Wednesday, 21 November 2018
(10.00 am)
SIR MARTIN MOORE-BICK: Good morning, everybody. Welcome to today's hearing. We are going to hear some more expert evidence about fire development and related topics.
MS GRANGE: Yes. Good morning, Mr Chairman.
I'm now going to call Professor Luke Bisby, please.
SIR MARTIN MOORE-BICK: Good, thank you.
PROFESSOR LUKE BISBY (affirmed)
Questions by COUNSEL TO THE INQUIRY
SIR MARTIN MOORE-BICK: Thank you very much, professor. Sit down and make yourself comfortable there.
Yes, Mr Millett.
MR MILLETT: Good morning, Professor Bisby.
A. Good morning.
Q. Can I ask you, please, to give the inquiry your full name.
A. My name is Luke Alexander Bisby.
Q. Thank you.
You have provided to the inquiry a preliminary or interim Phase 1 report dated 2 April 2018. I'll just give the reference to that: that's LBYR0000001, with an accompanying video showing vertical flame spread on the east elevation of the tower at LBYR0000002.
You've I think now updated that report in a revised

version dated 21 October 2018; is that right?
A. That's correct.
Q. Can that please be shown. That's LBYS0000001, at page 1.
Is that the first page of your updated report?
A. Yes.
Q. Is that signature yours?
A. It is.
Q. You summarise the main updates that you've made at paragraphs 24 to 28, and I'm just going to summarise them aloud to you and see if you agree that my summary is accurate.
First, an update to your original flame spread video.
A. Yes.
Q. And four new videos showing horizontal flame spread on the east, north, west and south facades of the tower.
A. That's correct.
Q. Those are, I think, LBYS0000004, LBYS0000005 and LBYS0000006.
You've also, I think, provided new updates on vertical and horizontal fire spread.
A. That's correct.
Q. Testing of hypotheses based on new evidence that's come to light since April this year.

A. Revisions of the hypotheses, yes.
Q. Yes. And I think you've update your opinions to take account of ingress of fire and smoke, taking account of the evidence from the bereaved, survivors and residents.
A. I've added a new section, yes.
Q. Thank you.
Turning to the scope of your work briefly, if I may, you're Phase 1 report, as we now have it, sets out your preliminary conclusions on two main things -- is this right? -- first of all, the ignition of the facade of the building.
A. Correct.
Q. And, secondly, fire spread to and on the exterior of the building.
A. That's right.
Q. You've also been instructed to provide a further report at Phase 2 of this inquiry.
Just correct me if I'm wrong about this, but summarising them, that will cover, first of all, your final conclusions about fire spread to and over the exterior of the building.
A. Yes.
Q. Secondly, performance of the materials which formed part of the exterior of the building.
A. Yes.

Q. Thirdly, their respective contributions, if any, to the spread of fire, which would include, I think -- is this right? -- a review of testing by the BRE and other relevant testing bodies, and also a review of the standard testing regime.
A. Yes, that's correct.
Q. You are going to do that?
A. To the extent that we can, yes.
Q. To the extent that you can, yes, of course.
Fourthly, I think -- is this right? -- you're also going to look at any issues relating to the mechanical response of the reinforced concrete structural frame, if relevant.
A. That's correct.
Q. Finally, recommendations about what, if any, changes could be made or should be made to the regulatory regime and industry practice to prevent a similar incident from ever happening again in the future.
A. Correct.
Q. Thank you very much.
In your report at section 1.3 -- this is page 12 -- you have summarised the structure of your report. If we can please have that on the screen.
You've set out there -- and we can see it -- how you've organised your report, running from paragraph 70,

"Section 2: Technical Background", to paragraph 75, "Section 7: Ingress", covering geometry, materials, fire spread and spread over cladding in between.

At section 9, first of all you've set out your future work as proposed for Phase 2, and that's paragraphs 1243 to 1263 at page 264. If we can just have that on the screen, please, just so that that is there.

You've I think set out also in your report a declaration at paragraph 90, if you can turn back to page 14, and I just want to make sure that you confirm these here now, paragraphs 88, 89, 90 and, indeed, 91 on pages 14 and 15, under the heading "1.6. Statements".

Can you confirm that those are paragraphs which you stand by today?

A. Yes.

Q. Thank you very much.

At section 1.4 of your report at page 13 -- I'm sorry to ask you to jump around a little bit -- you've set out your relevant experience and qualifications. I'm not going to go through all those today -- everybody can look at those if they want to -- but can I just pick out one or two bullet points from them so that people in the room and watching us today can hear from you some elements of your experience.

It's right, isn't it, that you are currently professor of fire and structures within the School of Engineering in the University of Edinburgh?

A. That's correct.

Q. You were formerly, I think, the head of the Research Institute for Infrastructure and Environment and Royal Academy of Engineering Research chair as well.

A. That's correct.

Q. You are, I think, co-editor-in-chief of the Fire Safety Journal.

A. Yes.

Q. And you have, I think, extensive experience of engineering research and consultancy, of university teaching and promotion of public understanding of science and engineering.

A. That's correct.

Q. You're a chartered structural engineer in the UK.

A. Yes.

Q. And a licensed professional engineer in Canada.

A. Correct.

Q. You are, I think, a fellow of the Institute of Fire Engineers.

A. Yes.

Q. And the Institution of Structural Engineers, the International Institute for FRP in Construction, and

Institution of Engineers and Shipbuilders in Scotland.

A. Correct.

Q. I think you've got a number of awards for your commitment to high quality engineering research and education, and your dedication to the broader academic and research communities.

A. That's correct.

Q. Two general questions, professor: are the factual matters that you set out in your report true to the best of your knowledge and belief?

A. They are.

Q. Does your report accurately set out your opinions on matters in respect of which you have been asked?

A. It does.

Q. Thank you.

Just to summarise where we've arrived at today with your evidence so far, we've seen already that you provided a first report or preliminary report to the inquiry in April this year.

On 20 June this year, you gave a presentation to the inquiry based on that report. You remember that.

A. Of course, yes.

Q. People can see that if they want to.

That presentation focused -- just to summarise it -- in part on the concepts of flammability and fire spread

and the different construction materials present on the facade of the building.

A. That's right.

Q. This is a continuation of that evidence; is that right?

A. Correct.

Q. I'm not going to go over the entirety of the detail that you've covered in your presentations in the past or, indeed, in this report, but I am going to ask you about a number of things. First, so you know where we're going, some questions about the materials installed on the facade and their performance in a fire, and also your conclusions on fire spread out of the compartment, over the building and back into flats.

A. Okay.

Q. I'm going to ask you to explain some of the aspects in which you've updated your earlier report.

I'm not going to ask you -- just so that we are clear -- about the cause and origin of the fire, because that's been dealt with by Professor Niamh Nic Daeid and Dr Glover, but your conclusion, if I can just look at that with you, is at paragraphs 12.12 to 12.16 of your report, which is at page 259, if we can please have that on the screen.

At section 8.1, you have set out your preliminary conclusions at 12.12 to 12.16 there.

You say in 12.12:

"There is a high level of evidence to support the hypothesis that the fire started somewhere between the edge of the cooker and the kitchen window in Flat 16 (see Figure 83)."

You may well know that we now have a report from Dr Glover, and we'll be hearing from him and Professor Niamh Nic Daeid, who is also going to come to give evidence. But in general, do you agree with Professor Niamh Nic Daeid and Dr Glover's opinions on matters of cause and origin?

A. To the extent that I'm sufficiently expert in cause to agree, then yes, I do.

Q. Your report in general -- again, for clarification -- represents your initial conclusions on ignition of the facade and spread up the building based on the evidence that we have to date.

A. Correct.

Q. I think it's right that you expect to carry out further research and testing later in order to firm up your conclusions so as to be ready for phase 2.

A. Indeed, yes.

Q. At this stage, are you able to express any firm conclusions about the relative contributions of different materials on the facade to the rate and the

extent of fire spread?

A. I think qualitatively, yes, in some cases. Quantitatively, it is quite difficult.

Q. I'm going to ask you, please, to go to page 74 of your report and look at paragraph 290. I'm going to ask you one or two questions next about the familiarity that you have with the building after the fire.

At paragraph 290 and following, you set out a summary of the materials and products presented in this section. You explain those, and at 291 you say there were:

"291. Six accompanied post-fire inspections of Grenfell Tower that I conducted (the details of which are provided in Appendix A of this report)."

Then at 295 you say:

"... I have not personally undertaken an exhaustive physical post-fire survey of the entire exterior, or the interior of all compartments, of Grenfell Tower; such work has been undertaken in part by Inquiry Expert Dr Barbara Lane's team, and also by the BRE forensic team with and on behalf of the MPS."

Just so that we can understand, what investigations of the facade did you undertake at the tower during your visits?

A. So I have on several occasions -- well, initially, I went to the tower when there was no scaffolding external to the tower, so we undertook investigations internal to the tower and could only see the exterior of the tower by leaning or looking out the windows of the tower at that time.

I subsequently went back on several occasions once the scaffolding was in place -- and those specific occasions are noted in the noted table in the appendix -- and walked the scaffolding to the extent that we were permitted to, typically based on health and safety considerations on site.

So I have on three or four occasions visited the exterior of the building at the lower levels, so levels 3 through 5 or 6. On one occasion, I walked every level of the building on the scaffold from bottom to top, full perimeter, up and down, and then I've been back on two separate occasions to inspect the details of the architectural crown at the top of the building.

Q. On two separate occasions?

A. That's correct.

Q. In paragraph 295, as we got there on the screen, you refer to the work undertaken by Dr Lane.

Have you relied on Dr Lane's survey of the building in any way in your work?

A. I think the only place where I've relied uniquely on Dr Lane's work would be in the identification of a specific product called purlboard, where during her surveys she was able to identify the specific manufacturer of that product via some photographs that are in her report. So I've relied on that as a confirmation of the supplier of those materials. But that I think is probably the only specific location when I've done that, yes.

Q. We'll come to purlboard later on.

I think you were also present when cladding was removed by the police.

A. That's correct, on two separate occasions, yes.

Q. Is it also right that you looked at cladding removal photographs which were provided by the police?

A. That's correct, yes, some 12,000 photographs.

Q. Are you satisfied in your mind that the sections of cladding that you observed being removed from the building were properly representative of the materials and the construction of the cladding over the whole building?

A. To the extent that it's possible to conclude that, given that much of the cladding was destroyed in the fire. So it's impossible to know with certainty, but I have no reason to suspect that there was significant variation, yes.

Q. Breaking that answer down a bit more, were you able during your work to consider or calculate the volume of different materials making up the facade that were, number 1, installed, and actually were installed there?
A. I mean, I've not done those calculations myself. It would be possible based on the geometry of the cladding system to do that. We have a sense of the respective quantities of different materials from purchase orders and materials supplied to the site, but obviously we couldn't confirm definitively that the materials that were purchased or sent to site were actually installed.
Q. Would it follow from that answer that you were also not able to calculate or consider the volume of materials that disintegrated, combusted, melted or fell off during the fire?
A. That's correct, only in an approximate way by surveying the visual appearance of the building. I have done that, that was my reason for wanting to do a walk of the full extent of the tower, just to get a sense of the extent to which the insulation materials in particular were still present.
Another means that I've used to try to develop that information is looking at all of the drone photos that were taken on various instances by various parties at various stages, immediately after the fire and then

during the months following the fire.
Q. Were you able to analyse, of the material that remained on the building at the moment the fire was extinguished, what was later removed from the building as opposed to what remained on it?
A. I mean, that was my rationale for looking at the drone photos and requesting additional drone photos to the extent that I could get my hands on them.
It's very difficult. Immediately after the fire, my understanding is that there were some health and safety concerns about debris continuing to fall off the building, so loose debris, and that some crews were sent up in a basket and were pulling some of the loose materials off the building, and that we may not have that information recorded in the drone photos that are available to us.
So I think, in general, yes, that information is at least visually available through the drone photos, with some caveats about some uncertainties, and that is some work that we do intend to do at Phase 2, to try to get a sense of the amount of insulation consumed in the fire in particular.
Q. Were you able to undertake any kind of analysis or investigation into the depth and extent of charring of the insulation which was left behind on the building

after the fire?
A. Beyond a cursory visual examination, no. Nothing systematic.
Q. Would such an analysis have helped you in your conclusions that you've arrived at in your report?
A. I mean, I think it would be interesting information to have. One of the issues with that is -- the reason that I, given my scope of work, would be interested in the answer to that question in terms of charring to the amount of insulation remaining, is that one of the questions I'm interested in is the extent to which the predominantly PIR insulation within the cavity will have contributed to the fire spread mechanisms that we observe on the building.
One of the challenges with using char depth or the amount of material remaining in that context is that we know that, after the fire front passed a particular location on the building, we had a significant number of compartment fires burning within the building as a consequence of the ingress of the fire into the building. The consequence of those compartment fires is that you have fires venting from the windows, with significant external heat fluxes applied to the insulation. That will continue to burn and char the PIR in the regions around the windows, but that burning and

charring of the PIR is so far behind the fire spread that led to that that it isn't telling me anything useful about the contribution to the fire spread mechanisms.
So whilst it's interesting, I don't know -- having not looked at it yet and thought that detailed about what information is available to us, which is a topic we've been leaving for Phase 2, I wouldn't be able to say how useful it would be.
I think it would be interesting. I don't have a huge amount of optimism that it's going to be particularly constructive as regards fire spread mechanisms.
Q. I want to turn to a different topic, namely materials which were to be found on the facade.
In your report, you have identified a number of materials present on or within the facade of Grenfell Tower following the refurbishment. I'm going to ask you a number of questions about how those materials behave in a fire, starting, if I can, with the Reynobond 55 PE.
Can we begin, please, by going to page 78 of your report.
On that page, we have a table, table 2, which is entitled -- if we can have that highlighted -- "ACM

product variants used in Grenfell Tower refurbishment (all at 4mm total thickness)". There are three products there set out with their different finishes and colours, as you can see.

In the table, you identify in the last column that the PE colour, the polyethylene colour, is different between column panels and some of the spandrel panels, I think.

First of all, am I right to identify that difference?

A. That's right. The polyethylene in one case is a clear translucent and in the other case is black.

Q. You say later in your report -- I'll just give you the reference, it's page 77, paragraph 314, there's no need to go to it -- that testing is underway to establish whether there are any significant differences in terms of the fundamental material and reaction to fire properties.

At this stage, professor, do you know or can you say with any confidence whether the different core colour has any bearing on fire performance?

A. We've been doing thermogravimetric analysis and differential scanning calorimetry on those two core materials, which are essentially tests to characterise the way these particular core materials respond to

heating, and looking for signatures that would indicate some differences between the two of them. We've not found anything yet that I would consider significant as regards the performance of these materials.

Q. Are you considering continuing those tests?

A. Of course, yes.

Q. Would you be able to report on that at Phase 2?

A. I hope to report on that very early in Phase 2, yes.

Q. Very good.

Did the pattern of fire spread that you've observed from your visits to the tower and from the flame spread videos that you've presented indicate the possibility, beyond the negligible, of any significant difference between these two colours of polyethylene?

A. No, I haven't observed anything to lead me to believe any significant differences.

Q. I don't think in your table here, which we can have back up again -- table 2, page 78 -- you've identified anything on the surface of the aluminium, but have you identified whether the ACM contained a powder coating on the surface?

A. The colour of the external finish, I'm not sure if that is a PPC or powder coating. I imagine that the purchase orders would specify whether or not that is the case.

Q. But you haven't looked at that?

A. The nature of the painting of the panels is not something I've looked at specifically.

Q. Again, would that be something you are going to look at at Phase 2?

A. I mean, I hadn't planned on it because I didn't observe any surface effects on the exterior of the aluminium, either during the fire or in any of the testing we've done, for instance cone calorimeter testing, looking at how it responds to heat flux.

So without any compelling reason to do so, I wouldn't intend to. If there is a compelling reason, I would love to hear it.

Q. That leads me to this questions: in your experience, would a powder coating, if there was one, have any impact on the spread of fire in terms of speed or heat transfer?

A. I think it's hard to say. I wouldn't expect a significant difference. Powder coatings tend to be very thin, so the mass of material is very small. It could potentially have a minimal impact, but I wouldn't expect anything significant.

Q. Leaving aside powder coating on the surface, have you identified whether these panels had any adhesive between the aluminium skin and the polyethylene filler or core?

A. The product information for the specific product

indicates that the aluminium skins, if you like, are bonded to the PE filler via a thermal bonding process. I'm not entirely sure how that works or what that is, but given that it's a thermoplastic material at the core, I would expect that would mean that you heat the thermoplastic so that it softens a bit on its surface, and you bond the aluminium to it in that context. Once it cools, you have a bond, but I've not been able to confirm that.

Q. Paragraph 431 of your report, if I can please ask you to go to that. It's at page 100.

You say there:

"431. The fact that thermoplastic polymers such as PE present particularly challenging behaviour as regards its reaction-to-fire has been well known (and documented) for decades, and this fact therefore cannot, in my opinion, be considered at all surprising by any competent fire safety professional."

You go on at paragraphs 432 to 434 to identify what you describe in the second line of 432 as "decades old literature" being available.

In 433, you identify a paper written in 1975 by Murty Kanury. Is that a partnership or a single individual?

A. A single author.

Q. Is that the earliest date at which these issues were documented or is there even earlier reliable literature?
A. There is even earlier commentary in the literature, but those are some of the earliest papers we could find specifically dealing with polyethylene. There is considerable earlier work looking at thermoplastics in general.
Q. In the next paragraph, paragraph 434, you refer to the work of Tewarson and Pion.
Taking those two together, the 1975 and 1976 work, would that work be, in particular, specifically known to competent fire safety professionals?
A. I would be surprised if most fire safety professionals, competent or otherwise, were specifically aware of those two papers.
Q. But what about the principles in them?
A. I mean, I think that the general principle that a thermoplastic will melt and drip and burn quite vigorously is very clearly highlighted in any of the reference text that one would expect a competent fire safety professional to have at least skimmed, if not know quite well. So, for instance, Dougal Drysdale's book on fire dynamics or the SFPE handbook would be references where they clearly highlight the risks associated with these materials. I would certainly

think it reasonable to expect fire safety professionals to have some awareness of those references, yes.
Q. If we can then turn to the next paragraph of your report, 435, and have that on the screen and identify it, you actually pick up your reference there to the SFPE handbook of fire protection and engineering.
My question there is -- you identify I think in the footnote it was published in 1988, it doesn't say so there -- is it fair to say that, since 1988, there has been a recognised body of opinion on the dangers of thermoplastic materials from a fire safety perspective?
A. Absolutely.
Q. I want to turn to the details of the properties of polyethylene at page 101 of your report.
At that page, you've out table 3, and you've selected there, as we can see, the typical properties of low density polyethylene.
We can note the melting temperature of polyethylene at 130 to 135 degrees centigrade, and the surface temperature at ignition, which is the last but one entry, at 377 degrees centigrade.
Is there any data about the time to ignition of polyethylene?
A. I mean, yes, there will be studies on the ignition of polyethylene, which is where some of these data -- for

instance, surface temperature at ignition -- will come from.
One of the issues with polyethylene is with the orientation of the sample and the way that the fuel responds to heating, and that it does melt and drip. So it will depend on the particular configuration.
Q. Can you give us a sense of time to ignition for low density polyethylene?
A. I mean, that will depend on the heat flux that you apply to it. So you see in the table, table 3, critical heat flux for polyethylene is listed at 15 kilowatts per metre squared, so that is the heat flux. If you had a lower heat flux then that and you were to test it -- I presume that reference is using testing in what we call a cone calorimeter -- a heat flux less than 15 kilowatts per square metre will not result in ignition of the sample within a defined period, a period of minutes. Higher heat fluxes would cause ignition eventually. The higher the heat flux, the faster it will ignite.
Q. Are you able to give us a clue about its thermal inertia?
A. Its thermal inertia is comparatively high in comparison, for instance, to a polymer insulating foam. One of the reasons I presented the data in these tables, it is

probably worth me mentioning, is not because they necessarily represent definitive values in all cases for materials; if we additives or fillers or fire retardants, we might get slightly different values. So these are ballpark reference values that I've placed in the report to give an overview of the kinds of behaviours we can expect.
The key thing to recognise there is that the thermal inertia of the polyethylene, the low density polyethylene, you can see 0.43, and you compare that to, for instance, PIR, bottom of the same page, 0.06, the key message to take away from that is there's an order of magnitude difference in the thermal inertia of those two materials. That's why I've presented them.
So I think it is important that we not focus on the actual values but focus on the comparative nature of the values. That's why they've been presented.
I should also point out that the work we're doing at Edinburgh right now is seeking to characterise, specifically to the materials at Grenfell Tower, what these values are. So for the actual materials that we have on site at Grenfell Tower. So we'll report that early in Phase 2.
Q. Thank you.
Still focusing on PE, as to the heat release rate,

which I think is the rate at which energy releases per unit time as a material burns, expressed in watts, kilowatts and I think megawatts, you've set out in your report that the heat release rate can extrapolated to quantify the size of any fire; is that right?

A. Yes. I mean, that's typically how we quantify the size of the fire.

Q. For reference, it's footnote 12 in your report on page 23. We don't need to go to it.

My question is this: knowing the approximate quantity -- maybe this is the problem, but tell me -- of polyethylene in panels which were used on floors 4 to 23 of the building, are you able to quantify the size of the resultant fire?

A. No, because it will depend on the amount of the material that's burning at any given instant in time. So the more material that's burning, the more heat release you'll get; the less material, the less heat release. So it's going to be dependent on the time at which you ask the question.

So early on, the fire is going to be quite small. At some stage, the fire is a very, very, very large fire. To quantify that in any way that I would be able to defend scientifically would be very difficult.

Q. At paragraph 461, just moving ahead, if I can, we come

to section 4.12. This is page 104, where you deal with aluminium and its reaction to fire.

You say:

"461. Upon exposure to heat, aluminium will melt at approximately 660°C."

First, does the physical evidence that you've seen from your surveys of the building suggest that this temperature was reached anywhere on the building?

A. Yes. I mean, there is considerable evidence of melted aluminium.

Q. Where would that have been, from your observations?

A. I mean, if you were to walk the surface of the scaffolding, as I did, you would see remnants of melted aluminium in most areas of the building and, to be honest, small droplets, small pools, bits of re-solidified aluminium throughout the site. Yes, it's quite widespread.

Q. Would melting aluminium itself, taken as a single product, have any effect or play any role in the extent and rate of fire spread?

A. I wouldn't expect it to, no. I mean, aluminium is reactive, but typically only in a finally divided powder form, which is not what we have here.

Q. Does that mean that the temperature at which aluminium is reached was relevant because of delamination away

from the polyethylene?

A. You mean why have I bothered to mention this temperature?

Q. Well, that's another way of putting it.

A. Yeah. I think because the aluminium for many products that we find at Grenfell Tower, the aluminium is there and is providing some protection to the underlying combustible material. So that's true for the ACM, it's also true for the Celotex and the Kingspan insulation products, it's true for the window infill panels, all of which have aluminium skins of various thicknesses. So it's important to understand the extent to which those protective layers will have remained in place.

As opposed to, for instance, if we had steel skins of a similar thickness, the outcome could potentially have been quite different, because steel has a much higher melting temperature than aluminium.

So I put the value there to simply indicate this particular weakness, if you like, of aluminium, in that it melts at temperatures which are comparatively low.

Q. It's interesting.

Can I ask you to pick up paragraph 462 on page 105, where you make this point.

You say there:

"462. It is notable that aluminium also has a

comparatively high coefficient of thermal expansion (about twice that of steel or concrete) and so under heating (as in a cladding fire), it can be expected to warp and deform under the influence of thermal gradients and differential thermal expansion with other materials. This may lead to connection failures or to the opening up of cavities and products formed by aluminium sheets, including ACM rainscreen cassettes."

Are you able to tell us anything about the speed at which this warping or deformation would occur once aluminium had reached 660 degrees?

A. Well, I mean, that's a difficult question. It's a good question but a difficult one. The warping of the aluminium will depend on the rate of change of temperature. So the thermal expansion is, you know, the hotter something gets, the longer it gets, right? So that is relevant to an aluminium sheet, both because if the entire aluminium sheet -- take a two-dimensional sheet of aluminium -- if its temperature is increased, the entire sheet wants to expand in all directions. If the material that is behind the aluminium sheets has a different coefficient of thermal expansion, you will generate mechanical stresses at the interface between the two materials, which could lead to debonding failure between those two materials.

Additionally, if you have a temperature gradient through your aluminium sheets, ie the surface is hot and the face which is against whatever the core material is is colder, then that aluminium sheet is going to curve as a consequence of the thermal gradient. The external surface is getting hotter, it wants to get larger; the rear surface is cold, it doesn't want to get larger, and that induces a curvature in the aluminium, which again can induce mechanical stresses in your panel and could lead to opening up of the panel or some kind of failure.

So the thermal expansion is potentially quite important for aluminium, in particular.

I mean, I should point out that both concrete and steel also experience thermal expansion, just less than aluminium.

Q. At different temperatures as well?

A. The rate of change of length is less significant for a given change in temperature for steel and concrete.

Q. I see, okay.

Can I turn then to Aluglaze, which is the next product I just want to ask you about.

You cover that at page 95 of your report at paragraph 389 under section 4.9.1. The title of this part is "Window Infill Panels (Aluminium/Polystyrene Composite Panels)".

At paragraph 394, over the page at page 96, and at paragraph 402 at page 97, you refer to these as Aluglaze. You say that the infill panels around the kitchen extract fans and the window infill panels are made of the same product, namely Aluglaze.

A. That appears to be the case, yes.

Q. Aluglaze I think is made up of extruded polystyrene, or XPS, sandwiched between aluminium sheeting.

A. Correct.

Q. Just for our note, that's figure 56 at page 96. There's no need to go to it -- well, we have it there.

Is that it?

A. That's it, yes.

Q. Is it right that these panels that we see here are similar to the panels that were involved in the Lakanal House fire?

A. Yes, in terms of the type of product. Yes, that's true.

Q. Is there any difference you know about between these panels on Grenfell and the panels on Lakanal House?

A. I've not specifically looked at the details of the panels that were installed on Lakanal House.

Q. What about the Shepherds Court fire?

A. Yes, I mean, based on the LFB presentation that deals specifically with the Shepherds Court fire, which has been discussed here at the inquiry on a number of

occasions, those panels appear to be quite similar to these panels, yes.

Q. Did the Aluglaze panels -- I call them that as a shorthand -- which were at Grenfell have exposed edges of XPS?

A. They were mounted within the window frame assemblies, so the edges in general were not exposed, no.

Q. Right.

A. I mean, let me just caveat that: one instance where the edges became exposed, which I think is a relevant instance, and I'm sure we'll come to this at some stage today, is that we know that the extract fans that were mounted within these panels in the kitchens of the refurbishment windows tended to fail quite early on when exposed to heating. When those fans fell out of the mounting panels that they were sitting within, which are these Aluglaze panels so far as we can tell, you then have a hole through an Aluglaze panel, and obviously the inside of that hole has the exposed XPS showing in that location.

Q. I was going to ask you that. In that instance, is it your opinion that that exposed XPS foam within the circle in which the fan was previously mounted facilitated fire spread in any way?

A. I mean, that's certainly plausible. I think it's

important to recognise that the XPS insulation is a low density product. So despite the fact that it looks like there's quite a lot of it -- there's 25 millimetres of that XPS as opposed to 3 millimetres of the PE, for instance, in the ACM panels -- both the density and the heat of combustion of polystyrene in this configuration are considerably less than is the case for the PE.

So the total mass of polystyrene that's available here is actually quite small, so even if we assume that all of that mass is consumed to deliver energy to the fire, we're talking about a comparatively small quantity of energy. A few per cent, not a huge amount of the total.

Q. So, in summary, can you quantify the contribution that this material as exposed by the falling out of the fans had to the overall spread of fire?

A. If I were to assume that it all burns as efficiently as possible, I could come up with a back-of-the-envelope quantification, yes.

Q. No, let's not do that.

A. But given that under the conditions we would experience, we don't know how complete the combustion will have been, it's difficult to do that in any way that would be scientifically defensible. We could do a sanity check on it and find it's quite small.

SIR MARTIN MOORE-BICK: It sounds as though you don't think it's likely to have been significant.
A. Certainly as regards an escalating fire, once the fire gets big. When the fire is small, I think it could potentially have contributed, for instance, to flaming out the window early on.
MR MILLETT: Yes, thank you. We will come back to that in due course.
Before I leave this material, can I ask you, please, to go to page 97 of your report, paragraph 406.
You quote here from the product literature for Aluglaze, published by Panel Systems Limited, PSL. At paragraph 406, it says:
"There are several basic queries in terms of the fire performance of panels that may form part of designing the panel composition. These may include:
"a) Class 1 Surface Spread of Flame
"b) Class '0' to Building Regulations
"c) Non-Combustible Core."
Do you know if any of those questions could be answered in relation to this material as you saw it installed at Grenfell?
A. So that statement has come from Panel Systems Limited. I believe that was one of the statements that they submitted to the inquiry. I'd have to check the

reference to confirm that; it may be from their position statement.
At paragraph 405, just above the section that you've quoted, it says:
"PSL do not manufacture a panel that has been subjected to any independent fire testing."
So on that basis, I would say no, there is no evidence that this material would meet any of those subsequently listed requirements, if that answers your question. I'm not sure that it does.
Q. It gives rise to the next question, which is: are you aware of any other fire test data for this material produced by or for anybody else?
A. Not specifically, no. I have never seen either BS 476, part 6 or 7 testing, which would be the tests required for class 1 and class 0. For any other similar product, no.
Q. The second question that arises out of that is if you look at paragraph 407, the product literature says:
"To achieve (a) [Class 1 Surface Spread of Flame] we may propose an aluminium skin, to achieve (b) a polyisocyanurate foam and for (c) a lamella mineral fibre."
Do you know if any of those were present on these panels at Grenfell in either location?

A. Certainly these panels do have an aluminium skin 1.5 millimetres thick or thereabouts, so that would meet the requirement for point (a).
But, I mean, I find this statement slightly problematic, in that without actually performing the regulatory compliance tests, I don't understand the basis for those propositions, if you see what I mean.
I mean, I should say also that given that Dr Lane is commenting specifically on compliance issues, I think it would be very good to put those questions to her tomorrow, if possible.
Q. Yes, thank you.
Turning over to page 101, please, you've set out there table 4, where you give details of the properties of XPS. You covered those a little bit just now, and they are selected.
Have you calculated the heat release rate of a unit of this XPS?
A. Again, it will depend on the nature in which that piece of XPS is burning. So, you know, the heat flux it's subjected to, the manner in which it's burning, et cetera.
So, no, I couldn't calculate the heat release rate. As I mentioned, I could, in a back-of-the-envelope sort of sanity check sense, tell you the amount of energy it

is possible to liberate from a piece of this material, but that would be the maximum conceivable value. In reality, it would be somewhat less than that. How much somewhat less, I would be hard pressed to say.
Q. Comparing XPS and PE, you'll note that the thermal inertia you've got in the last entry in the box under table 4 is "N/A melts".
A. Mm.
Q. Whereas for low density polythene PE, you can see you've put a value in, 0.43-kilowatt squared per second.
Are there any key differences material to Grenfell between the behaviour of XPS and the behaviour of PE under heating?
A. Yes. So the reason for the discrepancy which you've pointed out between table 3 and table 4 -- as you've noted, in table 3 I've given a value for thermal inertia, in table 4 I've just said not applicable, melts -- the reason is it's very difficult to measure the thermal inertia for XPS under the conditions that we would expect in a fire, because when exposed to heat, it tends to shrink away from the source of heat as a consequence of its foam nature and low density.
People may have experienced -- you may have experienced this yourself -- if you hold a match up to a piece of this XPS, it tends to shrivel and shrink away

from the heat, which makes it difficult to measure its properties, if it's running away from you; whereas the polyethylene, which is higher density, you can actually measure a useful value.

Q. So the big difference is the density.

A. Well, the big difference is the way that it responds to the heating. The low density influences that behaviour.

Q. If they're subject to the same heating conditions, does that mean XPS would -- maybe this is not the appropriate question -- take longer to melt and form burning droplets than PE?

A. I would expect XPS to melt before PE as a consequence of its thermal inertia, which, despite me not giving a value in this table, its thermal inertia at room temperature, so its insulating properties, would be better than low density polyethylene and non-foamed polyethylene, which means I would expect the surface to heat up more rapidly than PE, all other conditions being equal.

Q. Dr Lane has said that this product made up some 13 per cent or so of the facade at Grenfell Tower. Just for a reference, that is paragraph 11.17.4 at page 63 of her latest report.

Are you able to agree with her about that?

A. I've not actually done a rigorous calculation, but it

polyisocyanurate foam.

Was that present in the building in the form of Celotex insulation on the columns and in the spandrels?

A. Yes.

Q. Is it right that this product, using that word advisedly, is made up of PIR foam with a thin layer of aluminium foil?

A. Both faces and in some cases with a glass fibre mesh as well within the foam.

Q. At paragraph 438, you say in the second line:

"The low thermal inertia of PIR means that it tends to have a comparatively low time to ignition and will support rapid flame spread."

Then you give under table 5 the selected typical properties of PIR foam insulation, and you can see the thermal inertia from a cone calorimeter of 0.06 kilowatts square per second.

Can you describe the process by which this material -- and I mean the material PIR -- supports rapid flame spread?

A. So in order for flame spread to occur, you have to have heating of the surface of the material, which leads to pyrolysis of the material. That results in the formation of combustible pyrolysis products adjacent to the material and, if those pyrolysis products mix with

seems about right, yes.

Q. Is XPS ever, in your professional and academic opinion, an appropriate material to use on a high-rise building such as Grenfell Tower?

A. I mean, that's a question that I would want to answer in the context of the overall fire safety strategy for the building. It's conceivable that it could be used by someone who takes adequate account of its response to fire.

Again, whilst my own remit for Phase 1 is not necessarily related specifically to compliance assessments of various materials, at Grenfell Tower this material is used in an insulating capacity, and Grenfell Tower is above 18 metres. My reading of Approved Document B would suggest that materials used in that type of application should be classed as A2, Euro class, which this material would not be.

So in that respect, no, it's not an appropriate material to be using, in my view.

But, again, I think that would be an excellent question to put to Dr Lane tomorrow.

Q. Can I then turn to a different product, which is the PIR insulation. Just some general points, first of all.

You cover that at paragraph 438 on page 101, so we're on the same page, and PIR, as you can see, is

air in the right proportions, and you have either an ignition source or an appropriate amount of heat in that gas mixture adjacent to the surface, you will have flaming. Then you need the next piece of material to be exposed to conditions that are sufficient for that response to sort of snowball, ignition to ignition to ignition, with the flame spreading along the surface.

So those are the conditions you need for flame spread to occur.

One of the things it's important to mention about PIR is that you tend to need an external source of heat flux in order for that flame spread to progress along a PIR material. So a piece of PIR material left to its own devices, in the absence of any heat flux being received by it from an external source, will tend to self-extinguish. Professor Torero mentioned this yesterday.

Q. Yes. That is PIR as a material.

If one then turns to Celotex as a product, the question is: does an aluminium foil covering on one or more faces affect the rate of flame spread or time to ignition?

A. Yes. I mean, it will, I think that's one of the reasons presumably that it's there. So the aluminium skin will prevent the pyrolysis gases, at least initially, from

exiting the surface of the PIR, which makes them unavailable for combustion, the surface of the PIR, so that would prevent surface spread of flame.

Additionally, when subjected to a radiant heat flux, the aluminium will essentially reflect some of that initial radiant heat flux and will prevent surface heating of the PIR to some extent so that it's less likely that it will pyrolyse early, despite its low thermal inertia.

Q. Would there be a difference of significance between the rate of flame spread across uncovered or unfoiled faces as opposed to the rate of flame spread within the material where there is a foil face when exposed to heat flux?

A. I would expect there to be a significant difference, yes, although I wouldn't be able to quantify it at this stage.

Q. Professor Torero has said that PIR has the potential to burn for a longer period of time compared with other components of the Grenfell facade system. And, again, a reference there: that's his report at page 64, lines 1748 to 1751. There's no need to go to it.

Do you agree with that?

A. Yes, in principle, yes.

Q. Do you think that that potential to burn for a longer

period is relevant in any way to the re-entry of fire back into flats at Grenfell Tower?

A. I mean, everything that can burn that is there is potentially relevant. I wouldn't consider that to be dominant by any stretch of the imagination, but the fact that it can pyrolyse and release combustible pyrolysis products must be relevant in some way, even if a small one.

Q. Again, another general question, I'm afraid: longer burning time of which Professor Torero speaks and with which you agree, is that relevant to vertical or horizontal fire spread?

A. Potentially to the horizontal, but given the horizontal modes of fire spread that, again, I'm sure we'll talk about in some detail later, I don't think it would play a significant role with horizontal.

With vertical, I think the timescales of vertical fire spread are too short for the burning of the PIR to be that important.

Q. We've talked about cut edges and faces that are or aren't exposed in the PIR.

Two questions about that.

First of all, would the fact that the Celotex as installed on the building with, in part, cut edges so that they're exposed affect the reliability of the

classification of this product for the purposes of the Building Regulations?

A. Again, I guess that's partly a compliance question, isn't it? These materials are tested for classification with respect to the requirements of the Building Regulations, both under the national classification system and under the European classification system, in a way such that they are protected by their foil face when those tests are performed, in all of the cases that would matter relevant to those classifications, yes.

So I guess that's a long-winded answer to the question.

Yes, it matters if the aluminium is not there.

Q. Is that because when the tests are done, they're tests done on PIR which is fully faced with an aluminium foil?

A. Correct, yes. And based on tests that I have seen, I would say also that any joints are also sort of overtaped with aluminium tape when those tests are performed, yes.

Q. Second question: is there any relevance in the difference in the thickness of the aluminium foil on the PIR insulation compared with the aluminium skin on the rainscreen when you're considering how readily each of those materials will pyrolyse?

A. That's a tricky one because of the differences in

thermal inertia and density of the underlying materials. The aluminium skin on the Celotex is much, much thinner, so I would expect it to heat up a more quickly and, therefore, be removed more quickly than is the case for the ACM. I think that's a fair statement, yes.

Q. Have you done any testing to determine the time and conditions under which the foil on the PIR would peel away or remove itself in comparison with the foil on the panels?

A. No.

Q. Could that be done?

A. It could be done. I'd have to think very hard and for longer than I have at the moment what we might get out of that in terms of useful information, yes.

Q. Turning to phenolic foam insulation. That's another material I want to ask you about.

Is it right that phenolic foam insulation was present on the building in the form of Kingspan insulation on some spandrel panels?

A. That's correct.

Q. That I think was used on upper floors; is that right?

A. I think I've seen it photographed on some of the lower floors, as well as during my walk-around on a few very localised locations on the upper floors, yes.

Q. Is it fair to say that it has similar properties to PIR

in terms of its ability to support rapid flame spread?
A. In a general sense, yes.
Q. Can you comment on how it would have contributed to the fire on the upper floors where it was used, if different from Celotex?
A. No, I mean, in a similar manner to the things I've already said about PIR.
Q. I think you've also referred to other types of insulation used in the building around the windows. Can I take you to paragraphs 337 and 338 on pages 81 and 82 of your report.
At the bottom of page 81, you pick up the fact that there was:
"337. A 25mm thick foil-faced PIR polymer foam insulation board manufactured by Celotex. The specific product name is yet to be confirmed.
"338. A 25mm thick foil-faced polymer foam insulation board manufactured by Kingspan. The specific product name is yet to be confirmed ..."
Dr Lane has identified these as respectively Celotex TB4000 and Kingspan Thermapitch TP10. Have you any reason to disagree with Dr Lane?
A. No, I have no reason to disagree.
Q. Do you know what materials those types of insulation are comprised of?

A. Those should be PIR materials, I believe, yes.
Q. Turning next, then, to a new material, PU foam, polyurethane foam, page 102 of your report.
It's table 7 under section 4.10.1.5, if I can just ask you to look at that, please. Middle of the page.
You described PU foam as a synthetic thermoset polymer, flexible or rigid.
In the table, you've identified the properties.
Just in general, professor, is it your opinion that PU foam has similar properties to PIR and phenolic foam in terms of its ability to support rapid fire spread?
A. In general, yes. Yes, it's sort of ballpark, yes.
Q. Ballpark?
A. Yes.
Q. It is a big or small ballpark?
A. Quite a small one, I would say.
Q. Next product: aluminium windows. Page 94, if I can ask you just to skip back to that, please, under section 4.9, paragraphs 386 and 387.
You've been able to identify now that the windows used in the refurbishment -- this is paragraph 386 -- are assumed, based on the available evidence, to be what you've set out there, "Metal Technologies 5-20 Hi Thermally Broken Aluminium Windows", and your conclusions about that product at 387, the next

paragraph, is that the aluminium alloys won't directly contribute to fire development and can be expecting to have melting temperatures exceeding 660 degrees.
The question is: would those aluminium windows deform at a lower temperature?
A. The loss of stiffness in aluminium prior to melting, yes, there would be some. I would have to reference technical literature to know for sure, but I would imagine you'd start to see loss of mechanical properties anywhere above 300 Celsius, something like that.
Q. Yes.
A. What proportion of mechanical properties you'd lose at what temperature would be something I'd want to do a bit more homework on before answering.
Q. I suppose the question really is: at what temperature would you expect these windows to deform sufficiently to fall out?
A. Very difficult question to answer, because it depends on the nature of the fixings, the way they're held in there, the loads that they're subjected to, the restraining forces that the structural frame imposes back on them, given that the window frames are trying to expand more than the concrete that they're attached to. So that's an extraordinarily difficult question to answer.

Q. Is it necessary, do you think, to answer it for the purposes of your reaching final conclusions at Phase 2?
A. I mean, my remit for Phase 1 is interested in ignition of the cladding and spread over the cladding. By the time that aluminium window frames falling out and off of the building becomes an issue, the fire front is already gone. So I think in terms of timescales, for me it's not a relevant issue.
Q. I understand.
A. There's certainly no evidence that the window frames were falling out of the building that I'm aware of as the fire was spreading.
Q. Next item: extract fans, which you've covered on page 98, if we can please turn to those, under section 4.9.2, paragraph 416. You cover it at 413 to 417 and I want to pick up what you say at 416.
You say there:
"416. Video and photographic evidence collected both during the fire and also during Post-fire site investigations, along with a number of Inquiry witness statements (see Section 7.4), suggests that the kitchen extract fans were in many cases the first components of the window assemblies (including frames, glazing units, infill panels and extract fans) to fail and fall away during the fire. This is the case both for the case of

fire exiting the compartment of origin in Flat 16 (see Section 5), and in the case external fire attack due to external fire spread elsewhere on and in the cladding ..."

Are you able to identify what these extract fans were themselves made of?

A. They're mechanical extract fans, so obviously they're made of a number of different materials, but the key materials that are sort of holding them in place, if you like, are a polycarbonate ABS blend, as far as I can tell.

So I do have a number of these fans at the University of Edinburgh and we've been subjecting bits of the fans to testing to try to determine precisely what they are.

They are marked as PC-ABS with markings on the various components, which is a polycarbonate ABS blend.

Q. At paragraph 417, if we can have that highlighted on the screen, you give us some details about that. PC-ABS.

This material itself I think you've analysed in a bit more detail in your report at page 104, if I can just ask you to go to that.

You have at table 9 on that page and table 10 where you've analysed the selected typical properties of neat ABS plastic and neat PC plastic respectively.

First of all, do you know whether the PC-ABS in these extract fans at Grenfell Tower were neat in the way you've described them?

A. So the reason that I've presented those two tables for what is effectively one material, if you like, is that the way PC-ABS works, based on my understanding -- I'm not a polymers chemist -- is that it's a physical blend. So you have some polycarbonate thermoplastic and some ABS thermoplastic, and you just physically mix them into a mixture in some relative proportions to one another and you end up with a PC-ABS blend, which is the polymer that you end up. So the respective proportions of ABS and PC will depend on the particular properties that you're interested in for your particular component.

So whether you want a shiny surface, a durable surface or a tough surface or a product that's resistant to cracking or a bit more amenable to being pushed around, you can play with the proportions of the two components.

The products are marked as PC-ABS, but I don't know what proportions those two components are in.

Q. Would it be relevant to your work to know those proportions?

A. We're trying to find out via testing at the University of Edinburgh what those proportions are. I was thinking about this this morning, funnily enough, over breakfast, and if the manufacturer of those fans can tell us, that would be very useful, yes.

Q. Would it help you know at what likely temperature these extract fans would deform and fail?

A. It would be sort of a secondary check on the testing that we're doing ourselves at Edinburgh. So we are subjecting samples of the materials from these fans to what's called dynamic mechanical analysis at the University of Edinburgh, where we actually measure the mechanical response of the material as it is heated and cooled. So we're actually measuring those reductions of mechanical properties at Edinburgh, and some of those data were presented yesterday during the questioning of Professor Torero.

Q. So is the answer that knowing those proportions would assist you in your work?

A. I think so, yes. I don't think it's critical, but it would be nice to know.

Q. Does that mean you're not able to say as at now the likely temperature at which these extract fans would deform and fail?

A. The testing we've done to date and the data that were presented yesterday when Professor Torero was giving evidence -- so the data that were presented yesterday were data we obtained at the University of Edinburgh using tests on the specific fans that were used at Grenfell Tower. Those tests indicated essentially a total loss of mechanical properties before you reach a temperature of about 100 degrees Celsius, which is clearly quite a low temperature in the context of a fire.

MR MILLETT: Thank you, professor.

Mr Chairman, I'm going to turn to a different material. Is that a convenient moment for a short break?

SIR MARTIN MOORE-BICK: I think it is, yes.

Professor Bisby, we're going to have a break now.

THE WITNESS: Okay.

SIR MARTIN MOORE-BICK: I am going to have to ask you, please, not to talk to anyone about your evidence while you're out of the room, and we'll start again at 11.25. All right?

If you would like to go with the usher, she'll look after you.

Good, 11.25, then, please.

(11.15 am)

(A short break)

(11.25 am)

SIR MARTIN MOORE-BICK: All right, ready to carry on,

professor?
THE WITNESS: Yes.
SIR MARTIN MOORE-BICK: Thank you.
Mr Millett.
MR MILLETT: Professor, I want to turn now, please, to the uPVC window surrounds.
We know from your report that uPVC was installed around the windows during the refurbishment; correct?
A. Yes.
Q. I think you've set out on page 103 of your report -- if we can go to that, please -- table 8, which shows the selected typical properties of PVC rubber membrane, which is under the heading which starts the page before at paragraph 447, under section 4.10.1.6, "Polyvinyl Chloride".
The table there shows that uPVC has a low melting point of between 75 and 105 degrees centigrade, and we can see that there.
We can keep that on the screen, if we can, please, Paul, but can we also have up on the screen the report of Professor Torero at page 41, where there is a diagram. It's his figure 9 on page 41. That's JTOS0000001. We see it on the lower part of the page there, professor.
He says that that shows:

"Mechanical properties of uPVC as a function of temperature [°c]. The modulus (in blue) is related to the elastic modulus of the material the plot indicates that the material begins to drastically lose stiffness at approx. 60°c, losing 80°c by 80°c and 100% by 90°c. tests were conducted at the University of Edinburgh and the data was provided by Prof. Bisby."
First of all, can you confirm that you're the source of that data set?
A. That's correct.
Q. Secondly, do you agree with Professor Torero's use of the data in this diagram?
A. I do.
Q. Do you agree in general terms that the risks inherent in use of uPVC window surrounds adjacent to combustible materials is well established?
A. Could I have that question again?
Q. Of course.
Do you agree that the risks inherent in the use of uPVC material adjacent to combustible material is well established?
A. I wouldn't say that, no. I mean, I think -- you mean uPVC specifically next to combustible materials, ie the use of uPVC essentially to provide a fire barrier to combustible materials?

Q. Let me show you something. Can I ask, please, the witness to be shown CTAR00000018, page 3.
This is a BRE report from 1992 after the Knowsley Heights fire.
You can see under the heading "Fire damage", if we can have that expanded:
"All the cladding on the eleven storeys was destroyed on one vertical face - note that the splayed corners were also damaged, Figure 3.1.3. Fire spread vertically up the cavity behind the cladding, melting the aluminium supports and also attacking the window reveals via the strand board and the uPVC frames ..."
Does that tell us anything about the risks of using uPVC surrounds adjacent to combustible materials?
A. I would query what specifically is meant by uPVC frames in this context. That might mean the actual window frames are made from uPVC, as opposed to the boards that surround the window opening, which is the case we have at Grenfell Tower. So I'm not certain we're talking about necessarily an apples to apples situation in this case.
But I think it's clear that uPVC is very well known to soften and lose mechanical properties at temperatures that are low. I think I've quoted typical surface temperature limits in the range of 50 degrees Celsius.

The manufacturers of uPVC products will quote these values in terms of surface temperature limits.
So if a surface temperature limit for a product is limited to 50 degrees Celsius, anyone who has thought about it will recognise that temperatures substantially higher than that are going to be problematic. If you're relying on this material to provide any sort of performance in a fire, you ought to be, in my opinion, deeply suspicious of the ability of uPVC to provide it. I think that would be fair, yes.
Q. Before I leave this, can I take you to figure 3.1.4, which is referred to in this report at page 5.
It's not the most wonderful picture, this is all we have, but this is a detail of the window damage at Knowsley Heights.
Does that tell you, professor, anything about the risks inherent in using uPVC window surrounds adjacent to combustible material?
A. It's hard. I mean, it's very difficult to say from this photo. Based on this photo, it looks to me like what we're talking about is the window frame itself is made from uPVC, so that the piece of frame that actually is enclosing the glazing, and the -- I mean, I haven't read the report in detail, but it may be that that warning that comes in the paragraph that was put up previously

is suggesting that when a uPVC window frame is subjected to heat from an externally escalating fire, the failure of the glazing will happen earlier. But having not read the report, I wouldn't be able to say for sure.

Q. Fair enough.

Putting that away and going back to Professor Torero's report, can I ask you to be shown page 44 of his report, please, and specifically lines 1266 to 1271, where he identifies the lower and upper bounds of temperature which would affect uPVC's behaviour.

Can I summarise this: in general terms, do you agree the heating of uPVC by smoke generated by a 300-kilowatt fire -- so 140 and 220 degrees centigrade -- will result in a loss of mechanical strength within approximately 5 to 11.5 minutes?

A. I mean, it's certainly plausible, yes. I'd want to do the calculation myself to verify that, to say definitively yes, but it's certainly plausible.

Q. Turning to page 47 of Professor Torero's report, I just want to show you five lines in the middle of that page. That's 1344 to 1349, if you could just look at those.

He picks up your report, and then in line 1347 says:

"None of these components would have ignited with the temperatures attained by the smoke layer, therefore

the conditions that will lead to direct impingement of flames on these materials need to be analyzed."

Do you agree with that?

A. Yes.

Q. Do you agree that the dimensions of the kitchen in flat 16 were sufficiently small that uPVC would've failed wherever the fire had been in that kitchen?

A. Yes, although I am basing that opinion on the analysis provided by Professor Torero.

Q. Absolutely, and thank you for that clarification.

Do you also agree that given the low temperature of smoke, you would need direct flame impingement on combustible elements around the windows below or behind the uPVC?

A. If we assume that the smoke temperatures are going to be 300 Celsius or lower, in accordance with Professor Torero's analysis, then yes, I would agree with that.

Q. I should have qualified the question in that way, but thank you for that.

Turning to the related question of adherence, do you agree that glue and silicon sealants which were used to install the uPVC window surrounds are also flammable?

A. Yes.

Q. Do you know from your own work at what temperature those

materials would ignite?

A. No, I've not been able to confirm precisely what those materials are as yet. Again, we're doing testing on those materials at Edinburgh and we hope to be able to say so soon.

Q. Assuming smoke at 100 degrees centigrade, would that in your opinion, professor, open a direct path for flame spread into the cladding structure via the uPVC deformation?

A. That's a difficult question to answer. UPVC, as we've discussed, does soften at relatively low temperatures, but it doesn't turn into a flowing liquid in the way that, for instance, polyethylene will. I believe Professor Torero said it turns to sort of gum. I would say it goes floppy, to use the technical lingo. So it doesn't flow, typically, although it can semi-flow in a very viscous way under certain heating conditions. So the rate at which it's heated matters in terms of what you get after it's heated.

UPVC is a very interesting material because in some cases -- and we have evidence of this on site at Grenfell Tower -- under some forms of heating, which we don't know, you see the uPVC remains essentially white and drips and almost flows like a molasses or something, certainly from the head of the window in cases and in

many cases on the jamb.

In other cases, I would imagine cases where it's subjected to higher heat fluxes under a shorter duration of time, the uPVC will intermesh which means it chars and bubbles and becomes sort of a black expanded char.

It will also, under some circumstances, in the manner I described for XPS, as a consequence of that charring and swelling, it will also shrink to some extent.

So the combination of it going floppy, it potentially dripping under some circumstances or potentially swelling and forming a char means it's very difficult to say definitively what would've happened to that uPVC.

That's quite a caveat, I admit. The short answer is I think it's certainly plausible and potentially likely that if you had the uPVC heated to temperatures around 100 degrees Celsius, that, yes, you would open up a gap adjacent to the window, yes.

Q. I am going to press you a little bit. You say certainly plausible and potentially likely.

Doing the best you can sitting here, with what degree of confidence would you say that, assuming smoke temperature of 100 degrees centigrade, that would open a path into the cladding?

A. If you said assuming a temperature of 200 to 300 degrees centigrade, I would be more confident.
Q. So is it right that your confidence level gets lower the lower the temperature?
A. Of course. Of course, yes.
Q. But at 100, which is our benchmark --
A. Yeah, I think it's likely that we will have had -- I mean, we know from having looked at post-fire photos in particular of the building, in apartments or in flats that were not subjected to very severe fires but where the fire was creeping in from the outside in the later stages of the fire, we know that the weak point in the window surrounds is that gap to the right or left of the window.
Q. Yes.
A. And so, yes, I think that's a likely weak point.
SIR MARTIN MOORE-BICK: While we're on this aspect of things, can you help with the adhesives? You just told me that the adhesives are the sort of materials that will deform --
A. They're polymeric materials, yes.
SIR MARTIN MOORE-BICK: If you contemplate a uPVC board fixed by adhesive to something else, and you've got smoke impingement -- let's take the 100-degree centigrade figure -- do you know how that is going to

affect the adhesive?
A. The issue there is that in order to affect the adhesive, the heat would have to get through the uPVC to the adhesive. So the adhesive is going to be in a sense insulated by the uPVC. But if we assume that the uPVC manages to get to 100 degrees Celsius and then the adhesive gets to 100 degrees Celsius, I presume the question is: does the adhesive fail and the board simply falls away as a consequence of the adhesive failing?
SIR MARTIN MOORE-BICK: Is that a possibility?
A. That is certainly a possibility. Again, whilst I haven't yet confirmed the specific nature of the adhesives used, I expect that the adhesive that was used is some type of acrylic adhesive. We're doing tests at Edinburgh. We will do the types of tests that we would need to do in order to understand similar aspects of the response of these materials, as we have already done for the uPVC. So that's a question we should be able to answer at some stage.
SIR MARTIN MOORE-BICK: As a layman, I'm getting this picture of a uPVC board which has gone soggy, if you like, has no mechanical stiffness left, being held onto whatever is behind it by an adhesive which is also starting to degrade.
A. Mm-hm.

SIR MARTIN MOORE-BICK: And then, I don't know --
A. Yes. Again, I think, yes, I agree with you. But the uPVC boards don't weigh that much in comparative terms, they're not super-high-density products. So the forces to which those adhesives would be subjected are not immense, and they tend to be quite strong adhesives at ambient temperature. So even if they lose virtually all of their mechanical properties, they may still have sufficient properties to hold something in place. So it's very difficult for me to say absolutely the uPVC falls away, absolutely we have a hole next to the window. I think it's likely, but I'm a cautious guy, so I wouldn't want to say absolutely.
SIR MARTIN MOORE-BICK: I suppose gravity plays its part, because depending on where they're fixed --
A. Of course. Yes, yes, of course.
SIR MARTIN MOORE-BICK: Right, thank you very much. Yes, Mr Millett.
MR MILLETT: Can I now turn to EPDM rubber, which stands for ethylene propylene diene monomer rubber, which you cover on page 103 at paragraph 4.10.1.7.
Correct me if I'm wrong, professor, this material was used as a weatherproof membrane in the window assembly at Grenfell Tower.
A. That's correct, at the sides of the windows.

Q. At paragraph 450 on this page, just under that heading there, you say:
"No specific details are available regarding the combustion properties of EPDM, and these will be studied by laboratory-based testing at Phase 2 for the specific EPDM identified at Grenfell Tower."
Nonetheless, do you agree that it is a thermoplastic material which would burn and melt?
A. It doesn't melt and drip; it will burn in situ.
Q. Dr Lane has some values for this material. This is a reference only, this is her report in section 10 at pages 11 and 12 under paragraphs 10.3.11 and 12. She says that it will ignite at temperatures between 180 and 378 degrees centigrade.
Does that sound about right to you?
A. I mean, it's a big range.
Q. It is.
A. That is a big range, and I think that's probably a consequence of the variations in manufacturing this particular product, which is one of the reasons why I've not provided data in my report. But I think that range is certainly plausible, yes.
Q. Was there adhesive used to bond the EPDM to the concrete structure at Grenfell?
A. Yes, it appeared to be some kind of mastic adhesive.

Again, I couldn't identify it.
Q. From your knowledge of mastic in general, would that also be flammable?
A. I would expect so, but I would want to check.
Q. Would you expect so because it's a polymer?
A. I presume it's polymer-based.
Q. Right, okay.
Next material: spray foam. We can take this, I think, quickly, but in your report at page 256, if I can jump ahead to that, you set out there at paragraphs 1190 to 1194 some evidence that you've summarised from the BSR witness statements and oral evidence about pre-existing gaps in the window framing, and, in particular, some evidence from some residents that additional foam or silicon was used by Rydon to fill up the gaps around the windows of which residents have given evidence that they complained.
At 1192, you say in the penultimate line:
"... additional foam and/or silicone was used to (ineffectually in some cases) address this problem."
Was that use of additional foam and/or silicon potentially significant in terms of the ingress of either smoke or fire back into flats?
A. I mean, it's very hard to say. There's sort of a double answer on this point, in that if we're talking about

ingress of smoke, and that smoke is relatively cool, cool to such an extent that it doesn't affect the polymer foam that's been sprayed in place, one can imagine the presence of that foam would be helpful as regards ingress of smoke.
However, if the smoke is sufficiently hot, or if you actually have fire, then that spray foam, that particular product, which is most likely a polyurethane, will provide essentially zero resistance to the spread of that fire through the gap.
Q. Have you been able to analyse or test in any way the foam or filler used to stop up the gaps around the windows in Grenfell?
A. That work is underway at the minute at Edinburgh.
Q. Where the gaps which you identify in the evidence here were not effectively stopped up, would that affect the ingress of smoke or fire?
A. Certainly smoke. Fire, it would depend on the mechanisms by which the fire was coming in, but potentially, yes.
Q. Next product or item is purlboard. I can take this very quickly.
You've covered legacy purlboard which was identified in the building at page 85 of your report, if we can just jump back to that, please.

Is it right just, in general terms, purlboard is a polyurethane foam board covered with a paper covering?
A. Correct.
Q. It formed part of the original construction of Grenfell Tower above the perimeter of the windows in each flat.
A. That's my understanding, yes. It's shown as an existing feature on some of the architectural drawings for the refurb. It's also present below the windows on the external wall of the building, covered with a layer of plasterboard.
Q. On page 85, at paragraph 357, you say that you don't believe that it:
"... played a central role in spread of the fire once the external cladding ignited, however it may have played an as yet undetermined role in fire spread and growth within the compartment of origin."
Do you mean flat 16 or do you mean all flats into which the fire then entered?
A. In this instance I mean flat 16.
Q. Was the presence of purlboard a route or mechanism by which fire could break back into flats or propagate within them once it had come back in?
A. Given its location in a band I believe 350 millimetres in width around the exterior wall of the entirety of

every flat that I'm aware of in the building, then that purlboard on the ceiling would be one of the first combustible materials that a fire coming into the flat through a window would find as it was coming in, notwithstanding the materials around the actual window itself.
So there is a potential that that could've been the first material ignited within a compartment where fire is spreading into it. Whether that is significant in terms of all the other combustible materials within that flat, and the very severe fire, certainly in upward fire spread, that we would expect, I think is hard to say.
Q. Very good.
A couple of slightly more stray questions.
Have you identified during your survey of Grenfell Tower the use of any polyethylene gripper rods or stays around the window detailing, for example to hold the aluminium frames in place?
A. I did observe, during the deconstruction of the cladding at lower levels of the building in the undamaged sections when I was on site with the Metropolitan Police and the BRE forensic team, what looked to be polymer sort of shims or pucks that have been used to position the window frames within or onto the cladding rails or the aluminium rails that are holding the windows in

place.

I'm not entirely sure if that's what that question is getting at. I'm not entirely sure what a polyethylene gripper rod is, if I'm being honest. But there are certainly little bits of polymer shim that seem to have been installed in an improvised manner to get the window exactly where they want it.

Q. Have you been able to form any view about whether those shims or pucks as you describe them contributed in any way to the spread of fire or smoke?

A. These are small shims, so the mass of material that is present is quite low. I wouldn't expect any significant impact in terms of the available fuel, that sort of thing. I suppose it's plausible, given the role that they appear to be performing, that loss of mechanical properties of those shims could lead to loosening of the window frames themselves under heat, but that would be speculative.

Q. Have you seen any evidence that that happened?

A. Not seen any evidence of that happening, no.

Q. I'm now going to turn to a different topic altogether, coming away from materials, and I'm going to turn to the geometry of the building and the presence of cavities and channels in the structure, and to see how and where some of those materials we've been discussing this

morning, professor, fit in.

Can I start by going to page 41 of your report and showing you section 3.2.4.

You summarise in that section there -- we can see it at paragraphs 232, 233 and 234 -- the three main sets of materials present in the cladding system: the foil-faced polymeric PIR insulation product, the ACM panels and the cavity barriers.

You've provided some sketches at figures 16 to 19 at pages 43 to 46 of your report. We'll come to those in a bit more detail shortly.

Can I start, though, by taking you to page 47. We'll start with PE and exposed edges. This is figure 20 on this page, page 47.

You've identified this in the text next to figure 20 as:

"Detail of edge of spandrel section ACM external cladding cassette from Level 4 of Grenfell Tower (outside Flat 16) provided to me by the MPS."

You go on to say what it is.

Then you say:

"Note multiple cut edges directly exposing PE filler material, both at the flat and (even more so) bevelled edges of the panel, and also along the re-entrant internal corners."

Can I ask you to unpack that a little bit for us and just explain these edges.

First of all, can you point out where the bevelled edges are for us? You can get up if you want to.

A. So the bevelled edge I'm referring to is this edge here (Indicates). For instance, comparing to this edge, this edge, the cut across the panel is perpendicular. Here that cut is at an angle. The reason I felt that was significant to mention is it exposes a larger surface area of polyethylene at that location.

Q. It's not immediately obvious to the naked eye looking at this photograph --

A. When you hold it, it's quite obvious.

Q. Really more for the transcript, the inner edges of the aluminium that we can see on figure 20 are set back from the outer edges, so the bevel is an angle from the bottom to the top.

A. That's correct.

Q. Similarly with the upright there, from the inner to the outer, there's an angle.

What kind of angle is the bevel, do you know?

A. I haven't measured it, but it is probably somewhere around 45 degrees, I would say, from memory.

Q. Right.

A. I should point out that this is one example of a cut

edge on one specific piece of spandrel cassette I was given, so I have no way of knowing if that is a uniform detail.

Q. From your knowledge, partly following up that last question, would this kind of configuration or this kind of feature be present on every ACM cassette on the tower?

A. It's hard to say. Yes.

Q. Have you any reason to think it wouldn't be?

A. Well, I mean, to me, the question is really where would it be, if you see what I mean, because on this particular panel, it's only along this one particular edge. All the other edges are cut at 90 degrees. I don't know the rationale for that bevel existing in the first place from a constructability perspective, so I don't know why whoever cut and folded these cladding elements has used a bevelled edge at that location, so it's hard for me to say what other locations might have the bevelled edge.

I mean, I point it out because it is something we observe in the photo. I think it's significant because we do see some more polyethylene in that location. As I'm sure we'll discuss later, I don't necessarily think that those exposed lines of polyethylene have a primary role in terms of the flame spread in any case.

So I point it out out of interest, but I don't think it's a hugely significant detail, if that's a helpful thing to say.

Q. Yes.

The other feature you point out in figure 20 is the re-entrant internal corners. The word re-entrant might be confusing because you use it in a different context when we come to the panels on the column, but do you mean by re-entrant the -- well, what you point out there, the lower edge?

A. I mean the inside --

Q. The inside lower edge.

A. This here (Indicates).

Q. Is that lower edge exposing PE simply because of the way in which this cassette was folded over and shaped?

A. Yes. My understanding of the way these cassettes are shaped is that you take a flat panel of the ACM sheet and then you route a groove into the back face of it and then you fold along that line. So you remove the aluminium skin and you remove a certain volume of the polyethylene, which allows you to get a nice straight fold line in your cladding cassette, in the same way you might score a box in order to make a box.

Q. At paragraph 241 on page 42 of your report, you explain the importance of this folding and exposure of PE. We

your report.

While we're on this -- and I know this is more going to be Phase 2 -- are you able at this stage to identify any obvious risks in that kind of installation?

A. The hanging of the cassettes on the rails in that way?

Q. With exposed PE.

A. I mean, yes. I mean, those rails as installed at Grenfell Tower, they also break through cavity barriers, as I'm sure we'll also discuss later. So you have routes where flames and hot gases can move up through the cladding and, in doing so, expose those exposed edges of polyethylene to heat. Perhaps as importantly, even if the spread up the cladding rail is not what we're particularly worried about, if the ACM cassette on the whole is exposed to heat and you have the polyethylene becoming liquid within the ACM cassette, what that means is some of that polyethylene is going to exit the ACM cassette within the cladding rail, which then provides a route for that polyethylene to flow down as well.

Q. Absolutely. I think we can make this clearer, actually, by reference to figure 16 on page 43.

A. Okay.

Q. If we can go to that. I think that's your drawing, isn't it, there?

can see what you say there.

But in simple terms, does this mean that exposed return edges go into the cladding rails which are then voids which run up the length of the spandrel?

A. What it means is that at the edges of ACM panels, you will always have exposed polyethylene, and on the insides of the boxes along every fold line you will also have exposed polyethylene, which means that there are multiple routes to expose that polyethylene directly to heating or flaming and, probably more importantly, there are multiple routes by which melted polyethylene can exit the ACM panel and then flow to other places.

Q. Do these return edges which are exposed in the way we've seen, either the bevelled ones or the return edges, fit into the cladding rails?

A. I'm not sure I follow. You mean as the cladding cassettes are hung onto the cladding rails?

Q. Yes.

A. Yes, within the cladding rails you will have exposed edges of ACM, yes.

Q. We know, because you said it, that those cladding rails provide voids which run up the length of the spandrel.

A. Yes, the length of the spandrel, and in some cases along the side of the column and the column tip as well.

Q. That was my next question. That is paragraph 243 of

A. That's correct, yes.

Q. It's a horizontal section detail, so we're looking at it, as it were, from above, at the join between the concrete spandrel beam and the concrete column, so at the return, if I can call it that, there.

You show the ACM rainscreen cassettes spandrel section turning at right angles and fitting into the aluminium cladding rail, and you put "Void" there.

Does this mean that the exposed edges of the ACM rainscreen cassettes are sitting within the void? In fact, there are two of them there.

A. That's correct.

Q. Does that mean that there is therefore exposed PE material sitting in that void?

A. Correct.

Q. And that if it burns, drips and melts, it will drip down the void, down the rail?

A. That would be my expectation, yes.

Q. Can I ask you to look at page 50, just picking this up and running with it a bit further. We can see a photograph, figure 23 on that page.

Is that the same location that compares with figure 16 on page 43 we've just been looking at?

A. Yes, yes, although the photograph is perhaps a bit confusing, given that multiple elements of the cladding

system have been removed on the left-hand side of that photo.

Q. Certainly. Can you identify from that photograph the return element that runs into the cladding rail? Are you able to do that?

A. Yes.

Q. Can you do that for us, please.

A. So I imagine what we're talking about is this line along the side of the spandrel cassette (Indicates), and there's this small cover strip of ACM which is sort of adhered to the side of that, and then there are these bars here running side to side in the cladding rail, the cassette has sort of hook-shaped cut-outs on the side it hangs onto, and that cut-out side is all exposed PE.

Q. Is that photograph representative of what you would find I suppose above and below the kitchen window of flat 16?

A. Yes, from level 4 to the top of the building, to the extent we can confirm that, given the damage of the upper levels, yes.

Q. Sorry, I may have to make you get up again, but can you also point out on this photograph where the cut edges of PIR insulation would be?

A. That is a slightly trickier one in this location.

Q. It may be we can do it in a better --

A. Yes, it's more obvious at the location next to the

window as opposed to next to the spandrel, so it's more obvious slightly up here (Indicates).

In this situation, it's probably worth pointing out that this construction detail that's shown on this slide, the two layers of the PIR foam on the spandrel section sort of framing into the interesting configuration of cuts in the PIR here where they join, into the 100-millimetre depth on the columns, because of the configuration of the building, it would appear that that's quite a straightforward thing to actually do from a constructability perspective. So given the geometries we're dealing with here, it seems that whoever installed the cladding and insulation was able to cut the insulation to kind of fit in the way that I've shown it here.

Adjacent to the window, which I guess is a different figure, I don't know if it's -- I won't ruin your plan, Mr Millett -- there's more variability next to the window in terms of how that was installed.

But having said that, you have essentially foil here and you have foil here, that is a cut edge, PIR, you have foil along this surface and along this surface, that is a cut edge, that is a cut edge (Indicates).

Q. In short terms, the two layers of PIR foam insulation we can see in your drawing are not actually visible in the

photograph, but the angled PIR foam insulation attached to the column is, albeit from below.

A. Yes, so these two are here and here (Indicates).

Q. Oh, I see.

A. Just barely visible.

Q. Yes, I see.

A. This one is coming in here.

Q. That one. Yes, I see.

A. That's correct.

SIR MARTIN MOORE-BICK: If we look on the photograph, there's a label showing what's described as foil face polymer foam insulation board column section.

It's the second label --

A. Correct, yes.

SIR MARTIN MOORE-BICK: That looks as though it's identifying a cut edge.

A. That is a cut edge. So this here is a cut edge. However, underneath -- so what you would have found here is a cavity barrier here and then you would've found another piece of the PIR coming down here. So this edge would've been butted up against the cavity barrier, and below the top surface would've been butted up against the cavity barrier.

SIR MARTIN MOORE-BICK: Thank you.

MR MILLETT: I think, just while we're at it, you can

actually see the voids -- is this right? -- created by the grooves in the concrete columns?

A. That's correct, yes. So, yes, you can see the surface of the pre-existing concrete columns were not flat. You have these sort of vertical channels in them.

It's worth saying in some locations on the building that I've inspected, there has been an attempt made apparently to close those at the locations of cavity barriers with spray foam. In other locations, not so, as is shown here.

Q. With spray foam?

A. With spray foam, yes.

Q. Returning to the subject of exposed PE edges, can I ask you to be shown, please, figure 10.26 in Barbara Lane's report. That is BLAS0000010, at page 26. This is paragraph 10.4.8 of Dr Lane's report.

You can see on the right-hand side of that figure the photograph we were looking at earlier with the bevelled edges. On the left-hand side of that figure there is a location photograph identifying where one would find those gaps on the building.

Dr Lane has related the bevelled edge to the edge of the panel, as you can see, under the return at 90 degrees back above the head of the window. Can you see that?

A. Yes.
Q. Do you agree with that?
A. I do.
Q. Does that tell us that, in fact, there were exposed polyethylene edges open to the atmosphere?
A. Yes.
Q. Can I ask you next to turn back to your own report at page 44, figure 17.
That shows the geometry of the cladding system at the junction of a window unit and a column on the east face; is that aright?
A. That's correct.
Q. There's a photograph I think we can relate to this.
Paul, if we can keep this on the screen and go, please, to page 55 of your report. There's a photograph there which is figure 27(b). We have a similar photograph as we had before under (a), and under (b) we have a different photograph.
Can you help us with this: first of all, in the photograph, is this representative of what you would find adjacent to the kitchen window of flat 16?
A. Yes.
Q. On this photograph, and using both the photograph and the diagram, can you help us, where would the exposed edges of ACM panel be in that assembly?

A. In this case, the exposed edges of ACM panel are sort of just there at the tip, where it comes in here (Indicates), and at this corner here internally, you would have an exposed re-entrant corner.
Q. Just at that little elbow joint I think you're pointing at --
A. Correct, just here (Indicates).
Q. -- in figure 17.
A. So you would have that routed joint there to create the fold.
Q. Is that like what you call the return edge in the photograph me looked at earlier?
A. Correct, though obviously a different angle.
Q. Are any of the voids that you can see in the diagram, figure 17, relevant to fire spread?
A. In this figure -- I mean, yes. I mean, one issue that is a bit of a sticking point is you can see that I have kind of lightened this piece of polymer foam, of PIR foam insulation, and that is because the condition of the insulation boards in that location adjacent to windows over the building is variable, so we don't always find that piece of foam existing. So in some cases, this piece of foam that I have here, which is a small piece that's cut to basically fill a very small, awkward bit of cladding next to the window, is just not

there.
Indeed, yesterday, I believe, Professor Torero was shown a picture where this piece of board has been cut square and it just comes up and it just stops, and there no piece of insulation here. That's from Dr Lane's report. We see variable configurations of the cuts in the PIR boards, certainly in the lower levels of the building.
So it's hard to say with any certainty at a given location what the condition was at that location, and certainly outside flat 16 there's so much damage I couldn't tell you, outside flat 16, if this piece of foam is there, if the board is cut at this acute angle like this or cut at the right angles. I just can't say.
Q. Just focusing on the exposed edge of the panel exposing the PE, you've identified the elbow joint, but at the top, which I think was the first edge you identified of the yellow hatched aluminium fixing -- sorry, ACM panel. Just exactly which edge is exposed, can you point that out?
A. You mean just here (Indicates)?
Q. Just there.
A. It's that little tiny edge (Indicates).
Q. Is that sitting in a void?
A. No. It's sitting, as you can see in this picture,

barely -- the detail alongside the window, it's very difficult to see, but you can see that you have the window frame, which is the darker grey, and then you have a secondary element here, which is a little metal angle which is connected to the window frame, and then the ACM panel is riveted through or screwed through that L-shaped channel. So the exposed edge of polyethylene here, alongside the window, is actually external to the L. So it's just there (Indicates), along that line.
Q. Does that mean that it would be visible or tangible from within the flat?
A. It's quite close to the frame, so it will probably be quite difficult to get a little at it, but in principle, yes.
Q. But it's exposed to the air?
A. It appears that way, yes.
Q. So is this right: there is actually an exposed longitudinal edge of some 3 millimetres of PE facing into each flat at that location about -- well, five or so centimetres, perhaps less, from the window frame?
A. Provided that this detail as shown here is consistent over the building, which is a hard thing to verify.
Q. I understand that.
A. So that gap may vary. This construction detail I've not been able to find on any drawings submitted to the

inquiry by anyone, so it appears to be an improvised detail, in some respects. That could be wrong, and of course material might come to light, but I've not seen this shown on any drawings.

Q. Have you considered the role that that exposed PE in that precise location would play in the initial ignition of the rainscreen on exit of the fire by whatever route from flat 16?

A. Yes.

Q. We'll come back to it.

A. Yes.

Q. Figure 18 is the next one we need to look at, page 45. This shows the geometry of the cladding at the column tip; is that right?

A. That's correct.

Q. Yes. If you go back -- I'm so sorry to make you jump around -- to the page where we were looking at the photographs, page 55, and look at figure 27(a). Just flip between them.

If we could have both of those on the screen, please, Paul, at the same time, figure 27(a) on the left-hand side and figure 18 on the right-hand side. Thank you.

First of all, is this to your knowledge or on your survey representative of all the columns in the tower?

A. Certainly columns that are on the faces of the tower. At the corner columns you have a slightly more complicated detail, because those columns are not triangular, they're more half squares.

Q. Yes.

A. But in principle, yes, it's essentially the same detail.

Q. On that assembly, can you identify for us, please, the location of the exposed edges of ACM?

A. Yes. So you would have exposed edges of ACM there, at the tip, there, at the tip. This is a little infill piece of ACM, so there, there, there, there, here and here (Indicates).

Q. You say "here and here", at the top in the acute angle --

A. The inside, the return of that acute angle.

Q. Because it's been grooved?

A. In order to fold it, yes. You route it to fold it.

Q. Can we take it that any fold of ACM panelling which we can see in this and, indeed, other configurations results in exposure of PE?

A. That's my understanding of the way these are manufactured, yes.

Q. We have, I think, six identified locations of exposed PE in the nose assembly.

A. Correct.

Q. If I call it that.

Again, are any of the voids in this diagram relevant to fire spread?

A. I mean, all voids are relevant to fire spread, but specifically this void here within the channel. So this cladding rail which you can see in this photo here is coming off the tip of the column. It's got this U-shaped feature with the bar going across, and this cladding rail here at the column tip is a continuous void which runs all the way from the base of the building, right the way to the roof, along the column tip unobstructed, and the cavity barriers are all cut around that rail, as you can see here. Actually, it's quite a nice picture, the way the cavity barrier has been cut in this instance. No guarantee that they're always cut in exactly this way, but clearly there's no way to have a cavity barrier continue through that U-shaped channel.

Q. Thank you.

The next one is figure 19 on page 46 of your report.

I'm not sure we have a correlative photograph to put with it, but this is a vertical section detailing the typical geometry of horizontal joints between the ACM cassettes along the vertical column lines. That's how you described it, more or less.

Again, is that representative of all the columns in the tower?

A. As far as I can tell, yes.

Q. Including the corners.

A. Yes. Yes in principle, yes.

Q. On that assembly, can you identify for us, please, where the exposed edges of ACM would be?

A. This is a vertical section through the cladding panels. So you have exposed edges of polyethylene, I mean certainly right at that location just there, at this location just here, at that location, right there, and along these edges (Indicates), although in section that's not necessarily an edge that we're interested in.

Q. In the third of those, which is the right angle we can see moving from left to right and bottom to top, just below the wiggly arrow --

A. Mm-hm.

Q. -- is the exposure of PE on the exterior, again, open to the air?

A. Yes, yes, it will be.

Q. That runs transversely, does it?

A. It would run across.

Q. It runs across.

A. Yes.

Q. I'm not sure you pointed this out, but would there also

be a transverse or running across exposure of PE in the inside of the right angle joint in the void, the rainscreen cavity.

A. Below?

Q. Below, just there, exactly.

A. Here and there (Indicates). Yeah, I mean, I should say at this point that this one here, I'm saying yes on the basis that every fold I've ever seen in an ACM cassette has a routed cut. Given we don't have a photo and I can't see it in my head right now, that is something I would want to check to verify, to be certain. But I can't think of a way they would make that cut without doing it. That's certainly something I'll check.

Q. You've identified these pictures and you say, I think, that these are particularly important to vertical fire spread.

Dr Lane -- I'll summarise her opinion, I hope accurately -- has identified the rainscreen cavity in the column as itself a route for fire spread. Do you agree with that?

A. Potentially, yes.

Q. You say potentially; what's the caveat?

A. It will depend on the effectiveness of the cavity barriers within that cavity at preventing vertical fire spread within the cavity, to the extent that the cavity

remains a cavity as the fire grows which wouldn't be for very long under a very high heat flux. Quite quickly, the rainscreen cassettes are deforming or gone or burning and you no longer have a cavity, which defeats the purpose of having a cavity barrier.

Q. Yes.

A. I'm sure we'll come to that.

Q. That answer might actually answer the next few questions I have on this topic, but let's see how we go.

Can I ask you, please, to be shown Dr Lane's report, section 10, BLAS0000010, page 16.

This is figure 10.13, which she says is a:

"3D image of the fuel, ventilation and heat available within the column cavity of Grenfell Tower to support combustion."

I think you've answered a question about that.

If I can show you the bottom of the page, and the text there, she says:

"An open state cavity barrier does not initially fully close the cavity. The particular cavity barriers installed in Grenfell Tower ... were designed to leave a 25mm gap between the outer surface of the cavity and the outer face of the cavity barrier."

And she explains why:

"The outside face of the horizontal cavity barrier

is lined with an intumescent material (visible as the black strip in Figure 10.17) ..."

Which we may need to look at if we need to:

"... which is intended to activate under heat and expand to close the 25mm gap. Therefore, initially in a fire, the entire column cavity over the entire building height was fully connected."

Do you agree with that conclusion?

A. Yes.

Q. Does that mean that there would be a continuous cavity up the column?

A. With the cavity barriers in an unreacted state, yes.

Q. If you look on at figure 10.19, in her report, that's page 20, she explains there:

"Rainscreen cladding panels can distort when heated, either through heating of the panel itself or by failure of the supporting fixtures. This can allow further gaps between the cavity barriers and the rainscreen cladding panels to form ..."

Do you agree with that?

A. Yes.

Q. Will that also provide a route or further route or exacerbated route to fire spread by with of bypassing the cavity barriers?

A. Absolutely, yes. Of course, all of this is predicated

on the assumption that the cavity barriers are installed as per the recommendations of the cavity barrier supplier, which may or may not be the case.

Q. Understood.

Can I show you also page 21 of her report at section 10.3.40, and figure 10.20.

She says there -- and there it is -- this is the text above it. We may need to have both the drawing and the text, Paul, if we can. She says there that:

"10.3.40. The performance of the cavity barriers in restricting the spread of fire was also compromised at the nose of the column, due to the specific geometry of the ACP and support bracket. As illustrated in Figure 10.20, a gap where the horizontal cavity barrier was not present existed at the nose, which provided another route of fire spread past the horizontal cavity barriers."

Do you agree with that?

A. Absolutely, yes. I mean, that is the same thing shown in figure 22 of my report in a photo that I pointed out previously. So, yes, it's precisely the same gap we've talked about before.

Q. Finally on this question of exposed polyethylene edges and their route or their assistance in fire spread or role in it, can I ask you, please, to go to figure 40 of

your report at page 68.
You'll see that's a photograph from site inspection during cladding deconstruction outside a typical kitchen window on level 4, looking vertically upwards.
Is that, do you think, so far as you've been able to ascertain, representative of the assembly outside flat 16?
A. As regards the cavity barriers?
Q. Yes -- oh, as regards all of the components you can see there.
A. My experience of having looked at how the cavity barriers were fitted into the awkward spaces, this being one example, is that it was improvised on a case-by-case basis. I wouldn't necessarily say that that -- I mean, as I say, I haven't done an exhaustive survey of every remaining cavity barrier installation on the building, so it would be hard to say, but my gut feeling, having looked at a lot of them, is that they vary.
Q. In terms of identification of exposed edges of polyethylene, would you be able to identify where those exposed edges would be when looking at this picture?
A. So there's going to be exposed edge along here, along there, here, not there, and you would've had a column cassette coming in here and being joined to this, so long this line on the outside of the angle (Indicates).

Q. Can I just ask you to still stand --
A. I'm a academic; I'm happier standing!
Q. Just help me. Above the extract fan which sits in its panel, you can see a gap where the rainscreen panel returns back on a horizontal plane towards the vertical plane of the window set, and we've blown it up there for you. You can see the dark edge below.
Can you help us with whether there would be any exposed polyethylene in that location?
A. So this corner that is forming this line with the shadow behind is not an exposed edge. But the photo that we have that showed the bevel previously shows you the back of this. So you have a slight upturn here, so there's a fold and it's going sort of that way into the screen, sort of yea big, an inch or so, I would say (Indicates). And at the top of that, you have exposed edge of polyethylene.
Q. I see. So underneath this, as it were, moving horizontally into the building and then coming up vertically, and then coming back out again, you have a flat, exposed, lengthways surface of polyethylene?
A. So you have a flat surface of exposed polyethylene which is horizontally looking up.
Q. Exactly.
A. Yes.

Q. That gap there that we see, the dark line we were just looking at a moment ago, is that an opening?
A. Yes.
Q. So any flame --
A. That's to provide ventilation to the ventilated rainscreen system. It's intended to be an opening.
Q. Does that mean that any flame emanating from the window set, wherever it is on the window set, could get up through that crack and melt or burn the exposed polyethylene?
A. Absolutely, yes.
Q. I'm now going to turn to a different feature of the building, professor, which is covered by you at paragraph 3.2.4.2 of your report on page 58, which is the column top and architectural crown details.
Can I start by diving into page 61 within that section, and figure 32, which we have there on the screen. This is, I think -- is this right? -- a drawing of the crown detail?
A. That's correct. Well, I mean, it's a design drawing of the crown detail.
Q. I was going to ask you. It looks as if it's come from CEL, so it's a design drawing.
Can I just have that on the screen at the same time as something else I'm going to show you, an image in

Dr Lane's report, and that is BLAS0000010 at pages 47 to 49. This i figures 10.46, 10.47 and 10.48. We probably can't get them all on the screen.
Starting with figure 10.46 to start with, if we can.
Can you tell us how that drawing, 10.46, relates to the original design drawing?
A. In terms of how the right-hand drawing relates to the left-hand drawing?
Q. Yes.
A. I mean, they're showing essentially the same thing. The right-hand drawing is showing a vertical section through the crown detail, whereas the left-hand is showing a front elevation of the crown detail.
Q. When we look at the blue part, the profiled cladding panels linking column cladding to top of crown, can you just help us with the orientation and geometry of that or those panels?
A. Right, okay. I should point out that I'm colour blind, so we need to be careful. You're referring to this (Indicates)?
Q. Yes.
A. Blues are good for me, so we're generally all right.
So this section here would be the top of a column, and that on this drawing would be this piece here or this piece here.

Q. Yes, I see.
You can see from the drawing that's been magnified, two lines coming down vertically at an angle. What does that signify?
A. That's just showing the way that the panel is folded in order to create the architectural detail that we see at the roof line. So the original reinforced concrete columns that sit behind these are tapered back, it's just an architectural detail, and so the cladding panels were tapered back in line with the concrete, although it's worth mentioning some distance from the pre-existing concrete. The pre-existing concrete stops at a lower level.
Q. The next figure is 10.47, if we can just look at that, please. That shows the presence of combustible Reynobond cladding panels formed into fins.
Where would they sit? Can you tell us where they would sit in relation to the figure at 32?
A. So these panels here (Indicates) -- yes, the red -- red is not a good colour for me -- are essentially these vertical slats.
Q. Yes.
A. I believe Dr Lane refers to them as fins.
Q. She does, fins.
A. I call them C channels.

Q. Ah, that was a question I had, fine. That answers that.
10.48 is the next drawing, which is the same drawing there. Well, first of all, is it the same drawing? Looks like it.
A. It appears to be, although the one in Dr Lane's report has been marked up by somebody at some stage along the way.
Q. Is there any significance in that drawing, in that --
A. In the marking up? No, I don't think so.
Q. In general terms, is there any insulation sitting behind the details we can see at the top of the columns?
A. At the top of the columns, no. The insulation is terminated above the level of the windows at the top floor.
Q. Is there any insulation at all within the crown detail?
A. No.
Q. What about cavity barriers?
A. No.
Q. Is there an aluminium coating --
SIR MARTIN MOORE-BICK: Before we go on, is there any insulation behind what looks like the top layer of spandrel panels? Looking at the previous drawing in Dr Lane's report, it looked to me as though there might have been.
A. I believe yes, but that it terminates before reaching

the actual line of the roof there.
SIR MARTIN MOORE-BICK: Yes.
A. Yes. But I could be wrong. I'd want to check that.
SIR MARTIN MOORE-BICK: I think we might be able to see it. I didn't make a note of the number of the red and blue drawing, but --
A. It's certainly indicated on the drawing. Whether it's present on site is --
SIR MARTIN MOORE-BICK: Another matter.
A. Yes.
SIR MARTIN MOORE-BICK: Yes.
MR MILLETT: We may be able to see it in figure 33 on page 62 of your report. That may help, professor.
A. 33, no.
Q. No.
A. I should point out at this point that the figure that was previously on the right from Dr Lane's report that showed essentially the same section as being shown on the left from my report -- I don't know what that is, if it's possible to bring it up. I do think it's important to point this out, actually.
Q. Okay.
A. No, so --
SIR MARTIN MOORE-BICK: It's the coloured version of figure 33?

A. The coloured version of my figure 33, yes, exactly.
MR MILLETT: If you --
A. So, yes, the one you had a second -- that one, yes.
So that figure there, unfortunately I was not aware of its existence before seeing Dr Lane's most recent report, so that only became available to me recently.
The figure that you had put up a moment ago, Mr Millett, which was from my figure 33, you can see that it does not include the details below the coping that goes over the side of the roof. It's just important for me to state that.
Q. That's helpful. So, in fact, using figure 10.47 in Dr Lane's report at page 48, section 10 -- is this right? -- you can actually see where the insulation stops and, therefore, there's no insulation behind the fins or any other part of the architectural crown details?
A. That's correct.
Q. I think that answers the chairman's question.
But there is also an aluminium flashing that we can see, which you may not be able to see this, I think it's in green -- oh, it's grey, is it? That makes two of us!
Did you know about that aluminium flashing over the top of the insulation?
A. Yes, I knew about the flashing, but I wasn't aware that

the drawing shows PIR insulation underneath. On the drawing that I've used, my figure 33, that's denoted in the design drawing as it's very small print, but it says:

"WSP PLY BONDED INSIDE COPING TO REDUCE SAG."

So that's indicated as an aluminium sheet with essentially a moisture-resistant plywood bonded to the underside to reduce its sag. So we had always assumed that was the detail in that location on the roof.

In light of this new drawing, I've asked to go back to the site and have a look myself.

Q. Subject to that later visit, are you able to identify on figure 10.47 where the exposed edges of polyethylene might be within the ACM?

A. In the crown detail?

Q. In the crown detail.

A. I mean, they're everywhere. The better drawing is my figure 34.

Q. 34, yes, let's go to that, and, indeed, the photograph at figure 35. This is page 63 of your report.

A. Yes, okay. So -- yes.

Q. So can you show us where --

A. Yes, so --

Q. You need to go back up to figure 34. There.

A. Yes.

Q. Have that expanded.

A. It's worth saying what you have in this detail is you have aluminium C-shaped channels, so these are vertical elements, so this is a horizontal section through the crown. So you have essentially C-shaped channels running vertically like fence posts. They have bolts running across them at various heights, and then you have essentially the inverse shape made out of an ACM slotting onto those rails. That just sort of -- you end up making essentially a fence of ACM and aluminium C channels as you go along the crown detail.

So this piece here is the column cassettes, the column top cassette, framing in to start the crown detail, and then you just have a repeating sequence of these C-shaped channels continuing across until you get to the next column.

You have exposed edges at this corner, at this edge -- sorry, this corner, this edge, at this edge, at this corner, the next corner, that edge, so just basically (Indicates) -- and on you go, all the way across.

So you have a lot of exposed edges, certainly.

SIR MARTIN MOORE-BICK: Presumably -- these are just vertical C channels, are they?

A. In this view, yes; in reality these cassettes are

box-shaped, so they have tops and bottoms --

SIR MARTIN MOORE-BICK: Ah.

A. -- like cassettes. So they have a bottom that returns, and at the a top it comes over the top.

SIR MARTIN MOORE-BICK: Where they have a return at the bottom is there a cut edge? It's an open cut edge --

A. Yes, imagine a cardboard box that doesn't have the flaps on it anymore.

SIR MARTIN MOORE-BICK: Yes. And at the top, the same?

A. At the top the same, yes.

SIR MARTIN MOORE-BICK: So every edge is exposed.

A. On the inside face of the crown, yes.

SIR MARTIN MOORE-BICK: Yes. Thank you.

MR MILLETT: In fact, I think you get a visual image from figure 35 on the same page.

Perhaps we can have that expanded, Paul, please.

Does that show us the C channels?

A. Yes. I mean, the crown elements in this figure are extremely badly damaged. This is immediately above the flat 6s, incidentally, this is where the fire will have first have come up the building.

Q. So it's the north-east corner?

A. Correct. Yes, correct. So here you can see these are the aluminium C channels. Those.

Then these very badly damaged and warped pieces of

aluminium are aluminium skins of the pre-existing ACM cassettes. Having gone up there and looked at them the polyethylene is essentially gone, there's some residue but the polyethylene has either burned or melted and dripped down from those cassettes at the top.

Q. The C channels, are those the indentations which move away from the camera in vertical grooves that we can see there?

A. These, yes, these are the C channels. So the ACM elements have been removed by the fire. The aluminium C channels are quite massive, they're quite thick, I think they are 3 millimetres thick aluminium, so they are quite beefy elements. So it was harder for the fire to remove them.

Q. Yes, I see.

SIR MARTIN MOORE-BICK: And nothing to prevent horizontal propagation?

A. No, no, I mean quite the opposite.

MR MILLETT: What do you mean when you use the expression "architectural crown"?

A. I mean that the only function of the crown that I can ascertain is that it was a visual and aesthetic feature of the building, and therefore it's an architectural feature of the building, as opposed to having some specific engineering functionality. It wasn't required,

there was already a parapet beam and a safety grating at roof level. So it served no purpose other than an aesthetic purpose, as far as I can tell. I mean, if we have evidence otherwise I would like to hear it, but as far as I can tell it was purely an aesthetic feature.

Q. We'll come back to the role of the crown in fire spread later in your evidence, professor.

Can I then turn to the question of windows.

At page 73 of your report, you have summarised the materials that you have identified as used in the window sets at paragraphs 279 to 284. Then at paragraphs, specifically 282, 283 and 284 itself, and then into 285 you explain what happens if any of those, or all three, are penetrated for any reason.

Now, it's Dr Lane's opinion -- and she's going to attend to give evidence, so we'll have to wait to see what she says -- but it's her opinion that once there was a localised fire near the window, the majority of materials around the window had no potential fire-resisting performance. I've summarised her opinion.

Do you agree with that?

A. I wouldn't use the word "no"; I would say "very little".

Q. So very little potential fire-resisting performance?

A. Correct.

Q. She's also concluded -- and this is paragraph 9.7.6 on page 48 of section 9 of her report -- that once there was a fire in a flat anywhere near a window, there was a very high likelihood that it would break out of the flat into the cladding.

Do you agree with that?

A. I mean, I guess it depends what one means by "very high likelihood", but I would say it's likely, yes.

Q. Would cavity barriers around the window have made a difference at all?

A. It's difficult to say because, to be honest -- and I have thought about this -- I'm not sure how one would put a cavity barrier around windows installed in this manner. It's almost an impossible question to answer because I can't imagine how one would actually achieve what one is attempting to achieve by putting a cavity barrier around a window.

Q. No, I understand.

Can I then turn to the topic of spread out of the compartment, which is a different topic all together.

You've based your analysis on your understanding of the way different materials react in a fire, and, secondly, the available video evidence, the visual evidence from video and photographs that you have.

A. That's correct, yes. The evidence I'm using with

respect to these questions of fire spread is predominantly visual evidence, yes.

Q. Now, have you had an opportunity to consider Dr Lane's and Professor Torero's analysis of spread out of flat 16 in their respective reports?

A. Yes, although not in any very deep way. I've read the reports, although admittedly under quite short time constraints.

Q. We know that Professor Torero gave evidence yesterday and explained that he's carried out some modelling -- I think he might describe it as "simple modelling" -- to assist with analysis of how the fire broke out of flat 16.

Am I right in thinking that you yourself haven't carried out a similar analysis?

A. That's correct.

Q. Do you agree with Professor Torero that, in order to have direct flame impingement onto the ACM panels sitting outside flat 16, you would need a fire of something like 830 kilowatts within the flat?

A. No. If I understand what Professor Torero said yesterday, if I were to attempt to summarise what Professor Torero said yesterday after quite a lengthy discussion about these issues, it would be that the gases exiting -- that his preferred fire is between 60

and 300 kilowatts --

Q. Yes.

A. -- based on his analysis of the compartment.

That the largest of those fires is going to provide smoke layer temperatures in a non-post-flashover scenario at a maximum of about 300 degrees Celsius, but he seems to be leaning to somewhat less than that, say 200 degrees Celsius. And so that the gases exiting the compartment via the window or the extract fan panel, or any other means, are going to be in that range, 200 to 300 degrees Celsius, for his preferred fire. And that you will also get flames exiting the flat for a 300-kilowatt fire that is sufficiently close to the window.

So that what you're getting coming out of the flat is hot gases, 200 to 300 degrees Celsius, as well as flames exiting the compartment -- well, flames, essentially a ceiling jet inside the compartment with some flames exiting the compartment.

So the 850, I think, kilowatt fire, is not necessary in order to have flames coming out of the window.

I could be wrong, but that was my understanding after the lengthy discussion yesterday.

Q. Yes. The question, I think, is: do you agree that in order to have direct flame impingement onto the ACM

panels above the window, through an open window, so as to be able to ignite them, you would need a fire of the magnitude of 830 kilowatts?

A. No, I think if you had a fire of 300 kilowatts that was sufficiently close to the window, you could have flames going out the window.

Q. In your work and analysis of fire spread, have you taken Professor Torero's modelling into account?

A. No. I mean, only to the extent that it was presented in his initial Phase 1 report, and only as a sort of sanity check on what is possible as opposed to having done any detailed analysis of it.

Q. What about Dr Lane's analysis, same question.

A. No, I had not considered that.

Q. I'll ask you questions about those as we go along.

Let's go a little bit further into some detail, if we can.

In your first report that you provided in April this year, you I think identified three hypotheses for fire egress, exit from flat 16. I'm not going to take you through those in detail, but just to summarise them if I can. For our record, they are at pages 128 to 129, paragraphs 575, 579 and 582.

I think you had three hypotheses: B1, B2 and B3.

Is this right: B1 is fire spread out of the

compartment via the infill sandwich panel within which the extract fan was mounted, or the extract fan itself, igniting the cladding adjacent to the window at flat 16. That's B1.

A. Yes.

Q. Or was B1.

B2: the fire spread from inside the kitchen due to flame impingement from the internal fire venting through the window opening, leading to the burning of the external cladding.

A. Yes.

Q. Am I right, that was B2 originally?

A. Yes.

Q. Then B3 was fire spread via the different parts of the internal window structure being penetrated by fire, allowing fire spread directly into the back of the cladding cavity from within the flat 16 kitchen. That was B3.

A. Yes.

Q. Now, you've now carried out further work, as I understand it, and have reformulated your hypothesis into two: B1 and B2.

Am I right in thinking that B1 is now an amalgamation, a blend, of your original hypotheses B1 and B2 in your first report?

A. That's correct, yes. I mean, B1 in the first report was essentially assigning the extract fan a causal role. So I think it probably would be fairer to say that the original B1 has just vanished because we have insufficient evidence, I think, to support that hypothesis now.

Q. B2 reflects your original B3, so fire getting through the materials in the sides of the window frames and getting into the cladding that way.

A. Correct.

Q. So essentially B1 is now out through a hole in the window, and B2 is out through the materials in the side or round the surrounds of the windows.

A. That's correct.

Q. In layman's terms.

A. Yes.

Q. Now, I think you've updated your conclusions. I want to show this to you. It's page 147 of your report, please. If you go to that, you can see at paragraph 712, you say:

"712. There is insufficient evidence to accept or reject Hypothesis B2 at present. On a balance of probabilities, I consider Hypothesis B2 to be equally likely as Hypothesis B1, above."

It looks from that -- and I may be wrong -- as if

you've changed your view, because in your original report you said that what is now B2 or was originally B3 was your most likely by a considerable margin. Is that right?

A. That's fair.

Q. Can you just explain why you've changed your view?

A. Essentially because additional evidence has come to light since I submitted that report. At the stage that I submitted my initial Phase 1 report earlier this year, the visual evidence that we had from outside the compartment of origin didn't show any significant external flaming prior to obvious escalation of the cladding fire. Whereas some really key pieces of video evidence came to light through the IWS submissions subsequent to that work, which shows that in those 2, 3, 4, 5 minutes that are critical when the fire starts to escalate, there is external flaming coming out of the kitchen window, and so it is possible that flames venting out from that window could have ignited the ACM panels. Previously I had no visual evidence to confirm that that was what we had seen.

In addition to that, the new video also shows evidence of melted dripping and burning polyethylene on the spandrel cassettes immediately below the window of flat 16, which would indicate a significant exposure of

the spandrel cassettes above the window, which would tend to support an idea or a hypothesis that the flames venting the window and heating the spandrel panel directly above the window could have been a mechanism by which the cladding fire gets going.

Q. Right.

A. If that makes sense.

Q. So, in short, further video evidence.

A. Correct, yes.

MR MILLETT: Now, we're going to spend a bit of time just analysing that just to understand fully what it is, and I will be showing you some parts of your newly updated fire spread video. I'm not going to do that yet, given the time.

Mr Chairman, what I'll do is I think to start with, the still photographs, as we go through it, and then perhaps take the video immediately after the lunch break.

SIR MARTIN MOORE-BICK: Well, that's something we could do. The alternative would be to break a bit early --

MR MILLETT: Yes.

SIR MARTIN MOORE-BICK: -- so as not to disrupt the flow of the presentation. What would you like to do?

MR MILLETT: I think that's sensible, actually, if I may say so. Break now. Then I may be able to take it slightly

more quickly by reference solely to the video as opposed to the photographs.

Can I actually just ask the professor, which would be more illustrative for the purposes of you explaining your opinion, the video, with pauses, or the photographs, figures 58 and following, in your report?

THE WITNESS: Do you have page numbers for those?

MR MILLETT: 58 is at page 117.

(Pause)

THE WITNESS: I mean, I think either would probably ... either one would work. The videos are perhaps more interesting.

MR MILLETT: We should certainly use what is more interesting.

In which case, Mr Chairman, I'm going to ask you to rise now, if I may, but I'm going to give a trigger warning, now and when we come back, in the usual way to which we've been accustomed, and that is this: we are going to be looking at video of fire spread on the exterior of Grenfell Tower in the period just after 1.00 am. Some people may well find this distressing. There's also audio that accompanies it, they may find that distressing. So if anybody who is watching or present in the room does not want to see that, then they should not come back at 2 o'clock or not be present in

front of the live stream at 2 o'clock when we resume. I'll repeat the warning at that stage.

So is that convenient?

SIR MARTIN MOORE-BICK: It is, certainly.

Can we afford to take the extra 5 minutes and come back at 2 o'clock?

MR MILLETT: Most unlikely.

SIR MARTIN MOORE-BICK: I think we'll do it anyway.

We're going to break now, professor, to have some lunch and so on.

Please don't talk to anyone about your evidence while you're out of the room, and we will start again at 2 o'clock. All right? The usher will look after you.

Good, 2 o'clock, then, please.

(12.55 pm)

(The short adjournment)

(2.00 pm)

SIR MARTIN MOORE-BICK: Ready to carry on?

THE WITNESS: Yes.

MR MILLETT: Professor Bisby, before we start, I'm going to repeat the trigger warning I gave before, Mr Chairman, just before we stopped for lunch.

SIR MARTIN MOORE-BICK: Thank you.

MR MILLETT: I'm going to be playing in a moment or two a part of your first video, video 1, showing fire spread

up the east elevation of the tower in the early stages. People may find that distressing to look at. There's also some audio which people may find distressing to hear, so they need to absent themselves from this room or the live stream while we play that.

Before I go to that, professor, can I ask you, please, to turn first of all to page 117 of your report and look at figure 58.

This sits within the part of your report dealing with vertical fire spread in the early part of the fire, and you identify this as a picture extracted from the video captured at 01.05.49, you say:

"Flames visible at left of window (inside compartment)."

I just want to pick this up with you as a data point.

At this point, 01.05.49, could smoke from within the compartment be heating up the uPVC window surround, causing it to deform?

A. Yes.

Q. What about radiated heat from the fire?

A. Yes.

Q. What I'm going to do, then, is to start the video and to run it up to 01.11. What I'd like you to do is to signal when you want to stop and identify things that

are important.
The reason I want you to do that is that we've heard earlier that you have changed your opinion between your first report and your second report, and what I need you do is to explain to me by reference to this video what we see which enables you to come to that conclusion, focusing particularly on the timing of the fan failing and also the timing and place of where we see melting droplets of polyethylene.
Okay?
A. Okay.
Q. So you're going to be in control --
A. I'll try.
Q. If we have to go back to anything, we can do that.
A. Okay.
Q. Can we start, please, Paul.
(Video Played)
A. I mean, I just stopped it here because that's coincident with the figure 58 that you showed me recently, that's about the same time. Again, we do see some flaming. That flaming does appear to be confined to inside the flat still, you don't see a lot of flames coming out the window. You do see a bit of smoke coming out of the window, which equally could be heating the cladding above the window or adjacent to the window, admittedly

to a limited extent.
Q. Do you know whether the window is open or closed at this point?
A. My understanding is that the larger pane, the tilt pane, is tilted inwards 40/50 millimetres, a couple of inches.
Q. So open?
A. Open at the top in an inwardly tilting position, and that the smaller pane between the extract fan is open, according to the witness statement, approximately 10 inches, I believe is what Mr Kebede says.
Q. Thank you.
A. So go ahead, Paul.
(Video Played).
Stop it, Paul.
So that's not a very good frame to stop on there, unfortunately. But at this stage, again, we can see flames inside the flats and, again, it's hard to say the extent to which those flames might be projecting outside the window, so we still see a similar condition, although the fire is growing a bit in time as we go forward.
Q. Still contained within the compartment at this stage?
A. It appears to be, yes.
Q. I think by this stage Professor Torero says that it has exited the compartment, or the earliest point at which

it could've done is passed at 01.05. Can you comment on that?
A. I think the basis on which Professor Torero is making that statement is related to a still image that does show some falling debris from the window, which could potentially be droplets of polyethylene burning and falling from the window. But it's very, very limited at this stage.
Q. Yes.
A. You will have noticed in my report that we've put that time where we would be more comfortable confirming that the fire was within the cladding and burning the polyethylene closer to 01.08/01.09 in my report.
Q. His image is at 01.05.57. For reference purposes, it's page 56 of his report.
Let's continue.
A. Okay, yes.
(Video Played)
Any time here, Paul.
So in this sequence here, around 01.07.51 and some seconds after that, what we see here is that flames are passing underneath the fan mounting unit. It's hard to say whether that's through the bottom of the infill panel or some flames coming out of the inwardly opening window immediately below the extract fan. It's also

difficult to say definitively whether or not the extract fan is still in place here, although it appears to be.
Q. Right.
A. Then I'll get you, Paul, to just continue a little bit more, please.
(Video Played)
Pause there. If you can go back a little bit, apologies.
So there is a moment there just at the end of that clip ...
(Video Played)
There. So in that view there, you can see a circular opening in the location where we would expect the extract fan to be.
Q. Does it appear to you that the extract fan is still in place?
A. No, it would appear to me on the basis of this that the extract fan has fallen out.
Q. Right.
A. Unfortunately, that could have occurred even before 01.05.49, it's possible, we just don't have very good views to be able to say definitively when the extract fan has fallen out.
Q. On this frame, you can see a circular orange disc but with a black bar across it. Might that tell you that

the extract fan was still in place or not?
A. I think what we're seeing there -- the larger, bright spot is I think the opening where the extract fan would've sat. So that is a hole through a window infill panel, a circular opening through a window infill panel, and the little piece of flame you can see under that I would suggest is either flames coming from the bottom of the infill panel or through the open window immediately below the extract fan.
Okay, go ahead, Paul
(Video Played)
Here, Paul.
So here, this next sequence, you really just see the fire continuing to grow within the flat. Increasingly, we see flames coming through the extract fan and through that either open or absent window beneath the extract fan and, indeed, a little bit of flaming coming, it would appear, through the inwardly tilting window as well.
Q. By this stage, 01.08.16, have we seen any falling burning material yet?
A. Aside from the still photo that Professor Torero has used, no significant -- we should see it in a few moments.
Q. The reason I ask is if you go -- I wonder whether

there's a way of having both on the screen at the same time -- to figure 60 of your report at page 119 -- I don't know if it is possible to have both on the screen at the same time -- you have -- it may be we haven't arrived at it yet --
A. Yes, we will see that in a moment, if we continue.
Q. Very good.
A. If everybody watches the lower left-hand side of the window, they should see debris dropping down in a moment.
Q. Before we do that, can you tell from this frame or the sequence that leads to it what is combusting?
A. No, I couldn't say.
It's also noteworthy here that there does appear to be flaming sort of more towards the left-hand side of the window, although given that it's sort of shielded by the view angle, it's hard to say for sure.
Q. Right. Can we continue, please.
(Video Played)
A. Pause it there, Paul.
Here you can see 01.09.34, and there you can see now sort of a semi-continuous stream of lit particles from the lower left-hand side of the window.
Q. Can I just ask you to go back to the end of the last sequence. I want you to look for burning, falling

material coming out of the window at that stage, before we get to 01.09. If we can just go back to that and just play from there.
(Video Played)
There.
A. Yes.
Q. We can see burning material at 01.08.19. What is that?
A. I couldn't say. It's possible it's polyethylene. It could also be things that are coming out from inside the flat. We have the purlboard immediately above the window which I would expect to be burned or burning at this stage, and you have various other things around the window that could potentially be burning.
The droplets we just saw falling are not falling sort of straight down in a very sort of dedicated seeming manner, they're a bit floating away from the building.
Later on, when we see the burning and dripping polyethylene, that tends to be sort of a more vertical -- the particles are falling with a bit more intent, if you see what I mean.
Q. Yes, okay, we can continue.
(Video Played)
A. Stop there, Paul.
So you did hear someone in the background there say, "It sounds like it's dropping down", so I would expect that they're commenting on things falling to the ground.
In this photo, you can clearly see that the extract fan is now absent from the panel; there's very clearly a hole there now. There's quite a lot of flame within the compartment and a little bit exiting the compartment at this stage.
Q. We saw at the end of the last sequence the flowing, dripping material. Do you say that's polyethylene?
A. I think it's probable that it's polyethylene, but I couldn't possibly say with certainty.
Q. If it were, where would it be coming from?
A. Given the location it's dripping from, it would be coming either from the column cassette to the left of the window, or from the spandrel cassette immediately above and to the left of the window, I would say, or some combination of those two potentially.
Q. If it were coming from the column cassette to the -- you say to the left of the window, you mean --
A. As I'm looking from the outside.
Q. As you're looking at it?
A. Yes.
Q. What is the mechanism by which that polyethylene would have ignited at this point?
A. Well, as we've discussed, we essentially have these two

candidates, my two hypotheses, B1 and B2. One is that the fire and hot gas gets into the cladding via the uPVC window boards, which we will have to assume have been removed in some way, or because flame and hot gas are exiting the compartment via the extract fan panel or the open window and impinging on that column cassette immediately outside the window or immediately above the window. It could be either.

To be honest -- I do say this at some stage in my report -- I think the only credible answer to that question is that it's going to be some combination of those two, because no matter what, the hot gas and flames exiting the compartment are going to be heating the cladding externally, and no matter what, you are going to be getting heat through the window surround, whether its there or not, and into the cladding. It's a question of the relative importance of those two modes of heating the cladding, and I would be very hard pressed to say which one I think is dominant, if that makes sense.

Q. On the basis of the visual inspection of these videos?

A. On the basis of any of the evidence that I've seen, yes.

SIR MARTIN MOORE-BICK: Can you help me make sure I've understood what I'm seeing in some of these pictures. If we look at the one on the screen at the moment --

A. Yes.

SIR MARTIN MOORE-BICK: -- we take it, do we, that the top of that brightly illuminated window is where the fan was?

A. The sort of circular opening, yes.

SIR MARTIN MOORE-BICK: Would it be right to infer from this and the previous films that the large window which is to the left of the small window with the fan as you stand in the kitchen, or to the right, is not as heavily involved?

A. Well, it is not open, so --

SIR MARTIN MOORE-BICK: Well --

A. It is -- it's hard to see on this screen, but it is here (Indicates).

SIR MARTIN MOORE-BICK: It's there, but I mean --

A. Yes?

SIR MARTIN MOORE-BICK: The impression I get from what I'm seeing here -- and it's true for the earlier shots -- is that the fire is impinging on the, as we view it from here, left-hand window where the fan was, but not nearly so much on the right-hand large window, which could be relevant for identifying the point at which break-out occurs.

A. Yes. I mean, the important thing to recognise in this view is that this smaller window here is an inward

swinging window that opens like that and it's open 10 inches, so it's essentially wide open. So you're looking straight into the kitchen here, whereas the right-hand window is closed from a visual perspective. It could have some soot deposition on it which is causing it to be slightly frosted at this stage in the fire, which is why it looks a lot darker.

Does that make sense?

SIR MARTIN MOORE-BICK: It does.

A. But it does appear to me that there is more flaming to the left of the window. That is certainly something that is true.

SIR MARTIN MOORE-BICK: I ask because I think you suggested that the fire might have come out of the kitchen at the top of the window rather than at the side of the window, to put it in a rather general way.

A. Yes.

SIR MARTIN MOORE-BICK: If it came out of the top of the window, it's going to be the top of the small window, not the top of the large window.

A. It's going to be the extract fan, the hole in the extract fan panel would be the primary route that I would suggest, as well as the window immediately below.

SIR MARTIN MOORE-BICK: Thank you.

A. Okay.

MR MILLETT: Different question: at this stage, was the XPS involved?

A. It appears to me that some of the flaming that we see around the extract fan infill panel will be associated with combustion of the XPS. I would consider that highly probable, given that we have flaming and hot gases there, yes. Although, as I've noted, there's not a huge mass of material there, so it could burn away quite quickly and then you're left with two aluminium sheets.

Q. Okay.

(Video Played)

A. There, Paul.

Okay, so I've stopped the video here because we can now see there is actually some burning debris on the ground directly beneath the window. My assumption would be that that would be polyethylene that has dripped whilst burning, forming a small pool fire on the ground.

So at this stage, 01.09.58, we're reasonably certain we have polyethylene burning and melting within the cladding by some means.

Q. Do you know whether that would be self-sustaining by this stage?

A. Within the cladding?

Q. Within the cladding.
A. If you have polyethylene burning and dripping out of cladding such as this, and either you have a continued source of external heat flux or you have pooling of that polyethylene in the location where it's continuing to burn, then yes, I would say at this stage you would have a fire that we would expect to propagate if left to its own devices.
Q. Yes.
A. Okay, Paul.
(Video Played)
Can you stop it here, Paul.
It's very difficult to see here through the trees, but what we do see in this next sequence is quite a lot of smoke coming out of the compartment and quite a lot of flame coming out of the compartment is well.
Go ahead, Paul.
(Video Played)
Here, yes.
So here what's interesting is you can see now quite a lot of flaming below the spandrel panel. It's difficult to say whether those flames are emanating from within the compartment itself or whether that is an indication that we have polyethylene within that spandrel panel that's actually burning and dripping and

burning whilst it falls away.
The location where you see a bright spot on the spandrel panel below the kitchen window of flat 16, the only explanation I could give for that is that that is burning polyethylene on the surface of the spandrel panel. The likely candidate for where that polyethylene would've come from would be the spandrel panel above the kitchen window.
Q. What about to the side, to the left of the kitchen window?
A. In the location that it is, I think it's unlikely it would come from the side and end up there. Yes.
Okay, Paul.
(Video Played)
Q. If I can ask you to pause there.
You can see the fire and flames now impinging upon the 90-degree return of the aluminium panel above the kitchen.
A. Yes.
Q. Would that tell you anything about ingress of fire into the dark crack that we looked at earlier this morning, behind which is exposed PE?
A. Certainly at this stage I would expect flaming inside the cavity behind the ACM panel, yes. I would expect those flames to travel up through that gap, yes.

Q. Right.
(Video Played)
A. Right here. Go back a bit, Paul, if you wouldn't mind. What I'm looking for is 01.13.31. We see a little pulse of flame.
(Video Played)
There.
Yes. So there we start to see now this pulsing of flames. Those flames are exiting the vertical gap between the first and second spandrel panels immediately above the kitchen window of flat 16, which would indicate that you have some pyrolysis or evaporation of liquefied polyethylene within the cavity above flat 16.
Q. That's behind the cassette?
A. There's something going on inside that cassette, and the gases are coming out, they're hot, they're finding oxygen and they're flaming.
Q. Had you seen any evidence visually of that phenomenon before this point?
A. At Grenfell Tower or in other fires?
Q. Yes, at Grenfell.
A. I think this is the first time we see this happening specifically at Grenfell in the footage that we have, yes.
Just before you continue, Paul, what you'll see in

a minute, if this continues, in just a couple more seconds, you'll see a similar licking or pulsing of flame slightly to the left, which is along the corner or the re-entrant corner where the column joins the spandrel panel above flat 16. You'll see that extend I think a little bit further up.
Go ahead.
(Video Played).
Yes, there it is. That's the joint between the column and the spandrel panel. Again, it indicates to me that there's something going on within those cassettes at that location.
(Video Played)
Stop it there, Paul.
So at this point, I think it's quite clear that the cladding is involved, the ACM cladding cassettes are involved, and that this fire is likely to escalate up the building, supported primarily by combustion of the ACM and the polyethylene.
So I think that's as far as we really need to go here.
Q. Right.
A. So just to say where does that leave me with respect to my two hypotheses -- that's probably the next question?
Q. That was the next question.

A. Yes. So where it leaves me is with a situation that I have Professor Torero's analysis which suggests to me that the gas layer in the kitchen is between 200 and 300 degrees Celsius, most likely, and that we have flame impingement on whatever is going on inside the kitchen at that stage.

If we assume that the uPVC is physically absent, and if we assume along with the uPVC goes the 25-millimetre thick PIR which is adhered to the back of the uPVC, then we have EPDM weatherproofing membrane, which would provide negligible resistance to flame impingement and those type of gas temperatures and it would burn through quite rapidly, and then we're into the back of the cladding, and as Professor Torero said yesterday, at that point, with flame impingement and those types of gas temperatures, it's anyone's guess as to which material is the first ignited material within the cavity.

Outside the window, I have flames and hot gases exiting. I have impingement of those flames and hot gases directly above and potentially to the left, if I'm outside the building and looking at the building, of the window, and at some stage we see polyethylene melting and dripping and falling from that region to the left-hand side of the window as I'm looking at it from

the outside.

I think where that leaves us is in a situation where, no matter how you look at this, you have some combination of those two heating mechanisms that are causing eventually the ignition of the cladding and the escalation of the fire spread up the building.

If you look at -- I was looking at this over the lunch break -- paragraph 713 in my report, I sort of finish this section on B1 and B2 -- it's immediately below the paragraph that you read previously, and I say:

"713. Indeed, it is probable that some combination of the fire spread routes suggested in hypotheses B1 and B2 conspired to cause the initial ignition and sustained burning of the external cladding."

That's kind of where I end up with it.

I guess I would like to say also, with respect to this issue, that for me, it's almost a secondary issue. I can understand why you want to get to knowing more confidently which one it is, but at the end of the day, there's a number of mechanisms by which rainscreen cladding of this nature could be ignited on the outside of the building, and to focus too heavily on the specifics of what has happened in this particular fire scenario I think in a way diminishes the importance of recognising the clear risks that it presents under any

scenario. So I wouldn't want to labour the point too much.

Q. No, I understand that.

Picking up 713 -- and the purpose of this exercise, in a sense, is to see if you can come to an opinion with a reasonable degree of confidence about, although they're combined, whether B1 or B2 is the more likely.

A. Yes. I mean, I think you can tell that I'm not enthusiastic to be drawn on this point, I think, at this stage. If you really push me, I would say that fire spread through the uPVC is ahead by a nose. Yes.

Q. All right. Let me try a different way.

You're obviously looking at it from a visual perspective and forming your opinions based on what you see.

A. Mm-hm.

Q. You can see burning droplets. They were coming, I think, from the bottom of the window.

A. That's where we see them exiting the window box, yes.

Q. My question is: is that not more consistent with hypothesis B2?

A. B2 being through the uPVC, yes?

Q. Yes.

A. I mean, perhaps, but as we discussed earlier, when I was pointing out the detail of the cladding cassette

alongside the window, the exposed edge of polyethylene in that particular location is external to the cavity. So that vertical line of PE immediately to the left of the window, if I'm looking at the window, is actually external. So if it is coming directly from that location, then I think we sort of have to hold our hands in the air and say we don't know.

Q. Right. Again, I think --

SIR MARTIN MOORE-BICK: That does depend on being able to see clearly enough where the droplets are coming from.

A. Indeed, and we can't because of the angle we're looking at it.

SIR MARTIN MOORE-BICK: Also the fact that if they were coming from above the window, they're falling past the window which is itself highly illuminated by the fire.

A. Mm-hm.

SIR MARTIN MOORE-BICK: Does that make it more or less difficult to --

A. And if they are coming from above the window, given the way that that cassette is configured, essentially it's a box that goes like that (Indicates), you essentially have a trough internal to the cavity at that location and your burning polyethylene is going to come out either end of the trough at the vertical cracks. Given that I would expect the predominant heating to be above

the extract fan, the left-hand side -- you know, it's possible, but, again, I don't know that we will ever know the answers to these questions.

MR MILLETT: Let me try something on you.

We've treated the uPVC as a single entity, but can you help us, with the temperatures that Professor Torero has identified within the compartment, would it be more likely that the uPVC would fail and fall away and open up at the top as opposed to the bottom?

A. I think so, yes.

Q. If that is so, would it not also be the case that, therefore, there was a more likely ingress of fire from the inside of the compartment through the gap created by the uPVC at the top by the window?

A. Indeed, yes.

Q. That would also, therefore, support hypothesis B2.

A. Indeed, yes.

Q. So that in fact, although the flaming droplets might well have been coming from the top end of the window jamb on the right-hand side as you look out, the ingress of fire into the cavity could well have come through the uPVC there?

A. Yes. Indeed, the way that the rail that holds the window framing onto the building terminates at that location would allow flames and hot gases exiting at the

top right-hand corner, if you're inside looking out, to access the spandrel panel as well as the column panel just above the window. So, yes, it's possible.

Q. Putting into the mix that possibility, how would that then square against the possibility of your hypothesis B1, namely flame impingement directly through the gap left by the extract vent or the open window?

A. I don't think that would necessarily impact my previous statement that I would say, you know, via the uPVC failing is ahead by a nose, but not by a significant margin.

It's important to say we also have the analysis by Professor Torero, and he clearly has a preference, I think, in his report. Dr Lane also, I think, expresses a clear preference for the uPVC failing mode in her report.

The only thing I would say -- and I'm sure Professor Torero would agree with me on this -- is that his analysis, as you've pointed out, is a simplified analysis, it's quite a straightforward, simple analysis, and it doesn't take account of, for instance, the purlboard immediately inside the window and the potential for that to burn and flame, or the potential for the extract fan infill panel to burn and provide some flames as well.

Q. No.

A. So his model only deals with gas layer temperatures and flame impingement due to a ceiling jet from an object burning at some distance from the window.

So there are a number of assumptions inherent in all of this that we have to keep in mind. Hence my inability to be more confident, with apologies.

Q. Thank you.

Can I take you back into your report at page 122. I want to pick up figure 66, which is actually page 123. I think it probably spans the two, in fact.

You identify in the text at figure 66, at the bottom of the page:

"... Intermittent flaming between the spandrel cassettes above between Level 4 and Level 5."

We saw that on the video and you showed us that.

A. Yes.

Q. Also:

"... intermittent flaming at the vertex of the column and the spandrel ..."

Is that more consistent with hypothesis B1 or B2?

A. The intermittent flaming at the junction between the spandrels I would say is more consistent with the flames venting hypothesis. The flaming at the column could be due to either to those hypotheses.

Q. Under hypothesis B1, would one expect to see the burning of the cladding more directly above the window as opposed to on the side, as we do?

A. I would expect that, given the buoyancy of hot gases and the tendency for flames to move in that direction, yes.

Q. Would that not, then, tend to support hypothesis B2 over B1, or is that just short nose again?

A. I think so, yes.

Q. Right.

Similar question. Look at figure 68(a), please. This is thermal imaging, page 126 of your report, and you've set out the relevant thermal images at the second pulse and a second after the second pulse at 01.14-odd.

Looking at this, is the picture that these show, particularly figure 68(a), the heat still there after the first pulse and the absence of it after the second pulse, is that consistent with your hypothesis B1, that the fire vented out of the open window or the extract fan?

A. As Professor Torero discussed yesterday, given the resolution of these images, it's difficult to say anything too conclusive about them. That hot-spot in this image does appear to be approximately in the location of the extract fan panel, which could indicate that this is a time -- and here we're at about 01.14.

Q. Yes.
A. So it could just simply be the extract fan panel burning or it could be -- I mean, it could be anything burning in that location, but it's in the approximate location of the extract fan panel, I would say.
Q. Does this evidence help us in any way to decide as between hypothesis B1 and B2?
A. Not really, in my opinion, no.
Q. Moving on to some other evidence.
We have some evidence from Firefighter Daniel Brown that after 1.20 am, so a little bit later, he could see within the cavity behind the panels and could see fire travelling up the building. You'll recall he lent out of the window and aimed his jet into them.
He says in his contemporaneous notes -- just for the record, this is MET00005251 at page 3 -- that the fire was travelling in an upwards direction behind the cladding. He says:
"... it was easy to see the material behind it was alight and travelling in an upwards direction however the vast majority of the cladding remained in place and any attempts to extinguish simply bounced off."
And similar evidence later when he gave evidence and in his statement to the police in a fuller form.
Does that help you, again, decide between B1 and B2?

A. No, because I think at that stage we're quite well along in the vertical progression of the fire up the cladding, and so regardless of how it started, we have a very well-developed fire in the cladding at that stage.
Q. In a similar vein, Charlie Batterbee said in his evidence -- this was his oral evidence in the transcript for 28 June, page 85:
"Once inside the room I could see the fire had vented because the window had gone."
Again, does that help you?
A. No, I wouldn't say so.
Q. Why is that? Because it's too late?
A. Too late. Not with respect to ignition of the cladding in any case.
Q. Is it fair to say that the fire would eventually have come out of the failed window in any event?
A. Yes. I mean, I think we have to assume when designing cladding systems of any type that a fire venting from a window is a likely scenario.
Q. You'll have seen Professor Torero's views about your hypothesis B1. He says that that is highly unlikely and easily to be disproved by testing.
What do you say to that?
A. I mean, I would be happy to attempt to disprove it by testing, with some assistance in how I might do that

from Professor Torero.
Q. Having considered his report and heard him give evidence yesterday, do you disagree with Professor Torero?
A. In what respect? In respect of that statement?
Q. Yes.
A. Yes, I think I do. I think I do.
Q. Let me show you what he says so we're clear about what I'm asking you to agree with.
Can you be shown, please, JTOS0000001 at page 46, lines 1314 to 1315.
He says:
"Hypothesis B1, as indicated by Prof. Bisby ..."
A. Is this his most recent version of his report? Because I think he's referring to my original B1.
Q. He may well be. I can hear mutterings around me, which rather indicates that I should be not asking you that question.
A. I think this is referring to the fire starts in the extract fan as the hypothesis, yes.
Q. Moving forward, then, to talk about direct flame impingement through an open window.
Is it relevant, having considered Professor Torero's report and also your own work based on the visual inspections of the video, that flames would've come out from a hot compartment into a relatively cool atmosphere

outside?
A. I mean, certainly one of the consequences of venting outside is a cooling effect, both on the gases and on the flames as a consequence of the cold air entrainment that would occur, yes.
Q. Would that have affected the ability of flames coming out of the open window or the gap left by the vent extract fan to impinge upon the ACM?
A. I mean, potentially, but we have -- I mean, we see flames impinging on the ACM in the footage, so we do know it's happened. The question is whether or not the time at which it happens, which is admittedly 2 to 3 minutes after we suspect that we see involvement of the ACM cladding, gives us enough confidence that that is the primary candidate for ignition of the cladding or whether that is a secondary effect that happens after the cladding has already ignited from within.
The take-away for me yesterday from Professor Torero's testimony with respect to all of these issues was that inside the compartment you have a hot-spot layer, 200 to 300 degrees Celsius, and you have flames impinging on the region near the window. Outside compartment, you have hot smoke which is venting from the compartment at a maximum of 200 to 300 degrees

Celsius and is, as a consequence of venting, now somewhat cooler than inside the compartment. And the same with the flames; you have flames venting from the compartment, impinging on the cladding, however, again somewhat less than inside the compartment.

So if we agree that the uPVC window framing boards absolutely are absent, then I agree with Professor Torero that the most likely candidate is the hypothesis where the ignition happens via the side of the window through the uPVC.

But as I've explained, I wasn't in the kitchen, so I don't know for sure that the uPVC boards were absent. I think it's likely, but I wouldn't be able to say that it is definitive.

Q. Yes.

A. And as I've said, I think, at the end of the day, it's some combination of the two.

Q. I want to turn next to a different topic, which is initial spread up the east face, if I can, please, professor.

I'll start by asking you about internal firefighting and then I'm going to turn to external firefighting.

Internal firefighting, first of all.

Do you agree in principle that there is a defined point in time at which compartmentation, in general

terms, is breached?

A. Yes. Yes.

Q. Is that point in time when smoke and/or flames extend out of the compartment of origin, or is it as soon as any of the combustible components of the facade in the case of Grenfell Tower ignites?

A. It's the moment when any secondary fire compartment is compromised by hot smoke or flames.

Q. What do you mean by secondary fire compartment?

A. So the flat of origin is a fire compartment.

Q. Yes.

A. It's a fire-rated box. The most likely candidate for next compromised would be the flat directly above, which is also intended to be a fire-rated box. Given fires aren't supposed to move from one fire-rated box to another fire-rated box, I would say that compartmentation is effectively lost when flat 26 is compromised by the vertically spreading fire.

Q. So not, then -- is this right? -- at the moment when the ACM panels ignite outside flat 16?

A. I mean, I think that one could argue that, but if the definition of fire compartmentation is that the fire is confined to a single compartment in a building -- I mean, let's take the case of a fire in a building that doesn't have a cladding system that spreads flame

externally and you have a fire in your kitchen, the kitchen window is open or has an extract fan, the fire vents from the kitchen window. You do have hot smoke and flame exiting your compartment and impinging on the cladding above that flat, but we wouldn't call that a failure of compartmentation unless the flat above the window breaks and the flames get in or whatever and then you have a secondary flat.

So, for me, if the fire had gone out into the cladding and the fire had spread in the cladding, but no other flats in the building had been at all affected by that, then whilst the fire has left the compartment of origin, it hasn't caused any other spaces in the building to be affected by the fire, and that's the key thing with the compartmentation strategy; it's the affecting of other spaces.

Q. So for you, a breach of compartmentation -- the line is crossed when the next fire box is breached, not when the first fire box is breached?

A. That's what I would say, yes.

SIR MARTIN MOORE-BICK: Doesn't that depend on how and why the first fire box is breached? Because in the ordinary instance that you've indicated, you don't know whether there's going to be a break-in in the flat above. But the nature of this fire was such that once it was

established in the cladding, it was almost inevitable, if not actually inevitable, that it would affect other boxes, wasn't it?

A. I agree in this case there is an inevitability, but, of course, cladding isn't supposed to do this. So I guess I'm struggling to understand what the point of the question is.

MR MILLETT: I think the point of the question is to work out -- people speak of compartmentation linked to stay put, and it's part of a bigger design principle, and it's not for me to tell you, but it's really a question of focusing on a point in time which we can all understand as what we mean by compartmentation has been breached or lost.

I'm suggesting to you that it's lost when the components of the cladding on the exterior of flat 16 in this particular case are alight.

A. I mean, I can go along with that in this case, but as I said, if we had a building that had a different cladding system where some element of the cladding system was combustible but it didn't result in a rapid escalation of vertical fire spread up the exterior of the building, would we call that loss of compartmentation? No, I don't think we would.

So I think it's the consequences that are the issue

as opposed to the potential consequences. It's what actually happens. So when that flat above flat 26 becomes involved, you now have lost your fire box, your fire-rated box in your building.

Q. There's a question I was going to ask you later on, but I might as well ask you it now: in your experience, do you know of a cladding fire which has not resulted in flats in a high-rise building other than the flat of origin being breached?

A. That has not resulted in?

Q. Yes. In other words, a cladding fire which didn't break back in.

A. Not specifically, because we tend not to hear about them because they don't, so they're not newsworthy in that sense.

My understanding from speaking to colleagues who work in the fire services internationally would be that it is reasonably routine to have fires in multi-storey buildings that don't spread to other fire compartments via the exterior. It depends on the characteristics of the cladding system.

Q. Right.

A. We could think of a number of cases where that has happened, and you have seen fire spread vertically where you didn't have ACM, maybe you had window infill panels

or some other type of cladding system that presented fire spread risks, but I think we only know about them because that occurred, if that makes sense.

Q. I am going to try to get a feel for the inevitability which the chairman has put to you, when we come back to Grenfell Tower, looking at the geometry and configuration of this cladding structure.

Was it in your opinion inevitable that, once the cladding had ignited, it would spread in the way you've identified and, therefore, inevitable that it would breach other compartments?

A. Yes.

Q. So in practical terms, would it be right to say that actually compartmentation, to all intents and purposes, was breached once the cladding was alight outside flat 16?

A. Sure, noting my slight disagreement with that definition, I'll go along with you.

MR MILLETT: External firefighting, moving ahead.

Can I ask you, please, to look at a video clip.

Mr Chairman, I'm not sure if I need to keep repeating the trigger warning --

SIR MARTIN MOORE-BICK: It's better if you do.

MR MILLETT: It probably is better.

I again repeat the trigger warning: I'm going to be

showing the professor, or he'll be showing us, his second clip, LBYS0000002, and this also will show pictures of the building on fire on the exterior and has audio attached to it. Some people will find it distressing and may need to leave the room or remove themselves from the live stream. I'll give people a few seconds before we show this.

Can I ask Paul if we can move to the sequence at 01.15.53.

(Video Played)

Now, I've shown you quite a bit of that.

In this clip, we can see a covering jet, which we can still see in the part we've frozen on, being started up and aimed underneath the window.

From what you've seen, professor -- and you've seen and analysed all the video clips you've got, and it may not be complete, of course -- is this the first visual confirmation of the jet being in use?

A. Yes.

Q. I don't need to take you to this, but we have a document from the LFB, which is their ORR, their operational response report, which has a time at 01.11, which suggests that a jet was being applied at 01.11, and that it was being applied above the window.

Have you seen anything to support that statement?

A. No, I've not.

Q. In your opinion, could earlier external firefighting -- in other words, earlier than 01.16 that we've seen -- have made a difference?

A. That's a very difficult question to answer. I think it's hard to say with any certainty. The only evidence that I could bring to answering that question is that I've seen a number of cladding fire tests on large-scale, 9-metre high rigs where fires involving combinations of materials similar to this, ie PIR backing insulation and an ACM PE rainscreen, in a fire that is developed and spreading up the cladding one to two storeys, not dissimilar to what we see here, although admittedly higher up in the air in this case, I've seen those fires extinguished with relative ease in test lab scenarios.

Obviously noting that there could be significant differences between those systems in those scenarios, not knowing the differences in terms of the firefighting kit that's used in order to do that, in terms of the volumes of water deployed by the hoses and the pressures, et cetera, et cetera, but I have seen fires visually similar to this involving similar materials extinguished in fire test laboratories, yes.

So I think it is not impossible in theory.

Q. Knowing what you do about the composition of the materials in this cladding structure and their geometry, in your opinion, would spraying a jet above the window of flat 16 have made a material difference to fire spread by 1.15 am?

A. That's a very, very difficult and, I recognise, very important question.

Again, I would say it's possible, but I'm not a firefighter. I would not want to say one way or another for sure.

Q. On the basis that the jet is being applied from the ground, would it have been possible for water to reach behind the cladding outside flat 16, whether in the column or in the spandrels, or indeed the spandrels above the kitchen, if that is where there was fire?

A. I mean, it's a ventilated rainscreen facade. It's meant to exclude rain, which would be water coming predominantly from above.

In terms of water coming from below, one imagines that water could get into the cladding via the cracks and openings that we've discussed in looking at the configuration of the cladding. Whether the amount of water that one could get into the cavity, and assuming there's burning going on within the cavity, would be sufficient to extinguish a growing fire of this nature,

again, it's very difficult to say with any certainty. I think it's possible but not definitive.

Q. Possible but not definitive. There's a range, though, in that.

Would it be probable or improbable?

A. I don't know. Genuinely, I couldn't say.

Q. All right.

Vertical fire spread, if I can turn to that.

Can I go first to your report at page 152. I'm going to ask you to look, please, at paragraphs 748 to 750.

A. Mr Millett, if it's all right, I would like, having thought about you just asked me, to come back to it and add a comment, if I may.

Q. Yes.

A. I assume that those questions on external firefighting are a consequence of some comments I added to my supplemental report in terms of the observations I made about external firefighting activities in the early stages of the fire.

The reason that I did that is because of the LFB document which states that there was a covering jet directed above the fire at around 01.11 that had no effect on the fire.

If that is the case, then it's important that we

know that, and if that isn't the case, it's equally important that we know that. Both in terms of truth in this event and in terms of the fact that we have a large number of buildings in the UK with non-compliant cladding systems on them, I would expect firefighting tactics would be influenced by whether or not an attempt was made and was proven effective or not in this context.

That's why I did it and I think it's important to state that.

Q. That's obviously left a factual question open.

On the hypothesis that the operational response report is correct and that a covering jet was applied above the window at 01.11 -- it may not have been for terribly long -- what conclusions would you draw from that if that was a fact?

A. That would indicate it is potentially very difficult to extinguish one of these fires, even if that is done very early on. I mean, keep in mind that at 01.11 -- we could look at the video of the fire in that region, and it's still quite small and localised. It hasn't extended anywhere near what it has by 01.15, when we see the covering jet applied.

So if it is genuinely not possible to relatively easily extinguish a fire which at that stage at least

visually is quite a small fire, although admittedly in the cladding, then that's an important piece of information as regards the safety of people who are potentially living in buildings with non-compliant cladding on them.

Q. Approaching it from a different angle, assuming that the fact as recorded in the operational response report at 01.11 is not a fact, in other words didn't happen, no covering jet above the window at that time, what conclusions would you draw from that, having seen the video that you've shown us of the progression of the fire?

A. That if there were a fire in a building and the Fire Brigade were to attend that fire, and they were to see a fire that looks not dissimilar to this and they were to be aware that that building had cladding on it that was not necessarily the cladding we would want on it, if it was one of these buildings identified with non-compliant cladding on it, they would attempt to spray the exterior of the building potentially before they send a crew in, which is what I understand prevented -- one of the reasons they didn't spray, in this case, the exterior of the building was because of some operational rules that are followed in the fire service that you don't spray into a compartment where

you may have colleagues inside for the sake of the safety of the colleagues inside.

So that may change a decision about what it is that you do first in that fire scenario. Maybe it would be better to put out the external cladding fire first to be sure that you've dealt with that and then attempt to fight the fire internally or some combination of activities that might be a bit different.

Q. Which leads, then, just to confirm the question I asked before, having done this little circuitous route: if, in fact, it turns out that there was no covering jet placed above the window of flat 16 at 01.11, is it right that you can't say whether it's probable or improbable that effective external firefighting would've extinguished this fire?

A. I couldn't say.

Q. You say it's possible but not definite, but you can't tell me where on the spectrum between those two it is?

A. I mean, my view is in the absence of any information, it's certainly worth a try.

Q. Vertical fire spread. I think I was showing you what's now on the screen, 748 to 750.

You've got regulation B4 up there, and you say the functional objective of B4 is that:

"The external walls of the building shall adequately

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

You say the functional objective was clearly not achieved at Grenfell Tower.

I think it's right that you haven't at this stage considered compliance with the guidance in Approved Document B, have you?

A. Not significantly, no.

Q. You do, though, go on to say at paragraph 751 and 752, and particularly in 752, picking it up in the third line:

"On the basis that fire compartmentation was not a credible component of any fire safety strategy, once the refurbishment cladding had been installed at Grenfell Tower, it follows logically that a 'stay put' policy was also not a credible component Safety strategy, once the refurbishment cladding had been installed."

There are three reasons, I think, why you say that in terms of directions of fire spread: upward, downward and horizontal.

Do those different theories underpin this basic thesis that a stay-put policy was not a credible component of any fire safety strategy at Grenfell after the refurbishment?

A. I mean, the fundamental assertion that I'm making here is that if a fire is ignited in a cladding system such as this made from these materials under any circumstances, we have to expect it to spread quickly and catastrophically because of the nature of the materials involved. On that basis, it is unreasonable to expect compartmentation to be maintained and, on that basis, it is unreasonable to have a stay-put policy in place.

Now, of course, that relies on someone recognising that they've got this material on their building, which is clearly not the case, apparently, here. So I recognise it's quite a strong statement but it's in a sense a philosophical one.

Q. You say philosophical; that's your opinion.

A. Yes, but it relies on this assumption that people actually are aware of the cladding that they have on their building.

Q. I'm going to ask you some detailed questions about your analysis of each of the three routes of fire spread: upward first, then downward, then horizontal, if I can.

Before I do that, can I just ask you to look briefly at Dr Lane's basic hypothesis. This is BLAS0000010 at page 5, and this is figures 10.2 and 10.3 of Dr Lane's report.

She has identified six different pathways for fire spread, and you can see those particularly in 10.2 and then you also have F in 10.3.

I have questions about A and D, the columns. They represent the two vertical channels I think that you say played an important role in the fire spread on the night.

A. That's correct.

Q. That's right, is it?

Dr Lane's also identified a third vertical pathway, E, you can see it as yellow in figure 10.2, which I think is via the insulating core panels which connect between the spandrel panels. Would you agree with her?

A. I mean, I would agree that those are continuous bands of material that can burn. I'm not sure that I would agree that I've seen either evidence or a physical mechanism by which that is a direction of travel of a fire front, if you see what I mean.

Q. I do.

Leaving aside fire front -- we may come back to that -- can I ask you to be shown page 39 of Dr Lane's report, figure 10.37 under paragraph 10.7.2, which is a photograph of the vertical fire spread up insulating core panels, estimated time at 01.26, taken off YouTube.

Her view is that this image shows evidence of fire

spread up the insulating core panels.
My first question is: have you considered that as a pathway?
A. I've considered the fact that the insulating core panels will burn.
Q. Yes.
A. So this is a photo that shows insulating core panels burning, yes?
Q. That is what she says.
A. It's not necessarily a photo that shows vertical fire spread because we can't see which way the fire is going in a still image.
Q. I follow.
A. Yes? That might seem a bit pedantic, but I do think it's an important point. So I could assert that the insulating core panels have been ignited by falling burning debris rather than an upward fire spread mechanism, and on the basis of this image, I don't think you'd be able to say that I'm wrong. Does that make sense?
Q. Thank you. It does. It makes sense to me.
A. I'm not saying it isn't, I'm just saying it's difficult to assert that. We can discuss in detail my fire spread mechanisms. I suspect that we will. Yes.
Q. So you say that on the basis of this photograph, you

couldn't confirm to a degree of confidence that the insulating core panels were a route of vertical fire spread?
A. That's correct. The insulating core panels burn, or the core material, the XPS inside, is a combustible material and it will burn under some conditions.
How it is that any one of those particular insulating core panels that appears to be burning in this image came to be burning I think is almost a different question.
Q. I'm going to ask you next to go to table 13 of your report at page 175.
You have a table at the top of that page, 13, "Approximate upward vertical fire spread rates in the Grenfell Tower fire as a function of building level".
I think we can see -- is this right? -- that in general, the rate of spread gets faster as the flame front gets further up the building?
A. Yes, that's true.
Q. You can see that. It takes 80 seconds to go from level 10 to 13, but it takes only 15 seconds to go from 19 to 23.
A. That's correct.
Q. Travelling at a rate of 0.17 metres a second.
A. Yes.

Q. You say -- this is paragraph 847, just under that -- that this is similar to vertical fire spread up a solid fuel surface. It's the last sentence of that paragraph.
A. Yes. I mean, on a solid fuel surface, you would expect an exponential increase in the rate of spread based on the available research, yes.
Q. When you say a solid fuel surface, could you explain what you mean by that?
A. So the scientific literature on vertical fire spread dating back many decades, people have been running experiments on vertically oriented fuels so we can try to understand the physics of the upward concurrent fire spread mechanism. Obviously if you want to understand something that is actually quite complex in terms of the physics, even for a vertically oriented fuel that is totally homogeneous, is a single material, doesn't melt, doesn't drip, doesn't flow, doesn't warp, you know, it's a very well behaved material, even studying upward concurrent fire spread on that very simple case is extremely complicated in order to reproduce the physics.
I was at a conference two weeks ago where the keynote lecture was by a chap who is still trying to do this for the very simple case. When you bring a second surface in, you have a cavity, and he just sort of put his hands in the air and said, "Forget it." The models

that we have, even the most advanced models, can't do this at this stage.
So it's important to recognise the complexity of the science we're dealing with here.
But the theory of that, the experiments for that case of the really quite well behaved fuel, show that as the fire spreads up, you will get -- so the fire spreads up, but of course the bit that started burning is still burning, so your fire is getting effectively bigger and bigger as the fire spreads.
At some stage, you'll run out of fuel where it started, and then you've got like a moving band of fire potentially, right? But as the fire is growing and the heat release rate as a consequence is growing as the amount of burning surface is growing, there's a snowballing effect. The more heat you have, the more preheating the material above you you get. The more preheating you get, the faster the fire will travel vertically upwards and you get this exponential increase in fire spread rate.
Obviously at Grenfell Tower, we don't have a well behaved fuel in the manner I just described, we have a fuel that has aluminium facing on it in places, we have multiple fuels interacting with each other, we have an external surface, we have a cavity, we have burning,

dripping, melting, falling, we have deformations, we have window openings, we have all sorts of complexities that we would have to account for if we wanted to model this in any meaningful way.

Nonetheless, what we have is a vertical surface with distributed fuel on it, and we observe a similar outcome, which is a growing fire vertically which causes this exponential increase in the rate of fire spread.

So it is just to say that that exponential increase in fire spread is not unexpected; it is supported by the physics that we understand in general terms.

Q. I think you agree -- is this right? -- with Professor Torero that the flame spread that was observed at Grenfell Tower was not as rapid as that which was observed at The Address in Dubai?

A. The progression of the upward spreading of fire was significantly faster at The Address fire, yes.

Q. That was also, wasn't it, a cladding fire involving polyethylene-filled ACM?

A. I mean, based only on media reports, yes.

Q. Are you able to identify any reasons why the vertical fire spread at Grenfell was slower than that observed at, for example, the Dubai tower, The Address?

A. No. I mean, I could postulate some things, but they would be speculative. The one thing that one does

observe at The Address fire that one doesn't observe at Grenfell is that The Address fire, based on media reports, I think started at the 20th floor of a building that is much, much taller than Grenfell Tower, it needs to be pointed out --

Q. Yes.

A. -- on sort of a terrace, and then started to spread vertically. So in the case of that fire -- and there was no external firefighting on the terrace early on -- all of the melting, dripping, burning polyethylene that fell, fell onto the terrace and generated a large pool fire at the base of the vertically spreading fire, which keeps the heat release rate at the base of the fire strong and, indeed, grows, which then feeds the vertically spreading fire, which would be one explanation for an increased rate of fire spread in that scenario.

Now, at Grenfell Tower, you don't have a pool fire burning at the base of the building because you've got Murphy and Cornelius, as evidenced in some of the videos, and whenever they have burning debris on the ground beneath flat 16, you actually will see them take their hose and direct it at the burning debris, they put it out and then they keep spraying the building. So the formation of a pool fire is prevented at Grenfell Tower.

That's one possible explanation of a number that we could come up with.

But, again, the combination of materials, I don't know what backing insulation was used within the cavity at The Address. PIR, of all the backing cavity insulations we might choose, is one of the least combustible of those materials that we might choose. It could've had XPS insulation, it could've had Styrofoam or something. Yes.

Q. Moving ahead, you say in your report -- this is page 169, I don't think there's a need to go to it -- the flames reached the roof level at 01.27.58 or thereabouts.

A. Thereabouts, yes.

Q. We can see from a picture or diagram at page 170 -- perhaps we ought to look at that, this is figure 99, it's a photograph captured at 01.27.42 -- that the crown was involved in the fire by this time. Is this about the earliest moment when the crown was involved or is it --

A. There or thereabouts. I would say give or take 2/3 minutes.

Q. Looking at this image, is there anything you can take from it which tells us anything about the mechanism for fire spread at the top of the building?

A. Not as yet, I would say. I think we do see it later in some of the videos and some of the photos, but on the basis of this photo, no.

Q. You've got, I think, five hypotheses of vertical fire spread which you cover under section 6.1.6 of your report at page 177 and following.

You conclude at paragraph 859, if I can just ask you to look at that, at page 178 -- if we just highlight that please, Paul -- that:

"859. All of the available evidence presented thus far in Section 6 of this report strongly supports Hypothesis C1. I consider the presence of PE filled ACM rainscreen cladding cassettes to be, by a considerable margin, the most important factor contributing to upward vertical fire spread (and indeed to external fire spread generally) during the Grenfell Tower fire."

A. Yes, that's correct.

Q. We'll look at some of this in a bit more detail, but Dr Lane's opinion is that the columns on the building were the principal route for vertical fire spread. Do you agree with her?

A. Yes. Yes, I do.

Q. Are you able to explain the mechanism by which flames were drawn into and up the columns?

A. Yes. I mean, I think it's a combination of mechanisms,

I wouldn't say it's necessarily one distinct mechanism. I think there are a combination of factors, the respective contributions of which are difficult to quantify. I mean, that's one of the reasons why I've taken a very mechanistic and systematic approach to dealing with this issue via a number of specific hypotheses which look individually at the various factors that we know can influence vertical fire spread.

Q. We know that Siderise open state intumescent cavity barriers were installed in the cladding system. Have you considered whether a different type of cavity barrier might have made a difference to vertical fire spread, whether through the columns or the spandrels?

A. In the manner that the cavity barriers -- assuming the same insulation was used, ie that the cavity barriers are broken at cladding rails, et cetera, et cetera?

Q. Yes, for example.

A. I wouldn't expect -- no, I wouldn't think there would be any significant difference necessarily.

MR MILLETT: Right.

Mr Chairman, I've got an eye on the clock, which I suppose I should've had earlier. It's 3.20. This might be an appropriate time for a short break.

SIR MARTIN MOORE-BICK: If it suits you, I think it would be a good time.

MR MILLETT: It does. I'm going to look at hypothesis C2 after the break.

SIR MARTIN MOORE-BICK: Professor, we're going to have a short break now. Please don't talk to anyone about your evidence while you're out of the room and we'll come back at 3.30. All right?

THE WITNESS: Okay.

SIR MARTIN MOORE-BICK: Thank you very much.

Good, 3.30, please. Thank you.

(3.20 pm)

(A short break)

(3.35 pm)

SIR MARTIN MOORE-BICK: Sorry about the delay, technical glitch, I believe.

THE WITNESS: No problem.

SIR MARTIN MOORE-BICK: Anyway, ready to go on now?

THE WITNESS: Yes.

SIR MARTIN MOORE-BICK: Yes, Mr Millett.

MR MILLETT: Professor, I'm sorry about that.

Can I, before I go back to hypothesis C2, just ask you a question about the application of water to the cladding.

Was this cladding -- I say cladding -- the rainscreen hydrophobic, in the sense that it repels water as a matter of course?

A. I mean, that's the purpose of it, so, yes, one would hope. Yes.

Q. Therefore, would it matter whether or not a covering jet was applied from above or below?

A. The reason I made a distinction between above and below is because of the nature of the openings in the rainscreen cladding.

So, I mean, I could demonstrate with a figure, if that's a useful thing to do very quickly.

Q. Always useful.

A. If we look at -- I'll find it now -- ah, perfect. So if we look at figure 19 ...

Q. That's page 46 of your report.

A. Page 46, yes.

Just as an example, that's showing the joint between column cassettes, and the point I was trying to make is if you're rain and you're coming down like this -- the reason this joint is configured in this way is to prevent the rain from getting inside cladding, to let air get in to ventilate it. If you're down here spraying up, one imagines you could somehow get some water in behind the cladding. That is the reason for that distinction.

Q. Okay. But in general, the fact is that since the very large majority of this facia is rain-repellent or

water-repellent --

A. It's going to repel water, yes.

Q. -- the actions of the Fire Brigade in external firefighting are -- is this right? -- likely to have little effect?

A. If the cladding system is still intact, in that it doesn't have holes having opened up in it, then yes, I would agree with that.

SIR MARTIN MOORE-BICK: This may be a completely wild idea, no doubt you'll tell me if it is, but if you could get above the fire and put water down the cavity, would that be likely to do any good?

A. I wouldn't want to hazard a guess at that one. One imagines it couldn't make matters worse, but I wouldn't want to say the extent to which it would make matters better.

SIR MARTIN MOORE-BICK: Fair enough, thank you.

MR MILLETT: Right, thank you.

Turning to hypothesis C, can I take you back, please, to the foot of page 178 and the top of page 179 of your report, where you set out hypothesis C. We can see at the top of page 179 what you say there. You say:

"The presence of combustible (PIR) thermal insulation within the external cladding system significantly contributed to the rate and/or extent of

upward vertical fire spread observed at Grenfell Tower."
Can you explain the mechanism by which it contributed?
A. Right, well, it's important to say firstly that that is the hypothesis that I'm testing rather than a statement, if you see what I mean.
Q. It is.
A. I then come later to a conclusion on that statement later in that section.
Q. You do, and --
A. On page 180. But I think it's important to note that those are stated as hypotheses rather than facts or conclusions, if you see what I mean.
Q. You're right, and I jumped a stage, perhaps in my eagerness to --
A. Okay.
Q. -- move on.
A. But the primary physical mechanisms by which I would think the PIR could contribute to -- we're in C -- upward vertical fire spread would be both that PIR is a combustible material, so when exposed to a heat flux that is sufficient to reach the pyrolysis temperature, it will pyrolyse, it will release combustible pyrolysis products. Those combustible pyrolysis products could contribute to an increase in local heat release rate of

a fire.
So the extent to which that pyrolysis will occur and contribute is unquantified at this stage, but that's one potential mechanism that could exacerbate heat release rate and thus accelerate upward vertical fire spread.
Q. Absolutely.
A. The other mechanism is that these materials are very low thermal inertia materials, which essentially means that the surface temperature of the PIR will rise very quickly when exposed to an external heat flux, and that hot PIR surface will radiate heat back at the ACM panels and effectively will insulate the cladding compartment or inside the cladding, and that could cause the -- well, it prevents loss of heat from the system, thus potentially accelerating the upward flame spread, as compared with a backing insulation that is less thermally efficient, ie has a higher thermal inertia.
Again, the degree to which that potential assistance to upward vertical fire spread can be quantified at this stage is not good. Yes, we don't know yet.
Q. On the basis of the mechanics of potential contribution which you've referred to, would the insulation, the PIR, have contributed to the initial heating of the aluminium panels and, particularly, the PE within it?
A. I mean, anything that keeps heat in the system, as a low

thermal inertia material would, will contribute to a higher rate of temperature increase of anything else in the system, yes.
Q. Would it follow from that that if there were no such insulation, or no such combustible insulation, the vertical spread of the fire would've been slower in its initial stages?
A. It's a slightly hypothetical question, but if the cavity were not insulated in any way, it would lose heat more rapidly and, therefore, yes, I would go along with that statement.
Q. Or if it were insulated by something that was wholly non-combustible, if there is such a thing?
A. Well, it's important not to mix ideas here. So the combustibility is related to the additional heat release resulting from pyrolysis and production of combustible pyrolysis products. The low thermal inertia is about heat loss to the system.
So the one situation is about heat production and the other situation is about reducing heat loss, and they're potentially independent mechanisms, so it's important we consider them differently.
So we could imagine, if the backing insulation has a higher thermal inertia, it's less thermally efficient as an insulator, that, yes, there would be additional

heat losses to that system and the vertical progression of the fire would be slowed.
My personal view is that in the context of the presence of the polyethylene, that would be hugely overshadowed by the fact that you have polyethylene in the system which is freely burning.
So, again, and as Professor Torero said a number of times yesterday, this is a hugely complex issue, and quantifying the relative contributions at this stage is very, very difficult, and we hope to do a lot of work at Phase 2 to try to quantify these things. But at this stage, I couldn't say.
Q. Just to be clear about that, is it possible in theory, at least, and for Phase 2 in your work, to quantify the difference between the rate of vertical fire spread with the insulation not burning, not pyrolysing, as opposed to the rate of vertical fire spread with the insulation pyrolysing?
A. Yes. We already have work underway at the University of Edinburgh to try to look at the respective influences of these two issues, contributing pyrolysis products, how that affects vertical fire spread, compared with low thermal inertia and insulating the system and how that affects vertical fire spread, although I should say for cavity cladding systems that, from a research

perspective, are far simpler than what we find on Grenfell Tower.

Q. That leads in, I think, to a related issue.

At paragraphs 877 to 879 on page 180, you refer to a large-scale test carried out by DCLG, as it then was, in the weeks following the Grenfell Tower fire. You say these demonstrated that the use of PIR insulation within the rainscreen cavity did not obviously exacerbate escalation of vertical fire spread, and you explain why.

Then you say at 879:

"It should be noted that the PIR used in these tests was, as far as I have understood from the available reports, protected from direct flame impingement by foil facings or foil tape (i.e. the joints and cut edges were not exposed within the cavity in these tests, as appears to have been the case at Grenfell Tower)."

Just expanding on that, first of all, what in your opinion was the utility of the DCLG tests in determining whether the PIR as installed at Grenfell Tower contributed to the rate and extent of vertical fire spread, given the lack of foil facings we've seen on the edges at Grenfell?

A. What is the utility of the DCLG post-Grenfell tests specifically with respect to the Grenfell Tower fire?

Q. Yes.

A. Simply illustrative, in that what those tests show is that if you have an ACM PE rainscreen, the test, regardless of the backing insulation, escalates vertical fire spread very, very quickly.

I mean, that is really the only reason I've presented that information in this report. Other than that, I would think they don't have much utility.

Q. Are you able to tell whether it makes a difference that the assembly used in that test did not have cut edges of PIR?

A. I couldn't say one way or another.

Q. Do you know whether in those tests the department used a riveted ACM panel rather than a cassette panel?

A. I believe that those were riveted.

Q. Would that make a difference?

A. There is some information -- again, I'm not dealing with compliance in my Phase 1 work -- I believe that we've received to the inquiry which indicates that a riveted system, as regards product classifications under standard testing, I think specifically through the test that we call the single burning item test, that the riveted system performs marginally better than the cassette system. The reason for that, I would presume, is because a riveted system it's riveted through both faces of the aluminium and they're held more tightly in

place, and it prevents them from opening up. But I've not tested that theory.

Q. Okay.

Moving to a slightly different issue, in terms of the state of the building after the fire, when you did your surveys, did you see areas where the ACM panelling remained intact even though there was extensive charring of the insulation behind it?

A. No. No. It's possible; I didn't see it.

Q. Did you see any areas on level 3 where there was widespread charring to a depth and where the damage to the PE was highly localised and more severe on the inner face than on the outer face?

A. The damage to the PIR?

Q. The ACM panelling was more severe on the inner face.

A. I've not observed that, no.

Q. Did you see any evidence low down on the corner columns where soot deposits at the joint in the panels might suggest that the fire was burning internally rather than within the panelling?

A. I didn't see that. Low down at the column tips, there's typically quite a bit of evidence of melted, dripped polyethylene which has solidified in that location. But I didn't see any soot, or at least I didn't notice it.

Q. Your next hypothesis is hypothesis C3 at page 180. This

is continuous vertical channels and extensive internal cavities.

Your conclusion is at 888, I think, which is, you say -- this is page 181:

"888. At the time of writing I am not aware of any definitive evidence that the continuous vertical channels and extensive cavities, which have been shown to exist within the refurbishment external cladding system of Grenfell Tower ... played a role in promoting or accelerating upward vertical fire spread."

Just taking that a little bit slowly, first of all, when you say "definitive", what do you mean?

A. I guess I mean I couldn't say for certain that it plays a role that would significantly accelerate the vertical fire spread.

Q. Are you able to say within a range of probabilities whether the continuous vertical cavities and channels on the columns played a role, some role, in the fire spread vertically?

A. Yes. I mean, yes, I think it's likely.

Q. Likely?

A. I think it's likely that they did, yes. I think I do come to that at the end of that section, 896, I believe. I think I say on a balance of probabilities, given the available video evidence and oral testimony, along with

the known importance of vertical channels, I consider it likely that these features contributed, although I can't quantify it at this stage.

Q. So you're not able to say how likely?

A. I think it's very likely that they contributed to some extent. I think it's almost certain that they contributed to some extent. Whether that's, you know, 1 per cent worse or 50 per cent worse, I wouldn't be able to say at this stage.

Q. So the difficulty you have is not the likelihood of the contribution, it's the extent of it?

A. It's the significance of that contribution to the outcome.

Q. Quantitatively?

A. Quantitatively, yes.

Q. Hypothesis C4, which is prevailing wind, you can reject, and you have.

Hypothesis C5, which is your last one on vertical fire spread, relates to the specific overall geometry of the building, and you cover that at paragraphs 903 and following on page 182, and you explain what the geometry is.

You say at paragraph 911 on page 183 in the pre-penultimate line:

"It is not possible to definitively determine ..."

Well, I'm not sure I picked up the complete conclusion. Perhaps it's 912. You say:

"912. On the basis of the available evidence it is not possible to accept or reject Hypothesis C5. However, in my opinion it is plausible to suggest that the presence of the protruding column 'wing wall' at 135 degrees could have played an as yet unquantified role in promoting rapid upward vertical fire spread. Additional work would be required at Phase 2 to confirm and quantify this."

To what level of confidence are you able to say that the presence of the protruding column wing wall did play a role?

A. Well, the physics at play here is two effects. One effect is that having the fire confined within a corner, even if it's not a right-angle corner, does two things. It changes the way that fresh air is entrained into the fire, which means essentially you're going to get less air entrained into the fire at its base because there's restricted access to the fire because of its confinement. That has an effect of elongating the flame as the flame searches for more air in order to continue burning. So you have flame elongation in a confined area, which would exacerbate upward vertical fire spread, in the same way as confining a flame within

a cavity causes flame extension.

The other effect, of course, is that if you have a flat wall, then the wall looks out and sees the cold world. If you have walls at some angle to each other, then part of what the one wall sees is the other wall, which is hot, and you get a re-radiation effect, which causes the temperature to increase locally, which again will exacerbate vertical fire spread.

So I think "plausible" is not perhaps as strong as I ought to have used. I think it's very likely that there will be some effect, but again quantifying it is the challenge.

I'm not aware of any work in the technical literature that looks at wing walls at angles other than 90 degrees. So the extent to which that is important, I couldn't say at this stage.

Q. Can further work be done at Phase 2?

A. Further work could definitely be done. I have a project planned, yes.

Q. Okay.

Just picking up a couple of points of detail.

Paragraph 906 within the hypothesis, you refer to:

"Column lines that offered continuous and unbroken vertical lines of combustible rainscreen cladding, along with combustible PIR insulation within the rainscreen

cavity (i.e. vertical lines of available fuel unbroken by windows). This created a continuous and uninterrupted vertical 'fuel bed' to support upward vertical fire spread and will have influenced (i.e. increased the propensity for) upward vertical fire spread."

You refer at footnote 56 to section 4.9.1.

Can I take you to page 32 of your report, which I don't think is something we've looked at today. It's figure 8. It's within section 3.1 of your report, professor, and it's a drawing, effectively, from Celotex.

Can you identify where the continuous vertical lines of combustible cladding in PIR insulation are by reference to that drawing?

A. Noting my previously stated colour blindness, I think the pink sections, left and right-hand sides, if they were to continue vertically up and down outside that image, those would be the continuous bands that I'm referring to.

Q. At 907 on page 183 you refer to:

"Spandrel lines that offered continuous and unbroken horizontal lines of combustible rainscreen cladding, along with combustible PIR insulation within the rainscreen cavity (i.e. horizontal lines unbroken around

the full perimeter of the building at all levels from Level 3 and above). This created a continuous and uninterrupted horizontal supply of fuel, capable of supporting horizontal fire spread by a number of routes and mechanisms."

Again, coming back to figure 8 on page 32, can you identify those very briefly for us?

A. Those are the blue sections. And to be fair, they're continuous and uninterrupted only because the columns also provide a means for them to pass by the column, if you see what I mean.

Q. Absolutely.

Finally on upward fire spread, Dr Lane says -- we don't need to go to this unless you want to, it's her report at paragraph 10.4.20 at page 28 -- that the cladding rails for spandrel panels provided a route for vertical fire spread because they essentially bypass the cavity barriers. Do you agree with her?

A. I do.

Q. I can now turn to downward fire spread. You cover that at section 6.2 of your report, starting on page 184.

Is it right, professor, that downward spread, in your opinion, is caused by two things: one, the melting and running downwards of the polyethylene and, secondly, opposed-flow flame spread?

A. Yes, with the first of those being the dominant one.

Q. The melting and running downwards of PE?

A. Correct.

Q. You've defined, I think, opposed-flow flame spread in your report on page 184 in footnote 58. I take it that that is the definition that you're using.

What role, in general terms, did opposed-flow flame spread play in the downward spread of fire in contradistinction to melting and dripping?

A. At Grenfell Tower?

Q. At Grenfell Tower.

A. I think likely to be a very small and potentially insignificant role.

Q. Your view, I think, is that you can see downward fire spread earliest along column lines; is that right?

A. Yes.

Q. That's paragraph 926 at page 189.

Can I just take you through a number of figures from that part of the report, starting at page 190, if we can just jump ahead to that, and start with figure 110. We're going to run through from that to figure 114 over three pages.

If you go through, starting with 110, you say there it's an extract from a video captured at approximately 02.50, and it appears to show dripping material and

downward fire spread at the corner of column A5 and the north face. So that's essentially the north-east corner, is it?

A. Mm-hm.

Q. You identify dripping, burning material there, just hanging down on the right-hand side from the main --

A. Sorry, that's the north-west corner.

Q. North-west corner. It's the north-west corner, is it?

A. Yes.

Q. Okay.

Then you have -- is it the same corner in the next photograph, downward fire spread?

Is one a continuation of the other?

A. Yes. In fact, in one of my videos -- it will be either the north face video or the west face video -- there is video footage of this, which is far more instructive, to be honest, than the images. But the images tell the story, if you like.

And, yes, the two things I would highlight there is that along the right-hand side of that corner column, you see clear downward fire spread. If it was a video, you'd see progression of that fire front down the column.

You also see the lines of light that are on the column. There's sort of one line and then a secondary

line slightly further below at storey heights. Those are the horizontal breaks in the cassettes along the column. And I believe that what we're seeing there is pooling of burning polyethylene on that little shelf that I showed previously in my diagram as the polyethylene drips down inside the columns.

Q. So just on this picture, if we could point that out.

A. Yes, sort of here and here (Indicates). And you see it actually on every column on the building where we have video evidence, you see this occurring. You see these lines light up ahead of the obvious external fire spread, and so you have this progression of the dripping polyethylene down, and it pools locally on horizontal surfaces within the building that could be these little shelves that you get at the junctions. It could actually be on top of cavity barriers within the system, which essentially provide shelves inside the cladding system, and I believe that's one of the key mechanisms of downward fire spread.

Then you have a locally burning pool fire of polyethylene which could heat the material here in these cladding cassettes, melt them, and then a progression further of the polyethylene down the building.

Q. Before we leave that picture, you can see some way below where the downward fire spread arrow is pointing,

there's another bright pinpoint of light, do you see?
A. Just here?
Q. There, yes. What is that?
A. It might just be falling debris. It's hard to say from a still. We could look at the video, I suppose.
Q. Moving on to the next figures, 112 and 113 on page 191, again, you could see dripping burning material in both of those pictures, falling and landing on window details. That's what you say in relation to figure 113.
Again, can you point anything specific out from there about how it is that that burning, dripping material is actually spreading fire?
A. Yes. I mean, it's actually, I think, a very important point. We see this inclined front of the flame here -- I mean, it's also interesting to point out that after that very bright line passes, we see much less flaming. We have compartment fires burning within these fires now, but we see dark patches on the cladding, which does go to this question of the extent to which the backing insulation is still contributing once the polyethylene has burned out of the rainscreen cladding, and indicates that not so much would be the answer to that question.
But nonetheless, we have this diagonal line here. The bits that we've circled here, again, if this was in a video, what you would see is material falling down,

landing on either the windowsills or, in cases where the cassettes have disappeared, on top of cavity barriers and forming these localised pool fires, which then cause generation of energy up and further fuel this diagonal line.
But the key thing I wanted to mention was if we imagine that this diagonal line stays a diagonal line, which is what we do observe when we watch the progression of these flame fronts or fire fronts across the face of the building, if it starts here at the top corner, which is where it does start based on the images we looked at a minute ago, we could imagine that diagonal line just moving down like this (Indicates), and the consequence of that would be an apparent lateral -- because it's a diagonal line just moving down, right?
We could also imagine that that line goes like this (Indicates), and it would look just the same.
So the question is: how much of a lateral fire spread is that, which is opposed-flow along the spandrel panel; how much of the lateral fire spread is that, which is dripping, burning polyethylene?
Clearly, it's some combination of those two. My view is it's predominantly this, the dripping and melting.

Q. What enables you from this or the other photographs we have been looking at to form that view?
A. It's a combination of the fact that opposed-flow fire spread on the spandrel panels would be quite a difficult thing to have happened, because these are aluminium-coated polyethylene rainscreen panels, so they tend not to spread fire laterally unless there's some other factor at play.
Opposed-flow fire spread in a lateral sense relies on there being fuel ahead of the flame front, and it relies on there being energy getting to the fuel ahead of the flame front. If you have a burning ACM PE cored rainscreen panel, there's two questions you have to ask. The first question is: where does the energy go? The energy goes mostly up. The second question you have to ask is: where does the fuel go? And the fuel goes mostly down. Granted some of the energy goes with it because it's burning.
So if your energy goes mostly up your fuel goes mostly down, you're not left with much to cause lateral. Right?
That combined with the fact that when we observe the video, in particular the thermal imaging video from the helicopters, the NPAS videos that were taken on the night, when they switch to a thermal imaging filter in

those videos -- hopefully we'll have a chance to see some of it -- it is really striking the amount of hot burning debris that is falling down this building which is not visually obvious when you look at an optical view. When you look at thermal imaging, it's like a waterfall of molten, burning material falling off the side of this building, contributing to heating of the cladding above the flame front.
So on these two bases, I think it's far more likely that the lateral is this diagonal line moving down rather than sideways.
Q. You have set out a number of hypotheses for downward fire spread, downward vertical fire spread, starting on page 197, and you've got essentially three hypotheses: D1, D2 and D3.
Starting with D1, if I can, at the top of page 198, that is:
"The downward vertical fire spread observed at Grenfell Tower was primarily due to the presence of aluminium composite (ACM) rainscreen cassettes with polyethylene (PE) filler material."
Your conclusion about that is to be found in the paragraph immediately below it at 948, where you say that it's considered to be the dominant and decisive factor contributing to downward vertical fire spread.

That's clear enough.
Can I ask you whether you formed a view about whether the Aluglaze panels contained in the infill panels and the panels supporting the extract fans contributed as a source of melting and dripping material contributing in turn to downward fire spread?
A. I think it's possible, but I think that the potential is, in comparative terms, quite small. I will base that opinion on two key arguments.
The first would be that, as I've already discussed, when XPS is exposed to a heat source, it tends to shrink away from the flame and then burn in situ. It is capable of forming a pool fire under the right conditions, but in small quantities, heated quite severely, I would expect it not to necessarily do that.
Indeed, the PowerPoint presentation we have from the LFB about the Shepherds Court fire, that shows some experiments done by Bureau Veritas in the wake of that fire to look at panels that have the same -- at least it appears to be the same, it's a blue XPS insulation. In that case, they actually do set alight some panels and they don't see pooling, but they do see shrinking away from the flame.
For that reason, I would say probably not that substantial an effect.

The secondary reason is that the XPS is 25 millimetres thick, but it has a density that's almost an order of magnitude less than the PE, and it's only present, as Dr Lane has said, over 13 per cent of the exterior of the building, as opposed to something more like 70 per cent for the ACM panels.
So the mass of material is a fraction of the mass of PE present, its heat of combustion is less by about 10 per cent than PE. So we have less of it, it has less heat of combustion, and it tends not to form pool fires when not in large quantities.
So for that basis, I would say -- I mean, clearly it's going to contribute, but I think it's probably small and negligible.
Q. Turning to your hypothesis D2, that's on page 199 at paragraphs 952 and following, you say there, and I summarise, that the exposed edges of the PIR insulation may have contributed indirectly to downward fire spread, but you say there's no "compelling evidence" that it played a role. That's paragraph 957.
A. Yes.
Q. If we have that up on the screen, "no compelling evidence".
I think you go on to say that it may have played a minor role by insulating or heating within the cavity.

We've covered that before.
Is that the same mechanism --
A. Same idea, yes.
Q. -- we saw in relation to vertical?
A. It's keeping heat within the system, which has to do something, and that would just accelerate the downward -- yes.
Q. Hypothesis D3 at the top of page 200 is the continuous vertical channels and extensive internal cavities contributing to downward fire spread. You cover that at paragraphs 958 to 962 there on that page.
Is your conclusion there that it's likely that downward fire spread would have been somewhat slower, as you say at 962, had these channels and extensive internal cavities not been present, confirmed by your visual evidence?
A. Yes, it is. Yes. So there is extensive evidence at Grenfell Tower of solidified polyethylene in the locations of those cavities that has dripped down from above to the cooler parts of the building near the base, and you have large quantities of polyethylene in the base of the building in those locations, which is fairly compelling evidence.
MR MILLETT: I want to turn to horizontal spread and the crown, if I can.

I am going to show you a little bit of video.
Again, I should repeat the trigger warning. This is very much this building, very much on fire, and a lot of people might find that distressing. There is also audio that goes with it. Again, people might find that distressing. So if they don't feel they're up to seeing it, they should either leave this room or remove themselves from the live stream.
This is video 4, Paul.
I'm going to ask you to pause if you think there is anything we should be looking at. This is in the context of horizontal spread and, particularly, the crown contributing to fire spread.
We can start at 5.29, or 5.30.
Mr Chairman, I think we should start now.
SIR MARTIN MOORE-BICK: Yes, I think that will be all right.
(Video Played)
A. Stop it there, Paul.
Yes, this is just a video showing that still that we looked at a few minutes ago, where you can clearly see the burning material dropping down the right-hand side of that corner column, this being the north-west corner. You can see the formation of these bands of light at the junctions between the columns, and hopefully this is one part of the video where we actually observe that

progression, but I couldn't say if it is for sure.
Go ahead.
(Video Played)
Okay, so this --
Q. This is some NPAS video footage.
A. Yes. Thank you for the pre-emptive stop, Paul.
So, yes, this is some of the NPAS image where it appears they're using some kind of thermal imaging filter here, night vision, and it's just instructive, I think, to look, as this video progresses -- obviously the regions that are burning appear to have saturated the filter because they're so hot, but you can see the amount of hot debris that is falling from the tower, which really, I think, supports this idea of the downward mechanism.
Q. Right. Do you want him to continue?
A. Yes, please -- well, I guess the other comment I would make here -- it's not so clear here, but you can see that the furthest extent of progression of this fire is along the crown on the west face. So the furthest horizontal progression as we move around the building as the fire progresses in all five of the videos that I've produced demonstrates that the fire progression around the building, both clockwise and anticlockwise, if you're looking from above, is at the crown, and that the

bit.
(Video Played)
I think we've probably come to the end of what may be useful for you to comment on, but if there is anything else in these sequences that you think assists illustrating horizontal spread, particularly at the crown --
A. No, I think what I commented on previously says it all, but the hypothesised mechanism at the crown is probably worth restating, that those crown elements burn and spread fire preferentially and create what is essentially a fuse around the top of the building. The mechanism is they burn, they drip polyethylene onto the coping directly below them, formation of a localised pool fire which progresses laterally, ignites the next crown elements and progresses around the building.
Q. Yes, thank you.
The other thing to pick up here is that you say in your report at page 238, moving ahead significantly in it to the end -- well, to the beginning of horizontal fire spread hypotheses, and you have a number of hypotheses, under E. At paragraph 1114, you say:
"1114. It is worth noting that, under normal conditions, upward spreading fires and fire plumes tend to spread outward as they travel upward. This is

rate of that spread is actually reasonably consistent throughout the duration of the fire. So it's almost like a linear fuse moving around the top of the building.
Q. Shall we continue and see if we can see more of that.
(Video Played)
Don't need that one at all.
Can we then go to 7.07. Let's move on to the next sequence, sequence 4.
Just tell us if there's anything you want to point out here.
(Video Played)
A. Any time here.
So, yes, here you get a nice close-up view at the level of the crown. It's hard to see, but you see the sort of vertical lines. These are the vertical elements of the crown. You can see that the crown itself is burning, and beneath the crown you have what appears to be, to my eye, a pool of polyethylene which is melting on the coping element that sits directly beneath the crown.
Q. Is that the leading edge of the flame front on that face at that point?
A. It is at that point in time, yes.
Q. Shall we continue to see how that progresses a little

because the heat and smoke, which travel upward from a fire, form an inverted cone that widens as it rises due to entrainment of fresh air into the fire plume."
You say that results in a characteristic V-pattern.
Is the spread at the crown simply an example of that V-pattern or is it different?
A. No, I mean, I believe that what is driving the spread at the crown is the lateral progression of the pool fire beneath it. Yes.
Q. Not the inverted cone effect from vertical spread?
A. No. If that were the case, then I would've expected the way we observe fire to progress around the building to be different than it is. I would've expected vertical fire spread up the east face to be more of a cone in the first place. Yes.
Q. Turning to your hypotheses -- I think I can take these quite quickly -- E1, paragraph 1115, page 328, is it right that your hypotheses are not as well developed in relation to horizontal fire spread as they are in relation to upward and downward spread?
A. The hypotheses are not as well developed? I think we have more of them because there were more things we wanted to just make sure, or rather I was -- many ideas were popping in as to what could be causing this lateral.

I mean, it's worth noting that, I think as Professor Torero said yesterday, the Grenfell Tower fire is quite unusual in the context of lateral or horizontal fire spread, in that when we've seen other fires in buildings that have similar rainscreen materials, we tend not to see the entire building engulfed. So the question is: why has that happened at Grenfell Tower?

The distinguishing feature appears to be the crown, but I wanted to make sure that I looked at every possible option. That's why we have a large number.

I'm not sure I'd agree they're less developed. I think it's such an unusual mechanism that I'm proposing, or hypothesising, in that it's not something we see every day. Upward fire spread on combustible material is pretty straightforward. Downward fire spread by burning dripping thermoplastics is pretty straightforward. This lateral mechanism is, if you like, a unique situation which is a consequence of the architectural features of Grenfell Tower.

So it's the fire spread mechanism for which I certainly want to do a lot more work at Phase 2 to make sure we interrogate that and test that hypothesis to show whether or not that is the dominant mechanism, as I believe it is.

Q. I think your initial assessment, at least at this stage,

perhaps subject to further work, is that the dominant cause -- your phrase -- of horizontal spread was a combination of pooling of melted and dripping polyethylene, and also the tendency of fire plumes to widen as they move upwards.

A. A combination of those two.

Q. Are you able to give us any quantification as to which is the dominant of those two?

A. Well, in the absence of the melting, dripping and pooling, the upwards wouldn't matter. So, you know, the upwards spreading is almost a consequence of the downward spreading.

Q. Dr Lane says that the horizontal spread would also have occurred across the exposed edges of polyethylene on the spandrel panels. Do you agree with that?

A. Again, that would be an opposed-flow fire spread mechanism on a fuel in a horizontal direction. As I discussed earlier, the important question there is: where does the energy go and where does the fuel go? And on the basis of my answer, you probably got a sense that I don't think that's a particularly important mechanism in this case.

Q. As to hypothesis E2, which is paragraph 1126 at page 239, I think your conclusion is that, in theory, PIR could contribute to the spread of flame, but you

can't quantify the extent of that contribution. Is that a fair way of summarising your view of that hypothesis?

A. I think it's possible, but I've no evidence to suggest that it did.

Q. Are you able to express any view now on the extent to which the presence of PIR contributed to the horizontal spread of fire?

A. Not in any quantified way, no.

Q. Dr Lane's view is that, at least at an early stage, the presence of cut and exposed PIR edges in the cladding structure along the spandrel panels may have supported horizontal flame spread. Can you agree with that or not offer a view?

A. I think it's possible. The thing that is important to recognise about that is that in order for flame to spread in an opposed-flow mode horizontally, even on a PIR, Celotex specifically, that isn't protected with a foil facing, ie at a cut edge, you need a significant external heat flux that is sustained. So in the absence of a significant external heat flux causing it to continue progressing, which means you kind of already need a fire already there, you're not going to see that. The lateral fire spread on PIR in the absence of an external heat flux will stop, generally.

Q. Hypothesis E3, page 240, paragraph 1135, that hypothesis

is that continuous vertical channels and extensive internal cavities present in the structure contributed to the rate of horizontal fire spread.

Your opinion is -- I think this is 1135 -- it was not likely.

A. I mean, not directly, although obviously indirectly as a consequence of having influenced both the vertical, upward and downward.

Q. Is there any evidence that cavity barriers were at all effective in initially preventing horizontal fire spread prior to the point at which the fire reached the crown?

A. Not that I'm aware of, no, and indeed, as I've mentioned, I think there is evidence that after the fire fronts had passed a particular level on the building, whatever polyethylene was remaining tended to form pools and burn locally on top of the cavity barriers, potentially making matters a bit worse.

Q. We can see hypotheses E4 and E5 and your conclusions about that. E4 you reject and E5 is about the architectural crown, and you've explained the role already that you say it played in relation to that.

There's also a hypothesis E6, which is the contribution made, if any, by the aluminium and XPS composite window infill panels, and I think your conclusion there is that they played a role but you

can't quantify it. I'm summarising perhaps inaccurately, but is that a fair description of your view about that?

A. This is with reference to the infill panels?

Q. Yes.

A. Yes, I mean, the infill panels, as we've discussed, they have fuel in them that is combustible and can burn. So in a fire that's progressing laterally, I would expect that fuel to become involved somehow and contribute. But, yes, quantifying it, I couldn't do that at this stage.

Q. Dr Lane says -- for reference purposes, it is page 31 of part 10 of her report at paragraph 10.5.9, this is her pathway C -- that these panels connect to the other combustible materials at the head and the sill of the window and, therefore, provided a route above and below for horizontal fire spread.

In reaching your own conclusion on hypothesis E6, did you take that view into account?

A. Yes. But, again, it seems to me that that would require what is effectively, again, an opposed-flow lateral fire spread mechanism, and for the same reasons that I think it's unlikely on the ACM panel, which is a combustible material with two aluminium skins, I think it's unlikely to occur on an infill panel.

Q. Given the way you've already described XPS behaving, which is in a different way, with a higher ignition point, I think, than polyethylene, would that also mean that you think it's unlikely that that would've been a route for horizontal fire spread?

A. To call it a route for horizontal fire spread is not something that I would --

Q. Mechanism?

A. -- confidently state. I think when the infill panels get hot, the foam inside them will potentially pyrolyse. That will release flammable pyrolysis products. Those products will burn if there's a fire around.

What the consequences of that are for a lateral fire spread mechanism, I couldn't say. I would expect them to have some influence, undoubtedly, but I wouldn't be able to quantify it, but I wouldn't suggest that it's a significant one.

Q. Very well. Very good.

Can I finally turn to the last topic, which is spread back into the building. Just one or two questions about that.

You've covered that at part 7 of your report at page 253, under section 7.3, "Possible Routes of Fire Ingress".

You've identified from paragraphs 1167 to 1172, five

possible routes for ingress of smoke and fire back into the building.

My question is: are these set out in any order of likelihood?

A. The five routes --

Q. Yes. So it's page 253. 1168, open windows; 1169, extract fan units; 1170, pre-existing gaps.

A. No, they're not set out in any order of likelihood, but throughout the following section, and in particular on the basis of evidence from the bereaved, survivors and residents, the conclusion that I get to on this -- incidentally, that evidence is very helpful in this regard -- is that it would appear the routes of ingress depend on the nature of the fire spread that is adjacent to the flat.

So early on in vertical upward fire spread, where the fire is still quite small, then the ingress routes are related to the extract fan and the window construction, and we have comments in the witness statements to that effect, in particular associated with the extract fans and early failures of the extract fans.

As the fire grows and becomes large, as Professor Torero said yesterday, glazing is actually not that resistant to high heat fluxes, and we have comments from certainly in the flat 6s as we move up the

building, as the fire is growing, people refer to their windows exploding inwards quite suddenly with very little warning and prior to failure of the extract fan.

So the ingress routes depend on the mechanism of upward. As the fire is larger, the mechanism changes. And whilst I haven't looked at the witness statements as regards the ingress during downward or lateral fire spread yet, my expectation would be, again, as Professor Torero commented yesterday, that the construction around the window and the influence of the extract fans would be more important, because the downward spread mechanism is locally a smaller fire with lower heat fluxes than the very large heat fluxes you get in the vertical upwards spread with a big fire plume.

Q. Yes. Thank you very much.

I think you summarise that effectively under section 7.5. There's a section summary at paragraphs 1204 to the end of that section.

A. Yes.

MR MILLETT: Professor, you'll be glad to know that I've come to the end of my questions, with 2 minutes to go before 4.30. I'm going to do what we customarily do, which is to ask the chairman to rise for a few minutes to see if there are any questions I have not asked this

afternoon which I should be asking. So if I can do that, that would be helpful.
SIR MARTIN MOORE-BICK: Yes. If you don't mind, we'll keep you a little bit longer and have a 5-minute break to let counsel take stock and see if there are any more questions. All right?
Would you like to go with the usher now and we'll keep this as short as we can.
(Pause)
I'm going to say 5 minutes Mr Millett or sooner if you can do it sooner. Thank you.
(4.30 pm)
(A short break)
(4.35 pm)
SIR MARTIN MOORE-BICK: All right, professor, I think there will be a few more questions, but before we continue, can I just remind everybody that there will be a routine fire alarm test at a 4.45. The announcement will tell you not to take any action, and that's quite right. Just be aware that that is going to happen, but just ignore it.
Yes, Mr Millett.
MR MILLETT: Mr Chairman, thank you.
Professor, one or two further questions.
First, I want to ask you about the failure of the

aluminium window frames.
When you were doing your work leading to this report, did you consider whether there was any evidence which showed that aluminium frames had failed?
A. Not in the early stages of the fire as would be relevant to the fire spread.
Q. Let me show you something. Can I please ask the witness to have up MET00010867, which is the witness statement provided to the police by Daniel Brown, Firefighter Brown, MET00010867.
I'd like you to be shown, please, page 10 of that.
In the second from last paragraph -- this is Daniel Brown's statement, he was in the first pair into flat 16 -- he says:
"I realised that where I had seen the curtain of flame was in fact where the window had been. The window and frame were no longer there and it had completely dropped out, leaving a hole in the wall. I carried on following the line on the ceiling to above the fridge and then noticed in the corner of my eye an orange ember fall outside the window area so I looked out of the window to investigate what this was."
He gives evidence that the frame had dropped out.
Does that tell you anything, does that affect your view of the means of egress of this fire from flat 16?

A. I mean, I'm reasonably certain the frame hadn't dropped out.
Q. He says it did.
A. I'm reasonably certain that it's still there after the fire. We should have photos to confirm that.
Q. Right.
A. I'm reasonably certain that the aluminium window frames of flat 16 are still there. So the entire frame has not drop out.
Q. On hypothesis, let's assume for the moment that the chairman were to find that it did, as a matter of fact, how would that affect your view, if at all?
A. How would it affect my view?
Q. Of the means of fire egress from the compartment?
A. Does he say at what time --
Q. This would be after 01.20.
A. Then it wouldn't affect my view.
Q. Right. Then it may not help that I ask this next question, but I'll ask it anyway.
You say in paragraph 386 -- I won't take you back to it -- that the windows used in Grenfell are constructed from an extruded aluminium profile with polyamide thermal break built into the frames.
Is that material something which melts at a much lower temperature than aluminium?

A. I haven't looked recently at the specific properties of polyamide, but it tends to be a polymer that has better than typical thermal performance. In fact, I believe their product sheet states that the reason they use polyamide is so that they can have a thermal break prior to coating, which involves elevated temperature processing. But I think certainly that temperature is below the 600 and 660 that we would expect for aluminium, yes.
Q. So if it has a polymer in it, and it melts, do you consider that the window frame would fail at a temperature lower than the normal temperature for aluminium, which is 660 degrees centigrade or so?
A. It depends what we mean by fail. So it depends what role the polyamide thermal break is playing from a mechanical perspective within the window frame. I wouldn't be familiar enough with the system at this stage to say if loss of that thermal break would cause a mechanical failure of the window frame. It's possible but, again, I'm speculating. It's certainly something I'll look at on the basis of that question.
Q. Can I please ask you to be shown your first clip and go to 01.12.
This is a question which I've been asked to ask you about jets.

The reason I've been asked to ask you this is in your evidence in July you said there was evidence of water being applied by jet at 01.12. I just want to look at the video just to be precise with you exactly what you were and maybe still are talking about.

A. I think -- at 01.12?

Q. At 1.12.

A. I hope what I said is that there's evidence of water on the ground at 01.12.

Q. Usual trigger warning, possibly seeing fire on the building, although this clip isn't supposed to.

Can I just wait 10 seconds and then ask the question.

Can we please be shown the clip at 01.12. Start at 01.120.00, please, Paul.

(Video Played)

Did you see any evidence there of the application of water at 01.12?

A. No. I mean, I think what you're referring to is there does appear to be water on the ground below flat 16 at 01.12.

Q. Yes.

A. There's two -- in my mind, this is something that I've considered at some length in looking at the issues we discussed previously with respect to the potential jet

at 01.11.

One explanation is that it's my understanding that when a hose is charged, it's not uncommon for a firefighter to just give it a quick spray to test that everything is fine as it should be before they start their deployment. So it could be that that is the reason for that water being on the ground at that time.

The other possibility is that there is, I believe, evidence of burning debris on the ground prior to 01.12, and it's conceivable that the firefighters who were on site there decided to put that burning debris out, as we no longer see it burning here at 01.12 and that is the reason for the water on the ground at 01.12.

So, yes, I've considered it at some length and those are the two explanations I can come up with.

MR MILLETT: Professor, thank you very much. Those are the extra questions I had for you.

It remains for me to say thank you very much to you for coming along today to assist us with our investigations and give your evidence. We're extremely grateful. Thank you.

SIR MARTIN MOORE-BICK: I'd add my thanks to those of Mr Millett. We're really grateful to you for putting your expertise at our disposal. You've produced some very substantial reports and you've explained them all

very fully. I, for one, found it very interesting and helpful, so thank you very much indeed.

THE WITNESS: Thank you, sir.

All right. Now you're free to go and the usher will look after you.

(The witness withdrew)

MR MILLETT: Mr Chairman, just before 4.45, that is the business for the day.

SIR MARTIN MOORE-BICK: Yes, thank you very much. 10 o'clock tomorrow, then, please

(4.45 pm)

(The hearing adjourned until Thursday, 22 November 2018 at 10.00 am)

I N D E X

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