding and running the full height of the building from at least level 4 up to the architectural crown at roof level.

As already noted, the architectural crown itself was formed largely from vertical channels of highly combustible Reynobond PE ACM panels.

With regard to flammability and fire spread, whilst all of the polymer materials present are combustible, different polymer materials, as I've explained, can burn in very different ways and therefore present very different fire hazards under a particular set of conditions.

The total amount of energy available for combustion is described by the heat of combustion, but there's no guarantee that all of this available energy will be released under particular fire conditions.

A material's thermal inertia relates to how quickly

its surface will increase in temperature when exposed to heating. This has consequences for ignition and surface spread of flame in particular, in that materials with a very low thermal inertia -- such as PIR foam insulation -- are likely to spread flame rapidly, particularly when their external surfaces are not protected by a metal facing.

Thermosetting polymers -- like PIR -- will char on heating, whereas thermoplastics -- like polyethylene and polystyrene -- will melt. This, again, has important consequences for the extent to which the total amount of energy available is actually released during a fire. I've illustrated that again here with respect to the non-charring and charring behaviour of various polymer solids.

All of these ideas will become important during this inquiry as we try to unpick the respective effects both of the geometry and of the materials and products present within the cladding system at Grenfell Tower.

These issues are central to understanding what happened at Grenfell Tower and to ensuring that it can never happen again.

That concludes section 2 of my presentation.

SIR MARTIN MOORE-BICK: Thank you very much.

MR MILLETT: Thank you very much, Professor.

Mr Chairman, this might be a convenient moment to take the midday break. I know that part 3, fire spread, will take a large portion of the afternoon, so it may be convenient to take an earlier lunch now.

PROFESSOR BISBY: Whatever you are happy with.

SIR MARTIN MOORE-BICK: Well, you've been on your feet for quite a long time. Would you like a break now?

PROFESSOR BISBY: Sure.

SIR MARTIN MOORE-BICK: Yes, all right.

Well, we'll have a rather extended lunch break. If we resume at 2 o'clock, that will give you plenty of time to finish your presentation, will it?

PROFESSOR BISBY: Sure, should do, yes.

SIR MARTIN MOORE-BICK: That's what we'll do then. We'll rise now and resume at 2 o'clock.

Thank very much.

(12.11 pm)

(The short adjournment)

(2.00 pm)

SIR MARTIN MOORE-BICK: Yes, Mr Millett.

MR MILLETT: Mr Chairman, I just ought to repeat, if I can, the trigger warning that this afternoon's presentation from Professor Bisby will contain a large number of images and videos depicting the external flame spread on the night of the fire, and that will include the playing

of his composite flame spread video, which I played in my opening, and detailed consideration of that and other flame spread material which shows the tower burning and on fire. Some of the videos include audio of people who witnessed the fire and it shows some of their distress at the events as they unfolded. It will also contain a number of images of the burnt-out tower after the fire and the playing of the first 999 call by Mr Kebede.

So I just repeat that warning.

SIR MARTIN MOORE-BICK: Thank you very much.

MR MILLETT: Thank you, Professor.

SIR MARTIN MOORE-BICK: When you're ready, Professor.

PROFESSOR BISBY: Thanks very much.

During this third part of my presentation, I will describe in general terms the spread of fire to and over the cladding at Grenfell Tower.

I will begin by providing an overview of the fire's early development, since this is relevant to the question of how the fire spread from within the kitchen of flat 16 out and into or onto the cladding.

I will then describe the external fire spread over the tower, breaking this down into upward fire spread, downward fire spread and horizontal or lateral fire spread in that order, for reasons that I hope will become clear during the course of the inquiry.

I will make extensive use of photos and video footage that was provided by members of the public via the Metropolitan Police Service uploads website. Much of this information has proved critical in understanding the events of 14 June 2017.

As I've reviewed the evidence, I've considered a number of hypotheses for the routes of fire spread from the compartment of origin onto the external cladding, the fire spread over the cladding and ingress of the fire and smoke back into the building.

These specific hypotheses are described in detail in my Phase 1 report and I understand that I'll have an opportunity to elaborate on these later this year.

Based on the available evidence, I've determined that the overall timeline for the progression of the fire to and over the cladding was as follows.

The fire was first reported at 12.54 am on 14 June 2017 within the kitchen of flat 16 on level 4 of Grenfell Tower.

Over the course of the subsequent 15 minutes or so, the fire burned within the kitchen of flat 16. The fire was observed to have spread to the cladding by about 1.09 am.

The fire then spread vertically upwards on the east face of Grenfell Tower, breaking into flats on the

floors above flat 16 as it spread.

It took approximately 20 minutes for the fire to spread from level 4 to the roof.

By about 1.29 am, the fire had reached the top of the east face. The vertical fire spread started slowly and accelerated as the fire grew in size.

The fire then spread northwards on the east face and, at approximately 1.36 am, spread horizontally on to the north face. This horizontal spread occurred first at the top of the tower.

The fire also spread southwards on the east face, again leading at the top of the tower.

At approximately 2.25 am, the fire spread from the east face to the south face, again leading at the top of the building.

Horizontal fire spread was coincident with downward fire spread, causing a larger area of the cladding to become involved in the fire.

The fire spread from the north face to the west face at approximately 2.49 am, and the cladding at the southwest corner was the last part to become involved in the fire at about 4.09 am. The fire approached this part of the building from both directions.

It took approximately 3 hours and 4 minutes for the fire to spread around the full perimeter of the

building. Note that here I'm referring to the spread at the top of the building, by which I mean at the location of the architectural crown.

After this time, the fire continued to spread downwards to ingress into the building and to burn within the building for many more hours.

Sir, you asked me to report specifically on the spread to the cladding from within the flat of origin. I've therefore reviewed the evidence associated with the early fire spread within the compartment of origin. Much of this was presented yesterday by Professor Nic Daeid and, given that I agreed broadly with Professor Nic Daeid's findings, I will only discuss this issue briefly here today.

My Phase 1 report provides a detailed description of the evidence of fire spread within the compartment of origin. This includes: witness statements; a 999 call transcript; interview transcripts; video evidence from Mr Kebede's phone; witness statements from the four firefighters who initially entered flat 16; thermal imaging camera -- or TIC -- footage from within flat 16; fire scene photos; and photos from my own post-fire investigations at Grenfell Tower.

There are several items of evidence to which I'd like to draw your attention as I believe they're

particularly relevant in understanding the fire spread from the kitchen of flat 16 to the cladding.

First, the initial 999 call that was made by Mr Kebede, the occupant of flat 16, who first discovered smoke within his kitchen. The call was made at 12.54.29. During this recording, I have interpreted that at 52 seconds and at 55 seconds into the audio file, the occupant states that the fire is by the fridge side.

I will play this call in full in a few minutes when I replay my composite fire spread video that was shown by Mr Millett during his opening remarks two weeks ago, but I wanted to raise that point here.

Second, during subsequent interviews with Mr Kebede, he makes comments about the location of the smoke that he has observed. An extract from one of these interview transcripts is shown here.

Mr Kebede says:

"I could see a 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 interviewer asks:

"So where was the smoke in your kitchen, whereabouts would you say the smoke was ... if you could say one point that the smoke was originated."

Mr Kebede replies:

"The smoke is behind the fridge and the window side."

This overall description of events has since been corroborated by additional interviews and witness statements from Mr Kebede.

Third, a segment of video footage recorded by Mr Kebede on his phone from outside the building. This video was captured beginning at 1.05 am or about 11 minutes after the beginning of the initial 999 call.

I will now play this video.

(Video played)

I've interpreted from this video that flames initially appeared predominantly visible at the left-hand side of the window when observed from outside the building. The window infill panel and mounting of the extract fan unit appears to be missing or burning. The extract fan unit appears to be absent, with flames passing through or around the infill panel mounting board and out of the small window opening. Smoke is visible outside the compartment and the glazed window pane beneath the extract fan appears to be open or absent.

Finally, I'd like to draw your attention to the

thermal imaging camera footage taken by the London Fire Brigade at the start of their intervention into the kitchen of flat 16. Professor Nic Daeid also showed this video yesterday.

Before doing so, I'd like to draw your attention to the fact that this first intervention by the London Fire Brigade occurs at 01.14.12, at least 5 minutes after what I consider to be the first clear evidence of fire having spread to the external cladding, as I'll describe in more detail in a few minutes.

The video was captured when the firefighters were in the corridor directly outside the kitchen door. The video shows footage captured by the thermal imaging camera when the firefighters briefly open the kitchen door of flat 16, and we will see that heat is visible at the far end of the kitchen when viewed from the kitchen entrance doorway. In the latter part of the clip, a jet of water can be seen that is sprayed by the firefighters.

In the clip that I'll show in a moment, the location of the firefighters who are holding the thermal imaging camera is shown here on a floor plan of flat 16. This location is represented by a red circle and their line of sight is approximately indicated by the red arrow pointing into the kitchen.

The firefighters are low down in this location and looking up and into the kitchen. The red shaded area is the region where the fire is considered most likely to have originated, as we heard yesterday.

I'll now play a short clip from the thermal imaging camera. Please note, as was mentioned yesterday, that the time stamps on this original footage are incorrect. I have included a corrected timer below the video in this clip, and I will play the clip twice.

(Video played)

I'll now play the clip a second time.

(Video played)

I've extracted a frame from this video on the left of this slide and provided my interpretation of this image on the right of this slide. Below the images, I've provided a schematic layout of the kitchen of flat 16 at the time of the fire.

It's my interpretation that the heat, which is indicated by the yellow region in these images, is primarily between the fridge freezer and the kitchen window. However, it's not possible to be more precise than this on the basis of the thermal imaging camera footage.

In summary, these four items that I've just brought to your attention lead me to agree broadly with the

evidence of the initial fire presented yesterday by Professor Nic Daeid. I won't speak any more about that particular issue today.

I'll now move on to present evidence concerning the spread of fire from within the kitchen of flat 16 out and onto or into the cladding.

To consider the evidence regarding fire spread to the cladding, I need to briefly re-visit the geometry of the kitchen window and its window surround.

This is a picture of the kitchen window of flat 13, also on the fourth floor at Grenfell Tower and having essentially the same layout as flat 16. Most of the relevant components of the window are visible in this image, although it should be noted that the uPVC window boards have been removed in this photo. This was done as part of the forensic deconstruction of flat 13, parts of which I attended after the fire.

In this photo, we can get a clear view of the configuration of the kitchen window from the inside of the building and the possible routes of fire spread from inside to the outside. These could include: through an open -- or broken -- window; through the extract fan or the infill panel in which the extract fan is mounted; or through any gaps or openings that might have formed around the window as a consequence of heating.

Because the uPVC window boards have been removed in this view, we can see that a gap exists between the edge of the refurbishment window frame and the pre-existing opening of the reinforced concrete facade of the building, which I have previously mentioned today. This is visible immediately to the right of the window frame.

We can also see that this gap has been bridged, as I've already mentioned, using a layer of EPDM rubber weatherproofing membrane, which is the black substance filling the gap, as discussed previously.

Behind this EPDM we would find the back of the cladding cavity, which contains both PIR foam insulation and exposed edges of polyethylene on the back side of the ACM rainscreen cassettes, again as I've already discussed.

I'd also like to quickly re-visit the drawing I showed earlier of the various materials that were present around the window to make sure that the configuration of materials around the window is clear in the present discussion.

Working my way from the inside of the building out, which simulates the route the fire would've taken had it entered the cladding via this route, we find:

First, uPVC window boards which, as already discussed, are comparatively resistant to ignition and

flame spread as compared with other polymers, but which lose essentially all of their mechanical strength and stiffness at temperatures well below 105 degrees Celsius.

Next, possibly a piece of 25-millimetre thick foil-faced PIR foam insulation. This is a combustible thermosetting polymer, as I have already mentioned, that chars on burning but can rapidly ignite and spread flame when not protected by a foil facing.

Then, a 1-millimetre thick layer of combustible EPDM rubber weatherproofing membrane, which can be assumed to offer very little resistance against attack from fire.

Then, the edge of a piece of PIR foam insulation on the adjacent column. And it is likely, based on my post-fire investigations of the cladding at Grenfell Tower, that the PIR insulation's protective foil facing would not have been present at this location due to the way the boards are cut.

Finally, the back of the Reynobond PE ACM rainscreen cassette which, as I noted earlier, would present a number of exposed surfaces of highly combustible polyethylene along cut edges and folding lines.

In relation to spread of fire to the cladding, I will drawn on several additional items of evidence. These include video taken from outside Grenfell Tower

during the early stages of the fire, and thermal imaging camera video captured by the firefighters during their intervention within flat 16.

In a moment, I will play a video that was captured outside Grenfell Tower at about 1.09 am. During this video, you will see falling debris from the lower left corner of the kitchen window of flat 16.

I've concluded that this falling debris is likely to be polyethylene originating from within the ACM rainscreen cassettes.

Consequently, this video is the earliest evidence of which I'm currently aware that shows that the fire has spread to the cladding.

I'll now play the video.

(Video played)

Also significant in this video is that the earliest evidence of burning polyethylene appears to be associated with the left-hand side of the kitchen window of flat 16 when viewed from outside the building. This is where the potential pathway described in the previous slides would cause fire and hot gases to impinge on the back of the ACM rainscreen cassettes, and also likely an exposed edge of PIR insulation board.

I'll now play a video captured by the firefighters using thermal imaging cameras within flat 16. This

video begins at 01.15.28 and shows the firefighters opening the kitchen door, again from the hallway within flat 16, and pulsing a spray of water into the kitchen.

(Video played)

Again, I've extracted stills from before and after the water was applied.

In the left-hand image, the thermal imaging camera footage shows heat across a wide area of wall and ceiling, both above and behind the fridge freezer.

In the subsequent right-hand image, immediately following application of water by the firefighters, the heat is more localised to the area around the window.

I've annotated these images with my interpretation in this next slide.

The significance of these images is that they indicate that the area around the window was very hot when other parts of the kitchen were not. I've interpreted from this image that there was burning in the window surround and possibly the back of the cladding cavity that was visible to the thermal imaging camera from a position in the kitchen entrance.

I've provided more detail about this sequence within my Phase 1 report.

There is thus considerable evidence to indicate that the fire had spread to the external cladding by about

1.09 am, if not slightly earlier. The precise mechanism by which this occurred, however, cannot currently be stated, and this is a topic of ongoing investigation, experimentation and analysis.

I'd now like to walk you slowly through the preliminary evidence of fire spread and to highlight some observations that I consider particularly noteworthy.

However, before I begin this portion of my presentation, I'd like to note regulation B4 of the UK Building Regulations 2010. We heard this also on Monday.

Whilst providing expert opinions on the compliance of various aspects of Grenfell Tower is not strictly within my scope of work for Phase 1, I believe that it's both important and useful to begin my presentation of fire spread evidence by reminding you of the statutory obligations of designers as regards external fire spread on buildings.

Regulation B4 of the UK Building Regulations 2010, sentence 1, states that:

"The external walls of the building shall adequately resist the spread of fire over the walls and from one building to another, having regard to the height, use and position of the building."

This functional objective clearly was not achieved at Grenfell Tower.

Furthermore, when the fire did spread vertically, none of the other fire safety design features of the building, all of which were described by Dr Lane on Monday, could be expected to function as intended.

Two main questions have therefore influenced my approach to studying the fire spread at Grenfell Tower.

First: why did this happen? By which I mean: can we develop a physical understanding of the fire spread mechanisms and factors influencing these, both on Grenfell Tower and potentially on a significant number of other buildings in the UK, irrespective of any assessment of the regulatory compliance of the materials, products and systems used in the cladding?

I will begin to address this question in my presentation today.

Second: how did this happen? By which I mean: how is it that this particular combination of materials, products and systems were installed on Grenfell Tower, and how is it that similar combinations of materials appear to have been installed on a large number of other buildings in the UK?

I will not address this question today.

With these questions in mind, I'll now proceed to

present my preliminary fire spread evidence. I'll present this evidence in three sections: upward fire spread from flat 16; downward fire spread on all four faces of the building; and horizontal fire spread around the building.

I will begin with upward fire spread from flat 16.

The upward vertical spread of fire from flat 16 is evidenced in my Phase 1 report using 25 videos that I've assembled into a single sequence. These have been analysed to identify the sequence in which they occurred. Where there is overlap between the videos, I've identified this based on matched background audio or matched visual content. The Metropolitan Police Service have also provided time stamps for some of these videos.

Sir, with your permission, I'd like to play this video sequence, with audio, that shows the vertical fire spread from flat 16. This is the same video that was shown by Mr Millett during his opening remarks at the beginning of the evidential hearings.

I will play the whole video uninterrupted and I will then spend some time discussing specific sections in much more detail.

(Video played)

From this video I've extracted a number of short

clips that I'd now like to play and discuss. I've removed the audio from these clips and, in some cases, processed and stabilised the video to allow close-up views of aspects to which I would like to draw your attention.

I will play each video on a loop, and I will describe what I've observed in the video while the loop is repeating.

The first clip was captured at 1.08 am and shows the kitchen window of flat 16 from the outside of the building.

From this short clip, I observe that: flames initially appear visible more to the left of the window; the extract fan appears to be absent from the window infill panel at the top-left of the kitchen window; the window infill panel and mounting of the extract fan unit appear to be burning; smoke is visible outside the compartment; and the windowpane below the extract fan unit appears to be absent or, alternatively, opened almost fully inwards.

I also observe that a small amount of burning material is falling from the region around the window opening.

A second clip was captured at 1.09 am and is part of the same clip that I previously played when discussing the route of fire spread to the cladding. From this clip, I observe that flames appear more intense than in the previous video, only 1 minute earlier, suggesting that the fire has grown further during the elapsed time from the previous video.

The more intense flames are observed to extend further out of the window and a regular flow of burning material is falling from the window. The material flows from the corner where the window meets the column line.

A third clip was captured at 1.12 am and shows the fire from a different vantage point. The fire now appears to be more intense than in the previous images; however, due to the exposure of the image, it is not possible to precisely determine the origin of the flames; by this I mean whether they originate from the cladding or from within the compartment itself.

Immediately below the window opening, there appears to be burning material on the surface of the ACM cladding. Burning material is falling from the window opening and some of the burning material is present on the ground.

Please note that there is also some water on the ground in the bottom left-hand corner of this clip -- there.

Again, note the time of this clip at approximately

1.12 am.

A fourth clip is a combination of three overlapping clips, all from slightly different vantage points and captured at about 1.15 am. From this clip, I observe that the upper tip of the external flaming is approximately between levels 6 and 7. A large amount of burning material is now falling from the area of the fire and the smoke from the fire is drifting from south to north.

At the end of this clip, the firefighters on the ground can also be observed to begin spraying water towards the fire.

This is the first visual evidence that I'm aware of showing application of firefighting water to the exterior of the building at 01.15.53; however, as noted in the previous clip, there is evidence of water on the ground as early as 1.12 am. This may indicate earlier external application of firefighting water, what the firefighters refer to as a covering jet, for which there is currently no direct visual evidence.

I will not comment any further on these early attempts at external firefighting as I understand that the inquiry's expert Steve McGuirk will comment on this issue in considerable detail in due course.

I have estimated that a fifth clip, for which I do

not have a confirmed time stamp, was captured some time between 1.16 and 1.19 am.

In this clip, I observe that intermittent external flaming exists between levels 6 and 7. The highest point of the intermittent external flaming appears to be at the vertex of the junction between the column line and the faces of the spandrel sections of the building, essentially in the small corner that's created there. You will recall from part 2 earlier in my presentation that a continuous vertical void exists within the cladding system at this location.

A covering jet is applied onto the external cladding from ground level, with firefighting water being applied to the cladding immediately below level 4.

The subsequent videos were mostly captured from vantage points further away from the base of the building, likely because of the danger from falling burning debris.

The evidence can be used to estimate the approximate extent and progression of the fire as it spread vertically up the east face of the tower.

In most of the videos that I'm about to show, it is not currently possible to identify the precise level to which the fire had spread on the building. In general, it's possible to deduce floor levels approximately shown

in these videos based on other images which clearly show the top of the building, or using flats where lights are turned on or off as the fire progresses.

A sixth clip was captured at 1.22 am. During this clip, at approximately 1.22.19 -- it plays on a loop so we'll see that again -- a firefighting jet can be observed to strike the column to the left of the vertically progressing fire some two to three floors above flat 16.

I'll be silent while we go past 19 here. You'll see a jet. There.

The angle of attack of this jet suggests that this is a firefighting jet which is being operated by firefighters who are within flat 16 leaning out the window and spraying upward in an unsuccessful attempt to extinguish the rapidly spreading cladding fire. This is consistent both with firefighter witness statements and with the thermal imaging camera footage from within flat 16.

The covering jet from ground level is visible near the end of this clip at bottom-right and has a markedly different angle of attack.

I'll just let it play through one more time so you can see that. There.

A seventh clip shows a combination of videos captured at 1.24 am. During this clip -- or this series of clips, rather -- I observe that the fire's maximum extent at this point is at approximately level 16 on the east face.

There are large pieces of burning debris falling from the building. These are likely to be ACM rainscreen cassettes or portions thereof based on photographs of the debris field taken after the fire.

Upwards fire spread is most advanced at the location of the vertex between the spandrel section and the column section. Along this line is both the re-entrant corner in the geometry of the cladding and a continuous vertical cavity within the cladding, as already discussed.

At this stage, the flames remain confined to the spandrel section forming the east wall of flats ending in the number 6. The fire is spreading slightly northwards as it moves up the building, but is not spreading significantly southwards past the column line immediately to the left of the line of kitchen windows.

An eighth clip was captured between 1.26 and 1.29 am. During this clip, I observed that the fire has now reached level 23 and, by the end of the clip, the flames are continuous at the level of the rooftop. Note that this is also the location of the architectural

crown that I mentioned earlier.

The 9th and final clip that I'll show to illustrate vertical fire spread on the east face was captured sometime between 1.29 and 1.36 am. During this clip, I observe that the fire has spread to the top of the east face and is beginning to spread horizontally around the building, both to the north face over the top of the northeastern-most column, and to the south along the architectural crown at the top of the east face. You can see the crown there in the top of the video clip.

On the basis of the sequence of videos that I've just shown, I have also determined the time, approximately, that the fire reached different floors. I've then plotted this on a graph.

This graph starts at 12.54 am at its left side, when the first 999 call was initially received, and finishes at 1.29 am at the right, approximately when the fire reaches the top roof level of the east face.

The dotted line in this graph is an illustrative exponential function I have fitted to the data, meaning that the available evidence shows that the rate of fire spread increased exponentially. Recalling my vertical upward fire spread on a match earlier, this is as expected. By this, I mean that the fire spread continued to accelerate until it reached the top of the

building.

Here I would like to reiterate a previous observation which is also evident from this analysis.

By 1.15 am, as we can see here, flames were observed to be extending at least two levels above flat 16. The fire service's first visual confirmation of the location of the fire from within flat 16 was at 01.14.16, and the firefighters were unable to make an effective intervention to extinguish the internal fire within the kitchen until approximately 1.21 am.

I therefore estimate that the fire had spread to the cladding and begun spreading up the east face of Grenfell Tower between 5 and 10 minutes before the initial internal fire had been effectively extinguished.

This concludes the key evidence to which I would like to draw your attention on upward vertical fire spread.

I will now present preliminary evidence of downward fire spread at Grenfell Tower.

The purpose of presenting specific evidence of downward fire spread is to highlight the key fire spread mechanisms which can help to explain the extent of external fire spread that was experienced at Grenfell Tower.

The Grenfell Tower fire is somewhat unusual in the

context of similar cladding fires that have occurred internationally in that the fire not only spread vertically upward, but it also spread downward and horizontally. It's my opinion that a combination of these fire spread directions and mechanisms conspired to cause the extensive fire spread which eventually included almost the entire exterior surface of the building.

There are two main sources of evidence to which I'd like to draw your attention: first, a series of videos captured by members of the public; and, second, photos taken by the Metropolitan Police Service after the fire.

I will begin by presenting several short video clips that provide visual evidence of downward fire spread. Again, I will play these without audio and, again, on a loop.

From these videos it will be observed that considerable melting and dripping of burning material occurred, primarily along the column lines. It is my opinion that this burning and dripping material is predominantly polyethylene from the ACM rainscreen cassettes. We will also see that falling flaming debris landed on horizontal ledges on the spandrel sections and in some cases resulted in localised burning at these locations.

The first clip shows the north and west faces of Grenfell Tower, and for the next series of clips I have a small diagram in the left-hand corner that shows where the view is from, again with my red circle and red arrow showing line of sight and the blue lines indicating the bits of the building that we're looking at.

So, again, the first clip shows the north and west faces of Grenfell Tower. It was captured sometime between 2.48 and 3.11 am.

This clip shows dripping, burning material at the column line. We can see this particularly near the top of the northwestern-most column, where the fire first spreads on to the west face from the north face, along the architectural crown and over the column top.

Here, I would also note the similarities between this video and the video of a burning sheet of polyethylene that I showed in part 1 of my presentation today.

A second clip shows essentially the same area of the building a short while later, sometime, in this case, between 3.20 and 3.33 am.

This clip again shows dripping, burning material at the column line, this time on one of the columns on the west face of the building, rather than a corner column as in the previous clip. Again, note the similarity to

my earlier video.

A third clip was captured as part of the same recording. In this clip, right in the centre of the image, we can also see evidence of burning debris falling, landing and accumulating on window ledges on the spandrel section of the building, where it continues to burn as a small localised fire.

(Pause)

A fourth and final clip that I'll show in the context of downward fire spread was captured sometime after 4.09 am and shows the leading edge of the fire spreading downwards along column lines on the west face of the building.

In this clip we can observe that the leading edge of the downward spreading fire is, again, along the column lines and possibly along the column tips.

Sir, I would again like to remind you that a continuous internal void runs the full height of the building at the column tip location as well.

Further evidence of the possible mechanisms for downward vertical fire spread is available in post-fire photos of damage to the cladding system. Of particular interest are areas of the cladding where a boundary exists between fire damaged cladding and undamaged cladding.

These areas present zones of partial damage where the progression of the fire has been stopped. Where the ACM rainscreen cassettes were fully burned by the fire, little physical evidence remains to support fire spread analysis.

However, at the interface between the unburned and burned regions of the cladding, a number of relevant observations can be made.

In relation to this point, it's noteworthy that both video and photo evidence appear to suggest that the downward vertical fire spread was halted as a result of fire service intervention during the fire. This was because water was applied directly to the external cladding, which was able to halt the downward progress of the fire. This can be observed in the photographs that I will present in a moment.

However, I have not personally undertaken any detailed analysis of fire service water application on the exterior of the tower in my Phase 1 report and this is a point being addressed by other experts.

I'll now show a series of post-fire photos that were captured by the Metropolitan Police Service using a drone on 25 July 2017.

In this photo, I observe that the ACM cassettes show locations where polyethylene has melted, dripped or

flowed and solidified. This is particularly evident along column lines, which in most cases represent the leading downward edge of the fire, as I've already noted. You can see that clearly here on the central column, the black material being polyethylene.

In this photo, I observe the following:

The ACM rainscreen cassettes show locations where polyethylene has melted, dripped or flowed and solidified.

At the interface between the burned and unburned sections of the external cladding, partially burned ACM rainscreen cassettes are present and these indicate that the aluminium layers had separated from the polyethylene contained within the ACM rainscreen cassettes. By this, I mean that debonding of the aluminium skins had occurred and the polyethylene had partially melted or burned away.

Debris, which I assume to be resolidified polyethylene, is present on the detail in front of the windows and below the burned sections of the cladding, essentially on the windowsills.

I also observed this during my own site inspections of the external cladding in the months following the fire.

This photo shows the debris field on 16 June 2017 in what was the children's play area on the west side of the being. Photos of the debris field and the firefighter witness statements suggest that a significant proportion of this falling debris consisted of ACM rainscreen cassettes. I believe this will also have included window infill panels or parts thereof, although I wasn't able to inspect the debris field myself.

This concludes the evidence to which I'd like to draw your attention on downward vertical fire spread.

I'll now present a summary of my preliminary evidence of horizontal or lateral fire spread.

The horizontal fire spread eventually resulted in all four faces of Grenfell Tower becoming involved in the fire. As I've already noted, this extent of horizontal fire spread must be considered unusual in the context of most other external cladding fires experienced internationally, and understanding the specific reasons and mechanisms for this is therefore very important.

The horizontal fire spread is documented in videos and images captured by members of the public, CCTV and other media.

Horizontal fire spread cannot be viewed totally in isolation from upward, vertical and downward vertical

fire spread, and it's important to recognise that these directions of fire spread surely interacted during the fire.

I've developed an approximate timeline of the location of maximum horizontal fire spread on each face of the building. For Phase 1, I based this timeline primarily on CCTV images available from around the tower. These were provided to the inquiry by the Metropolitan Police Service and are as follows: the upper east and south faces were captured in one sequence by a single CCTV camera; no CCTV footage was available for the north face of the tower; the upper west face was captured by a single CCTV camera.

I've developed my initial overall horizontal fire spread timeline by comparing the maximum extent of fire spread with subsequent and previous images. The exact times for fire spread to each face based on this analysis are unlikely to be sufficiently accurate to assure greater precision than plus or minus 5 minutes.

During my review of the available evidence, I observed that the furthest extent of horizontal fire spread usually -- but not always -- appears to be at the top of the building at the location of the architectural crown and column tops. I described the crown earlier in my presentation and I've just shown it again here.

I also observed that the external cladding detail at the top of the columns was generally the first location where the fire was observed to spread to the next spandrel section of the face when the fire spreads horizontally across the faces of the building.

To develop a timeline, I've therefore defined horizontal fire spread as the time at which the fire reached a column at the top of the building.

The columns at Grenfell Tower are defined on a grid and are denoted by the references A1 through D5, as I've shown here.

This slide shows the overall plan for the tower for levels 4 and above, with the column notations shown and the times that the fire reached the column tops as it spread horizontally around the building.

At 1.29 am, the fire had reached the top of the east face, as I've already said, at columns A5 and B5, as shown here.

At 1.56 am, the fire reached column C5 on the east face.

At 2.23 am, the fire reached the corner column at the southeast corner of the building, column D5. During this time, the fire was also spreading laterally across the north face, or horizontally across the north face, for which I don't currently have any CCTV imagery.

At 2.48 am, the fire reached the northwest corner of the building. Also at 2.48 am, the fire had spread to column D4 on the south side of the building.

At 3.11 am, the fire reached column D3, halfway across the south face.

At 3.20 am, the fire spread to column B1 on the west face.

At 3.33 am, the fire spread to column D2, on the west face.

At 3.48 am, the fire spread to column C1 on the west face.

Finally, at 4.09 am, the fire spread to the southwest corner of Grenfell Tower from both directions.

After this time, the fire continued to spread vertically down the building.

I will now present a series of specific images showing horizontal fire spread to which I'd like to draw your attention.

I will present these images with reference to each face of the building independently and I'll start with the east face.

Image 1 shows the east face of Grenfell Tower between 1.29 and 1.56 am. In this image, I'd like to draw your attention to the top of the column.

I've interpreted this image as showing that the fire has spread over the column top -- this is the column at the left of the fire zone. Video evidence of this is also referenced in my Phase 1 report.

Image 2 shows the north and east faces of Grenfell Tower between 1.29 and 2.23 am, and closer to about 1.56 am.

From this image, I observe that the furthest extent of horizontal fire spread is at the top of the building. The fire appears to have spread over the top of the column, and between the columns the flame front forms a slightly inclined angle over the face of the building.

Image 3 shows the east face of Grenfell Tower between about 1.56 and 2.23 am. From this image, I observe, again, the furthest extent of horizontal fire spread is at the top of the building, and the fire has spread to the column top at the southeast corner of the building.

Image 4, which is unfortunately quite low resolution, shows the south face of Grenfell Tower between 2.23 and 2.48 am. I've shown this image to illustrate that the horizontal fire spread between the east and south faces again occurred at the top of the column.

I will now move on to the north face.

Although I've not been able to provide definitive

timings for the spread of fire over the north face due to the lack of CCTV for this face, there is some photographic evidence showing the spread across the north face.

Images 5 and 6 are taken directly from the north of the building, as shown here. These are extracts from the start and end of a longer video.

The left-hand earlier image shows that the flames are visible at the horizontal joints between the ACM column cassettes. You can see those annotated on the photograph. My Phase 1 report shows that horizontal ledges between the rainscreen cassettes existed at these locations and would've presented locations where melted polyethylene could collect and continue to burn as small localised pool fires.

Over the course of the 2-minute-and-48-second video from which these images are extracted, the fire spreads from localised joints and becomes established across most of the height of the column.

This is visible in the right-hand image taken near the end of the clip.

The left-hand image also suggests that fire is spreading over the column top.

I will now show the full source video for further illustration of these points. This video is about

3 minutes long.

(Video played)

Just to say that the small triangular zone at the very top of the building, the column top to the right of that, is the architectural crown.

(Video continued)

From that clip we can see that the fire is most advanced again within the architectural crown slightly ahead of other locations on the north face.

Image 7 was taken between 1.29 and 1.56 am. From this image, I observe spread around the column top -- although it's quite difficult to see in this image -- and spread around the column lower down the building. So this is one case where the fire does spread horizontally around a column at a lower level.

Image 8 was taken between 2.23 and 2.48 am, and from this image I observe that the furthest extent of horizontal fire spread is at the top floors of the building, again, and particularly at the location of the architectural crown. Between the columns, the fire front again forms an inclined angle over the face of the building.

Image 9 was taken sometime between 2.48 and 3.11 am. From this image, I observe again that the furthest extent of the horizontal fire spread is at the top

floors of the building; the top of the column and the architectural crown is the first location where the fire spreads to the next bay; and the external flames formed at the column locations appear to be slightly larger or brighter than those formed between the columns.

I will now move on to the west face.

The first evidence of spread to the west face is the image I showed previously, image 9. This image shows that the first location of spread to the west face was over the column top in the northwest corner.

Image 10 was taken between 2.48 and 3.48 am, and in this image the fire has reached the next column on the west face at its top before any other location. Between the columns, the fire front again forms an inclined angle over the face of the building.

Image 11 was taken between 3.20 and 3.48 am. This image shows that the fire spreads within the architectural crown ahead of horizontal fire spread at any other location. And, again, between the columns the fire front forms an inclined angle over the face of the building.

Image 12 was taken between 3.20 and 3.48 am, closer to 3.48. From this image, I observe that the fire has reached the column top again before any other location, and, between the columns, the fire front forms an inclined angle over the face of the building.

Image 13 was captured between 3.48 and 4.09 am, closer to 4.09. From this image I observe that the fire is converging on the southwest corner of the building and that the fire is spreading within the architectural crown, again ahead of horizontal fire spread to any other level.

I will now move on to describing the fire spread over the final face, the south face of the building. For this face of the building I've relied more heavily on the CCTV footage from the southeast corner of Grenfell Tower.

That's the view for the CCTV from the southeast corner. So in the centre of this image is the top of the column in the southeast corner of the building.

From this footage I observe that the fire initially spread onto the south face via the column top, column D5, and the architectural crown at that location.

The furthest extent of horizontal fire spread was consistently at the top floors of the building, as shown here, as it's progressing further around the face, and again on the architectural crown, and a short while later, the fire is spreading rapidly downwards from this location along the column lines.

This horizontal fire spread followed by downward

fire spread I believe to be very significant.

All of these fire spread directions and mechanisms -- upward, downward and horizontal -- are subject to ongoing investigation, experimentation and analysis by the inquiry's experts.

This brings to a close the preliminary evidence of fire spread over the cladding on the building that I would like to bring to your attention at this stage of the inquiry.

This also, therefore, concludes the evidence that I would like to present today.

SIR MARTIN MOORE-BICK: Thank you very much indeed.

MR MILLETT: Mr Chairman, that concludes the work of the inquiry for today.

Thank you very much, Professor Bisby.

SIR MARTIN MOORE-BICK: Thank you very much, Professor.

We'll stop there, then, and we'll resume at 10 o'clock tomorrow morning, when we shall hear some evidence read.

Thank you very much.

(3.15 pm)

(The hearing adjourned until Thursday, 21 June 2018 at 10.00 am)

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