Grenfell Tower Inquiry

Day 68

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(10.00 am)

SIR MARTIN MOORE-BICK: Good morning, everyone. Welcome to today's hearing. Today we're going to hear a presentation by Dr Barbara Lane on testing materials.

MS GRANGE: Yes, Mr Chairman. Before Dr Lane comes in, I was just going to introduce what she was going to cover. She is going to explain the national testing and classification regime, including what is meant by class 0. She is also going to explain the European testing and classification regime, and also the large-scale testing which occurs under BS 8414, parts 1 and 2, and classification to BR 135.

It will be an oral presentation only and not a question-and-answer session.

Before she starts, I do need to give a trigger warning about the presentation and some of its content. There are included within the presentation some images and videos of fire scenarios, and also included are some images of Grenfell Tower on the night and when on fire, and some images of the damage to Grenfell Tower inside, taken afterwards.

So it's important to give that trigger warning for anybody who's watching and who would prefer not to see such material.

SIR MARTIN MOORE-BICK: Thank you very much.

MS GRANGE: So if I can now invite Dr Lane to come in, to be sworn in and to give her presentation.

SIR MARTIN MOORE-BICK: Thank you.

DR BARBARA LANE (sworn)

SIR MARTIN MOORE-BICK: Thank you very much, Dr Lane. Good morning, it's nice to see you again.

DR LANE: Thank you.

(Pause)

MS GRANGE: Yes, Dr Lane, if you would like to go ahead and give your presentation. Thank you.

SIR MARTIN MOORE-BICK: Thank you very much.

DR LANE: Okay, thank you.

Presentation

DR LANE: Good morning.

Throughout Module 2 of this Inquiry, regular reference will be made to the products used to create the new external wall during the Grenfell Tower refurbishment. Various fire performances will be referenced throughout the evidence. Various reaction to fire tests will also be referenced. Phrases such as "national classes" and "national testing", as well as "European classes" and "European testing", will become very familiar in the coming weeks. In my presentation today, I will explain what those classes mean and how

they were derived. I will also explain the reaction to fire tests upon which those classes rely.

Reaction to fire tests are a particular form of fire test used to characterise the performance of construction products. The Approved Document B refers to reaction to fire tests, national classifications and European classifications, when setting out the performance of products for use in external walls. It is by means of national and European classes the guidance document states that provisions are made to restrict the combustibility of external walls of high buildings.

Also, as stated at section 12.2 in the guidance documents, these are the provisions to reduce the surface's susceptibility to ignition from an external source and to reduce the danger from fire spread up the external face of the building.

It is critical to understand the difference in definition for each class, and the different reaction to fire tests associated with each class. This complexity lies at the heart of accurately communicating external wall performance in fire as presented in section 12 of the Approved Document B.

This is a technically complex subject, with many different fire tests, classes and definitions. It means

there is a precision needed when communicating the provisions made in the statutory guidance document, and so when considering the external wall products used at Grenfell Tower.

In general, my presentation relies exactly on the text provided in the relevant British and European Standard. Details most useful to wider activities within the test lab I have omitted, as I do not consider them relevant to the explanations I am giving here today. But they can be found in the reference documents, and I have provided those references on the slides as I progress.

As part of my work for this Inquiry, with technical assistance from Tom Parker, who is here with me today, I have carried out research into the history of these tests, classes and their definitions. I have also analysed how they have been presented over the years in the Building Regulations and the approved documents.

The statutory guidance document, Approved Document B 2013, was approved and issued by the Secretary of State for the purpose of providing practical guidance with respect to the requirements of the Building Regulations 2010 for England and Wales. My presentation focuses on this version and earlier versions; it does not deal at all with any changes that have occurred since the night of the Grenfell fire.

I have structured the presentation today into four main sections. In doing this, I will therefore explain in detail the eight reaction to fire tests referred to from within ADB, as well as the two larger-scale cladding tests referenced there also.

In each section, I will show various images and movies, and Tom Parker will also present the to-scale models we built at Arup of the specimens used in the eight reaction to fire tests.

We do not have the large cladding test samples due to their scale, and so I will show images and movies of those cladding tests only.

After I explain some classic fire behaviours and how those behaviours were observed at Grenfell, I will then explain the four national reaction to fire tests and the definitions then used when setting out the national classes relied upon within Approved Document B. I will show how these definitions have been relied on since 1965, and significant changes made to those definitions in that time.

In section 2, I will explain the four European reaction to fire tests, the European classification criteria, and the resulting European classes relied upon within Approved Document B.

I will explain the importance placed on the relevant field of application for products tested using European reaction to fire tests.

I will set out how European classes are referred to from Approved Document B, and then address some issues regarding equivalency when comparing the European classes with the national classes.

Finally, in section 3, I will provide a summary description of both the performance criteria given in the BRE Report 135, which considers cladding systems, not individual products.

I will also explain the full-scale tests and data produced from the fire tests called British Standard 8414, parts 1 and 2. The data obtained from these tests is assessed using BR 135, then a classification report can be produced for the cladding system tested.

I will explain earlier versions of these publications also, and how they have been referenced from the statutory guidance documents over time.

The first thing I will present to you today relates to the basic science of fire in a compartment or room.

A fire is characterised in a series of discrete stages for the purposes of scientific calculations and understanding, and it is very useful to understand those stages and how they relate to the reaction to fire tests

I'm setting out for you today.

I thought it was useful to explain in brief how fires behave in compartments or rooms, because of what is stated in British Standard 476-10. British Standard 476 contains a series of fire tests, four of which I'll be explaining in detail today. They are the four national reaction to fire tests. Part 10 of this standard examines the principles, objectives and outputs of fire testing in the BS 476 series, offering guidance on selecting appropriate test methods.

It states:

"Reaction to fire tests are used to characterise the performance of construction products and/or materials in terms of their contribution to the initiation and growth stages of a fire, leading up to flashover.

"The underlying philosophy is that, if a fire starts, its rate of growth should be such that there is adequate time for the building occupants to escape to a place of safety without being injured."

I will summarise the discrete stages of a fully developed fire in a room or compartment in the next few slides. This is a highly complex area of fire science and I make no attempt to cover the subject in depth. My intention is to provide an overview of the classic behaviours upon which fire science relies.

After ignition, the fire is typically initially small. Here at the three-second photo, from an experiment carried out in the USA by NIST, it is burning with visible flame. It then grows in size at shown at the 18-second image and the 32-second image. This is the result of flame spread over the item first ignited and spreading to nearby objects if sufficient oxygen is available.

At some point, due to the enclosure surrounding this localised fire and the available ventilation to that fire within the enclosure, those parameters influence further fire development, and so the power of the fire increases with time.

This graph represents the course of a well-ventilated compartment fire, expressed as the rate of heat release as a function of time within that compartment.

The internal compartment fire shown here is mostly divided into three substantial phases after ignition, but also incorporating a short transition phase called flashover.

So looking at the graph from left to right, after ignition, which occurs when fuel, energy and oxygen are available in sufficient quantities to initiate combustion, then we see the growth period on the graph.

This is flaming combustion leading to the ignition of additional fuel if sufficient oxygen is available. Then flashover can occur. During the growth phase of a fire, the thermal energy within the room increases to a point at which there is rapid ignition of the remaining unburned fuels, provided there is sufficient oxygen.

Afterwards is the fully developed fire phase. Now the energy release is at its greatest in the room or compartment.

Then decay, as the fully developed flame starts to run out of fuel or oxygen.

Flashover is, therefore, an important indicator of the onset of a fully developed fire and only occurs if there is sufficient air.

I recommend the Drysdale reference for a more detailed understanding.

Please watch this short video of an internal compartment fire growing.

(Pause)

I think I'll have to move on. It was meant to be connected to the internet.

It's from the helmet-cam of a firefighter in a room as a fire grows rapidly.

I wonder, is there a way of getting the movie to work? It would be very helpful, yes.

Yes, here we go, thank you.

(Video played)

Watch how quickly the fire takes hold of the stacked timber in the corner and forms a smoke and flame layer at the ceiling within the room. The flame spreads across the ceiling, seeking out ventilation along the corridor. The smoke and flame layer build down to floor level. This room contains very little combustible material, and so a prolonged, fully developed fire cannot occur.

So back to BS 476-10. It helpfully sets out what tests in the 476 series are relevant in the context of the classic room fire stages I have just summarised for you. It places the reaction to fire tests as relevant to the period of time before flashover. Flashover is marked with an X on this graph, and the reaction to fire test references can be observed in the red marked area underneath flashover.

The reaction to fire tests referred to for the external wall in the statutory guidance document are therefore associated with pre-flashover or early stage internal room fire growth. There are other tests referenced by the British Standard for the post-flashover condition, after the X marked on the graph here.

But what of reality, as we saw at Grenfell and have seen elsewhere? I will now use some photos from the Grenfell fire for the next five slides.

We know that the fire spread from the external wall back into many flats that night, then caused a fully developed fire, consuming everything in the room, the result of which I have shown in the photo here, and the fire curve representation of this fully developed fire is marked in red.

We know there was a prolonged decay phase, in that it occurred at different times in all different parts of the tower. In this phase, the rate of burning is diminishing, the fuel is depleted of volatiles, the gases formed when something is heated in a fire. Flaming eventually ceases, and this stage leaves a mass of glowing embers. This state may remain for long periods, and there can even remain high localised temperatures. Again, this behaviour is concerned with the performance inside the building.

But we know, too, that there were different types of internal fire. There were localised fires that night, of a scale as I presented in the earlier NIST experiment and shown on the left here, and as seen for example at flat 16, the image here showing the internal localised fire. But in this photo one can also see some external

flaming, despite this room fire still being in its early growth phase only, represented by the red area on the graph.

We know, too, that flashover did occur in many compartments, and so fully developed fires were observed throughout the night. The scale of these post-flashover fires or fully developed fires are much larger and their consequences more severe than the pre-flashover conditions.

Flames may emerge from ventilation openings, such as windows; the threat to neighbouring compartments or adjacent buildings is then at its highest. The fire can spread through any internal openings, such as doors or unsealed openings in the compartment, so this is the stage of the fire when damage to structure becomes a concern. It is the time of highest life safety risk to firefighters, and it is too late for anyone who has not already left the compartment.

But what about the external wall fire scenarios?

We know that early in the night at Grenfell, and shown here at 01.26, an external fire event in the external wall had occurred. In the beginning it was localised and external to one compartment, and then rapidly spread externally up the tower.

I hope, Mr Chairman, the panel can consider the following point: this external scenario, either when small or large, was separate to the internal room fire. This internal fire behaviour is characterised by the temperature time graphs I've shown you today. The external fire scenario is not the same as the early stage fire behaviour in a room. The external fire is not controlled by the room enclosure or room ventilation phenomena that cause classic room fire behaviours. Yet the statutory guidance document relies on reaction to fire tests for internal rooms. BS 476-10 states they are used to characterise the performance of construction products in terms of their contribution to the growth stages of a fire inside a room, leading up to flashover only. But pre- and post-flashover are not external fire phenomena; they are internal fire compartment phenomena. But every reaction to fire test I explain today was apparently created to characterise performance in an internal room fire.

The tests are not deemed to be representative of external fire behaviour if one relies on the British Standard explanation in itself. It will be useful to understand why, therefore, they formed such a fundamental part of the external wall fire performance set out in Approved Document B.

Throughout today you will also hear what those tests

do demonstrate regarding the fire performance of materials and products, and this is to assist you in your deliberations.

There are eight reaction to fire tests referenced within Approved Document B. There are four national test standards, and four European test standards. The national tests from the British Standard 476 series are parts 4, 6, 7 and 11. The European tests are not in a series and are four distinct tests: BS EN 13823, BS EN ISO 1716 and 11925-2, and BS EN 1182, where "EN" means European norms and "ISO" means International Standards Organisation.

I will now explain the set-up for each one of these tests, how the test is then done, and how the results from each test is then used and relied upon to classify the performance of construction products and materials.

The four national reaction to fire tests are part of the BS 476 series, as I said. Each part addresses a different element of contribution in a fire. Part 4 is the test of non-combustibility for materials. Part 6 is the test of fire propagation for products. This means a comparative measure of the contribution to the growth of fire of a combustible material. Part 7 is a test to classify the surface spread of flame of a product. Part 11 is a test to assess the heat

emission from materials.

British Standards are issued by the British Standards Institute. There are specific subcommittees made up of industry and governmental bodies that draft the standards. The second page of the standards typically lists the parties involved in drafting the standard. On screen now are examples taken from part 4 and part 6.

First, I will explain part 4, the non-combustibility test for materials. There has been one version of part 4 published, and this was in 1970, with two further amendments made in 1978 and 1983. Information was added to the foreword in 2014.

The test apparatus for the part 4 test consists of an electric furnace which is switched on until the furnace temperature reaches a constant 750 degrees Celsius for ten minutes prior to the test. A cuboid sample is placed in this furnace. The furnace temperature is measured by a thermocouple positioned so that its hot junction is 10 millimetres from the wall of the furnace and at mid-height of the specimen. A thermocouple is a device for measuring temperature.

A second thermocouple is placed in the centre of the specimen, inserted from the top. This shielded thermocouple shall maintain contact with the material at

the bottom of the hole, drilled down halfway into the specimen.

The image on screen shows a cross-section through the furnace. The key thing to observe here is that the heat is provided by running electricity through wire coils, wrapped around a central tube made of alumina refractory material. No direct flame impingement occurs in this test.

Three specimens are prepared, each side a length of 40 millimetres with a height of 50 millimetres.

My colleague Tom is now holding up an exact replica of the size of the part 4 specimen.

One complete test consists of testing three specimens, each specimen tested separately in the furnace. The specimen is placed in the specimen holder which is shown in the image on the left. This holder is 100 millimetres high.

If the thickness of the material is less than the height required of 50 millimetres, each specimen must then be made of a sufficient number of layers to achieve this thickness. These layers should occupy a horizontal position in the specimen holder and be held together firmly without compression of the specimen by steel wires to prevent air gaps.

For composite materials of a thickness such that an integral number of layers cannot be put together to give the specific size, the thickness of the different components should be adjusted so their proportions remain the same as the original specimen.

If either of these options cannot be followed, the test must be performed on the individual component layers of the material and reported accordingly.

No part 4 test report has been submitted to the Inquiry to date, so I cannot confirm what option is typically used in practice for products associated with Grenfell Tower.

I will now present a video of the test procedure.

(Video played)

For a tested material to be considered non-combustible by means of this test, none of the three specimens during the test must either cause the temperature reading from either of the two thermocouples to rise by 50 degrees Celsius or more above the initial furnace temperature, or be observed to flame continuously for 10 seconds or more inside the furnace, otherwise the material shall be deemed combustible.

The requirements of the test report are shown here, with the single designation to be provided.

That concludes my description of the part 4 non-combustibility test for materials.

The second national reaction to fire test I will explain is part 11, which is the method for assessing the heat emission from building materials. This was current during the primary refurbishment, and it is the national test for materials of limited combustibility, the performance for insulation in external walls. This standard has had no amendments and, again, information was added to the foreword in 2014.

The fire vocabulary British Standard BS 4422 defines fire as the process of combustion characterised by the emission of heat and effluent accompanied by smoke, flame or glowing, so the purpose of this test is to assess the heat emission. It is done by measuring the temperature rise from the specimen as a result of being in a furnace, as well as the specimen mass loss and any observed flaming during the test.

The test apparatus in this heat emission test is similar to that used in the non-combustibility test, with a notable exception being the design of the specimen holder. Other amendments include a prescribed design for the electrical furnace windings; a mirror is proposed to allow the operator to observe flaming easier. The apparatus also includes an additional support to the specimen insertion device.

Part 11 also consists of an electric furnace with

the power input to the furnace such that the temperature measured by the furnace thermocouple is stabilised at 750 degrees Celsius. This specimen holder has a circular base to accommodate cylindrical test specimens.

The furnace thermocouple is to be located 10 millimetres from the furnace tube wall and at a height corresponding to the mid-point of the furnace tube. The specimen thermocouple is positioned at the geometric centre of the specimen. A third thermocouple is also added to allow a horizontal contact with the interior of the furnace wall.

The procedure for part 11 is similar to the non-combustibility test I've just explained, such that temperature measurements and flame observations are also taken. However, the duration of this test can be up to 120 minutes, and the mass of the sample is obtained before the tests.

This time five specimens must be prepared, each one a cylinder 45 millimetres in diameter, and 50 millimetres in height.

My colleague Tom is now showing you an exact replica of a part 11 test specimen.

The specimen is then put into the holder, as shown in the image on the left, and again a thermocouple is

inserted through a two-millimetre drilled hole at the top of the specimen.

Again, specimens must meet the minimum height required for the test specimen of 50 millimetres. For a material with a normal thickness greater than 50-mil it should be reduced. If the thickness of the material is less than 50-mil, the right height should be made using a sufficient number of layers of the material or adjusting the material thickness.

The video on screen now shows this test procedure.

(Video played)

Following the test, two results are calculated. First, the furnace temperature rise is calculated, as the maximum furnace temperature minus the final furnace temperature. Secondly, the specimen temperature rise is calculated by taking the maximum specimen temperature minus the final specimen temperature. This is calculated for each of the five specimens and an average value is obtained. The average duration of total sustained flaming is also calculated for the five samples and recorded in the report.

The operator is also required to calculate and record the density, calculate the arithmetic mean of the density, calculate and record the mass loss of each individual specimen, calculate the arithmetic mean of the mass loss of the specimens tested as a percentage. These five measurements must be recorded in the fire test report.

It is a requirement of the test report that the following text is stated:

"The results relate only to the behaviour of the specimens of the material under the particular conditions of the test. The results obtained on an individual material used in a combination should not be construed as reflecting the performance of the material combination as a whole, which may be influenced by the mechanism of combining the individual materials together, such as with adhesives. The results are not intended to be the sole criterion for assessing the potential fire hazard of the material in use."

This is the important test for materials of limited combustibility, noting no evidence of such a test has been submitted to the Inquiry at this time.

The third national test I will explain is BS 476-6. This is the method of test for fire propagation of products. It is this test combined with a second test, BS 476-7, which, taken together, formed the basis of class 0, about which you have heard and will continue to hear a lot about.

The fire propagation index is defined in the fire

vocabulary British Standard, BS 4422, as "a comparative measure of the contribution to the growth of fire of a combustible material". This is a very different kind of reaction to fire test to those I've shown you so far today, and part 6 relies on a different form of test apparatus.

It was first published in 1968. Since then, three further versions were published, with the most recent dated 2009. In 2014, this too had a change made to its foreword. The version relevant to the Grenfell Tower refurbishment was the 2009 version.

The scope section of part 6 states:

"This part of BS 476 specifies a method of test, the result being expressed as a fire propagation index, that provides a comparative measure of the contribution to the growth of fire made by an essentially flat material, composite or assembly. It is primarily intended for the assessment of the performance of internal wall and ceiling linings."

The test apparatus comprises a combustion chamber with a specimen holder that is fixed onto the front face. The combustion chamber contains a horizontal gas burner tube and two electrical heating elements, and is surmounted by a removable steel chimney and cowl. The specimen holder is made from calcium silicate board,

having the same dry density and properties as that of the walls of the combustion chamber.

The holder is recessed to take a specimen of area 225-mil by 225-mil, with a recessed depth of 12.5, 25 or 50 millimetres, depending on the specimen to be tested.

A non-combustible compressible gasket one millimetre thick is provided for interposing between the specimen holder and the combustion chamber to assist in obtaining an adequate seal.

On screen now is a close-up of the combustion chamber showing the three heat sources. Two electric heating elements and a gas burner as shown. The internal dimensions of the combustion chamber are 190 millimetres by 190 millimetres and a depth of 90 millimetres. I show a cross-section on the next slide. At the top of the combustion chamber is a chimney where hot gases can leave the chamber.

As indicated by the dashed arrow, the combustion chamber is 90 millimetres deep. It is useful to understand the depth of the specimen holder, which is marked green, and attached to the front face of the chamber.

The image on screen shows the specimen being held up in front of the opening to the combustion chamber. The opening to the combustion chamber recess is slightly

smaller than the green specimen on the screen. Each specimen is square and measures 225 by 225, as I said.

My colleague Tom is now holding up an example of the part 6 specimen.

Whilst the sample is of dimension 225 millimetres, the opening in the combustion chamber is 190 by 190 millimetres. The result of this is that a boundary around the edge of the sample is not directly exposed to the heat from the electric heaters and gas burner.

Products with a normal thickness of 50 millimetres or less are tested at full thickness. For products of normal thickness greater than 50-mil, the specimen is obtained by cutting away the unexposed face of the product to reduce the thickness to the required 50-mil.

It is stated in the standard:

"Where the product is normally used as a freestanding sheet, then an air space should be provided at the back of the product by testing over non-combustible perimeter batons.

"Where the specimen is backed by an air gap ... ensure that the perimeter of the specimen will not permit flame to penetrate into the cavity. Similarly, where a flame-retardant coating is applied to a surface, the edge detail shall be such as to prevent ignition of the underlying layers."

This detailed information in this British Standard emphasises the importance of preventing heat transfer through the cut edges of the sample, therefore. This is to make sure the front-face heating occurs only, and that the fire propagation index calculated is as a result of this front-face heating regime only.

Part 6 also makes a clear statement on the influence of underlying layers on the performance of the assembly when being tested in this combustion chamber. It advises that increasing the thermal capacity of the underlying construction increases the heat sink effect, and this may delay ignition of the exposed surface. It states that care should be taken to ensure the result obtained on any assembly is relevant to its use in practice.

Several options are then provided with regard to the preparation of the test specimen and if it can rest directly on the specimen holder, or if it requires a substrate between it and the specimen holder, and these are all shown on the screen here.

Prior to the test, the specimen holder is then firmly fixed in place, as shown on screen. During the test, both the gas burner and the two electric heating elements are used, which I will explain later. The temperature output from the thermocouples of the flue

gases in the chimney is measured throughout the test, with specific temperature measurements noted at set time intervals, which I will also describe later.

The image on screen now shows the rear of the apparatus. This features an observation window and an air inlet below. Visual observations are made during the test through the window. These must include: intumescence or deformation or spalling of the specimen that tends to block the burner ports so that the required gas input cannot be maintained; melting or slumping of the specimen that results in material escaping from the air inlet or being confined to the recess of the specimen holder, where it is not exposed to the heating conditions; air flow through the apparatus being obstructed owing to obstruction of the inlet port by fallen material or by soot accumulation in the chimney.

Occurrence of any of the above phenomena shall deem the test on that specimen to be invalid.

This test consists of data measured from two different materials. As well as the specimen to be tested, the test also requires a specimen of calcium silicate to be prepared. Calcium silicate is a non-combustible material, and Tom is now holding up a piece of that board for reference.

In its board form, it is used in the test combustion chamber as a benchmark, and the data from the test specimen is then compared to the data obtained when the calcium silicate board is tested first. Only one calcium silicate specimen is required; however, at least three of the material specimens must be tested.

I will now present a video of this test procedure.

(Video played)

The output from the two thermocouples located in the chimney is recorded at specific intervals we need to discuss: at 0.5-minute intervals up to and including three minutes from the time at which the gas was ignited, and this is then converted to a parameter called s1; at one-minute intervals up to and including ten minutes from when the gas was ignited, and this is converted to a parameter called s2; two-minute intervals up to and including 20 minutes from the time at which the gas was ignited, which is then converted to a parameter called s3.

All the visual observations should be recorded during the test, as observed through the window, as I have already explained.

The ultimate output of this part 6 test is a parameter called the fire propagation index I, and sub-indices i1, i2, and i3. These parameters are

directly referenced by Approved Document B, as shown on the screen, as part of the fire definition of class 0.

It is critical people understand the fire propagation index and the sub-indices only come from BS 476-6. I will now explain how the indices are derived.

Regarding the sub-indices s1, s2 and s3, I have provided the formulae to calculate them circled in the green box, which uses the measured temperatures shown on the screen now. These s values are then averaged and used to calculate i1, 2 and 3 and as shown in the orange box. Sub-index i1, sub-index i2 and sub-index i3 are then summed to obtain the index of overall performance, I, of the product.

Please just remember that the only measurement taken as part of this test methodology is the temperature from the thermocouples within the chimney at the top of the combustion chamber at set time periods, which are then converted to temperatures.

The standard specifies the required contents of the test report. I particularly note the report must state:

"Details of the form in which the specimens were tested (material, composite or assembly), together with specimen thickness and, where appropriate, orientation, backing material and the face or faces subjected to the test and whether the material was tested in a modified form."

The statement that the suffix R to the fire propagation index indicates that the results should be treated with caution, and the test report must contain the statement again:

"The test results relate only to the behaviour of the test specimens of the product under the particular conditions of test; they are not intended to be the sole criterion for assessing the potential fire hazard of the product in use."

The test set-up is designed to prevent heating through the cut edges of the test specimen. For a composite material, therefore, such as ACM, it would mean the outer aluminium surface is heated first, and the products of combustion from any other material behind it, should they receive sufficient heat, together may cause a temperature rise in the chimney. This is why it is important to understand how much heat energy is applied to the sample in this standard test, which has a duration of 20 minutes.

I have found some historic work regarding this heating dose received on the surface of the specimen tested in part 6. In 1968, the BRE issued Fire Note 710, titled, "The fire propagation test as a

measure of the fire hazard of a ceiling lining". As stated in the note, part of the study involved measuring the rate of heat transfer to a specimen in the fire propagation test.

On screen now, I've shown some text explaining the heat exposure measurements produced in this paper. This is for background information only, because the key information I want to present is the graph referenced within this text.

This is figure 1 from Fire Note 710, and it shows the gross heat flow, the heat flux, received at and on the surface of the asbestos wood sample used in the test. The paper, for any fire scientists listening, defined the gross heat flow as the algebraic sum of the rates of heat transfer into the specimen by conduction, from the surface by radiation and from the surface by convection.

So to understand if a similar heat received on a surface of a different type of specimen, as a result of this scale of heating, is then sufficient to ignite the specimen being tested, I present the following.

I have compared the received heat measured in this paper on asbestos wood shown by the dark blue line on the screen, and I have compared it with critical heat flux values associated with the materials used in the

external wall of Grenfell Tower. I have done this purely to give a sense of scale of the heating regime within the combustion chamber only.

Fire Note 710 states:

"The gross heat transfer rates will be higher for good insulators ... although they will be of the same order and will vary with time in much the same way ..."

So it is reasonable, in trying to understand the scale of heat applied to the surface of materials in the part 6 test, to rely on the dark blue line for comparison.

I have used dashed lines to overmark the graph with values of typical critical heat fluxes needed for the piloted ignition of the materials. This is the ignition that occurs when a flame is impinged on the specimen. I have provided those classic and typical values for PIR foam and phenolic foam, polyethylene, and wood.

Therefore, with the heating dose from the part 6 test, the applied heat flux to the sample made of wood, the wood would be expected to ignite between three and four minutes. For polyethylene, this would be after four minutes. PIR would ignite between four and five minutes, and phenolic foam after eight minutes. The part 6 test has a total duration of 20 minutes.

I note that the melting point of polyethylene is

approximately 130 degrees Celsius, whereas the melting point of aluminium is over 660 degrees Celsius. Based on the test reports submitted to the Inquiry, when ACM panels are tested in this apparatus, the aluminium can sometimes act as a protection to the polyethylene, protecting it from direct flame exposure, and therefore the polyethylene sometimes melts and flows away rather than ignites within the panel during the test. If it does not ignite, the temperatures measured in the chimney are lower.

I have now added to this comparison graph the time period when the temperatures forming the index s1 are actually calculated. During this period, please note the heat exposure to the specimen is actually less than that required to ignite wood or polyethylene. I have also marked the time periods when the temperatures forming s2 and s3 are also calculated.

To sum up, the part 6 test is the fire propagation index test and is based on the temperatures measured in the chimney, the product tested is then assigned a s1, s2 and s3 sub-index. These are averaged across three tests to obtain the sub-indices i1, 2 and 3.

The sub-index i1 is therefore an average of measurements taken during the first few minutes of the test only, when the heating dose is relatively low.

I have shown how i1 is referred to in the ADB on the screen marked in purple.

There the ADB also refers to a fire propagation index I. This is the overall index and is based on the heating dose received over the 20-minute period.

Composites can be tested; however, when they are tested, the specimen is arranged to ensure the front-face heating of the specimen only.

The fourth and final national reaction to fire test is BS 476-7, method of test to determine the classification of the surface spread of flame of products. This must be combined with part 6, as I have just explained, when understanding the derivation of class 0 as set out in the ADB.

I want to stress that class 0 is not simply a surface spread of flame test, as so commonly stated; only the part 7 test on its own is, and there is no national class that relies solely on part 7. Class 0 is defined on the basis of the two tests, and this is a critical distinction that must be incorporated in any evidence given to the Inquiry regarding class 0.

There have been three versions of part 7 published, first in 1971, with two further revisions in 1987 and 1997, and a change to the foreword only in 2014.

The foreword section of part 7 states:

"The test takes account of the combined effect of factors such as ignition characteristics and the extent to which the flame spreads over the surface of the product under opposed flow conditions. The influence of any underlying materials on these factors, in relation to their ability to influence the rate of fire growth, is also taken into account. The test result is a function of the distance and rate of, the lateral spread of flame; and this is classified according to performance as classes 1 to 4."

The scope section of part 7 states:

"This part ... provides data suitable for comparing the end-use performance of essentially flat materials, composites or assemblies, which are used primarily as the exposed surfaces of walls or ceilings."

The scale of apparatus used in the part 7 test is very different to the other three national reaction to fire tests and, relatively speaking, is a much larger test. However, it is still important to note how much smaller this sample size is, when considering the scale of a cladding panel used in construction. I will show an image to help understand this later.

The part 7 apparatus consists of a 850-mil by 850-mil radiation panel mounted vertically in a surround and supported on a framework. The specimen holder

protrudes perpendicular from the radiating surface. A small pilot flame tube is also provided as part of the apparatus.

This is the largest specimen required for a national reaction to fire test, and each specimen is a rectangle measuring 885 millimetres long and is 270 millimetres in height.

Tom is now holding up an exact replica of the part 7 sample.

When the product is of insufficient size to allow the specimen size to be achieved in width or length, it is permissible for small pieces of the product to be placed adjacent to each other to obtain the required dimension, providing that an essentially flat surface can be achieved, and it is considered in the test standard that such a procedure does not have any influence on the surface spread of flame, but the use of such specimens shall be reported.

The specimen holder comprises a water-cooled steel frame with water-cooled face plates. The face plates overlap the specimens by 20 millimetres on their top and bottom edges, and over the vertical edge adjacent to the radiation panel. A spring-loaded clamp is positioned to clamp the specimen against the water-cooled face plates. The water supplied to the specimen holder is such that

the maximum temperature does not exceed 35 degrees Celsius at the outlet from the specimen holder.

Specimens are tested at full thickness, so long as they fit into the test frame. Where a material is more than 50 millimetres, it is cut down from the unexposed side to allow it to fit. In the test position, the specimen holder assembly is located at 90 degrees to the face of the radiation panel. The height of the specimen holder is such that the horizontal reference line marked on the specimen and shown on the screen here is brought to the mid-height of the radiation panel. The specimen holder is hinged to allow it to be swung horizontally, away from the face of the radiation panel between tests.

To assist with interpreting the results, the specimen is marked with reference lines before it is mounted into the test rig, and these lines are at set distances, as shown on the green face of the specimen on this slide.

The part 7 standard sets out how the exposed face of each specimen shall be marked in detail on its surface, with a reference line along its length and 95 millimetres above its bottom edge.

To assist in the observation of flame travel, the specimen shall be marked at intervals along its length with lines normal to the reference line and at intervals shown in figure 7 of the standard, which is on screen now. The four vertical lines that run full height are the classification limit distances along the sample for class 1, class 2, class 3 and class 4.

However, there are a number of other requirements for the specimen, which I will briefly run through.

A minimum of six and a maximum of nine test specimens shall be provided, and they shall be representative of the exposed surface of the product.

The product shall be tested on that face which is normally exposed in practice, taking account of the following:

If it is possible for either or both of the faces to be exposed in use then, if the faces are different or if the core of those faces is asymmetrical, both faces shall be tested.

If the face of the product contains a surface irregularity that is specifically directional, for example corrugations, the product shall be tested in both orientations.

If the exposed face contains distinct areas of different surface finish or texture, then the appropriate number of specimens shall be provided for each distinct area of such finish or texture.

All specimens shall be tested at full thickness or cut away, as I explained earlier.

When the product is a thin film, it shall be applied to an appropriate substrate, using a method and application rate recommended by the manufacturer. The lab shall determine whether a product incorporates a thin film on its surface and shall note if this is the case.

When the material is a material or composite which would normally be attached to a substrate, it shall be tested in conjunction with the appropriate substrate, also using the fixing technique recommended by the manufacturer.

Please note the significance that this standard makes to the effect of the underlying substrate, and the reader is referred to appendix B of part 7 for more information.

Part 7 also provides a clear explanation regarding the impact of any underlying construction on the ignition performance of the surface. The test standard again provides rules on how the sample should be tested as a result.

I will now explain the heating apparatus.

It essentially consists of a radiation panel mounted vertically in a surround and supported on a framework so

that the centre of the panel is 1.25 metres above floor level. The radiation panel shall be supplied with a gas/air mixture. The radiation panel is 850-mil by 850-mil square, designed to give efficient combustion of the air/gas/air mixture, with no flaming occurring on the face of the panel under operational conditions.

The radiation panel shall be fitted with a refractory concrete surround. This surround shall project from the face of the radiation panel on its four edges by 50 millimetres. Any small gaps between the surround and the radiation panel shall be tightly packed with a flexible, non-combustible insulating material.

A separate small pilot flame is also provided in addition to the radiant heat panel and immediately adjacent to the test specimen. This pilot burner shall consist of a steel tube with an internal diameter of nominal value 3 millimetres, and an external diameter of nominal value 6.4 millimetres. The burner shall be designed in such a way that, with the specimen in the test position, the centre of the burner is positioned exactly as set out in the standard, which I have reproduced here.

The video on screen now shows this test procedure.

(Video played)

Throughout the test, it is required to carefully

observe the behaviour of the product and make a note of the following phenomena: flashing, transitory flaming. Observe and note other phenomena, such as debris falling away from the specimen and whether it is flaming or not, any intumescent or deformation of the specimen. These additional observations do not influence the classification of surface spread of flame.

Part 7 sets out four classifications based on the spread of flame at 1.5 minutes and the final flame spread after 10 minutes. These are class 1, class 2, class 3 and class 4, and the limits for each are on screen now.

I also note that it is stated that this statement must be included in the test report. Again:

"The test results relate only to the behaviour of the test specimens of the product under the particular conditions of test; they are not intended to be the sole criterion for assessing the potential fire hazard of the product in use."

The Inquiry panel should consider that only one of these four tests actually measures the rate of flame spread across a specimen, and then the purpose of that test was to measure horizontal spread stated for along walls and ceilings.

Finally, I want to explain what "extending the field of application" means; again, a phrase that will be used over the coming months when referencing test reports and test standards.

As I've shown, each test report for the national reaction to fire tests must contain specific information, including the limits of what was physically tested.

Part 10, the guide to the principles of fire testing and their outputs, states at paragraph 5.3:

"Within the field of reaction to fire, direct field of application is the application of the test results for a material or product in accordance with the details of how they were tested. Specifically, this means that the mounting and fixing arrangement used in the test method is applied directly to the use of the material or product in real end use conditions. Any variation in the physical properties or thickness of material or product in the end use application, or variations in the mounting and fixing arrangements, should be either quantitatively determined through a carefully designed test programme or, in some cases, be the subject of an assessment or expert judgement by an expert."

I am aware of one British Standard that gives guidance on the application and extension of results, but this focuses particularly on fire resistance tests,

not reaction to fire tests.

There is also an industry document issued by the Passive Fire Protection Federation titled "Guide to undertaking assessments in lieu of fire tests". This again sets out guidance on assessing the fire resistance performance of products and systems in lieu of undertaking further British national fire tests.

Both documents make passing references only to the reaction to fire tests. Within the industry document, it states on page 4:

"Examples of complex assessments are ... Interpolation/extrapolation of a range of test data to cover the reaction to fire performance of different thicknesses of a product."

I have not found any other publications for reaction to fire tests relevant at the time of works on Grenfell Tower.

However, one extended field of application report for a national reaction to fire test has been submitted to the Inquiry. This was done by Exova Warringtonfire on behalf of Kingspan {KIN00000283}. This was an assessment of the ability of a range of foil-faced polyisocyanurate insulation board materials to comply with the requirements of class 1 when tested in accordance with part 7.

No analysis is presented within this report, just a statement. No such field of application extensions have been submitted to the Inquiry for cladding panels at this time.

I have provided my opinion on how the BBA relied on a limited number of tests to issue a BBA certificate for cladding panels at length in my Phase 1 report.

I would like now, if possible, to take a short break, please.

SIR MARTIN MOORE-BICK: Yes. Well, that's a very convenient moment. Thank you very much.
We will break until 11.30. Would that be suitable?
DR LANE: Yes, please, thank you.
SIR MARTIN MOORE-BICK: Thank you.
(Pause)
11.30, please.
MS GRANGE: Thank you.
(11.15 am)
(A short break)
(11.30 am)
SIR MARTIN MOORE-BICK: Yes, Dr Lane. Well, when you are ready to carry on, we're all agog, thank you.
DR LANE: Yes.
I will now explain all the national classes and their relationship with these four tests.

So the first important point is there is no overarching British Standard for the classification of products and materials to the national reaction to fire test regime. There is in Europe, which we will discuss in the next section of this presentation. Instead, the national classes rely on fire definitions by means of text in the statutory guidance Document B only. The relevant definitions are: non-combustible, limited combustibility, class 1 to 4, index I and sub-index i1, and class 0.

These specific fire definitions were provided within Approved Document B 2013. Section 12, the external wall construction, refers to these definitions, both in the main text and in the text written on diagram 40, also part of section 12. I will go through this in detail in the next few slides.

It is necessary to read appendix A of Approved Document B to understand the fire definitions. In table A6 of appendix A, it explains the use and definitions of non-combustible materials. In table A7, it explains the use and definitions of materials of limited combustibility. Class 0 is defined separately in paragraph 13 of appendix A, and class 1 is referred to at paragraph 13 of appendix A also.

The fire propagation index I and the sub-index i1 as calculated in the part 6 test are referred to at paragraph 12 and paragraph 13 of appendix A only.

So knowledge of all these classes and indices is essential, as well as knowledge of the non-combustible and limited combustibility definitions, and I will now present each of these definitions in turn.

"Non-combustible" is defined in table A6 of Approved Document B. There are two definitions for "non-combustible" provided, as you can see highlighted on the screen now. Each relies on either the national reaction to fire test from part 11 or from part 4. These are the national class for non-combustible materials.

Paragraph (d), the lower box marked here, states that products classified as non-combustible under part 4 are non-combustible for the purposes of this guidance.

The other method referred to in table A6 is any material tested to BS 476-11, the method for assessing the heat emission from building materials, as shown in the upper blue box here.

Tom is holding up both samples again now as a reminder.

The part 11 test standard itself does not provide any limits on temperature rise or duration of flaming. Instead, these are set out in appendix A only, at

point (a), as marked in the upper blue box. There, table A6 states that the material, when tested to part 11, does not flame nor cause any rise in temperature on either the specimen or furnace thermocouple. This is the national class for non-combustible also.

The table on screen compares the two limits set for the national class non-combustible using table A6 of Approved Document B 2013. So one can either do a part 4 test or a part 11 test. All results must have been recorded as zero if one relies on part 11.

The second fire definition provided in Approved Document B is in table A7, "Use and definitions of materials of limited combustibility". This is a key definition regarding the products used on Grenfell, as the insulation material in the external wall should have been a material of limited combustibility. You can see in paragraph (a) that any material defined as non-combustible will also satisfy the national class for limited combustibility too.

The primary test that can be done to demonstrate limited combustibility using national test standards is part 11. Density limits are set, as well as flame and temperature rise limits. I have drawn out the text on the right-hand side of the screen.

The column on the left-hand side provides references to specific sections of Approved Document B where limited combustibility is referenced with respect to the situations where such materials should be used. The references as shown in row 8 of the table apply only to insulation used as part of an external wall. It is critical to understand the explicit reference to insulation in the external wall made in this table A7.

The definition of a material of limited combustibility sets out not just temperature and flaming limits, but also makes a distinction regarding the density of the insulation material. If the material density is more than 300 kilograms per metres cubed, the limit on specimen furnace temperature rise is 20 degrees C, with zero seconds of flaming to have been observed in the part 11 test.

If the material is of density less than 300 kilograms per metres cubed, the limits for observed flaming increase to a total of 10 seconds over the course of the whole test. The limit on specimen furnace temperature rise is slightly higher at 25 degrees Celsius, with an additional limit set on specimen thermocouple temperature rise of 35 degrees C. The requirement for materials less than 300 kilograms per metres cubed density is therefore less onerous when

relying on the part 11 test.

It's worth noting that insulation materials are often foam-based and may well have a density less than 300 kilograms per metres cubed. For example, the density of phenolic foam and PIR, the insulation used on Grenfell, may have a density of around 35 kilograms per metres cubed.

However, a material of limited combustibility is also referenced for another component of the external wall, and this is a complex matter which I will try to explain carefully.

In table A7, up at row 6, marked in blue here on the left, there is a general row which states:

"Class 0 materials meeting the provisions in appendix A, paragraph 13(a)."

There, at appendix A, paragraph 13(a), it defines class 0 as the highest national product performance classification for lining materials. This is achieved if a material or the surface of a composite product is one of two performances set, the first being composed throughout of materials of limited combustibility.

Therefore, those materials must comply with the limits set in table A7, and this is done by means of the part 4 or part 11 tests also.

Again, it is essential to be very aware this is not part of the insulation row below, highlighted in the orange box, and I will come back to this matter again later.

I want to now explain how Approved Document B refers to the classes 1, 2, 3 and 4 as calculated in the part 7 surface spread of flame test.

Classes 1 to 4 are surface spread of flame classifications, and these are defined within part 7 itself. It's not referred to again in Approved Document B.

The resulting class is simply a measure of how far along the specimen the flame spreads horizontally over two time steps. Of the four classes, class 1 is the highest and 4 is the lowest. This means the flame travels the least horizontally along the surface when a material is a class 1, and it travels the furthest along the surface on a class 4 material.

The 1.5-minute measurement assesses the initial flaming, so how quickly the material reacts immediately after it is exposed to high temperatures. The final spread of flame, shown on the screen also, assesses how effectively the flame is sustained and can propagate along the surface. The flame spread must be within both limits set for a class to achieve that class.

I will now explain class 0.

Class 0 is defined at paragraph 13 of appendix A. It is stated as:

"The highest National product performance classification for lining materials ..."

And it is given two definitions as described in Approved Document B.

First, as shown in the orange box, (a), it is a product "composed throughout of materials of limited combustibility", as I explained earlier. But there is a second definition relying both on the part 6 fire propagation index and part 7, the surface spread of flame test, as shown in the blue box. Class 1 is obtained from part 7, and the fire propagation index and sub-index is obtained from part 6.

Remember the calculations for the indices in part 6, and how they are calculated from the gas temperatures measured in the chimney above the furnace, as shown on the screen now.

Two temperature time curves are produced during the test. The upper dark blue line on screen now is an example of the temperature measurement for a combustible specimen. The lower light blue line on screen now is an example of the temperature measurement for the known non-combustible specimen tested as a benchmark in part 6.

From the graph of temperature versus time, three distinct time periods are then considered: from 0.5 to three minutes, where the difference in temperature is calculated at 0.5-minute intervals; from four minutes to ten minutes, where the difference in temperature is calculated at one-minute intervals; and from 12 minutes to 20 minutes, where the difference in temperature is calculated at two-minute intervals. These values are then used in the formulae shown on the screen now to obtain s1, s2 and s3. The calculated s1, s2 and s3 values are then averaged to obtain i1, i2 and i3, where I is then the sum of these sub-indices.

Please now look again at the definition of class 0 on the screen marked in yellow. There it states for class 0 the fire propagation index must be not more than 12, and sub-index i1 must be not more than 6. So the test results from part 6 on a material or composite product must fall within these limits.

Additionally, the class value of 1 must be achieved when the same product is tested to part 7. Class 1 means the flame must not spread more than 165 millimetres from the heated end after 1.5 minutes into the test, but in class 1, it must not also exceed this limit for the entire duration of the test for up to ten minutes. I have shown you where class 1 is located

most closely to the radiant panel shown on the screen now.

Because the fact that two test result types formed the definition of class 0 is so regularly ignored, with the surface spread of flame test mostly only referred to when discussing class 0, I think it's important I repeat this point again: the class 0 material must be tested to achieve class 1 and tested again to determine its fire propagation index, and fall under the limits set in Approved Document B.

Crucially, regarding the external wall at Grenfell Tower, class 0 is also referred to within diagram 40, which presents the provisions for external surfaces or walls.

Taking Grenfell Tower as the building example, the external surface classification was class 0 for the building because it had a dimension over 18 metres, and it was 1,000 millimetres more from the relevant boundary to adjacent buildings, and this applied to the part of the building over 18 metres. See the dark grey shading on the right-hand side highlighted in yellow.

This meant the composite product used for the external surface needed to have been tested to part 7, the surface spread of flame, and to achieve class 1 in that test, and tested to part 6 and achieve a fire propagation index I not more than 12, and sub-index i1 not more than 6, exactly as set out on the right-hand side of diagram 40, marked in the upper blue box.

Some important points I suggest to the Inquiry panel to note:

I have shown so far today that both part 6 and part 7 tests can incorporate a composite specimen. I have shown both tests do not directly heat the cut edge of the specimen. I have also shown that the scope of part 6 states it is for internal walls and ceilings. The scope of part 7 states it is for walls and ceilings, and that it measures horizontal flame spread. And I have shown class 0 is referred to as the highest national product performance classification for lining materials.

But I have also shown it clearly referenced from this diagram 40 for external surfaces or walls, for the purpose of exactly as written in the guidance. This is in order to reduce the surface's susceptibility to ignition from an external source and to reduce the danger from fire spread up the external face of the building.

Some final points about class 0, due to its significance to the work of this Inquiry. I now want to set out how long class 0 and the two tests upon which it

relies, part 6 and part 7, have been referred to as the fire safety performance class for external walls in England and Wales.

The first national Building Regulations in England were the Building Regulations 1965. Prior to this, individual local authorities set their own performance requirements through local byelaws. London retained their own byelaws until 1985.

In 1965, the external wall construction was not to include any combustible material except specific internal linings or specific external cladding.

The cladding is explained later on in regulation E7 at part 3(b), shown on screen now. It required cladding on any external wall more than 3 feet from the boundary in a building greater than 50 feet in height to have a surface complying with the requirements for class 0. Class 0 at that time was defined by prescribed construction typologies, and with the only test referenced the surface spread of flame test as existed in 1953.

The table on screen now shows the changes in external wall requirements as defined in the national Building Regulations and then subsequently in Approved Document B through time.

In the following slides, I have provided all of the

supporting fire performance requirements and national definitions from 1965 up to the night of the fire. I will not go through each one in detail, but instead I will point out some significant changes, and that font is marked in blue.

This is 1965, as I have just summarised.

In 1972, the external cladding above 15 metres was still required to achieve class 0. However, the definition was changed this year to refer to the newly introduced part 6 test.

In 1976, external cladding above 15 metres was still required to achieve class 0. However, the definition of class 0 was changed again this year to refer to both part 6 and part 7 tests.

In 1985, the fire performance for the external wall performance was dropped down from non-combustible to constructed of materials of limited combustibility, and the part 11 test standard was introduced. There were some changes too to class 0, and I will explain these later.

In 1992, for the first time, a separate performance standard was introduced for insulation as distinct from the external wall surface. The insulation performance standard was a material of limited combustibility. The definition of high-rise increased in 15 to 20 metres.

In 2000, an alternative for the external surface only was introduced by means of a BRE Fire Note Number 9, with the insulation performance limits now set only for a ventilated cavity. The definition of high-rise was also lowered to 18 metres.

In 2002, the European classification system was introduced as an alternative to the national classes.

In 2006, an alternative approach for the whole performance of the external wall was introduced by means of BR 135, and the insulation definition changed again, as shown on the slide. This has remained the case until 2013.

I have shown how class 0 has been referred to in the Building Regulations, and then the statutory design guidance for that time period. It's important for the panel to understand the primary changes to the definition of class 0 in that time period also.

Class 0 was originally based on a surface spread of flame test only from the 1953 test standard, but it was also defined in three different ways: either non-combustible throughout, or a material with a non-combustible background and a specific test at fire performance of the surface, or a material with a combustible background but with a non-combustible face. Note the careful distinction between substrate and surface.

There were a few changes in the 1972 Building Regulations. Part 6, the fire propagation test, had been created by the BRE in 1968, after they had identified that the highest classification, class 1, from the surface spread of flame test, could not differentiate between different combustible linings. The definition of class 0 reference was therefore changed to refer to part 6 only.

The combustible substrate with a non-combustible surface definition was dropped, leaving two options for the definition of class 0 instead of three. Again, constructed as non-combustible throughout was retained, and the second option, as shown on the screen now, relying on the part 6 test.

This changed again in 1976, when the definition of class 0 became defined based on both part 6 and part 7, and this combination of tests has been relied on ever since. The two distinct definitions for class 0 remained: either constructed throughout with non-combustible materials, or a surface tested with a substrate, as shown on the slide.

However, in 1985 the definition of class 0 was significantly changed. First, the definition stopped relying on non-combustible materials, and instead

a class 0 material or surface of a composite product could be composed throughout of materials of limited combustibility, a lower standard.

Secondly, the requirement to consider the substrate with the surface was removed from the text in the statutory guidance document. This remained the definition to the time of the Grenfell fire.

During the primary refurbishment works, the national class standards were relevant. These were, first, referring to section 12 of Approved Document B in accordance with external surfaces, at section 12.6, the external surfaces of walls should meet the provisions in diagram 40, and there the national class 0 is cited, as I have explained.

For insulation materials and products, at section 12.7:

"In a building with a storey 18m or more above ground level any insulation product, filler material (not including gaskets, sealants and similar), etc. used in the external wall construction should be of limited combustibility."

The Celotex FR5000, RS5000 and the Kingspan K15 insulation were presented as achieving national class 0. They were not presented as the required material of limited combustibility.

ADB in table A7 for materials of limited combustibility, at row 8, for insulation, makes no reference to class 0.

The Arconic Reynobond panels were also presented as achieving a national class on their BBA agrément certificate, which stated:

"Behaviour in relation to fire - in relation to the Building Regulations for reaction to fire, the panels may be regarded as having a Class 0 surface ..."

This certificate then goes on to state at 6.2, if you look at that on the screen:

"A fire retardant sample of the product, with a metallic grey PVDF finish, when tested in accordance with BS 476-6:1989 achieved a fire propagation index (I) of 0 and, when tested in accordance with BS 476-7:1997 achieved a Class 1 surface spread of flame."

It goes on to state at 6.3:

"As a consequence of the sections 6.1 [which I will explain later] and section 6.2 [as shown on the screen now], the products may be regarded as having a Class 0 surface in relation to the Approved Document B of The Building Regulations 2000 ..."

I wanted to show you the test results from the test report upon which the BBA relied. There you can see the

fire propagation index is recorded as 1, and the sub-index i1 as 0.

That concludes my section of the presentation on the national classes and classifications.

SIR MARTIN MOORE-BICK: Thank you.

DR LANE: I'm just going to do a short pause.

(Pause)

Okay, I will now explain the European reaction to fire tests.

It is useful to note that some of the test methods are similar to those relied upon in the national class system, and others are very different. Also, there's a dedicated classification process presented in a bespoke classification standard. Therefore, the European system does not rely on definitions within the statutory guidance document, as occurs for the national classes.

I'm going to explain four European test standards. Unlike the British tests, which all sit within the 476 series of tests, the European reaction to fire tests each have their own unique numbering, as does the associated classification standard, which is called BS EN 13501-1. First I will explain each of the four tests, and then I will explain the classification standard.

The European reaction to fire standards are issued by CEN. This is the European Committee for Standardisation. It is an association that brings together the national standardisation bodies of 34 European countries.

CEN is made up of a series of committees and subcommittees that issue standards. The overarching technical committee for fire safety is CEN/TC 127, fire safety in buildings. The subcommittee that is responsible for reaction to fire is called working group 4, and I have provided the references on the slide for the record.

Unlike the British Standards, the industry/government bodies that draft the European standards are not listed within it. Based on information available on the CEN website, the chairperson of the overarching technical committee for fire safety in buildings is listed as Dr Debbie Smith, a director at BRE, and the convener of working group 4 is a Mr Roy Weghorst, head of regulatory affairs at Kingspan.

Before I introduce the European reaction to fire test standards, I want to highlight this quote from Birgitte Messerschmidt, an employee of Rockwool International in Denmark at the time she gave

a presentation at the FireSeat Conference at Edinburgh University in 2008. She raised the issue of a new reference standard for externally applied products, and stated the work to define a new test method for façades had been transferred to EOTA. Again, I have provided the references on the slides. EOTA is the European Organisation for Technical Assessment in the area of construction products and it is based in Brussels. There are eight companies listed in the UK membership area, including the BRE, the BBA, and Exova Warringtonfire.

There are four European reaction to fire tests referenced by the classification standard for construction products. Each part addresses a different element of contribution in a fire. BS EN ISO 1182 is a test of non-combustibility for materials. BS EN ISO 1716 is a test to determine the gross heat of combustion in a bomb calorimeter. BS EN 13823 tests how a specimen reacts when exposed to thermal attack by a single burning item in the corner of a room. Finally, BS EN ISO 11925-2 measures the extent of vertical fire spread and production of flaming droplets and particles when a specimen is exposed to a single flame source for a defined period of time only.

The first European reaction to fire test I will

describe is the non-combustibility test. The 2010 version was relevant during the Grenfell Tower refurbishment. It is cited as the fifth edition of the standard, cancelling and replacing the fourth edition before it.

This test is used for determining the non-combustibility performance under specified conditions of homogeneous products and substantial components of non-homogeneous products. The test apparatus is very similar to that used in BS 476-11, as it comprises an electric furnace capable of maintaining a steady temperature of 750 degrees C.

In the European test, the thermocouples are used to measure the temperature within the furnace. A specimen thermocouple can be added optionally and it is not subsequently used in the classification.

Five cylindrical specimens are prepared, each with a diameter of 45 millimetres and a height of 50 millimetres. They are tested individually, but data is required from all five specimens to determine the final test result.

If the thickness of the material is different to 50-mil, specimens may be layered and then secured with steel wires or the material thickness may be adjusted.

Tom is now holding up examples of these specimens

for the European test.

Prior to the test, specimens are conditioned and each specimen is weighed and its mass recorded.

I'm showing a video of this test now.

(Video played)

As you can see, very detailed requirements are set out for the temperature measurements in this test: the initial temperature, the maximum temperature, and the final temperature, as well as the specimen centre thermocouple and the final specimen centre thermocouple, so a lot of data is produced in this test.

The test report has to include a general description of the product tested, including the density, mass per unit area, and thickness, together with the form of construction of the test specimen, and the statement that:

"The test results relate to the behaviour of the test specimens of a product under the particular conditions of the test; they are not intended to be the sole criterion for assessing the potential fire hazard of the product in use."

So the same statement again.

The second European reaction to fire test I will describe is BS EN ISO 1716, determination of the gross heat of combustion.

Heat of combustion is defined as the thermal energy produced by combustion of a unit mass of a given substance. Gross heat of combustion is the heat of combustion of a substance when the combustion is complete, and any produced water is entirely condensed under specified conditions.

This test specifies a method for determining the gross heat of combustion in a rig called a bomb calorimeter. The version dated 2010 was the version relevant during the refurbishment, and it is cited as the fourth edition of this test standard.

The screen now shows the bomb calorimeter apparatus. There are two components: the bomb and the calorimeter. The bomb is a watertight vessel and contains pure oxygen. The bomb is contained within a larger enclosure which is filled with water. When the specimen is burnt in the inner watertight vessel, it releases heat, which is transferred through the walls of the vessel into the water surrounding it and, in doing so, heats up the water. The increase in water temperature is measured using a thermometer, and a stirrer, driven by a constant speed motor, is placed in the calorimeter.

50 grams of the specimen is taken and ground into a fine powder. Tom is now holding up a small bag of 50 grams of ground polyethylene.

0.5 grams of the specimen is placed in a crucible along with 0.5 grams of benzoic acid. This is to assist the sample to combust. This crucible is just a non-combustible holder that is used to store the material within the bomb. The specimen is not directly exposed to flame, but a firing wire is inserted into the crucible holder. When an electrical current is passed through this wire, the material is ignited and the temperatures begin to rise.

It is important to note that metal powders are not suitable for use in the bomb calorimeter, as they represent an explosion hazard due to overpressures created within the test vessel. Therefore, where metallic components are present within a composite material, their gross heat of combustion is deemed to be zero and no test is required.

I will show you a video of this test now.

(Video played)

So, again, very detailed activities are required, as defined in the test standard.

Three 0.5-gram specimens are tested, and the gross heat of combustion for each is then calculated based on the increase in temperature of the water. This can be done as it is a scientific constant that it takes 4,184 joules of heat energy to heat 1 kilogram of water

by 1 degree. As the quantity of water in the calorimeter is a known value, the amount of energy it took to heat up can be back-calculated.

The average of the three specimen results is taken, and the final result is given in units of joules or megajoules. To be a valid test, the results must comply with the criteria shown in table 1 on the slide.

The test report has to include the information as I have shown on the screen, including the similar statement I've referred to a few times this morning.

The third European reaction to fire test I will now describe is known as the single burning item test. This British Standard is the UK implementation of a European norm, and the 2014 version was relevant to the Grenfell Tower refurbishment. It superseded a 2010 version, which was withdrawn.

In the single burning item test, a specimen forming a corner is tested. Tom is now standing to an exact to-scale replica of the BS EN 13823 single burning item test specimen.

The specimen holder is a metal frame with a calcium silicate board facing called the backing board. The specimen to be tested is then fixed onto the backing board according to the fixing conditions in the end-use application required.

The specimen holder comprises two wings, designated a short and a long wing. It is the largest specimen used in any of the reaction to fire tests in either Europe or nationally. The long wing has a length of 1 metre and a height of 1.5 metres. The short wing has a height of 1.5 metres but a shorter length of 495 millimetres.

The maximum depth or thickness of the total specimen tested in the single burning item test is 200 millimetres. Specimens with a normal thickness greater than 200 millimetres are again cut away from the unexposed side, so they fit into the test rig. Materials with a thickness less than 200 millimetres are tested at their normal thickness with no requirement for scaling up. A total of three specimens are tested, and both long and short wings must be replaced after each test run.

The single burning item test also refers to further information about how the specimen is mounted in its end-use application, including the presence of substrates. These are products used immediately beneath the product about which information is required. The single burning item test standard sets out clear guidance regarding the issue of mounting and substrates.

This is the test upon which Arconic relies regarding

Reynobond products.

When products are tested and mounted as in their end-use applications, the test results are then valid only for that application. When products are tested using a standard mounting, additional guidance is provided. For example, boards in the end-use application of a ventilated cavity behind it shall be tested with a cavity of at least 40 millimetres. Boards to be mechanically fixed to a substrate in their end use should be test fixed to a substrate using appropriate fixings. Products that, in that their end-use application, are glued to a substrate shall be tested glued to a substrate.

The test rig contains two burners: a primary burner, as is shown in the diagram, and an auxiliary burner, and I will explain that next.

This primary burner is located at the corner of the two wings offset from the front face by 40 millimetres. It is a triangular tray filled with sand with two equal sides of 250 millimetres and a height of 80 millimetres. A gas pipe is attached to the tray so the gas flows through the sand diffusing it. The burner is calibrated to give a heat output of 30.7 kilowatts, which is intended to represent a wastepaper bin on fire in the corner of the room. Although the burner is offset from

the front face, flames given off by the burner can make direct contact with the outside face of the test material.

The auxiliary burner is located remote from the test apparatus on a post opposite to the specimen corner and at a height of 1.45 metres from the floor. The auxiliary burner is ignited with the same propane gas supply as the primary burner, but simply to provide a baseline average burner heat and smoke output at the start of the test.

In order to subtract the contribution of the primary burner from the measured results at the end of the tests, and to carry out calculations with the results and attribute them only to the specimen, the only purpose of the auxiliary burner is to run it for a period of 180 seconds before the primary burner is ignited, and then subtract those values from the total heat and smoke output of the burner and specimen at the end of the main test.

An exhaust system is located above the test apparatus. In addition to the practical purpose of extracting smoke from a burning specimen, several measurements are taken in the duct exhausting the smoke. These are thermocouples to measure the temperature of the smoke, a pressure-sensing probe to measure the flow

induced pressure difference in the duct, a gas sensor that measures the oxygen and carbon dioxide content of the air being extracted, and a light source and light sensor that shines through the smoke to measure how much light is being blocked, hence how dense the smoke is.

The video on screen now shows the test procedure for the single burning item test.

(Video played)

So, again, there are very detailed sets of requirements for the data to be measured in this test. The horizontal flame spread is recorded as the occurrence of sustained flames reaching the far edge of the long wing specimen. The fall of flaming droplets or particles shall be recorded only within the first 600 seconds of the exposure period, and only when the droplets or particles reach the floor level of the trolley outside the burner zone.

After 26 minutes the gas supply is terminated and the automatic recording is also stopped, and I've explained all the sensors in the exhaust duct. These quantities are recorded automatically and used to calculate the volume flow, the heat release rate and the smoke production rate from the specimen during the test.

Section 9 of the standard sets out how the results of this test must be expressed. There is a lot of data

and analysis required, and it is essential to read the BS EN in full to understand this. These are key to the European classes.

In short, the burning behaviour is represented by a series of graphs showing the average heat release rate, the total heat release rate and the fire growth rate indices versus time. The smoke production behaviour is given as a further series of graphs of the average smoke production, the total smoke production and the smoke growth rate index.

Later in the classification standard, the designation s will appear, and it is calculated here.

The production of flaming droplets and particles must be confirmed as an occurrence or not for the product. Later in the classification, the designation d will appear, and it is calculated here.

On the slide now are the requirements to be included in the test report. Again, a general description of the product tested, including its density, mass, form of construction, description of the substrate, and fixing to the substrate must be recorded, and again that statement regarding the test results.

Annex A of this standard goes on to set out in detail the series of parameters that must be calculated to evaluate the performance of the product. I have marked only some of them in yellow here. These include the total heat release rate noted as THR on the screen, and the fire growth rate indices noted as FIGRA values on the screen, but all of the calculations listed here must be carried out using the test data.

The standard provides a detailed calculation method for THR600s, which I have shown on the screen now. I am not going to talk through these equations today. But instead, it's to note that THR600s is defined as the total heat release rate of the specimen in the first 600 seconds of the exposure period.

The standard provides a calculation method for FIGRA, which I have shown on screen now. Again, I'm not going to talk through these equations today.

FIGRA also has a very complex definition, which I have presented on the screen here, and I will come back to that again later.

It is a little easier to understand the data analysis by observing here how the results are then presented in a test report. On screen now are the heat release rate versus time; THR and FIGRA graphs for the Arconic Reynobond 55 PE riveted panel.

Ultimately, as I have presented already, section 9 of the test standard sets out exactly how the results of the test must be expressed, and all the calculations

I have shown result in this required expression, as shown again on the screen here. These results are referred to for nearly every European class. So, despite their complexity, an awareness of them helps in understanding the European classifications later in my presentation.

Finally, the fourth European reaction to fire test is BS EN ISO 11925-2, the ignitability of building products subjected to direct impingement of flame. This is referred to as the European single-flame source test. It is designed to simulate a small flame being directly applied to the surface or to the edge of a material. The standard is dated 2010, as the version relevant to the Grenfell Tower refurbishment. It superseded a version dated 2002, which was withdrawn.

On screen now is the apparatus for the single-flame source test. The apparatus comprises of a Bunsen burner housed within an outer housing called the combustion chamber.

The image on screen now shows a cross-section through the combustion chamber looking side on. The sample is suspended from the back wall of the outer housing and the Bunsen burner is mounted onto a horizontal plate so that it moves smoothly forwards and backwards in a horizontal plane along the centre

line of the combustion chamber. An aluminium tray containing sheets of paper is placed below the sample so that any flaming droplets will land on the paper and potentially ignite the paper.

A test specimen 250 millimetres long by 90 millimetres wide is prepared. The maximum permitted thickness of the specimen is 60 millimetres. A material that is normally less than 60 millimetres can therefore be tested to its full thickness, and a material that is greater than 60 millimetres should be cut down from the unexposed side to fit into the test rig.

Tom is now holding up a to-scale replica of the test specimen.

As stated on the screen, a total of six representative specimens are required in one test. Another key point is if a product is installed with covered edges, but can also be used with unprotected edges, tests shall be performed on both covered and uncovered specimens. This is different to part 6 and part 7, discussed earlier, where the tests are designed to prevent edge exposure.

Again, the issue of incorporating the influence of the substrate on the specimen behaviour is addressed clearly in the standard.

The specimen is vertically mounted into the test

frame. A burner is fitted on a track and applies a flame directly to the surface of the material. This burner uses a propane gas fuel, and the flame length must be calibrated to be no longer than 20 millimetres.

You can see in the diagram on the left that the flame is angled at 45 degrees. Two different exposures are used: surface exposure and edge exposure. A surface exposure test must always be undertaken. Edge exposure tests are only undertaken if the edges can be exposed under end conditions. Therefore, if in the envisaged end-use application direct flame attack on the edge cannot occur, the product does not need to be tested.

When a surface exposure is used, the flame is applied 40 millimetres up from the bottom of the specimen on its front face. A reference line is marked on the sample, and I will show you this on the next slide. When an edge exposure is used, the flame is applied on the bottom edge of the specimen.

The flame is then applied to the material for either 15 or 30 seconds, depending on the classification the sponsor wishes to obtain. The higher European class B down to the European class D are based on a 30-second exposure. Once the flame is applied the extent of vertical flame spread is observed and recorded. The image here is from a test video that we will watch in a few moments. The bottom blue line is the 40-millimetre line where the flame is applied for a surface exposure test, and the second line marks 150 millimetres above the flame application point.

If the flame application time is 15 seconds, then the end of test is 20 seconds, to allow 5 seconds of observation time. If the flame application time is 30 seconds, then the end of test is at 60 seconds, allowing a further 30 seconds' observation time.

For the edge exposure version of the test, the burner has specific required locations set out in the test standard. For a material greater than 3 millimetres thick but less than 10 millimetres, the flame is applied to the underside using the 45-degree angle burner, 1.5 millimetres behind the front face of the specimen. This is whether it's a single layer, as shown by the image on the left, or multiple layers, as shown in the figure on the right.

Where the material is less than 3 millimetres thick, the flame is applied at the mid-point of the bottom edge, as shown in the test standard.

For all multilayer products greater than 10 millimetres, an additional set of tests shall be carried out, with the specimen turned at 90 degrees round its vertical axis, and the flame impinging at the

bottom edge of the centre line of each different layer. A test is done for each of the layers that make up the sample.

I'm now showing you a video of this test procedure.

(Video played)

Regarding the results, first it is noted whether the flame extent reaches the 150-millimetre line marked on the screen. Also, the presence of any flaming on the specimen once the pilot flame is removed is recorded. The test report must identify whether any flaming debris falling from the specimen ignites the filter paper.

On the slide now are the requirements for the test report. The results of the test shall be expressed by a record of the following: the position of flame application; whether ignition occurs; whether the flame tip reaches 150 millimetres above the flame application point and the time at which this occurs; presence of flaming droplets or particles which cause ignition of the filter paper; and observations of physical behaviour of the test specimen.

Again, the test report has to include a general description of product tested, the form of construction of the specimen, including the description of substrate used and methods of fixing. This test also requires information on the intended application of the product,

if known, and it contains the same statement again.

To finish this session: finally, when I was explaining the single burning item test earlier, the large-scale specimen heated in the corner, I mentioned that smoke production and flaming droplets were recorded in that test. I have also explained that flaming droplets are recorded in this last test, the single-flame source test.

In the classification standard which I'm about to explain, it sets limits for s and d. As shown on the screen, it is useful to understand the smoke production is obtained from the single burning corner test only, whereas the flaming droplet performance is obtained from both the single burning item and single-flame source test.

This ends my description of the detailed test procedures presented in the four European reaction to fire test standards.

SIR MARTIN MOORE-BICK: Good, thank you very much indeed.

DR LANE: Thank you.

MS GRANGE: Mr Chairman, I think that's the moment that we were going to take lunch, so we're in your hands. We could either take around an hour and begin again at 1.45, or -- just to be aware, I think there is around an hour's worth of presentation left.

DR LANE: Yes, probably just under an hour.

MS GRANGE: Just under an hour left, so equally we could break now and start again at 2.00.

SIR MARTIN MOORE-BICK: I'm going to ask Dr Lane what she would prefer to do.

DR LANE: I think that I'm communicating an extensive quantity of information, so maybe we should wait until 2.00.

SIR MARTIN MOORE-BICK: I'm very happy to do that.

DR LANE: If you're happy to do that, yes.

SIR MARTIN MOORE-BICK: Right. We will stop at that point and then resume at 2 o'clock, please.

MS GRANGE: Yes, thank you.

DR LANE: Okay, thank you.

SIR MARTIN MOORE-BICK: Thank you very much.

(Pause)

Thank you, 2 o'clock, please.

MS GRANGE: Thank you very much.

(12.40 pm)

(The short adjournment)

(2.00 pm)

SIR MARTIN MOORE-BICK: Dr Lane, before you start, Ms Grange has been asked to repeat the warning so that people who have joined us halfway through aren't taken by surprise.

DR LANE: Oh, right, yes.

MS GRANGE: Yes, thank you, Mr Chairman.

So I need to give a trigger warning about some of the content of this presentation. Included in this presentation are some images and videos of fire scenarios, and also included are some images of Grenfell Tower on the night and when on fire, including some images taken from inside the tower after the fire. So anyone who doesn't want to see those kind of images shouldn't watch this presentation.

Okay, thank you very much.

SIR MARTIN MOORE-BICK: Yes, thank you very much.

Yes, Dr Lane. Well, I think we're ready to continue, if you are, thank you.

DR LANE: Yes.

Okay, so for the next hour I'm going to cover two final subjects.

First, the European reaction to fire test classification system.

So I've explained the four European reaction to fire tests, so now I need to explain the classification system which is published to use with them. I will explain how the classification system considers all that data produced from those tests, and explains how to use the data to classify construction products.

The overarching classification standard for European

reaction to fire testing is presented in BS EN 13501-1, the fire classification of construction products and building elements using test data from reaction to fire tests.

The scope of the standard states:

"This European Standard provides the reaction to fire classification procedure for all construction products, including products incorporated within building elements. Products are considered in relation to their end use application. This document applies to three categories, which are treated separately in this European Standard."

I will focus on construction products only today.

I have excerpted some key definitions set out in the standard for substrate, standard substrate and end-use application. It's important to understand those definitions.

Substrate is a product which is used immediately beneath the product about which information is required. The classification standard also communicates something called a standard substrate, a product which is representative of the substrate used in end-use applications. And the end-use application is also given a definition: the real application of a product in relation to all aspects that influence the behaviour of

that product under different fire situations.

First, in the classification standard, it provides at table 1 all the different European classes. These are in letter form, unlike the national classes which are typically numeric in form. For each class, this table states a classification can only be obtained by undertaking the tests or the extended application process required for that particular product. The table lists the specific tests relevant to the particular European class, as presented on the slide now. It provides a narrative explanation of the requirements in the main body of the text in the standard that follows.

Table 1 contains seven material classifications possible, ranging from the highest European class A1 down to the very lowest European class F. It lists the combination of specific tests required, and it lists the specific classification criteria required within each test. You will start to see where all this extensive analysis to form parameters is starting to become relevant.

I will now go through each of the European classes, starting with the highest performance, A1. The limits I am about to describe are for homogeneous materials and substantial components of non-homogeneous products. Note that for composite materials, each layer must be

tested. Composite materials use the same tests; however, the relevant limits are a little more complicated, depending on where each material sits relative to each other and the thickness of the layers.

Evidence of an A2-cored ACM panel has been submitted to this Inquiry, and this was considered as a composite and hence the limits for composites was applied, and I just wanted to make that point clear.

No relevant test evidence has been submitted to the Inquiry for an insulation material achieving A1 or A2, so I'm actually not clear whether it would be treated as a homogeneous material or whether the foil facing would result in it being considered a composite material.

Class A1 requires test data from two reaction to fire tests: the gross heat of combustion, measured in the bomb calorimeter, and the non-combustibility furnace test. On the screen we have shown the requirements and a reminder of the test apparatus.

To be classified as A1, the material must also be tested in the BS EN ISO 1182 furnace, and cause a rise in furnace temperature no greater than 30 degrees Celsius. The specimen should not degrade by more than 50% during the test, and there should be no sustained flaming observed on the specimen. Only where a material meets all these criteria can it be classified as A1.

There are two combinations of tests that can be used to classify a material as class A2. Remember that a class A2 material would be considered a material of limited combustibility under Approved Document B and so would apply to an insulation material.

In either combination, the single burning item test is required, and that's the test with the corner specimen shown in the bottom photograph.

The material must achieve a fire index growth rate, FIGRA, of less than 120 watts per second in the single burning item test. The flame front must not extend to the edge of the long wing, and the total heat release in the first 600 seconds after the primary burner is ignited must not exceed 7.5 megajoules.

In addition to the single burning item test, the material should be tested in the bomb calorimeter or the electric furnace as part of the non-combustibility test.

For BS EN ISO 1716 the requirement for class A2 is that the heat of combustion does not exceed 3 megajoules per kilogram. For the non-combustibility test, the furnace thermocouple temperature must not rise by more than 50 degrees C, and the material specimen must not degrade by more than 50%. Finally, the specimen must

not flame more than 20 seconds.

It is at the discretion of the sponsor whether they test in accordance with combination 1 or combination 2 to demonstrate class A2. Both are acceptable means under the European classification system.

The next European classification is class B. From European class B downwards, there is a different set of test combinations required. The non-combustibility test and the bomb calorimeter are no longer used, and the remaining classifications rely on the single burning item test and the single-flame source tests only.

The next five slides highlight the requirements to classify a material as class B, C, D, E and down to the lowest classification possible, F. As you will see, the testing remains much the same, but the requirements when analysing the data recorded in the test become less onerous as the classifications move down to F.

A class B material must achieve a fire growth rate of less than 120 watts per second in the single burning item test. The flame front must not extend to the edge of the long wing, and the total heat release in the first 600 seconds must not exceed 7.5 megajoules.

In the single-flame source test, a class B material must have had a 30-second exposure, and the flame must not have spread to the reference line at the end of the

test, which is 60 seconds.

The material must satisfy the criteria for both the single burning item test and the single-flame source test to be classified as class B.

As we move down to a class C material, you will notice the testing combination require doesn't change. But, as I have highlighted in blue, the fire index growth rate may now go up to 250 watts per second, and the total heat release rate in the first 600 seconds has increased to 15 megajoules, and this is class C.

For class D, the fire index growth rate, FIGRA, increases to 750 watts per second. Note that the lateral flame spread and total heat release rate are no longer criteria in the classification standard.

There is no change in criteria from the single-flame source test.

The next important change occurs at class E. Now only a single test, the single-flame source test, is required, and the exposure time has decreased to 15 seconds, with a 5-second observation period.

Class F is applied when a product has no performance criteria. It also applies if a product fails to obtain class E when tested to the single-flame source test.

I have summarised the classifications and the tests required to obtain them here for the seven

European classes for reference.

Now, I need to talk again about s and d.

The image on the screen now is taken from section 14 from the classification standard. It lists all the possible combinations of European classification as I have just presented, and it shows the sliding scale from A1 down to F. But each of these is further subdivided based on the volume of smoke production and flaming droplets production.

Classification s1, s2, s3 for smoke production are deduced from the measuring data obtained in the single burning item test, specifically from the data that produces the smoke growth rate, or SMOGRA. Classifications d0, d1 and d2 for flaming droplets and particles are deduced from observations of flaming droplets and particles in the single-flame source test and the single burning item tests.

I have set out the limits for all the ss and ds, I'm not going to go through them again now, but it is important to understand that the Approved Document B cited s3 and d2 only in 2013, and therefore set no limit for smoke production or flaming droplets and particles.

A final note regarding classification to the European standards.

The classification standard states the field of application of the classification is identical to the field of application resulting from the tests or from the extended application process. If different end-use applications are envisaged for a particular product, this may result in different classifications.

In considering substrates and backings which can be applied in practice, the classification specifies standard substrates for use in tests and also gives rules for the field of application of test results obtained using those standard substrates. Use of standard substrates is not mandatory. Instead, the product may also be tested in its end-use conditions, with a substrate representative of the end use.

When such a representative substrate is used, the test result is limited only to that same substrate in its end-use application.

The applicability of test results obtained for products attached to a substrate is limited to the method of attachment used in the test.

An extended field of application is the outcome of a process involving the application of defined rules that predict a test result but based on one or more test results to the same standard.

For any product or material, a fire test report and a classification report is required. These photos are

taken from the French test reports for Reynobond. It is not possible to understand the substrate or the full details of the fixing for the system being tested by this visual means only.

On screen now is the specific field of application stated in that particular assessment report for the Arconic Reynobond 55 PE riveted system. It's important to read the specific nature of the field of application. It refers to a system riveted on any metallic substructure, and it makes clear the substrate must be to an A1 or A2 standard, with a particular density greater than 700 kilograms per metres cubed. It also specifies a minimum air gap of 50 millimetres.

The European classes are also referred to from Approved Document B.

Back to table A6, but this time in the European class part of the table. There, there are two definitions of non-combustible provided, as you can see highlighted on the screen. The first blue box at (a) relies on testing and classification as I've just described. The second option in the lower blue box is by means of specific materials deemed to satisfy the performance.

Back up at paragraph (a), it states there that non-combustible materials are any material classified as

class A1 to the classification standard.

The second fire definition provided in Approved Document B is in table A7. This is a key definition regarding the insulation products. You can see in paragraph (a) that any material defined as non-combustible will also satisfy the European class for limited combustibility too.

Secondly, as marked at point (b), a material of limited combustibility is defined as a material or product classified as class a2-s3, d2 or better. This relies on the test evidence from the two combinations of testing I explained earlier.

However, a material of limited combustibility, which has a European class designation, is also referenced for another part of the external wall.

So back again to table A7, up at row 6, marked here, "Class 0 materials meeting the provisions in appendix A, paragraph 13(a)", which states if a material or the surface of a composite product is one of two performances, again the first being "composed throughout of materials of limited combustibility", and that means class A2-s3, d2 or better, as I have just described. It's essential to be aware this is not in the insulation row in table A7.

But I want to discuss diagram 40 when considering

the European classes.

Taking Grenfell Tower as the building example, the external surface classification was class B-s3, d2 or better for the building, because it had a dimension over 18 metres and it was 1,000 millimetres more from the relevant boundary to adjacent buildings, and this applied to the part of the building over 18 metres, so looking at the yellow box highlighted on the building there on the screen, and the reference to class B in the blue box marked on the screen. This meant the composite products used for the external surface needed to have been tested as a minimum to the single burning item test and the single-flame source test, exactly as set out on the right-hand side of diagram 40.

But if you look at the national and European classes together for the external surface of the building, this means the surface must either be class 0 or class B-s3, d2. But the issue is, by definition, using European classifications, class 0 can only be achieved via clause 13(a) and so must be class A2-s3, d2 or better. This is a higher performance standard than set out in diagram 40, which refers to class B. There is, therefore, a disparity between the national class designation and the European class designation.

Finally, when I was explaining the test procedures for the European tests, I referred regularly to various calculations required from the test data. I now want to show briefly their relevance to the European classes.

First, for insulation required to achieve class A2-s3, d2 or better, table 1 states data is required from two test standards, and the limits from the data recorded in the test is also made clear in the classification standard, and those limits are shown on the screen.

Also, A2 can be obtained using these two test standards, and again the limits when using this combination are clearly shown on the screen.

The requirement for the external surface was to achieve class B-s3, d2, and table 1 of the classification standard again sets out clearly the criteria for the classification standard using the data and calculations from those tests.

So for all of the possible combinations of European classification and the sliding scale down from A1 to F, the test data and the calculations are clearly set out in the classification standard and each one has limits set for the relevant European class.

The Inquiry has made me aware of a study on equivalency regarding the national and European classes.

In 2000, Exova Warringtonfire Research issued

a report entitled "RADAR 2 Project-Correlation of UK Reaction to Fire Classes for Building Products with Euroclasses and Guidance on Revision of Approved Document B". A total of 64 products were tested to the national and European reaction to fire tests across seven so-called sectors of wood, mineral wool, paints, cellular plastics, wall coverings, boards and sheets, and plastics.

The introduction to part 2 of the report states:

"The objective of this Part 2 work is to consider how the test results and classifications obtained in [the part 1 report] may be compared so that classification transpositions may be identified and if satisfactory correlations can be established, to propose to DETR how a supplementary guidance document for Approved Document B may be prepared."

When comparing the equivalence of class 0 and the European classifications, 35 class 0 products were compared: four wood-based, three mineral wool insulation products, six types of paint, seven types of cellular plastic insulation product, six different wall coverings, six board and sheet products, and three plastic-based products.

I do not understand the purpose of testing three mineral wool insulation products, nor the cellular

plastic insulation for class 0, as this was not the relevant performance requirement, as I've stated earlier. The only cladding panel tested was an FR high-pressure decorative laminate panel.

On screen now is table 2, taken from part 2 of the report. That shows products that were tested and achieved class 0 and their subsequent European classification.

I have taken these results and I've shown them on the screen now. It can be seen that the majority of the class 0 samples achieved class B. However, one of the samples was as low as class E. This was a wood fibre board. The class C product was an aluminium-faced phenolic foam insulation, and the class D product was an aluminium-faced PIR insulation. The only panel tested was an FR HPL panel and it achieved class B.

On screen now I have excerpted the conclusions of part 2 of the RADAR report with regards to PIR and phenolic foam insulation:

"With these products it was observed that in the [single burning item] test, the aluminium foil facing was penetrated such that the underlying foam was then available to contribute to the rate of heat release calculation whereas in the ... BS 476:Part 6, the heat release found in that test was not sufficient to

displace the classification away from the UK class 0.

"Clearly, the introduction of a simple replacement of the UK Class 0 by Euroclass B requirement in any regulatory procedure would discriminate against products [listed on the slide] against the practical experience of their acceptability in the UK market for class 0 applications."

The RADAR reports are very detailed and require careful study, but I found this particular paragraph particularly striking:

"Any reference to Class 0 being equivalent to Euroclass A2 would severely restrict the market choice in terms of materials for specifiers and clients. This applies to virtually all organic containing materials. In Germany and France the authorities have a single classification. Thus Euroclass B could be a cross-border compromise which is supported by the high product density obtained at the class 0/Euroclass B transposition point."

Finally, the European classes were referred to regarding the Grenfell Tower primary refurbishment external wall products.

Only one product installed on Grenfell Tower was presented as relying on the European classification system, and this was the Reynobond 55 PE panel. Celotex did not test their insulation to the European tests until after the Grenfell Tower fire.

On screen now is the BBA agrément certificate for the Arconic Reynobond panels. I have highlighted how the BBA represented the standard sample it relied on with a classification of B-s2, d0. No field of application information was provided.

This concludes my presentation on the European classification and reaction to fire testing methods.

SIR MARTIN MOORE-BICK: Thank you.

(Pause)

DR LANE: Okay, the last section.

This is the final section of my presentation, and it focuses on the subject of cladding systems and not individual products, as I have dealt with so far.

I explain the fire tests for cladding systems referred to within the Approved Document B, and these are called British Standard 8414, parts 1 and 2.

I explain the performance criteria given in the BRE Report BR 135 on the subject of fire performance of external thermal insulation for walls of multistorey buildings, also referred to within Approved Document B. This explains the performance criteria to assess the test data from the 8414 tests.

As a reminder, paragraph 12.5 of ADB states:

"The external envelope of a building should not provide a medium for fire spread if it is likely to be a risk to health or safety. The use of combustible materials in the cladding system and extensive cavities may present such a risk in tall buildings.

"External walls should either meet the guidance given in paragraphs 12.6 to 12.9 or meet the performance criteria given in the BRE Report ... for cladding systems using full scale test data from BS 8414 [parts 1 and 2]."

So the full-scale data ADB refers to is generated using the 8414 test, and it is then evaluated using the performance criteria and classification method described in the BRE document.

First, however, I want to explain the derivation of these tests and their performance criteria. These methods are founded on principles aired since the 1980s. In 1988, Rogowski et al undertook experiments at the BRE Cardington Laboratory due to the rise in what was then the new technique of the application of thermal insulation on the outside face of buildings. Rogowski stated:

"The use of appropriately designed systems particularly on the walls of high rise buildings

provides an attractive method of energy conservation."

He stated the need for improved thermal insulation of buildings had led to the introduction of a range of systems originally designed for external application to solid masonry walls, but noted they were now being extended in application by means of installation on the outside of multistorey developments, done so as not to disturb occupants during the installation.

Rogowski, as part of the introduction to the report, identified that control over the external surface of walls of buildings, particularly those of multistorey flats, was controlled by reference to BS 476-6 and 7. However, he advised that this only provided information on the surface fire behaviour, going on to state that the overall fire performance of ventilated cladding systems could only be investigated under actual fire conditions on a full-scale building façade.

To identify the design principles affecting the safety of occupants and the probable extent of fire spread, Rogowski of the BRE conducted large-scale tests in a four-storey experimental building that was 9.2 metres high and 3.7 metres square in plan.

On screen now are three of the key conclusions made by Rogowski as a result of his large-scale experimental work:

"To reduce the risk of vertical fire spread in existing and proposed external insulation systems the following recommendations based on this test programme are proposed by the Department of the Environment:

"Proposed systems incorporating combustible insulants with sheeted overcladding should be designed to incorporate fire barriers in the ventilated cavity every two storeys.

"Surface protection applied directly to all combustible insulants must be carefully designed and installed, round windows and other openings.

"Timber cladding should continue to be used only in low rise developments ... to avoid extensive self-propagating flame spread over the surface."

The BRE were at the time an executive agency of the Department of the Environment.

Three years later in 1991, a fire occurred in an 11-storey tower block called Knowsley Heights in Merseyside. The fire occurred when rubbish was set alight outside the building. The fire spread from the ground floor up the full height of the external wall of the building, and this triggered further work at the BRE, undertaken by Dr Raymond Connolly in 1994.

In relation to Knowsley Heights fire, Dr Connolly states in his 1994 report, which was titled

"Investigation of the behaviour of external cladding systems in fire - a report on 10 full-scale fire tests", that the overcladding system involved achieved a class 0 rating and the insulation was non-combustible. He also stated that one of the reasons for the rapid spread of the fire was an unusual construction detail which effectively created a flue that travelled up through the height of the building.

Dr Connolly's 1994 report goes on to detail out an experimental investigation into the performance of external cladding systems on exposure to fire. The objective of this particular investigation was to assess the effectiveness of installation of fire barriers in reducing the fire hazard. Non-combustible insulation was used in each test, and two types of external overcladding that achieved class 0, relying on British Standard 476-6 and 7 tests, were installed. The test rig was of a similar scale to Rogowski et al.

The overall conclusions formed by Connolly included the need to install fire barriers in external systems with cavities to reduce the potential fire spread; that fire protection solely around the windows was inadequate; that reduction of the width of a cavity reduced the surface spread of flame over the cladding material.

Of particular relevance was he concluded that small-scale reaction to fire properties of the cladding materials did not reflect the fire hazard associated with the full-scale cladding system. He concluded too that the provision and nature of fire barriers and cavity width needed to be considered.

Finally, he concluded the clear need for full-scale testing of performance in fire for what he termed rational design of cladding systems.

It is important to note that, within his overall paper, Connolly highlighted in his "Discussion of results" for "Surface spread of flame over the façade" the following two key points.

Connolly states:

"It is clear that the BS.476 Parts 6 and 7 tests do not accurately reflect the fire hazards that may be associated with cladding systems. Reasons may include the fact that the flame movement in a real cladding fire is in the vertical direction, as opposed to the horizontal direction in the test."

Secondly, he states that:

"It is clear from the experimental work undertaken at Cardington that a cladding material achieving a Class 0 rating may suffer extensive surface burning."

On 11 June 1999, a fatal fire occurred at

Garnock Court in Scotland. This fire involved the external wall of the building, as was the case with the Knowsley Heights fire.

On screen now is an excerpt from the parliamentary inquiry into this fire. Firstly, the Inquiry references the previous fire at Knowsley Heights. It then appears to reference the Connolly tests in 1994 as I have just presented. This inquiry then goes on to state:

"BRE proceeded to develop an appropriate full-scale fire test, known as 'A test for assessing the fire performance of external cladding systems'. This test was submitted to the DETR in 1996."

This test standard, which had been submitted to the DETR prior to the fire, had not been adopted into Approved Document B at the time.

However, in the Garnock Inquiry, DETR themselves stated that, going forward, this test will be referenced in Approved Document B and that it was intended that it become a British Standard.

The Inquiry has disclosed to me one test standard created by the BRE in 1996 titled "CR 213/96". The Inquiry has also given to me a second test standard created by the BRE in 1998, one year before the Garnock fire. This is called Fire Note 3. Neither of these documents were publicly issued by the BRE, and the

authors were Morris, Colwell, Connolly, Smit and Andrews, noting Morris only worked on Fire Note 3. I have compared these two BRE documents and there is no material difference between them.

However, one month following the Garnock Court fire in 1999, the BRE published another large-scale cladding test document titled Fire Note 9. This should not be confused with Fire Note 3.

I have reviewed the test rig in these three publications, and there is no material difference between them, so I will now only refer to Fire Note 9. But I have compared it right back with Rogowski's work in 1988 and Connolly's work in 1994, as I wanted to understand how Fire Note 9 had been adapted over the years, and I wanted to know if any fundamental issues observed in those founding experiments had been either retained or omitted.

Fire Note 9 was written by S Colwell and D Smit of the BRE.

I have provided in the script to my slide information on the dimensions of the test rig, which were in general the same as Rogowski and Connolly's test rig. The Fire Note 9 rig did contain a wing wall, which I will explain later, whereas Rogowski and Connolly's test rig did not. Importantly, Fire Note 9 does not include windows in the test rig, whereas Rogowski and Connolly did.

The proposed crib in Fire Note 9 was very similar to Rogowski and somewhat similar to Dr Connolly's experiments. Again, an extensive read of these publications is needed.

Fire Note 9 contained pass/fail criteria for a proposed full-scale fire test. These were: a fire test would fail if the temperature rise above ambient, 5 metres above the top of the combustion chamber exceeded 600 degrees Celsius for at least 30 seconds, within 15 minutes of the start time.

These pass/fail criteria continued into later versions of BR 135, with additional failure criteria introduced in the third version of BR 135.

This is important because Fire Note 9 was first referenced in Approved Document B 2000 as an alternative means for complying with the Building Regulations for external surfaces. This aligns with what DETR had said to the Garnock Inquiry.

Three years later, in 2002, Fire Note 9 was converted into a British Standard, British Standard 8414-1, as shown on the slide here. The Approved Document B was not updated to refer to this British Standard at that time.

There were minor changes made to the test rig for the publication of the British Standard. These included the main wall width being reduced from 2.8 to 2.6 metres.

This British Standard did not contain pass/fail criteria for the fire tests; however, instead, the second edition of BR 135 was published. Again, Approved Document B was not updated to refer to this. This second edition was authored by Brian Martin and Sarah Colwell. Annex A of the second edition contained the performance criteria and classification method of British Standard 8414-1. The performance criteria were unamended when compared with those presented in Fire Note 9.

From 2005 onwards, various amended versions of BS 8414 and the classification method publication BR 135 were made, and I have listed them here on this slide.

I will now explain both the British Standard test method and the BR 135 classification method in the following slides. I will explain the fire test procedure first and then the classification method, in the same style as all the other tests I have explained to you today.

First, the tests.

British Standard 8414 is a two-part

British Standard. The scope of both is defined as:

"... a test method for determining the fire performance characteristics of non-load-bearing external cladding systems when exposed to an external fire under controlled conditions. The fire exposure is representative of an external fire source or a fully developed (post-flashover) fire in a room, venting through an opening such as a window aperture that exposes the cladding to the effects of external flames, or from an external fire source."

Part 1, shown on the left image on the screen, is the test method for non-load-bearing external cladding systems when applied to the masonry face of a building, so this scope includes rainscreen overcladding systems and external wall insulation systems when applied to the face of a building.

Part 2 on the right of the screen is the test method for non-load-bearing external cladding systems fixed to and supported by a structural steel frame. Its scope includes curtain walling, infill panels and insulated composite panels fixed to and supported by a structural steel frame.

So the primary difference between the two standards is the substrate and framework of the final cladding system.

The purpose of the test is to evaluate the ability of the system to resist the propagation of the fire upwards or penetration through the system. Part 1 was the relevant standard for Grenfell Tower.

BR 135 contains two annexes, and each provides performance criteria to be observed and measured during the 8414 tests. Annex A and annex B address BS 8414-1 and 2 respectively.

Regarding the test rig used in the British Standard test, the test apparatus consists of a combustion chamber in which a fuel source is located at ground level with an opening area of 2 metres by 2 metres. The chamber is positioned such that the fire can project through the opening at the base of the main vertical test wall. There are two 8-metre high test walls arranged at 90 degrees to represent the inner angle of a corner.

The test specimen on the main wall must be a minimum of 2.6 metres wide when measured from the corner, and a minimum of 6 metres in height when measured from the top of the combustion chamber. The return wall must be a minimum of 1.5 metres wide and 8 metres in height.

British Standard 8414 states that:

"The test specimen shall include all relevant components assembled and installed in accordance with the manufacturer's instructions ."

Where cladding systems are defined as "includes sheeting rails, fixings, cavities, insulation and membranes, coatings, flashings or joints". This is provided at note 1 of the definition of "external cladding system".

During the test, two types of data are recorded: temperature and visual observations of significant events.

First, I will explain how temperature is measured.

An array of thermocouples are located on the exterior surface of the cladding system at 2.5 metres and 5 metres above the test opening. Thermocouples do not make direct contact with the cladding and are positioned at a distance of 50 millimetres from the surface. Those located at 2.5 metres are considered representative of a level 1. Those located 5 metres above the combustion chamber are considered representative of a level 2.

Thermocouples on the main wall are positioned on the centre line of the wall and then at 500 or 1,000 millimetres either side of this centre line. This creates an array of five thermocouples at level 1 and level 2 on the main wall.

Thermocouples on the return wall are positioned at

150, 600, and 1,050 millimetres from the junction with the main wall. This creates an array of three thermocouples at two heights on the return wall.

Internal thermocouples are also placed within the cladding system in any combustible layers that are greater than 10 millimetres in thickness or more. These internal thermocouples are positioned at level 2 only.

All internal thermocouples are positioned at the mid-point of the layer and temperature measurements taken for the duration of the test, as shown in the image on the right of the screen.

In this example, on the right-hand side, there is an external thermocouple by the grey layer and two additional internal thermocouples, one at the mid-point of the cavity and one at the mid-depth of the insulating material.

If the external cladding system does not offer any protection to openings in practice, ie there are no cavity barriers around the openings, then the interface between the test specimen and the combustion chamber must also remain unprotected. This is as stated at note 1 to the definition of "external cladding systems" in the British Standard.

If horizontal and vertical joints are incorporated into the external cladding system, the test specimen

shall be representative of these joints.

In practice, if the size of panels in their end use are smaller than the area of wall represented by the apparatus, there may be multiple horizontal and vertical joints.

On the left-hand image is an elevation of a panel system and I have overmarked the joints in orange on the right.

The fuel source used in the test is a timber crib, comprising alternating layers of softwood sticks. The crib has a plan area of 1.5 by 1 metre and a height of 1 metre. The crib is ignited with strips of fibre board soaked in white spirit, and is designed to represent a nominal total heat output of 4,500 megajoules, with a peak heat release rate of 3 megawatts. To give that size some context, in the Eurocode 1, "Action on structures", the typical residential apartment is assumed to contain a fire load density of 780 megajoules per metre squared. This translates approximately into an area of 5.7 metres squared when fully alight.

I have overmarked a 5.7 metre squared area in the drawing of flat 16 on the image on the left of the slide just to give a sense of scale.

Secondly, visual observations of significant events are to be recorded. The standard states:

"The times of significant events such as change of flaming conditions and mechanical behaviour of the cladding system are to be recorded; especially detachment of any part of the cladding system (whether flaming or otherwise) or any other fire penetrations through firestops incorporated within the cladding system."

A continuous audio-visual record of the full height of the test face is taken throughout the test to allow for analysis. Cameras should provide coverage of the entire external surface of the material. In addition, internal audio-visual coverage is required for tests to the part 2 standard to assess any burn through to the internal face of the cladding system.

Five minutes before the crib is ignited, the thermocouples and audio-visual equipment begin taking measurements. The crib is ignited. Temperatures and visual recordings are made from five minutes before ignition until 60 minutes after ignition. The crib is allowed to burn for 30 minutes, at which point it is extinguished. The test continues for a further 30 minutes, during which time any observed flaming on the test specimen is allowed to continue burning.

The test is stopped early if at any point during the test flames extend above the test apparatus, or if there is a risk to the safety of personnel within the test facility. This stopping of the test aspect was only introduced into the test standards in 2005. It was not cited within part 1 of British Standard 8414 until 2015, when both parts 1 and 2 were updated. The reference to this early termination was added to the third edition of BR 135 in 2013, and this is important to note when reading historic test reports.

I'm just going show the video first.

(Video played)

In this short video, we see a test being carried out. You can see that the fire in the crib in the combustion chamber has ignited, with flames projecting above the combustion chamber and impacting on the cladding assembly several metres above. The graphs of temperature shown on the right here are measurements taken at level 2, so 5 metres above the opening. These are measured by thermocouples external to the cladding surface, inside the cavity between the cladding and insulation, and within the insulation product itself. I'll explain this later.

A test report should be provided for each test undertaken, including if the test is terminated early, and this is required by the British Standard. It should include a full description of the cladding system,

together with details of materials and components used and fixing details, details of the results of the test and observations we discussed earlier, and a record of visual observations made during the test, including flaming and mechanical response, supplemented by suitable photographic records. For tests to part 2, full details of the test frame must also be included.

It's worth noting that, by the time of the Grenfell fire, the BRE were the UK's only testing lab with accreditation to undertake British Standard 8414 testing.

Finally, I will summarise the performance criteria and classification method set out in the classification standard.

Three editions of BR 135 have been published by BRE: the first was Rogowski's work, the second in 2003, and the third in 2013.

BR 135 makes clear the application of its classification only applies to the system as tested and detailed in the classification report. When specifying or checking a system, therefore, it is important to check that the classification documents cover the end-use application.

BR 135 focuses on three main performance criteria: external fire spread, internal fire spread, and

mechanical performance. Failure due to external fire spread is deemed to have occurred if the temperature rise above TS -- that's the initial, ambient temperature before the crib is ignited -- of any of the external thermocouples at level 2 exceeds 600 degrees Celsius for a period of at least 30 seconds and within 15 minutes of the start time TS.

This start time isn't the point at which the crib is ignited. It is defined as the point at which any thermocouple at level 1 equals or exceeds 200 degrees Celsius for a period of 30 seconds.

If the temperature of 600 degrees Celsius is not exceeded within 15 minutes, then the system passes the external fire spread performance criteria.

To explain the context of this 15-minute window relied upon in the classification method, I have as an example marked up the level 2 external temperature versus time graph taken from a recent MHCLG test report by the Fire Protection Association, and the references are provided here.

This was a part 1 test of a HPL panel over a class A1 insulation material. The grey dashed line shown on the screen now indicates 600 degrees above ambient temperature. The blue dashed line indicates 15 minutes after TS. The area in the green box

indicates the envelope of time and temperature within the test that BR 135 considers for external fire spread performance. You can see the peak external temperatures in this particular test do not occur in this window, and instead occur later, at around 30 minutes after TS.

Next, failure due to internal fire spread is deemed to have occurred if the temperature rise above TS of any of the internal thermocouples at level 2 exceeds 600 degrees C for a period of at least 30 seconds within 15 minutes of the start time.

An example graph taken from BR 135 is shown at figure A6 on the screen now. Please note the clear peak occurring in this graph at 15 minutes after TS.

Again, to give some context regarding the 15-minute window relied upon in the BR 135 classification method, I have assessed the level 2 cavity temperature versus time graph from those MHCLG tests again, but considering the measured internal fire spread data. Again, the grey dashed line indicates 600 degrees Celsius above ambient temperature limit, and the dashed blue line indicates 15 minutes after TS limit.

You can see in this particular test the measured peak internal temperatures occurred at around 32 minutes after TS.

I decided to take this analysis a little further and

I've analysed 21 BS 8414 test reports. 12 were tested to part 1 and nine to part 2. Of these 21, seven were the MHCLG tests undertaken after the Grenfell fire, one of which was the HPL test I've referred to already, and the remaining 13 were from tests disclosed to the Inquiry by Kingspan, Celotex and Siderise.

On screen now are individual dots representing the peak temperatures measured at level 2 in each of the 21 tests and the time they occurred.

I have also coloured the graph to indicate in red what would be considered a failure to meet the current BR 135 performance criteria, as shown in the red area there on the left-hand side of the blue dashed line.

If one takes the performance criteria as not exceeding 600 degrees C -- so the red dashed line -- in 30 minutes instead of the current 15 minutes, please note the increased number of failed tests above the dashed red line.

The panel should consider if modern materials and modern façades typically reach peak flaming combustion within 15 minutes of the start of a BS 8414 test.

But back to the third performance criterion in BRE classification method, which is mechanical performance. No failure criteria are set in BR 135 annex A for mechanical performance when considering test data from

part 1.

Reading from the extract shown on the screen:

"No failure criteria have been set for mechanical performance. However, ongoing system combustion following extinguishing of the ignition source shall be included in the test and classification reports, together with details of any system collapse, spalling, delamination, flaming debris or pool fires. The nature of the mechanical performance should be considered as part of the overall risk assessment when specifying the system."

This extract tells us that occurrences of mechanical failure, such as system collapse or delamination, can be recorded in the test report but do not constitute a failure when classifying in accordance with BR 135.

Finally, references to this test and classification method during the Grenfell refurbishment.

These were referred to as part of the primary refurbishment works. On screen now is the Celotex RS5000 datasheet {RYD00018155}. I have marked up the sections that refer to British Standard 8414 and BR 135.

Page 3 of the datasheet provides the following description of the Celotex assembly that was stated as tested and formed part of the classification report.

That system was not installed on Grenfell Tower.

Just to make a final point, the image on screen now shows the sizes of the small-scale test requirements for the sample sizes to determine material performance as we have discussed today. The final item on the far right is representative of the smaller size flat panel of Reynobond 55 PE that Arconic sold as referenced in the BBA agrément certificate.

I have redone that slide, including the 8414 test, which is the very large sample before the Arconic panel.

I have also summarised the test duration for each one of the tests I have told you about today.

That ends my explanation of the cladding tests, and I was just going to provide some final points to consider after what has been a very detailed presentation.

Throughout this presentation, I have made reference to various issues I thought the panel might like to consider, and I wanted to sum them up now, after three hours or so of communicating some very detailed information:

That the reaction to fire testing regime is associated with internal room fire phenomena, yet they are relied upon in the statutory guidance document to reduce the surface's susceptibility to ignition from

an external source and to reduce the danger from fire spread up the external face of the building.

That the national reaction to fire tests includes one surface spread of flame test, and this measures spread in the horizontal direction.

That the external surface and the insulation have been considered separately for several decades, and that class 0 has been the reference for the external surface performance since 1965.

That the definition of class 0 has degraded with time, reduced from non-combustible materials throughout, and also the role of the substrate removed from the statutory guidance document, yet both the national and European reaction to fire testing regime very carefully set out rules regarding substrates and their impact on fire performance when testing.

And that the window of assessment of the data from the large-scale British Standard 8414 test is early in the fire, and may be before peak temperatures are measured for relevant cladding materials.

Overall, though, I hope I have communicated the intricacies of each standard test, the careful explanation provided in each test standard of the physical features of the test rig, how each test rig has been created to represent specific fire performance characteristics, and how specific parameters have been derived for each test, with a requirement then for very careful analysis of the data produced from these tests.

Extensive work seems to have gone into defining these tests, how to derive results from them, and how to rely on them to classify construction products and materials. It would be of considerable interest to hear the perspective from those that created and monitored the reaction to fire test standards in this country, those companies that carried out the tests, those companies that issued classification reports, and those companies that issued certificates, their understanding of how those parameters were derived, how those parameters were relied upon, and how relevant they consider them to be to the fire performance of external walls.

Thank you.

SIR MARTIN MOORE-BICK: Well, Dr Lane, thank you very much indeed. It's very interesting. There is a lot there to digest though.

DR LANE: Yes, I know. As requested, yes.

SIR MARTIN MOORE-BICK: Yes, Ms Grange.

MS GRANGE: Yes, Mr Chairman. There's a huge amount of work gone into that, to make it quite so clear.

SIR MARTIN MOORE-BICK: Yes.

MS GRANGE: So I would like to extend my thanks, and I'm sure those behind me would as well, to Dr Lane and her team for putting together such a comprehensive and clear presentation.

SIR MARTIN MOORE-BICK: Certainly. We are all very grateful --

DR LANE: No problem.

SIR MARTIN MOORE-BICK: -- for the enormous amount of work that's been put in and for a very clear exposition. Thank you very much.

DR LANE: Yes, okay. Right, thank you.

SIR MARTIN MOORE-BICK: So we can let Dr Lane go, can we?

MS GRANGE: Yes, we say goodbye to Dr Lane for now. I'm sure she'll be back at some point.

DR LANE: Yes, okay. Thank you.

SIR MARTIN MOORE-BICK: All right. Thank you very much indeed. And thank you, Tom, for your assistance.

(The witness withdrew)

MS GRANGE: Then we start with the first of the Celotex witnesses tomorrow, Mr Roome, whom Mr Millett will be questioning.

SIR MARTIN MOORE-BICK: Yes. And that is it for today?

MS GRANGE: That is it for today. We have an early finish. We don't get those very often.

SIR MARTIN MOORE-BICK: No, we don't.

Good. Thank you very much. So we will break there and we'll resume at 10 o'clock tomorrow, when we shall hear from the first of the Celotex witnesses.

MS GRANGE: Thank you.

SIR MARTIN MOORE-BICK: Thank you very much, 10 o'clock tomorrow, please.

(3.12 pm)

(The hearing adjourned until 10 am on Wednesday, 11 November 2020)

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