Tuesday, 20 November 2018
(10.04 am)
SIR MARTIN MOORE-BICK: Good morning, everybody. Welcome to today's hearing.
Today we are going to start hearing from expert witnesses instructed by the inquiry to advise us in relation to various aspects of the fire.
Yes, Ms Grange.
MS GRANGE: Good morning, Mr Chairman. Yes, we will be hearing today from Professor Jose Torero, who is one of three experts who will be giving evidence this week. Professor Bisby and Dr Lane will follow tomorrow and Thursday.
So if I can now call Professor Torero.
SIR MARTIN MOORE-BICK: Thank you, yes.
PROFESSOR JOSE LUIS TORERO (affirmed)
Questions by MS GRANGE
SIR MARTIN MOORE-BICK: Thank you very much, professor. Sit down and make yourself comfortable.
Ms Grange, before you start, I'm sure the professor is well used to delivering lectures and other material for quite extended periods, but I think we should have a break during the middle of the morning. I think possibly one break will be sufficient, unless you, professor, indicate that you would like one at any other

stage. If you do, of course let me know.
THE WITNESS: Okay, thank you.
SIR MARTIN MOORE-BICK: Is that all right?
MS GRANGE: Yes, absolutely. Thank you.
Please would you give the inquiry your name?
A. Jose Luis Torero Cullen.
Q. You have provided to the inquiry a preliminary Phase 1 report dated 23 May, and you have updated that report in a revised version dated 21 October 2018, and also with an accompanying two-page addendum document dated 20 October; is that right?
A. Yes.
Q. That report addresses your preliminary conclusions on the ignition of the Grenfell Tower facade materials; fire spread to and on the exterior of Grenfell Tower; and fire and smoke spread within Grenfell Tower; that's right, yes?
A. Yes, that's correct.
Q. It's important to note that you have also been instructed to provide a further report at Phase 2 which will address forensic fire and smoke spread throughout Grenfell Tower; the correlation between the fire safety provisions and the fire safety strategy for Grenfell Tower, and various aspects of the adequacy of the London Fire Brigade's procedures and training; an

overview of conclusions to be drawn about the Grenfell Tower fire; an overview of lessons to be learned when comparing the Grenfell Tower fire with other fires, both international and domestic; and any recommendations arising from the same.
Is that correct?
A. Yes, that's correct.
Q. As you indicate in the declaration in section 1.5 of your report, you have provided it in the same way as you would've provided a report to a court; is that right?
A. Yes, that's correct.
Q. In section 1.4 of your report you have outlined your background and experience relevant to the matters in this inquiry. We don't need to rehearse all of that today, but I just want to pick out some key points.
A. Sure.
Q. You specialise in fire safety, having originally trained as a mechanical engineer and then gone on to specialise in fire safety; is that correct?
A. Yes.
Q. You are currently the John L Bryan chair at the Department of Fire Protection Engineering, and the director of the Center for Disaster Resilience at the Department of Civil Engineering at the University of Maryland in the USA; is that correct?

A. Yes, that's correct.
Q. Previously, you were the professor of civil engineering and head of the School of Civil Engineering at the University of Queensland in Australia between 2012 and 2017; is that correct?
A. Yes, that's correct.
Q. Before moving to Australia, you held the Landolt & Co chair for innovation for a sustainable future at the Ecole Polytechnique Fédéral de Lausanne in Switzerland in 2012.
A. Yes.
Q. And you also held the BRE Trust/Royal Academy of Engineering chair in fire safety engineering at the University of Edinburgh between 2004 and 2011.
A. Yes.
Q. In 2008, you were awarded the Arthur B Guise Medal by the Society of Fire Protection Engineers in the USA, and in 2011, the David Rasbash Medal by the Institution of Fire Engineers in recognition for eminent achievement in education, engineering and science over fire safety; is that's correct?
A. Yes, that's correct.
Q. You were the editor-in-chief of the Fire Safety Journal between 2010 and 2016?
A. Yes.

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Q. You have been involved in numerous fire investigations, many of which have been landmark studies.
A. Yes.
Q. Between 2001 and 2010, you were involved in an independent investigation of the World Trade Center buildings 1 and 2 collapses.
A. Yes.
Q. You have conducted a cause and origin investigation into the Texas City explosion at subsequent fires, as well as a damage correlation exercise.
A. Yes.
Q. You conducted dispersion fire modelling supporting the litigation relevant to the Buncefield explosion and the Sego mine explosion in the USA.
A. Yes, that's correct.
Q. You conducted a post-fire structural assessment of the Abu Dhabi Plaza fire in Kazakhstan, probably the biggest ever fire of a building under construction; is that correct?
A. Yes, that's correct.
Q. You've been awarded a number of prizes in this field for your writing. I just want to pick out one.
You have, together with your co-authors, been awarded the FM Global Best Paper Award for a paper on the precision of fire models and the required skills for

fire modelling; is that correct?
A. Yes, that's correct.
Q. Thank you.
Are the factual matters set out in your report true to the best of your knowledge and belief?
A. I believe so.
Q. Does your report accurately set out your opinions on matters relevant to this inquiry?
A. Yes, it does.
Q. Thank you.
I want to start by just asking you a few general questions about fire safety strategies in high-rise buildings.
In section 2 of your report, you have explained the concept of a fire safety strategy for high-rise buildings. You've explained that this is a concept by which measures are taken to ensure societally acceptable levels of fire safety; is that correct?
A. Yes, that's correct.
Q. But you have not defined that at this stage by reference to any specific document which may have been produced in the context of Grenfell Tower; you are talking about fire safety strategies generally for high-rise buildings; is that correct?
A. Yes, that's correct.

Q. At page 17 of your report, you've explained that the main characteristic that defines a high-rise building is what you call a convergence of timescales.
A. Yes.
Q. Can you just explain for us what you mean by that?
A. Yes. There are several factors that happen when you have a fire. Fire is unusual in the sense that it's one of the few hazards that actually evolves in space and time. So it is going to grow as a function of time and it can grow slower or faster.
Normally, for example, if you were to have a low-rise building, egress time, so the time that it takes for people to get out, is extremely fast. So, effectively, that is an independent timescale. In a few minutes, you will get everybody out, while the fire can take half an hour or an hour to grow. In a similar manner, the structure is going to take a significant time to heat up.
So you can separate the timescales and basically get the life safety aspects of the building taken care of in a few minutes, while everything else has a different timescale.
Now, in the case of a tall building, that is not possible because you have multiple levels, so it will normally take a very significant period of time for

people to be able to descend through those levels. Therefore, the number of minutes that it will take to address the life safety issues of people can be well within an hour, and, therefore, it will converge with the time that it takes for the fire to take its full extent, and it will also converge with the time it will take for the structure to start heating up and start being deteriorated by the fire.
So what you get in the case of a high-rise is a very unique scenario, that because the egress timescales are very, very long, then what you have is a situation where all the timescales converge, so you have to address structural behaviour, fire growth and egress in a simultaneous manner when you address the problem of fire safety.
Q. You said in your report that the time for occupants to evacuate is often of the same order of magnitude as the time for failure or the time required for fire and rescue service intervention.
Can you just be clear what you mean by "failure" in that context?
A. Yes. So in a very short period of time, you will probably have a situation by which the fire has not yet grown to a point that is affecting any component of the building. So you will not expect, for example,

a structure to fail, a door to fail, a window to crack; you would expect people to be out of those spaces before that.

In a similar manner, we have pre-specified required times for the fire service to arrive on site. Depending on which country and which jurisdiction you have, that will be a few minutes, 5 minutes, 6 minutes. Therefore, all life safety aspects of the building in principle would have been taken care of before the firefighters arrive or before anything has failed. So people will be out of the building and they will be safe before any of these things happen.

In a tall building, because it takes much longer for people to arrive[sic], you would expect that the firefighters would have arrived on scene before everybody is out of the building, and you would have expected that before everybody is out of the building, some components of the building will already be experiencing some element of distress or failure.

Q. Can you explain the significance of that convergence of timescales for a high-rise strategy? Does it mean, for example, that you need safe areas to exist in the building?

A. Yes. Because you cannot take everybody out in such a short period of time that they are not being affected

by the fire itself. People are going to be in the building while certain areas of the building are already going to be fully compromised.

So you can have a fire that starts, like in the case of Grenfell, in the kitchen, and that fire has already fully compromised the kitchen before people have had enough time to be able to get out of the building.

So a way in which we address the problem is we sectorise the building and we create safe areas. So what we are considering as our time to egress is the time that it takes not to get out of the building, but the time that it takes to enter a place that is considered to be a safe place.

So by creating the sectors and separating the building in different components, we are allowing certain parts of the building to be fully compromised, while other parts of the building remain perfectly safe, so people can actually be in those parts while the building is being affected by the fire.

Q. You say in your report that the most common safe areas are the stairwells. You also say that there's no limit to the time that stairwells need to remain safe. Can you just expand on that?

A. Yes, because in a high-rise you're going to have a situation in which people are going to be evacuating

for a very long period of time. There's very significant uncertainty on human behaviour. So the timescales are very difficult to predict, so it's very difficult to calculate how long a person would be within a building.

There have been cases, for example, like the first bombing of the World Trade Center, where effectively people were inside the stairs for many hours, and so we have to make provisions to protect those areas in such a way that they remain viable for as long as it is necessary. And because "as long as it's necessary" is not very well defined, you know, we have to make that almost a permanent feature of the building.

Q. You talk about redundancies being necessary for all safety systems, and you explain also that lobbies are typical of redundancies built into a fire safety strategy.

Can you explain why those redundancies are so important? You probably just explained that, but with reference to lobbies as well as stairs.

A. Yes. Every time you design a safety system, safety systems are not perfect, and there will always be a probability of failure. So you cannot rely on a single safety system to protect the lives of people. So what you do is you always introduce multiple levels

of redundancy until you're satisfied that the overall probability of the entire chain is so low that you can almost guarantee the safety of people.

So depending on the complexity of the system, you will introduce more levels of redundancy. If a system is very simple, you might need just two levels of redundancies, but if a system is very complex, for example if you're dealing with a nuclear power plant, you will have multiple levels of redundancy to make sure that the system doesn't fail.

So as a common practice in any matter of safety, we will always introduce to all safety systems levels of redundancy to make sure that in case something doesn't work, there is something else to cover for us.

Q. In your report in general, what you've done is you've broken down the substance of that report into four seminal stages in the progress of the fire at Grenfell Tower. You say that these four stages are where distinctive interactions between the fire, the building, its occupants and the Fire Brigade were observed.

I'm just going to establish what these four stages are at this stage.

So stage 1 is initiation of the fire event through to breach of the compartment of origin, which is

approximately 00.54 am to 1.05 am.
Stage 2 is from the breaching of that compartment of origin to the point where the fire reaches the top of the building on the east face, approximately 1.05 am to 1.30 am.
Stage 3 you characterise as lateral fire spread and internal migration of the fire and smoke, until the full compromise of the interior of the building, including the stairs. Again, that's approximately 1.30 am to 2.30 am.
Stage 4 is what you describe as the untenable stage, where significant parts of the building are untenable. We'll come back to this. Approximately 2.30 am until extinction is the untenable stage.
As I say, we're going to come back to each of those stages in detail during your evidence, but at this stage, can you just explain why you have chosen to divide the fire into those four stages in your report?
A. Yes. I mean, beyond just trying to keep a little bit of order to all this information, I think the different stages have very distinct characteristics that are quite fundamental to the behaviour of a building. Therefore, I believed it was very important to separate those.
The first stage is, to me, fundamental, because as I explained in my report, at the backbone of the fire

safety strategy is the concept of no spread, external spread, of the fire.
So we make this assumption that the fire will be boxed in within one floor, and on the basis of boxing in the fire within one floor -- even beyond that, within one unit -- we make this assumption that the fire is boxed in, and on the basis of that, we construct the whole fire safety strategy.
So the primary assumption behind every component of the fire safety strategy remains this concept of having the fire boxed in within one unit.
So that initial stage represents the period where the building is actually behaving as designed, where effectively the fire is boxed in within the unit and it has not managed to come out and penetrate other units within the building.
So that particular stage effectively represents the building operating as designed.
The second stage, again, it is fundamental in the sense that the building is now not operating as designed. Nevertheless, within that process of vertical flame spread, which is quite rapid, there is no significant evidence that the means of egress in the building have been severely compromised.
So, effectively, there is still the ability that the

redundancies that we have in the building have provided of enabling people to actually migrate out of the building.
By the time you get to the third stage of the building, the process becomes a very dynamic process, in which effectively we have sufficient evidence that the means of egress have been compromised.
Now, the fact that they are compromised doesn't necessarily mean that people cannot get into those means of egress and successfully get out; all that it means is that there is significant evidence that there is a deterrent for people to do so, in the sense that there will be smoke in many ways, people will be identifying smoke.
So, effectively, the means of egress are not acting the way they should be acting, so we have fundamentally breached all levels of redundancy and we have reached to the core of the safe area of the building.
Now, the final stage of the fire is when there is a generalised perception that that core safety area of the building has been lost and, therefore, there is very little evidence that people can actually use the means of egress to exit the building.
Q. Let's start, then, and look in detail at stage 1, which is the breach of that first compartment. We've got this

time frame of 00.54 through to roughly 1.05 am.
At section 3.1 of your report, you've explained that you have conducted a simple modelling analysis, what you describe as a "simple first principles elimination analysis" of the fire scenario in the compartment of origin; is that correct?
A. Yes.
Q. You say that you've done this to "bound the actual fire scenario within the kitchen more precisely". Can you explain what you mean by "bound the actual fire scenario"?
A. Yes. I think one of the things that is always very important to try to establish is if this event was outside the expected conditions that the building was designed for. So if you are in a housing complex, there are certain fire events that we accept as being events that are a regular occurrence, what I call in my report an event of probability of 1.
Now, people sometimes believe that fire is a rare event, and actually fires are not rare events; fires occur very regularly. What happens is generally we have put so many provisions to try to protect us from fire that what becomes a rare event is an event of a magnitude that is sufficient to actually affect people or affect the building in a significant way.

So we have all these provisions and we design these provisions to be able to cope with certain scenarios, and those scenarios are considered to be the common scenarios.

So the first thing that I was trying to establish is given the evidence that we have, and the actual nature of the evidence that we have that is quite coarse -- and this is quite common to a reconstruction of a fire, that you are working from debris, so it's very difficult to get detailed information of everything that was happening in the space. So what we're aiming at is to try to look and see if the fires that created the situation were of a nature that was extraordinary.

Now, by doing this very small bounding analysis, which is we took the worse possible fire growth, the slowest possible fire growth and we applied it into the kitchen. The kitchen has a very small floor plan, so effectively it is very rapidly filled up with smoke. For a fire to burn, you need fuel and you need oxygen. So lack of either of the two of them will actually stop the fire.

Now, if the fire gets strong enough, then what happens is that the temperature of the smoke gets so hot that the fire follows this process that is called flashover. So, effectively, everything within the

compartment ignites and effectively the fire flashes over.

So what we had observed was that in the particular kitchen of Grenfell Tower, the fire had never reached flashover. So, effectively, what happened was that at some point during the growth of the fire, the fire either was lacking fuel or it was lacking oxygen in such a way that it could not get to temperatures that were high enough to bring the room to flashover.

Q. Pausing there, what would you have expected to see in a flashover event that we didn't see in the kitchen of flat 16?

A. So in a flashover event, every combustible material would have ignited, because there is enough heat coming from the smoke to bring them to ignition. So what you would get is effectively the full destruction of all the components.

Now, you can see, for example, in Grenfell, there are appliances, for example, on which the paint remains undamaged. So the fact that the paint remains undamaged, that means the fire did not reach flashover because the paint would have blistered and ignited.

So, effectively, there's sufficient evidence within the space of elements that were in sufficient proximity that actually were not ignited by the fire, which

basically meant that there was no attainment of flashover.

So given that we have that evidence, that is our key piece of evidence and we can go back and try to then put as much fuel as we can and as small fuel as we can given the typical fuels that you have in there, and see when it stops having enough oxygen. Effectively, the smoke has descended to the floor and the oxygen is prevented from reaching the fire and, therefore, the fire cannot continue to increase, not because the fuel is not there but because the oxygen is not getting there.

By doing that, we can ascertain that the fire that actually was occurring in that space was somewhere between 60 and 300 kilowatts.

Q. I am going to come to that.

So in your simple modelling that you've done in the main body of your report, just to be clear what the parameters are for that simple model, you've assumed that all windows and doors to the kitchen were closed, and you've plotted different fire scenarios, the size of the fire and its heat release rate. We see that reference, HRR, heat release rate.

Can you explain what a heat release rate is?

A. Yes. So the heat release rate is the actual energy that is being released by the fire.

Q. As you said, you've looked at fire growth and you've classified the fire as either slow, medium, fast or ultrafast.

Are those general classifications that are routinely used in fire modelling?

A. Yes. Those are classifications used mostly for design, and, therefore, they are the classic classifications we will use to test our design.

So it's what we normally will use as a reference to try to bound the fire. So a slow fire will be as slow as possible and an ultrafast as fast as possible.

Q. They're your two extremes?

A. Extremes.

Q. Is it right your simple model also assumes that the fire is in the middle of the room?

A. Well, the kind of model that we're doing, it doesn't make any difference where the fire is. It basically treats the problem in a way such that it doesn't really matter where you put the fire. The reason for that is that in a small compartment of that nature, the impact of the fire will effectively affect the entire compartment almost simultaneously, so it really doesn't matter where you put the fire.

Q. Let's go to one of your figures which help illustrate this. Can we go to your figure 6. We have a new reference for this document because it didn't appear as clearly as we'd like in your report.

Can we go to JTOS0000003, please, on the screen.

Can we zoom in on the top diagram, please.

Just to be clear, unfortunately in the PDF of your report that we released, the grey smoke layer wasn't very clear.

Can you just explain what this basic model is showing?

A. Yes. So basically that shows a little bit of a schematic of the model that we presented. Basically what it shows is an upper smoke layer in grey, which will be basically a homogeneous layer that represents the smoke, then in the bottom you have the air.

So the fire acts as a pump; it basically takes fresh air and sends smoke to the top. That is called a two-zone model and it's the most simple representation that we have as a tool, as a regularly used tool, of a fire.

Q. If we now go to figure 7, which if we can pull up JT0S0000001 at page 39.

If we can zoom in on the graph at the top, please, figure 7.

This explains the results of your simple modelling --

A. Yes.

Q. -- in basic terms; is that correct?

A. Yes.

Q. Can you talk us through what we see here?

A. Yes. Basically what you get is the temperature of the smoke on the vertical axis and you get the time on the horizontal axis. The red curve shows the evolution of the temperature of the smoke as a function of time. So as you see, because that is the ultrafast fire, the temperature will grow faster.

By the time it reaches, in this particular example -- I need to clarify that we ran this model multiple times under different conditions. So in this particular example, the smoke will reach the floor and the fire will stop growing at a temperature of about 230 degrees.

In the other extreme will be the case of the slow growth fire. What you can see is the temperatures are growing much, much slower, and the smoke layer will touch the floor and the fire will stop growing at that point when the temperatures reach slightly above 100 degrees.

Q. So in this very simple model, we have a peak heat release rate before smoke filled the kitchen during the ultrafast fire of approximately 300 kilowatts, which

corresponds to a hot layer of approximately 220 degrees; is that right?

A. Yes.

Q. In contrast with the slow fire growth, that results in a peak heat release rate of approximately 60 kilowatts and a hot layer temperature of approximately 110 degrees centigrade; is that correct?

A. Yes.

Q. So you've put your fire in the size range 60 to 300 kilowatts in terms of heat release rate on your simple modelling?

A. Yes.

Q. Is that a small or a large fire?

A. So a 60-kilowatt fire will be no bigger than a waste-paper basket. A 300-kilowatt fire will be about half a chair. So in both cases, those will be fires that we will expect to be below our typical design values. So these are the kinds of fires you will expect we will regularly have in a house and building and, therefore, the building has to respond appropriately to these fires.

Q. You say on page 39 of your report that you've used a computation zone modelling tool which enables you to look at different fire scenarios in your analysis; is that right?

A. Yes.

Q. That's a computer modelling tool developed in the USA; is that correct?

A. Yes, it's a computer model developed by the National Institute of Standards and Technology and CFAST.

Q. CFAST.

A. Yes.

Q. You say this enabled you, for example, to model the fire including with an open kitchen door.

A. Yes.

Q. You say that the results of that show that if the door was open, the smoke layer will exit the kitchen, allowing the fire to grow because of the oxygen, resulting in higher temperatures and a flashover; is that correct?

A. Yes.

Q. Is it right that the heat release rate necessary to deliver that flashover was around 1,000 kilowatts?

A. Yes, it would be approximately 1,000 kilowatts.

Q. What you've said about that very basic modelling is it confirms that the kitchen door was probably closed during the early stages of the fire; is that correct?

A. Yes.

Q. Just turning then to appendix B of your revised report, can you confirm that in that appendix you've now

provided some more detail of the additional modelling work that you have done?
A. Yes.
Q. Is it right that you've expanded appendix B in your most recent report served in October compared with what we saw in May?
A. Yes.
Q. In general, can you just explain in very general terms what you've sought to do in appendix B?
A. Yes. I think one of the very important aspects of an analysis of this nature is to be able to use the tool that is appropriate for the precision of the input elements that we have.
So we have some information from the scene, we have some information from videos, and on the basis of that, we have to use a model that has a consistent level of precision.
If we use a model that is more precise, effectively what we're doing is giving a false sense of precision. So we have to stick to a model that is of adequate or comparable level of precision to the information that we have. So the simple model is that.
Now, what I do is to gain confidence on my simple model, I use more sophisticated tools to inform me and run a whole bunch of other different scenarios, all

different characteristics, try to play with different variables that are enabled by a more sophisticated model, just to make sure that the answers I provided with my simple model are correct.
So, effectively, this whole exercise of appendix B is a mechanism to gain confidence on the validity of the simple model.
Q. You've explained that you've done two different forms of modelling: you've done the computation zone modelling, the CFAST modelling you just talked about --
A. Yes.
Q. -- and you've also done something called computational fluid dynamics, or CFD, modelling using a simulator. Can you just explain the difference between the two and what that is?
A. Yes. So the simple model that I use effectively uses two layers, so it has a hot layer and a cold layer and it has no opening, so effectively you're just filling a box.
The CFAST uses the same two layers, but it allows you to open and close doors and windows so that you can allow flows through the doors and the windows.
So it is the same model conceptually, but it allows you to have that possibility of taking smoke out and getting more fresh air in.

The computational fluid dynamics model, it was developed by the same organisation, the National Institute of Standards and Technology, and it's called the Fire Dynamics Simulator. Effectively what it does is breaks the room into slightly little cubes. So instead of having two big layers, what you have is thousands of little cubes, and you're basically modelling every little cube. So you can resolve in every position of the room what the temperature is going to be, and basically the heat release rate and the flows and all the details.
So it's just simply a higher spatial resolution so you can see what is happening in every point.
Q. Is what we see in appendix B the same as a sensitivity analysis?
A. It's beyond a sensitivity analysis, because a sensitivity analysis, normally what it is, is you take the input parameters that you put in and you vary them through a certain percentage, just to make sure your inputs are correct.
Here we're trying to test also the physics. By using a much more sophisticated physics with the same inputs, we're trying to make sure that, actually, the simple model is delivering the right answers to the questions that we want to answer.

Q. So let's just start with the computation zone modelling that you've carried out.
You've explained in appendix B that two zone model variations have been used for this more specific analysis: first, trying to model the assumed ventilation conditions based on the available evidence, for example kitchen door closed, main window partially open; and then, secondly, exploring other scenarios, for example kitchen door open or closed or other windows open.
Before we discuss the results of those models, I just want to remind ourselves what the kitchen window looked like in flat 16 because I think that's helpful to remind ourselves of that.
Can we go to one of the figures in Dr Lane's report. That's BLAS0000008 at page 23.
Thank you.
I think this is the kitchen window. I believe it's in flat 13 on the opposite side, but can you confirm this is effectively the same window that we had in flat 16?
A. Yes.
Q. We see on the top-right a kitchen extractor fan with a surrounding panel. Yes? And then a large window on the left.
Can you just confirm how that window could open?

A. So that window could open tilted inwards or open completely, so --
Q. Swinging in or tilting in?
A. Yes.
Q. How about the little window underneath the kitchen extractor fan?
A. I believe it can only swing open.
Q. So when you talk about looking at different modelling, different scenarios of different windows open, we're talking about these windows here?
A. Exactly.
Q. Thank you.
In terms of your modelling, for scenario 1, which is the assumed ventilation conditions based on the existing evidence, which is kitchen door closed, large window partially open, what you've said is that your more sophisticated modelling shows that the heat release rate is in the range 110 to 360 kilowatts; is that right?
A. Yes.
Q. You say that compares well with the your simple model of 60 to 300 kilowatts?
A. Yes.
Q. In scenario 2, you say that the extra ventilation from the open door means a flashover scenario with a peak heat release rate of 1.5 megawatts; is that correct?

A. Yes.
Q. Turning then to the computational fluid dynamics. You just talked about these tiny little pieces of the jigsaw in the box.
A. Yes.
Q. You've explained the results in appendix B. Is it right that you've modelled the whole flat, save for, I think, the second bedroom and the living room, where it was assumed that these doors were closed?
A. Yes, figure 82 of my report will show the model that we conducted.
Q. If we could go to that.
Yes, so if we go to figure 82, JT0S000001 --
A. So you will see we modelled --
Q. -- at page 141. Just wait for it to come up on the screen.
A. Yes.
Q. If we can zoom in on figure 82. Thank you.
A. So we can see on the right-hand side that we are modelling the kitchen and all the rooms adjacent to the kitchen under the assumption that the partition is closed, and basically the smoke can leave the corridor and enter only the bedroom in the back.
Q. You've looked at the fire being located both on the floor and behind the fridge; is that right?

A. Yes.
Q. Can you explain why you've done that?
A. The dynamics of the fire are very different if you have a fire that is on the floor then if you have one that is progressing behind an obstacle. When you have a fire that is progressing behind an obstacle, you will restrain the amount of air that can get into the fire, so the flames will be longer, because the fuel requires to get air from higher points to be able to be fully consumed, while if you put it in the middle, the flames will be shorter because you have air coming from all directions. So you have to model both extremes.
In the simple model, we only model the one in the middle because we were looking for the smaller possible fire because we were bounding the conditions. But in here we tried both, just to make sure that we covered both potential scenarios.
Q. You say that you've modelled several ventilation conditions in terms of the windows being open or shut.
In terms of the fire size for the fridge, is it right that you've used results from some of the stand-alone tests carried out by the BRE for the Metropolitan Police to estimate the potential heat release rate for the fridge?
A. Yes.

Q. So what happened, as I understand it, is that the Metropolitan Police did some testing, setting fridges on fire similar to those in flat 16 to see what heat release rate they got; is that correct?
A. Yes.
Q. Can we just look at the results in graph form from that. If we go to figure 57, which is on page 144 of your report -- that's JT0S000001, page 144 -- and if we can zoom in -- there we go.
What you said in your report is that the tests that were carried out which are represented here showed an initial peak heat release rate of 400 kilowatts after 7 minutes from the start of the stand-alone fridge test. It then reduces to between 75 and 100 kilowatts, before much later, after about 32 minutes, it peaks in the range of a megawatt to 1.6 megawatts; is that correct?
A. Yes, that's correct.
Q. That's effectively what we see depicted in this graph here; is that right?
A. Yes.
Q. So we can see that initial peak of 400 after 7 minutes, but then a diminishing profile.
A. Yes.
Q. You say in your report that these results are relatively consistent with the 60 to 300-kilowatt heat release rate

range you've used for your simple model. Can you just explain that?
A. Yes. So the tests conducted by BRE were conducted under a hood, so you're basically allowing for all the oxygen that is necessary to reach the fire. So this will be the maximum burning capacity of the refrigerator, without considering the fact that oxygen might not get there, like will happen in a compartment.
So if you look at the timeline of about 7 minutes until reaching 400, that is fairly consistent with somewhere in between a slow and an ultrafast. So it falls more or less in between the range of values that we worked with.
We observed also that the smoke layer descended in less than 5 minutes. So, effectively, you will not reach to 400 kilowatts; you will probably stop a little bit earlier because the smoke would've gone down. That's more or less what the results show, that effectively the fire stops growing because there is not enough air being able to feed the fire.
So, in many ways, using this as an input is quite effective in trying to compare it with the simple model to show that, effectively, all the numbers are within the same ranges that we were operating.
Q. So that explains why you haven't gone back in your main

report and adjusted your range of 60 to 300 to make it 60 to 400.
A. Absolutely. Again, I go back to the fact that we need to use the right tool for the right problem. So I do not want to, with my report, make anybody think that we have more precision than the precision that the simple model has.
Q. So turning, then, to the results of your CFD model, you say that the results from that model for a fire located in the back of the fridge, and with the large window tilted open, the small window open but the door closed, show that temperature magnitudes both by the window and by the door are within the bounds of the predictions in the simple model; is that correct?
A. That's correct.
Q. You've also run the same analysis, but with a higher heat release rate, just to check the figures --
A. Yes.
Q. -- at 400 to 500 kilowatts; is that right?
A. Yes.
Q. You say again that for a fire located in the back of the fridge, and with the large window open, small window open but the door closed, the model managed to maintain the 400-kilowatt level, but it didn't maintain the 500-kilowatt level. Can you just explain that?

A. Yes. So this type of model, because it's modelling things in a lot more detail, it allows you to see really how much energy is being released. So it's taking into account how much air is meeting with the fuel and how much energy really is releasing.
So I can input energy, but I can measure also the output. So effectively what this model does is whatever cannot burn, then it's left as unburned smoke that just goes away and I can actually account for that.
So effectively with the model, I can tell that no matter how much energy I put in, only 400 burns. I can put 1,000, I can put 500, and it will immediately go back down and only 400 will burn.
So effectively it verifies that you are oxygen starved, so you cannot burn more because you don't have enough air getting into the fire.
Q. You've also said in your appendix B that your 60 to 300-kilowatt simple model gave a good estimate of average compartment temperatures, but that only the CFD model can establish something called the spatial distribution.
Can you explain what spatial distribution is?
A. Yes. Because in the CFD we are modelling the small little cubes that fill up the entire compartment, each cube will have a temperature. So I can know exactly

what the temperature is in that point. So spatially, in all the directions, I can know exactly what the temperature is.
In the other models, I'm assuming that the hot layer, the smoke, is only one temperature and the cold layer is only one temperature. So I only have two numbers and I don't have the spatial distribution in the compartment.
Q. You've also said that your CFD model delivers more accentuated temperatures. Can you explain what you mean by accentuated temperatures?
A. I think the easiest way to describe it is to look at --
Q. Figure 91, I think.
A. -- figure 91, yes.
Q. If we go JTOS0000001, at page 149.
Can you just explain it by reference to this figure?
A. Yes. So as you can see, the dotted line represents the simple model, and effectively gives you the same temperature all along the height, because the whole smoke layer has the same temperature.
The CFD will show that the temperatures are slightly lower at the bottom and slightly hotter at the top, and therefore gives you the distribution with height of the temperature.
Now, one of the things that I need to clarify in

there is that while it shows this accentuated temperatures and it shows that it's obviously going to be hotter at the top and colder at the bottom, we cannot rely on those numbers.
So those numbers are beyond the precision of the information that we have.
So, effectively, the fact that the red curve shows that you are at 300 degrees might not necessarily be correct. At the top, you probably don't have 300 degrees, you might have a little bit lower, and those things we will never be able to ascertain because the precision of the information that we're inputting into the model is not good enough.
So being able to say that is 260, 250, is about as precise as we can be. And, yes, we can see it's plus/minus 50 degrees and that will be perfectly fine, but we cannot claim that the precision of the field curve is actually correct.
Q. Within the CFD modelling that you've carried out, you've also looked at variability by fire location, as we discussed before, both at floor level and at the back of the fridge freezer; is that correct?
A. Yes.
Q. You've said -- I think you've mentioned this before -- that a floor fire produces what you called more scatter

of the data. Again, can you just explain what that means?
A. Yes. What happens when you put a fire in the floor is that the way in which the hot gases go up and they bring the cold gases in creates a situation by which the flames fluctuate. You're going to have the hot gases going up, then they bring cold air, and then the flame shrinks, because everything burns, then the hot gases so up again. So you have flames that go like this, pulsating.
That creates data points that are going to change. When the flames are up, the temperature goes up; when the flames go down, the temperature goes down.
But when you have a vertical fire and it's burning as a wall, everything is pushing up. So effectively it's much more stable. Then what you get is fairly consistent temperatures at all the different heights.
Q. Does it follow from that that you accept that a fire located in a corner or against a wall will behave differently from a fire in the middle of the room?
A. Oh, yes. They will behave differently. Nevertheless, the more you confine the fire -- so if you're behind something or you're in a corner -- effectively what you get is a taller flame. So it's the scenario that is already considered when you consider the smallest fire.

Because remember, we're bounding. All we're doing is trying to find what are the fires that effectively could do what they did.
Q. In your simple analysis that you did in your main report, it was based on a calculation from Dougal Drysdale, which was based on a fire in an open space; is that correct?
A. Yes.
Q. Do you agree that other aspects of that Drysdale paper deal with fires closer to a wall or in a corner?
A. Yes. So, basically, if you look at Dougal Drysdale's book, you will find he will produce different equations for fires in a wall, fires around a corner, but in all those cases, the flame will be taller. So, effectively, it will be already included in my bounding analysis, I'm just setting the boundary. So if I did all those refinements, I will find points that are already included in my two limits.
Q. That was my next question: does your modelling take account of that?
A. Yes. Because, effectively, you are looking at the smallest possible and the biggest possible, so everything is already -- all the in-betweens that are more precise are already included.
Q. So you don't accept your simple models should've

referred to those other Drysdale calculations?
A. No, no, I mean, you know, you could do it just as a further validation to show that they fall in between, but the CFD model already does all that. So, effectively, if I'm already running the CFD model, there is really no point in using again simple calculations for a situation that I have already calculated.
Q. You've also looked at variability in ventilation in the kitchen, with different windows open and closed. That includes the large window in the open tilt position and the small window open; is that correct?
A. Yes.
Q. You've said that this produces a peak heat release rate of about 400 kilowatts, which can be sustained.
A. Yes.
Q. Can we just look at what you say in your report about this. It's on page 152, JT0S0000001. Can we zoom in on lines 3431, to 3438.
So there you say:
"Results presented in Figure 88 indicate that for the large window in the tilted position and small window fully open ... a peak HRR of approximately 400kW can be sustained. This means that a larger fire will result in higher overall compartment temperatures as shown in Figure 89 as there is more air available to support

combustion."

Again, does that mean that there's any difficulty with your simple model of 60 to 300 kilowatts?

A. **No, all that it means is that the model says that if I put 400 -- if I open the window, the heat release rate will increase a little bit. Now, the model says that is 400 kilowatts, but that level of precision is not granted. So all we can say is that the temperatures that I gave are approximately right, but they could be potentially slightly bigger if the window was open.**

Q. Do you think it makes much difference whether it's 300 kilowatts or 400 kilowatts?

A. **Well, it does make a difference, but when you say it makes "much difference", I think you have to ask that question in the context. It makes much difference for what? And I think that's the important question.**

So in some cases it will make a difference, and then at that point I will have to say this model is not sufficient to do that. But for other things, it doesn't make any difference because we are way outside the ranges, for example.

Q. As you go on to say on the same page in the next paragraph, we have it here on the screen:

"Models were run to analyse the difference in thermal profiles created by the opening of the small

kitchen window in addition to the tilted kitchen window ... The results, shown in Figure 95, indicate that there is little difference between the two, with the lower ventilation resulting an only slightly higher temperatures, attributable [to] the lower heat losses from the compartment."

So that's what you were just explaining.

A. **Yes.**

Q. Can we just look at that in figure 95. I think it will help to look at that. That's JTOS0000001 at page 153.

Here, basically this is showing, between the continuous lines and the dotted lines, the difference between whether the small window is open or closed; is that correct?

A. **Yes.**

Q. So in case 1, the small window was closed, but in case 2 the small window is open.

Can you just explain why you're saying this shows that there's little difference between those two scenarios?

A. **Basically, given the coarseness of the inputs that go into this model, you will consider all those lines to be the same. The way you will normally represent that is that will be an average plus an error of about 10 to 15 degrees on both sides. So there is really not much**

of a significant difference other than a slight trend upwards.

But, effectively, given the inputs that we're putting, I could not ascertain that even that difference is actually that real.

So normally what I will do in a plot of that nature is average everything, give a single plot and put an error bar of plus/minus 10 degrees.

Q. Just testing that, then, what about potential gaps around the doors? So there's the sliding door to the kitchen and then there's also the kitchen door itself. Is it possible that the doors would not have provided a complete seal, and could that have made a difference?

A. **It would've been a very, very minor difference. I mean, generally leaks will be considered as being a much, much smaller flow rate than an open window.**

I mean, clearly the one thing that does make a big difference is an open door, and that has to be taken into account. But leakages are lower in the pecking order than an open window. An open window will be a much, much more -- so if an open window can change things by 10 or 15 degrees, I would imagine that leakages will not change it by 1 or 2 degrees.

Q. What about evidence from witnesses of draughts around the windows and from under the doors post-refurbishment?

Again, would you think that that could change the results in your modelling?

A. **No. Again, it will fall way within the category of noise.**

Q. What if the doors were not fully shut, could that affect your modelling?

A. **When you say not fully shut, I mean, if you're talking about 5 per cent, it's going to be a very, very small gap and, therefore, again, it will make no difference, but if you're talking about 20/30 per cent, then of course, as you start opening the door, you're making a very significant area --**

Q. That's where you got to flashover scenarios?

A. **That's when you get to flashover.**

Q. What about if the extractor fan was in the "on" mode and sucking air out of the kitchen? Again, could that make a difference?

A. **Again, it would make a slight difference. If you look at the typical flow rates of an extractor fan, in general they're very small compared to the types of flow rates that you will get by smoke production or by egress of smoke out of a door.**

So imagine what you see when you have a fire and you open a window. You see an enormous amount of smoke coming out. So that is clearly much, much more than

what a fan can extract.
So of course all these things will make a slight difference, but it will not be a significant difference.
Q. Would you agree that if you did allow for some additional ventilation, such as around the doors, and for the possibility that the fire was not positioned in the centre of the room but was against a wall or in a corner, there might be local areas within the smoke layer, for example at ceiling level, where the fire could have reached approximately 550 degrees C? Would you accept that?
A. Yes.
Q. Can you explain why you've not taken that account in your modelling, or have you taken that into account?
A. No, we have taken it into account. So, basically, we made a clear distinction between heating by means of the smoke and heating by means of flame impingement. So what you're talking about of hot-spots, localised heating areas, is effectively the flame in itself reaching that location and creating a hotter area within the smoke layer.
So the conclusion that we came up with is that the temperatures that the smoke layer can reach cannot reach the typical ignition temperatures of most of these materials. But the flames, if they actually touch any

of these components, will actually reach those temperatures.
We did a detailed analysis of that.
Q. I am coming to that. Is that about spill plume temperatures --
A. The spill --
Q. I'm coming to that next, yes.
Before we get to that, can you just explain why you used an average smoke layer temperature in your modelling?
A. Yes, because you have to differentiate two things: one is the smoke and one is the flame impingement. So I wanted to separate both. So if the smoke gets hot enough that it can ignite the components, that basically means any component within the room could have ignited when it enters the smoke layer.
If the smoke layer cannot reach those temperatures, that basically means that only the components that were in reach of the flames could have ignited. So that allows me to establish how far the fire can be before it cannot touch any combustible material.
So I'm separating the two things to make sure that I establish what is igniting what.
Q. Is it also right that you've used a steady state fire in your CFD modelling as opposed to a growing fire?

A. Yes.
Q. Why have you done that?
A. Because what we were testing with the CFD was effectively if there was enough oxygen to burn. So there was no point in increasing the fire; you just put it at the maximum value and see if you have enough oxygen to burn.
So many times you use different modelling strategies depending on what you're testing, and because in this case what we were testing is do we have enough oxygen, then I want to fix the fire at the maximum and see if I actually have enough oxygen, or the fire starts going down on its own because it doesn't have enough oxygen to burn.
Q. We're nearly finished with the modelling. Let's turn to the external spill plume temperatures.
A. Yes.
Q. So you've done some modelling which assists in terms of what you refer to as these external spill plume temperatures. Those are temperatures if the fire had vented out of the kitchen window; is that correct?
A. Yes, but that's different to what I was talking about, which is the flame impingement.
Q. Yes. Can you explain the difference?
A. No, no, there's three things. So when you have the

compartment, okay, you're going to produce a smoke layer, so the smoke has a certain temperature.
Within the smoke, there will be the fire, and the fire can penetrate the smoke sometimes and get hotter in a certain region. So there's a whole section in my report when I discuss what I call the ceiling jet temperatures. So it's effectively how far the flames can reach. It's not the hot smoke temperature, it is the flame itself touching.
Then the third one is what is happening to the outside, and that's the spill plume. So you have a compartment that has hot smoke and the hot smoke will come out of the compartment, mix with cold air and that will create a spill plume.
Q. On the external spill plume temperatures analysis, you say that this shows that smoke temperature would only reach temperatures capable of igniting the ACP cladding if there was a large fire size with ventilation able to support it and thus under post-flashover conditions; is that correct?
A. Yes.
Q. In general, you've said that this more sophisticated modelling confirms your confidence in the simple model; is that correct?
A. Yes.

Q. Do you think it's likely that you would like to do more modelling at Phase 2?
A. I do think that the modelling will only become necessary as a function of more detailed testing. So if there is a need to refine what are the exact conditions that led to ignition of the external system, you know, then tests will have to be done before modelling because you have to produce the right input data so that you actually get -- it is justifiable to do a more precise model.
Q. I'm coming on to look at the role of the uPVC window surrounds, and that section of your report I think you were just talking about.
A. Yes.
Q. But before we leave this modelling topic, I just have a question about table 7 of your report. Can we go to that: JT0S0000001 at page 140.
In that table, you've summarised some of the results from your zone modelling. In the fourth substantive line, you have a smoke-filling time of 50 seconds for an ultrafast fire with a corresponding peak heat release rate of 360 kilowatts; is that right?
A. Yes.
Q. If you look in the fourth line down, the last of the 1s under scenario 1.
Is it right that this does not use the standard heat

release rate calculation from an ultrafast fire which would result in figure of 470 kilowatts?
A. There's a confusion on what that 475 is. So when we use an input, we utilise as standard what is called an alpha t-squared fire. So effectively we plug in a time and we get a heat release rate, but that is the input, that is the fuel that we're putting in there.
What this model does, it calculates how much it's burning. So what happens is that I am inputting 475, but at some point the model stops me because it says I don't have enough air, and it stops me at 360.
As you can see for all the cases when I tried to push it, in all the cases it will pretty much stop at the same place because that's the amount of air that is available.
So you can see in the far right column, you will see 350, 355, 360, 360, because that's where it tells you this is as much air as I have.
When I open the door, now I have as much air as 1550, then I can get much more.
So we cannot confuse the input with the output. So what is being presented there is the output that incorporates fuel and oxygen, while the number you quoted is the input. But I cannot burn all that fuel because I don't have enough air.

Q. So let's turn, now, to the section of your report where you looked at the role of the uPVC window surrounds.
When looking at the breaching of the compartment, you focus quite heavily on the role of the uPVC around the windows. In general, can you just explain why you've done that?
A. Yes, because the uPVC serves as a cover for a whole array of other materials that potentially could burn.
Now, uPVC is a material that, from a flammability perspective, is a very robust material, it's a material that is very difficult to burn. So, in principle, it could potentially be an adequate protection layer for those materials.
Nevertheless, the uPVC has a particularity, which is that it loses its mechanical strength at very low temperatures, so effectively can actually fall off.
So this is the reason why I thought it was important to focus on the uPVC.
Q. You've explained in your report that is has a melting range of between 75 and 105 degrees C --
A. Yes.
Q. -- is that correct?
And it rapidly loses stiffness at 60 degrees Celsius; is that right?
A. Yes.

Q. It loses 80 per cent by 80 degrees and 100 per cent by 90 degrees.
A. Yes.
Q. Can we just look at table 1 of your report. That's JT0S000001, at page 37.
SIR MARTIN MOORE-BICK: Can I just ask you, when it gets to 90 degrees/100 degrees centigrade, does it actually flow?
A. No, it will behave like gum. So it does flow, but it's very, very viscous, so it is more like a gum.
SIR MARTIN MOORE-BICK: Yes. All right. Thank you.
MS GRANGE: So in this table, you've given various material properties of a number of materials that are important in terms of the kitchen.
Can you just explain here what we see for the uPVC in the bottom two lines?
A. Yes. What you see for the uPVC are two characteristics: one is ignition temperature and the second one is the melting temperature. You can see that the melting temperature is of the order of 100 degrees, while the ignition temperature is almost 400 degrees.
Q. While we're here, on the top line we see polyethylene, that's the material that was inside the ACM panels --
A. Yes.
Q. -- is that correct? And you've put that there at --

that has an ignition temperature of 377 degrees C; is that right?
A. Yes.
Q. That's just the polyethylene; is that right?
A. Yes.
Q. It's not related to the aluminium. We'll come later to the panels.
A. Yes.
Q. Then we have PIR, which is effectively insulation --
A. Yes.
Q. -- in the second column, and you have that with an ignition temperature of 306 to 377 degrees C; is that correct?
A. Yes.
Q. In terms of the uPVC, you've talked about the fact that it has this elastic modulus, which is of importance, which I think is what you were just describing.
Can we just look at that. Let's look at figure 9 of your report. That's JTOS0000001 at page 41.
Can you just describe for us what we see here and what the red and the blue lines are? We have blue as the modulus, I think.
A. Yes.
Q. Can you just explain what that is, and also what the red line is showing?

A. Yes. So this is a test conducted by Professor Bisby and basically shows you what is the elastic modulus for uPVC at ambient, which is 2.5 times 10 to the 9 and you can see that as you start increasing the temperature -- sorry, ambient temperature it's a little bit above 2, times 10 to the 9. So as you start increasing the temperature, what happens is that the value starts dropping, so that's the blue line. So you get a decaying value that eventually hits 0, so in other words it has no strength by the time it gets to about 80/90 degrees, and by 100 clearly has nothing left. So that will be the blue line.
What the red line is, it just shows you the rate at which that happens. So what you can see is that at the beginning, there's very little change, you can see it's flat, very little change, and then eventually it starts changing drastically, and that happens at about 60 degrees.
So what you're looking for on the red line is when it starts going up, because that's telling you when it starts to change.
What you're looking from the blue line is when it ends, because that tells you when it doesn't have any more strength. So between 60 and 100 degrees, you effectively are going from having almost its full strength to having no strength.

Q. You said in your report that most fires originating from fuels typical of a domestic kitchen will have the capacity to significantly damage the uPVC; is that right?
A. Absolutely, because if we go back to the original discussion that we were having, we established that we needed a fire the size of a frying pan to be able to bring the smoke layer to the floor, and that was the limits in which we were operating. So this particular fire could not be bigger than a frying pan.
Then if you look at the smoke layer temperature, the smoke layer temperature is around at the most 200 degrees, so it cannot ignite anything. But nevertheless, it's 100 degrees above the temperature that you need to basically take the PVC down. In other words, it loses all its mechanical properties.
We did a detailed heat transfer calculation, actually a very conservative one, and we showed we had plenty of time to heat the uPVC to the point it would have lost all its mechanical integrity.
This is very important because, again, it separates -- and this is a reason behind the strategy we follow for modelling -- the smoke temperature from the flame temperatures. So the smoke cannot ignite

anything, but it can actually mechanically fail the uPVC. To ignite things, we need a flame.
Q. You've said in your report that the uPVC would've reached temperatures with a total loss of mechanical strength in approximately 5 to 11 minutes; is that right?
A. Yes.
Q. You also say that the kitchen is sufficiently small that it doesn't matter where in the room the fire is to cause that total loss of mechanical strength; is that right?
A. Exactly. So with the CFD and all the other validations we did, we showed that, effectively, the very simple model that doesn't take into account spatial resolution -- in other words, you can place it anywhere you want -- will effectively be sufficient to be able to establish that.
Q. You've noted in your report that the uPVC is held in place by an adhesive, a kind of glue, which you also say is vulnerable to heating. You say the ability to secure the uPVC at elevated temperatures is considered negligible.
Can we look at that. If we go to figure 55 of your report. That's JTOS0000001_0042.
So what we're seeing here is underneath the uPVC surround; is that correct?

A. Yes.
Q. Can you just draw your attention to the adhesive, is it the bottom label there?
A. Yes, it's the bottom label and you can see the mark of the adhesive. So adhesive is a polymer and it will actually behave in a very similar way as a uPVC. It will lose all its mechanical integrity by the time it gets to about 60/70 degrees. So effectively both the adhesive and the PVC will have no mechanical strength. So the adhesive has no capacity to keep the uPVC in place, and the weight of the uPVC is much more than what the uPVC can hold itself.
Q. What we can see the reference of under there are the PIR foam insulation which was all the way around the windows; is that's correct?
A. Yes.
Q. Top, bottom, left, right -- yes.
What is your view about this arrangement in terms of any potential path of fire spread out of the window?
A. Well, effectively, the smoke, even though its temperature is very low, is capable, with a big margin of safety, to mechanically fail the uPVC. So it opens a direct path for any flame to actually impinge on any of the combustible materials on the inside.
Q. Just on this topic, can we look at some of the photos

that you've used in your report to illustrate the failure of the uPVC we saw at Grenfell Tower. Can we go to JTOS0000001 at page 43 to start with.
Can we zoom in on the top one for the moment.
You said in your report that the failures are usually around the head and the jamb. Can you explain what you mean by the head and the jamb by reference to these photographs?
A. So you can see the piece of uPVC hanging in there, and you see where it came from. So effectively this will rip off downwards, falling all the way to the bottom. That's kind of what I meant.
Q. You've also used the word "fall-off" in this context. Is that just it falls off?
A. Falls off. It basically first starts forming and eventually falls off. You see it more clearly in the next photograph.
MS GRANGE: Mr Chairman, I'm now going to turn to a different topic.
SIR MARTIN MOORE-BICK: Did you want to show us the next photograph?
THE WITNESS: Yes, if you can look.
MS GRANGE: Oh, sorry. Let's finish these photographs. Let's go to the one at the bottom of the page.
A. You can see how the top how it fell off.

Q. I believe there's actually one on the next page as well, if we can go to that.
A. Yes, you can see it on the side, and in this case also on the top.
MS GRANGE: Yes, thank you. Sorry.
So I think that's a convenient moment for a break.
SIR MARTIN MOORE-BICK: Would it be a good idea?
MS GRANGE: Yes, I think it would.
SIR MARTIN MOORE-BICK: I think we'll all have a break now, professor.
I'm going to ask you not to talk to anyone about your evidence while you're out of the room. If you go with the usher, she'll look after you. We'll come back at 11.30. All right?
Thank you very much, you go with the usher now.
All right, 11.30, please.
(11.20 am)
(A short break)
(11.30 am)
SIR MARTIN MOORE-BICK: All right, professor? Ready to carry on?
THE WITNESS: Yes, thank you.
SIR MARTIN MOORE-BICK: Thank you.
Yes, Ms Grange.
MS GRANGE: Thank you.

I now want to turn to the topic of the break-out of the fire from flat 16 and the method of ignition of the facade materials.
I'm going to give a trigger warning at this point because in about 5 to 10 minutes I'm going to be showing a video of the early stages of the fire at Grenfell Tower, going up the east face from flat 16. This contains images and audio that some may find distressing.
SIR MARTIN MOORE-BICK: Yes.
MS GRANGE: I will also be taking Professor Torero to a number of stills and photographs of the fire in this section of my questioning.
SIR MARTIN MOORE-BICK: Right.
MS GRANGE: I will give another warning when I get to that video, but I wanted to give it now in case anyone wants to be prepared for that.
SIR MARTIN MOORE-BICK: Thank you, that's very helpful.
MS GRANGE: In section 3.5 of your report -- first of all, just to be clear, you have not addressed cause and origin of the fire in your report, which is dealt with by other inquiry experts; is that correct?
A. Yes, I've taken the information from Professor Nic Daeid and Professor Bisby on that matter.
Q. Thank you.

Have you considered the different hypotheses posited by Professor Bisby in terms of the method of ignition of the cladding materials on the facade?
A. Yes.
Q. In his latest report, Professor Bisby discusses two particular hypotheses.
First, what is now called hypothesis B1, which is essentially the impingement of flaming and hot gases through an open window, whether that be through the extract panel or via the extract fan itself, and then subsequent ignition of the external ACM panels immediately above the kitchen window.
Is that correct?
A. Yes.
Q. He's also discussed what's now called hypothesis B2, which is the ignition by flame of exposed flammable materials in the window surround and the external cladding system being penetrated by fire, allowing flame spread back into the back of the cladding cavity.
Is that correct?
A. Yes.
Q. Do you agree that these are the two possible routes of ignition out and into the cladding?
A. Yes.
Q. Do you think there are any other plausible candidates

for that?
A. They are clearly the two most probable causes.
Q. I just want to start by discussing hypothesis B1, the venting through the window opening and up into the panels above the window.
As we discussed just before the break, does it remain your view that the smoke itself is not going to be hot enough for the smoke that's venting through the window opening to ignite the cladding?
A. Yes.
Q. You say that the maximum temperature of the smoke layer is around 220 degrees Celsius, even with an ultrafast fire; is that correct?
A. Yes.
Q. So ignition of the materials even surrounding the window, specifically the PIR insulation which is behind the uPVC, that requires 306 degrees Celsius; is; that right?
A. Yes.
Q. You've calculated that direct ignition via direct flame or plume impingement through the window would require a fire of around 830 kilowatts to ignite the ACP through the window; is that correct?
A. Yes.
Q. Can you just explain for the chairman how you've

calculated that?
A. Yes. So, basically, if we provide enough ventilation to allow the temperature of the flames to reach those temperatures, you can establish what is the heat release rate that will deliver the necessary temperature so that you can ignite the cladding from the outside.
The one thing that is very different about both hypotheses -- and maybe this is the time to clarify that -- is that when we have a compartment fire, the compartment is always going to be hotter than the plume outside. So from a physical perspective, a path that ignites from the inside is a more probable cause of ignition because the temperatures are always going to be higher in the inside than in the outside.
Now, Professor Bisby comes from a different angle, which is also perfectly possible, which is once something ignites, that something can create a flame, and that flame can be the one that results in the ignition of the subsequent materials.
Now, he's coming from the observation, so he's looking at different images and he's basically looking at the different flames that are moving in different directions. He is observing that there is a high probability that a flame could have impinged on the external cladding.

So the two options and the weighing that we are giving to the two options, and the reason why I didn't feel there was any need for me to clarify any further in my report, is because we are coming from different angles, and I believe that the chairman needs to consider both, in the sense that one comes from a purely physical analysis of the problem, that shows that the hotter part and the closest to a flame will be from the inside, but the other one is more a probabilistic one, it is: what ignited first? And if there is a sequence of ignitions that resulted in a flame, that could perfectly be the case of igniting on the outside. But that comes more from observations of images and evidence.
Q. It might be helpful at this point to look at your table 3, JTOS0000001 at page 50.
If we can zoom in on the table at the top of the page.
Can you just talk us through in basic terms what this table is showing us in terms of fire size and distance and these three materials?
A. Yes. So, basically, what you see in the table is, depending on the location of the material and its ignition characteristics, we looked into having a flame -- maybe we should look at the diagram first.

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Q. Is that figure 14?
A. That would be ...
Q. Or is it figure 13? Which one?
A. That would be figure 13.
Q. So if we go to JTOS0000001_0047.
If we can zoom in on figure 13 at the bottom.
A. Okay.
Q. Is that what you're referring to?
A. Yes. So, basically, those are the two potential options. So you can have a fire that is unobstructed that directly impinges on a target, and that target could be the PIR or the uPVC or the cladding.
So we know what the position of these components is, so we can establish what the distance is between the fire and the target. On the basis of that, I can establish how big of a fire do I need so that the flame at the position of the target has sufficient temperature to ignite. Okay?
If there's an obstacle, the flames will have to go to the ceiling, then progress along the ceiling, and effectively hit the target.
So given that the smoke cannot ignite, it has to be direct impingement from the flame.
So what we looked into was, given the position of the fire, how big of a fire we had to have to be able to ignite the targets, and that's what you have on the table.

Q. You just talked about the phenomenon of a ceiling jet that might occur behind an object.
A. Yes.
Q. So the fire goes up behind the object and then across the ceiling and out --
A. Yes.
Q. -- towards the window.
How likely do you think that might have been here?
A. Well, if the fire was established behind any obstacle, that would've had to be the case because effectively it had to go through the obstacle before it reaches a target. So the only way that could've happened is it going up, hitting the ceiling and then propagating across the ceiling towards the target. So it would be highly probable.
SIR MARTIN MOORE-BICK: Can I ask you to consider a slightly different hypothesis, which is that the fire breaks out behind an obstacle but to the side of the target. In other words, it doesn't have to go over the obstacle to get to the target, it might go at a different angle.
A. It would be bounded by the two of them. So this is the worst-case scenario and the other one is the best case scenario. So it would be somewhere in between. That's why we're giving the two ranges.

SIR MARTIN MOORE-BICK: Yes.
MS GRANGE: So this helps explain what we see in your table 3 --
A. Exactly.
Q. -- is that correct? Do you want to just go back to that now?
A. Yes.
Q. So if we just go back to table to 3, which is on page 50.
If you can now just talk us through for each of the elements what we're seeing.
A. Yes. So we know how big a fire can be now because we've done the analysis. So if we take that size of a fire, then the distance you see there is: how far do I need to move the fire away from the target before it cannot reach the ignition temperature?
Q. That's where we see the figure of 830 kilowatts.
A. That's where you see the maximum distance.
Q. Yes.
A. The final column.
Q. Yes. But I put to you the smallest fire, 830 kilowatts would be needed to ignite the polyethylene --
A. Yes.
Q. -- at the top of the window.

A. Yes, exactly.
Q. You say that's a flashover fire, so you think that's unlikely.
A. Yes.
Q. In terms of direct flame impingement through an open window, is it therefore relevant that the flames would've fed out into the open atmosphere outside the flat?
A. Yes, it would've had to ignite something in between because the flame would've had to be placed closer to the opening to be able to be smaller and still reach the ignition temperatures of the cladding.
Q. Does the flame get cooled in the process of coming out of an open window, and is that relevant to the analysis of whether or not that's a likely method of impingement?
A. Yes. So the moment the flame exits the compartment, there is going to be fresh air and that's going to cool the temperatures of the flame. It is always going to be the case that the spill flame is going to be colder than the interior compartment. It cannot be the opposite. So, yes, that will definitely influence the analysis.
But I want to make this point again, that in this particular type of scenarios, because we're talking about flames that can impinge on numerous things, there can be a sequence of ignitions. So one thing can ignite

another one and ignite another one, and those things you can only ascertain by looking into the visual evidence that you have.
So I think when comparing my conclusions with Professor Bisby's conclusions, we have to make sure that we understand that I did not do the detailed analysis of the images, that's what he did, and he didn't do the detailed analysis of the fire dynamics, which is what I did, and the two things complement each other.
Q. Can we just look for a moment about what the method of impingement might have been for the ACP panels above the window.
Can we look at a picture of what we see above the window. Can we go to figure 40 of Professor Bisby's report. That's LBYS0000001 at page 68.
This is a good photograph which shows you what you see. Just to make clear, the ACM material on the column has been removed here to the left of the picture, but to the right, we're looking directly up from the window to the ACM cassettes that were immediately above; is that correct?
A. Yes.
Q. We see there the way the cassettes were fabricated was there was a 90-degree return and then a kind of level --
A. Yes.

Q. -- underneath the window, immediately above the extractor fan; is that correct?
A. Yes.
Q. Can we also look at another picture, a picture from Dr Lane's report. That is BLAS0000010 at page 26, figure 10.26.
This is another photograph of the window, this is to the right-hand side of the window, and we can see those cassettes above. She's put a ring in there which we'll come to in a moment.
Just looking at these photos, what do you think the mechanism could've been for igniting those ACM cassettes above the window if the flames had vented out through an open window?
A. Well, I mean, you need to ignite the polyethylene. That has a specific temperature that you need to attain.
Not only that, the polyethylene is a thin film in between two aluminium plates. The aluminium plates have very high thermal conductivity, so they take a lot of energy away from the polyethylene. So normally these type of materials are actually quite difficult to ignite, because what happens is that the heat that you apply goes away through the aluminium and the polyethylene tends to melt instead of igniting. So it requires a significant amount of heat to be able to

ignite those panels.
The mechanism would've been that eventually, either through melting or through splitting, you would've had a surface of the polyethylene that is exposed, a flame will have crept in there and that's what would have ignited the material.
Q. Are there any exposed edges of polyethylene above the window?
A. I would imagine that there would be.
Q. Dr Lane had some I think marked here on the --
A. Yes.
Q. -- right-hand side.
Does that affect the analysis in terms of whether or not there are those --
A. Well, if there were no exposed edges, it would be even more difficult to ignite because you would have to breach the encapsulation of the material. So all those details will have some impact on the way it ignites, but one that it would be very, very difficult to predict.
Q. If this had been the mechanism of fire spread, would you have expected a time delay, given the factors you were just talking about, when compared with other possible routes?
A. Not necessarily.
Q. Can we just look at the thermal imaging from flat 16,

which indicates that the fire may have vented from the window in the corner of the room.
If we go again within Dr Lane's report to BLAS0000009 at page 43. Can we go to figure 9.37.
So in the image at the top we have a still from the thermal imaging that was taken; is that correct?
A. Yes.
Q. Does this image help at all in your view about what the route of escape may have been through the window?
A. Not from my perspective because it is too late. So 01.14 I believe is the thermal image camera footage, and at that point you would've been already at least about 10 minutes into the event. As you saw from all the other diagrams, that is already very late in the whole process.
That doesn't mean that that could've not been the moment in which or the area in which it breached. All that that means is that inferring that back from an image that was taken at 01.14 is very difficult because it's so late in time. A lot of things would've happened in between.
Q. Do you infer anything from the thermal imaging about which side of the window would've been getting the most heat in terms of temperatures inside the compartment?
A. Again, I mean, clearly at that point it is clear that

those are the areas that seem to be the hottest.
Q. Just to be clear, which areas do you think?
A. The areas are in yellow.
Q. Yes.
A. But as you can see, still the temperatures are 150 degrees. So clearly there is a concentration of heat in there, but it is more the smoke layer type of heat.
One of the things that many times our thermal images cameras mislead us is the different materials have different emissivities. So while the camera might think it is reading more heat, it might actually reading less heat it's the material that is emitting more energy.
So I wouldn't make too much out of that image other than the fact there seems to be a slight concentration of heat in that area.
Q. You have concluded in your report that you think the most likely route of ignition of the facade is by flame of exposed flammable materials in the window surrounds; is that correct?
A. Yes.
Q. Does that remain your view, despite reading Professor Bisby's report?
A. That remains my view from a physical perspective, I think that that is the case, but I do not discount by

any means, you know, what the visual evidence might show, because clearly, as I say, you can have a random sequence of ignitions that can actually lead to an external ignition. So I cannot discard that as a possibility.
Q. Can you summarise for us why you think that's the most likely route?
A. Fundamentally because the fire dynamics will tell you that the highest temperatures and the closest proximity to the flames is going to be in the compartment. Anything outside the compartment is going to be colder and further unless you find the path of ignition after ignition that brings you there, and that you can only tell by a detailed analysis of images.
Q. Can we be clear on what you think the most likely path is. So we've talking about the melting and deforming of the uPVC --
A. Yes.
Q. -- possibly via the smoke layer itself --
A. Yes.
Q. -- without any direct flame impingement.
What's the next thing you think is most likely to have ignited?
A. That's impossible to say because all the materials in there will have ignition temperatures that are lower

than the temperatures that the flame could provide. Effectively, as soon as the flame reaches a certain size, you will create a condition by which any of these materials could ignite.
Q. What materials are we talking about here? Let's be clear what the candidates are. We talked before by reference to the photograph of immediately behind the uPVC we have the insulation.
A. Yes.
Q. The small layer of insulation that we have top, bottom, left and right; is that correct? That's PIR insulation --
A. Yes.
Q. -- around the window.
Then we also have an EDPM membrane on the column side.
A. Yes.
Q. Do you think those two are both candidates for --
A. So is the uPVC.
Q. Itself?
A. Of course.
Q. From there, if those materials had ignited around the window sides -- let's take the column sides, so we have the insulation, the EPDM membrane -- what happens then in terms of the column? What's next?

A. Then you will get flames into a cavity, and effectively you are affecting the ACM panel, you are affecting everything. So what follows after will be just the progression of the fire through the space, and it could come out as easy as it went in.
So, in principle, the sequence that follows after is, again, almost impossible to detail step by step. But all the different components as you could see in the previous photograph that you showed, they're all so much in proximity that there is no question that there will be a sequence of ignitions of all of them.
Q. So you think all of those would have ignited as part of the path out?
A. Yes.
Q. It's right, isn't it, there were no cavity barriers around the windows?
A. I don't believe so.
Q. You've calculated that a fire with characteristics similar to that of a kitchen fire, if placed within 3 metres of the window, is capable of igniting those combustible materials adjacent to the window; is that correct?
A. Yes.
Q. For example, you've said in your report that a fire at floor level of just 20 kilowatts is capable of igniting

materials at windowsill level, ie at the lower parts of the level.
A. Yes.
Q. Again, what materials are we talking about there?
A. Basically we took as a reference the ignition temperatures of all of them, so it could've ignited any of them.
Q. As you say, you've also looked at fires behind an obstacle because of the fact that it may have been behind the fridge; is that correct?
A. Yes, where the two bounding -- so the fire that is unobstructed is the smallest possible fire and the other extreme will be the one that is fully confined behind an obstacle.
Q. In terms of that fire we were just discussing behind an obstacle and then a ceiling jet across the ceiling, you've noted in your report that there was a strip of purlboard --
A. Yes.
Q. -- a kind of legacy strip of purlboard above the window on the flat side of the window before you got to the uPVC surround.
A. Yes.
Q. Is that something that you remain interested in?
A. Yes, because obviously that will be the one that will be

in closest proximity to a flame, so it would be the first one to be affected.
Q. So you think it's possible that the ceiling jet may have impinged on that first and then onto the uPVC or the insulation?
A. Yes.
Q. Do you think that's something that should be the subject of further consideration and testing at Phase 2?
A. I mean, I think that clearly it is important to try to have as many pieces of the puzzle as possible. Nevertheless, the importance to the overall outcome of what was the first thing to catch on fire is probably not that significant.
Q. It's right, isn't it, that the different materials around the window would've had different thermal inertias; is that correct?
A. Yes.
Q. That's the speed at which they flame, at which they pyrolyse and release combustible gases.
A. Yes. It's the speed at which they can absorb energy towards ignition.
Q. If something has a low thermal inertia, does that mean it's first to ignite compared to something with a material of a high thermal inertia?
A. Yes, a material with low thermal inertia will ignite

much faster.
Q. Is it right that the PIR insulation would've had the lowest thermal inertia of any of those materials we were just discussing?
A. Yes.
Q. Is it right that the polyethylene would've had the highest thermal inertia?
A. Yes.
Q. Do those thermal inertia values assist in working out which is likely to have been the route of ignition?
A. Not clearly, they just give you an estimate of what could've gone first. But these numbers are only valid in the sense that they had to be under exactly the same conditions. So if you have a flame impinging on the polyethylene but 10 centimetres away from the PIR, the polyethylene will ignite faster than the PIR.
So the way in which the fire evolves and how it interacts with those materials is really the dominant function. I mean, what we're talking about here is a very small fire being capable of igniting any of these things. That's the ultimate question.
What the sequence is and all the details is extremely difficult, because while they are related to all these material properties, they're much more related to where the flame was in relationship to the material.

Q. Again, just to test this a little bit more, what about the aluminium skins that we have on different materials? You've talked previously when we looked at the ACM cassettes that they had an aluminium skin that may well have been relevant in terms of whether it was first to ignite.
What about the PIR and the foil that is on the PIR?
A. The foil on the PIR and in as much as the aluminium skin are going to have an impact in trying to slow down ignition, that's clear.
The aluminium skin of the ACM being thicker obviously has a bigger impact, so it is actually quite difficult to ignite an ACM panel. But all these things, again, you know, they do have an impact. So obviously exposed PIR will be more susceptible to ignition than PIR covered by an aluminium film.
SIR MARTIN MOORE-BICK: Just help me with this: is the purpose of the -- because it's a very thin skin of aluminium, isn't it, on the PIR? Is its function to dissipate the heat or exclude the oxygen or what?
A. Its function is to actually -- it's not to dissipate the heat in this case, although it does have a reflective -- so part of the heat gets reflected out. Its function is mostly to separate the fuel from the oxidiser. So that delays the whole process of ignition. Because once the

material reaches the point where it starts evaporating, it still has to reach the oxygen before it ignites, and the barrier serves to block that transfer.
SIR MARTIN MOORE-BICK: Thank you.
MS GRANGE: Do you think that the exposed sides of the insulation in the columns -- so they had a foil face but they had exposed sides -- might be significant in this context?
A. Well, they are going to change the outcome, in the sense that the exposed sides will ignite faster than the areas that are not exposed. But in this context, I think, given, as I say, the proximity of all these materials, the complexity of the cavity, and the nature of the fire event, it's extremely difficult to figure out to what extent that would've mattered or not.
Q. Can we look at a picture of that just to orientate ourselves on that.
If we go to figure 8.37 in Dr Lane's report, that's BLAS0000008 at page 35.
So this is a picture where we can see the column insulation, which was 100 millimetres, with the foil skin. The ACM column panels have been taken off, so we see it inside, and we can see the exposed edge there.
Is that what you were just talking about?
A. Yes.

Q. You are saying, therefore, that may have played a slightly different -- in terms of if it's got into the column, you've got potentially an exposed edge there.
A. Yes. But, again, going back to the point I was making, you will see also other materials involved a very intricate geometry.
From an idealised perspective, a designer would like to be able to model performance. So I would like to be able to create some calculations that allow me to tell you what the performance is of the system.
Here we have designed and built a system, and we've made it so intricate and complex that we have no capacity to be able to predict performance.
So when we are discussing these little details, we have to put that into context, that effectively this is such a complex system that being able to say, "This is how it went and this is the direction and it jumped from here to here", is a complete impossibility because the system is way too complex.
Q. Can we also look at figure 10.10 of Dr Lane's report. That's BLAS0000010.
So here what we're seeing is we're looking at the column -- let's focus on the right -- we're looking at some on the column panels, the ACM panels covering those columns, and we can see that she's highlighted some exposed PE cores where it's been cut in relation to those columns.
Again, do you think that that could've been significant in terms of the route of fire spread out of flat 16?
A. Again, you know, all those elements are potentially significant, they could potentially have an influence. But once again, I mean, look at the complexity of the system. Being able to predict to what extent it mattered to me is completely overwhelmed by the fact that you have a very small fire in the interior that can actually have the capacity to ignite any of those components. That at the end remains to me the bottom line. The details are very, very difficult to articulate in a separate way.
MS GRANGE: I now want to turn to the visual evidence which, as you say, Professor Bisby has considered in a lot of detail.
I'm about to play Professor Bisby's video, so I want to repeat the trigger warning at this point. We're now going to be showing a video of the early stages of the fire at Grenfell Tower at the east face. This contains images and audio that some may find distressing.
I'm then going to be asking you about a number of stills that we see in relation to that visual evidence.

I'm going to just play the first part of the video, approximately 8 minutes, and we're going to look at the time period between 01.05 and 01.17 in this video. We're going to stop it there.
So if I can now --
SIR MARTIN MOORE-BICK: Shall we just pause for a minute because -- well, I can't see anyone making to leave this room, but there might be people in the overflow room who might want to get out.
(Pause)
All right, shall we go on then?
MS GRANGE: Yes. So if I can now play that video.
(Video Played)
Can you stop that there.
I've shown that now because that passage is going to be relevant to a number of topics that we're going to come to in a moment.
That visual evidence has been addressed, as you say, in Professor Bisby's report. Can we just turn up what Professor Bisby has said about it in particular. If we look at his report, LBYS0000001, at page 145, paragraph 692 to start with.
If we can just zoom in on that -- that's great, yes.
So there he says:
"Since I submitted my initial Phase 1 — Expert

Report, additional video evidence of the early fire spread to the cladding — taken from outside the tower — has become available ... This shows that, beginning at approximately 01:11:45 ... molten material is burning on the upper surface (i.e. sill) of the spandrel rainscreen cassettes immediately below the kitchen window of Flat 16. This is coincident with external flaming venting through the hole created by the failure and movement of the extract fan and infill panel. It is considered likely that this burning material is melted PE filler from the ACM cassettes located directly above the window. It should be noted that this material could also be XPS core material from the window infill panel housing the extract fan; however, I consider this less likely."

Just pausing there, can we look, before I ask you some questions about this, at figure 65 of Professor Bisby's report, which is a still which he's referring to there.

That is at LBYS0000001 at page 122, figure 65.

If we can zoom in on 65 at the bottom.

Professor Bisby appears to be highlighting in particular at this point that we have molten material burning immediately below the kitchen window. Is that what we can see there in this photograph, burning on the

edge of the kitchen window?

A. Yes, I would agree with that.

Q. What conclusions would you draw from the presence of that burning material in that bottom left-hand corner of the window?

A. That clearly the ACM is already involved at that point in the fire.

Q. Do you think it likely that that burning material is melted PE filler from the ACM cassettes located directly above the window?

A. Most likely.

Q. Does that affect your view that the most likely route of ignition is by flame of exposed flammable materials in the window surrounds?

A. Not necessarily. I think you have to keep in mind that we're talking about 01.12. So if we take the moment in which the fire was noticed by the detector, we're already about 17 minutes into the fire.

Now, fires, before they start the period of growth, they sometimes have a very long incubation period where they might be just simply simmering in there, but they have the capacity, depending on their location, to activate the detector. So the detector could have detected the fire at that very early stage and could've given us maybe 5, 6, 10 minutes of incubation before the

growth started. In that case, then that conclusion will be probably most appropriate.

But if the incubation period would've been very short, then all the major events would've happened in the first 10 minutes. So effectively that would've been too late and most likely would've ignited from the inside before.

So there's a lot of uncertainty on the way in which the fire actually evolves at the beginning, and the fact that we have an alarm doesn't necessarily tell us what was the stage of the fire and how long it will take it before it starts affecting things.

In a similar manner, the image is what we're seeing from the outside, so we have no capacity to see what is happening behind.

So I think this is a very important piece of evidence that shows you that there is significant involvement of the external cladding in the fire at this point, but it is not necessarily conclusive that that is the only way in which the fire could have ignited, because it really depends on the way the fire evolved and that's something we will probably never know.

Q. When you talked a moment ago about "we know we had the alarm", are you talking about the smoke alarm going off in flat 16?

A. Yes.

SIR MARTIN MOORE-BICK: If we look at that picture on the screen at the moment, would it be right to understand that the whole of the area surrounding the window is now involved in the fire?

A. Potentially, although not necessarily. Cameras saturate very rapidly, and then the smoke reflection and numerous different things. So at that distance, it will be quite hard to pinpoint exactly what sectors are actually burning. But because of the demarcation lines, it is quite clear that there is a significant event going on in there.

SIR MARTIN MOORE-BICK: All right, thank you.

MS GRANGE: If we can just finish off what Professor Bisby says, then. If we can go back to LBYS000001 at page 145, and look at paragraph 693.

There he says:

"If the external cladding was first ignited (and sustained burning) due to heat from flames venting from the kitchen window of Flat 16 (i.e. by an external fire plume (see Drysdale [1]), one would expect to observe the earliest evidence of dripping burning ACM PE filler originating from the location directly above the fan mounting and inward swinging kitchen window that was located directly beneath the extract fan panel. The dripping PE would most likely originate from directly above the extract fan panel. However, as already noted the available visual evidence presented in this section suggests that dripping, burning PE spears to have first been observed falling from the base of the window at its southernmost edge."

So would you agree with Professor Bisby in what he's saying in that paragraph, that you would've expected the dripping and melting ACM, had it been as a result of the flaming through the extract panel, to have been dripping and melting at the top of the window, not at the bottom left-hand corner of it?

A. Yes, I couldn't disagree with that, which doesn't mean that dripping could not have been happening inside that we couldn't see. So in many ways, this is the difference between putting some physical arguments and putting evidence from images that we need to contrast, because that's really what we have.

But I think the points being made are fundamentally correct and they stem from visual imaging. It's information that is extremely valuable that should complement the analysis from the inside. But it's very difficult to put a sequence of events and say which one comes first.

Q. Because what you're saying is you wouldn't see it if

it's come round the inside because it may have gone inside the column and been burning there before we actually see it visually on the outside.

A. Exactly.

Q. Can I take you back to another image. This is an earlier image at 01.05 from Mr Kebede's mobile phone.

If you go in your report to JTOS0000001 at page 56, line 1582. If we can focus in on that image there.

So this is a screenshot taken from the video recovered from Mr Kebede's mobile phone at time stamp 01.05.57.

Do you agree that this image appears to show flames around the extractor fan in the window of the kitchen of flat 16 and a visible fire plume behind the window?

A. Yes.

Q. Is it possible that a fire located by the wall or in the corner of flat 16 would've produced an adhered fire plume?

A. Well, firstly, I guess, we need to define the concept of what an adhered fire plume is.

Q. What is an adhered fire plume?

A. So when you have a fire, there is two types of compartment fires. There are types of fires where you have the smoke layer that dominates the problem, in other words what you get is gases that fill the

compartment, but there is no great motion going on. In those cases, the smoke would just simply spill and it will be adhered to the wall. So effectively you will have smoke just literally touching the walls and moving up.

Now, many times, for example, when you have a door open and you have some ventilation, what you get is a flow. So the fire acts like a pump and it pushes the smoke out, in which case you get a disattached smoke plume, because the smoke is pushed away by the flow that gets created in the compartment.

So in this particular case, given the fact that the door was closed, and given the fact that most of the openings were closed, it is very unlikely that you had high velocities inside the compartment. So it will be most likely that you have an adhered fire plume, in other words you will have the smoke touching the --

Q. Sticking to the surfaces.

A. Sticking to the surfaces and moving out.

Q. Yes.

A. So, effectively, at this point you do have ignition that has happened of a component that is partially in, partially out, and how that happened is very difficult to define.

Again, the interesting thing is that this is

10 minutes from the moment of the smoke alarm. So we already have 10 minutes of gap happening in there.

So as a symptom, that the fire is emerging out of the compartment is a very clear symptom, but it's hard to relate to anything else beyond that.

Q. Do you think this sheds any light on whether there might have been direct flame impingement from an adhered fire plume on the external wall materials at the head of the window?

I think what is being suggested is it comes out of the window where the extract fan has gone and sticks to the surface of the ACM cassette that we looked at before that's immediately above the window and ignites it that way. Do you think that visual evidence helps on that?

A. Well, basically what you have is a flame. Now, that particular flame will result in a heat flux that is applied to all that section, and effectively it is true that the flame will impinge.

This in size is a fairly small flame and it is entraining a lot of air. So the question here will be: does that flame have enough heat to be able to ignite the cassette? That question is one that we have not resolved, and I do think that probably, if that path is going to be followed, then that needs to be tested, because effectively it is not about having a flame, it's

about having a flame that is sufficiently strong to provide sufficient heat flux to be able to ignite the cassette.
Q. Just to be clear, I think both you and Professor Bisby have excluded the idea that the flame could've started in the extract fan and produced sufficient heat to then ignite the panels above; is that correct?
A. Yes, basically, if you do a simple analysis of the size of the flame, by the time you get to the cassette, even if it's adhered, the heat flux will have already decayed enough. That is quite unlikely that that is the only source of ignition.
Now, if other things are burning around, then it's a slightly different story, because you're supporting with an extra flame an already existing amount of heat. But just the fan by itself doesn't have the capacity to produce enough heat to be able to do that.
Q. Just a few more questions on this topic.
I've been asked to put to you that there was firefighter evidence from Firefighter Brown that when he was leaning out of the kitchen window and trying to squirt the hose back at the fire, he could see flames travelling within the cavity.
Now, that's certainly after 01.20. Is that of any assistance at all in terms of this question of breakout

from the compartment?
A. Well, the only information that that provides is the fact that the uPVC was gone, because he could actually see through, and the fact that there were flames in the cavity, that tells you that the fire had already progressed into the cavity.
So, if anything, the conclusion that you can make is at that point the fire service knew that the fire was in the cavity.
Q. But does it help us at all, his evidence, about break-out from the compartment?
A. It's too late.
Q. It's too late in time?
A. Yes.
Q. Finally on this topic, I've asked you before about the possibility that with additional ventilation in that room, in that kitchen, for example around the doors, and if the fire was not in the centre of the room but in a corner or against a wall, whether there could've been local areas within the smoke layer where temperatures could've been higher and might have melted, for example, the following elements: the window frame and its fixings -- is that possible?
A. Of course. I mean, it doesn't need the extra ventilation, it doesn't need the flames to be in any

particular position. Effectively what you have is a flame, and if the flame for whatever reason is tilted in a certain direction, it might be impinging on many of the objects that are there, and could potentially heat them up quite significantly.
Q. So you're talking about direct flame impingement potentially could've melted the window frame and its fixings. What about weakening the plastic thermal disrupter that held the two-part window together?
A. Everything is possible.
Q. And the XPS core of the window infill panels, which are to the left of the kitchen window?
A. Same. I mean, I think --
Q. It's possible?
A. Yes.
Q. Melting of the components between the ends of the window assemblies and the original structure.
A. These are made of aluminium, I presume.
Q. Yes.
A. So the melting temperatures are about 600, and so you will have to have -- you know, for melting of aluminium you will have to be able to demonstrate what kind of size of a fire you will be able to need to get to those temperatures. But, effectively, if you put it close enough, you will be able to get to those temperatures.

Q. I am now going to turn to some connected but different topics.
Compartmentation.
Do you agree that a high degree of compartmentation around each flat, enclosing every surface riser, the stairs, the lobbies, is the first layer in the layer of safety forming the basis of fire safety guidance in high-rise buildings?
A. Compartmentation is the one layer that not only gives you protection, but gives robustness to the strategy. It's very difficult to break the compartmentation.
So it's not the first layer of protection; it is a very important layer of protection because it's the only one that really brings robustness into the system. The other ones can all fail, and there's no recovery from them. So if the smoke detector doesn't work, the smoke detector does not work, while if the compartmentation gets a crack, you might get a little bit of a leak, but you still get a significant amount of protection.
So the compartmentation in itself provides that component of robustness that no other layer of protection provides.
Q. So you agree that's the critical feature in the design of high-rise buildings?

A. **For this type of high-rise building, yes, it is a critical feature.**
Q. Is it your evidence that in the event of any fire starting near a window at Grenfell Tower, there was a disproportionately high probability of fire spread into the cladding system?
A. **Absolutely.**
Q. You've said in your report that, based on your analyses, the size of the fire that could breach the uPVC and ignite the combustible materials around the window are within a range that can be considered a feasible event within a residential kitchen; is that correct?
A. **Beyond that; I think it will be an event that will happen inevitably in a kitchen in a residential house. So it has what I call a probability of 1.**
Q. Yes, I've been asked to ask you about that.
When you say it's got a probability of 1, precisely what do you mean by that? You mean it's inevitable?
A. **A fire of a frying pan is going to happen in a kitchen within the life of the building, and when we design, for example, for compartmentation, we design for a post-flashover fire. So we accept everything smaller than that is very highly probable, so we have to design our compartmentation to withstand a post-flashover fire.**
So, yes, I mean, this is an inevitable, perfectly

foreseeable event.
Q. You also say that because a fire of this nature can be expected, the building is required to respond appropriately. Precisely what do you mean by that?
A. **What I said at the beginning was that fires are very common events, but fires that create significant damage are rare events and we design buildings to make that happen. So we produce all these layers of safety to try to make sure that we turn a very high probability event into a very rare event.**
So the building is required to respond to deliver that so that a fire of this nature doesn't progress beyond a kitchen.
Q. I now want to focus for a moment, before we leave stage 1, on the end of stage 1, of breach of the compartment of origin.
Do you agree that, in principle, there is a defined point in time at which compartmentation is breached?
A. **Yes. I mean, obviously it is very hard to pinpoint exactly when that point is, but by 01.05 you already see dripping or burning polyethylene. So it is clear that at that point there is external propagation happening somewhere in there.**
So that already in itself gives you a clear idea that the fire is progressing in a manner that is

unexpected, because it is not a flame being projected outside and not igniting anything or propagating into other spaces; it is a flame that has barely come outside, but it is already creeping into the external components of the building.
Q. So that is your evidence about the time when compartmentation has failed.
A. **That's an estimate of time that I put as the end of my stage 1.**
Q. Which is 01.05 to 01.08, or 01.05?
A. **Well, 01.05 to 01.08.**
Q. A slightly different question: at what time do you think compartmentation had visibly failed, or is it the same answer?
A. **Well, it has clearly failed by 01.08/01.09, and there's evidence of failure by 01.05. So between those two times, you have an evolution of the images, as you saw from the video, that by the time you end the minute 01.08, it is very clear that you have external components burning. By the time you are in 01.05, you have the first evidence. So you have that range of time where it becomes absolutely clear that there is external burning.**
Q. Do you think that that is the point that firefighters ought to have realised that compartmentation had been

breached?
A. **I mean, that's a very difficult question to answer because it is: how do you interpret the images?**
Now, clearly firefighters are used to seeing flame projections, because a post-flashover fire will normally break the window and you will have a flame projecting to the outside.
Being able to identify that that flame is not a flame projection, but it is actually a flame that is creeping into the building, requires a level of training that enables them to understand the complex structural system, and that's a very different question.
Now, obviously by the time you get to 01.11, then it is fairly obvious. Pieces are beginning to fall down. So by 01.11 you can say it is clear that something is burning on the outside. But the interpretation is the hard part; it's how you interpret what you're seeing.
Q. At the stage that compartmentation is breached, is your evidence that ignition of other components of the facade and the external flame spread is inevitable in this situation?
A. **Yes.**
Q. You also say that the assumption underlying the stay-put policy or approach is no vertical flame spread; is that correct?

A. Yes.
Q. Is it right that once the compartment has been breached and you have ignition of the facade, it is going to be undermining and invalidating of the stay-put policy?
A. It invalidates by definition the stay-put policy, because it's based on a required boxing of the fire into one compartment.
Q. Is it your view at that point that once compartmentation is breached, egress or rescue rather than stay put is a preferred option?
A. It is my opinion that that will be the case.
Q. I now want to turn to stage 2 of your analysis.
You have stage 2 as covering the fire ascending to the top of the east elevation and the associated vertical fire spread, and that's between approximately 1.05 am and 1.30 am; is that correct?
A. Yes.
Q. I want to consider first the importance of this vertical fire spread.
You say in your report that the flame spreads rapidly from level 4 to the architectural roof detail in approximately 12 to 15 minutes from the establishment of flames on the facade; is that correct?
A. Yes.
Q. You also say that, in general, vertical flame spread is

much faster than horizontal flame spread, and this was the case at Grenfell Tower; is that right?
A. Yes.
Q. We heard something about this when Professor Bisby gave his presentation back in June, but can you explain again in simple terms why vertical fire spread is expected to be so much faster?
A. Yes. I think here it's really important to understand the physics behind it, because when we're talking about a fire, we're thinking about fuel burning with air and producing energy. That is the concept of a fire. If it's in a box, the energy will be used to heat up that box, and the energy is accumulating.
In the case of flame spread, it is extremely important to understand where the energy goes, because depending on where the energy goes, you have a capacity to continue to spread the fire, because if you think about it, it's the energy that you're producing that is heating up the other material until it makes it ignite and allows the flame to spread. So the flame is going to be jumping up as we provide energy and we heat the material and we allow that material to ignite.
So if I'm in a vertical wall and I'm producing energy here, the energy is going to go up, so it's going to start heating up all this area. So, effectively, all

the energy that I'm producing is being delivered to the material step by step.
So, effectively, I'm not losing energy; all the energy is going to where it's supposed to go. So it is heating up the material very rapidly and allowing it to ignite and allowing the flame to spread.
Now, if I'm trying to spread down, which is what we call opposed spread, then I'm producing the energy here, the energy's mostly going up, and only a minute fraction is going down because all the gases are going up, no? So effectively what you're getting is very weak spread because you have very little energy heating up the material and bringing it to ignition.
If you spread laterally, in that case what you have is the heat is going up and you're trying to heat on the side. Obviously the flames are sometimes going to tilt, so you're going to get a slightly better condition, but still, you are going against the flow because the flow is coming here and bringing the heat up.
So because all the heat is going in the direction of spread, vertical spread is going to be significantly faster than downward spread or lateral spread. Both cases are what we call opposed flame spread, where this is what we call forward spread.
The final nuance to this is that if I don't have

enough energy, it will not spread, while with vertical, I will always have enough energy because all the energy's going there, it just takes longer. So if this was a weaker fire, it will take slightly longer, but eventually it will get there. But here, because I'm fighting against cold air, I might not have enough energy, so it actually will not spread.
So in the case of opposed spread, you might get a condition where it actually just doesn't even spread at all, whereas in vertical spread, it will most likely go all the way up.
Q. You say this is all very well traversed in the available literature, including in Drysdale, who has vertical spread at ten times faster -- is that than horizontal fire spread?
A. I don't remember exactly the ten times faster, but I would imagine it would be the lateral, yes, the horizontal fire spread.
Q. You've said that whilst there's not much reliable data on the characteristics of other international fire events, the most common scenario is fire spread rapidly upwards, with very limited lateral fire spread; is that right?
A. Yes, because the third factor is the available fuel that you have. So if you don't have the capacity to spread

fast enough laterally by the time you've burned out all the material, then you stop having the energy supply and then it stops burning. So depending on what is the amount of fuel that you have, you will have a longer time to assist the spread. So if you don't have very much fuel, which is normally the case in this particular type of installations, then you will not be able to spread horizontally or downwards.

Q. You've given some examples of what you were just talking about. Can we go to those at figure 21. That's JTOS0000001, at page 59.

So you've given us three examples here: The Torch building in Dubai, the Lacrosse building fire in Melbourne and The Address building in Dubai.

Can you briefly talk us through each of those by reference to this concept of vertical flame spread, much more rapid, and less horizontal flame spread.

A. Yes. The most clear ones are the top two, so it would be The Torch and the Lacrosse building.

So as you can see, in The Torch building you have a very large fire that propagates upwards, and on the right-hand figure you will see in the left corner -- it's unfortunately a different angle -- the damaged area of the building, and you can see the very narrow strip that has propagated all the way from the bottom to the

top.

In the case of the Lacrosse building, you have a fire that starts in a balcony, in an air conditioning unit, and it spreads over the cladding all the way to the top. But as you can see from the right picture, there's only one row of apartments that gets affected and it never spreads laterally.

In the case of The Address, it's slightly more complicated because there is a bit of lateral flame spread in the case of The Address because, as you can see, it was a windy day, so the wind is carrying the flames to the one side. But the rate at which it propagated vertically was easily much more than ten times greater than the lateral spread, and eventually this fire dies on its own before it actually manages to go more than two and a half apartments.

Q. You said the available footage from these incidents indicates that once flames spread to the top, they proceed to decay and eventually extinguish; is that right?

A. Yes.

Q. You've actually quantified the flame spread rates in those other international fires compared with Grenfell. Can we just look at that. That's figure 23, at page 61 of your report.

Can you just explain to us here -- we seem to have lots of different fires at the bottom, and then what do we see in the graph?

A. Yes, so what you see in the horizontal axis is the different events from the Andraus building in 1972 all the way to the Grenfell Tower, and then you get an average vertical external flame spread.

Given that the quality of the images is not always consistent, what we opted to do here was just take a few data points that we could actually see and then just take an average, knowing that normally the flame spread starts slower and then it starts speeding up, so it accelerates at the end, but we didn't include that. That's why we have the error bars in there to show that, for example, the case of the Water Club, the maximum value was 25, the minimum value was 5. So it gives you a sense of the range. But the average value is the one that is important.

So as you can see, Grenfell falls in the category of the fires that actually spread slower.

Q. So we have Grenfell on the bottom right hand here, and it's placed amongst some of the slowest vertical fire spread rates.

A. Yes, with an average speed of about 4 metres per minute, as opposed to the extreme case of The Address, for

example, where you have about 22 metres per minute.

Q. You've said in your report that the expected heat fluxes on an external wall can be of a magnitude of 120 kilowatts per metre squared; is that correct?

A. Yes.

Q. Can you explain very briefly how you've calculated that? You've referred to the Agarwal global research technical report. Is it right that you've taken that as an extrapolation from that report?

A. Yes. So, effectively, if you look at the data that you have on internal compartment fires, you will find that internally you can get above 200 kilowatts per metre squared. So inside the compartment, you're going to have about 200. Once that heat starts coming out, it starts decaying, and it drops.

So this report by Agarwal effectively tries to use that information to create a test, and in their test, they try to create a profile of how this heat flux is going to decay. So it's going to go from this originally more than 200 inside and start dropping until it goes to about 5 or something lower than that.

So they produce a curve that stops at about 15 centimetres from the edge, or from the bottom, and that 15 centimetres is at about 112 kilowatts. So basically I just filled it up and put above 120, because

I know it has to go from about 200, you know, to 110 in that corner or that little part.
Q. I now want to discuss some of the architectural elements that might impact on the rate of vertical flame spread.
You've explained in your report that there's a complex interrelationship between a number of different elements of these kind of systems in terms of the impact on vertical flame spread; is that correct?
A. Yes.
Q. And that you've got effectively multiple processes interacting with one another.
A. Yes.
Q. Can we focus for a moment on the ACM panels themselves.
Can we go to the text of your report, that's JTOS0000001, page 60, lines 1649 and 1651.
If we can just read that. You say there:
"The polyethylene infill was placed between two aluminium plates that will melt in the range 580 - 650°C. Thus, in the presence of a significant flame the aluminium would have represented no protection to the polyethylene. Flames are typically between 600°C-800°C, thus are hotter than the melting temperature of aluminium."
Is that correct?
A. Yes.

Q. So you've explained in your report that the high thermal conductivity of the aluminium is resulting in a heat transfer to the polyethylene infill; is that correct?
A. And also away.
Q. Away from it as well?
A. Yes.
Q. And the significance of the away from it?
A. That it can potentially melt it and produce a gap that splits the two panel faces.
Q. Exactly. We're just going to come to the splitting in a moment.
In fact, let's go to that. Let's took at your figure 26. Again, there's a new reference to that because the version in your report is not very clear. That's JTOS0000003, the bottom diagram.
So here, as I understand it, you've attempted to explain what processes are occurring when we get vertical flame spread with an ACM panel where you have aluminium on the outside and then the polyethylene on the inside; is that correct?
A. Yes.
Q. You talked a moment ago about the splitting -- you've got a little diagram there -- can you just explain that and the significance of it?
A. Yes. Would you mind if I actually stand up and point?

Q. Please do.
A. So, to me, this is where the great complexity of the system stands, in the sense that you have multiple layers, so you have the concrete structure in here, you have a material that is a charring material that eventually is going to consume itself, you have a gap between the two of them and then you have a composite system that has two layers of aluminium plus the polyethylene in the middle.
This polyethylene is going to melt as it heats up. The rate at which it heats up in the aluminium is going to result in altering the rate at which it's going to melt. So how this material is going to start falling off is going to depend on how fast the heat goes through the aluminium.
Now, how fast the heat goes through the aluminium depends on if you have a fire inside or you have a fire outside. It depends on the wind that you have, it depends on the width of the cavity, and it depends on how the insulation is burning.
So, effectively, you have all these systems of incredible complexity all interacting with each other to try to give you the final outcome, and eventually the system is so complex in nature that it's almost impossible to predict what is its true behaviour.

Q. So when we were talking a moment ago about these complex systems with multiple processes interacting, that's what you're trying to show in this diagram; is that right?
A. Absolutely. So this diagram basically gives you a schematic that is actually quite simplified of all the different processes that you can actually have all interacting with each other in one of these particular systems.
Q. One of the things you say in your report is that the aluminium provides no protection to the polyethylene inside. Can you explain precisely why that is?
A. Yes. So if you have a flame here, and that is a very significant flame that has already been established, that flame is going to have heat fluxes that are quite significant and can bring the aluminium far above its melting temperature. So you might have dripping of the aluminium.
Not only that, you're going to have melting of the polyethylene, which results in splitting. So you will have the two of them separating, so the flames are going to creep inside. So the aluminium cannot be seen once the flame is established as a protection to the polyethylene, it is just simply a barrier that is going to disappear very rapidly once you have a flame that is established.

Q. You've also highlighted in your report the important role of these open vertical cavities, these open vertical columns.
You've said that the acceleration of vertical fire spread can be explained in part by these channels producing chimney effects.
A. Yes.
Q. Is that because flames elongate possibly up to five to ten times in a concealed space; is that right?
A. Well, what happens is that, depending on the size of this gap, if this gap is too narrow, it's going to block the oxygen and the flame is going to try to creep outside. In that case, it will not spread.
Now, as I start increasing this, what you create is a chimney effect, and this flow becomes very dominant. So you get a flow that is going in that direction and is carrying the fuel away, so it's elongating the flame and allowing it to spread much faster.
Q. You say that the width of the cavity is playing a fundamental role in terms of determining the flame spread?
A. Absolutely. So if you make the width of the cavity very, very small, you might end up choking the fire because the air cannot get in, but as you start opening it up, you might accelerate it. But as everybody knows,

if you make a chimney too big, it doesn't draw the air, so in that case you will start decaying again.
So it's a very sensitive parameter that can have a huge impact on the outcome. But it's difficult to know if it's going to be beneficial or detrimental, because it also depends on all the other interplay. For example, if this material burns very vigorously, it's going to have a huge impact on the temperature in here and the nature of the chimney.
Q. We're going to come to that material in a moment.
When you say "this material", you were pointing there, I think, to the PIR insulation; is that right?
A. Yes.
Q. We'll come to that just in a moment.
Have you specifically considered the width of the cavities created by both the columns and the spandrels at Grenfell Tower in terms of its impact on vertical flame spread?
A. No, I don't think I have the capacity to be able to consider that in a quantitative way and establish how that width is going to determine a flame spread.
Q. Do you think that, in general terms, the presence of that cavity would've promoted vertical flame spread?
A. Not necessarily. I do not have a clear opinion of it. I think clearly it would have influenced the nature of

the flame spread, but I'm not 100 per cent sure if it's going to be detrimental or positive. But the cavity clearly has an effect.
Q. Does it have an effect -- we're going to talk about this in a moment -- combined with the PIR insulation? If you have a cavity where the insulation is on fire or flaming, does the fact that you have a cavity there potentially grow in importance?
A. Well, absolutely. Well, I think that if you have a cavity in here, and you have a material here, you're going to hit an exchange of heat between these two. So not only the PIR is going to support burning within the cavity, but actually the cavity and the burning in the cavity is going to support the burning of the PIR.
PIR requires a fairly significant heat flux to continue to burn. So if I was to remove everything and eliminate the cavity, it is very likely that the PIR will extinguish. But if I put all this ensemble, and I have this exchange of heat between all the surfaces and the flow and the burning in between the cavity, I can sustain the burning of the PIR.
So all these things are playing with each other in this system at a level of complexity that is incredibly difficult to come up with a prediction of what leads to what.

Q. We will come on in a moment -- and we may have to do it after the break -- to look at the PIR in a bit more detail.
You've referred in your report to other complex geometries of the system that might affect the rate of fire spread.
Would you agree that angular geometry, including, for example, wing walls or re-entrant corners, might have played a role?
So take, for example, column corners, where we have an angle of 135 degrees as between the column and then the face of the spandrels.
A. It would have most definitely played a role. I think the most difficult question to answer is: would it actually help the spread or deter the spread? That's a question I have no capability to answer.
Q. How could it have deterred the spread?
A. Because if you look at the geometry, it is all about how the heat is being exchanged. So if I have something, for example, that has an angle like this (Indicates), then the way in which the heat is being transferred from one surface to the other one is actually far. So if it's sufficiently far, this might not have ignited, in which case it represents a barrier.
But if I slightly move it, and I put it close enough

and then it ignites, then the two of them are exchanging heat with each other, in which case it will become much faster.

So it really depends on the detailed characteristics. And many times, unfortunately, it will be even coupled to the conditions of the day. If it was a windy day, maybe 130 degrees would not be enough, you would need 140 to stop the spread.

So all these things -- we can really not ignore the level of complexity of what we're talking about. This really is not a very simple system, it's an incredibly complex system.

Q. As we discussed before, the presence of films or skins or coatings on material, they have the potential to affect the vertical flame spread?

A. Absolutely. Films that are combustible are what we call thermally thin. Materials like paper. So, for example, a log of wood is thermally tick, and a log of wood will have a very, very hard time burning on its own because it's a big bulk of material. So if I take the log of wood out of the chimney, it will extinguish, while a piece of paper, which has the same composition as a log of wood, because it's very thin, it will burn very easily.

So thin films, when they're combustible, will have

a significant impact on spreading flames.

Q. Just to round this off, then, can we just go to what you said at lines 91 to 95 of your report. That's JTOS000001 at page 4.

If we can highlight in our 91 to 95.

There you say:

"Details of the cladding will have an impact on flame spread rates, although in the case of Grenfell Tower, upward flame spread rates are not uniquely fast. A comparison with other international events shows that upward flame spread for the Grenfell Tower is among the slowest. It is therefore possible to ascertain that detailing of the facade system (as opposed to its material composition) has only a minor impact on the evolution of this fire."

Can you explain for us why you say that, particularly in that last sentence?

A. When we design this type of facade, we introduce all sorts of different components that are intended to slow potential flame spread or to protect -- like, for example, the thin film in front of the PIR and the cavity barriers and so forth. So we put all these components in principle to try to reduce the rate of spread.

Now, if you compare the spread of Grenfell Tower

with most other international events, and you see that actually the spread rate is not among the fastest, it's actually on the lower end, you can tell that all these things more or less worked okay to try to slow the spread. But effectively they didn't solve the main problem, which is the fact that we had a combination of materials that could sustain the problem.

So I could've put many other of these little corrections and probably would've not made even any improvement, and some of the faults that you might find in some of the components might have not been responsible for any worse behaviour. What we can see is that given the type of materials that we have, we are more or less at the baseline of the type of spread that we're going to have.

Q. So you're saying that the important thing is the material composition of those materials --

A. Yes.

MS GRANGE: -- here, yes.

Sir, I think that is an appropriate moment.

SIR MARTIN MOORE-BICK: Is that a good point?

MS GRANGE: Yes.

SIR MARTIN MOORE-BICK: Well, time we had a break for some lunch, professor. So we'll stop now and we'll come back and resume at 2 o'clock.

Again, I'm going to ask you not to talk to anyone about your evidence while you're out of the room.

THE WITNESS: Thank you.

SIR MARTIN MOORE-BICK: All right? Thank you very much.

All right, 2 o'clock, please. Thank you.

(1.00 pm)

(The short adjournment)

(2.00 pm)

SIR MARTIN MOORE-BICK: All right, professor, ready to go again?

THE WITNESS: Yes.

SIR MARTIN MOORE-BICK: Good, thank you.

Yes, Ms Grange.

MS GRANGE: Thank you.

I just want to return to one aspect of your evidence this morning and then I'll pick up where we left off on vertical flame spread.

You said for this type of high-rise building, compartmentation is critical; yes?

A. Yes.

Q. Do you mean a high-rise building with a stay-put strategy?

A. Well, it would be even more critical with a stay-put strategy, but it also applies to buildings with stage egress and simultaneous evacuation.

Q. You agreed with me that once compartmentation is breached, evacuation becomes the preferred option; yes?
A. When vertical compartmentation -- yes, when the fire starts spreading beyond the floor of origin.
Q. Would you agree that once compartmentation is breached, evacuation is necessary to secure the fire safety of those in the building?
A. Yes.
Q. Is it the only viable option at that point?
A. Yes.
Q. I just want to return to the importance of the PIR insulation. We were just talking about it before the break.
Just to be clear, just to kind of remind ourselves, there was PIR insulation behind the spandrel panels, the ACM panels, in two layers of 80 millimetres, and also a single layer of 100 millimetres on the columns. That was Celotex RS5000 PIR insulation.
There was some Kingspan K15 phenolic foam boards also used on some of the spandrels, also that's possibly only about 7 per cent of the total insulation. Just to be clear what we're talking about here.
A. Yes.
Q. As we've discussed, PIR has a low thermal inertia, and you've agreed that that means a low time to ignition.

You've also said that the PIR is liable to char.
A. Yes.
Q. Can you explain what impact those features of the PIR -- ie low thermal inertia and propensity to char -- have on flame spread?
A. Yes. The low thermal inertia results in very little energy required to ignite the material. All the energy gets stuck very close to the surface. So with very little energy, you can bring the surface to a temperature of ignition and it starts burning.
When a charring material starts degrading and burning, it produces a layer of carbon that effectively starts protecting the material behind.
So as opposed to a non-charring material that will burn completely, this material will burn only a fraction and the layer that is produced prevents the heat from burning any further.
So you need to have some heat from the outside to help it burn. The moment you remove the heat from the outside, it tends to extinguish on its own because, effectively, no heat can get from the flame to the fuel to keep evaporating the fuel.
So the charring has one fundamental outcome, which is that it will reduce the fraction of the mass of the material that is actually going to burn and leave this

big residue of carbon, and that big residue of carbon is going to eventually lead to extinguishment of the material itself. It's going to stop burning on its own.
Q. You've explained in your report that the features of the PIR give rise to the potential to burn for a much longer time period.
Again, first of all, what data or other information have you relied upon when you say that the PIR has the potential to burn for longer periods?
A. Well, this is relative, and the reason why it's relative is because the duration of burning is a function of the total mass that burns. So if you have a certain thickness of PIR, that will give you a certain amount of mass, and that certain amount of mass will determine how long it's going to burn.
Now, obviously, the mass that you're considering is the fraction that burns, not the fraction that remains as char. So when you compare the amount of mass that you have of PIR, compared to other combustible materials like polyethylene or the EDPM, the mass of PIR is more significant and, therefore, it has a propensity to remain burning for a fairly long period of time relative to the other materials.
Q. Can you just explain your view about the interaction that we may have got on the building between the ACP

panels and the PIR insulation?
You talk, for example, about radiative feedback. Can you just explain what radiative feedback is as between those two?
A. Yes. As I mentioned, the PIR by itself, it will self-extinguish. So effectively the char layer forms and, unless you put an external heat to try to keep the burning going, it will just fade out and die. So when you have the polyethylene burning in front, that polyethylene provides that extra source of heat. That's what we call radiative feedback. So between the two of them, they are supporting each other.
So what we see in the images of the burning of the tower, it's quite complex in the sense that there is different forms of behaviour. There's certain areas where you have fairly intense burning, where that radiative feedback is having both materials burning quite significantly. But then, later on, when you see the PE has disappeared, then you will have self-extinction of the PIR and you get residue of unburnt PIR left behind.
So eventually you will get multiple forms of interaction, and the question if it's going to continue burning or not continue burning is a question of how the two of them are interacting in any particular location.

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Q. How does the PIR affect the rate at which the aluminium composite panels burn?
A. That is a very difficult question to answer, but I believe that it is likely that the PIR will have a minor effect on the rate of burning, because the polyethylene, being thermally thin, once it ignites and starts spreading, it will spread at a much faster rate than the PIR.
So the support that the PIR can provide to the rate of spread is probably of secondary importance.
Q. Why does the fact that they're going to burn out at different stages matter in terms of the development of this fire?
A. Because one determines the rate at which it spreads, the other determines how long it's going to be burning. So while the second one is still burning, dripping and all sorts of other potential interactions that can happen between the two of them can extend the duration of burning at any localised space. So effectively it's that interaction, that one is determining the speed at which it's propagating, the other one is basically keeping that area burning.
Q. Just briefly, because we'll get into testing in much more detail at Phase 2, Professor Bisby has drawn attention to the DCLG tests after Grenfell which

compared PIR with mineral wool insulation but using otherwise similar materials to Grenfell.
Do you agree that a complex but different interaction will also apply to a system incorporating a mineral fibre insulation and a PE-cored ACM?
A. Yes. It will be a different interaction because the mineral material will not burn by itself. Nevertheless, it still has the capacity of insulating; in other words, it can support the continuous burning of the ACM, and also it can absorb dripping fuel and it can serve as a wick to keep things burning.
So there will be other forms of interactions that the mineral wool will have with the ACM that could potentially lead to no difference or a significant difference, depending on the characteristics of the assembly.
Q. Would you say that the current evidence is inconclusive on the precise role played by the presence of the PIR at Grenfell and that further testing would be helpful?
A. Yes, I think that while it is clear that some level of interaction exists, it is not really clear exactly what is the level of interaction that is occurring, and it's actually even less clear what would've been the outcome in the absence of one or the other.
I think the standard testing evidence that exists

right now, the particular tests that are being conducted, and that's BS 8414, is a test that in many ways doesn't give enough detail to be able to come up to any real conclusions. It doesn't have adequate instrumentation and the scenario is a scenario that doesn't really honour the complexity of the system.
Q. So in terms of those DCLG tests after Grenfell using the mineral wool insulation, what significance do you place on the results of those tests?
A. I would say very little.
Q. You've said it's very difficult to quantify the impact that the PIR insulation had.
At this stage, in terms of your preliminary view, can you give an overall view as to whether you think it had a contribution and, if so, broadly in what respect?
A. It clearly did have a contribution, but I would not be able to say what kind of a contribution it had, if it was very significant or mildly significant. But clearly there is burning of the PIR and there's evidence that it had been contributing to the energy that is being released.
But to quantify that to the extent of being able to say how important that was is still not very clear.
Q. In terms of the state of the building after the fire, would you attach any significance to any areas where,

despite extensive charring of the insulation, the ACM remains intact? Does that tell us anything?
A. Not really. I mean, once again, it is one of those situations where the complexity of the interactions is such that there might have been a convergence of different things that effectively led to an area where the insulation burnt first and then the ACM never caught fire. So that is a possibility. A very good example would be areas that were wetted by the firefighters, for example.
Q. Yes, I was going to ask you. For example, on level 3 it's been suggested that there were some areas where there was deep widespread charring to the insulation but where damage to the ACM panels were much more minor, insignificant. That's level 3. Does that tell you anything?
A. The only thing that I could probably conclude from that is that there was some element of cooling going on, and that would have -- the cooling wouldn't get to the insulation, so the insulation might still have been burning through the cavity, while the external part of the ACM was being protected by the water from the firefighters.
Q. What about any evidence on the corner columns where there might have been soot deposition at the joints of

the panels, suggesting that the fire was burning behind the panels rather than on the exterior? Does that have any significance in terms of the contribution of the two materials?

A. Well, it's significant in the sense that it actually does show that the PIR at least to a certain extent can actually burn in the absence of the ACM.

Now, the real question is -- I mean, you might have soot deposition after the fact, but that could've just simply been from a very, very short period of burning. So the PIR could have extinguished very rapidly and we would not have been able to tell that unless we did a very systematic analysis of cross-sections to see the charring thickness.

Q. Do you think it would be helpful or, indeed, practicable to do a survey of the insulation to try to work out what remained after the fire versus what remained of the ACM or other components? Do you think that would be a helpful exercise?

A. I do believe so, because in many ways the interactions between the two materials or the two systems are relatively unknown, and it will be very important to be able to establish if one can burn without the other one and to what extent that can happen. All those details can only be done with a very detailed and general survey

of the remnants of the insulation.

Q. Is that something you think could be done at Phase 2, based on the existing evidence?

A. Well, I mean, I think if the insulation was available and properly catalogued, yes, something that could be done.

Q. We could to do that, yes.

Going back to the other international fires we looked at earlier, the Dubai fires and the Lacrosse fire an Australia, did those other fires involve PE-cored ACM panels?

A. That's difficult to know. I think that unfortunately the information that is available in most of these fires is generally quite inaccurate, most of it coming from the media.

There are reports on all the details of -- the one that is well investigated is the Docklands fire, and there's details of all the materials in there, and the report is publicly available --

Q. Is that the same as the Lacrosse fire?

A. Yes, the Lacrosse fire, yes.

Q. Yes.

A. So I wouldn't be able to say off the top of my head exactly what was the insulation material, but we reviewed all those. But it was difficult to establish

any kind of correlation between them because one of the terrible things about most of these incidents is that they were very poorly investigated, and none of the information was ever made public. So it's very difficult to come up with a good correlation of what was in each of these events.

Q. Do you know whether any of them featured mineral fibre insulation as opposed to a PIR-type insulation?

A. I wouldn't know.

Q. Let's move on, then. I want to ask you some questions about the white window infill panels for a moment.

Just, again, to orientate ourselves as to what we're talking about, can we look at a figure in your report, figure 24, that's JTOS0000001 at page 62. If we can focus on figure 24 at the top of that, it's the right-hand image.

So the white infill panels we're talking about are the ones we can see down on the bottom right-hand side; is that right?

A. Yes.

Q. That are in between the windows in each of the flats.

These were extruded polystyrene, is that your understanding?

A. Yes.

Q. Often referred to as XPS, extruded polystyrene?

A. Yes.

Q. Dr Lane has estimated in her report that these panels made up approximately 13 per cent of the external surface between levels 4 and 23.

Again, is that consistent with your understanding?

A. Yes.

Q. Professor Bisby has set out the properties of XPS in his report, that it has a melting temperature of 230 degrees C, compared to, for example, 130 degrees C of PE; is that correct?

A. Yes.

Q. There's no figure given for thermal inertia, it just says that they melt; is that right?

A. Yes, they tend to melt. They generally have a very low thermal inertia.

Q. Do you think these white window infill panels could've played a role in terms of the vertical flame spread we saw at Grenfell Tower?

A. I mean, the issue with those white window infill panels is the cover. The nature of the cover was slightly different to the rest.

Now, clearly because they have an infill of a combustible material, they will play a role, and if it was a significant or more or less significant role, that is mostly associated on how they are protected.

Q. When you talk about the cover, is what you're talking about the fact that there's two skins of aluminium --
A. Exactly.
Q. -- and then the XPS inside?
A. Yes.
Q. The aluminium skins, I think, are 1.5 millimetres thick.
A. Yes.
Q. Something like that.
So you're saying that the fact that you've got those skins on the outside affects the potential for them to contribute to vertical flame spread?
A. Yes. This is the basic concept of encapsulation. So when you have a combustible material that is exposed to the outside, it is encapsulated, and the thickness, the characteristics of the encapsulation you put is going to make it more or less susceptible to engage in the flame spread.
Eventually, given the nature and size of the fire, it is quite clear that they would have participated in the process. How late or how early would've been determined by the capacity of the aluminium layer to.
MS GRANGE: Protect them from the flames.
Q. Dr Lane has an image in her report which she says potentially shows vertical flame spread through those Aluglaze panels. That's BLAS -- sorry, actually, before

we go to this, can I give a warning that I'm about to go to an image of the tower on fire, so if anybody's going to be distressed by that, they should leave now.
(Pause)
Sorry, I should have given a warning before the last image of the burnt-out tower.
SIR MARTIN MOORE-BICK: That's all right. You've given it now.
MS GRANGE: So BLAS0000010, then page 39, figure 10.37.
In fact, the corrected time for this is 1.29 am, not 1.26, although I don't think that matters at all.
Dr Lane has highlighted there with little blue dots where the insulating panels were on the building. This is on the east face.
Do you think that that potentially shows that we are seeing some vertical fire spread across those Aluglaze panels, particularly in the higher levels of the building?
A. Well, we are seeing them burn. If you look at those images, what you see is that the panels are burning to the left of the -- the burning has reduced.
So just by looking at the image, I could possibly say that, in this particular case, the panels were igniting, they were contributing to the burning, but the aluminium protection layer actually prevented them from

being the ones driving the burning, they were just burning a little bit later than everything else.
But I think that the same way this image is there, I believe there's others where you will see slightly different processes.
So it's something that I think, again, the interactions between the systems is quite complex. So in some cases you will get one side burning faster, in other cases you will get another side burning faster.
Q. Is it possible that one of the mechanisms by which these ignite and then melt is that you then get a pool of XPS formed at the base of the panels which could then ignite? Is that a possible mechanism of failure?
A. It could potentially be, but generally XPS is a very low density material. So when it actually melts, it produces very, very little liquid fuel. It's mostly air.
So, in principle, the exact density is not very clear, what was the exact density of these materials, but in principle, as a pool fire, probably the contribution will be secondary.
Q. Do you think that these panels could've contributed to the total heat release rate during the fire on the facade?
A. Well, everything would have.

Q. Yes.
A. But keep in mind that their mass is relatively small compared to everything else, so the total amount of energy they can release is actually less.
Q. These window panels are mentioned in three of Dr Lane's potential flame spread routes: horizontally across the edges, top and bottom, vertically along the sides, and then this route, which is vertically across the panels up the length of the tower.
Do you agree that those are potential mechanisms by which these panels could've contributed to the flame spread?
A. They're all clearly potential mechanisms, but given the nature of the protective aluminium plate, I would imagine that anything that is vertical will be a mechanism that we should need to consider. For this type of materials horizontal or downward might be a very minor mechanism of spread.
Q. Can I just ask you briefly, then, a different material, the EDPM membrane. That's the damp-proof membrane --
A. Yes.
Q. -- that's there on the columns between the windows and the columns. So after you've got the insulation, you've got the EDPM membrane, a thin, black membrane, then you're into the columns.

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Have you done any work to look at whether that could've contributed to vertical flame spread?
A. That would have contributed, as all the other components. In this particular case, it is thermally thin, so this would've been a material that would've spread quite rapidly. Its particular location, might not necessarily be as effective for vertical flame spread but, nevertheless, it's a material that will burn, its density is not low, so it will have a significant amount of mass, and it will contribute to the burning.
Q. I now want to come on to talk about the role of cavity barriers in the facade.
Can we just remind ourselves again, just to orientate ourselves, what these looked like on site. I'm going to show you some pictures of the open state horizontal cavity barriers. If you go to an image in Dr Lane's report, BLAS0000008 at page 42, figures 8.45 and 8.46.
So the image at the bottom is taken from the manufacturer's literature in terms of these cavity barriers, and then at the top we see an example of the installation of one of these, I think underneath one of the spandrel panels here.
Can you explain in general terms what a cavity

barrier is?
A. Yes. When you have a cavity, and particularly if that cavity has combustible materials, there is a possibility that a chimney effect can be formed that will actually maintain spread through the cavity.
The cavity barrier in principle is a mechanism by which you try to stop, so you close the barrier in such a way that you prevent the flames from progressing from one place to another.
Q. Is it right that this kind of cavity barrier has an intermittent strip that expands with heat to close the gap?
A. Yes, potentially, some of the solutions that we apply when we have intricate geometries and the cavity barrier cannot be cut exactly with the geometry of the material, you will put the strips of intumescent material. The intumescent material with heat, will expand, and it will allow the cavity to close.
Q. In your report, you say that no matter how well designed or implemented, you do not think the cavity barriers could've prevented vertical or lateral flame spread at Grenfell Tower; is that right?
A. Yes.
Q. Can you just explain why you're of that view?
A. A cavity barrier is a system that is designed to close

a duct when you expect that your propagation is within the duct.
If you put combustible materials outside the cavity barrier, the cavity barrier actually has no meaning, because effectively the burning can happen around the cavity barrier.
Obviously the cavity barrier will result in potentially slowing what is going on, because it will prevent part of the burning, but it's not going to stop the spread.
Unfortunately, the cavity barriers, once they've been overcome, then melting material can actually deposit on the cavity barrier and the cavity barrier in itself can become a mechanism of spread.
So in this particular type of scenario, the fundamental principle behind why we put cavity barriers is inappropriate because we have combustibles at both ends. So it is not blocking any path of propagation.
Q. So is it right that you think any non-conformity of cavity barriers would not have significantly affected the rate of vertical flame spread we saw at Grenfell Tower?
A. If you look at the photographs up there, what you see is that the spaces that are left open -- and let's assume those are the non-conformities -- are generally a small

fraction of the overall space. Given the fact that the cavity barrier has already been misused by principle, I don't believe that all those non-conformities will have a very significant effect in altering the outcome.
Q. You've talked about concerns about these barriers where you've got combustible materials potentially either side, and certainly with an ACM panel you've got it on the outside.
A. Mm.
Q. Is it relevant that you can get deflection and warping of the aluminium panels? How does that affect the operation of the barriers?
A. It's the same thing. If the aluminium panels warp, deform or fall off, then the whole concept of a cavity barrier doesn't apply.
Q. Professor Bisby has said in his report that horizontal cavity barriers are considered important within rainscreen cladding systems, particularly when combustible cladding and insulation products are used. Would you agree with that statement?
A. I do agree with the statement if they are applied in a way such that they meet their objectives. So, yes, of course, cavity barriers are a mechanism that we have to try to control a fire, but we do have to do it in a manner such that effectively we're delivering what we

want.
So, for example, if I have the cavity barrier and I have the cladding sitting on top of it so that the barrier actually crosses and produces a true barrier that cannot be jumped through, then of course they actually are a very important aspect of the problem.
The cavity barrier is a tool that we have to try to reduce the spread of a fire, and the tool has to be used appropriately. So if it's used appropriately and within the bounds of what we want it for, then of course it is a good tool that we can put in place.
Q. So you think there might be circumstances in which it could work but it would all depend on the configuration?
A. It's the design.
Q. Do you think it can ever work where your combustible material is external to the barrier?
A. Well, then it will not be used as a cavity barrier, it will be used simply as a mechanism of trying to decelerate a process, but not necessarily under the principles of a cavity barrier, because it is not a cavity barrier anymore if it actually has combustible materials outside.
Q. Do you think at Grenfell Tower that the cavity barriers wouldn't have been rendered as ineffective if they'd been positioned differently? So, for example, if they'd

been put at the base of the spandrel panels rather than partway up, do you think that could've affected the situation?
A. I think that a better design would've perfectly been possible that would've resulted in a better outcome. I think it's difficult to say, "If I did this, I will get a better outcome". I think in this particular case we have to be extremely careful because, as I said before, the cavity barriers by themselves are just a tool.
So yes, but I do believe that if you use them appropriately and do an appropriate design, I do think that they could improve the way in which the system behaves.
Q. What about in stabilising the panels themselves, is that a role they might be able to perform?
A. Well, I mean you can grant them a structural role but they're not generally designed for that purpose. You could design them for that purpose if that's what you needed, but it is not the conventional use of a cavity barrier.
Q. At Grenfell, what we saw was that the fixing rails for the cassettes, that the cassettes were fixed to, penetrated the cavity barriers, so you have these gaps.
Do you think that may have played a role in terms of

allowing vertical flame spread?
A. Look, when you start looking into all those details of the cavity barriers, the conclusion you immediately come up to is that the system that was designed could not be built correctly. So effectively you have penetrations, complex geometries, all sorts of different things that by themselves rendered any possible interpretation of them in reality very, very difficult.
So I think in this case we're talking more about taking a step back and saying this should've been designed better so that it could be implemented appropriately so that the cavity barriers could actually deliver it's objective.
Q. Do you think these gaps and these rails could've played a role in terms of either convective or conductive transfer of heat from level to level?
A. They would play a role; the question, once again, is to what extent that was a significant role, and that's not clear.
So everything will play a role, but the significance of these elements I think is questionable, because, again, these are relatively small gaps compared to the area that is covered, so how much a flame can actually creep compared to the flames actually burning on the outside would affect the ultimate outcome.

I do think that this is probably a secondary role.
Q. Do you think that it would be helpful to do some further investigations to better understand the reasons for some different flame spread rates, including by reference to cavity barriers? Is that work you think would be useful to do?
A. This is one of those cases where I do not believe so. I think a system that is poorly designed, it is poorly designed by definition, so taking a step back and trying to understand it in detail from a forensic perspective might help us design something better, but only in that sense, not necessarily in the sense of trying to establish if it would've affected the rate of spread.
The system in itself is so complex that trying to fully understand that system to try to correlate it to flame spread rates is going to be extremely complex, almost, I would say, impossible to achieve.
Nevertheless, doing a detailed analysis of the role of a cavity barrier so that we can actually design things better might be a very fruitful path to go.
Q. Just pausing there and thinking about the windows, we established earlier that there were no cavity barriers around the windows. That's something that Dr Lane and Professor Bisby have both identified.
Do you agree that cavity barriers do play a useful

role around window openings to delay both break-out and re-entry?
A. I think that that is absolutely correct, and I think given the context in which we are operating, but I think you have to keep in mind that we do not protect buildings from fires exiting the building. So the concept of protecting the frame requires us understanding that we have a cavity behind that effectively is going to bring the fire back into the building. So in the context in which we're operating, absolutely it is a fundamental problem, but in the context of design, I think we have to take a step back and first think, effectively: what are we protecting? We've never considered the idea of protecting the exit path of a fire; we always consider the problem of the re-entry path of a fire. So we have to be very careful when we state that, but I agree, given the context, it's fundamental.
Q. Let's move now, then, to stage 3 of your analysis, which you say is characterised by lateral flame spread and then internal migration of smoke and fire.
This is between approximately 1.30 and 2.30 am.
You've explained that Grenfell Tower is unusual in that horizontal spread enveloped the entirety of the building in less than 3 hours; is that right?

A. Yes.
Q. You have also said whilst there are multiple pathways for the fire to spread through the facade system laterally, none of them really explain the lateral propagation of the fire that we saw; is that correct?
A. Yes.
Q. Are you still of the view that there is no dominant pathway conclusively established in terms of explaining that lateral fire spread?
A. Well, there is one that appears as very important, which is the propagation to the crown, and that seems to control, through dripping and dropping of burning debris, the rate at which it propagates. It doesn't necessarily answer the question if it would've propagated in the absence of the crown. But it does set the pace at which the propagation is occurring.
Q. So just to be clear what you're talking about there, what you're suggesting is that the fire propagates laterally around the crown very quickly -- is that correct?
A. Yes.
Q. And then you get burning and dripping PE from the crown -- we'll look at its composition in moment -- down on to lower levels, which then establish their own fires; is that right?

A. Yes.
Q. Then propagate upwards?
A. Yes.
Q. Is that why on some of the faces we see almost a diagonal effect. We see it particularly acutely on the west face, for example?
A. Yes.
Q. You believe the dominant mechanism is the crown melting and dripping and then lower fires making their way up?
A. Yes. I believe that that sets the pace of the propagation. So the crown is the one that defines at what rate it's propagating, and that mechanism you just described is exactly the mechanism that I believe is setting the speed at which the lateral spread is happening.
Q. Let's look at the crown in a bit more detail. This is a parapet of strips of ACM, kind of C-shaped columns, or some people have described them as "fins", vertical fins installed right at the top of the building to hide the previous concrete parapet; is that right?
A. Yes.
Q. We can see a useful picture of that in Dr Lane's report. This is at BLAS0000010, page 69, figure 10.73.
So here we see the crown at the very top, and what we see are these vertical fins. They are made of

aluminium composite ACM panels; is that correct?
A. Yes.
Q. They're mounted on C-shaped aluminium channels that all fit into one another --
A. Yes.
Q. -- in rows.
Can you explain why you think it was that the fire spread so quickly round the crown?
A. I think it's primarily because as the components of the crown start burning, and the polyethylene starts melting, it pools underneath. I mean, we did a preliminary analysis of the rate, you know, showing a bit of this and -- but I think in the revised report of Professor Bisby, this is analysed in much more detail and I will concur that that is probably the main mechanism is the pooling of the polyethylene below the elements of the crown that effectively serves as a feedback loop that accelerates the burning of these elements.
Q. So you're talking about pool fires at the bottom of these fins --
A. Yes.
Q. -- which then help it propagate laterally --
A. Yes.
Q. -- and then also are dripping down; is that right?

A. As they are burning and they start dismembering, you're going to have dripping down and pieces falling off, and that is what effectively starts the fires in other locations.
Q. Yes. As we'll hear --
SIR MARTIN MOORE-BICK: Can I just ask: am I right in understanding that each of these fins has an exposed core along the edges?
A. Yes.
SIR MARTIN MOORE-BICK: So it's all there waiting to propagate from one to the next?
A. Exactly.
MS GRANGE: Exactly. So I was about to take you to that.
Professor Bisby has highlighted a number of characteristics which he thinks are important in terms of fire propagation around the crown.
He refers to the fins as semi-continuous paths for fire to spread. Do you agree with that?
A. Yes.
Q. He's highlighted the numerous exposed ACM edges with exposed polyethylene on the edges?
A. Yes.
Q. Again, do you think that's important?
A. Yes.
Q. He's also drawn attention to the fact that they are

effectively C-shaped chimneys which in themselves would support flame extension and flame spread. Do you agree with that?
A. Yes.
Q. Also that there's no cavity barriers around the top of the building?
A. No, it's beyond that. I mean, there's not only nothing to stop it, but also, as it pools down, you have a mechanism to keep pushing it. So any gaps that you might have are being covered by the pool that is being formed underneath.
Q. Does your view remain that the rapid internal penetration of flats above level 20 can be attributed to the presence of the crown and the debris that was falling from it?
A. Our analysis showed that effectively the rate at which these apartments were being penetrated effectively was pretty much the same rate as the progression of the fire in the crown.
Q. So those flats at the top were particularly prone to the effects of the melting, the dripping, the heating; is that correct?
A. Yes, yes.
Q. But just testing the role of the crown, do you agree that, in any event, the fire would be more severe and of

longer duration at the higher levels because of rising hot gases and flames, ie the flame plumes out towards the top of the building?
A. That is questionable because it really depends on the time that is available. So like in the case of The Torch, for example, the vertical burning happened so much faster than any lateral spread that the plume never really opened. It basically remained very, very narrow. Yes, of course it opened a little bit, you can see slightly more damage on the top than you have at the bottom, but it's truly almost a vertical plume.
So, in principle, it depends a lot on the capacity of the system to sustain burning to the point that you can use that energy to enhance the spread on the upper part.
Q. Do you think that the effect that we saw around the top of the crown could simply be explained by the vertical flame pluming at the top? Is that an explanation for it?
A. What do you mean exactly by the effect that we --
Q. Could the lateral flame spread, the horizontal flame spread that we saw, actually be explained by the shape of the flames pluming and widening at the top of the building rather than it being about the crown?
A. No.

Q. I just want to take you to a figure in Dr Lane's report, that's figure 10.47 in her report, BLAS0000010, page 48.
This is a diagram of the crown and, just to explain, in the bottom part, what we're seeing is the top of the building with a Reynobond ACM panel which overlays some insulation which wraps around the top of the building. Do you see that?
A. Yes.
Q. Above that, Dr Lane has marked "PPC Aluminium flashing over top of insulation". As I understand it, that's polyester powder coated aluminium flashing which sat on top of the ACM and the insulation at the top of the building. Then what we see above that are these fins sitting on top of that.
Does that make sense?
A. Yes.
Q. It's been suggested that the lateral fire spread we see at the top of the building might have been more to do with the presence of combustible insulation at the top of the building and the Reynobond panels rather than the fins.
Would you like to comment on that?
A. I mean, you have combustible insulation, you have the Reynobond and you have a platform in which you can actually pool molten polyethylene. I do not believe

that there is any conclusive evidence that would show that this is coming from the insulation, and, in principle, an exposed pool fire is clearly a much more severe form of heating than any heating that could come from that insulation that is covered at all ends.
Q. It's also said that the aluminium coping that we see over the top there, which had projected, some of it had not melted, it had not melted across the top, but it had melted a bit on the face of it.
Again, would you attach any significance to that?
A. Absolutely, because if you have melted polyethylene -- keep in mind that the polyethylene is going to melt at a very low temperature, so the polyethylene is going to start gasifying at 300-something degrees, which is way below the melting temperature of aluminium, so will not let the aluminium heat up beyond that temperature until it's fully consumed.
So, effectively, the fact that you don't have melting of the aluminium shows that you have something else that is acting as a heat sink, that is taking the energy away and keeping it at a low temperature. It's like boiling water, it will not change above 100 until you finish boiling all the water. It's exactly the same in the case of the polyethylene. It will not reach the melting temperatures of aluminium.

And it's quite telling, the fact that the exposed area where you don't have that molten material is the one that disappears, while all the area that is covered is the one that remains unmelted.
Q. Is it significant that the fins were not backed by any insulation? Does that change your view about the role of the crown?
A. I think in this particular case, I believe it's driven by the pool fire. I think that that clearly needs to be studied in a lot more detail.
But I do think that under those circumstances, probably having insulation in the back would have had a very minor impact.
Q. Let's come on to lateral flame spread at lower levels of the tower. Again, we've touched on this.
You've said that smoke plumes and heat plumes from lower down the building will widen with height and preheat other sections of the cladding, facilitating later ignition.
You've highlighted that a key mechanism for lateral flame spread further down the building is that we have burning debris falling from the areas already on fire and then accumulating on horizontal surfaces, igniting new localised fires which then spread upwards; is that right?

A. Yes.
Q. That's what you were talking about earlier when you said actually you think that is a real candidate to explain why the fire at Grenfell Tower spread laterally so quickly.
A. Yes.
Q. Is that substantiated by the mapping out of the lateral flame spread that you've done in each direction? So in your figure 35 -- let's just go to that, that's JTOS0000001 at page 78.
You have depicted the lateral spread, as I understand it, from top to bottom --
A. Yes.
Q. -- for each face in time; is that right?
A. Yes.
Q. Can you just explain how that supports the analysis that we get this debris falling down and igniting other fires that then go up?
A. So if you look at the top symbols, you will see as they are progressing, we're changing the shape and colour of the symbol. So, basically, the top symbols reach the end faster than anything else. So that will be the top of the building. So that's the progression that is driven by the crown.
Then what you will see is once -- for example, if

you take the yellow triangle, you will see the fire reaches the yellow triangle at about 110 minutes.
Q. That's right in the middle of that top diagram. We see the yellow triangle at the top.
A. Yes.
Q. So it's hit the top of the building --
A. Yes.
Q. -- at that point. That's west 5, yeah?
A. Yes. So then debris falls, it ignites the fire in the next one, which is the 120, and very rapidly progresses up again. So you can see the three triangles. So in a period of 10 minutes it's gone down and then all the way come up.
If you look where the next triangles are, so you will move all the way down now to about 145, and you can see that a piece of debris falls all the way down and then it creeps up.
So each of those columns represents a piece of debris that landed below and then it spread up again.
Q. Once it's gone below and landed and then is going up vertically, do you agree with Dr Lane that there's then a number of vertical pathways through which the fire could then spread across the facade?
A. Yes. I mean, you can see that there's a multiplicity of vertical pathways and it's hard to determine which one

is more important than the other.
Q. She has the columns as the first one, and then along window edges and edges of the white infill panels. Would you agree with that?
A. **In some parts of the building, potentially that's correct; in other parts of the building, I think there might be other different mechanisms of spread.**
It's not very clear when you look at the progression of the fire when each mechanism dominates. It many times depends to the proximity of the column, where the debris landed. There's a number of different factors that are going to affect what is the mechanism that dominates.
But I think in some areas, yes, she's correct.
Q. In terms of the lateral flame spread, you talked earlier about opposed-flow flame spread. Professor Bisby explained about this in his presentation back in June with reference to the match and looking at the match going much slower sideways.
A. **Yes.**
Q. Do you think there's any role for opposed-flow flame spread in terms of what we see at Grenfell?
A. **I think it's very minor to negligible.**
Q. Because you think the primary mechanism is this burning debris down --

A. **Yes.**
Q. -- with fires then going upwards, as opposed to it just migrating laterally across the building?
A. **Yes, so if you look at the dots, for example, if you see at 50 minutes, you look at the yellow dots, you will not see progression to the right. So a little bit later, you will not see another dot appearing. The dot has to wait for the debris to come down and go up. Nowhere in the diagram you see that you have lateral progression.**
There are very few exceptions and they are very rare situations, many times when you have debris falling in two places. Like, for example, what happens between 01.30 and 01.40, in the top diagram, the triangles and the squares, they seem to burn very close in time, so you could actually interpret that that was lateral spread. But the reality is that it was actually two pieces of debris dropping almost at the same time, falling in places that were very close to each other and then creeping up.
Q. Have you actually tracked that on the videos?
A. **We've tracked it in a number of places, but it's quite difficult because tracking down where the debris lands generally is -- from the type of images we have is not that precise. So we tried to emphasise in these diagrams as close as possible that process. The process**

became quite evident and none of other mechanisms seemed to play any significant role.
So, again, within the error bars that you can expect in this type of analysis, I don't seem to believe that I found any case where I could unequivocally ascertain that the flame was spreading in opposed mode, either laterally or downwards, in any significant way.
Q. Do you agree, though, that there are some pathways laterally that it could have followed, albeit slowly?
A. **Oh, absolutely.**
Q. So, for example, on the tops and bottom of the windows, along edges of the ACM cassettes where, for example, there may have been exposed edges, or, indeed, along the window infill panels?
A. **Yes. I mean, once again, I go back to this issue that these are incredibly complex systems, and I would not be surprised that there would be some places in which the flames actually creep under a cavity that was horizontal, that could've possibly happened. But it was by no means a dominant mechanism.**
Q. What about the potential contribution of the cut edges of the PIR insulation? Is it possible that that could've played a role, either because debris was falling down and by that time it was hitting that, or because it was burning along the edge?

A. **Well, I mean, again, you go back to the same point. In such level of complexity, yes, it is possible that it played a role, but would that be considered one of the dominant factors for the lateral spread? I don't believe so.**
Q. Finally on this topic, you've explained that internationally there are some exceptions in terms of high-rise fires where the fire did propagate laterally. Can we just look at a couple of those examples.
If we go to figure 25 in your report. That's JTOS000001 at page 62.
So this is the Sulafa Tower in Dubai, where you say the lateral flame spread extended to almost half of the building; is that correct?
A. **Yes.**
Q. That's what we see in these images here.
Does it remain the case that there's limited information about the construction details which could've explained that in this particular case?
A. **Yes. I think this is one of those cases where there's very limited information. One thing that appears regularly, particularly in media descriptions of this case, is that the wind was quite significant. So you can see that the spread in one direction is much more significant than in the others. So there is**

a possibility that that had an effect.
But, again, this is an example where you can see a systematic line of lateral flame spread that is very different to what you see in Grenfell.
Q. You've also drawn attention to the Monte Carlo Casino & Hotel fire in 2008, where the fire spread laterally across a parapet.
Can we just look at that. Figure 32, JTOS0000001, page 75.
So these are images of the Monte Carlo Casino & Hotel fire.
Can you explain why you think this has particular parallels with the fire at Grenfell?
A. Well, I mean, I think that this particular case, the upper part of the building is a thick layer of combustible material that is rendered with a non-combustible protection.
The rendering of the non-combustible -- of protection, performed very poorly, so it effectively exposes the material quite rapidly, so it allows the combustible material to propagate laterally quite rapidly.
An interesting aspect of this one -- you can see it in figure (D) -- is that this material drips down and basically deposits in the edges that you can see, and

that's really the mechanism that continues propagating the fire.
So what you get is molten material depositing in that ledge, and that pool that forms in there is the one that keeps igniting the material forwards. So in that sense, it does show some similarities with Grenfell.
Q. I now want to look at re-entry of the fire in stage 3.
We might take a break in about another 10 minutes after that.
You say that your stage 3 is also marked by re-entry into flats and the interior migration of smoke and fire.
You've said that the external fire generates thermal loads as high as 120 kilowatts per metre square. We discussed that earlier.
A. Yes.
Q. You've said that that level of heat flux would inevitably cause a failure of -- you've said the window glazing, the extract fans, the uPVC window surrounds, allowing flame re-entry; is that right?
A. Yes.
Q. And that flames will then ignite other combustible materials inside the compartment, causing internal fires.
A. Yes.
Q. Can we just explore some of the methods of re-entry that

we have seen in the evidence.
In section 7.4 of his report, Professor Bisby has drawn attention to a large number of witnesses who comment specifically on the early failure and ignition of the extract fans unit and the surrounding XPS panels. So you have the extractor fan -- we looked at the kitchen window earlier -- in the middle, it's got a panel surrounding it, which is extruded polystyrene; is that correct?
A. Yes.
Q. And Professor Bisby has drawn attention to that as a potential route for ingress. You've also highlighted that mode of failure in your report.
Many of these that Professor Bisby has drawn attention to were in the flat 6s on the east face of the tower.
Do you think that this evidence is potentially significant in terms of the route of fire spread back into apartments?
A. Potentially. I think that, once again, when we think of the design of a window, we are designing a window keeping in mind that we don't want fire spreading from one building to another one. So we set a certain criteria, which is 12.6 kilowatts per metre squared as being the criteria that is used for the design of all

the window components.
So, in principle, there is no expectation that any of these components will withstand anything above 12.6 kilowatts per metre squared.
So, in principle, yes, I wouldn't be surprised that one of these elements is weaker than the others. We found quite a bit of evidence of exactly the same, as we found evidence of other mechanisms. And I would imagine that, yes, this could be potentially a significant way for the fire to get back in.
Q. Do you think it might have been significant in terms of the timing of the ingress on that face, ie is it possible that during the early stages of the fire, this was a more predominant ingress path, and that perhaps, say, you get glazing failures later in the fire?
A. There is nothing that makes me believe that time in this particular case would have been an issue, because keep in mind that you're exposing the systems to a heat flux that is an order of magnitude bigger. So, effectively, the failure times are going to be generally quite fast. So what difference it could make from a time perspective is very difficult. I wouldn't say it would be too significant.
Q. Professor Bisby's also highlighted some other possible routes of ingress and I want to briefly ask you about

some of these.
Gaps in the window framing. Many residents have referred to gaps and draughts around the windows after the refurbishment, and some have actually referred to fire directly ingressing through those window surrounds.
Again, do you think that might have had a role to play?
A. It would've had a role. I mean, clearly, if there is a gap, in as much as there could be a window open or something like that, then there would be no barrier, so that delay that you would have from the moment the flames arrive until the smoke starts getting in -- and also, early on -- I mean, from the perspective of smoke migration, it could've been significant because smoke goes up and envelops the building, so you could have areas where, effectively, you have no heat, but you actually have smoke. So the smoke could've easily penetrated through those gaps.
So from the perspective of smoke migration, I think it might have a significant role, but from the perspective of re-entry of flames, that's probably not as significant.
Q. Just to be clear, I was going to come on to open window in a moment. I was talking here about -- we know the windows were pushed out during the refurbishment and

there were gaps down the side that were filled with insulation, and residents have talked about draughts round those gaps, or some have.
Just to be clear, do you think that's a potential path of fire or smoke spread back in?
A. Any gap is a potential path for smoke. Any potential path for spread requires a condition of failure, and that condition either is ignition of the insulation, heat flux sufficient to break it, heat flux sufficient to melt something. So then because you require a condition for failure, and your heat insult is so much higher than it was designed for, then I think that's what makes the difference minor. Because at those heat fluxes, everything will fail very rapidly.
Q. We've also heard instances of the softening and the melting of the uPVC and then entry. I mean, that's a similar route. Do you agree?
A. Yes.
Q. You've talked about thermally induced breakage of window glazing.
Then open windows. Do you think they may have played a role? It was a hot night, windows being open, flame spread going up, is that --
A. I think, again, more than flame spread, the role of windows is probably more significant in regards to smoke

migration.
Q. It's been suggested that double glazed units are resistant to fire attack and that it's by no means certain that they will fail during a fire; would you agree with that?
A. No.
Q. Spray foam. Professor Bisby has identified the use of spray foam to seal gaps around the windows to provide a final airtight seal. He has considered this to be potentially significant in terms of the ingress of fire and smoke around the windows.
Do you think that the presence of spray foam could've exacerbated the ingress on the night?
A. I mean, it would have, like everything else, but I do think, again, this falls in that category where I would not be able to establish a ranking between all of this because they will all fail in a very short period of time.
Q. What about whether any of the internal compartment fires themselves on the night, once they're burning, could've contributed to the external flame spread, the extent or the severity of the external flame spread, is that a possibility?
A. That is actually a true fact. Clearly if you have a fire that starts in a compartment, the compartment has

a fuel load, so it has a significant amount of energy that is being released, and that energy is going to partially spill out, particularly if doors are closed. So it's going to spill out and it is going to contribute to the energy that is being released.
Now, clearly, again, the interplay between how fast it is spreading and how fast you reach conditions in which this internal fire starts contributing is what really matters. But, effectively, once you start releasing that energy, that energy has to go somewhere, and part of it is going to go out and going to contribute to the process.
Q. Do you think there are any times in the fire or particular aspects of the burning we see on any of the facades where you think that's happening?
A. There's nothing in particular. I mean, I think there's obviously certain areas, like as is explained by Dr Lane and Professor Bisby, the areas around the 12th floor, where you have particularly unusual burning, where potentially what is happening inside is having more effect on the rest. But those seem to happen generally after the fire has passed, and if they are contributing, they're contributing to the heat that is in the plume and, thus, contributing to what is happening much, much further.

MS GRANGE: I'm now going to move to a separate topic, so this might be a good moment for a break.
SIR MARTIN MOORE-BICK: I was going to say, would that be a good time?
MS GRANGE: Yes.
SIR MARTIN MOORE-BICK: Well, professor, I think we'll have a break now for 10 minutes.
Go with the usher. No talking about your evidence, please, and be back at 3.20.
All right, 3.20, please.
(3.10 pm)
(A short break)
(3.20 pm)
SIR MARTIN MOORE-BICK: All right, professor? Ready to go on?
THE WITNESS: Yes.
SIR MARTIN MOORE-BICK: Yes, Ms Grange.
MS GRANGE: Just one question relating to that last topic about ingress through windows.
We were talking about the fact that given you've got a 120-kilowatt per metre square fire going up vertically, weaknesses in the window arrangement may not have made much difference in terms of ingress, given you get glazing failure anyway.
What about downward flame spread? So the primary

mechanism you were talking about earlier of melting and dripping debris which then accumulates on ledges or window ledges and themselves create smaller fires which go up, is it possible in that situation that weaknesses in windows, whether it's the extract fan unit or other weaknesses around the sides, could've then played a role, or a more significant role?
A. Yes. I think that if you have debris then obviously you have much less insult from the fire on the external part, and weaknesses in the window design would've had a more significant impact on potential ingress of the flames.
Q. I now want to move to consider the internal migration of smoke and fire, and at this point I think it's important to draw attention to your addendum to your Phase 1 report, where you've essentially highlighted that there's a need to do a lot of further work at Phase 2, specifically to correlate the firefighter activity and the smoke spread during both stages 2 and 3 of the fire; is that correct?
A. Yes.
Q. Can we just go to what you've said in your addendum. So if we bring that up, that's JTOS0000002 at page 1. I just want to highlight a couple of paragraphs here.
In the second main paragraph, you've said -- because

you have done a 999 call analysis, haven't you, of people reporting smoke in certain areas?
You've said:
"There are multiple 999 calls during Stage Two (01:05:57 — 01:30:00) reporting smoke in the lobbies, as the fire spread vertically up the building from Flat 16 on Level 4 to the roof above Level 23. Most of these calls centre around the middle of the building, with smoke in lobbies reported by callers on Levels 10, 11, 12, and 14 timed between 01:25:16 and 01:28:26 ... Of these reports, only Level 14 is clearly reported as having a significant amount of smoke. Prior to this there is also a report of a smoke-filled lobby higher up the building on Level 22 at 01:21:24 ... This latter report is likely to be due to internal spread of smoke, as the fire had not reached Level 22 by this stage."
So, there, is it right that you're mainly highlighting what the pattern of the 999 calls were showing --
A. Yes.
Q. -- in terms of the spread of smoke?
You say this in your third paragraph:
"From the onset of Stage Three (01:30 — 02:00), 999 callers consistently report thick black smoke considered unpassable by residents in the lobbies. These include

the 12th, 14th, 16th, 18th, and 21st to 23rd Level lobbies within the period 01:30 — 01:40 alone ... Further 999 calls for the rest of Stage Three report a similar situation on the 10th, 11th, 19th and 20th Levels ... Some of these also report smoke in the stairwell itself. It is clear that, from the onset of Stage Three, internal smoke spread is fairly ubiquitous above Level 10."
Is that correct?
A. Yes.
Q. You've noted the levels there in terms of smoke spread.
Do you think there's any significance in terms of where smoke's being reported at that point in the building?
A. Can you extend a bit, what do you mean?
Q. Well, you've highlighted certain parts of the building, 12th, 14th, 16th, 18th, 21st to 23rd, effectively the middle of the building and then the top of the building.
A. Mm-hm.
Q. Do you think that's significant in terms of the pattern of what we're seeing?
A. Well, it is significant in the sense it's somehow unusual that you have concentrated calls in certain areas of the building, which clearly show you that there was something unusual that was happening in there, and

we have not been able to gather the complete amount of information to be able to establish exactly what is going on.

Q. What caused those, yes.

You've highlighted some examples in your report from the available footage that we have of the tower of smoke emerging from flats on the opposite side of the tower to the fire front, the flame front of the east side.

Can we just have a look at those images, but before we do, I probably ought to issue another trigger warning. We're going to be looking at images of the tower. We're just looking at smoke spread through the tower, it's not the tower on fire, but some people may find these images upsetting or distressing, in which case they should leave now.

(Pause)

Those images are figures 48 to 52. That's JTOS0000001, starting on page 88, if we can bring that up.

So these are images, my understanding is, on the west face of the facade.

A. Yes.

Q. We see, as early as 01.57/01.58, that there is smoke emerging.

Just explain to us, the top image, where is the

smoke emerging from on that image?

A. You can see --

Q. Where are you referring to?

A. You can see a darker colour --

SIR MARTIN MOORE-BICK: Would you like to get up and point it out to us?

A. So these are the types of images that you can see.

MS GRANGE: You can see it very clearly on that bottom image. On the top image --

A. It's hard to tell, but it would be somewhere in there.

SIR MARTIN MOORE-BICK: Thank you.

MS GRANGE: So this is west face, 1.57/2.00 am. You say that the significance of this is that that movement of smoke would only be possible if compartmentation is breached for two units; is that right?

A. Yes.

Q. So it's got through one flat, into the lobby, through the lobby, and into another flat?

A. Yes.

Q. Is that correct?

A. Yes.

Q. Why did you think it was so important to highlight that?

A. Because the conditions are such that the doors themselves would've not failed. The flats on the west facade were not on fire yet, so that clearly tells you

that the doors had to be open as opposed to the doors having failed because of an event.

Q. Because what you're saying is there is no flame front there --

A. Yes.

Q. -- on the west face to cause a flame-induced failure of the doors.

A. Yes.

Q. So you're deducing from that that it must have been smoke spreading through an open door?

A. Yes.

Q. That was left open by a fleeing occupant?

A. Well, that could potentially be the case. It could potentially be firefighting intervention. These are the kinds of things that I think before any conclusions are drawn, we have to be very, very careful that all the available information is correlated.

Q. There's also some factual evidence that firefighters found considerable smoke in certain lobbies very early on in the fire, for example Firefighter O'Beirne, who goes up and finds smoke in the lobbies as early as 01.20 in some areas.

You're aware of that?

A. Yes.

Q. In the light of that and your analysis of the 999 calls

that you've done -- I realise this is only a preliminary analysis -- do you agree that the lobbies appear to have been compromised on a number of floors very early in the fire, for example by 01.20 and certainly by 01.25/01.26?

A. Yes. I mean, there is sufficient evidence to say that there was a level of compromising of the lobbies quite early on. I think it's really not 100 per cent certain to me the exact timings because we do not always have exactly the times, for example, when the firefighters were in different places.

SIR MARTIN MOORE-BICK: Is it possible that that was a result of what we've called the flat 6s being exposed to fire, and therefore smoke, and then people leaving the flat 6s and the doors not being closed?

A. Yes, absolutely.

SIR MARTIN MOORE-BICK: Because that would compromise the lobby in each case, wouldn't it?

A. Absolutely. I think that that is a possibility and that would imply that the self-closing mechanisms were not working and that people didn't close the doors. So I think clearly that is a possibility that needs to be evaluated very carefully.

MS GRANGE: Is that the kind of detailed work you'd want to do at Phase 2 --

A. Yes.

Q. -- which is to try and look very specifically about occupant egress, door condition, firefighter activity, floor by floor, flat by flat --
A. Yes.
Q. -- to try and piece it together?
A. So you can make a correlation to gain certainty on all the timings and, in particular, the level at which they had been compromised by smoke.
Q. Given that you have said you want to do much more detailed work at Phase 2, at this stage what I'm proposing to do is just explore some of the broad themes that you have identified in your report which are potentially important in terms of internal smoke spread.
Just before we get to that, it's right to note that you've emphasised, again, the importance of maintaining these internal compartmentation lines of defence.
A. Yes.
Q. You've said that internal smoke spread, particularly into the lobbies and stairwells, correlates strongly with past fire events that do result in a high number of casualties; is that right?
A. Yes.
Q. So in contrast, some very large international fires with comparable internal fire spread have not resulted in penetration of smoke and flames into the lobby or

stairs; is that right?
A. Yes.
Q. I know it's very difficult in general terms, but can you give us an indication of why in those events it didn't penetrate into the lobby and the stairs? What was it about those buildings that was potentially different to what we saw at Grenfell?
A. Well, I mean, I think in many of these cases, it was the layout of the building. For example, in the case of The Address, one of the main structural walls of the building basically separates the apartments from the corridor. So you have a very significant compartmentation barrier in there.
Clearly a big issue is obviously the doors, and not in the sense of the doors withstanding the event but more the case of the doors being left open or closed. So the quality of the maintenance of the building is clearly appropriate. Some of these fires happened in buildings that were fairly new, so they had not been damaged, so things like self-closers were probably all working appropriately.
So, in general, conceptually, it's very simple, in the sense that it is about keeping the barrier in place, and that's the quality of the barrier in itself and the quality of the doors and their capability of

self-closing.
Q. Is it therefore right to assume that the compartmentation separating each flat from the neighbouring flats should be capable of resisting any significant passage of smoke, heat and fire from one flat to another?
A. Yes.
Q. That's the case even in the event of a very significant external facade fire?
A. Eventually you might end up having a problem, but the compartmentation in principle should be designed to a level in which it withstands the fire for a very significant period of time. And compartmentation, as I said, is designed on the basis of a post-flashover fire. So you already have the time that it takes for the fire to enter, the time that it takes for the fire to transition to flashover, and then the time that you have for the failure of the compartmentation under those conditions.
So you have all these significant delays that, in principle, should allow people to migrate to the lobby and then from the lobby to the stair. So you have already two layers of compartmentation that you have to breach.
So, in principle, compartmentation is a very robust

way of giving a very significant amount of time for people to enter the stairs and be safe in the stair for an even longer period of time.
Q. Moving to some themes we can pick up. I want to discuss door failure by fire for a moment. We'll come to penetration of smoke in a moment, but concentrating on door failure by fire.
You've noted that the flat doors that were removed from the building, or one of those exemplar flat doors, when tested, demonstrated 15 minutes' integrity when it was tested by the BRE on behalf of the Metropolitan Police; that's right, isn't it?
Is it right to note that that's a test with a 740 degrees C failure temperature?
A. Yes.
Q. Which is above flashover temperature; is that right?
A. Yes.
Q. So flashover temperature is about 500/600 degrees; is that correct?
A. Yes.
Q. Does it remain your view that the failure of the doors by fire is most likely to occur in cases where flashover is reached?
A. Yes.
Q. Where flashover's not reached, it's unlikely the door is

going to fail due to internal fire?
A. Yes.
Q. You've highlighted in your report that, despite major damage in many of the flats, a significant number did not attain flashover. You also say in your addendum report that fire-induced door failure could be a contributing factor in the latter part of stage 3.
A. Yes.
Q. Is that correct?
A. Yes.
Q. But you don't think it's going to be a significant contributing factor during stage 2 or earlier; is that right?
A. Yes.
Q. Does that remain your view?
A. That remains my view.
Q. Let's turn, then, to penetration of flat doors by smoke.
We know from Dr Lane's report that there are a number of difficulties with many of the flat doors, including that they don't comply with relevant cold smoke leakage requirements and an absence of test evidence which correlates with those doors.
Is it your view, based on what you've seen and the general themes emerging, that the doors failed to maintain compartmentation in terms of smoke spread?

A. Yes, that's possible.
Q. You have noted yourself in your report, reports of smoke coming through flat doors, for example at 01.25 and 01.26, just based on the 999 calls.
A. Yes.
Q. What do you think is the significance of that in that early stage?
A. Again, it goes back to the problem of multiple breaches of compartmentation. So if there is a call that indicates that smoke is coming into that flat through the door, that basically means that the flat is not on fire and the smoke is coming through the lobby, and that must have come through from another apartment. So effectively you have again this path where you have multiple levels of failure before it starts entering the apartment.
So I think this needs to be explored in very significant detail, because given the long period of time that people spent in those places, it is fundamental to try to understand what were those breaches.
Q. I was going to draw attention to that, that obviously it's right, isn't it, any door will fail after a certain amount of time, or may fail after a certain amount of time, but here it may have been very significant for

those that were trapped in flats that there was smoke spread coming through the doors --
A. Yes.
Q. -- in terms of their ability to survive in those flats or potentially be rescued; is that correct?
A. Yes, that's correct.
Q. It's fair to mention there are some instances of doors apparently performing slightly better on the night. So take Antonio Roncolato, who was there until 06.00 in the morning, potentially Natasha Elcock, another example, some examples of it performing more effectively.
What do you think is the potential significance of that in terms of the overall pattern that we're seeing, or is it too early to say?
A. Well, I think it is actually very difficult to ascertain, because clearly we, in theory, should be operating under the assumption that the doors are all homogeneous and, therefore, every flat should've been designed in a fairly similar manner, and it should've been maintained and kept, and that generally is not the case. What we get is significant variance in the level of maintenance and the care that these things are given, even the way in which they're designed or built.
So variations are expected, both in the use and in the construction. So I believe that that is probably

one of the main reasons why you find some differences in what people observe.
Q. Occupant egress. You have also discussed -- and you've already mentioned it a number of times -- the effect of occupant egress on compartmentation.
Does it remain your view that that would have a negligible effect unless the doors are not closed behind people when they leave?
A. Yes.
Q. You think just the opening and closing of a flat door onto a lobby is unlikely to affect the overall pattern of smoke spread significantly; is that right?
A. Yes. I think if you think of the process of egress, if people are evacuating, that basically means that the smoke that they're exposed to within their apartment is still not the type of smoke that will threaten their lives.
So whatever is coming into the lobby from people evacuating their own apartments will be very far from tenability, and so I would not expect that that will have a significant impact on the lobby itself.
Now, if the door is left open, then there will be a significant delay under which conditions can actually change, and then you can actually have a different kind of smoke entering the lobby area.

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Q. So if those door-closers are ineffective or not installed, is it your position that the contribution to the spread of smoke is going to be greater?
A. Much more significant, yes.
Q. Is it also going to be significant in terms of the oxygen potentially getting into those flats and the fires you have in those flats?
A. Yes, although I believe that that, in a scenario like this, will be a secondary effect. I mean, clearly when you have a post-flashover fire, it's considered to be an under-ventilated fire, so the more oxygen you put in, the more intense it burns. But in this particular case, given that the fire is coming from the outside and you have window breakage and so forth, probably the impact would be secondary. But yes, of course, it would add some more air into the fire.
Q. Imagine you are fleeing a flat 6 and you've seen your kitchen window on fire and potentially your kitchen starting to burn. You flee out the door, and the closer doesn't shut behind you. Is that compartment likely to come to flashover quicker because you've left the door open?
A. No, no, actually, it will be the opposite.
Q. The opposite?
A. Yes, because you're going to be losing smoke, so effectively that will delay the transition to flashover.

Q. But there will be an easy transmission of smoke from the flat into the lobby.
A. From the flat into the lobby. Then once the flat transitions to flashover, you have a better ventilation of the flat, so the fire will be more intense.
Q. Both Dr Lane and Professor Bisby have emphasised a significant body of evidence which suggests that many of the door-closers were not effective on the night. Professor Bisby has emphasised a number of flat 6s on the east face where this may have been the case.
Have you formed any views at this stage as to how significant you think that might have been in terms of the overall compromise of the lobbies with smoke?
A. I mean, that is a very difficult question to answer, because I think obviously if the door doesn't close, the effect on compromising the lobbies is very, very significant.
Now, unfortunately, self-closing mechanisms are not necessarily the most reliable of systems. Just to give you a very simple example, the door between the witness room and the coffee room, somebody has removed the self-closing mechanism. This is done regularly, because effectively it creates -- self-closing mechanisms tend to disturb our usual way of using living environments.

So I think having an enormous reliance on self-closing mechanisms is probably asking too much of a system that is a very secondary means of protection.
In principle, if the fire would have not emerged from the compartment of origin, it would've remained compartmentalised, then all these secondary elements are just extra redundancies that we're putting in place; they are not truly significant to the fire safety strategy.
Now, the problem is that when everything else fails, these are the only things that can pick up the pieces, and then they acquire a significance they were never intended to have.
Q. I mean, are there other options to door-closers?
A. No, no, we should have them, under the expectation that there will be a very significant rate of failure. That's why it becomes sort of an ultimate redundancy and not a primary means of protection.
SIR MARTIN MOORE-BICK: But the door is the one, as it were, weak link in the whole compartmentation design, isn't it? Because in a building like Grenfell -- forget the cladding for a minute -- the rest is concrete.
A. Yes.
SIR MARTIN MOORE-BICK: So I would've thought that to have effective self-closers on the doors was pretty much critical to the concept of compartmentation.

A. It is in a certain sense, okay? So, effectively, if the compartment fails and people evacuate and leave the door, you would have compromised the lobby, but then you have, from the lobby to the door of the stair, another fire resistant door. So you're putting multiple layers of protection to try to make sure that one picks it up.
Now, if the fire remains within the unit and it compromises the lobby, then you have a smoke extraction system that will try to clear that up, but the people that are staying in the other flats will be protected by their own compartmentation.
So, in principle, yes, you're putting all these elements in because we recognise that the door is the weakest link in compartmentation. This is why we put the self-closing mechanisms. But we have to also recognise that these are not systems that are generally maintained at a level that we have an absolute guarantee that they're going to work.
SIR MARTIN MOORE-BICK: Yes, thank you.
MS GRANGE: Does it follow, then, that actually the stair door is of really fundamental, critical importance --
A. Absolutely.
Q. -- in terms of protecting your egress route?
A. Yes. And you would imagine that the stair door,

a public space of the building, the maintenance level of the door, the self-closing mechanisms, will be of a much higher quality than you would expect could happen in the interior of a flat.
Q. And because it's a firefighting shaft, it has to have a higher rating, et cetera, and all of that. We are going to explore all of that with Dr Lane on Thursday.
A. Yes.
Q. Another topic is firefighter activity -- you've highlighted this -- including running hoses through stairwell doors or breaking down flat doors, for example the breaking down of the flat 16 door.
In terms of the significance of this, what you say is that this is arguably less significant if you're just fighting a one-fire floor. It's kind of what you just said.
A. Yes.
Q. But that becomes really problematic once you've got multiple floors on fire, if you have doors held open, particularly to the stairs; is that correct?
A. Absolutely, because effectively if the fire remains within the compartment, the stay-put strategy stands and, therefore, people are not required to evacuate the building. So the stair, in a way, will not be used until the firefighters establish or deem that the stair

can be used again. So during their operations, the possibility of filling the stair with smoke is real, and it is part of the concept of the stay-put strategy. So, in that sense, it is not a very significant problem.
But if you have multiple-floor fires, then you have to evacuate people while they are operating. There's a convergence of timescales. And then their operations become in conflict with the actions of the occupants of the building.
Q. You also make this point, which is it prevents a change of strategy from stay put to evacuation if you've already compromised your evacuation route.
A. Exactly. It makes it much more difficult to take the decision of moving from one strategy to another.
Q. Have you formed any preliminary views about how significant the holding open of doors or the battering down of doors might have been in explaining the early egress of smoke onto lobbies or compromise of egress routes?
A. From the preliminary information that we have, it seems that the evolution of the conditions of the stairs and in some cases the lobbies is very dynamic. So I think that this opening and closing of doors and so forth seems to be a very significant aspect over the problem.
Q. Missing or damaged fire-stopping, here you've relied on

the assessment by Dr Lane.
Does it remain your view that there were only minor weaknesses in, for example, the stair enclosure in terms of compartmentation? Have you seen anything that would suggest that there were any penetrations that were causing issue with the compartmentation?
A. I think that's correct.
Q. Ingress as a result of the smoke control system and the vents onto the lobbies, have you had a chance to consider appendix J of Dr Lane's report?
A. Yes, I have.
Q. And her concerns, based on some of the factual evidence that we've heard, about the possible passage of smoke via the vents, the dampers, in the smoke control system between lobbies.
Do you have any views about the potential significance of that at this stage, or is that something you'd like to do further work on?
A. Well, as Dr Lane indicates at the beginning of appendix J, the system was designed for a one-floor fire. So while there's a number of non-compliances she highlights in the appendix, it is clear to me that a system that was designed for a one-floor fire, in particular when we're talking about vertical shafts, fans and dampers, it is very clear that its performance

is completely unreliable. So whether it was properly designed or improperly designed, it would not surprise me at all that the system didn't perform at all.
Q. But does it concern you that we have factual evidence where people are reporting smoke coming through those vents straight into the lobbies? Is that concerning?
A. Well, the evidence is that the system is performing poorly because it's bringing smoke into the lobbies. Now, that could have been because of the non-compliances, but it could also have been because the system was designed to basically deal with one floor.
One of the things that is not clear yet from appendix J, and I think it should be explored a bit more in detail, was the way in which the dampers were activated, because effectively the detection of smoke within a lobby will activate the dampers for that specific floor, but what was the algorithm supposed to do if you had smoke in ten different floors?
So the way in which the system is operating -- smoke management systems are a very precise balance of pressures, where you effectively have to push the smoke in one direction so that you clear another space without necessarily altering what is happening in a fire. So many times when you change the equilibrium of the systems, smoke might end up going in all the wrong

directions.
So I think that there is a reason for concern, and there is a reason to look into the space, but I think we have to keep in mind that it was a system that was designed for a one-floor fire, and that is a fundamental weakness of the system, not necessarily the non-compliances.
Q. In general, at this stage, before we move to your untenable stage 4, do you have any more developed views about smoke migration in the light of the Phase 1 evidence, or is that something you want to go away and look at in more detail?
A. Yes, I think I'd rather not comment any further because I do think that that requires a bit more detailed analysis.
Q. So your stage 4 you describe as the untenable stage, and you say this is from 2.30 am until extinction of the fire. This marks significantly untenable conditions in the fire.
Can you just be clear what you mean by "untenable" here?
A. Yes. Untenability is a very complex concept to define because it is partially perception and partially reality.
An individual that walks into smoke might encounter

conditions that will not allow him or her to survive. So, in principle, that is the definition of untenability. So it's when the concentrations of carbon monoxide, of toxics, or even visibility are such that it disables the individual and eventually leads to its death.
But there's another concept, as I say, to tenability, which is purely the perception of the individual. Sometimes the conditions might not be such that they threaten the life to the person, but the fact that they see dense smoke billowing from some door is sufficient to deter somebody from crossing a stair or a lobby, and they will return back and turn around. So that could also be perceived as a condition of tenability.
So in this particular case, I think at this stage, when I refer to tenability, I refer to both, because effectively there is a number of instances where people will see the smoke and decide that they couldn't go through without really recognising that they could've potentially gone through, and other people that might have chosen to go through, they might have actually managed to get out. So there is a little bit of variability in there that then is highlighted by Dr Purser's report afterwards.

But I think that that's what I referred to as tenability, is basically both: conditions that are actually harmful to the individual, but also conditions that the individual perceives as harmful and therefore changes his actions because of them.
Q. Linked to that, can you explain the capacity of some residents to succeed in self-evacuations after 3.00 am? I mean, we've got numerous examples of people who were able to get out after 3.00 am down those stairs.
A. Yes, I think it's a combination of both. It's people that actually made a better choice, in the sense that despite perceiving that the conditions were dangerous, they probably simply took the decision of moving through.
But also there is a component -- and it's quite clear from the 999 calls -- the system is very dynamic. So there are moments where effectively the stairs seem to clear up more than other moments. So I think they might just simply have got the right window.
So I think it's a combination of both, very difficult to ascertain, but I think if we can manage to pinpoint the way in which smoke is migrating, then we will be able to at least establish which are the conditions that were acceptable, which ones were not, so that then we can ascertain more or less what was the

interaction of the people with the smoke.
Q. So just to be clear, you think on the evidence you've seen at the moment that there probably was real variability in the conditions of the stairs over time --
A. Yes.
Q. -- in this phase?
A. Yes, clearly.
Q. In terms of the hotspot or hot zone that Dr Lane identified in her report between levels 13 to 16, where we saw, for example, the stair lights had really completely melted, in contrast to other lights higher up the tower, where they were still intact.
A. Yes.
Q. She suggested in her most recent report that this may have been due most likely to firefighter activity, possibly because of the holding open of doors at or near these levels and the migration of very hot smoke and gases into the stair at that point.
Is that consistent with your reading of the evidence so far in terms of what might explain this hot zone?
A. Yes. That's perfectly possible, and I do think that a little bit more detail is necessary in ascertaining the timing of the firefighting actions, particularly the timing.
But I do think that that form of behaviour is not

conventional behaviour in a stair. Having a hot zone requires having hot gases entering, but at the same time exiting, because the heat doesn't carry over, it just stops after a certain region.

So it does require quite an unusual pattern of behaviour that needs to be really carefully looked at, and it could be potentially associated to firefighter activity.

Q. Could it be to do with multiple doors being held open at different levels, thereby allowing the passage of smoke and then an exiting of the passage of smoke?

A. It is most likely necessary that there will be multiple doors open at the same time.

Q. Finally, there was a refuse chute door off the lobbies with a refuse chute down with doors onto it. Those refuse chutes -- is it right? -- were relatively undamaged?

A. Yes.

Q. Do you think those could've been some kind of refuge in this fire?

A. My attitude towards this type of thing is that if you design a place to be a refuge, then that place shall be treated as such. In this particular case, we designed the stair to be such and the stair failed, and so there is no guarantee that any of the spaces could have been

an appropriate refuge for people.

MS GRANGE: Professor Torero, that's the end of my questions.

The convention is now that we just pause and have a short break to see if there are any more questions that I need to absorb.

THE WITNESS: Okay.

SIR MARTIN MOORE-BICK: We would normally have 5 minutes. Do you want a bit longer?

MS GRANGE: It depends on what the people to my left are planning. We've got the time, so can we have 10 minutes?

SIR MARTIN MOORE-BICK: I'll say 4.10.

MS GRANGE: Yes, thanks.

SIR MARTIN MOORE-BICK: All right, we'll have a break for 10 minutes. Would you like to go with the usher, please.

All right, 4.10, then, please.

(4.00 pm)

(A short break)

(4.10 pm)

SIR MARTIN MOORE-BICK: I think a few questions still.

Yes, Ms Grange.

MS GRANGE: Not many, thankfully.

SIR MARTIN MOORE-BICK: Not many? There we are.

MS GRANGE: Two topics, really: first the stair doors and then the roof.

On the stair doors, I take it you're aware of Dr Lane's more detailed investigation into the stair doors and the fact that they may have actually been as low as 20 minutes' integrity, fire resistance; is that correct?

A. Yes.

Q. Do you agree with Dr Lane that the stair doors being held open or being jammed open, for example, by firefighting equipment or other objects, appears to be the primary reason for the failure to maintain compartmentation as between the lobby and the stairs?

A. Well, whatever the reason was why they were left open, if the doors were open, that would've been the primary mechanism by which the stairs would've been compromised.

Q. As opposed to any issue about the integrity of those doors.

A. As I explained for the doors of the flats, the temperature at 20 minutes would've been of the order of 800-and-something degrees. So the lobby would already have had to be at about 800 degrees for the doors to fail. So if the doors were not at the best of their capabilities, it would've still taken a lot to make them fail. So I think opening of the doors is clearly a much

more viable mechanism.

Q. Do you think any issues about the integrity to those doors are insignificant or do you think that they still have a role?

A. When we're talking about compartmentation, and, again, we've discussed this issue that it is how you gain robustness to the system, the moment the doors are not of the desired quality, clearly you're losing robustness to your system.

The problem with having poor quality doors is that their modes of failure are not necessarily only because of heat; they might sometimes not be placed appropriately, so they might introduce leaks. There's numerous other mechanisms by which a poor quality door can actually affect the performance of compartmentation.

Q. Finally, one question about the roof.

Based on what you know, had people been able to access the roof, do you think that could have provided a kind of safe space, a safe refuge?

A. There is no evidence that evacuation through the roof or the roof as a safe haven can actually be appropriate. I think there's been numerous incidents and there's been many people thinking of ways by which you can gain the benefit of being outside, but it is something that should not be promoted because there is no evidence that

the roof represents a safe space for people.
MS GRANGE: Okay. Those are all my questions. Thank you.
SIR MARTIN MOORE-BICK: Right.
MS GRANGE: I'd like to say thank you very much, Professor Torero. I know you have put a huge amount of work into your Phase 1 report, and I'm sure a huge amount of work is going to go into your Phase 2 report as well. We are extremely grateful for your time and commitment to this inquiry. Thank you.
SIR MARTIN MOORE-BICK: Yes, and I'd like to endorse that. We're really grateful to you for putting your undoubted expertise at the disposal of the inquiry. You've produced a very full and comprehensive report for us already, for which we're very grateful, and now you've explained certain aspects of it today. So it's been extremely useful and, may I say, very interesting.
THE WITNESS: Thank you.
SIR MARTIN MOORE-BICK: Thank you very much indeed.
THE WITNESS: Thank you very much.
(The witness withdrew)
MS GRANGE: So, sir, yes, it's Professor Bisby tomorrow at 10.00, and Mr Millett will be taking him.
SIR MARTIN MOORE-BICK: Thank you very much.
Well, that's it for today. We'll break at this point and resume tomorrow at 10 o'clock.

Thank you all very much.
(4.15 pm)
(The hearing adjourned until Wednesday, 21 November 2018 at 10.00 am)

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