

<p>1 Wednesday, 20 June 2018</p> <p>2 (10.00 am)</p> <p>3 SIR MARTIN MOORE-BICK: Well, good morning, everyone, and</p> <p>4 welcome to today's hearing. We are going to hear</p> <p>5 a further presentation from one of the inquiry's</p> <p>6 experts.</p> <p>7 Yes, Mr Millett.</p> <p>8 MR MILLETT: Good morning, Mr Chairman.</p> <p>9 This is the final day of the experts' presentations</p> <p>10 for this week. Today, Professor Luke Bisby, who sits on</p> <p>11 your right, will be explaining certain key scientific</p> <p>12 concepts relevant to flammability and to flame spread.</p> <p>13 He will be describing the material properties of certain</p> <p>14 materials present in the facade and in the windows of</p> <p>15 Grenfell Tower. He will also set out the preliminary</p> <p>16 evidence which assists in understanding the pattern of</p> <p>17 flame spread out of flat 16 and over the exterior of the</p> <p>18 tower on the night of the fire.</p> <p>19 Before I call Professor Bisby formally, I should</p> <p>20 give certain trigger warnings about the content of his</p> <p>21 presentation.</p> <p>22 His presentation, and particularly this afternoon,</p> <p>23 will include a large number of images, videos and audio</p> <p>24 depicting the external flame spread on the night of the</p> <p>25 fire. That will include the playing of his composite</p> <p style="text-align: center;">Page 1</p>	<p>1 section 1.6 of your report, you have provided it in the</p> <p>2 same way as you would have provided a report to a court.</p> <p>3 PROFESSOR BISBY: That's correct.</p> <p>4 MR MILLETT: In section 1.4 and appendix D to your report,</p> <p>5 you have outlined your background and your experience</p> <p>6 relevant to the matters in this inquiry.</p> <p>7 PROFESSOR BISBY: Yes, I have.</p> <p>8 MR MILLETT: I'm not going to ask you to repeat the detail</p> <p>9 of that today, we can take that as read, but in terms of</p> <p>10 key points, would you agree you are a professor of fire</p> <p>11 and structures within the school of engineering at the</p> <p>12 University of Edinburgh in Scotland?</p> <p>13 PROFESSOR BISBY: That's correct.</p> <p>14 MR MILLETT: And prior to taking on your expert witness role</p> <p>15 for this inquiry, you were also head of the research</p> <p>16 institute for infrastructure and environment at the</p> <p>17 University of Edinburgh?</p> <p>18 PROFESSOR BISBY: Yes.</p> <p>19 MR MILLETT: You are a co-editor-in-chief of the technical</p> <p>20 and scientific publication Fire Safety Journal?</p> <p>21 PROFESSOR BISBY: That's correct.</p> <p>22 MR MILLETT: And you are, I think, a chartered structural</p> <p>23 engineer with the Institution of Structural Engineers</p> <p>24 and a licensed professional engineer in Ontario in</p> <p>25 Canada?</p> <p style="text-align: center;">Page 3</p>
<p>1 flame spread video, which was played during my opening,</p> <p>2 and the detailed consideration of that and other flame</p> <p>3 spread material which shows the building burning and on</p> <p>4 fire. Some of the videos include the audio of people</p> <p>5 witnessing the fire, and their distress at the unfolding</p> <p>6 events.</p> <p>7 The presentation will also contain a number of</p> <p>8 images of the burnt-out tower after the fire and the</p> <p>9 playing of the first 999 call by Mr Kebede.</p> <p>10 So, Mr Chairman, I will now call Professor Bisby.</p> <p>11 SIR MARTIN MOORE-BICK: Thank you.</p> <p>12 PROFESSOR LUKE BISBY (affirmed)</p> <p>13 SIR MARTIN MOORE-BICK: Thank you.</p> <p>14 MR MILLETT: Thank you.</p> <p>15 Professor Bisby, could you please give the inquiry</p> <p>16 your flame?</p> <p>17 PROFESSOR BISBY: Luke Alexander Bisby.</p> <p>18 MR MILLETT: You have provided to the inquiry a written</p> <p>19 report which is dated 2 April 2018.</p> <p>20 PROFESSOR BISBY: That's correct.</p> <p>21 MR MILLETT: That report addresses the ignition of the</p> <p>22 facade materials and your preliminary conclusions on the</p> <p>23 fire spread to and on the exterior of the building.</p> <p>24 PROFESSOR BISBY: Yes, it does.</p> <p>25 MR MILLETT: As you indicate in the declaration in</p> <p style="text-align: center;">Page 2</p>	<p>1 PROFESSOR BISBY: That's correct.</p> <p>2 MR MILLETT: You are also an active member of the UK</p> <p>3 Standing Committee on Structural Safety, or SCOSS, and</p> <p>4 Confidential Reporting on Structural Safety, CROSS, and</p> <p>5 a fellow of both the Institution of Fire Engineers and</p> <p>6 the Institution of Structural Engineers?</p> <p>7 PROFESSOR BISBY: That is correct.</p> <p>8 MR MILLETT: Are the factual matters set out in your report</p> <p>9 true to the best of your knowledge and belief?</p> <p>10 PROFESSOR BISBY: Yes, they are.</p> <p>11 MR MILLETT: And does your report accurately set out your</p> <p>12 opinions on matters relevant to this inquiry?</p> <p>13 PROFESSOR BISBY: Yes, it does.</p> <p>14 MR MILLETT: Thank you very much, Professor Bisby. Please</p> <p>15 do now go ahead and give your presentation.</p> <p>16 PROFESSOR BISBY: Thank you and good morning.</p> <p>17 The Grenfell Tower fire initiated in the early hours</p> <p>18 of Wednesday, 14 June 2017 and continued for many hours,</p> <p>19 with tragic effect. This catastrophic event resulted in</p> <p>20 71 fatalities on that night and continues to cause</p> <p>21 immense trauma to the bereaved, survivors and affected</p> <p>22 community. I'd like to begin my presentation by</p> <p>23 acknowledging this central, continuing and human aspect</p> <p>24 of the fire.</p> <p>25 During the preparation of my report, I have reviewed</p> <p style="text-align: center;">Page 4</p>

<p>1 harrowing evidence from victims, survivors and emergency                  2 services, and I extend my deepest sympathies to those                  3 whose lives and loved ones were and continue to be                  4 caught up in this tragic event.                  5 As an instructed expert witness to the                  6 Grenfell Tower inquiry with a specific and technical                  7 remit, my Phase 1 report necessarily focuses on                  8 scientific and physical information and analysis related                  9 to the construction of the building and its external                  10 cladding.                  11 It is my hope that my Phase 1 report, along with the                  12 presentation and subsequent Phase 1 evidence, will help                  13 you, sir, as well as experts and laypeople alike, to                  14 begin to understand, particularly in physical and                  15 scientific terms, how and why the Grenfell Tower fire                  16 14 June 2017 spread so rapidly and so extensively, with                  17 devastating effect.                  18 My Phase 1 report is intended to serve two purposes:                  19 first, to provide an initial understanding of the                  20 ignition of the cladding materials at Grenfell Tower;                  21 second, to set out preliminary conclusions on fire                  22 spread to and on the exterior of the building.                  23 During my presentation today, I will focus on                  24 presenting the preliminary evidence that I've gathered,                  25 rather than on my hypotheses and conclusions with</p> <p style="text-align: center;">Page 5</p>	<p>1 inquiry's core participants.                  2 For the benefit of yourself and the wider                  3 participants to the inquiry, I'd like to place my work                  4 for the inquiry within the context of the work being                  5 undertaken by the inquiry's other instructed experts.                  6 As Mr Millett has previously explained, Phase 1 of the                  7 inquiry is intended to investigate the development of                  8 the fire itself, where and how it started, how it spread                  9 from its original location to other parts of the                  10 building, and the chain of events that unfolded during                  11 the course of the hours until it was finally                  12 extinguished or burned out.                  13 Phase 1 is also examining the response of the                  14 emergency services and the evacuation of the residents.                  15 For Phase 1, you asked me to provide a report on                  16 a subset of these issues.                  17 The first of these is ignition of the building's                  18 cladding materials, and if I may paraphrase: how did the                  19 fire get from inside the building out and onto the                  20 exterior cladding?                  21 My second task is to provide preliminary evidence on                  22 fire spread to and on the exterior of the building.                  23 Again, if I may paraphrase: how and why did the fire                  24 spread so rapidly and so extensively over all four faces                  25 of the building?</p> <p style="text-align: center;">Page 7</p>
<p>1 respect to that evidence, although I will touch on these                  2 where necessary, at this early stage of the inquiry's                  3 hearings.                  4 My preliminary evidence includes images and video                  5 submitted by members of the public. I am particularly                  6 grateful for these as without them my task would have                  7 been even more challenging.                  8 My preliminary evidence also includes: evidence                  9 collected by the London Fire Brigade and the                  10 Metropolitan Police Service; information obtained from                  11 my own site investigations at Grenfell Tower; testing                  12 undertaken by various organisations, including the                  13 University of Edinburgh, on behalf of the inquiry; and                  14 information obtained by or provided to the inquiry from                  15 a range of organisations, including core participants to                  16 the inquiry.                  17 I've also drawn on my own background knowledge and                  18 on that of a core of my specialist colleagues at the                  19 University of Edinburgh, specifically Dr Angus Law                  20 Dr Rory Hadden and Emeritus Professor Dougal Drysdale.                  21 In addition, I've drawn on the academic literature                  22 and, in a limited number of cases, information which is                  23 publicly available via the worldwide web.                  24 All of this information is referenced within my                  25 Phase 1 report and has been made available to the</p> <p style="text-align: center;">Page 6</p>	<p>1 My focus is therefore on the cladding materials,                  2 products and systems at Grenfell Tower and the rapid and                  3 extensive external fire spread.                  4 I will not comment extensively on the fire's origin                  5 and cause, the emergency service response, spread of                  6 fire and smoke within the building or the building's                  7 evacuation. These are of course all critically                  8 important topics but are being addressed by the                  9 inquiry's other experts.                  10 I will also avoid commenting on the regulatory                  11 compliance of the materials, products and systems used                  12 at Grenfell Tower as regards the applicable Building                  13 Regulations and guidance documents.                  14 In line with your instructions, my Phase 1 work has                  15 been concerned with identifying what aspects of the                  16 building design and construction played a significant                  17 role in enabling the disaster to occur. It is only by                  18 understanding the specific make-up of the cladding and                  19 the physical processes by which the fire spread over the                  20 building that you will be able to evaluate the relative                  21 roles of materials, products and systems during the                  22 fire.                  23 To address the relevant issues, my presentation is                  24 structured in three parts:                  25 First, fire science. I will provide a brief</p> <p style="text-align: center;">Page 8</p>

<p>1 overview of the fire science that is necessary to                  2 adequately understand the factors influencing fire                  3 spread to and on the cladding. This will also help to                  4 explain the potential contributions of different                  5 materials to exacerbating the speed and extent of the                  6 external fire spread.                  7 Second, cladding materials and products. I will                  8 describe, in considerable detail, the various materials                  9 and products used within the external cladding system                  10 and briefly how each of these responds to heating from                  11 a fire.                  12 The third and final part of my presentation will                  13 focus on fire spread to and on the cladding on the night                  14 of the fire.                  15 I will re-visit the video shown during the opening                  16 remarks by Mr Millett, and I will use this, along with                  17 other evidence, to provide a detailed summary of both                  18 the timelines and the physical mechanisms of fire                  19 spread.                  20 So part 1 deals with fire science.                  21 The first part of my presentation deals with two                  22 particular aspects of fire science that are central to                  23 what occurred at Grenfell Tower: flammability and fire                  24 spread. Together, these will help us to understand how                  25 the fire spread to the cladding and on the cladding.</p> <p style="text-align: center;">Page 9</p>	<p>1 understanding of the physical mechanisms that govern                  2 both flammability and flame spread.                  3 I will avoid technical language and jargon to the                  4 extent possible; however, this is science and the                  5 subject matter is rather complex. Indeed, highlighting                  6 the complexities of the science is one of the key things                  7 that I hope to accomplish today. The topic therefore                  8 demands a certain level of technical terminology.                  9 Fire.                  10 We all have a sense of what fire is and a sense of                  11 which materials will burn and which will not, but fire                  12 is not, in reality, a single and simple process; rather,                  13 it is the result of a sequence of interrelated processes                  14 that may occur when fuel, oxygen and an ignition source                  15 are combined under the correct conditions.                  16 Fire is the visible flame, smoke and heat produced                  17 by an uncontrolled combustion reaction. This results                  18 from a chemical reaction between flammable gases and                  19 oxygen, which makes up 21 per cent of air. The                  20 combustion reaction occurs rapidly and is exothermic, by                  21 which I mean that it releases energy and we perceive                  22 this as heat and light.                  23 In the case of burning of solid materials -- such as                  24 wood, plastics or, indeed, insulating foams -- the                  25 flammable gases which enter the flame are produced by</p> <p style="text-align: center;">Page 11</p>
<p>1 Both flammability and flame spread are intuitively                  2 understood by most people in general terms; however,                  3 I believe it's important to begin my presentation of my                  4 preliminary evidence by discussing their more precise                  5 technical meanings as well. Otherwise, developing                  6 a deep understanding and unpicking the causal roles                  7 associated with cladding materials products and systems                  8 is impossible.                  9 Flammability refers to the ease of ignition of                  10 a material and the manner in which it burns. The                  11 flammability of a material is governed by the physical                  12 properties of the material, its chemical composition,                  13 and to some extent the manner in which its flammability                  14 is evaluated. A range of different flammability test                  15 are used, both in the UK and internationally.                  16 Flammability is not a yes/no proposition; there is                  17 a gradation of performance amongst materials and                  18 products.                  19 Flame spread, however, is governed by a material's                  20 properties, its immediate environment and its geometry.                  21 As with flammability, a range of different tests can be                  22 used to assess the flame spread on different materials                  23 and products.                  24 To interpret and understand the evidence of fire                  25 spread at Grenfell Tower, it's necessary to have a basic</p> <p style="text-align: center;">Page 10</p>	<p>1 a process of thermal decomposition. This process is                  2 referred to as pyrolysis.                  3 Gases produced by pyrolysis of the solid are                  4 flammable when they react with oxygen in the air and                  5 form gaseous products such as carbon dioxide and water                  6 vapour. In addition, very small solid particles are                  7 generated. These form the visible component of smoke or                  8 soot.                  9 In order for flaming to occur, the fuel must be in                  10 the form of a gas. This means that it's able to mix and                  11 react with oxygen from the surrounding air. Critically,                  12 this means that solids do not burn directly. Instead,                  13 it is the gaseous fuel produced by the thermal                  14 decomposition of the solid that is burning.                  15 This distinction may at first seem unimportant, but                  16 I hope that my reasons for making it become clear during                  17 the course of my presentation.                  18 The combustion of solids can be readily illustrated                  19 using the familiar example of a flame produced by the                  20 burning of a wooden matchstick, as I have shown here.                  21 Here I should like to say, sir, that while I'm going                  22 to use a matchstick to illustrate some of the key                  23 concepts of flammability and flame spread, in reality                  24 the processes at play in the ignition and burning of                  25 a match are even more complex than I will be able to</p> <p style="text-align: center;">Page 12</p>

<p>1 describe in my limited time today.</p> <p>2 The solid in this case is the wood from which the</p> <p>3 matchstick is made. Wood, as we all intuitively</p> <p>4 understand, is a combustible material. When wood is</p> <p>5 heated, in this case by the flame from the match itself,</p> <p>6 the molecules that make up the solid wood thermally</p> <p>7 decompose and are released as flammable gases. By this</p> <p>8 I mean the wood undergoes pyrolysis.</p> <p>9 These flammable gases are transported into the flame</p> <p>10 by a buoyant flow due to the fact that hot gases rise.</p> <p>11 As the flammable gases are transported into the flame,</p> <p>12 they mix with oxygen which is available from the</p> <p>13 surrounding air. We say that the surrounding air is</p> <p>14 entrained into the flame.</p> <p>15 Provided that sufficient heat is present within the</p> <p>16 flame, and that the mixture of flammable gases and</p> <p>17 oxygen is in the correct proportions, the gases and</p> <p>18 oxygen will react. This reaction releases energy, which</p> <p>19 heats up the gases, which then radiate energy.</p> <p>20 This reaction also produces combustion products such</p> <p>21 as carbon dioxide, water vapour and tiny soot particles,</p> <p>22 as I have already mentioned. It is the glowing, by</p> <p>23 which I mean the emission of thermal radiation and</p> <p>24 light, of these heated soot particles that produces the</p> <p>25 characteristic yellow flame that we associate with fire.</p> <p style="text-align: center;">Page 13</p>	<p>1 pyrolysis. The rate at which pyrolysis occurs will then</p> <p>2 influence whether a flammable mixture of pyrolysis gas</p> <p>3 and air will form and sustain a flame. By this I mean</p> <p>4 that the rate at which pyrolysis occurs will dictate</p> <p>5 whether a material ignites and whether it will continue</p> <p>6 to burn.</p> <p>7 Not all mixtures of flammable gas and oxygen can</p> <p>8 burn. The gas and oxygen have to be in the correct</p> <p>9 proportions, and in the presence of an appropriate</p> <p>10 ignition source. Those mixtures that can burn are</p> <p>11 called flammable mixtures.</p> <p>12 Furthermore, both the thermal properties of</p> <p>13 a material and its geometry play important roles in</p> <p>14 determining both its ignition and its burning behaviour,</p> <p>15 and both are central to developing a physical</p> <p>16 understanding of what occurred at Grenfell Tower.</p> <p>17 I would now like to discuss some particular</p> <p>18 technical concepts and terminology which relate to the</p> <p>19 heating of a solid material.</p> <p>20 When discussing the fire behaviour of materials, it</p> <p>21 is conventional to differentiate between materials that</p> <p>22 are known as thermally thick and thermally thin</p> <p>23 materials. This distinction is based on the physical</p> <p>24 dimensions of the material, the material properties and</p> <p>25 the thermal characteristics of the surrounding</p> <p style="text-align: center;">Page 15</p>
<p>1 The flame can therefore heat objects by two</p> <p>2 processes of heat transfer: convection of buoyant hot</p> <p>3 gases -- typically above the flame, as I have shown</p> <p>4 here -- and by radiation to any materials that are</p> <p>5 within sight of the flame.</p> <p>6 In the case where the match is held horizontally, as</p> <p>7 shown here, it is radiation from the flame -- shown</p> <p>8 there -- and conduction along the matchstick -- shown by</p> <p>9 that arrow -- which heats the unburned wood. Conduction</p> <p>10 refers to the transfer of heat within the solid. This</p> <p>11 heating of the wood causes further release of flammable</p> <p>12 gases and so on in a self-sustaining process that we</p> <p>13 call fire.</p> <p>14 As I've just outlined, the process of thermal</p> <p>15 decomposition of a solid material is called pyrolysis.</p> <p>16 This process is endothermic, meaning that it requires</p> <p>17 a supply of energy from an external source in order to</p> <p>18 occur.</p> <p>19 Pyrolysis is fundamental to determining how, or</p> <p>20 rather if, a solid material will ignite and continue to</p> <p>21 burn and the conditions under which this can occur.</p> <p>22 Pyrolysis, like any chemical reaction, is strongly</p> <p>23 temperature-dependent, in that higher temperatures</p> <p>24 result in faster pyrolysis. This means that the rate at</p> <p>25 which a solid can be heated will depend on its rate of</p> <p style="text-align: center;">Page 14</p>	<p>1 environment.</p> <p>2 Essentially, a thermally thin fuel is one which</p> <p>3 heats uniformly and can be characterised by one</p> <p>4 temperature. In this case, the response of the material</p> <p>5 is limited by the transfer of heat from its</p> <p>6 surroundings.</p> <p>7 A thermally thick fuel is one which heats</p> <p>8 non-uniformly and exhibits an internal temperature</p> <p>9 gradient as energy is transferred into the body of the</p> <p>10 material. By this I mean that the surface of the</p> <p>11 material gets hot but the interior stays relatively</p> <p>12 cool. In this case, the response of the material is</p> <p>13 influenced by the rate of heat transfer within the</p> <p>14 material via the process of heat conduction, as I've</p> <p>15 already mentioned.</p> <p>16 Thermally thin fuels ignite more readily than</p> <p>17 thermally thick fuels, all other factors being equal.</p> <p>18 A familiar example of thermal thickness can be</p> <p>19 understood by comparing the ease of ignition of wood</p> <p>20 shavings versus a solid block of wood. Both are</p> <p>21 composed of the same material: wood; however, the wood</p> <p>22 shavings are thermally thin and can be readily heated</p> <p>23 such that ignition occurs.</p> <p>24 The large block of wood, however, is thermally thick</p> <p>25 and, when exposed to a flame, the heat is conducted into</p> <p style="text-align: center;">Page 16</p>

<p>1 the block and away from the surface, thus making it 2 harder to ignite. 3 The difference between these two cases, as regards 4 both ignition of a material and the chances that it will 5 continue to burn, are shown in these side-by-side videos 6 of wood shavings and the block of wood, in both cases 7 ignited by a match. 8 I'll play this now. 9 (Video played) 10 You can see, actually, multiple attempts to ignite 11 the block of wood with subsequent matches. 12 You get the point, I hope. 13 For thermally thick fuel, when exposed to a heat 14 source, the surface temperature of the solid material 15 will begin to increase. The rate of increase is 16 determined in part by the physical properties of the 17 material. 18 The key parameters in this situation are: 19 First, the thermal conductivity of the material, 20 this is a measure of the ability of the material to 21 transfer thermal energy internally by conduction; 22 second, the density of the material, and this is 23 a measure of the material's mass per unit volume; and, 24 third, the material's specific heat capacity, and this 25 is a measure of the amount of energy required to</p> <p style="text-align: center;">Page 17</p>	<p>1 help us to understand, and hopefully eventually to 2 quantify, the potential roles of the various materials 3 and products that made up the cladding at 4 Grenfell Tower. 5 As a result of the factors that I've now described, 6 it's common to assume a pyrolysis temperature at which 7 pyrolysis will occur for a given material. All other 8 factors being equal, materials with higher pyrolysis 9 temperatures are more difficult to ignite than those 10 with lower pyrolysis temperatures. 11 Let me now turn my attention to the issue of 12 flammability. 13 On a day-to-day basis we tend to think of materials 14 as either being flammable or not, or as being either 15 combustible or not. Indeed, the word "combustible" has 16 received a great deal of attention and use in the media 17 since the Grenfell Tower fire. 18 In reality, for materials that have the potential to 19 burn, by which I mean those materials that are 20 combustible, flammability is a relative rather than 21 absolute property. 22 Depending on the circumstances, therefore, 23 combustible materials can either be more or less 24 flammable, and this distinction is actually very 25 important.</p> <p style="text-align: center;">Page 19</p>
<p>1 increase the temperature of 1 kilogram of the material 2 by 1 degree Celsius. 3 A heat transfer analysis can show that the product 4 of these three parameters -- thermal conductivity 5 multiplied by the density multiplied by the specific 6 heat -- governs the rate at which the surface 7 temperature of a solid material increases when exposed 8 to a heat source. This is called the thermal inertia of 9 the material, and it represents, if you like, the ease 10 with which the surface temperature of a material will 11 change when exposed to heating. 12 Materials with a high thermal inertia -- such as 13 metals, for example -- are comparatively slow to heat at 14 the surface, all other factors being equal. Conversely, 15 the surface temperature of material with low thermal 16 inertia -- such as polymer foam insulation, for 17 instance -- will increase rapidly when heated. 18 As I've already stated, pyrolysis is 19 a temperature-dependent process. Thus, there is 20 a strong coupling between heating of the solid and 21 pyrolysis. Consequently, materials with a low thermal 22 inertia, where the surface will heat more rapidly, will 23 initially experience more rapid pyrolysis than materials 24 with higher thermal inertia. 25 It's very important to understand this because it</p> <p style="text-align: center;">Page 18</p>	<p>1 In a regulatory context, material flammability 2 quantifies the degree to which a material will burn with 3 a flame under specified conditions. Material 4 flammability tests therefore allow different materials 5 to be ranked as regards their suitability in certain 6 applications based on results from tests in standardised 7 test apparatus. 8 It should be noted, however, that material 9 flammability parameters are not fundamental material 10 properties. This is precisely because they depend on 11 the method of evaluation. 12 Flammability testing outcomes may be influenced by 13 a range of phenomena and I believe it's worth taking 14 a bit of time now to discuss these in general terms 15 before moving on to look at the specific materials, 16 products and systems that were installed in the cladding 17 at Grenfell Tower. 18 First, ignition. 19 In the context of most fire safety applications, 20 ignition is defined as the initiation of what is known 21 as gas phase combustion. By this I mean sustained 22 flaming or burning of pyrolysis gases in the manner 23 I described earlier using the photo of the wooden 24 matchstick. Ignition is the moment that the visible 25 flame first appears.</p> <p style="text-align: center;">Page 20</p>

<p>1 Whether ignition of a solid material occurs in 2 a given situation is strongly time-dependent. This 3 means that ignition only occurs after a period of 4 heating of the solid such that its surface temperature 5 reaches the pyrolysis temperature and flammable gases 6 are produced by pyrolysis in sufficient quantities to 7 sustain a flame. 8 Common ignition tests used in practice apply 9 a radiant heating source to heat a material. The 10 magnitude of the heating is defined in terms of what's 11 called the incident heat flux. Heat flux is a measure 12 of the thermal energy delivered to a surface over 13 a given period of time. We can think of it as, if you 14 like, the severity of heating. This is typically 15 expressed in units of kilowatts per square metre, where 16 one kilowatt is equivalent to 1,000 joules per second. 17 Joules are the scientific units used to quantify energy, 18 be it thermal, electrical or any other form of energy. 19 Radiation heat fluxes are called irradiances, and 20 values of up to 50 kilowatts per square metre are 21 typically used in materials testing to represent fire 22 exposures in buildings, although I should note that much 23 higher heat fluxes may actually be experienced in 24 reality. 25 To put this in perspective for you, a solid block of</p> <p style="text-align: center;">Page 21</p>	<p>1 (Video played) 2 For a solid block of wood like the one I've shown 3 here, if I were to then remove the external heat 4 source -- in this case, the radiant heater to the right 5 of the block of wood -- the heat transfer to the wood 6 would actually be insufficient to continue to generate 7 the necessary pyrolysis gases and the flaming combustion 8 would stop -- the flame would go out. Higher heat 9 fluxes therefore lead to more rapid ignition, all other 10 factors being equal. 11 As I've already discussed, the rate of heating for 12 thermally thick fuels depends strongly on the thermal 13 inertia of the material. The time to ignition under 14 a given heat flux exposure is therefore also strongly 15 dependent on the thermal inertia of the material. 16 Materials with low thermal inertia -- for example, 17 polymer foams -- heat rapidly at their exposed surfaces, 18 generally resulting in short times to ignition. 19 Materials with higher thermal inertia -- for example, 20 common synthetic polymers, which we more commonly call 21 plastics -- have longer times to ignition. 22 It follows from the preceding discussion that there 23 is a level of heating, by which I mean a level of heat 24 flux, below which ignition will not occur for a given 25 material when tested in a given configuration. This is</p> <p style="text-align: center;">Page 23</p>
<p>1 wood, as I showed previously, would ignite within 2 a matter of seconds under a heat flux of 50 kilowatts 3 per square metre. This scenario is shown in a sequence 4 of video clips that I will show in a moment. 5 Here what you can see is a thermally thick solid 6 block of wood which is exposed to a heat flux of 7 50 kilowatts per square metre, as I just mentioned, from 8 the right-hand side, as shown here. So imagine a very 9 powerful heat lamp pointing at this block of wood from 10 the right-hand side. 11 On exposure to thermal radiation from the right-hand 12 side, as I've mentioned, the timber surface temperature 13 increases rapidly, pyrolysis occurs and flammable gases 14 are released, and you can see that happening here. 15 (Video played) 16 With additional heating, additional pyrolysis gases 17 are released and this is shown in the next clip about 18 15 seconds later for this particular sample. 19 (Video played) 20 These gases mix with the surrounding air, which 21 provides oxygen, as I've mentioned, and eventually, 22 under the right conditions, ignition may occur, 23 followed -- again, under the right conditions -- by 24 sustained flaming combustion or fire. I'll show that 25 here, again about 15 seconds later.</p> <p style="text-align: center;">Page 22</p>	<p>1 called the critical heat flux for ignition. Materials 2 with low values of critical heat flux for ignition are 3 in general easier to ignite than those with high values 4 of critical heat flux for ignition. 5 Understanding how materials ignite is essential, for 6 instance in order to confidently suggest how the fire at 7 Grenfell Tower spread from within the kitchen of flat 16 8 onto or into the cladding adjacent to the kitchen 9 window. The ignition properties of the material are 10 also critical in evaluating their ability to spread 11 flame for reasons that I will discuss in a few minutes. 12 Before doing so, however, I'd like to discuss heat 13 of combustion. 14 Once a material has ignited, the primary variable of 15 interest is the rate at which energy continues to be 16 released, since this is what drives the growth and 17 spread of a fire. 18 The total amount of energy that is available to be 19 released from a material is known as its heat of 20 combustion. This is a measure of the total energy that 21 can be released per unit mass of a material under 22 optimal conditions for combustion. The rate at which 23 energy is released, however, and the fraction of the 24 total available energy that actually is released under 25 a given set of circumstances, is a function of its</p> <p style="text-align: center;">Page 24</p>

<p>1 heating conditions, its geometry and its orientation.                  2 This distinction is critically important because, as                  3 I've already suggested, just because a material can burn                  4 under some circumstances doesn't necessarily mean that                  5 it will burn under a particular set of circumstances,                  6 and this idea will be familiar to anyone who has                  7 attempted to start a log fire without using kindling.                  8 Just because wood can burn doesn't mean it always will.                  9 The heat of combustion of a material is measured by                  10 burning a unit mass of material in an atmosphere of pure                  11 oxygen. This increased reactivity of this atmosphere                  12 compared to air, which as I've already noted is only                  13 21 per cent oxygen, results in complete combustion of                  14 the material and the conversion of virtually all of the                  15 stored chemical energy into thermal energy. The heat of                  16 combustion thus provides an upper limit on the amount of                  17 energy that can be released by the burning of                  18 a material.                  19 However, the heat of combustion on its own does not                  20 give any information regarding the rate at which energy                  21 is released after a material is ignited, nor does it                  22 account for the heat transfer processes that lead to                  23 ignition, the material geometry or the physical changes                  24 that may occur, all of which also affect a material's                  25 burning behaviour.</p> <p style="text-align: center;">Page 25</p>	<p>1 combustion may burn in very different ways once ignited.                  2 At a material level, the heat release rate behaviour                  3 is dictated to a large extent by the pyrolysis behaviour                  4 of the solid material. If the material melts -- such as                  5 in the case of the synthetic polymer material                  6 polyethylene, for example -- then after ignition, the                  7 heat release rate will increase to an essentially steady                  8 value until virtually all of the material is consumed.                  9 This is illustrated schematically in the left-hand                  10 figure shown here.                  11 This is a key point and I'll return to burning of                  12 polyethylene, which I abbreviate in some cases to PE,                  13 later in my presentation.                  14 If, however, the material chars, such as in the                  15 familiar case of wood or the less familiar case of                  16 a thermosetting polymer foam insulation, which I will                  17 also return to later, then under most conditions there                  18 will be an initial period of high heat release, followed                  19 by a period of lessening heat release rate. This is due                  20 to the formation of a protective char layer on the                  21 surface of the material. This is illustrated in the                  22 right-hand figure shown here.                  23 The formation of the char layer decreases the rate                  24 of energy transfer into the material and, hence, reduces                  25 the rate of pyrolysis and therefore the quantity of</p> <p style="text-align: center;">Page 27</p>
<p>1 To give you a sense of the variability of heats of                  2 combustion amongst materials, this chart shows the heats                  3 of combustion of a number of familiar and not so                  4 familiar but relevant materials.                  5 Materials with grey bars are common and in some                  6 senses familiar, but are not considered significant as                  7 regards my preliminary evidence relating to the                  8 Grenfell Tower fire. These are shown because these                  9 materials may be familiar to you and you may have some                  10 understanding of how they react to heating.                  11 Whereas materials in red are less familiar -- aside                  12 from wood, of course -- but were present in significant                  13 quantities within the cladding system at Grenfell Tower.                  14 You may note the broadly similar values for the                  15 synthetic polymer of plastic materials polyethylene and                  16 polystyrene as compared with diesel fuel, for instance.                  17 I'll return to this point later on.                  18 Next, heat release rate.                  19 As I have mentioned, the rate at which energy is                  20 released from a material -- by which I mean whether the                  21 available energy is released quickly or slowly in                  22 a given set of circumstances -- is described by the heat                  23 release rate. The heat release rate describes the rate                  24 of energy released per unit time as an object burns.                  25 Objects made from materials with the same heat of</p> <p style="text-align: center;">Page 26</p>	<p>1 flammable gases produced.                  2 The heat release rate of a material also depends,                  3 again, on its physical geometry and surrounding                  4 conditions, and on the presence of any external heat                  5 sources. The heat release rate of an object burning in                  6 the presence of an external heat source -- such as                  7 a large fire -- will be a strong function of the                  8 magnitude of the external heat source for the reasons                  9 I've already discussed.                  10 The heat release rate is therefore important for                  11 evaluating the fire hazard associated with an object.                  12 This is because it determines the energy released from                  13 a material that is available to be transferred back to                  14 the fuel -- thinking again about my match -- thus                  15 creating a feedback loop which may sustain the flaming.                  16 Materials with a high heat release rate therefore                  17 typically result in more rapid fire growth and/or fire                  18 spread, and, sir, the growth and spread of fire are                  19 obviously of fundamental importance to this inquiry.                  20 So, finally, having discussed these foundational                  21 concepts of fire science, I will turn to flame spread.                  22 Flame spread occurs when sufficient heat is                  23 transferred from a burning region to an adjacent unburnt                  24 material region. The rate at which a fire will grow                  25 depends in part on how rapidly flame can spread on the</p> <p style="text-align: center;">Page 28</p>

<p>1 surface of the material.</p> <p>2 Flame spread is strongly influenced by the physical</p> <p>3 configuration of the system, such as its material</p> <p>4 geometry and orientation. The process of flame spread</p> <p>5 is most easily thought of -- very helpfully, in my</p> <p>6 opinion -- as a series of localised ignitions, and the</p> <p>7 processes required to sustain flame spread are thus the</p> <p>8 same as those that I previously used to describe</p> <p>9 ignition.</p> <p>10 So as already discussed for ignition, sufficient</p> <p>11 energy must be supplied to the combustible solid ahead</p> <p>12 of the flames to heat the material such that pyrolysis</p> <p>13 occurs and flammable gases can be released.</p> <p>14 As the area where the pyrolysis is occurring</p> <p>15 advances, so too does the flame that we can visually</p> <p>16 observe. This is flame spread.</p> <p>17 It is common to distinguish between what is known as</p> <p>18 concurrent flame spread and opposed-flow flame spread.</p> <p>19 Concurrent flame spread occurs when the flame spreads in</p> <p>20 the same direction as the flow of air. I'll show</p> <p>21 examples in a moment. Opposed-flow flame spread occurs</p> <p>22 when the flame spreads in the opposite direction to the</p> <p>23 flow of air. These two extremes are commonly observed</p> <p>24 when a flame spreads upwards -- which we call concurrent</p> <p>25 flame spread -- or downwards -- which is the case of</p> <p style="text-align: center;">Page 29</p>	<p>1 When considering the flame spread on synthetic</p> <p>2 polymers -- which are more commonly called plastics, as</p> <p>3 I've mentioned -- it's important to consider the effects</p> <p>4 of melting and deformations associated with their</p> <p>5 softening. Melting and dripping significantly</p> <p>6 complicate flame spread processes by removing material</p> <p>7 from the system and, with it, some of the available</p> <p>8 energy to drive flame spread. I'll demonstrate this in</p> <p>9 a moment.</p> <p>10 In a moment I'll show a short video that shows</p> <p>11 ignition and upward flame spread on a vertically</p> <p>12 oriented matchstick. I will use this simple, familiar</p> <p>13 example again because of its intuitive value in</p> <p>14 demonstrating the relevant physics.</p> <p>15 In upward flame spread, the heat transfer to the</p> <p>16 unburnt material ahead of the burning region increases</p> <p>17 the size of the burning zone and, hence, the flame</p> <p>18 spread rate. The flame and pyrolysis products produced</p> <p>19 by the burning of the material rise due to buoyancy and</p> <p>20 heat the surface of material, and this results in high</p> <p>21 rates of heat transfer to the surface of the material.</p> <p>22 As the unburnt material ahead of the burning region</p> <p>23 is heated, it begins to pyrolyse and generate flammable</p> <p>24 gas. As the gas ignites, the visible flame spreads</p> <p>25 rapidly. Typically, but not always, the rate at which</p> <p style="text-align: center;">Page 31</p>
<p>1 opposed-flow flame spread.</p> <p>2 Because of the importance to my Phase 1 scope of</p> <p>3 work and to the preliminary evidence that I will present</p> <p>4 later today, I'm now going to describe in some detail</p> <p>5 the key processes associated with upward and downward</p> <p>6 flame spread.</p> <p>7 I will also describe horizontal or lateral flame</p> <p>8 spread. This is in fact a special case of opposed-flow</p> <p>9 flame spread as I'll explain in a few minutes.</p> <p>10 My discussion of flame spread draws on many of the</p> <p>11 fundamental concepts that I've already described, and</p> <p>12 hopefully you can see this is all building.</p> <p>13 The rate of flame spread is dependent on the heat</p> <p>14 transfer to the material and the material's thermal</p> <p>15 inertia. This is because the rate of flame spread is</p> <p>16 governed by the rate at which the material adjacent to</p> <p>17 the burning region can be heated to its pyrolysis</p> <p>18 temperature.</p> <p>19 Upward flame spread is generally faster than</p> <p>20 downward flame spread. This is because in upward flame</p> <p>21 spread, the flames and hot gases which rise due to the</p> <p>22 effect of buoyancy, as I've already mentioned, will</p> <p>23 preheat the material ahead of the advancing flames.</p> <p>24 This preheating does not occur in downward flame spread,</p> <p>25 which is therefore slower.</p> <p style="text-align: center;">Page 30</p>	<p>1 the pyrolysis front advances is faster than the rate at</p> <p>2 which fuel is consumed. This is an important point.</p> <p>3 Consequently, the burning region becomes larger,</p> <p>4 producing flammable pyrolysis products at an increasing</p> <p>5 rate.</p> <p>6 This can be seen in my video in a moment as the</p> <p>7 bottom of the match, you'll see, is still burning as the</p> <p>8 top ignites. The flame becomes larger and thereby</p> <p>9 increases the height of the heated material, which</p> <p>10 further increases the burning area. This positive</p> <p>11 feedback loop results in a self-accelerating process and</p> <p>12 rapid upward spread of flame.</p> <p>13 The sequence of events is shown in this short video.</p> <p>14 (Video played)</p> <p>15 My next short video shows downward or opposed-flow</p> <p>16 flame spread on an otherwise identical vertically</p> <p>17 oriented matchstick. In the case of downward flame</p> <p>18 spread, the rate of heat transfer to the unburnt</p> <p>19 material is much less than in upward flame spread, as</p> <p>20 I have already described. Consequently the length of</p> <p>21 the preheated zone is much smaller, resulting in</p> <p>22 a smaller pyrolysis region, a smaller volume of evolved</p> <p>23 pyrolysis gases and a much slower rate of flame spread.</p> <p>24 Indeed, in this case, flame spread eventually</p> <p>25 extinguishes rather than continuing to spread downwards.</p> <p style="text-align: center;">Page 32</p>

<p>1 This sequence of events is shown in this short video.                  2 (Video played)                  3 You can just see the flame creeping down the                  4 matchstick there slowly.                  5 (Video played)                  6 Then you can see insufficient pyrolysis gases being                  7 released to sustain the flame.                  8 A further special case of opposed-flow flame spread                  9 is horizontal or lateral flame spread. This is similar                  10 to downward flame spread and my next video shows the                  11 flame spreading from right to left.                  12 In this case, the rising hot gas draws air into the                  13 flame from left to right, hence referring to this as                  14 opposed-flow flame spread, as in the case of downward                  15 flame spread. The heat transfer from the flame to the                  16 match is higher than in the downward case, as evidenced                  17 in the spread of the flame horizontally along the match.                  18 In this case, the rate at which the pyrolysis front                  19 advances is approximately equal to the rate at which the                  20 solid fuel is consumed, as evidenced by a steady                  21 movement of the flame from right to left and a flame                  22 with a reasonably uniform size. I'll show this here.                  23 (Video played)                  24 That flame just continues to the left and off the                  25 screen.</p> <p style="text-align: center;">Page 33</p>	<p>1 I'll play this clip in three segments.                  2 In the first segment, we see that a few seconds                  3 after ignition, the molten material is already beginning                  4 to fall down and burn on the floor beneath the sample.                  5 At this point, the flames on the polyethylene are                  6 relatively small.                  7 (Video played)                  8 In the second segment, which begins about 3 minutes                  9 later, we see that the sample is burning on both sides                  10 and that there is an almost constant flow of molten                  11 burning polyethylene falling from the sample to the                  12 floor.                  13 (Video played)                  14 I should point out that the vertical streaks are                  15 rivulets of melted, burning polyethylene.                  16 In the third segment, which begins about 6 minutes                  17 later still, the sample has been significantly consumed                  18 and molten polyethylene continues to fall.                  19 (Video played)                  20 The fact that polyethylene burns in this manner is                  21 not at all surprising. This behaviour has been well                  22 known and documented in the scientific and technical                  23 literature for decades.                  24 This particular issue will become very important                  25 later in my presentation when I discuss the fire spread</p> <p style="text-align: center;">Page 35</p>
<p>1 Now, of course, matchsticks don't melt and drip.                  2 This is not the case, unfortunately, for all materials.                  3 Rapid downward vertical fire spread may occur due to                  4 melting and dripping, in particular for certain                  5 synthetic polymer materials.                  6 When heated in a vertical orientation molten,                  7 possibly burning material may flow downwards. Flame                  8 spread by this mechanism is governed by the viscosity of                  9 the molten material. If heated sufficiently, the molten                  10 material may also form burning droplets which may fall                  11 downwards.                  12 Both of these processes are clearly visible in my                  13 next video clip, and both may contribute to the                  14 formation of pool fires below and in front of the                  15 burning material, as is also clear from my next video.                  16 This slide shows a vertically oriented sheet of                  17 a white-coloured polymer. In fact, the particular                  18 polymer used here is polyethylene. The sheet is                  19 3 millimetres thick.                  20 I should point out that this is a demonstration, not                  21 a scientific test.                  22 The sheet has been ignited at its base using                  23 a butane torch. This butane torch is just barely                  24 visible as a blue flame to the bottom-left of the                  25 sample. It's quickly withdrawn out of frame.</p> <p style="text-align: center;">Page 34</p>	<p>1 that was observed on the exterior of Grenfell Tower.                  2 I've now spent considerable time discussing the most                  3 important, fundamental fire science concepts and                  4 terminology relevant to developing a physical                  5 understanding of the circumstances of external fire                  6 spread during the Grenfell Tower fire.                  7 It is very important to note that my presentation of                  8 concepts such as ignition, burning and flame spread                  9 relate primarily to single materials rather than to                  10 composite products. By this I mean products that are                  11 composed of a combination of materials, all of which may                  12 display substantially different flammability and flame                  13 spread properties.                  14 I should also note that very little useful                  15 fundamental experimental data are available in relation                  16 to flammability and flame spread on composite products                  17 since most of these products violate the basic                  18 assumptions of many of the existing experimental and                  19 compliance testing methods.                  20 This issue is of particular relevance to this                  21 inquiry, not least because of the large number of other                  22 buildings in the UK and internationally that are                  23 apparently clad using similar materials and products to                  24 those used at Grenfell Tower.                  25 Despite this disclaimer, a series of useful</p> <p style="text-align: center;">Page 36</p>

<p>1 conclusions can be drawn on the basis of the discussion                  2 provided in this first section of my presentation today.                  3 These are as follows:                  4 Ignition, flammability, flame spread and fire growth                  5 are all influenced by numerous factors, including                  6 material properties, chemical composition, orientation,                  7 geometry and interactions with other materials.                  8 Upward flame spread on a solid fuel is rapid because                  9 the hot flame and gases preheat the material ahead of                  10 the burning zone.                  11 Downward and horizontal flame spread is generally                  12 slower because preheating of the fuel ahead of the flame                  13 front is greatly reduced.                  14 Almost all of these concepts are important in order                  15 to understand even my most basic matchstick                  16 demonstrations of some of the relevant flame spread                  17 mechanisms.                  18 On this slide I've placed all three of the                  19 matchstick videos. I'm going to run them concurrently                  20 so you can see just how important the relevant phenomena                  21 are as regards both the rate and the extent of flame                  22 spread.                  23 (Video played)                  24 However, as I've just mentioned, downward flame                  25 spread may also be significantly influenced by melting</p> <p style="text-align: center;">Page 37</p>	<p>1 As I have already described, the orientation,                  2 thermal properties and chemical composition are all                  3 important in understanding how materials and products                  4 may respond to fire.                  5 During this second part of the preliminary evidence                  6 that I will present today, I'll describe the materials                  7 and products used in the refurbishment cladding system                  8 at Grenfell Tower. I will describe where they can be                  9 found on the building and how they're arranged. I will                  10 also describe how they burn.                  11 The summary of materials and products presented in                  12 this section is based on a range of sources of evidence                  13 as follows: four post-fire inspections of Grenfell Tower                  14 that I've conducted prior to submitting my Phase 1                  15 report; a range of documentation and photos made                  16 available to the public inquiry via formal disclosures;                  17 and materials and product samples taken from                  18 Grenfell Tower by the Metropolitan Police Service and                  19 provided to me for small-scale materials testing at the                  20 University of Edinburgh.                  21 Before I describe the materials in detail, I'd like                  22 to ensure that I'm clear about the terminology that                  23 I will use to describe different parts of the building.                  24 I will do this by presenting a number of annotated                  25 photographs and drawings to identify the terminology for</p> <p style="text-align: center;">Page 39</p>
<p>1 and dripping of burning material, as I showed a few                  2 moments ago with reference to polyethylene.                  3 In all cases of upward, downward and horizontal                  4 flame spread, the spread is dominated by the heat                  5 release rate of the existing fire, how the resulting                  6 fire transfers heat to the unburnt material, and the                  7 thermal properties of the material itself.                  8 Sir, that concludes my summary of the key fire                  9 science concepts and processes to which I'd like to draw                  10 your attention at this early stage of the inquiry.                  11 All of these concepts must be kept clearly in mind                  12 when considering the rest of the preliminary evidence                  13 that I will present today and, indeed, during Phase 1.                  14 SIR MARTIN MOORE-BICK: Thank you very much.                  15 MR MILLETT: Mr Chairman, I wonder if that's a convenient                  16 moment for the break.                  17 SIR MARTIN MOORE-BICK: I think it would be a good moment.                  18 Shall we break now and resume at 11.10, please.                  19 Thank you.                  20 (11.00 am)                  21 (A short break)                  22 (11.15 am)                  23 SIR MARTIN MOORE-BICK: Yes, Professor Bisby, when you're                  24 ready.                  25 PROFESSOR BISBY: Thank you.</p> <p style="text-align: center;">Page 38</p>	<p>1 parts of the exterior of the building that are relevant                  2 to my preliminary evidence.                  3 This image shows a portion of the west face of the                  4 building following the fire. This photo was obtained by                  5 the Metropolitan Police Service using a drone on                  6 25 July 2017.                  7 During my presentation, when I refer to columns,                  8 these are the areas of the building indicated on this                  9 image.                  10 I should like to point out that the east and west                  11 faces of the building each have four column lines, as                  12 shown here, whereas the north and south faces of the                  13 building each have five column lines, as noted by                  14 Mr Millett during his opening remarks.                  15 When I refer to spandrels, this is a generic term                  16 that I use for the parts of the building between the                  17 windows, as indicated on this image.                  18 I also use the terminology spandrel section to refer                  19 to the building exterior between the column lines, the                  20 sections shown here.                  21 When I refer to rainscreen cassettes, these are the                  22 external panels as indicated on this image, for example                  23 here, here are spandrel section rainscreen                  24 cassettes, and here and here on the column sections of                  25 the building. It's worth noting that these are grey in</p> <p style="text-align: center;">Page 40</p>

<p>1 colour from level 4 upwards.</p> <p>2 When I refer to the window sections of the building,</p> <p>3 these are the sections of the building as shown</p> <p>4 indicated on this image.</p> <p>5 Within the window sections there are several</p> <p>6 individual components, including windows, extract fans,</p> <p>7 mounting panels and window infill panels. I'll describe</p> <p>8 these in a moment.</p> <p>9 When I refer to window infill panels, these are as</p> <p>10 indicated here in yellow. These are unglazed sections</p> <p>11 of the window units. It's worth noting that these are</p> <p>12 white in colour from level 4 upwards.</p> <p>13 The kitchen windows are indicated on this image.</p> <p>14 Here I'd like to draw your attention to the fact that</p> <p>15 the kitchen windows are actually made up of three</p> <p>16 separate areas, and I'll describe each of these in more</p> <p>17 detail in a few moments.</p> <p>18 When I refer to cavity barriers, which will be very</p> <p>19 rarely, these elements are running vertically and</p> <p>20 horizontally within the cladding on the building, as</p> <p>21 indicated on this image, and visible only where the</p> <p>22 rainscreen cassettes have been damaged or removed during</p> <p>23 the fire. You can just see them as the ragged lines</p> <p>24 underneath the yellow bars.</p> <p>25 When I refer to the floor slabs, I'm referring to</p> <p style="text-align: center;">Page 41</p>	<p>1 turning -- by which I mean swinging -- manner, and</p> <p>2 hinged on the right when observed from outside the</p> <p>3 building; an extract fan, which is mounted within</p> <p>4 an infill panel, and this infill panel appears to be</p> <p>5 made from the same materials and construction as the</p> <p>6 window infill panels that I noted previously, and I'll</p> <p>7 come back to these in a moment; and a small glazed</p> <p>8 windowpane beneath the extract fan and mounting infill</p> <p>9 panel, which operates in an inward turning manner and is</p> <p>10 hinged on the left when observed from outside the</p> <p>11 building.</p> <p>12 I'd now like to look in some detail at the</p> <p>13 composition and geometry of the cladding in various</p> <p>14 locations around this kitchen window, which has the same</p> <p>15 design as the kitchen window of flat 16, as I mentioned.</p> <p>16 To do this, I will use my own hand-drawn sketches of the</p> <p>17 relevant sections through the building. These are based</p> <p>18 on my own post-fire investigations at Grenfell Tower,</p> <p>19 and I'll do this in the hope that my sketches will be</p> <p>20 more easily understood by you and by the other parties</p> <p>21 to the inquiry.</p> <p>22 I will necessarily be covering some of the ground</p> <p>23 already covered by Dr Lane and Professor Nic Daeid;</p> <p>24 however, I believe that this is useful repetition and</p> <p>25 that a detailed focus on the cladding materials and</p> <p style="text-align: center;">Page 43</p>
<p>1 the structural reinforced concrete floors within the</p> <p>2 building, and these are at the levels approximately</p> <p>3 indicated by the yellow lines on this image.</p> <p>4 I will now describe the cladding system and its</p> <p>5 geometry in more detail by zooming in on one specific</p> <p>6 part of the building, specifically the section shown of</p> <p>7 the building's exterior which I'm showing here.</p> <p>8 This part of the building has the same arrangement</p> <p>9 of windows as those around the external east wall of</p> <p>10 flat 16, which is acknowledged by at least three of the</p> <p>11 inquiry's experts as the room of fire origin. The</p> <p>12 internal layout of this particular flat is also the same</p> <p>13 as that in flat 16, approximately, so the kitchen window</p> <p>14 is on the left, and the two windows to the right of the</p> <p>15 kitchen window are associated with the living room.</p> <p>16 I'll now zoom in even further to look only at the</p> <p>17 region around the kitchen window, which is shown as</p> <p>18 highlighted there. Here I've highlighted one of the</p> <p>19 kitchen windows in the vertical line of flats in the</p> <p>20 tower ending with the number 3. These are flats</p> <p>21 positioned in the southwest corner of the building.</p> <p>22 I will now zoom in even further to the kitchen</p> <p>23 window specifically.</p> <p>24 The window comprises: a large glazed windowpane,</p> <p>25 which operates in both an inward tilting or inward</p> <p style="text-align: center;">Page 42</p>	<p>1 geometry is warranted under the circumstances.</p> <p>2 It should be noted that my sketches are only</p> <p>3 indicative and are not to scale.</p> <p>4 I should also like to note that my post-fire</p> <p>5 inspections at Grenfell Tower have confirmed that there</p> <p>6 is local variation of the refurbishment cladding</p> <p>7 geometry due to the geometry of the existing building</p> <p>8 and the presence of the original window openings. I've</p> <p>9 carefully considered this variability in examining the</p> <p>10 available evidence and drawing my preliminary</p> <p>11 conclusions.</p> <p>12 In my sketches, I will not show the location of</p> <p>13 cavity barriers within the cladding. This point has</p> <p>14 already been discussed in some detail by Dr Lane and</p> <p>15 I don't consider it critical to my own scope of work.</p> <p>16 So let me look now in detail at the cladding</p> <p>17 immediately above and below the kitchen window opening.</p> <p>18 Please imagine if I were to cut through the cladding</p> <p>19 along a vertical line, as shown here, and then look</p> <p>20 inside the cladding to see the various layers that I cut</p> <p>21 through. I will look specifically at the cladding</p> <p>22 materials and geometry here above and below the kitchen</p> <p>23 window.</p> <p>24 The following slide sequence shows the build-up of</p> <p>25 the different cladding materials, starting with the</p> <p style="text-align: center;">Page 44</p>

<p>1 pre-existing or original cladding construction and                  2 adding the various components of the refurbishment                  3 cladding as I go.                  4 This slide shows a sketch of the original concrete                  5 construction at the location of the kitchen window --                  6 and, remember, this is over a vertical slice through the                  7 building.                  8 The left-hand side of this image shows the outside                  9 of the building and the right-hand side is inside the                  10 flat. Please note that I've removed the windowpane and                  11 brought these two sections closer together vertically in                  12 this drawing than they actually are in reality.                  13 The original concrete structure can be seen in grey.                  14 The concrete slab that forms the ceiling is shown                  15 top-right, and the concrete wall below the windows is                  16 shown below.                  17 There were also original timber battens and a window                  18 framing board, and purlboard foam insulation both on the                  19 ceiling in a band and on the interior wall. I'll                  20 describe these in more detail shortly.                  21 The original windows were located approximately as                  22 shown here. Below the windows, the purlboard insulation                  23 was covered by a sheet of gypsum plasterboard as                  24 an internal finish within the flat.                  25 During the 2012 through 2016 refurbishment</p> <p style="text-align: center;">Page 45</p>	<p>1 board, which was bonded in place using a polymer                  2 adhesive, as shown there. Any small visible gaps were                  3 then filled with a silicone sealant.                  4 UPVC stands for unplasticised polyvinyl chloride and                  5 is a specific type of polymer -- ie a plastic --                  6 material that I will describe in more detail later in                  7 this presentation.                  8 We will look at each of these materials and products                  9 in more detail in a moment, but for now I simply wanted                  10 to show their locations within the cladding.                  11 Please note that the location of the glazing has                  12 been moved outwards as a consequence of the recladding,                  13 and that the windows themselves now sit some distance                  14 outside the original reinforced concrete construction.                  15 I would now like to take a horizontal slice through                  16 the building and look at the cladding build-up                  17 immediately to the left of the kitchen window when                  18 viewed from outside the building at this location here.                  19 When viewed from inside the building, this slice is                  20 across the window as shown in this image. Please note                  21 that the dark material on the windowsill in this photo                  22 is debris from the fire. This is a partially                  23 fire-damaged flat.                  24 In this photo, the uPVC window boards are clearly                  25 visible, as are the lines of silicone sealant used to</p> <p style="text-align: center;">Page 47</p>
<p>1 programme, the original windows were removed, and                  2 installed over the top of this original construction was                  3 the refurbishment overladding system.                  4 This comprised supporting aluminium rails and                  5 fixings which were anchored into the pre-existing                  6 reinforced concrete floor slabs and spandrel beams.                  7 Polymer foam thermal insulation was applied in two                  8 layers on this section of the building, each                  9 80 millimetres in thickness, and the aluminium composite                  10 material -- or ACM -- rainscreen cassettes were then                  11 applied.                  12 Between the rainscreen cassettes and the foam                  13 insulation was an open, ventilated void, hence the                  14 terminology "ventilated rainscreen cladding system" to                  15 describe this particular type of cladding. I'm                  16 referring to the voids shown with the writing there.                  17 The new aluminium framed double glazed windows,                  18 extract fan units and window infill panels were fitted                  19 into the openings and mounted on the aluminium rails, as                  20 shown here.                  21 You can see here how I've cut and reduced the                  22 vertical size of the window.                  23 Inside the building was placed some additional                  24 polymer foam insulation in approximately those                  25 locations, and a finishing detail of a uPVC window</p> <p style="text-align: center;">Page 46</p>	<p>1 fill the gaps between them, here.                  2 Please also carefully note this thin strip of uPVC                  3 window board now highlighted in yellow. This has been                  4 installed in order to fill what would otherwise be a gap                  5 between the new refurbishment window frame and the                  6 pre-existing window opening within the original                  7 reinforced concrete facade, as I'll showing a moment.                  8 This appears to be held in place with a bead of silicone                  9 sealant.                  10 Cutting through the wall of the building at this                  11 location and looking from the top down, you can see                  12 a portion of the octagonal-shaped reinforced concrete                  13 column on the left side of this sketch.                  14 Inside the building is at the top of this slide and                  15 outside the building is at the bottom.                  16 Again, the original construction included timber                  17 battens and timber window framing board, and the                  18 original single glazed windows within aluminium frames.                  19 Here, the line showing the glazing fades at the                  20 right, and this is to indicate an indefinite distance in                  21 this direction in my sketch, so the window continues off                  22 to the right.                  23 As before, the original windows were removed, and                  24 the new double glazed windows were installed on the                  25 horizontal aluminium rails which I showed previously but</p> <p style="text-align: center;">Page 48</p>

1 which are not shown in this view.  
 2 In this location, to the left of the window -- ie on  
 3 the column -- the overcladding comprised the polymer  
 4 foam thermal insulation, in this case a single layer  
 5 100 millimetres thick, and the ACM rainscreen cassette.  
 6 As highlighted a moment ago, in this location there was  
 7 a gap between the edge of the new window frame and the  
 8 pre-existing reinforced concrete column. There's a void  
 9 in the rainscreen and that is the gap that I'm referring  
 10 to.  
 11 A weatherproofing membrane made of EPDM rubber sheet  
 12 was positioned across the gap formed in this location.  
 13 Foam insulation was present both on the inside and  
 14 outside of this gap, as shown there, and the uPVC window  
 15 board was again applied as an internal finish, as shown  
 16 there.  
 17 I should like to note at this point that the  
 18 specific geometry of the small section of polymer foam  
 19 insulation directly outside the kitchen window -- sorry,  
 20 that's the strip of uPVC window board that I highlighted  
 21 a moment ago -- which is now highlighted appears to have  
 22 varied over the building. In some cases, the insulation  
 23 boards were cut differently at this location, and in  
 24 some cases the smaller pieces of foam insulation  
 25 immediately outside the EPDM rubber membrane appear not

Page 49

1 to have been installed at all. This is important as  
 2 regards potential routes for fire spread from inside the  
 3 building to the cladding.  
 4 As I will discuss later today, this is as ongoing  
 5 item for investigation.  
 6 Moving lower down to the spandrel section of the  
 7 exterior cladding below the kitchen window, I will now  
 8 take a horizontal slice across this part of the building  
 9 in this location shown here.  
 10 In this location -- again, looking down at the  
 11 surface of my slice through the building -- we can see  
 12 the original concrete column and spandrel beam. Here,  
 13 again, the spandrel beam fades at the right to indicate  
 14 that, in reality, it continues to the right.  
 15 There are one or two layers of PIR foam insulation,  
 16 depending on the location on the building. On the  
 17 columns, one layer was present with a thickness of  
 18 100 millimetres -- this is shown here -- whereas on the  
 19 spandrel, as I've already noted, two layers each of  
 20 80 millimetres in thickness were present.  
 21 The aluminium cladding rails -- shown here --  
 22 support the spandrel ACM rainscreen cassettes, as was  
 23 described in detail by Dr Lane on Monday. These were  
 24 attached to the refurbishment window frames using  
 25 a series of metal brackets not shown in this view.

Page 50

1 Here are shown the connection to the ACM rainscreen  
 2 cassettes on the cladding rails.  
 3 Spray foam was used liberally to fill gaps and small  
 4 voids within the external cladding system. Aluminium  
 5 tape also appears to have been used liberally within the  
 6 cladding.  
 7 Finally, the ACM rainscreen cassettes were hung from  
 8 the cladding rails and, again, please note the void  
 9 within the cladding between the rainscreen cassettes and  
 10 the PIR foam thermal insulation.  
 11 I'd now like to draw your attention to a particular  
 12 feature of the cladding geometry that exists along the  
 13 vertical line where the spandrel sections of the  
 14 building meet the column sections of the building.  
 15 Remembering the two horizontal sections that I've  
 16 just taken through this location and where they're  
 17 positioned in the building, both through the window  
 18 section and through the spandrel section -- shown  
 19 here -- I've identified that a continuous vertical void  
 20 exists within the cladding at the location shown in this  
 21 figure.  
 22 This void is continuous on all columns from level 4  
 23 all the way to the top of the tower.  
 24 If I show the location of these voids on the column  
 25 to the left of this particular kitchen window --

Page 51

1 I should note it's the same on all columns as far as  
 2 I can tell at this point -- they are as shown here.  
 3 If I show these voids on a section of the full west  
 4 face of the tower, they are as shown here.  
 5 The final part of the cladding that I'd like to  
 6 examine in detail is at the location that I have called  
 7 the column tip in my Phase 1 report. This is  
 8 highlighted in yellow in this figure. I wish to  
 9 highlight this both for completeness and because of  
 10 another particular feature of the cladding geometry at  
 11 this location -- that location just there.  
 12 This image shows a sketch of a horizontal slice  
 13 across the column tip, as shown by the dashed line in  
 14 the previous slide, and again looking down at the  
 15 surface of my slice.  
 16 The tip of the original concrete column's external  
 17 precast concrete surface is seen in grey. The  
 18 overcladding in this location comprises the aluminium  
 19 fixings and rails -- shown here -- the single layer of  
 20 foil-faced PIR foam insulation, 100 millimetres in  
 21 thickness, and the ACM rainscreen cassettes, again with  
 22 a ventilated rainscreen cavity.  
 23 Within the cladding rail, at the column tip, I've  
 24 identified that there is another uninterrupted void that  
 25 spans the entire height of the building. The location

Page 52

<p>1 of this void is illustrated here.</p> <p>2 Again, if I show these additional column tip voids</p> <p>3 on a section of the full west face of the tower, they</p> <p>4 are as shown here.</p> <p>5 Combining these with the continuous vertical voids</p> <p>6 discussed previously -- here -- we can see that the</p> <p>7 column lines in particular provide numerous vertical</p> <p>8 voids and channels that run uninterrupted from at least</p> <p>9 level 4 right the way to the top of the building.</p> <p>10 Sir I've now described my key preliminary evidence</p> <p>11 with respect to the geometric arrangements of the</p> <p>12 cladding.</p> <p>13 Having dealt with the geometry, I will now describe</p> <p>14 the various materials and products that were present</p> <p>15 within the cladding system of Grenfell Tower at the time</p> <p>16 of the fire.</p> <p>17 Before I begin, I believe it's important to make</p> <p>18 clear a distinction between materials and products.</p> <p>19 Materials are comprised of, well, a single material;</p> <p>20 products, on the other hand, can be comprised of</p> <p>21 multiple materials. For example, aluminium is</p> <p>22 a material and polyethylene is a material.</p> <p>23 However, Reynobond PE -- shown here, for instance --</p> <p>24 is a product consisting of two aluminium sheets</p> <p>25 separated by a gap which is filled with polyethylene.</p> <p style="text-align: center;">Page 53</p>	<p>1 section of my presentation.</p> <p>2 ACM rainscreen cassettes were provided on both the</p> <p>3 spandrels and columns of Grenfell Tower as highlighted</p> <p>4 here in yellow.</p> <p>5 ACM products were also used to form the ornamental</p> <p>6 architectural crown at the top of the building, as shown</p> <p>7 here with substantial fire damage from a drone photo</p> <p>8 taken after the fire on 25 July 2017, with much of the</p> <p>9 crown now missing.</p> <p>10 The crown elements would have been configured</p> <p>11 approximately as I've shown them here before the fire.</p> <p>12 The specific geometry and materials of the architectural</p> <p>13 crown are discussed in detail in my Phase 1 report and</p> <p>14 will be the focus of considerable additional work at</p> <p>15 Phase 2.</p> <p>16 For my presentation today, it's sufficient to note</p> <p>17 that the architectural crown was comprised largely of</p> <p>18 closely spaced, vertically oriented, C-shaped channels</p> <p>19 formed from ACM panels. These were mounted on closely</p> <p>20 spaced aluminium rails, which were supported off the</p> <p>21 original reinforced concrete parapet beams at roof</p> <p>22 level.</p> <p>23 As we heard on Monday, the ACMs at Grenfell Tower</p> <p>24 were a product called Reynobond PE, where the PE stands</p> <p>25 for polyethylene. This was and is manufactured and sold</p> <p style="text-align: center;">Page 55</p>
<p>1 Even at this early stage of the inquiry, Reynobond PE</p> <p>2 will no doubt be familiar to you, and I will discuss</p> <p>3 this product in more detail in a few minutes.</p> <p>4 It has been common to refer to Reynobond PE and</p> <p>5 similar rainscreen products as aluminium composite</p> <p>6 materials, or ACMs. The use of the word "material" in</p> <p>7 this context is in some ways a misnomer; however,</p> <p>8 because the word "composite" precedes the word</p> <p>9 "material", the name tells us that this is actually</p> <p>10 a product consisting of multiple materials.</p> <p>11 Another example of a product is Celotex RS5080,</p> <p>12 which is shown here. This product is composed of</p> <p>13 several materials: polyisocyanurate -- or PIR -- foam,</p> <p>14 which is highlighted here; a thin aluminium foil facing,</p> <p>15 which is shown here and is on both sides of this</p> <p>16 material; and a glass fibre mesh which sits within the</p> <p>17 PIR foam, as indicated by the lines shown here.</p> <p>18 I will also return to the product Celotex RS5080,</p> <p>19 which is part of the Celotex RS5000 range of insulation</p> <p>20 products, later in my presentation.</p> <p>21 With this distinction between materials and products</p> <p>22 made, I will now move on to describe the different</p> <p>23 cladding materials and products used on Grenfell Tower</p> <p>24 and the respective locations within the cladding system.</p> <p>25 I apologise, this does get a bit repetitive in this</p> <p style="text-align: center;">Page 54</p>	<p>1 by Arconic Architectural Products.</p> <p>2 This image shows the corner of a Reynobond PE panel</p> <p>3 taken from Grenfell Tower after the fire and provided to</p> <p>4 me by the Metropolitan Police Service. It is comprised</p> <p>5 of a 0.5-millimetre thick aluminium outer surface, which</p> <p>6 is bonded to a 3-millimetre thick polyethylene filler</p> <p>7 material and a 0.5-millimetre thick aluminium inner</p> <p>8 surface.</p> <p>9 To form the product into rainscreen cassettes, flat</p> <p>10 sheets of the material are cut and folded. This image</p> <p>11 shows various different cuts and folds in a typical ACM</p> <p>12 rainscreen cassette taken from Grenfell Tower after the</p> <p>13 fire, again provided to me by the Metropolitan Police</p> <p>14 Service.</p> <p>15 I would like to draw your attention to the exposed</p> <p>16 edges of black polyethylene material that this image</p> <p>17 reveals. This image is showing the back of a typical</p> <p>18 rainscreen cassette, by which I mean it is showing the</p> <p>19 face of the cassette that would've been looking into the</p> <p>20 ventilated rainscreen cavity. The black areas in this</p> <p>21 image therefore present surfaces of polyethylene that</p> <p>22 would be directly exposed to any flame or heat within</p> <p>23 the cladding cavity should a fire penetrate by</p> <p>24 essentially any means into the cladding system.</p> <p>25 Two different colours of polyethylene are present in</p> <p style="text-align: center;">Page 56</p>

<p>1 the Reynobond PE ACMs used on Grenfell Tower: the black  2 polyethylene that I've shown here, or a light-coloured  3 translucent polyethylene which I've not shown. Testing  4 will be undertaken at the University of Edinburgh to  5 assess if there are any discernible differences between  6 these two different colours of polyethylene in terms of  7 their reaction to fire.</p> <p>8 Next, I'd like to look at the PIR foam insulation  9 products that were used at Grenfell Tower, where PIR,  10 again, stands for polyisocyanurate.</p> <p>11 Some of these products are also visible in this  12 image in the locations where the ACM cassettes again  13 have been damaged or removed by the fire. For instance,  14 we can see some insulation here and here.</p> <p>15 Most of the PIR foam in this photo has had its  16 external aluminium skin removed and has been charred on  17 its outer surface during the fire, thus having  18 a darkened, cracked, blackened appearance. This  19 charring behaviour is significant as regards the manner  20 in which PIR foams may burn, and I will return to this  21 point later in my presentation.</p> <p>22 Just to remind you, the locations of the PIR foam on  23 my sketches of vertical slices through the building are  24 illustrated in yellow here, where you can see where PIR  25 foam is located both above and below the window and</p> <p style="text-align: center;">Page 57</p>	<p>1 mentioned. The specific product name is therefore  2 Celotex RS5080, where, again, the 80 represents  3 a product 80 millimetres thick.</p> <p>4 Also on this photo we can see some of the  5 polyurethane polymer spray foam that was present -- in  6 comparatively small volumes, I should say -- in many  7 locations within the cladding.</p> <p>8 In addition to the PIR insulation identified during  9 post-fire inspections at Grenfell Tower, phenolic  10 foam -- or PF -- insulation has also been found on some  11 areas of Grenfell Tower.</p> <p>12 This product, the phenolic product, not shown here,  13 has been identified as Kingspan Kooltherm K15 and, based  14 on the available evidence, accounts for only a very  15 small proportion of the insulation and only on a small  16 number of spandrel sections of the building.</p> <p>17 Two further PIR foam insulation products have been  18 identified during my post-fire investigations of the  19 undamaged and partially damaged sections of the  20 building. These were located around the window framing  21 of the refurbishment windows, as I've mentioned, and are  22 shown in this photo -- again provided to me by the  23 MPS -- a 25-millimetre thick foil-faced PIR polymer foam  24 insulation board manufactured by Celotex, this is shown  25 top-right on this slide and has yet to be definitively</p> <p style="text-align: center;">Page 59</p>
<p>1 within the window surround, and again here, around the  2 column to the left of the window in my horizontal slice.</p> <p>3 This image shows a piece of the PIR foam taken from  4 one of the columns at Grenfell Tower and, again,  5 provided to me by the Metropolitan Police Service.  6 Visible in this photo are the PIR foam, which is yellow  7 in colour, and one of the foil faces. I should note  8 that the bottom surface of this product also has a foil  9 face but it's not visible in this photo.</p> <p>10 This insulation product is manufactured by Celotex  11 under the generic product name RS5000. The specific  12 product name is Celotex RS5100, where the last three  13 digits, 100, correspond to the thickness of the product  14 in millimetres.</p> <p>15 This image shows a piece of PIR foam insulation that  16 was taken from one of the spandrel sections at  17 Grenfell Tower.</p> <p>18 Again, visible are the PIR foam -- again, yellow in  19 colour -- the foil faces -- again, top and bottom -- and  20 in this particular product, a glass fibre weave within  21 the PIR in two layers, as noted earlier.</p> <p>22 This product is also from the Celotex RS5000 PIR  23 insulation product range, and at Grenfell Tower this  24 product was anchored to the concrete spandrels in two  25 layers, each of 80 millimetres thickness, as I've</p> <p style="text-align: center;">Page 58</p>	<p>1 identified; and a 25-millimetre thick foil-faced polymer  2 foam insulation board manufactured by Kingspan. This is  3 shown bottom-left. The specific product name is yet to  4 be confirmed, although, based on its markings, it is  5 likely to also be PIR foam and from the Kingspan Therma  6 product range.</p> <p>7 I've previously mentioned an insulation product  8 called purlboard. This appears to have been part of the  9 original construction of Grenfell Tower and was located  10 inside the building, both above the window on the  11 ceiling -- as shown here -- and in a continuous band  12 around the perimeter of all flats, and below the window  13 on the inside face of the reinforced concrete spandrel  14 beams. These locations are indicated here in my  15 vertical slice through the cladding.</p> <p>16 The purlboard insulation is a polyurethane foam  17 board. The product is approximately 13 millimetres  18 thick and is faced on both sides with a paper covering.</p> <p>19 The purlboard on the internal wall of the spandrel  20 sections was, as already noted, adhered to a layer of  21 plasterboard, as shown in this photo, with the purlboard  22 being the top portion of this sandwich and the  23 plasterboard being the bottom.</p> <p>24 I've not yet been able to determine if the purlboard  25 on the ceiling was also faced with a layer of</p> <p style="text-align: center;">Page 60</p>

<p>1 plasterboard as I've been prevented from disturbing this  2 product due to an apparent asbestos risk associated with  3 the Artex plaster on the ceilings.  4 Around the windows are uPVC window framing boards  5 that form the final internal finish of the refurbishment  6 cladding system. The location of these uPVC boards is  7 indicated in this image, here, here, here, here, and,  8 importantly, as I've already mentioned, here in a thin  9 strip.  10 This image, which I've shown previously, shows  11 a portion of a uPVC horizontal windowsill and the  12 vertical uPVC window jamb, by which I mean the side of  13 the window enclosure, after the fire. This is shown in  14 my vertical slice -- again in yellow -- above and below  15 the kitchen window, as shown here, and again here in my  16 horizontal slice at the side of the kitchen window.  17 This slide shows a close-up image of one of the uPVC  18 boards taken from Grenfell Tower. These had a smooth  19 surface and were approximately 9.5 millimetres thick.  20 As already discussed, there is an EPDM rubber  21 weatherproofing membrane that extends between the  22 edge of the refurbishment cladding window frame and the  23 original reinforced concrete column. This is  24 illustrated in this photo looking up at the building  25 during the forensic deconstruction of the cladding that</p> <p style="text-align: center;">Page 61</p>	<p>1 identical in terms of materials and construction.  2 That concludes my presentation of preliminary  3 evidence as regards the geometry and materials of  4 construction of the refurbishment cladding at  5 Grenfell Tower.  6 In the final section of my part 2 presentation, I'd  7 like to briefly describe the burning behaviour of some  8 of these materials.  9 In discussing specific material burning behaviour --  10 which includes flammability, ignition, et cetera --  11 I will focus on those materials which I consider to be  12 most important with respect to the Grenfell Tower fire.  13 Please note that I'm using the word "materials"  14 intentionally here.  15 At this stage of the inquiry, I will avoid  16 commenting on the burning behaviour of products other  17 than to reiterate my previous statement that very little  18 useful fundamental experimental data are available in  19 relation to the burning behaviour of composite products,  20 since most products, again, violate the basic  21 assumptions of many of the existing experimental and  22 compliance methods.  23 The discussion below is therefore based on samples  24 of pure material; by this I mean a single material in  25 the absence of coatings, protective layers or</p> <p style="text-align: center;">Page 63</p>
<p>1 occurred following the fire, such that the rainscreen  2 cassette and insulation boards have been removed from  3 the column at the left-hand side of this photo.  4 The EPDM membrane is the material highlighted here  5 in yellow. As you can see, this is a flexible sheet  6 which was adhesively bonded to the existing reinforced  7 concrete structure.  8 The EPDM rubber membrane is highlighted in yellow in  9 my horizontal slice drawing to the left of the kitchen  10 window, here.  11 This image shows a roll of the EPDM rubber membrane  12 and a single sheet of the material, both taken from  13 Grenfell Tower and provided to me again by the  14 Metropolitan Police Service. The product used in the  15 sections of Grenfell Tower that I've inspected is  16 1 millimetre thick, as shown.  17 The window infill panels, as I have already  18 discussed, are the non-glazed sections of the window  19 units and are highlighted in yellow in this image.  20 These are comprised of two sheets of aluminium, each  21 with a thickness of 2 millimetres, and a polystyrene  22 foam insulation core 25 millimetres in thickness, and  23 this is shown here.  24 The smaller window infill panels that house the  25 kitchen extract fans were similar to these if not</p> <p style="text-align: center;">Page 62</p>	<p>1 incorporation into composite products. This is actually  2 a very important point.  3 This part of my preliminary evidence gives a very  4 brief introduction to the reaction to fire of materials  5 that have been identified to date as being present in  6 the refurbishment external cladding of Grenfell Tower.  7 I will present selected information based on data  8 available in the scientific and technical literature  9 rather than based on the specific materials themselves.  10 However, in most cases the information available in  11 the technical literature has a strong dependence on the  12 exact material formulations and test methods used, so at  13 this point these properties and values are provided  14 simply for the purposes of illustration.  15 I expect to study the burning behaviour of a range  16 of relevant products in considerable detail as part of  17 my ongoing work for the inquiry, and also to comment in  18 some detail at some stage on compliance testing methods  19 which are currently used to assess the burning behaviour  20 of materials and products, both within the UK and in  21 European regulatory environments.  22 Again, I will try to avoid technical language and  23 jargon; however, again, the subject matter demands  24 a certain level of technical terminology.  25 Most of the materials of interest in this discussion</p> <p style="text-align: center;">Page 64</p>

<p>1 are polymers. Polymers are synthetic or naturally                  2 occurring compounds that have large molecules made up of                  3 many relatively simple repeated units called monomers.                  4 Polymers are created by joining together the short                  5 monomer molecules to form long molecular chains. As                  6 already mentioned, a generic term to describe synthetic                  7 polymers is plastics.                  8 Polymers can be grouped, importantly, into two main                  9 types: thermosetting polymers and thermoplastic                  10 polymers.                  11 The differences between these two classes of                  12 polymers are, in my opinion, very important as regards                  13 the events that occurred at Grenfell Tower.                  14 A thermoplastic polymer will melt and can be                  15 deformed on heating, and in some cases can be returned                  16 to its original form. If heated under the correct                  17 conditions, the polymer will also undergo pyrolysis and                  18 will directly produce flammable gases.                  19 A thermosetting polymer will not melt on heating but                  20 instead will thermally decompose, by which I mean                  21 undergo pyrolysis.                  22 These contrasting behaviours strongly affect how                  23 these different classes of polymers burn.                  24 Upon exposure to heat, a thermoplastic polymer will                  25 soften and melt. Once in a liquid state, the polymer</p> <p style="text-align: center;">Page 65</p>	<p>1 also reduces the rate of heat transfer into the material                  2 and, as I've already mentioned, the pyrolysis rate                  3 subsequently decreases.                  4 Consequently, the gases may not be released at                  5 a sufficient rate to sustain a flame without some                  6 additional external source of heat. Therefore, the                  7 flame may go out.                  8 The heat release rate of a burning thermosetting                  9 polymer is therefore typically characterised by a high                  10 initial value, as I've already mentioned, which rapidly                  11 decreases due to the formation of a char layer.                  12 I will now describe the burning behaviour of some of                  13 the key materials found at Grenfell Tower in more                  14 detail.                  15 Both thermoplastics and thermosetting polymers were                  16 present within the cladding system in significant                  17 quantities. As we have seen, polyethylene was present                  18 within the Reynobond PE ACM rainscreen product which was                  19 used extensively at Grenfell Tower, both in the                  20 rainscreen cassettes and in the architectural crown.                  21 The polyethylene is highlighted here in yellow.                  22 Polyethylene is a highly flammable synthetic                  23 thermoplastic polymer. Upon exposure to heat,                  24 polyethylene will melt and drip, possibly flowing whilst                  25 burning or generating flaming droplets, as I showed in</p> <p style="text-align: center;">Page 67</p>
<p>1 may break down into constituent monomer parts. These                  2 may evaporate or pyrolyse to generate a flammable gas                  3 mixture. It is also possible for the solid to undergo                  4 direct pyrolysis to generate flammable gases.                  5 Thermoplastics may spread fire by burning as they                  6 flow or burning as droplets, as I've already mentioned.                  7 Since thermoplastic polymers will melt and flow, their                  8 reaction to fire is strongly dependent on their                  9 orientation. When burning in a horizontal orientation,                  10 a thermoplastic will melt and form a pool of liquid                  11 which will burn at a relatively steady rate.                  12 In the vertical orientation, as I've already shown                  13 in part 1 of today's presentation, melting and dripping                  14 will likely dominate the burning behaviour of                  15 a thermoplastic and, as noted previously, contribute to                  16 the formation of a pool fire at the base of or in front                  17 of the material.                  18 Conversely, thermosetting polymers do not melt, and                  19 instead chemically decompose, by which I mean pyrolyse,                  20 when exposed to heat. In this case, the pyrolysis                  21 process produces a flammable gas and leaves behind                  22 a solid char. The formation of this char means that                  23 some of the potential fuel is effectively locked up in                  24 the solid char and is therefore not available for                  25 releasing heat in the flame. The formation of the char</p> <p style="text-align: center;">Page 66</p>	<p>1 part 1 of my presentation.                  2 Its melting temperature is around 130 to 135 degrees                  3 Celsius, and its heat of combustion -- which, to remind                  4 you, is a measure of the total energy that a material is                  5 capable of releasing under optimum combustion                  6 conditions -- is about 46 megajoules per kilogram.                  7 Sir, you will no doubt have noted the commentary in                  8 the media comparing the polyethylene material within the                  9 ACM rainscreen cassettes at Grenfell Tower to petrol or                  10 diesel. This is likely to be on the basis, as I've                  11 already shown, that the heats of combustion of petrol                  12 and diesel are similar to the polyethylene used in                  13 Reynobond PE ACM products.                  14 It's perhaps worth reiterating here, however, that                  15 the heat of combustion is only one of the important                  16 parameters dictating how a material will burn, as I've                  17 already discussed in some detail.                  18 Polyisocyanurate -- or PIR -- foam materials were                  19 also used in significant volumes within the cladding                  20 system at Grenfell Tower. This was as part of the four                  21 insulation products that I've already discussed and                  22 which are shown here. The PIR foam is again highlighted                  23 here in yellow, so makes up the bulk of these products.                  24 PIR is a synthetic thermosetting polymer which is                  25 primarily produced as a rigid foam. It has a very low</p> <p style="text-align: center;">Page 68</p>

<p>1 thermal inertia, which you will remember I discussed                  2 earlier. Its material properties make it extremely                  3 attractive for providing thermal insulation in                  4 buildings.                  5 However, the very low thermal inertia of PIR, as                  6 I've discussed already, means that it tends to have                  7 a comparatively low time to ignition and will support                  8 rapid flame spread without protection from an external                  9 barrier, for instance an aluminium foil facing.                  10 The very low thermal inertia means that PIR may also                  11 accelerate flame spread of adjacent materials by                  12 preventing the loss of energy from the system. By this                  13 I mean by insulating, for example, the rainscreen cavity                  14 and reducing losses, thus possibly accelerating flame                  15 spread.                  16 Sorry, thus possibly accelerating fire spread -- the                  17 difference in terminology is actually quite important.                  18 The precise formulation of PIR foams varies by                  19 manufacturer, as does the manufacturer's use of                  20 different fire retardants. As a result, comparison                  21 between products and the available technical literature                  22 is not strictly possible. Nevertheless, to give you                  23 an idea of comparative hazard, the heat of combustion of                  24 PIR is about 26 megajoules per kilogram, or about                  25 60 per cent that of polyethylene.</p> <p style="text-align: center;">Page 69</p>	<p>1 thermoplastic polymer and, therefore, rapidly melts at                  2 its surface when exposed to heat or flame. Once melted,                  3 polystyrene foam typically forms burning droplets or                  4 burns as a liquid pool. Its melting temperature is                  5 about 230 degrees Celsius and its heat of combustion is                  6 about 40 megajoules per kilogram. Again, compare with                  7 polyethylene at about 46 megajoules per kilogram.                  8 Polyvinyl chloride -- or PVC -- is a synthetic                  9 thermoplastic polymer. With relevance to                  10 Grenfell Tower, I am discussing rigid PVC, commonly                  11 referred to as uPVC or PVCu. The U simply stands for                  12 "unplasticised", meaning the PVC is rigid at room                  13 temperature.                  14 Upon exposure to fire, uPVC may char. However, its                  15 particular chemical nature means that its heat of                  16 combustion is lower than for any other synthetic                  17 polymers. As a result, its ability to spread flame is                  18 also comparatively less than many other polymers. Its                  19 heat of combustion, for instance, is only about                  20 18 megajoules per kilogram.                  21 However, the temperatures at which uPVC will soften                  22 and experience significant reductions of mechanical                  23 properties are very low in comparison with other                  24 construction materials. As a result, typical day-to-day                  25 upper service temperature limits for uPVC are in the</p> <p style="text-align: center;">Page 71</p>
<p>1 But this comparison must clearly be considered in                  2 light of my previous comments noting the potential                  3 importance of other burning behaviours.                  4 I have already noted that phenolic foam insulation                  5 has also been identified in comparatively small                  6 quantities during post-fire investigations at                  7 Grenfell Tower.                  8 Phenolic foam is also a synthetic thermosetting                  9 polymer and is also primarily produced as a rigid foam                  10 with a cellular structure.                  11 Like PIR, phenolic foam has a very low thermal                  12 inertia and, consequently, it will have a comparatively                  13 low time to ignition and will support flame spread,                  14 again, when its surfaces are unprotected. As for PIR,                  15 the precise formulation of phenolic foams varies by                  16 manufacturer, as does the manufacturer's use of                  17 different fire retardants.                  18 Specific properties of phenolic foam are given in my                  19 Phase 1 report, but there's limited value discussing                  20 them in this presentation due to the comparatively small                  21 quantities that appear to have been used at                  22 Grenfell Tower.                  23 Polystyrene foam is used within the core of the                  24 window infill panels at Grenfell Tower, as highlighted                  25 here. Polystyrene foam is a low thermal inertia</p> <p style="text-align: center;">Page 70</p>	<p>1 range of about 50 degrees Celsius. Its melting                  2 temperature is between 75 and 105 degrees Celsius.                  3 This is highly significant, in my view, in the                  4 context of Grenfell Tower because, as I've already                  5 explained, uPVC window boards form the initial barrier                  6 for flames to prevent fire spread from the kitchen of                  7 flat 16 into the cladding cavity beside the kitchen                  8 window. This issue receives considerable attention in                  9 my Phase 1 report.                  10 Ethylene propylene diene monomer -- or EPDM --                  11 rubber -- shown here -- is an elastomer or synthetic                  12 rubber. The chemical composition of EPDM rubber means                  13 that it will burn.                  14 No specific details were available regarding the                  15 combustion properties of the EPDM rubber used at                  16 Grenfell Tower at the time of writing my Phase 1 report.                  17 These will be studied by laboratory-based testing on                  18 an ongoing basis.                  19 Thus far today, I've presented quite a large volume                  20 of technical information. I'd like to summarise the key                  21 points that I think are most important when considering                  22 the evidence as regards fire spread to and on the                  23 exterior cladding of Grenfell Tower.                  24 With regard to materials and geometry, the                  25 refurbishment external cladding system at Grenfell Tower</p> <p style="text-align: center;">Page 72</p>

<p>1 has an extremely complex geometry and incorporates                  2 a number of different materials and products. Many of                  3 the materials and products installed within the cladding                  4 system are combustible, predominantly synthetic polymer                  5 materials.                  6 Particular features of the cladding geometry, which                  7 I've described during my presentation, resulted in the                  8 presence of a number of vertical cavities and channels                  9 within the cladding and running the full height of the                  10 building from at least level 4 up to the architectural                  11 crown at roof level.                  12 As already noted, the architectural crown itself was                  13 formed largely from vertical channels of highly                  14 combustible Reynobond PE ACM panels.                  15 With regard to flammability and fire spread, whilst                  16 all of the polymer materials present are combustible,                  17 different polymer materials, as I've explained, can burn                  18 in very different ways and therefore present very                  19 different fire hazards under a particular set of                  20 conditions.                  21 The total amount of energy available for combustion                  22 is described by the heat of combustion, but there's no                  23 guarantee that all of this available energy will be                  24 released under particular fire conditions.                  25 A material's thermal inertia relates to how quickly</p> <p style="text-align: center;">Page 73</p>	<p>1 Mr Chairman, this might be a convenient moment to                  2 take the midday break. I know that part 3, fire spread,                  3 will take a large portion of the afternoon, so it may be                  4 convenient to take an earlier lunch now.                  5 PROFESSOR BISBY: Whatever you are happy with.                  6 SIR MARTIN MOORE-BICK: Well, you've been on your feet for                  7 quite a long time. Would you like a break now?                  8 PROFESSOR BISBY: Sure.                  9 SIR MARTIN MOORE-BICK: Yes, all right.                  10 Well, we'll have a rather extended lunch break. If                  11 we resume at 2 o'clock, that will give you plenty of                  12 time to finish your presentation, will it?                  13 PROFESSOR BISBY: Sure, should do, yes.                  14 SIR MARTIN MOORE-BICK: That's what we'll do then. We'll                  15 rise now and resume at 2 o'clock.                  16 Thank very much.                  17 (12.11 pm)                  18 (The short adjournment)                  19 (2.00 pm)                  20 SIR MARTIN MOORE-BICK: Yes, Mr Millett.                  21 MR MILLETT: Mr Chairman, I just ought to repeat, if I can,                  22 the trigger warning that this afternoon's presentation                  23 from Professor Bisby will contain a large number of                  24 images and videos depicting the external flame spread on                  25 the night of the fire, and that will include the playing</p> <p style="text-align: center;">Page 75</p>
<p>1 its surface will increase in temperature when exposed to                  2 heating. This has consequences for ignition and surface                  3 spread of flame in particular, in that materials with                  4 a very low thermal inertia -- such as PIR foam                  5 insulation -- are likely to spread flame rapidly,                  6 particularly when their external surfaces are not                  7 protected by a metal facing.                  8 Thermosetting polymers -- like PIR -- will char on                  9 heating, whereas thermoplastics -- like polyethylene and                  10 polystyrene -- will melt. This, again, has important                  11 consequences for the extent to which the total amount of                  12 energy available is actually released during a fire.                  13 I've illustrated that again here with respect to the                  14 non-charring and charring behaviour of various polymer                  15 solids.                  16 All of these ideas will become important during this                  17 inquiry as we try to unpick the respective effects both                  18 of the geometry and of the materials and products                  19 present within the cladding system at Grenfell Tower.                  20 These issues are central to understanding what                  21 happened at Grenfell Tower and to ensuring that it can                  22 never happen again.                  23 That concludes section 2 of my presentation.                  24 SIR MARTIN MOORE-BICK: Thank you very much.                  25 MR MILLETT: Thank you very much, Professor.</p> <p style="text-align: center;">Page 74</p>	<p>1 of his composite flame spread video, which I played in                  2 my opening, and detailed consideration of that and other                  3 flame spread material which shows the tower burning and                  4 on fire. Some of the videos include audio of people who                  5 witnessed the fire and it shows some of their distress                  6 at the events as they unfolded. It will also contain                  7 a number of images of the burnt-out tower after the fire                  8 and the playing of the first 999 call by Mr Kebede.                  9 So I just repeat that warning.                  10 SIR MARTIN MOORE-BICK: Thank you very much.                  11 MR MILLETT: Thank you, Professor.                  12 SIR MARTIN MOORE-BICK: When you're ready, Professor.                  13 PROFESSOR BISBY: Thanks very much.                  14 During this third part of my presentation, I will                  15 describe in general terms the spread of fire to and over                  16 the cladding at Grenfell Tower.                  17 I will begin by providing an overview of the fire's                  18 early development, since this is relevant to the                  19 question of how the fire spread from within the kitchen                  20 of flat 16 out and into or onto the cladding.                  21 I will then describe the external fire spread over                  22 the tower, breaking this down into upward fire spread,                  23 downward fire spread and horizontal or lateral fire                  24 spread in that order, for reasons that I hope will                  25 become clear during the course of the inquiry.</p> <p style="text-align: center;">Page 76</p>

<p>1 I will make extensive use of photos and video                  2 footage that was provided by members of the public via                  3 the Metropolitan Police Service uploads website. Much                  4 of this information has proved critical in understanding                  5 the events of 14 June 2017.                  6 As I've reviewed the evidence, I've considered                  7 a number of hypotheses for the routes of fire spread                  8 from the compartment of origin onto the external                  9 cladding, the fire spread over the cladding and ingress                  10 of the fire and smoke back into the building.                  11 These specific hypotheses are described in detail in                  12 my Phase 1 report and I understand that I'll have                  13 an opportunity to elaborate on these later this year.                  14 Based on the available evidence, I've determined                  15 that the overall timeline for the progression of the                  16 fire to and over the cladding was as follows.                  17 The fire was first reported at 12.54 am on                  18 14 June 2017 within the kitchen of flat 16 on level 4 of                  19 Grenfell Tower.                  20 Over the course of the subsequent 15 minutes or so,                  21 the fire burned within the kitchen of flat 16. The fire                  22 was observed to have spread to the cladding by about                  23 1.09 am.                  24 The fire then spread vertically upwards on the east                  25 face of Grenfell Tower, breaking into flats on the</p> <p style="text-align: center;">Page 77</p>	<p>1 building. Note that here I'm referring to the spread at                  2 the top of the building, by which I mean at the location                  3 of the architectural crown.                  4 After this time, the fire continued to spread                  5 downwards to ingress into the building and to burn                  6 within the building for many more hours.                  7 Sir, you asked me to report specifically on the                  8 spread to the cladding from within the flat of origin.                  9 I've therefore reviewed the evidence associated with the                  10 early fire spread within the compartment of origin.                  11 Much of this was presented yesterday by                  12 Professor Nic Daeid and, given that I agreed broadly                  13 with Professor Nic Daeid's findings, I will only discuss                  14 this issue briefly here today.                  15 My Phase 1 report provides a detailed description of                  16 the evidence of fire spread within the compartment of                  17 origin. This includes: witness statements; a 999 call                  18 transcript; interview transcripts; video evidence from                  19 Mr Kebede's phone; witness statements from the four                  20 firefighters who initially entered flat 16; thermal                  21 imaging camera -- or TIC -- footage from within flat 16;                  22 fire scene photos; and photos from my own post-fire                  23 investigations at Grenfell Tower.                  24 There are several items of evidence to which I'd                  25 like to draw your attention as I believe they're</p> <p style="text-align: center;">Page 79</p>
<p>1 floors above flat 16 as it spread.                  2 It took approximately 20 minutes for the fire to                  3 spread from level 4 to the roof.                  4 By about 1.29 am, the fire had reached the top of                  5 the east face. The vertical fire spread started slowly                  6 and accelerated as the fire grew in size.                  7 The fire then spread northwards on the east face                  8 and, at approximately 1.36 am, spread horizontally on to                  9 the north face. This horizontal spread occurred first                  10 at the top of the tower.                  11 The fire also spread southwards on the east face,                  12 again leading at the top of the tower.                  13 At approximately 2.25 am, the fire spread from the                  14 east face to the south face, again leading at the top of                  15 the building.                  16 Horizontal fire spread was coincident with downward                  17 fire spread, causing a larger area of the cladding to                  18 become involved in the fire.                  19 The fire spread from the north face to the west face                  20 at approximately 2.49 am, and the cladding at the                  21 southwest corner was the last part to become involved in                  22 the fire at about 4.09 am. The fire approached this                  23 part of the building from both directions.                  24 It took approximately 3 hours and 4 minutes for the                  25 fire to spread around the full perimeter of the</p> <p style="text-align: center;">Page 78</p>	<p>1 particularly relevant in understanding the fire spread                  2 from the kitchen of flat 16 to the cladding.                  3 First, the initial 999 call that was made by                  4 Mr Kebede, the occupant of flat 16, who first discovered                  5 smoke within his kitchen. The call was made at                  6 12.54.29. During this recording, I have interpreted                  7 that at 52 seconds and at 55 seconds into the audio                  8 file, the occupant states that the fire is by the fridge                  9 side.                  10 I will play this call in full in a few minutes when                  11 I replay my composite fire spread video that was shown                  12 by Mr Millett during his opening remarks two weeks ago,                  13 but I wanted to raise that point here.                  14 Second, during subsequent interviews with Mr Kebede,                  15 he makes comments about the location of the smoke that                  16 he has observed. An extract from one of these interview                  17 transcripts is shown here.                  18 Mr Kebede says:                  19 "I could see a light-coloured smoke in the area next                  20 to the fridge freezer and window. It was in the general                  21 area there, I cannot be more specific about exactly                  22 where it was coming from."                  23 The interviewer asks:                  24 "So where was the smoke in your kitchen, whereabouts                  25 would you say the smoke was ... if you could say one</p> <p style="text-align: center;">Page 80</p>

<p>1 point that the smoke was originated."                  2 Mr Kebede replies:                  3 "The smoke is behind the fridge and the window                  4 side."                  5 This overall description of events has since been                  6 corroborated by additional interviews and witness                  7 statements from Mr Kebede.                  8 Third, a segment of video footage recorded by                  9 Mr Kebede on his phone from outside the building. This                  10 video was captured beginning at 1.05 am or about                  11 11 minutes after the beginning of the initial 999 call.                  12 I will now play this video.                  13 (Video played)                  14 I've interpreted from this video that flames                  15 initially appeared predominantly visible at the                  16 left-hand side of the window when observed from outside                  17 the building. The window infill panel and mounting of                  18 the extract fan unit appears to be missing or burning.                  19 The extract fan unit appears to be absent, with flames                  20 passing through or around the infill panel mounting                  21 board and out of the small window opening. Smoke is                  22 visible outside the compartment and the glazed window                  23 pane beneath the extract fan appears to be open or                  24 absent.                  25 Finally, I'd like to draw your attention to the</p> <p style="text-align: center;">Page 81</p>	<p>1 The firefighters are low down in this location and                  2 looking up and into the kitchen. The red shaded area is                  3 the region where the fire is considered most likely to                  4 have originated, as we heard yesterday.                  5 I'll now play a short clip from the thermal imaging                  6 camera. Please note, as was mentioned yesterday, that                  7 the time stamps on this original footage are incorrect.                  8 I have included a corrected timer below the video in                  9 this clip, and I will play the clip twice.                  10 (Video played)                  11 I'll now play the clip a second time.                  12 (Video played)                  13 I've extracted a frame from this video on the left                  14 of this slide and provided my interpretation of this                  15 image on the right of this slide. Below the images,                  16 I've provided a schematic layout of the kitchen of                  17 flat 16 at the time of the fire.                  18 It's my interpretation that the heat, which is                  19 indicated by the yellow region in these images, is                  20 primarily between the fridge freezer and the kitchen                  21 window. However, it's not possible to be more precise                  22 than this on the basis of the thermal imaging camera                  23 footage.                  24 In summary, these four items that I've just brought                  25 to your attention lead me to agree broadly with the</p> <p style="text-align: center;">Page 83</p>
<p>1 thermal imaging camera footage taken by the London Fire                  2 Brigade at the start of their intervention into the                  3 kitchen of flat 16. Professor Nic Daeid also showed                  4 this video yesterday.                  5 Before doing so, I'd like to draw your attention to                  6 the fact that this first intervention by the London Fire                  7 Brigade occurs at 01.14.12, at least 5 minutes after                  8 what I consider to be the first clear evidence of fire                  9 having spread to the external cladding, as I'll describe                  10 in more detail in a few minutes.                  11 The video was captured when the firefighters were in                  12 the corridor directly outside the kitchen door. The                  13 video shows footage captured by the thermal imaging                  14 camera when the firefighters briefly open the kitchen                  15 door of flat 16, and we will see that heat is visible at                  16 the far end of the kitchen when viewed from the kitchen                  17 entrance doorway. In the latter part of the clip, a jet                  18 of water can be seen that is sprayed by the                  19 firefighters.                  20 In the clip that I'll show in a moment, the location                  21 of the firefighters who are holding the thermal imaging                  22 camera is shown here on a floor plan of flat 16. This                  23 location is represented by a red circle and their line                  24 of sight is approximately indicated by the red arrow                  25 pointing into the kitchen.</p> <p style="text-align: center;">Page 82</p>	<p>1 evidence of the initial fire presented yesterday by                  2 Professor Nic Daeid. I won't speak any more about that                  3 particular issue today.                  4 I'll now move on to present evidence concerning the                  5 spread of fire from within the kitchen of flat 16 out                  6 and onto or into the cladding.                  7 To consider the evidence regarding fire spread to                  8 the cladding, I need to briefly re-visit the geometry of                  9 the kitchen window and its window surround.                  10 This is a picture of the kitchen window of flat 13,                  11 also on the fourth floor at Grenfell Tower and having                  12 essentially the same layout as flat 16. Most of the                  13 relevant components of the window are visible in this                  14 image, although it should be noted that the uPVC window                  15 boards have been removed in this photo. This was done                  16 as part of the forensic deconstruction of flat 13, parts                  17 of which I attended after the fire.                  18 In this photo, we can get a clear view of the                  19 configuration of the kitchen window from the inside of                  20 the building and the possible routes of fire spread from                  21 inside to the outside. These could include: through                  22 an open -- or broken -- window; through the extract fan                  23 or the infill panel in which the extract fan is mounted;                  24 or through any gaps or openings that might have formed                  25 around the window as a consequence of heating.</p> <p style="text-align: center;">Page 84</p>

<p>1 Because the uPVC window boards have been removed in                  2 this view, we can see that a gap exists between the edge                  3 of the refurbishment window frame and the pre-existing                  4 opening of the reinforced concrete facade of the                  5 building, which I have previously mentioned today. This                  6 is visible immediately to the right of the window frame.                  7 We can also see that this gap has been bridged, as                  8 I've already mentioned, using a layer of EPDM rubber                  9 weatherproofing membrane, which is the black substance                  10 filling the gap, as discussed previously.                  11 Behind this EPDM we would find the back of the                  12 cladding cavity, which contains both PIR foam insulation                  13 and exposed edges of polyethylene on the back side of                  14 the ACM rainscreen cassettes, again as I've already                  15 discussed.                  16 I'd also like to quickly re-visit the drawing                  17 I showed earlier of the various materials that were                  18 present around the window to make sure that the                  19 configuration of materials around the window is clear in                  20 the present discussion.                  21 Working my way from the inside of the building out,                  22 which simulates the route the fire would've taken had it                  23 entered the cladding via this route, we find:                  24 First, uPVC window boards which, as already                  25 discussed, are comparatively resistant to ignition and</p> <p style="text-align: center;">Page 85</p>	<p>1 during the early stages of the fire, and thermal imaging                  2 camera video captured by the firefighters during their                  3 intervention within flat 16.                  4 In a moment, I will play a video that was captured                  5 outside Grenfell Tower at about 1.09 am. During this                  6 video, you will see falling debris from the lower left                  7 corner of the kitchen window of flat 16.                  8 I've concluded that this falling debris is likely to                  9 be polyethylene originating from within the ACM                  10 rainscreen cassettes.                  11 Consequently, this video is the earliest evidence of                  12 which I'm currently aware that shows that the fire has                  13 spread to the cladding.                  14 I'll now play the video.                  15 (Video played)                  16 Also significant in this video is that the earliest                  17 evidence of burning polyethylene appears to be                  18 associated with the left-hand side of the kitchen window                  19 of flat 16 when viewed from outside the building. This                  20 is where the potential pathway described in the previous                  21 slides would cause fire and hot gases to impinge on the                  22 back of the ACM rainscreen cassettes, and also likely                  23 an exposed edge of PIR insulation board.                  24 I'll now play a video captured by the firefighters                  25 using thermal imaging cameras within flat 16. This</p> <p style="text-align: center;">Page 87</p>
<p>1 flame spread as compared with other polymers, but which                  2 lose essentially all of their mechanical strength and                  3 stiffness at temperatures well below 105 degrees                  4 Celsius.                  5 Next, possibly a piece of 25-millimetre thick                  6 foil-faced PIR foam insulation. This is a combustible                  7 thermosetting polymer, as I have already mentioned, that                  8 chars on burning but can rapidly ignite and spread flame                  9 when not protected by a foil facing.                  10 Then, a 1-millimetre thick layer of combustible EPDM                  11 rubber weatherproofing membrane, which can be assumed to                  12 offer very little resistance against attack from fire.                  13 Then, the edge of a piece of PIR foam insulation on                  14 the adjacent column. And it is likely, based on my                  15 post-fire investigations of the cladding at                  16 Grenfell Tower, that the PIR insulation's protective                  17 foil facing would not have been present at this location                  18 due to the way the boards are cut.                  19 Finally, the back of the Reynobond PE ACM rainscreen                  20 cassette which, as I noted earlier, would present                  21 a number of exposed surfaces of highly combustible                  22 polyethylene along cut edges and folding lines.                  23 In relation to spread of fire to the cladding,                  24 I will drawn on several additional items of evidence.                  25 These include video taken from outside Grenfell Tower</p> <p style="text-align: center;">Page 86</p>	<p>1 video begins at 01.15.28 and shows the firefighters                  2 opening the kitchen door, again from the hallway within                  3 flat 16, and pulsing a spray of water into the kitchen.                  4 (Video played)                  5 Again, I've extracted stills from before and after                  6 the water was applied.                  7 In the left-hand image, the thermal imaging camera                  8 footage shows heat across a wide area of wall and                  9 ceiling, both above and behind the fridge freezer.                  10 In the subsequent right-hand image, immediately                  11 following application of water by the firefighters, the                  12 heat is more localised to the area around the window.                  13 I've annotated these images with my interpretation                  14 in this next slide.                  15 The significance of these images is that they                  16 indicate that the area around the window was very hot                  17 when other parts of the kitchen were not. I've                  18 interpreted from this image that there was burning in                  19 the window surround and possibly the back of the                  20 cladding cavity that was visible to the thermal imaging                  21 camera from a position in the kitchen entrance.                  22 I've provided more detail about this sequence within                  23 my Phase 1 report.                  24 There is thus considerable evidence to indicate that                  25 the fire had spread to the external cladding by about</p> <p style="text-align: center;">Page 88</p>

<p>1 1.09 am, if not slightly earlier. The precise mechanism                  2 by which this occurred, however, cannot currently be                  3 stated, and this is a topic of ongoing investigation,                  4 experimentation and analysis.                  5 I'd now like to walk you slowly through the                  6 preliminary evidence of fire spread and to highlight                  7 some observations that I consider particularly                  8 noteworthy.                  9 However, before I begin this portion of my                  10 presentation, I'd like to note regulation B4 of the UK                  11 Building Regulations 2010. We heard this also on                  12 Monday.                  13 Whilst providing expert opinions on the compliance                  14 of various aspects of Grenfell Tower is not strictly                  15 within my scope of work for Phase 1, I believe that it's                  16 both important and useful to begin my presentation of                  17 fire spread evidence by reminding you of the statutory                  18 obligations of designers as regards external fire spread                  19 on buildings.                  20 Regulation B4 of the UK Building Regulations 2010,                  21 sentence 1, states that:                  22 "The external walls of the building shall adequately                  23 resist the spread of fire over the walls and from one                  24 building to another, having regard to the height, use                  25 and position of the building."</p> <p style="text-align: center;">Page 89</p>	<p>1 present my preliminary fire spread evidence. I'll                  2 present this evidence in three sections: upward fire                  3 spread from flat 16; downward fire spread on all four                  4 faces of the building; and horizontal fire spread around                  5 the building.                  6 I will begin with upward fire spread from flat 16.                  7 The upward vertical spread of fire from flat 16 is                  8 evidenced in my Phase 1 report using 25 videos that I've                  9 assembled into a single sequence. These have been                  10 analysed to identify the sequence in which they                  11 occurred. Where there is overlap between the videos,                  12 I've identified this based on matched background audio                  13 or matched visual content. The Metropolitan Police                  14 Service have also provided time stamps for some of these                  15 videos.                  16 Sir, with your permission, I'd like to play this                  17 video sequence, with audio, that shows the vertical fire                  18 spread from flat 16. This is the same video that was                  19 shown by Mr Millett during his opening remarks at the                  20 beginning of the evidential hearings.                  21 I will play the whole video uninterrupted and I will                  22 then spend some time discussing specific sections in                  23 much more detail.                  24 (Video played)                  25 From this video I've extracted a number of short</p> <p style="text-align: center;">Page 91</p>
<p>1 This functional objective clearly was not achieved                  2 at Grenfell Tower.                  3 Furthermore, when the fire did spread vertically,                  4 none of the other fire safety design features of the                  5 building, all of which were described by Dr Lane on                  6 Monday, could be expected to function as intended.                  7 Two main questions have therefore influenced my                  8 approach to studying the fire spread at Grenfell Tower.                  9 First: why did this happen? By which I mean: can we                  10 develop a physical understanding of the fire spread                  11 mechanisms and factors influencing these, both on                  12 Grenfell Tower and potentially on a significant number                  13 of other buildings in the UK, irrespective of any                  14 assessment of the regulatory compliance of the                  15 materials, products and systems used in the cladding?                  16 I will begin to address this question in my                  17 presentation today.                  18 Second: how did this happen? By which I mean: how                  19 is it that this particular combination of materials,                  20 products and systems were installed on Grenfell Tower,                  21 and how is it that similar combinations of materials                  22 appear to have been installed on a large number of other                  23 buildings in the UK?                  24 I will not address this question today.                  25 With these questions in mind, I'll now proceed to</p> <p style="text-align: center;">Page 90</p>	<p>1 clips that I'd now like to play and discuss. I've                  2 removed the audio from these clips and, in some cases,                  3 processed and stabilised the video to allow close-up                  4 views of aspects to which I would like to draw your                  5 attention.                  6 I will play each video on a loop, and I will                  7 describe what I've observed in the video while the loop                  8 is repeating.                  9 The first clip was captured at 1.08 am and shows the                  10 kitchen window of flat 16 from the outside of the                  11 building.                  12 From this short clip, I observe that: flames                  13 initially appear visible more to the left of the window;                  14 the extract fan appears to be absent from the window                  15 infill panel at the top-left of the kitchen window; the                  16 window infill panel and mounting of the extract fan unit                  17 appear to be burning; smoke is visible outside the                  18 compartment; and the windowpane below the extract fan                  19 unit appears to be absent or, alternatively, opened                  20 almost fully inwards.                  21 I also observe that a small amount of burning                  22 material is falling from the region around the window                  23 opening.                  24 A second clip was captured at 1.09 am and is part of                  25 the same clip that I previously played when discussing</p> <p style="text-align: center;">Page 92</p>

<p>1 the route of fire spread to the cladding. From this                  2 clip, I observe that flames appear more intense than in                  3 the previous video, only 1 minute earlier, suggesting                  4 that the fire has grown further during the elapsed time                  5 from the previous video.</p> <p>6 The more intense flames are observed to extend                  7 further out of the window and a regular flow of burning                  8 material is falling from the window. The material flows                  9 from the corner where the window meets the column line.</p> <p>10 A third clip was captured at 1.12 am and shows the                  11 fire from a different vantage point. The fire now                  12 appears to be more intense than in the previous images;                  13 however, due to the exposure of the image, it is not                  14 possible to precisely determine the origin of the                  15 flames; by this I mean whether they originate from the                  16 cladding or from within the compartment itself.</p> <p>17 Immediately below the window opening, there appears                  18 to be burning material on the surface of the ACM                  19 cladding. Burning material is falling from the window                  20 opening and some of the burning material is present on                  21 the ground.</p> <p>22 Please note that there is also some water on the                  23 ground in the bottom left-hand corner of this clip --                  24 there.</p> <p>25 Again, note the time of this clip at approximately</p> <p style="text-align: center;">Page 93</p>	<p>1 not have a confirmed time stamp, was captured some time                  2 between 1.16 and 1.19 am.</p> <p>3 In this clip, I observe that intermittent external                  4 flaming exists between levels 6 and 7. The highest                  5 point of the intermittent external flaming appears to be                  6 at the vertex of the junction between the column line                  7 and the faces of the spandrel sections of the building,                  8 essentially in the small corner that's created there.</p> <p>9 You will recall from part 2 earlier in my presentation                  10 that a continuous vertical void exists within the                  11 cladding system at this location.</p> <p>12 A covering jet is applied onto the external cladding                  13 from ground level, with firefighting water being applied                  14 to the cladding immediately below level 4.</p> <p>15 The subsequent videos were mostly captured from                  16 vantage points further away from the base of the                  17 building, likely because of the danger from falling                  18 burning debris.</p> <p>19 The evidence can be used to estimate the approximate                  20 extent and progression of the fire as it spread                  21 vertically up the east face of the tower.</p> <p>22 In most of the videos that I'm about to show, it is                  23 not currently possible to identify the precise level to                  24 which the fire had spread on the building. In general,                  25 it's possible to deduce floor levels approximately shown</p> <p style="text-align: center;">Page 95</p>
<p>1 1.12 am.</p> <p>2 A fourth clip is a combination of three overlapping                  3 clips, all from slightly different vantage points and                  4 captured at about 1.15 am. From this clip, I observe                  5 that the upper tip of the external flaming is                  6 approximately between levels 6 and 7. A large amount of                  7 burning material is now falling from the area of the                  8 fire and the smoke from the fire is drifting from south                  9 to north.</p> <p>10 At the end of this clip, the firefighters on the                  11 ground can also be observed to begin spraying water                  12 towards the fire.</p> <p>13 This is the first visual evidence that I'm aware of                  14 showing application of firefighting water to the                  15 exterior of the building at 01.15.53; however, as noted                  16 in the previous clip, there is evidence of water on the                  17 ground as early as 1.12 am. This may indicate earlier                  18 external application of firefighting water, what the                  19 firefighters refer to as a covering jet, for which there                  20 is currently no direct visual evidence.</p> <p>21 I will not comment any further on these early                  22 attempts at external firefighting as I understand that                  23 the inquiry's expert Steve McGuirk will comment on this                  24 issue in considerable detail in due course.</p> <p>25 I have estimated that a fifth clip, for which I do</p> <p style="text-align: center;">Page 94</p>	<p>1 in these videos based on other images which clearly show                  2 the top of the building, or using flats where lights are                  3 turned on or off as the fire progresses.</p> <p>4 A sixth clip was captured at 1.22 am. During this                  5 clip, at approximately 1.22.19 -- it plays on a loop so                  6 we'll see that again -- a firefighting jet can be                  7 observed to strike the column to the left of the                  8 vertically progressing fire some two to three floors                  9 above flat 16.</p> <p>10 I'll be silent while we go past 19 here. You'll see                  11 a jet. There.</p> <p>12 The angle of attack of this jet suggests that this                  13 is a firefighting jet which is being operated by                  14 firefighters who are within flat 16 leaning out the                  15 window and spraying upward in an unsuccessful attempt to                  16 extinguish the rapidly spreading cladding fire. This is                  17 consistent both with firefighter witness statements and                  18 with the thermal imaging camera footage from within                  19 flat 16.</p> <p>20 The covering jet from ground level is visible near                  21 the end of this clip at bottom-right and has a markedly                  22 different angle of attack.</p> <p>23 I'll just let it play through one more time so you                  24 can see that. There.</p> <p>25 A seventh clip shows a combination of videos</p> <p style="text-align: center;">Page 96</p>

<p>1 captured at 1.24 am. During this clip -- or this series  2 of clips, rather -- I observe that the fire's maximum  3 extent at this point is at approximately level 16 on the  4 east face.</p> <p>5 There are large pieces of burning debris falling  6 from the building. These are likely to be ACM  7 rainscreen cassettes or portions thereof based on  8 photographs of the debris field taken after the fire.</p> <p>9 Upwards fire spread is most advanced at the location  10 of the vertex between the spandrel section and the  11 column section. Along this line is both the re-entrant  12 corner in the geometry of the cladding and a continuous  13 vertical cavity within the cladding, as already  14 discussed.</p> <p>15 At this stage, the flames remain confined to the  16 spandrel section forming the east wall of flats ending  17 in the number 6. The fire is spreading slightly  18 northwards as it moves up the building, but is not  19 spreading significantly southwards past the column line  20 immediately to the left of the line of kitchen windows.</p> <p>21 An eighth clip was captured between 1.26 and  22 1.29 am. During this clip, I observed that the fire has  23 now reached level 23 and, by the end of the clip, the  24 flames are continuous at the level of the rooftop. Note  25 that this is also the location of the architectural</p> <p style="text-align: center;">Page 97</p>	<p>1 building.</p> <p>2 Here I would like to reiterate a previous  3 observation which is also evident from this analysis.</p> <p>4 By 1.15 am, as we can see here, flames were observed  5 to be extending at least two levels above flat 16. The  6 fire service's first visual confirmation of the location  7 of the fire from within flat 16 was at 01.14.16, and the  8 firefighters were unable to make an effective  9 intervention to extinguish the internal fire within the  10 kitchen until approximately 1.21 am.</p> <p>11 I therefore estimate that the fire had spread to the  12 cladding and begun spreading up the east face of  13 Grenfell Tower between 5 and 10 minutes before the  14 initial internal fire had been effectively extinguished.</p> <p>15 This concludes the key evidence to which I would  16 like to draw your attention on upward vertical fire  17 spread.</p> <p>18 I will now present preliminary evidence of downward  19 fire spread at Grenfell Tower.</p> <p>20 The purpose of presenting specific evidence of  21 downward fire spread is to highlight the key fire spread  22 mechanisms which can help to explain the extent of  23 external fire spread that was experienced at  24 Grenfell Tower.</p> <p>25 The Grenfell Tower fire is somewhat unusual in the</p> <p style="text-align: center;">Page 99</p>
<p>1 crown that I mentioned earlier.</p> <p>2 The 9th and final clip that I'll show to illustrate  3 vertical fire spread on the east face was captured  4 sometime between 1.29 and 1.36 am. During this clip,  5 I observe that the fire has spread to the top of the  6 east face and is beginning to spread horizontally around  7 the building, both to the north face over the top of the  8 northeastern-most column, and to the south along the  9 architectural crown at the top of the east face. You  10 can see the crown there in the top of the video clip.</p> <p>11 On the basis of the sequence of videos that I've  12 just shown, I have also determined the time,  13 approximately, that the fire reached different floors.  14 I've then plotted this on a graph.</p> <p>15 This graph starts at 12.54 am at its left side, when  16 the first 999 call was initially received, and finishes  17 at 1.29 am at the right, approximately when the fire  18 reaches the top roof level of the east face.</p> <p>19 The dotted line in this graph is an illustrative  20 exponential function I have fitted to the data, meaning  21 that the available evidence shows that the rate of fire  22 spread increased exponentially. Recalling my vertical  23 upward fire spread on a match earlier, this is as  24 expected. By this, I mean that the fire spread  25 continued to accelerate until it reached the top of the</p> <p style="text-align: center;">Page 98</p>	<p>1 context of similar cladding fires that have occurred  2 internationally in that the fire not only spread  3 vertically upward, but it also spread downward and  4 horizontally. It's my opinion that a combination of  5 these fire spread directions and mechanisms conspired to  6 cause the extensive fire spread which eventually  7 included almost the entire exterior surface of the  8 building.</p> <p>9 There are two main sources of evidence to which I'd  10 like to draw your attention: first, a series of videos  11 captured by members of the public; and, second, photos  12 taken by the Metropolitan Police Service after the fire.</p> <p>13 I will begin by presenting several short video clips  14 that provide visual evidence of downward fire spread.  15 Again, I will play these without audio and, again, on  16 a loop.</p> <p>17 From these videos it will be observed that  18 considerable melting and dripping of burning material  19 occurred, primarily along the column lines. It is my  20 opinion that this burning and dripping material is  21 predominantly polyethylene from the ACM rainscreen  22 cassettes. We will also see that falling flaming debris  23 landed on horizontal ledges on the spandrel sections and  24 in some cases resulted in localised burning at these  25 locations.</p> <p style="text-align: center;">Page 100</p>

<p>1 The first clip shows the north and west faces of                  2 Grenfell Tower, and for the next series of clips I have                  3 a small diagram in the left-hand corner that shows where                  4 the view is from, again with my red circle and red arrow                  5 showing line of sight and the blue lines indicating the                  6 bits of the building that we're looking at.                  7 So, again, the first clip shows the north and west                  8 faces of Grenfell Tower. It was captured sometime                  9 between 2.48 and 3.11 am.                  10 This clip shows dripping, burning material at the                  11 column line. We can see this particularly near the top                  12 of the northwestern-most column, where the fire first                  13 spreads on to the west face from the north face, along                  14 the architectural crown and over the column top.                  15 Here, I would also note the similarities between                  16 this video and the video of a burning sheet of                  17 polyethylene that I showed in part 1 of my presentation                  18 today.                  19 A second clip shows essentially the same area of the                  20 building a short while later, sometime, in this case,                  21 between 3.20 and 3.33 am.                  22 This clip again shows dripping, burning material at                  23 the column line, this time on one of the columns on the                  24 west face of the building, rather than a corner column                  25 as in the previous clip. Again, note the similarity to</p> <p style="text-align: center;">Page 101</p>	<p>1 These areas present zones of partial damage where                  2 the progression of the fire has been stopped. Where the                  3 ACM rainscreen cassettes were fully burned by the fire,                  4 little physical evidence remains to support fire spread                  5 analysis.                  6 However, at the interface between the unburned and                  7 burned regions of the cladding, a number of relevant                  8 observations can be made.                  9 In relation to this point, it's noteworthy that both                  10 video and photo evidence appear to suggest that the                  11 downward vertical fire spread was halted as a result of                  12 fire service intervention during the fire. This was                  13 because water was applied directly to the external                  14 cladding, which was able to halt the downward progress                  15 of the fire. This can be observed in the photographs                  16 that I will present in a moment.                  17 However, I have not personally undertaken any                  18 detailed analysis of fire service water application on                  19 the exterior of the tower in my Phase 1 report and this                  20 is a point being addressed by other experts.                  21 I'll now show a series of post-fire photos that were                  22 captured by the Metropolitan Police Service using                  23 a drone on 25 July 2017.                  24 In this photo, I observe that the ACM cassettes show                  25 locations where polyethylene has melted, dripped or</p> <p style="text-align: center;">Page 103</p>
<p>1 my earlier video.                  2 A third clip was captured as part of the same                  3 recording. In this clip, right in the centre of the                  4 image, we can also see evidence of burning debris                  5 falling, landing and accumulating on window ledges on                  6 the spandrel section of the building, where it continues                  7 to burn as a small localised fire.                  8 (Pause)                  9 A fourth and final clip that I'll show in the                  10 context of downward fire spread was captured sometime                  11 after 4.09 am and shows the leading edge of the fire                  12 spreading downwards along column lines on the west face                  13 of the building.                  14 In this clip we can observe that the leading edge of                  15 the downward spreading fire is, again, along the column                  16 lines and possibly along the column tips.                  17 Sir, I would again like to remind you that                  18 a continuous internal void runs the full height of the                  19 building at the column tip location as well.                  20 Further evidence of the possible mechanisms for                  21 downward vertical fire spread is available in post-fire                  22 photos of damage to the cladding system. Of particular                  23 interest are areas of the cladding where a boundary                  24 exists between fire damaged cladding and undamaged                  25 cladding.</p> <p style="text-align: center;">Page 102</p>	<p>1 flowed and solidified. This is particularly evident                  2 along column lines, which in most cases represent the                  3 leading downward edge of the fire, as I've already                  4 noted. You can see that clearly here on the central                  5 column, the black material being polyethylene.                  6 In this photo, I observe the following:                  7 The ACM rainscreen cassettes show locations where                  8 polyethylene has melted, dripped or flowed and                  9 solidified.                  10 At the interface between the burned and unburned                  11 sections of the external cladding, partially burned ACM                  12 rainscreen cassettes are present and these indicate that                  13 the aluminium layers had separated from the polyethylene                  14 contained within the ACM rainscreen cassettes. By this,                  15 I mean that debonding of the aluminium skins had                  16 occurred and the polyethylene had partially melted or                  17 burned away.                  18 Debris, which I assume to be resolidified                  19 polyethylene, is present on the detail in front of the                  20 windows and below the burned sections of the cladding,                  21 essentially on the windowsills.                  22 I also observed this during my own site inspections                  23 of the external cladding in the months following the                  24 fire.                  25 This photo shows the debris field on 16 June 2017 in</p> <p style="text-align: center;">Page 104</p>

<p>1 what was the children's play area on the west side of                  2 the being. Photos of the debris field and the                  3 firefighter witness statements suggest that                  4 a significant proportion of this falling debris                  5 consisted of ACM rainscreen cassettes. I believe this                  6 will also have included window infill panels or parts                  7 thereof, although I wasn't able to inspect the debris                  8 field myself.</p> <p>9 This concludes the evidence to which I'd like to                  10 draw your attention on downward vertical fire spread.</p> <p>11 I'll now present a summary of my preliminary                  12 evidence of horizontal or lateral fire spread.</p> <p>13 The horizontal fire spread eventually resulted in                  14 all four faces of Grenfell Tower becoming involved in                  15 the fire. As I've already noted, this extent of                  16 horizontal fire spread must be considered unusual in the                  17 context of most other external cladding fires                  18 experienced internationally, and understanding the                  19 specific reasons and mechanisms for this is therefore                  20 very important.</p> <p>21 The horizontal fire spread is documented in videos                  22 and images captured by members of the public, CCTV and                  23 other media.</p> <p>24 Horizontal fire spread cannot be viewed totally in                  25 isolation from upward, vertical and downward vertical</p> <p style="text-align: center;">Page 105</p>	<p>1 I also observed that the external cladding detail at                  2 the top of the columns was generally the first location                  3 where the fire was observed to spread to the next                  4 spandrel section of the face when the fire spreads                  5 horizontally across the faces of the building.</p> <p>6 To develop a timeline, I've therefore defined                  7 horizontal fire spread as the time at which the fire                  8 reached a column at the top of the building.</p> <p>9 The columns at Grenfell Tower are defined on a grid                  10 and are denoted by the references A1 through D5, as I've                  11 shown here.</p> <p>12 This slide shows the overall plan for the tower for                  13 levels 4 and above, with the column notations shown and                  14 the times that the fire reached the column tops as it                  15 spread horizontally around the building.</p> <p>16 At 1.29 am, the fire had reached the top of the east                  17 face, as I've already said, at columns A5 and B5, as                  18 shown here.</p> <p>19 At 1.56 am, the fire reached column C5 on the east                  20 face.</p> <p>21 At 2.23 am, the fire reached the corner column at                  22 the southeast corner of the building, column D5. During                  23 this time, the fire was also spreading laterally across                  24 the north face, or horizontally across the north face,                  25 for which I don't currently have any CCTV imagery.</p> <p style="text-align: center;">Page 107</p>
<p>1 fire spread, and it's important to recognise that these                  2 directions of fire spread surely interacted during the                  3 fire.</p> <p>4 I've developed an approximate timeline of the                  5 location of maximum horizontal fire spread on each face                  6 of the building. For Phase 1, I based this timeline                  7 primarily on CCTV images available from around the                  8 tower. These were provided to the inquiry by the                  9 Metropolitan Police Service and are as follows: the                  10 upper east and south faces were captured in one sequence                  11 by a single CCTV camera; no CCTV footage was available                  12 for the north face of the tower; the upper west face was                  13 captured by a single CCTV camera.</p> <p>14 I've developed my initial overall horizontal fire                  15 spread timeline by comparing the maximum extent of fire                  16 spread with subsequent and previous images. The exact                  17 times for fire spread to each face based on this                  18 analysis are unlikely to be sufficiently accurate to                  19 assure greater precision than plus or minus 5 minutes.</p> <p>20 During my review of the available evidence,                  21 I observed that the furthest extent of horizontal fire                  22 spread usually -- but not always -- appears to be at the                  23 top of the building at the location of the architectural                  24 crown and column tops. I described the crown earlier in                  25 my presentation and I've just shown it again here.</p> <p style="text-align: center;">Page 106</p>	<p>1 At 2.48 am, the fire reached the northwest corner of                  2 the building. Also at 2.48 am, the fire had spread to                  3 column D4 on the south side of the building.</p> <p>4 At 3.11 am, the fire reached column D3, halfway                  5 across the south face.</p> <p>6 At 3.20 am, the fire spread to column B1 on the west                  7 face.</p> <p>8 At 3.33 am, the fire spread to column D2, on the                  9 west face.</p> <p>10 At 3.48 am, the fire spread to column C1 on the west                  11 face.</p> <p>12 Finally, at 4.09 am, the fire spread to the                  13 southwest corner of Grenfell Tower from both directions.</p> <p>14 After this time, the fire continued to spread                  15 vertically down the building.</p> <p>16 I will now present a series of specific images                  17 showing horizontal fire spread to which I'd like to draw                  18 your attention.</p> <p>19 I will present these images with reference to each                  20 face of the building independently and I'll start with                  21 the east face.</p> <p>22 Image 1 shows the east face of Grenfell Tower                  23 between 1.29 and 1.56 am. In this image, I'd like to                  24 draw your attention to the top of the column.                  25 I've interpreted this image as showing that the fire</p> <p style="text-align: center;">Page 108</p>

<p>1 has spread over the column top -- this is the column at                  2 the left of the fire zone. Video evidence of this is                  3 also referenced in my Phase 1 report.                  4 Image 2 shows the north and east faces of                  5 Grenfell Tower between 1.29 and 2.23 am, and closer to                  6 about 1.56 am.                  7 From this image, I observe that the furthest extent                  8 of horizontal fire spread is at the top of the building.                  9 The fire appears to have spread over the top of the                  10 column, and between the columns the flame front forms                  11 a slightly inclined angle over the face of the building.                  12 Image 3 shows the east face of Grenfell Tower                  13 between about 1.56 and 2.23 am. From this image,                  14 I observe, again, the furthest extent of horizontal fire                  15 spread is at the top of the building, and the fire has                  16 spread to the column top at the southeast corner of the                  17 building.                  18 Image 4, which is unfortunately quite low                  19 resolution, shows the south face of Grenfell Tower                  20 between 2.23 and 2.48 am. I've shown this image to                  21 illustrate that the horizontal fire spread between the                  22 east and south faces again occurred at the top of the                  23 column.                  24 I will now move on to the north face.                  25 Although I've not been able to provide definitive</p> <p style="text-align: center;">Page 109</p>	<p>1 3 minutes long.                  2 (Video played)                  3 Just to say that the small triangular zone at the                  4 very top of the building, the column top to the right of                  5 that, is the architectural crown.                  6 (Video continued)                  7 From that clip we can see that the fire is most                  8 advanced again within the architectural crown slightly                  9 ahead of other locations on the north face.                  10 Image 7 was taken between 1.29 and 1.56 am. From                  11 this image, I observe spread around the column top --                  12 although it's quite difficult to see in this image --                  13 and spread around the column lower down the building.                  14 So this is one case where the fire does spread                  15 horizontally around a column at a lower level.                  16 Image 8 was taken between 2.23 and 2.48 am, and from                  17 this image I observe that the furthest extent of                  18 horizontal fire spread is at the top floors of the                  19 building, again, and particularly at the location of the                  20 architectural crown. Between the columns, the fire                  21 front again forms an inclined angle over the face of the                  22 building.                  23 Image 9 was taken sometime between 2.48 and 3.11 am.                  24 From this image, I observe again that the furthest                  25 extent of the horizontal fire spread is at the top</p> <p style="text-align: center;">Page 111</p>
<p>1 timings for the spread of fire over the north face due                  2 to the lack of CCTV for this face, there is some                  3 photographic evidence showing the spread across the                  4 north face.                  5 Images 5 and 6 are taken directly from the north of                  6 the building, as shown here. These are extracts from                  7 the start and end of a longer video.                  8 The left-hand earlier image shows that the flames                  9 are visible at the horizontal joints between the ACM                  10 column cassettes. You can see those annotated on the                  11 photograph. My Phase 1 report shows that horizontal                  12 ledges between the rainscreen cassettes existed at these                  13 locations and would've presented locations where melted                  14 polyethylene could collect and continue to burn as small                  15 localised pool fires.                  16 Over the course of the 2-minute-and-48-second video                  17 from which these images are extracted, the fire spreads                  18 from localised joints and becomes established across                  19 most of the height of the column.                  20 This is visible in the right-hand image taken near                  21 the end of the clip.                  22 The left-hand image also suggests that fire is                  23 spreading over the column top.                  24 I will now show the full source video for further                  25 illustration of these points. This video is about</p> <p style="text-align: center;">Page 110</p>	<p>1 floors of the building; the top of the column and the                  2 architectural crown is the first location where the fire                  3 spreads to the next bay; and the external flames formed                  4 at the column locations appear to be slightly larger or                  5 brighter than those formed between the columns.                  6 I will now move on to the west face.                  7 The first evidence of spread to the west face is the                  8 image I showed previously, image 9. This image shows                  9 that the first location of spread to the west face was                  10 over the column top in the northwest corner.                  11 Image 10 was taken between 2.48 and 3.48 am, and in                  12 this image the fire has reached the next column on the                  13 west face at its top before any other location. Between                  14 the columns, the fire front again forms an inclined                  15 angle over the face of the building.                  16 Image 11 was taken between 3.20 and 3.48 am. This                  17 image shows that the fire spreads within the                  18 architectural crown ahead of horizontal fire spread at                  19 any other location. And, again, between the columns the                  20 fire front forms an inclined angle over the face of the                  21 building.                  22 Image 12 was taken between 3.20 and 3.48 am, closer                  23 to 3.48. From this image, I observe that the fire has                  24 reached the column top again before any other location,                  25 and, between the columns, the fire front forms</p> <p style="text-align: center;">Page 112</p>

<p>1 an inclined angle over the face of the building.</p> <p>2 Image 13 was captured between 3.48 and 4.09 am,</p> <p>3 closer to 4.09. From this image I observe that the fire</p> <p>4 is converging on the southwest corner of the building</p> <p>5 and that the fire is spreading within the architectural</p> <p>6 crown, again ahead of horizontal fire spread to any</p> <p>7 other level.</p> <p>8 I will now move on to describing the fire spread</p> <p>9 over the final face, the south face of the building.</p> <p>10 For this face of the building I've relied more heavily</p> <p>11 on the CCTV footage from the southeast corner of</p> <p>12 Grenfell Tower.</p> <p>13 That's the view for the CCTV from the southeast</p> <p>14 corner. So in the centre of this image is the top of</p> <p>15 the column in the southeast corner of the building.</p> <p>16 From this footage I observe that the fire initially</p> <p>17 spread onto the south face via the column top, column</p> <p>18 D5, and the architectural crown at that location.</p> <p>19 The furthest extent of horizontal fire spread was</p> <p>20 consistently at the top floors of the building, as shown</p> <p>21 here, as it's progressing further around the face, and</p> <p>22 again on the architectural crown, and a short while</p> <p>23 later, the fire is spreading rapidly downwards from this</p> <p>24 location along the column lines.</p> <p>25 This horizontal fire spread followed by downward</p> <p style="text-align: center;">Page 113</p>	
<p>1 fire spread I believe to be very significant.</p> <p>2 All of these fire spread directions and</p> <p>3 mechanisms -- upward, downward and horizontal -- are</p> <p>4 subject to ongoing investigation, experimentation and</p> <p>5 analysis by the inquiry's experts.</p> <p>6 This brings to a close the preliminary evidence of</p> <p>7 fire spread over the cladding on the building that</p> <p>8 I would like to bring to your attention at this stage of</p> <p>9 the inquiry.</p> <p>10 This also, therefore, concludes the evidence that</p> <p>11 I would like to present today.</p> <p>12 SIR MARTIN MOORE-BICK: Thank you very much indeed.</p> <p>13 MR MILLETT: Mr Chairman, that concludes the work of the</p> <p>14 inquiry for today.</p> <p>15 Thank you very much, Professor Bisby.</p> <p>16 SIR MARTIN MOORE-BICK: Thank you very much, Professor.</p> <p>17 We'll stop there, then, and we'll resume at</p> <p>18 10 o'clock tomorrow morning, when we shall hear some</p> <p>19 evidence read.</p> <p>20 Thank you very much.</p> <p>21 (3.15 pm)</p> <p>22 (The hearing adjourned until Thursday, 21 June 2018 at</p> <p>23 10.00 am)</p> <p>24</p> <p>25</p> <p style="text-align: center;">Page 114</p>	

<b>A</b>	<b>addition</b> 6:21 12:6 59:8	<b>alternatively</b> 92:19	20:19	<b>asks</b> 80:23
<b>A1</b> 107:10	<b>additional</b> 22:16,16 46:23 53:2 55:14	<b>aluminium</b> 46:4,9 46:17,19 48:18,25	<b>applied</b> 46:7,11 49:15 88:6 95:12	<b>aspect</b> 4:23
<b>A5</b> 107:17	67:6 81:6 86:24	50:21 51:4 52:18	95:13 103:13	<b>aspects</b> 8:15 9:22 89:14 92:4
<b>abbreviate</b> 27:12	<b>address</b> 8:23 90:16 90:24	53:21,24 54:5,14	<b>apply</b> 21:8	<b>assembled</b> 91:9
<b>ability</b> 17:20 24:10 71:17	<b>addressed</b> 8:8 103:20	55:20 56:5,7	<b>approach</b> 90:8	<b>assess</b> 10:22 57:5 64:19
<b>able</b> 8:20 12:10,25 60:24 103:14	<b>addresses</b> 2:21	57:16 62:20 69:9	<b>approached</b> 78:22	<b>assessment</b> 90:14
105:7 109:25	<b>adequately</b> 9:2 89:22	104:13,15	<b>appropriate</b> 15:9	<b>assists</b> 1:16
<b>absence</b> 63:25	<b>adhered</b> 60:20	<b>amount</b> 17:25 24:18 25:16 73:21	<b>approximate</b> 95:19 106:4	<b>associate</b> 13:25
<b>absent</b> 81:19,24 92:14,19	<b>adhesive</b> 47:2	74:11 92:21 94:6	<b>approximately</b> 33:19 42:2,13	<b>associated</b> 10:7 28:11 30:5 31:4
<b>absolute</b> 19:21	<b>adhesively</b> 62:6	<b>analysed</b> 91:10	45:21 46:24 55:11	42:15 61:2 79:9 87:18
<b>academic</b> 6:21	<b>adjacent</b> 24:8 28:23 30:16 69:11	<b>analysis</b> 5:8 18:3 89:4 99:3 103:5	60:17 61:19 78:2	<b>assume</b> 19:6 104:18
<b>accelerate</b> 69:11 98:25	86:14	103:18 106:18	78:8,13,20,24	<b>assumed</b> 86:11
<b>accelerated</b> 78:6	<b>adjourned</b> 114:22	114:5	82:24 93:25 94:6	<b>assumptions</b> 36:18 63:21
<b>accelerating</b> 69:14 69:16	<b>adjournment</b> 75:18	<b>anchored</b> 46:5 58:24	95:25 96:5 97:3	<b>assure</b> 106:19
<b>accomplish</b> 11:7	<b>advanced</b> 97:9 111:8	<b>and/or</b> 28:17	98:13,17 99:10	<b>atmosphere</b> 25:10 25:11
<b>account</b> 25:22	<b>advances</b> 29:15 32:1 33:19	<b>angle</b> 96:12,22 109:11 111:21	<b>April</b> 2:19	<b>attached</b> 50:24
<b>accounts</b> 59:14	<b>advancing</b> 30:23	112:15,20 113:1	<b>architectural</b> 55:6 55:12,17 56:1	<b>attack</b> 86:12 96:12 96:22
<b>accumulating</b> 102:5	<b>affect</b> 25:24 65:22	<b>Angus</b> 6:19	67:20 73:10,12	<b>attempt</b> 96:15
<b>accurate</b> 106:18	<b>affirmed</b> 2:12	<b>annotated</b> 39:24 88:13 110:10	79:3 97:25 98:9	<b>attempted</b> 25:7
<b>accurately</b> 4:11	<b>afternoon</b> 1:22 75:3	<b>apologise</b> 54:25	101:14 106:23	<b>attempts</b> 17:10 94:22
<b>achieved</b> 90:1	<b>afternoon's</b> 75:22	<b>apparatus</b> 20:7	111:5,8,20 112:2	<b>attended</b> 84:17
<b>acknowledged</b> 42:10	<b>ago</b> 38:2 49:6,21 80:12	<b>apparent</b> 61:2	112:18 113:5,18	<b>attention</b> 19:11,16 38:10 41:14 51:11
<b>acknowledging</b> 4:23	<b>agree</b> 3:10 83:25	<b>apparently</b> 36:23	113:22	56:15 72:8 79:25
<b>ACM</b> 46:10 49:5 50:22 51:1,7	<b>agreed</b> 79:12	<b>appear</b> 49:25 70:21 90:22 92:13,17	<b>Arconic</b> 56:1	81:25 82:5 83:25
52:21 55:2,5,19	<b>ahead</b> 4:15 29:11 30:23 31:16,22	93:2 103:10 112:4	<b>area</b> 29:14 32:10 78:17 80:19,21	92:5 99:16 100:10
56:11 57:12 67:18	37:9,12 111:9	<b>appearance</b> 57:18	83:2 88:8,12,16	105:10 108:18,24 114:8
68:9,13 73:14	112:18 113:6	<b>appeared</b> 81:15	94:7 101:19 105:1	<b>attractive</b> 69:3
85:14 86:19 87:9	<b>air</b> 11:19 12:4,11 13:13,13 15:3	<b>appears</b> 20:25 43:4 48:8 49:21 51:5	<b>areas</b> 40:8 41:16 56:20 59:11	<b>audio</b> 1:23 2:4 76:4 80:7 91:12,17
87:22 93:18 97:6	22:20 25:12 29:20	60:8 81:18,19,23	102:23 103:1	92:2 100:15
100:21 103:3,24	<b>air</b> 11:19 12:4,11 13:13,13 15:3	87:17 92:14,19	<b>arranged</b> 39:9	<b>available</b> 6:23,25 13:12 24:18,24
104:7,11,14 105:5 110:9	22:20 25:12 29:20	93:12,17 95:5	<b>arrangement</b> 42:8	26:21 28:13 31:7
<b>ACMs</b> 54:6 55:23 57:1	29:23 33:12	106:22 109:9	<b>arrangements</b> 53:11	36:15 39:16 44:10
<b>active</b> 4:2	<b>Alexander</b> 2:17	<b>appendix</b> 3:4	<b>arrow</b> 14:9 82:24 101:4	59:14 63:18 64:8
<b>adding</b> 45:2	<b>alike</b> 5:13	<b>applicable</b> 8:12	<b>Artex</b> 61:3	
	<b>allow</b> 20:4 92:3	<b>application</b> 88:11 94:14,18 103:18	<b>asbestos</b> 61:2	
		<b>applications</b> 20:6	<b>aside</b> 26:11	
			<b>asked</b> 7:15 79:7	

64:10 66:24 69:21 72:14 73:21,23 74:12 77:14 98:21 102:21 106:7,11 106:20 <b>avoid</b> 8:10 11:3 63:15 64:22 <b>aware</b> 87:12 94:13	<b>beginning</b> 35:3 81:10,11 91:20 98:6 <b>begins</b> 31:23 35:8 35:16 88:1 <b>begun</b> 99:12 <b>behalf</b> 6:13 <b>behaviour</b> 15:14,20 25:25 27:2,3 35:21 57:19 63:7 63:9,16,19 64:15 64:19 66:14 67:12 74:14 <b>behaviours</b> 65:22 70:3 <b>belief</b> 4:9 <b>believe</b> 10:3 20:13 43:24 53:17 79:25 89:15 105:5 114:1 <b>beneath</b> 35:4 43:8 81:23 <b>benefit</b> 7:2 <b>bereaved</b> 4:21 <b>best</b> 4:9 <b>Bisby</b> 1:10,19 2:10 2:12,15,17,17,20 2:24 3:3,7,13,18 3:21 4:1,7,10,13 4:14,16 38:23,25 75:5,8,13,23 76:13 114:15 <b>bit</b> 20:14 54:25 <b>bits</b> 101:6 <b>black</b> 56:16,20 57:1 85:9 104:5 <b>blackened</b> 57:18 <b>block</b> 16:20,24 17:1 17:6,11 21:25 22:6,9 23:2,5 <b>blue</b> 34:24 101:5 <b>board</b> 45:18 47:1 48:3,17 49:15,20 59:24 60:2,17 81:21 87:23 <b>boards</b> 47:24 49:23	61:4,6,18 62:2 72:5 84:15 85:1 85:24 86:18 <b>body</b> 16:9 <b>bonded</b> 47:1 56:6 62:6 <b>bottom</b> 32:7 48:15 58:8,19 60:23 93:23 <b>bottom-left</b> 34:24 60:3 <b>bottom-right</b> 96:21 <b>boundary</b> 102:23 <b>brackets</b> 50:25 <b>break</b> 38:16,18,21 66:1 75:2,7,10 <b>breaking</b> 76:22 77:25 <b>bridged</b> 85:7 <b>brief</b> 8:25 64:4 <b>briefly</b> 9:10 63:7 79:14 82:14 84:8 <b>Brigade</b> 6:9 82:2,7 <b>brighter</b> 112:5 <b>bring</b> 114:8 <b>brings</b> 114:6 <b>broadly</b> 26:14 79:12 83:25 <b>broken</b> 84:22 <b>brought</b> 45:11 83:24 <b>build-up</b> 44:24 47:16 <b>building</b> 2:3,23 5:9 5:22 7:10,19,22 7:25 8:6,12,16,20 30:12 39:9,23 40:1,4,8,11,13,16 40:19,25 41:2,3 41:20 42:2,6,8,21 43:3,11,17 44:7 45:7,9 46:8,23 47:16,18,19 48:10 48:14,15 49:22 50:3,8,11,16	51:14,14,17 52:25 53:9 55:6 57:23 59:16,20 60:10 61:24 73:10 77:10 78:15,23 79:1,2,5 79:6 81:9,17 84:20 85:5,21 87:19 89:11,20,22 89:24,25 90:5 91:4,5 92:11 94:15 95:7,17,24 96:2 97:6,18 98:7 99:1 100:8 101:6 101:20,24 102:6 102:13,19 106:6 106:23 107:5,8,15 107:22 108:2,3,15 108:20 109:8,11 109:15,17 110:6 111:4,13,19,22 112:1,15,21 113:1 113:4,9,10,15,20 114:7 <b>building's</b> 7:17 8:6 42:7 <b>buildings</b> 21:22 36:22 69:4 89:19 90:13,23 <b>bulk</b> 68:23 <b>buoyancy</b> 30:22 31:19 <b>buoyant</b> 13:10 14:2 <b>burn</b> 11:11 12:12 14:21 15:6,8,10 17:5 19:19 20:2 25:3,5,8 27:1 35:4 39:10 57:20 65:23 66:11 68:16 72:13 73:17 79:5 102:7 110:14 <b>burned</b> 7:12 77:21 103:3,7 104:10,11 104:17,20 <b>burning</b> 2:3 11:23 12:14,20,24 15:14	20:22 25:10,17,25 27:11 28:5,23 30:17 31:16,17,19 31:22 32:3,7,10 34:7,10,15 35:9 35:11,15 36:8 37:10 38:1 63:7,9 63:16,19 64:15,19 66:5,6,9,14 67:8 67:12,25 70:3 71:3 76:3 81:18 86:8 87:17 88:18 92:17,21 93:7,18 93:19,20 94:7 95:18 97:5 100:18 100:20,24 101:10 101:16,22 102:4 <b>burns</b> 10:10 26:24 35:20 71:4 <b>burnt-out</b> 2:8 76:7 <b>butane</b> 34:23,23
				<b>C</b>
				<b>C-shaped</b> 55:18 <b>C1</b> 108:10 <b>C5</b> 107:19 <b>call</b> 1:19 2:9,10 14:13 23:20 29:24 76:8 79:17 80:3,5 80:10 81:11 98:16 <b>called</b> 14:15 15:11 18:8 21:11,19 24:1 31:2 52:6 55:24 60:8 65:3 <b>camera</b> 79:21 82:1 82:14,22 83:6,22 87:2 88:7,21 96:18 106:11,13 <b>cameras</b> 87:25 <b>Canada</b> 3:25 <b>capable</b> 68:5 <b>capacity</b> 17:24 <b>captured</b> 81:10 82:11,13 87:2,4 87:24 92:9,24

93:10 94:4 95:1 95:15 96:4 97:1 97:21 98:3 100:11 101:8 102:2,10 103:22 105:22 106:10,13 113:2 <b>carbon</b> 12:5 13:21 <b>carefully</b> 44:9 48:2 <b>case</b> 11:23 13:2,5 14:6 16:4,12 23:4 27:5,15,15 29:25 30:8 32:17,24 33:8,12,14,16,18 34:2 49:4 66:20 101:20 111:14 <b>cases</b> 6:22 17:3,6 27:12 38:3 49:22 49:24 64:10 65:15 92:2 100:24 104:2 <b>cassette</b> 49:5 56:12 56:18,19 62:2 86:20 <b>cassettes</b> 40:21,24 41:22 46:10,12 50:22 51:2,7,9 52:21 55:2 56:9 57:12 67:20 68:9 85:14 87:10,22 97:7 100:22 103:3 103:24 104:7,12 104:14 105:5 110:10,12 <b>catastrophic</b> 4:19 <b>caught</b> 5:4 <b>causal</b> 10:6 <b>cause</b> 4:20 8:5 87:21 100:6 <b>causes</b> 14:11 <b>causing</b> 78:17 <b>cavities</b> 73:8 <b>cavity</b> 41:18 44:13 52:22 56:20,23 69:13 72:7 85:12 88:20 97:13 <b>CCTV</b> 105:22	106:7,11,11,13 107:25 110:2 113:11,13 <b>ceiling</b> 45:14,19 60:11,25 88:9 <b>ceilings</b> 61:3 <b>cellular</b> 70:10 <b>Celotex</b> 54:11,18 54:19 58:10,12,22 59:2,24 <b>Celsius</b> 18:2 68:3 71:5 72:1,2 86:4 <b>cent</b> 11:19 25:13 69:25 <b>central</b> 4:23 9:22 15:15 74:20 104:4 <b>centre</b> 102:3 113:14 <b>certain</b> 1:11,13,20 11:8 20:5 34:4 64:24 <b>cetera</b> 63:10 <b>chain</b> 7:10 <b>chains</b> 65:5 <b>Chairman</b> 1:8 2:10 38:15 75:1,21 114:13 <b>challenging</b> 6:7 <b>chances</b> 17:4 <b>change</b> 18:11 <b>changes</b> 25:23 <b>channels</b> 53:8 55:18 73:8,13 <b>char</b> 27:20,23 66:22,22,24,25 67:11 71:14 74:8 <b>characterised</b> 16:3 67:9 <b>characteristic</b> 13:25 <b>characteristics</b> 15:25 <b>charred</b> 57:16 <b>charring</b> 57:19 74:14	<b>chars</b> 27:14 86:8 <b>chart</b> 26:2 <b>chartered</b> 3:22 <b>chemical</b> 10:12 11:18 14:22 25:15 37:6 39:2 71:15 72:12 <b>chemically</b> 66:19 <b>children's</b> 105:1 <b>chloride</b> 47:4 71:8 <b>circle</b> 82:23 101:4 <b>circumstances</b> 19:22 24:25 25:4 25:5 26:22 36:5 44:1 <b>clad</b> 36:23 <b>cladding</b> 5:10,20 7:18,20 8:1,18 9:3 9:7,9,13,25,25 10:7 19:3 20:16 24:8 26:13 39:7 41:20 42:4 43:13 43:25 44:6,13,16 44:18,20,21,25 45:1,3 46:14,15 47:10,16 50:3,7 50:21 51:2,4,6,8,9 51:12,20 52:5,10 52:23 53:12,15 54:23,24 56:23,24 59:7 60:15 61:6 61:22,25 63:4 64:6 67:16 68:19 72:7,23,25 73:3,6 73:9 74:19 76:16 76:20 77:9,9,16 77:22 78:17,20 79:8 80:2 82:9 84:6,8 85:12,23 86:15,23 87:13 88:20,25 90:15 93:1,16,19 95:11 95:12,14 96:16 97:12,13 99:12 100:1 102:22,23	102:24,25 103:7 103:14 104:11,20 104:23 105:17 107:1 114:7 <b>classes</b> 65:11,23 <b>clear</b> 12:16 34:15 39:22 53:18 76:25 82:8 84:18 85:19 <b>clearly</b> 34:12 38:11 47:24 70:1 90:1 96:1 104:4 <b>clip</b> 22:17 34:13 35:1 82:17,20 83:5,9,9,11 92:9 92:12,24,25 93:2 93:10,23,25 94:2 94:4,10,16,25 95:3 96:4,5,21,25 97:1,21,22,23 98:2,4,10 101:1,7 101:10,19,22,25 102:2,3,9,14 110:21 111:7 <b>clips</b> 22:4 92:1,2 94:3 97:2 100:13 101:2 <b>close</b> 114:6 <b>close-up</b> 61:17 92:3 <b>closely</b> 55:18,19 <b>closer</b> 45:11 109:5 112:22 113:3 <b>co-editor-in-chief</b> 3:19 <b>coatings</b> 63:25 <b>coincident</b> 78:16 <b>colleagues</b> 6:18 <b>collect</b> 110:14 <b>collected</b> 6:9 <b>colour</b> 41:1,12 58:7 58:19 <b>colours</b> 56:25 57:6 <b>column</b> 40:11,13 40:19,24 48:13 49:3,8 50:12 51:14,24 52:7,13	52:23 53:2,7 58:2 61:23 62:3 86:14 93:9 95:6 96:7 97:11,19 98:8 100:19 101:11,12 101:14,23,24 102:12,15,16,19 104:2,5 106:24 107:8,13,14,19,21 107:22 108:3,4,6 108:8,10,24 109:1 109:1,10,16,23 110:10,19,23 111:4,11,13,15 112:1,4,10,12,24 113:15,17,17,24 <b>column's</b> 52:16 <b>columns</b> 40:7 50:17 51:22 52:1 55:3 58:4 101:23 107:2 107:9,17 109:10 111:20 112:5,14 112:19,25 <b>combination</b> 36:11 90:19 94:2 96:25 100:4 <b>combinations</b> 90:21 <b>combined</b> 11:15 <b>Combining</b> 53:5 <b>combustible</b> 13:4 19:15,15,20,23 29:11 73:4,14,16 86:6,10,21 <b>combustion</b> 11:17 11:20 12:18 13:20 20:21 22:24 23:7 24:13,20,22 25:9 25:13,16,19 26:2 26:3 27:1 68:3,5 68:11,15 69:23 71:5,16,19 72:15 73:21,22 <b>come</b> 43:7 <b>coming</b> 80:22
--	---	---	--	--

<p><b>comment</b> 8:4 64:17 94:21,23</p> <p><b>commentary</b> 68:7</p> <p><b>commenting</b> 8:10 63:16</p> <p><b>comments</b> 70:2 80:15</p> <p><b>Committee</b> 4:3</p> <p><b>common</b> 19:6 21:8 23:20 26:5 29:17 54:4</p> <p><b>commonly</b> 23:20 29:23 31:2 71:10</p> <p><b>community</b> 4:22</p> <p><b>comparative</b> 69:23</p> <p><b>comparatively</b> 18:13 59:6 69:7 70:5,12,20 71:18 85:25</p> <p><b>compare</b> 71:6</p> <p><b>compared</b> 25:12 26:16 86:1</p> <p><b>comparing</b> 16:19 68:8 106:15</p> <p><b>comparison</b> 69:20 70:1 71:23</p> <p><b>compartment</b> 77:8 79:10,16 81:22 92:18 93:16</p> <p><b>complete</b> 25:13</p> <p><b>completeness</b> 52:9</p> <p><b>complex</b> 11:5 12:25 73:1</p> <p><b>complexities</b> 11:6</p> <p><b>compliance</b> 8:11 36:19 63:22 64:18 89:13 90:14</p> <p><b>complicate</b> 31:6</p> <p><b>component</b> 12:7</p> <p><b>components</b> 41:6 45:2 84:13</p> <p><b>composed</b> 16:21 36:11 54:12</p> <p><b>composite</b> 1:25 36:10,16 46:9</p>	<p>54:5,8 63:19 64:1 76:1 80:11</p> <p><b>composition</b> 10:12 37:6 39:2 43:13 72:12</p> <p><b>compounds</b> 65:2</p> <p><b>comprised</b> 46:4 49:3 53:19,20 55:17 56:4 62:20</p> <p><b>comprises</b> 42:24 52:18</p> <p><b>concepts</b> 1:12 12:23 15:18 28:21 30:11 36:3,8 37:14 38:9,11</p> <p><b>concerned</b> 8:15</p> <p><b>concerning</b> 84:4</p> <p><b>concluded</b> 87:8</p> <p><b>concludes</b> 38:8 63:2 74:23 99:15 105:9 114:10,13</p> <p><b>conclusions</b> 2:22 5:21,25 37:1 44:11</p> <p><b>concrete</b> 42:1 45:4 45:13,14,15 46:6 47:14 48:7,12 49:8 50:12 52:16 52:17 55:21 58:24 60:13 61:23 62:7 85:4</p> <p><b>concurrent</b> 29:18 29:19,24</p> <p><b>concurrently</b> 37:19</p> <p><b>conditions</b> 11:15 14:21 20:3 22:22 22:23 24:22 25:1 27:17 28:4 65:17 68:6 73:20,24</p> <p><b>conducted</b> 16:25 39:14</p> <p><b>conduction</b> 14:8,9 16:14 17:21</p> <p><b>conductivity</b> 17:19 18:4</p>	<p><b>Confidential</b> 4:4</p> <p><b>confidently</b> 24:6</p> <p><b>configuration</b> 23:25 29:3 84:19 85:19</p> <p><b>configured</b> 55:10</p> <p><b>confined</b> 97:15</p> <p><b>confirmation</b> 99:6</p> <p><b>confirmed</b> 44:5 60:4 95:1</p> <p><b>connection</b> 51:1</p> <p><b>consequence</b> 47:12 84:25</p> <p><b>consequences</b> 74:2 74:11</p> <p><b>consequently</b> 18:21 32:3,20 67:4 70:12 87:11</p> <p><b>consider</b> 31:3 44:15 63:11 82:8 84:7 89:7</p> <p><b>considerable</b> 9:8 36:2 55:14 64:16 72:8 88:24 94:24 100:18</p> <p><b>consideration</b> 2:2 76:2</p> <p><b>considered</b> 26:6 44:9 70:1 77:6 83:3 105:16</p> <p><b>considering</b> 31:1 38:12 72:21</p> <p><b>consisted</b> 105:5</p> <p><b>consistent</b> 96:17</p> <p><b>consistently</b> 113:20</p> <p><b>consisting</b> 53:24 54:10</p> <p><b>conspired</b> 100:5</p> <p><b>constant</b> 35:10</p> <p><b>constituent</b> 66:1</p> <p><b>construction</b> 5:9 8:16 43:5 45:1,5 46:2 47:14 48:16 60:9 63:1,4 71:24</p> <p><b>consumed</b> 27:8</p>	<p>32:2 33:20 35:17</p> <p><b>contain</b> 2:7 75:23 76:6</p> <p><b>contained</b> 104:14</p> <p><b>contains</b> 85:12</p> <p><b>content</b> 1:20 91:13</p> <p><b>context</b> 7:4 20:1,19 54:7 72:4 100:1 102:10 105:17</p> <p><b>continue</b> 5:3 14:20 15:5 17:5 23:6 110:14</p> <p><b>continued</b> 4:18 79:4 98:25 108:14 111:6</p> <p><b>continues</b> 4:20 24:15 33:24 35:18 48:21 50:14 102:6</p> <p><b>continuing</b> 4:23 32:25</p> <p><b>continuous</b> 51:19 51:22 53:5 60:11 95:10 97:12,24 102:18</p> <p><b>contrasting</b> 65:22</p> <p><b>contribute</b> 34:13 66:15</p> <p><b>contributions</b> 9:4</p> <p><b>convection</b> 14:2</p> <p><b>convenient</b> 38:15 75:1,4</p> <p><b>conventional</b> 15:21</p> <p><b>converging</b> 113:4</p> <p><b>Conversely</b> 18:14 66:18</p> <p><b>conversion</b> 25:14</p> <p><b>cool</b> 16:12</p> <p><b>core</b> 6:15,18 7:1 62:22 70:23</p> <p><b>corner</b> 42:21 56:2 78:21 87:7 93:9 93:23 95:8 97:12 101:3,24 107:21 107:22 108:1,13 109:16 112:10</p>	<p>113:4,11,14,15</p> <p><b>correct</b> 2:20 3:3,13 3:21 4:1,7 11:15 13:17 15:8 65:16</p> <p><b>corrected</b> 83:8</p> <p><b>correspond</b> 58:13</p> <p><b>corridor</b> 82:12</p> <p><b>corroborated</b> 81:6</p> <p><b>coupling</b> 18:20</p> <p><b>course</b> 7:11 8:7 12:17 26:12 34:1 76:25 77:20 94:24 110:16</p> <p><b>court</b> 3:2</p> <p><b>covered</b> 43:23 45:23</p> <p><b>covering</b> 43:22 60:18 94:19 95:12 96:20</p> <p><b>cracked</b> 57:18</p> <p><b>created</b> 65:4 95:8</p> <p><b>creating</b> 28:15</p> <p><b>creeping</b> 33:3</p> <p><b>critical</b> 24:1,2,4,10 44:15 77:4</p> <p><b>critically</b> 8:7 12:11 25:2</p> <p><b>CROSS</b> 4:4</p> <p><b>crown</b> 55:6,9,10,13 55:17 67:20 73:11 73:12 79:3 98:1,9 98:10 101:14 106:24,24 111:5,8 111:20 112:2,18 113:6,18,22</p> <p><b>currently</b> 64:19 87:12 89:2 94:20 95:23 107:25</p> <p><b>cut</b> 44:18,20 46:21 49:23 56:10 86:18 86:22</p> <p><b>cuts</b> 56:11</p> <p><b>Cutting</b> 48:10</p> <hr/> <p style="text-align: center;"><b>D</b></p> <hr/>
---	---	--	--	---

<b>D</b> 3:4	<b>deep</b> 10:6	77:11 87:20 90:5	<b>diesel</b> 26:16 68:10	85:10,15,25 97:14
<b>D2</b> 108:8	<b>deepest</b> 5:2	106:24	68:12	<b>discussing</b> 10:4
<b>D3</b> 108:4	<b>defined</b> 20:20	<b>describes</b> 26:23	<b>difference</b> 17:3	15:20 36:2 63:9
<b>D4</b> 108:3	21:10 107:6,9	<b>describing</b> 1:13	69:17	70:19 71:10 91:22
<b>D5</b> 107:10,22	<b>definitive</b> 109:25	113:8	<b>differences</b> 57:5	92:25
113:18	<b>definitively</b> 59:25	<b>description</b> 79:15	65:11	<b>discussion</b> 23:22
<b>Daeid</b> 43:23 79:12	<b>deformations</b> 31:4	81:5	<b>different</b> 9:4 10:14	30:10 37:1 63:23
82:3 84:2	<b>deformed</b> 65:15	<b>design</b> 8:16 43:15	10:21,22 20:4	64:25 85:20
<b>Daeid's</b> 79:13	<b>degree</b> 18:2 20:2	90:4	27:1 36:12 39:23	<b>display</b> 36:12
<b>damage</b> 55:7	<b>degrees</b> 68:2 71:5	<b>designers</b> 89:18	44:25 54:22 56:11	<b>distance</b> 47:13
102:22 103:1	72:1,2 86:3	<b>Despite</b> 36:25	56:25 57:6 65:23	48:20
<b>damaged</b> 41:22	<b>delivered</b> 21:12	<b>detail</b> 3:8 9:8 30:4	69:20 70:17 73:2	<b>distinction</b> 12:15
57:13 59:19	<b>demands</b> 11:8	39:21 41:17 42:5	73:17,18,19 93:11	15:23 19:24 25:2
102:24	64:23	43:12 44:14,16	94:3 96:22 98:13	53:18 54:21
<b>danger</b> 95:17	<b>demonstrate</b> 31:8	45:20 46:25 47:6	<b>differentiate</b> 15:21	<b>distinguish</b> 29:17
<b>dark</b> 47:21	<b>demonstrating</b>	47:9 50:23 52:6	<b>differently</b> 49:23	<b>distress</b> 2:5 76:5
<b>darkened</b> 57:18	31:14	54:3 55:13 64:16	<b>difficult</b> 19:9	<b>disturbing</b> 61:1
<b>dashed</b> 52:13	<b>demonstration</b>	64:18 67:14 68:17	111:12	<b>documentation</b>
<b>data</b> 36:15 63:18	34:20	77:11 82:10 88:22	<b>digits</b> 58:13	39:15
64:7 98:20	<b>demonstrations</b>	91:23 94:24	<b>dimensions</b> 15:24	<b>documented</b> 35:22
<b>date</b> 64:5	37:16	104:19 107:1	<b>dioxide</b> 12:5 13:21	105:21
<b>dated</b> 2:19	<b>denoted</b> 107:10	<b>detailed</b> 2:2 9:17	<b>direct</b> 66:4 94:20	<b>documents</b> 8:13
<b>day</b> 1:9	<b>density</b> 17:22 18:5	43:25 76:2 79:15	<b>direction</b> 29:20,22	<b>doing</b> 24:12 82:5
<b>day-to-day</b> 19:13	<b>depend</b> 14:25 20:10	103:18	48:21	<b>dominate</b> 66:14
71:24	<b>dependence</b> 64:11	<b>details</b> 72:14	<b>directions</b> 78:23	<b>dominated</b> 38:4
<b>deal</b> 19:16	<b>dependent</b> 23:15	<b>determine</b> 60:24	100:5 106:2	<b>door</b> 82:12,15 88:2
<b>deals</b> 9:20,21	30:13 66:8	93:14	108:13 114:2	<b>doorway</b> 82:17
<b>dealt</b> 53:13	<b>depending</b> 19:22	<b>determined</b> 17:16	<b>directly</b> 12:12	<b>dotted</b> 98:19
<b>debonding</b> 104:15	50:16	77:14 98:12	49:19 56:22 65:18	<b>double</b> 46:17 48:24
<b>debris</b> 47:22 87:6,8	<b>depends</b> 23:12 28:2	<b>determines</b> 28:12	82:12 103:13	<b>doubt</b> 54:2 68:7
95:18 97:5,8	28:25	<b>determining</b> 14:19	110:5	<b>Dougal</b> 6:20
100:22 102:4	<b>depicting</b> 1:24	15:14	<b>disaster</b> 8:17	<b>downward</b> 30:5,20
104:18,25 105:2,4	75:24	<b>devastating</b> 5:17	<b>discernible</b> 57:5	30:24 32:15,17
105:7	<b>describe</b> 9:8 13:1	<b>develop</b> 90:10	<b>disclaimer</b> 36:25	33:10,14,16 34:3
<b>decades</b> 35:23	29:8 30:4,7 39:6,8	107:6	<b>disclosures</b> 39:16	37:11,24 38:3
<b>declaration</b> 2:25	39:10,21,23 41:7	<b>developed</b> 106:4,14	<b>discovered</b> 80:4	76:23 78:16 91:3
<b>decompose</b> 13:7	41:16 42:4 45:20	<b>developing</b> 10:5	<b>discuss</b> 15:17 20:14	99:18,21 100:3,14
65:20 66:19	46:15 47:6 53:13	15:15 36:4	24:11,12 35:25	102:10,15,21
<b>decomposition</b>	54:22 63:7 65:6	<b>development</b> 7:7	50:4 54:2 79:13	103:11,14 104:3
12:1,14 14:15	67:12 76:15,21	76:18	92:1	105:10,25 113:25
<b>deconstruction</b>	82:9 92:7	<b>diagram</b> 101:3	<b>discussed</b> 23:11	114:3
61:25 84:16	<b>described</b> 19:5	<b>dictate</b> 15:4	28:9,20 29:10	<b>downwards</b> 29:25
<b>decreases</b> 27:23	20:23 26:22 30:11	<b>dictated</b> 27:3	44:14 53:6 55:13	32:25 34:7,11
67:3,11	32:20 39:1 50:23	<b>dictating</b> 68:16	61:20 62:18 68:17	79:5 102:12
<b>deduce</b> 95:25	53:10 73:7,22	<b>diene</b> 72:10	68:21 69:1,6	113:23

<b>Dr</b> 6:19,20 43:23 44:14 50:23 90:5	<b>ease</b> 10:9 16:19 18:9	24:23,24 25:15,15 25:17,20 26:19,21 26:24 27:24 28:12 29:11 31:8 68:4 69:12 73:21,23 74:12	<b>evaluating</b> 24:10 28:11	69:13
<b>draw</b> 38:9 41:14 51:11 56:15 79:25 81:25 82:5 92:4 99:16 100:10 105:10 108:17,24	<b>easier</b> 24:3	<b>engineer</b> 3:23,24	<b>evaluation</b> 20:11	<b>examples</b> 29:21
<b>drawing</b> 44:10 45:12 62:9 85:16	<b>easily</b> 29:5 43:20	<b>engineering</b> 3:11	<b>evaporate</b> 66:2	<b>exhibits</b> 16:8
<b>drawings</b> 39:25	<b>east</b> 40:10 42:9 77:24 78:5,7,11 78:14 95:21 97:4 97:16 98:3,6,9,18 99:12 106:10 107:16,19 108:21 108:22 109:4,12 109:22	<b>Engineers</b> 3:23 4:5 4:6	<b>event</b> 4:19 5:4	<b>existed</b> 110:12
<b>drawn</b> 6:17,21 37:1 86:24	<b>edge</b> 49:7 61:22 85:2 86:13 87:23 102:11,14 104:3	<b>ensure</b> 39:22	<b>events</b> 2:6 7:10 32:13 33:1 65:13 76:6 77:5 81:5	<b>existing</b> 36:18 38:5 44:7 62:6 63:21
<b>draws</b> 30:10 33:12	<b>edges</b> 56:16 85:13 86:22	<b>ensuring</b> 74:21	<b>eventually</b> 19:1 22:21 32:24 100:6 105:13	<b>exists</b> 51:12,20 85:2 95:4,10 102:24
<b>drifting</b> 94:8	<b>Edinburgh</b> 3:12,17 6:13,19 39:20 57:4	<b>enter</b> 11:25	<b>evidence</b> 1:16 5:1 5:12,24 6:1,4,8,8 7:21 9:17 10:4,24 26:7 30:3 38:12 39:5,12 40:2 44:10 53:10 59:14 63:3 64:3 72:22 77:6,14 79:9,16 79:18,24 82:8 84:1,4,7 86:24 87:11,17 88:24 89:6,17 91:1,2 94:13,16,20 95:19 98:21 99:15,18,20 100:9,14 102:4,20 103:4,10 105:9,12 106:20 109:2 110:3 112:7 114:6 114:10,19	<b>existed</b> 110:12
<b>drip</b> 34:1 67:24	<b>effect</b> 4:19 5:17 30:22	<b>entered</b> 79:20 85:23	<b>evicted</b> 33:16,20 91:8	<b>existing</b> 36:18 38:5 44:7 62:6 63:21
<b>dripped</b> 103:25 104:8	<b>effective</b> 99:8	<b>entire</b> 52:25 100:7	<b>evidential</b> 91:20	<b>exists</b> 51:12,20 85:2 95:4,10 102:24
<b>dripping</b> 31:5 34:4 38:1 66:13 100:18 100:20 101:10,22	<b>effectively</b> 66:23 99:14	<b>entrained</b> 13:14	<b>evolved</b> 32:22	<b>exothermic</b> 11:20
<b>drive</b> 31:8	<b>effects</b> 31:3 74:17	<b>entrance</b> 82:17 88:21	<b>evolved</b> 32:22	<b>expect</b> 64:15
<b>drives</b> 24:16	<b>eighth</b> 97:21	<b>environment</b> 3:16 10:20 16:1	<b>evolved</b> 32:22	<b>expected</b> 90:6 98:24
<b>drone</b> 40:5 55:7 103:23	<b>either</b> 19:14,14,23	<b>environments</b> 64:21	<b>evolved</b> 32:22	<b>experience</b> 3:5 18:23 71:22
<b>droplets</b> 34:10 66:6 67:25 71:3	<b>elaborate</b> 77:13	<b>EPDM</b> 49:11,25 61:20 62:4,8,11 72:10,12,15 85:8 85:11 86:10	<b>evolved</b> 32:22	<b>experienced</b> 21:23 99:23 105:18
<b>Drysdale</b> 6:20	<b>elapsed</b> 93:4	<b>equal</b> 16:17 18:14 19:8 23:10 33:19	<b>evolved</b> 32:22	<b>experimental</b> 36:15 36:18 63:18,21
<b>due</b> 13:10 27:19 30:21 31:19 34:3 44:7 61:2 67:11 70:20 86:18 93:13 94:24 110:1	<b>elastomer</b> 72:11	<b>equivalent</b> 21:16	<b>evolved</b> 32:22	<b>experimentation</b> 89:4 114:4
<hr/> <b>E</b> <hr/>	<b>electrical</b> 21:18	<b>essential</b> 24:5	<b>evolved</b> 32:22	<b>expert</b> 3:14 5:5 89:13 94:23
<b>earlier</b> 20:23 58:21 69:2 75:4 85:17 86:20 89:1 93:3 94:17 95:9 98:1 98:23 102:1 106:24 110:8	<b>elements</b> 41:19 55:10	<b>essentially</b> 16:2 27:7 56:24 84:12 86:2 95:8 101:19 104:21	<b>evolved</b> 32:22	<b>experts</b> 1:6 5:13 7:5 8:9 42:11 103:20 114:5
<b>earliest</b> 87:11,16	<b>emergency</b> 5:1 7:14 8:5	<b>established</b> 110:18	<b>evolved</b> 32:22	<b>experts'</b> 1:9
<b>early</b> 4:17 6:2 38:10 54:1 76:18 79:10 87:1 94:17 94:21	<b>Emeritus</b> 6:20	<b>estimate</b> 95:19 99:11	<b>evolved</b> 32:22	<b>explain</b> 9:4 30:9 99:22
	<b>emission</b> 13:23	<b>estimated</b> 94:25	<b>evolved</b> 32:22	<b>explained</b> 7:6 72:5 73:17
	<b>enabling</b> 8:17	<b>et</b> 63:10	<b>evolved</b> 32:22	<b>explaining</b> 1:11
	<b>enclosure</b> 61:13	<b>Ethylene</b> 72:10	<b>evolved</b> 32:22	<b>exponentially</b> 98:22
	<b>endothermic</b> 14:16	<b>European</b> 64:21	<b>evolved</b> 32:22	<b>exposed</b> 16:25 17:13 18:7,11 22:6 23:17 56:15 56:22 66:20 71:2 74:1 85:13 86:21 87:23
	<b>energy</b> 11:21 13:18 13:19 14:17 16:9 17:21,25 21:12,17 21:18 24:15,18,20	<b>evacuation</b> 7:14 8:7	<b>evolved</b> 32:22	<b>exposure</b> 22:11 23:14 65:24 67:23 71:14 93:13
		<b>evaluate</b> 8:20	<b>evolved</b> 32:22	<b>exposures</b> 21:22
		<b>evaluated</b> 10:14	<b>evolved</b> 32:22	<b>expressed</b> 21:15

<b>extend</b> 5:2 93:6	<b>extremely</b> 69:2	100:22 102:5	2:23 3:10,20 4:5	99:6,7,9,11,14,16
<b>extended</b> 75:10	73:1	105:4	4:17,24 5:15,21	99:19,21,21,23,25
<b>extending</b> 99:5	<b>extremes</b> 29:23	<b>familiar</b> 12:19	6:9 7:8,19,22,23	100:2,5,6,12,14
<b>extends</b> 61:21		16:18 25:6 26:3,4	8:3,6,19,22,25 9:1	101:12 102:7,10
<b>extensive</b> 8:3 77:1	<b>F</b>	26:6,9,11 27:15	9:2,6,11,13,14,18	102:11,15,21,24
100:6	<b>facade</b> 1:14 2:22	27:15 31:12 54:2	9:20,22,23,25	103:2,3,4,11,12
<b>extensively</b> 5:16	48:7 85:4	<b>fan</b> 43:3,8 46:18	10:24 11:9,10,11	103:12,15,18
7:24 8:4 67:19	<b>face</b> 40:3 52:4 53:3	81:18,19,23 84:22	11:16 13:25 14:13	104:3,24 105:10
<b>extent</b> 9:5 10:13	56:19 58:9 60:13	84:23 92:14,16,18	15:20 19:17 20:19	105:12,13,15,16
11:4 27:3 37:21	77:25 78:5,7,9,11	<b>fans</b> 41:6 62:25	21:21 22:24 24:6	105:21,24 106:1,2
74:11 95:20 97:3	78:14,14,19,19	<b>far</b> 52:1 72:19	24:17 25:7 26:8	106:3,5,14,15,17
99:22 105:15	95:21 97:4 98:3,6	82:16	28:7,11,17,17,18	106:21 107:3,4,7
106:15,21 109:7	98:7,9,18 99:12	<b>faster</b> 14:24 30:19	28:21,24 34:3	107:7,14,16,19,21
109:14 111:17,25	101:13,13,24	32:1	35:25 36:3,5,6	107:23 108:1,2,4
113:19	102:12 106:5,12	<b>fatalities</b> 4:20	37:4 38:5,6,8 39:4	108:6,8,10,12,14
<b>exterior</b> 1:17 2:23	106:12,17 107:4	<b>feature</b> 51:12 52:10	40:4 41:23 42:11	108:17,25 109:2,8
5:22 7:20,22 36:1	107:17,20,24,24	<b>features</b> 73:6 90:4	47:22 50:2 53:16	109:9,14,15,21
40:1,19 42:7 50:7	108:5,7,9,11,20	<b>feedback</b> 28:15	55:7,8,11 56:3,13	110:1,17,22 111:7
72:23 94:15 100:7	108:21,22 109:11	32:11	56:23 57:7,13,17	111:14,18,20,25
103:19	109:12,19,24	<b>feet</b> 75:6	61:13 62:1 63:12	112:2,12,14,17,18
<b>external</b> 1:24 5:9	110:1,2,4 111:9	<b>fellow</b> 4:5	64:4 66:5,8,16	112:20,23,25
8:3 9:6,9 14:17	111:21 112:6,7,9	<b>fibre</b> 54:16 58:20	69:16,20 70:17	113:3,5,6,8,16,19
23:3 28:4,6,8 36:5	112:13,15,20	<b>field</b> 97:8 104:25	71:14 72:6,22	113:23,25 114:1,2
40:22 42:9 51:4	113:1,9,9,10,17	105:2,8	73:15,19,24 74:12	114:7
52:16 57:16 64:6	113:21	<b>fifth</b> 94:25	75:2,25 76:4,5,7	<b>fire's</b> 8:4 76:17
67:6 69:8 72:25	<b>faced</b> 60:18,25	<b>figure</b> 27:10,22	76:15,19,21,22,23	97:2
74:6 75:24 76:21	<b>faces</b> 7:24 40:11,12	51:21 52:8	76:23 77:7,9,10	<b>fire-damaged</b>
77:8 82:9 88:25	58:7,19 91:4 95:7	<b>file</b> 80:8	77:16,17,21,21,24	47:23
89:18,22 94:5,18	101:1,8 105:14	<b>fill</b> 48:1,4 51:3	78:2,4,5,6,7,11,13	<b>firefighter</b> 96:17
94:22 95:3,5,12	106:10 107:5	<b>filled</b> 47:3 53:25	78:16,17,18,19,22	105:3
99:23 103:13	109:4,22	<b>filler</b> 56:6	78:22,25 79:4,10	<b>firefighters</b> 79:20
104:11,23 105:17	<b>facing</b> 54:14 69:9	<b>filling</b> 85:10	79:16,22 80:1,8	82:11,14,19,21
107:1 112:3	74:7 86:9,17	<b>final</b> 1:9 9:12 52:5	80:11 82:1,6,8	83:1 87:2,24 88:1
<b>extinguish</b> 96:16	<b>fact</b> 13:10 30:8	61:5 63:6 98:2	83:3,17 84:1,5,7	88:11 94:10,19
99:9	34:17 35:20 41:14	102:9 113:9	84:17,20 85:22	96:14 99:8
<b>extinguished</b> 7:12	82:6	<b>finally</b> 7:11 28:20	86:12,23 87:1,12	<b>firefighting</b> 94:14
99:14	<b>factors</b> 9:2 16:17	51:7 81:25 86:19	87:21 88:25 89:6	94:18,22 95:13
<b>extinguishes</b> 32:25	18:14 19:5,8	108:12	89:17,18,23 90:3	96:6,13
<b>extract</b> 41:6 43:3,8	23:10 37:5 90:11	<b>find</b> 85:11,23	90:4,8,10 91:1,2,3	<b>fires</b> 34:14 100:1
46:18 62:25 80:16	<b>factual</b> 4:8	<b>findings</b> 79:13	91:4,6,7,17 93:1,4	105:17 110:15
81:18,19,23 84:22	<b>fades</b> 48:19 50:13	<b>finish</b> 45:24 49:15	93:11,11 94:8,8	<b>first</b> 2:9 5:19 7:17
84:23 92:14,16,18	<b>fall</b> 34:10 35:4,18	61:5 75:12	94:12 95:20,24	8:25 9:21 12:15
<b>extracted</b> 83:13	<b>falling</b> 35:11 87:6,8	<b>finishes</b> 98:16	96:3,8,16 97:8,9	17:19 20:18,25
88:5 91:25 110:17	92:22 93:8,19	<b>finishing</b> 46:25	97:17,22 98:3,5	35:2 37:2 76:8
<b>extracts</b> 110:6	94:7 95:17 97:5	<b>fire</b> 1:18,25 2:4,5,8	98:13,17,21,23,24	77:17 78:9 80:3,4

82:6,8 85:24 90:9 92:9 94:13 98:16 99:6 100:10 101:1 101:7,12 107:2 112:2,7,9 <b>fitted</b> 46:18 98:20 <b>five</b> 40:13 <b>fixings</b> 46:5 52:19 <b>flame</b> 1:12,17,24 2:1,2,16 10:1,19 10:22 11:2,16,25 12:19,23 13:5,9 13:11,14,16,25 14:1,3,5,7 15:3 16:25 20:3,25 21:7 23:8 24:11 28:21,22,25 29:2 29:4,7,15,16,18 29:18,19,19,21,22 29:24,25 30:1,6,7 30:9,10,13,15,19 30:20,20,24 31:1 31:6,8,11,15,17 31:18,24 32:8,12 32:16,17,19,23,24 33:3,7,8,9,10,11 33:13,14,15,15,17 33:21,21,24 34:7 34:24 36:8,12,16 37:4,8,9,11,12,16 37:21,24 38:4 56:22 66:25 67:5 67:7 69:8,11,14 70:13 71:2,17 74:3,5 75:24 76:1 76:3 86:1,8 109:10 <b>flames</b> 29:12 30:21 30:23 35:5 72:6 81:14,19 92:12 93:2,6,15 97:15 97:24 99:4 110:8 112:3 <b>flaming</b> 12:9 20:22 22:24 23:7 28:15	67:25 94:5 95:4,5 100:22 <b>flammability</b> 1:12 9:23 10:1,9,11,13 10:14,16,21 11:2 12:23 19:12,20 20:1,4,9,12 36:12 36:16 37:4 63:10 73:15 <b>flammable</b> 11:18 11:25 12:4 13:7,9 13:11,16 14:11 15:2,7,11 19:14 19:24 21:5 22:13 28:1 29:13 31:23 32:4 65:18 66:2,4 66:21 67:22 <b>flat</b> 1:17 24:7 42:10 42:12,13 43:15 45:10,24 47:23 56:9 72:7 76:20 77:18,21 78:1 79:8,20,21 80:2,4 82:3,15,22 83:17 84:5,10,12,16 87:3,7,19,25 88:3 91:3,6,7,18 92:10 96:9,14,19 99:5,7 <b>flats</b> 42:19,20 60:12 77:25 96:2 97:16 <b>flexible</b> 62:5 <b>floor</b> 35:4,12 41:25 46:6 82:22 84:11 95:25 <b>floors</b> 42:1 78:1 96:8 98:13 111:18 112:1 113:20 <b>flow</b> 13:10 29:20,23 34:7 35:10 66:6,7 93:7 <b>flowed</b> 104:1,8 <b>flowing</b> 67:24 <b>flows</b> 93:8 <b>flux</b> 21:11,11 22:2 22:6 23:14,24	24:1,2,4 <b>fluxes</b> 21:19,23 23:9 <b>foam</b> 18:16 27:16 45:18 46:7,12,24 49:4,13,18,24 50:15 51:3,10 52:20 54:13,17 57:8,15,22,25 58:3,6,15,18 59:5 59:10,17,23 60:2 60:5,16 62:22 68:18,22,25 70:4 70:8,9,18,23,25 71:3 74:4 85:12 86:6,13 <b>foams</b> 11:24 23:17 57:20 69:18 70:15 <b>focus</b> 5:23 8:1 9:13 43:25 55:14 63:11 <b>focuses</b> 5:7 <b>foil</b> 54:14 58:7,8,19 69:9 86:9,17 <b>foil-faced</b> 52:20 59:23 60:1 86:6 <b>folded</b> 56:10 <b>folding</b> 86:22 <b>folds</b> 56:11 <b>followed</b> 22:23 27:18 113:25 <b>following</b> 40:4 44:24 62:1 88:11 104:6,23 <b>follows</b> 23:22 37:3 39:13 77:16 106:9 <b>footage</b> 77:2 79:21 81:8 82:1,13 83:7 83:23 88:8 96:18 106:11 113:11,16 <b>forensic</b> 61:25 84:16 <b>form</b> 12:5,7,10 15:3 21:18 34:10 55:5 56:9 61:5 65:5,16 66:10 72:5	<b>formal</b> 39:16 <b>formally</b> 1:19 <b>formation</b> 27:20,23 34:14 66:16,22,25 67:11 <b>formed</b> 49:12 55:19 73:13 84:24 112:3 112:5 <b>forming</b> 97:16 <b>forms</b> 45:14 71:3 109:10 111:21 112:14,20,25 <b>formulation</b> 69:18 70:15 <b>formulations</b> 64:12 <b>found</b> 39:9 59:10 67:13 <b>foundational</b> 28:20 <b>four</b> 7:24 39:13 40:11 68:20 79:19 83:24 91:3 105:14 <b>fourth</b> 84:11 94:2 102:9 <b>fraction</b> 24:23 <b>frame</b> 34:25 48:5 49:7 61:22 83:13 85:3,6 <b>framed</b> 46:17 <b>frames</b> 48:18 50:24 <b>framing</b> 45:18 48:17 59:20 61:4 <b>freezer</b> 80:20 83:20 88:9 <b>fridge</b> 80:8,20 81:3 83:20 88:9 <b>front</b> 32:1 33:18 34:14 37:13 66:16 104:19 109:10 111:21 112:14,20 112:25 <b>fuel</b> 11:14 12:9,13 16:2,7 17:13 26:16 28:14 32:2 33:20 37:8,12 66:23	<b>fuels</b> 16:16,17 23:12 <b>full</b> 52:3 53:3 73:9 78:25 80:10 102:18 110:24 <b>fully</b> 92:20 103:3 <b>function</b> 24:25 28:7 90:6 98:20 <b>functional</b> 90:1 <b>fundamental</b> 14:19 20:9 28:19 30:11 36:3,15 63:18 <b>further</b> 1:5 14:11 32:10 33:8 42:16 42:22 59:17 93:4 93:7 94:21 95:16 102:20 110:24 113:21 <b>Furthermore</b> 15:12 90:3 <b>furthest</b> 106:21 109:7,14 111:17 111:24 113:19
<b>G</b>				
<b>gap</b> 48:4 49:7,9,12 49:14 53:25 85:2 85:7,10 <b>gaps</b> 47:2 48:1 51:3 84:24 <b>gas</b> 12:10 15:2,7,8 20:21 31:24,24 33:12 66:2,21 <b>gaseous</b> 12:5,13 <b>gases</b> 11:18,25 12:3 13:7,9,10,11,16 13:17,19 14:3,12 20:22 21:5 22:13 22:16,20 23:7 28:1 29:13 30:21 32:23 33:6 37:9 65:18 66:4 67:4 87:21 <b>gathered</b> 5:24 <b>general</b> 10:2 20:14				

24:3 76:15 80:20 95:24 <b>generally</b> 23:18 30:19 37:11 107:2 <b>generate</b> 23:6 31:23 66:2,4 <b>generated</b> 12:7 <b>generating</b> 67:25 <b>generic</b> 40:15 58:11 65:6 <b>geometric</b> 53:11 <b>geometry</b> 10:20 15:13 25:1,23 28:3 29:4 37:7 42:5 43:13 44:1,7 44:7,22 49:18 51:12 52:10 53:13 55:12 63:3 72:24 73:1,6 74:18 84:8 97:12 <b>give</b> 1:20 2:15 4:15 25:20 26:1 69:22 75:11 <b>given</b> 19:7 21:2,13 23:14,24,25 24:25 26:22 70:18 79:12 <b>gives</b> 64:3 <b>glass</b> 54:16 58:20 <b>glazed</b> 42:24 43:7 46:17 48:18,24 81:22 <b>glazing</b> 47:11 48:19 <b>glowing</b> 13:22 <b>go</b> 4:15 23:8 45:3 67:7 96:10 <b>going</b> 1:4 3:8 12:21 30:4 37:19 <b>good</b> 1:3,8 4:16 38:17 <b>govern</b> 11:1 <b>governed</b> 10:11,19 30:16 34:8 <b>governs</b> 18:6 <b>gradation</b> 10:17 <b>gradient</b> 16:9	<b>graph</b> 98:14,15,19 <b>grateful</b> 6:6 <b>great</b> 19:16 <b>greater</b> 106:19 <b>greatly</b> 37:13 <b>Grenfell</b> 1:15 4:17 5:6,15,20 6:11 8:2 8:12 9:23 10:25 15:16 19:4,17 20:17 24:7 26:8 26:13 36:1,6,24 39:8,13,18 43:18 44:5 53:15 54:23 55:3,23 56:3,12 57:1,9 58:4,17,23 59:9,11 60:9 61:18 62:13,15 63:5,12 64:6 65:13 67:13,19 68:9,20 70:7,22 70:24 71:10 72:4 72:16,23,25 74:19 74:21 76:16 77:19 77:25 79:23 84:11 86:16,25 87:5 89:14 90:2,8,12 90:20 99:13,19,24 99:25 101:2,8 105:14 107:9 108:13,22 109:5 109:12,19 113:12 <b>grew</b> 78:6 <b>grey</b> 26:5 40:25 45:13 52:17 <b>grid</b> 107:9 <b>ground</b> 43:22 93:21 93:23 94:11,17 95:13 96:20 <b>grouped</b> 65:8 <b>grow</b> 28:24 <b>grown</b> 93:4 <b>growth</b> 24:16 28:17 28:18 37:4 <b>guarantee</b> 73:23 <b>guidance</b> 8:13	<b>gypsum</b> 45:23 <hr/> <b>H</b> <hr/> <b>Hadden</b> 6:20 <b>halfway</b> 108:4 <b>hallway</b> 88:2 <b>halt</b> 103:14 <b>halted</b> 103:11 <b>hand</b> 53:20 <b>hand-drawn</b> 43:16 <b>happen</b> 74:22 90:9 90:18 <b>happened</b> 74:21 <b>happening</b> 22:14 <b>happy</b> 75:5 <b>harder</b> 17:2 <b>harrowing</b> 5:1 <b>hazard</b> 28:11 69:23 <b>hazards</b> 73:19 <b>head</b> 3:15 <b>hear</b> 1:4 114:18 <b>heard</b> 55:23 83:4 89:11 <b>hearing</b> 1:4 114:22 <b>hearings</b> 6:3 91:20 <b>heat</b> 11:16,22 13:15 14:1,2,10 16:5,13 16:14,25 17:13,24 18:3,6,8,13,22 21:9,11,11,19,23 22:2,6,9 23:3,5,8 23:14,17,23 24:1 24:2,4,12,19 25:9 25:15,19,22 26:18 26:22,23,25 27:2 27:7,18,19 28:2,4 28:5,6,8,10,16,22 29:12 30:13 31:15 31:20,21 32:18 33:15 38:4,6 56:22 65:24 66:20 66:25 67:1,6,8,23 68:3,15 69:23 71:2,5,15,19 73:22 82:15 83:18	88:8,12 <b>heated</b> 13:5,24 14:25 16:22 18:17 30:17 31:23 32:9 34:6,9 65:16 <b>heater</b> 23:4 <b>heating</b> 9:10 14:11 15:19 18:11,20 21:4,9,10,14 22:16 23:11,23 25:1 26:10 65:15 65:19 74:2,9 84:25 <b>heats</b> 13:19 14:9 16:3,7 26:1,2 68:11 <b>heavily</b> 113:10 <b>height</b> 32:9 52:25 73:9 89:24 102:18 110:19 <b>held</b> 14:6 48:8 <b>help</b> 5:12 9:3,24 19:1 99:22 <b>helpfully</b> 29:5 <b>high</b> 18:12 24:3 27:18 28:16 31:20 67:9 <b>higher</b> 14:23 18:24 19:8 21:23 23:8 23:19 33:16 <b>highest</b> 95:4 <b>highlight</b> 52:9 89:6 99:21 <b>highlighted</b> 42:18 42:18 48:3 49:6 49:20,21 52:8 54:14 55:3 62:4,8 62:19 67:21 68:22 70:24 <b>highlighting</b> 11:5 <b>highly</b> 67:22 72:3 73:13 86:21 <b>hinged</b> 43:2,10 <b>holding</b> 82:21 <b>hope</b> 5:11 11:7	12:16 17:12 43:19 76:24 <b>hopefully</b> 19:1 30:12 <b>horizontal</b> 30:7 33:9 37:11 38:3 47:15 48:25 50:8 51:15 52:12 58:2 61:11,16 62:9 66:9 76:23 78:9 78:16 91:4 100:23 105:12,13,16,21 105:24 106:5,14 106:21 107:7 108:17 109:8,14 109:21 110:9,11 111:18,25 112:18 113:6,19,25 114:3 <b>horizontally</b> 14:6 33:17 41:20 78:8 98:6 100:4 107:5 107:15,24 111:15 <b>hot</b> 13:10 14:2 16:11 30:21 33:12 37:9 87:21 88:16 <b>hours</b> 4:17,18 7:11 78:24 79:6 <b>house</b> 62:24 <b>human</b> 4:23 <b>hung</b> 51:7 <b>hypotheses</b> 5:25 77:7,11 <hr/> <b>I</b> <hr/> <b>idea</b> 25:6 69:23 <b>ideas</b> 74:16 <b>identical</b> 32:16 63:1 <b>identified</b> 51:19 52:24 59:8,13,18 60:1 64:5 70:5 91:12 <b>identify</b> 39:25 91:10 95:23 <b>identifying</b> 8:15
---	--	---	---	--

<b>ignite</b> 14:20 16:16 17:2,10 19:9 22:1 24:3,5 86:8	<b>imagery</b> 107:25	<b>including</b> 6:12,15 37:5 41:6	25:20 64:7,10 72:20 77:4	<b>insufficient</b> 23:6 33:6
<b>ignited</b> 17:7 24:14 25:21 27:1 34:22	<b>images</b> 1:23 2:8 6:4 75:24 76:7 83:15	<b>incorporates</b> 73:1	<b>infrastructure</b> 3:16	<b>insulating</b> 11:24 69:13
<b>ignites</b> 15:5 31:24 32:8	83:19 88:13,15 93:12 96:1 105:22	<b>incorporation</b> 64:1	<b>ingress</b> 77:9 79:5	<b>insulation</b> 18:16 27:16 45:18,22
<b>ignition</b> 2:21 5:20 7:17 10:9 11:14	106:7,16 108:16 108:19 110:5,17	<b>incorrect</b> 83:7	<b>initial</b> 5:19 27:18 67:10 72:5 80:3	46:7,13,24 49:4 49:13,19,22,24
12:24 15:10,14 16:19,23 17:4	<b>imagine</b> 22:8 44:18	<b>increase</b> 17:15,15 18:1,17 27:7 74:1	81:11 84:1 99:14 106:14	50:15 51:10 52:20 54:19 57:8,14
20:18,20,24 21:1 21:3,8 22:22 23:9	<b>imagining</b> 79:21 82:1 82:13,21 83:5,22	<b>increased</b> 25:11 98:22	<b>initially</b> 18:23 79:20 81:15 92:13	58:10,15,23 59:8 59:10,15,17,24
23:13,18,21,24 24:1,2,4,9 25:23	87:1,25 88:7,20 96:18	<b>increases</b> 18:7 22:13 31:16 32:9 32:10	<b>initiated</b> 4:17	60:2,7,16 62:2,22 68:21 69:3 70:4
27:6 29:9,10 31:11 35:3 36:8	<b>immediate</b> 10:20	<b>increasing</b> 32:4	<b>initiation</b> 20:20	74:5 85:12 86:6 86:13 87:23
37:4 63:10 69:7 70:13 74:2 85:25	<b>immediately</b> 44:17 47:17 49:25 85:6	<b>indefinite</b> 48:20	<b>inner</b> 56:7	<b>insulation's</b> 86:16
<b>ignitions</b> 29:6	88:10 93:17 95:14 97:20	<b>independently</b> 108:20	<b>inquiry</b> 2:15,18 3:6 3:15 4:12 5:6	<b>intended</b> 5:18 7:7 90:6
<b>illustrate</b> 12:22 98:2 109:21	<b>immense</b> 4:21	<b>indicate</b> 2:25 48:20 50:13 88:16,24	6:13,14,16 7:3,4,7 28:19 36:21 38:10	<b>intense</b> 93:2,6,12
<b>illustrated</b> 12:18 27:9,21 53:1	<b>impinge</b> 87:21	94:17 104:12	39:16 43:21 54:1 63:15 64:17 74:17	<b>intentionally</b> 63:14
57:24 61:24 74:13	<b>importance</b> 28:19 30:2 70:3	<b>indicated</b> 40:8,17 40:22 41:4,10,13	76:25 106:8 114:9 114:14	<b>interacted</b> 106:2
<b>illustration</b> 64:14 110:25	<b>important</b> 8:8 10:3 15:13 18:25 19:25	41:21 42:3 54:17 60:14 61:7 82:24	<b>inquiry's</b> 1:5 6:2 7:1,5 8:9 42:11	<b>interactions</b> 37:7
<b>illustrative</b> 98:19	25:2 28:10 31:3 32:2 35:24 36:3,7	83:19	94:23 114:5	<b>interest</b> 24:15 64:25 102:23
<b>image</b> 40:3,9,17,22 41:4,13,21 42:3	37:14,20 39:3 50:1 53:17 63:12	<b>indicating</b> 101:5	<b>inside</b> 7:19 44:20 45:9 46:23 47:19	<b>interface</b> 103:6 104:10
45:8 47:20 52:12 56:2,10,16,17,21	64:2 65:12 68:15 69:17 72:21 74:10	<b>indicative</b> 44:3	48:14 49:13 50:2 60:10,13 84:19,21	<b>interior</b> 16:11 45:19
57:12 58:3,15 61:7,10,17 62:11	74:16 89:16 105:20 106:1	<b>individual</b> 41:6	85:21	<b>intermittent</b> 95:3,5
62:19 83:15 84:14 88:7,10,18 93:13	<b>importantly</b> 61:8 65:8	<b>inertia</b> 18:8,12,16 18:22,24 23:13,15	<b>inspect</b> 105:7	<b>internal</b> 16:8 42:12 45:24 49:15 60:19
102:4 108:22,23 108:25 109:4,7,12	<b>impossible</b> 10:8	23:16,19 30:15 69:1,5,10 70:12	<b>inspected</b> 62:15	61:5 99:9,14 102:18
109:13,18,20 110:8,20,22	<b>incident</b> 21:11	70:25 73:25 74:4	<b>inspections</b> 39:13 44:5 59:9 104:22	<b>internally</b> 17:21
111:10,11,12,16 111:17,23,24	<b>inclined</b> 109:11 111:21 112:14,20	<b>infill</b> 41:7,9 43:4,4 43:6,8 46:18	<b>installed</b> 20:16 46:2 48:4,24 50:1 73:3	<b>internationally</b> 10:15 36:22 100:2 105:18
112:8,8,8,11,12 112:16,17,22,23	113:1	62:17,24 70:24 81:17,20 84:23	90:20,22	<b>interpret</b> 10:24
113:2,3,14	<b>include</b> 1:23,25 2:4 75:25 76:4 84:21	92:15,16 105:6	<b>instance</b> 18:17 24:6 26:16 53:23 57:13	<b>interpretation</b> 83:14,18 88:13
	86:25	<b>influence</b> 15:2	69:9 71:19	<b>interpreted</b> 80:6 81:14 88:18 108:25
	<b>included</b> 48:16 83:8 100:7 105:6	<b>influenced</b> 16:13 20:12 29:2 37:5 37:25 90:7	<b>institute</b> 3:16	<b>interrelated</b> 11:13
	<b>includes</b> 6:4,8 63:10 79:17	<b>influencing</b> 9:2 90:11	<b>Institution</b> 3:23 4:5 4:6	
		<b>information</b> 5:8 6:10,14,22,24	<b>instructed</b> 5:5 7:5	
			<b>instructions</b> 8:14	

<b>intervention</b> 82:2,6 87:3 99:9 103:12	103:23	24:19 29:17 35:22	42:14 43:10 47:17	71:4
<b>interview</b> 79:18 80:16	<b>junction</b> 95:6	<b>Kooltherm</b> 59:13	48:13 49:2 51:25	<b>literature</b> 6:21 35:23 64:8,11 69:21
<b>interviewer</b> 80:23	<b>June</b> 1:1 4:18 5:16 77:5,18 104:25 114:22	<b>L</b>	58:2 62:9 83:13	<b>little</b> 36:14 63:17 86:12 103:4
<b>interviews</b> 80:14 81:6	<b>K</b>	<b>laboratory-based</b> 72:17	87:6 92:13 96:7	<b>lives</b> 5:3
<b>introduction</b> 64:4	<b>K15</b> 59:13	<b>lack</b> 110:2	97:20 98:15 109:2	<b>living</b> 42:15
<b>intuitive</b> 31:13	<b>Kebede</b> 2:9 76:8	<b>lacked</b> 100:23	<b>left-hand</b> 27:9 45:8 62:3 81:16 87:18	<b>local</b> 44:6
<b>intuitively</b> 10:1 13:3	80:4,14,18 81:2,7 81:9	<b>landing</b> 102:5	88:7 93:23 101:3 110:8,22	<b>localised</b> 29:6 88:12 100:24 102:7 110:15,18
<b>investigate</b> 7:7	<b>Kebede's</b> 79:19	<b>Lane</b> 43:23 44:14 50:23 90:5	<b>length</b> 32:20	<b>located</b> 45:21 57:25 59:20 60:9
<b>investigation</b> 50:5 89:3 114:4	<b>kept</b> 38:11	<b>language</b> 11:3 64:22	<b>lessening</b> 27:19	<b>location</b> 7:9 44:12 45:5 47:11,18 48:11 49:2,6,12 49:23 50:9,10,16 51:16,20,24 52:6 52:11,11,18,25 61:6 79:2 80:15 82:20,23 83:1 86:17 95:11 97:9 97:25 99:6 102:19 106:5,23 107:2 111:19 112:2,9,13 112:19,24 113:18 113:24
<b>investigations</b> 6:11 43:18 59:18 70:6 79:23 86:15	<b>key</b> 1:11 3:10 11:6 12:22 17:18 27:11 30:5 38:8 53:10 67:13 72:20 99:15 99:21	<b>large</b> 1:23 16:24 27:3 28:7 36:21 42:24 65:2 72:19 75:3,23 90:22 94:6 97:5	<b>level</b> 11:8 23:23,23 27:2 41:1,12 51:22 53:9 55:22 64:24 73:10,11 77:18 78:3 95:13 95:14,23 96:20 97:3,23,24 98:18 111:15 113:7	<b>located</b> 45:21 57:25 59:20 60:9
<b>involved</b> 78:18,21 105:14	<b>kilogram</b> 18:1 68:6 69:24 71:6,7,20	<b>largely</b> 55:17 73:13	<b>levels</b> 42:2 94:6 95:4,25 99:5 107:13	<b>location</b> 7:9 44:12 45:5 47:11,18 48:11 49:2,6,12 49:23 50:9,10,16 51:16,20,24 52:6 52:11,11,18,25 61:6 79:2 80:15 82:20,23 83:1 86:17 95:11 97:9 97:25 99:6 102:19 106:5,23 107:2 111:19 112:2,9,13 112:19,24 113:18 113:24
<b>inward</b> 42:25,25 43:9	<b>kilowatt</b> 21:16	<b>larger</b> 32:3,8 78:17 112:4	<b>liberally</b> 51:3,5	<b>locations</b> 43:14 46:25 47:10 54:24 57:12,22 59:7 60:14 100:25 103:25 104:7 110:13,13 111:9 112:4
<b>inwards</b> 92:20	<b>kilowatts</b> 21:15,20 22:2,7	<b>lateral</b> 30:7 33:9 76:23 105:12	<b>licensed</b> 3:24	<b>locked</b> 66:23
<b>irradiances</b> 21:19	<b>kindling</b> 25:7	<b>laterally</b> 107:23	<b>light</b> 11:22 13:24 70:2	<b>log</b> 25:7
<b>irrespective</b> 90:13	<b>Kingspan</b> 59:13 60:2,5	<b>Law</b> 6:19	<b>light-coloured</b> 57:2 80:19	<b>London</b> 6:9 82:1,6
<b>isolation</b> 105:25	<b>kitchen</b> 24:7,8 41:13,15 42:13,15 42:17,19,22 43:14 43:15 44:17,22 45:5 47:17 49:19 50:7 51:25 61:15 61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>layer</b> 27:20,23 49:4 50:17 52:19 60:20 60:25 67:11 85:8 86:10	<b>lights</b> 96:2	<b>long</b> 65:5 75:7 111:1
<b>issue</b> 19:11 35:24 36:20 72:8 79:14 84:3 94:24	45:5 47:17 49:19 50:7 51:25 61:15 61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>layers</b> 44:20 46:8 50:15,19 58:21,25 63:25 104:13	<b>limit</b> 25:16	<b>longer</b> 23:21 110:7
<b>issues</b> 7:16 8:23 74:20	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>layout</b> 42:12 83:16 84:12	<b>limited</b> 6:22 13:1 16:5 70:19	<b>look</b> 20:15 42:16 43:12 44:16,19,21 47:8,16 57:8
<b>item</b> 50:5	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>layers</b> 44:20 46:8 50:15,19 58:21,25 63:25 104:13	<b>limits</b> 71:25	<b>looking</b> 48:11
<b>items</b> 79:24 83:24 86:24	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>laypeople</b> 5:13	<b>line</b> 8:14 42:19 44:19 48:19 51:13 52:13 82:23 93:9 95:6 97:11,19,20 98:19 101:5,11,23	
<b>J</b>	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>lead</b> 23:9 25:22 83:25	<b>lines</b> 40:11,13,19 41:23 42:3 47:25 53:7 54:17 86:22 100:19 101:5 102:12,16 104:2 113:24	
<b>jamb</b> 61:12	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>leading</b> 78:12,14 102:11,14 104:3	<b>liquid</b> 65:25 66:10	
<b>jargon</b> 11:3 64:23	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>leaning</b> 96:14		
<b>jet</b> 82:17 94:19 95:12 96:6,11,12 96:13,20	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>leaves</b> 66:21		
<b>joining</b> 65:4	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>ledges</b> 100:23 102:5 110:12		
<b>joints</b> 110:9,18	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10	<b>left</b> 33:11,13,21,24		
<b>joules</b> 21:16,17	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10			
<b>Journal</b> 3:20	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10			
<b>July</b> 40:6 55:8	61:16 62:9,25 72:6,7 76:19 77:18,21 80:2,5 80:24 82:3,12,14 82:16,16,25 83:2 83:16,20 84:5,9 84:10,19 87:7,18 88:2,3,17,21 92:10,15 97:20 99:10			

50:10 52:14 56:19 61:24 83:2 101:6 <b>loop</b> 28:15 32:11 92:6,7 96:5 100:16 <b>lose</b> 86:2 <b>loss</b> 69:12 <b>losses</b> 69:14 <b>loved</b> 5:3 <b>low</b> 18:15,21 23:16 24:2 68:25 69:5,7 69:10 70:11,13,25 71:23 74:4 83:1 109:18 <b>lower</b> 19:10 50:6 71:16 87:6 111:13 111:15 <b>Luke</b> 1:10 2:12,17 <b>lunch</b> 75:4,10	25:10 <b>match</b> 12:25 13:5 14:6 17:7 28:14 32:7 33:16,17 98:23 <b>matched</b> 91:12,13 <b>matches</b> 17:11 <b>matchstick</b> 12:20 12:22 13:3 14:8 20:24 31:12 32:17 33:4 37:15,19 <b>matchsticks</b> 34:1 <b>material</b> 1:13 2:3 10:10,11,12 13:4 14:15,20 15:5,13 15:19,24,24 16:4 16:10,11,12,14,21 17:4,14,17,19,20 17:22 18:1,7,9,10 18:15 19:7 20:1,2 20:3,8,9 21:1,9 23:13,15,25 24:9 24:14,19,21 25:3 25:9,10,14,18,21 25:23 26:20 27:2 27:4,4,5,8,14,21 27:24 28:2,13,24 29:1,3,12 30:14 30:16,23 31:6,16 31:19,20,21,22 32:9,19 34:7,9,10 34:15 35:3 37:6,9 38:1,6,7 46:10 47:6,21 53:19,22 53:22 54:6,9,16 56:7,10,16 62:4 62:12 63:9,24,24 64:12 66:17 67:1 68:4,8,16 69:2 76:3 92:22 93:8,8 93:18,19,20 94:7 100:18,20 101:10 101:22 104:5 <b>material's</b> 10:19 17:23,24 25:24	30:14 73:25 <b>materials</b> 1:14 2:22 5:20 7:18 8:1,11 8:21 9:5,7,8 10:7 10:17,22 11:11,23 14:4 15:20,21,23 18:12,21,23 19:2 19:8,13,18,19,23 20:4,15 21:21 23:16,19 24:1,5 26:2,4,5,9,11,15 26:25 28:16 34:2 34:5 36:9,11,23 37:7 39:3,6,11,17 39:19,21 43:5,25 44:22,25 47:8 53:14,18,19,21 54:6,10,13,21,23 55:12 63:1,3,8,11 63:13 64:4,9,20 64:25 67:13 68:18 69:11 71:24 72:24 73:2,3,5,16,17 74:3,18 85:17,19 90:15,19,21 <b>matter</b> 11:5 22:2 64:23 <b>matters</b> 3:6 4:8,12 <b>maximum</b> 97:2 106:5,15 <b>McGuirk</b> 94:23 <b>mean</b> 11:21 13:8,23 15:3 16:10 19:19 20:21 23:23 25:4 25:8 26:20 36:10 43:1 56:18 61:12 63:24 65:20 66:19 69:13 79:2 90:9 90:18 93:15 98:24 104:15 <b>meaning</b> 14:16 71:12 98:20 <b>meanings</b> 10:5 <b>means</b> 12:10,12 14:24 21:3 56:24	66:22 69:6,10 71:15 72:12 <b>measure</b> 17:20,23 17:25 21:11 24:20 68:4 <b>measured</b> 25:9 <b>mechanical</b> 71:22 86:2 <b>mechanism</b> 34:8 89:1 <b>mechanisms</b> 9:18 11:1 37:17 90:11 99:22 100:5 102:20 105:19 114:3 <b>media</b> 19:16 68:8 105:23 <b>meet</b> 51:14 <b>meets</b> 93:9 <b>megajoules</b> 68:6 69:24 71:6,7,20 <b>melt</b> 34:1 65:14,19 65:25 66:7,10,18 67:24 74:10 <b>melted</b> 35:15 71:2 103:25 104:8,16 110:13 <b>melting</b> 31:4,5 34:4 37:25 66:13 68:2 71:4 72:1 100:18 <b>melts</b> 27:4 71:1 <b>member</b> 4:2 <b>members</b> 6:5 77:2 100:11 105:22 <b>membrane</b> 49:11 49:25 61:21 62:4 62:8,11 85:9 86:11 <b>mentioned</b> 13:22 16:15 22:7,12,21 26:19 30:22 31:3 37:24 43:15 59:1 59:21 60:7 61:8 65:6 66:6 67:2,10 83:6 85:5,8 86:7	98:1 <b>mesh</b> 54:16 <b>metal</b> 50:25 74:7 <b>metals</b> 18:13 <b>method</b> 20:11 <b>methods</b> 36:19 63:22 64:12,18 <b>metre</b> 21:15,20 22:3,7 <b>Metropolitan</b> 6:10 39:18 40:5 56:4 56:13 58:5 62:14 77:3 91:13 100:12 103:22 106:9 <b>midday</b> 75:2 <b>Millett</b> 1:7,8 2:14 2:18,21,25 3:4,8 3:14,19,22 4:2,8 4:11,14 7:6 9:16 38:15 40:14 74:25 75:20,21 76:11 80:12 91:19 114:13 <b>millimetre</b> 62:16 <b>millimetres</b> 34:19 46:9 49:5 50:18 50:20 52:20 58:14 58:25 59:3 60:17 61:19 62:21,22 <b>mind</b> 38:11 90:25 <b>minus</b> 106:19 <b>minute</b> 93:3 <b>minutes</b> 24:11 30:9 35:8,16 54:3 77:20 78:2,24 80:10 81:11 82:7 82:10 99:13 106:19 111:1 <b>misnomer</b> 54:7 <b>missing</b> 55:9 81:18 <b>mix</b> 12:10 13:12 22:20 <b>mixture</b> 13:16 15:2 66:3 <b>mixtures</b> 15:7,10
<b>M</b>				
<b>magnitude</b> 21:10 28:8 <b>main</b> 65:8 90:7 100:9 <b>make-up</b> 8:18 <b>making</b> 12:16 17:1 <b>manner</b> 10:10,13 20:22 35:20 43:1 43:9 57:19 <b>manufactured</b> 55:25 58:10 59:24 60:2 <b>manufacturer</b> 69:19 70:16 <b>manufacturer's</b> 69:19 70:16 <b>markedly</b> 96:21 <b>markings</b> 60:4 <b>MARTIN</b> 1:3 2:11 2:13 38:14,17,23 74:24 75:6,9,14 75:20 76:10,12 114:12,16 <b>mass</b> 17:23 24:21				

15:11	<b>name</b> 54:9 58:11,12 59:1 60:3	89:10 93:22,25 97:24 101:15,25	92:7 93:6 94:11 96:7 97:22 99:4	<b>opinion</b> 29:6 65:12 100:4,20
<b>molecular</b> 65:5	<b>naturally</b> 65:1	<b>noted</b> 20:8 25:12	100:17 103:15	<b>opinions</b> 4:12 89:13
<b>molecules</b> 13:6 65:2,5	<b>nature</b> 71:15	40:13 43:6 44:2	104:22 106:21	<b>opportunity</b> 77:13
<b>molten</b> 34:6,9,9 35:3,10,18	<b>near</b> 96:20 101:11 110:20	50:19 58:21 60:20	107:1,3	<b>opposed-flow</b> 29:18,21 30:1,8 32:15 33:8,14
<b>moment</b> 20:24 22:4 29:21 31:9,10 32:6 38:16,17 41:8 43:7 47:9 48:7 49:6,21 75:1 82:20 87:4 103:16	<b>necessarily</b> 5:7 25:4 43:22	66:15 68:7 70:4	<b>obtained</b> 6:10,14 40:4	<b>opposite</b> 29:22
<b>moments</b> 38:2 41:17	<b>necessary</b> 6:2 9:1 10:25 23:7	73:12 84:14 86:20	<b>obviously</b> 28:19	<b>optimal</b> 24:22
<b>Monday</b> 50:23 55:23 89:12 90:6	<b>need</b> 84:8	94:15 104:4	<b>occupant</b> 80:4,8	<b>optimum</b> 68:5
<b>monomer</b> 65:5 66:1 72:10	<b>never</b> 74:22	105:15	<b>occur</b> 8:17 11:14 12:9 14:18,21 19:7 22:22 23:24 25:24 30:24 34:3	<b>order</b> 12:9 14:17 24:6 37:14 48:4 76:24
<b>monomers</b> 65:3	<b>Nevertheless</b> 69:22	<b>noteworthy</b> 89:8 103:9	<b>occurred</b> 9:23 15:16 62:1 65:13 78:9 89:2 91:11 100:1,19 104:16 109:22	<b>organisations</b> 6:12 6:15
<b>months</b> 104:23	<b>new</b> 46:17 48:5,24 49:7	<b>noting</b> 40:25 41:11 70:2	<b>occurring</b> 29:14 65:2	<b>orientation</b> 25:1 29:4 34:6 37:6 39:1 66:9,9,12
<b>MOORE-BICK</b> 1:3 2:11,13 38:14 38:17,23 74:24 75:6,9,14,20 76:10,12 114:12 114:16	<b>Nic</b> 43:23 79:12,13 82:3 84:2	<b>number</b> 1:23 2:7 6:22 26:3 36:21 39:24 42:20 59:16 73:2,8 75:23 76:7 77:7 86:21 90:12 90:22 91:25 97:17 103:7	<b>occurs</b> 11:20 15:1,4 16:23 21:1,3 22:13 28:22 29:13 29:19,21 82:7	<b>oriented</b> 31:12 32:17 34:16 55:18
<b>morning</b> 1:3,8 4:16 114:18	<b>non-charring</b> 74:14	<b>numerous</b> 37:5 53:7	<b>octagonal-shaped</b> 48:12	<b>origin</b> 8:4 42:11 77:8 79:8,10,17 93:14
<b>mounted</b> 43:3 46:19 55:19 84:23	<b>non-glazed</b> 62:18	<hr/> <b>O</b> <hr/>	<b>offer</b> 86:12	<b>original</b> 7:9 44:8 45:1,4,13,17,21 46:1,2 47:14 48:6 48:16,18,23 50:12 52:16 55:21 60:9 61:23 65:16 83:7
<b>mounting</b> 41:7 43:8 81:17,20 92:16	<b>non-uniformly</b> 16:8	<b>o'clock</b> 75:11,15 114:18	<b>once</b> 24:14 27:1 65:25 71:2	<b>originate</b> 93:15
<b>move</b> 54:22 84:4 109:24 112:6 113:8	<b>north</b> 40:12 78:9 78:19 94:9 98:7 101:1,7,13 106:12 107:24,24 109:4 109:24 110:1,4,5 111:9	<b>object</b> 26:24 28:5 28:11	<b>ones</b> 5:3	<b>originated</b> 81:1 83:4
<b>moved</b> 47:12	<b>north-eastern-most</b> 98:8	<b>objective</b> 90:1	<b>ongoing</b> 50:4 64:17 72:18 89:3 114:4	<b>originate</b> 93:15
<b>movement</b> 33:21	<b>northwards</b> 78:7 97:18	<b>objects</b> 14:1 26:25	<b>Ontario</b> 3:24	<b>originating</b> 87:9
<b>moves</b> 97:18	<b>northwest</b> 108:1 112:10	<b>obligations</b> 89:18	<b>open</b> 46:13 81:23 82:14 84:22	<b>ornamental</b> 55:5
<b>moving</b> 20:15 50:6	<b>northwestern-most</b> 101:12	<b>observation</b> 99:3	<b>opened</b> 92:19	<b>ought</b> 75:21
<b>MPS</b> 59:23	<b>notations</b> 107:13	<b>observations</b> 89:7 103:8	<b>opening</b> 2:1 9:15 40:14 44:17 48:6 76:2 80:12 81:21 85:4 88:2 91:19 92:23 93:17,20	<b>outcomes</b> 20:12
<b>multiple</b> 17:10 53:21 54:10	<b>note</b> 21:22 26:14 36:7,14 44:4 45:10 47:11,20 48:2 49:17 51:8 52:1 55:16 58:7 63:13 79:1 83:6	<b>observed</b> 29:23 36:1 43:2,10 77:22 80:16 81:16	<b>openings</b> 44:8 46:19 84:24	<b>outer</b> 56:5 57:17
<b>multiplied</b> 18:5,5			<b>operated</b> 96:13	<b>outlined</b> 3:5 14:14
<hr/> <b>N</b> <hr/>			<b>operates</b> 42:25 43:9	<b>outside</b> 43:2,10 45:8 47:14,18 48:15 49:14,19,25 81:9,16,22 82:12 84:21 86:25 87:5 87:19 92:10,17

<b>outwards</b> 47:12	34:4,17 35:24	109:3 110:11	<b>placed</b> 37:18 46:23	<b>points</b> 3:10 72:21
<b>overall</b> 77:15 81:5 106:14 107:12	36:20 42:12 46:15 51:11,25 52:10	<b>phenolic</b> 59:9,12 70:4,8,11,15,18	<b>plan</b> 82:22 107:12	94:3 95:16 110:25
<b>overcladding</b> 46:3 49:3 52:18	53:7 58:20 71:15 73:6,19,24 74:3	<b>phenomena</b> 20:13 37:20	<b>plaster</b> 61:3	<b>Police</b> 6:10 39:18
<b>overlap</b> 91:11	84:3 90:19 102:22	<b>phone</b> 79:19 81:9	<b>plasterboard</b> 45:23 60:21,23 61:1	40:5 56:4,13 58:5 62:14 77:3 91:13 100:12 103:22 106:9
<b>overlapping</b> 94:2	<b>particularly</b> 1:22 5:14 6:5 74:6	<b>photo</b> 20:23 40:4 47:21,24 55:7	<b>plastic</b> 26:15 47:5	<b>polyethylene</b> 26:15
<b>overview</b> 9:1 76:17	80:1 89:7 101:11 104:1 111:19	<b>photograph</b> 110:11	<b>plastics</b> 11:24 23:21 31:2 65:7	27:6,12 34:18
<b>oxygen</b> 11:14,19 12:4,11 13:12,17 13:18 15:7,8 22:21 25:11,13	<b>parties</b> 43:20	<b>photographic</b> 110:3	<b>play</b> 12:24 15:13 17:8 35:1 80:10	35:5,11,15,18,20
	<b>parts</b> 7:9 8:24 39:23 40:1,16 66:1 84:16 88:17 105:6	<b>photographs</b> 39:25 97:8 103:15	81:12 83:5,9,11 87:4,14,24 91:16 91:21 92:1,6 96:23 100:15 105:1	38:2 53:22,25 55:25 56:6,16,21 56:25 57:2,3,6 67:17,21,22,24 68:8,12 69:25 71:7 74:9 85:13 86:22 87:9,17 100:21 101:17 103:25 104:5,8,13 104:16,19 110:14
	<b>passing</b> 81:20	<b>photos</b> 39:15 77:1 79:22,22 100:11 102:22 103:21 105:2	<b>played</b> 2:1 8:16 17:9 22:15,19 23:1 32:14 33:2,5 33:23 35:7,13,19 37:23 76:1 81:13 83:10,12 87:15 88:4 91:24 92:25 111:2	<b>polyisocyanurate</b> 54:13 57:10 68:18
<b>P</b>	<b>pathway</b> 87:20	<b>physical</b> 5:8,14 8:19 9:18 10:11 11:1 15:15,23 17:16 25:23 28:3 29:2 36:4 90:10 103:4	<b>playing</b> 1:25 2:9 75:25 76:8	<b>polymer</b> 18:16 23:17 26:15 27:5 27:16 34:5,17,18 46:7,24 47:1,5 49:3,18 59:5,23 60:1 65:14,17,19 65:24,25 67:9,23 68:24 70:9 71:1,9 73:4,16,17 74:14 86:7
<b>pane</b> 81:23	<b>pattern</b> 1:16	<b>physics</b> 31:14	<b>plays</b> 96:5	<b>polymers</b> 23:20 31:2 65:1,1,4,7,8 65:9,10,12,23 66:7,18 67:15 71:17,18 74:8 86:1
<b>panel</b> 43:4,4,9 56:2 81:17,20 84:23 92:15,16	<b>Pause</b> 102:8	<b>picture</b> 84:10	<b>please</b> 2:15 4:14 38:18 44:18 45:10 47:11,20 48:2 51:8 63:13 83:6 93:22	<b>polystyrene</b> 26:16 62:21 70:23,25 71:3 74:10
<b>panels</b> 40:22 41:7,7 41:9 43:6 46:18 55:19 62:17,24 70:24 73:14 105:6	<b>PE</b> 27:12 53:23 54:1,4 55:24,24 56:2 57:1 67:18 68:13 73:14 86:19	<b>piece</b> 58:3,15 86:5 86:13	<b>plotted</b> 98:14	<b>polyurethane</b> 59:5 60:16
<b>paper</b> 60:18	<b>penetrate</b> 56:23	<b>pieces</b> 49:24 97:5	<b>plus</b> 106:19	<b>polyvinyl</b> 47:4 71:8
<b>parameters</b> 17:18 18:4 20:9 68:16	<b>people</b> 2:4 10:2 76:4	<b>PIR</b> 50:15 51:10 52:20 54:13,17 57:8,9,15,20,22 57:24 58:3,6,15 58:18,21,22 59:8 59:17,23 60:5 68:18,22,24 69:5 69:10,18,24 70:11 70:14 74:4,8 85:12 86:6,13,16 87:23	<b>pm</b> 75:17,19 114:21	<b>pool</b> 34:14 66:10,16
<b>parapet</b> 55:21	<b>perceive</b> 11:21	<b>period</b> 21:3,13 27:18,19	<b>point</b> 17:12 26:17 27:11 32:2 34:20 35:5,14 40:10 44:13 49:17 52:2 57:21 64:2,13 80:13 81:1 93:11 95:5 97:3 103:9 103:20	
<b>paraphrase</b> 7:18,23	<b>performance</b> 10:17	<b>permissible</b> 91:16	<b>pointing</b> 22:9 82:25	
<b>part</b> 9:12,20,21 17:16 28:25 39:5 42:6,8 50:8 52:5 54:19 60:8 63:6 64:3,16 66:13 68:1,20 75:2 76:14 78:21,23 82:17 84:16 92:24 95:9 101:17 102:2	<b>perimeter</b> 60:12 78:25	<b>personally</b> 103:17		
<b>partial</b> 103:1	<b>period</b> 21:3,13 27:18,19	<b>perspective</b> 21:25		
<b>partially</b> 47:22 59:19 104:11,16	<b>permission</b> 91:16	<b>petrol</b> 68:9,11		
<b>participants</b> 6:15 7:1,3	<b>personally</b> 103:17	<b>PF</b> 59:10		
<b>particles</b> 12:6 13:21,24	<b>perspective</b> 21:25	<b>phase</b> 5:7,11,12,18 6:25 7:6,13,15 8:14 20:21 30:2 38:13 39:14 52:7 55:13,15 70:19 72:9,16 77:12 79:15 88:23 89:15 91:8 103:19 106:6		
<b>particular</b> 9:22 15:17 22:18 25:5	<b>petrol</b> 68:9,11			

71:4 110:15 <b>portion</b> 40:3 48:12 60:22 61:11 75:3 89:9 <b>portions</b> 97:7 <b>position</b> 88:21 89:25 <b>positioned</b> 42:21 49:12 51:17 <b>positive</b> 32:10 <b>possible</b> 11:4 66:3 69:22 83:21 84:20 93:14 95:23,25 102:20 <b>possibly</b> 34:7 67:24 69:14,16 86:5 88:19 102:16 <b>post-fire</b> 39:13 43:18 44:4 59:9 59:18 70:6 79:22 86:15 102:21 103:21 <b>potential</b> 9:4 19:2 19:18 50:2 66:23 70:2 87:20 <b>potentially</b> 90:12 <b>powerful</b> 22:9 <b>practice</b> 21:8 <b>pre-existing</b> 45:1 46:5 48:6 49:8 85:3 <b>precast</b> 52:17 <b>precedes</b> 54:8 <b>preceding</b> 23:22 <b>precise</b> 10:4 69:18 70:15 83:21 89:1 95:23 <b>precisely</b> 20:10 93:14 <b>precision</b> 106:19 <b>predominantly</b> 73:4 81:15 100:21 <b>preheat</b> 30:23 37:9 <b>preheated</b> 32:21 <b>preheating</b> 30:24	37:12 <b>preliminary</b> 1:15 2:22 5:21,24 6:4,8 7:21 10:4 26:7 30:3 38:12 39:5 40:2 44:10 53:10 63:2 64:3 89:6 91:1 99:18 105:11 114:6 <b>preparation</b> 4:25 <b>presence</b> 15:9 28:4 28:6 44:8 73:8 <b>present</b> 1:14 13:15 26:12 30:3 38:13 39:6 49:13 50:17 50:20 53:14 56:21 56:25 59:5 64:5,7 67:16,17 73:16,18 74:19 84:4 85:18 85:20 86:17,20 91:1,2 93:20 99:18 103:1,16 104:12,19 105:11 108:16,19 114:11 <b>presentation</b> 1:5,21 1:22 2:7 4:15,22 5:12,23 8:23 9:12 9:21 10:3 12:17 27:13 35:25 36:7 37:2 40:7 47:7 54:20 55:1,16 57:21 63:2,6 66:13 68:1 70:20 73:7 74:23 75:12 75:22 76:14 89:10 89:16 90:17 95:9 101:17 106:25 <b>presentations</b> 1:9 <b>presented</b> 39:11 72:19 79:11 84:1 110:13 <b>presenting</b> 5:24 39:24 99:20 100:13 <b>prevent</b> 72:6	<b>prevented</b> 61:1 <b>preventing</b> 69:12 <b>previous</b> 52:14 63:17 70:2 87:20 93:3,5,12 94:16 99:2 101:25 106:16 <b>previously</b> 7:6 22:1 29:8 43:6 48:25 53:6 60:7 61:10 66:15 85:5,10 92:25 112:8 <b>primarily</b> 36:9 68:25 70:9 83:20 100:19 106:7 <b>primary</b> 24:14 <b>prior</b> 3:14 39:14 <b>proceed</b> 90:25 <b>process</b> 11:12 12:1 12:1 14:12,14,16 16:14 18:19 29:4 32:11 66:21 <b>processed</b> 92:3 <b>processes</b> 8:19 11:13 12:24 14:2 25:22 29:7 30:5 31:6 34:12 38:9 <b>produce</b> 65:18 <b>produced</b> 11:16,25 12:3,13,19 21:6 28:1 31:18 68:25 70:9 <b>produces</b> 13:20,24 66:21 <b>producing</b> 32:4 <b>product</b> 18:3 39:17 53:24 54:3,10,11 54:12,18 55:24 56:9 58:8,10,11 58:12,13,20,22,23 58:24 59:1,3,12 59:12 60:3,6,7,17 61:2 62:14 67:18 <b>products</b> 8:2,11,21 9:7,9 10:7,18,23	12:5 13:20 19:3 20:16 31:18 32:4 36:10,10,16,17,23 39:3,7,11 47:8 53:14,18,20 54:5 54:20,21,23 55:5 56:1 57:9,11 59:17 63:16,19,20 64:1,16,20 68:13 68:21,23 69:21 73:2,3 74:18 90:15,20 <b>professional</b> 3:24 <b>professor</b> 1:10,19 2:10,12,15,17,20 2:24 3:3,7,10,13 3:18,21 4:1,7,10 4:13,14,16 6:20 38:23,25 43:23 74:25 75:5,8,13 75:23 76:11,12,13 79:12,13 82:3 84:2 114:15,16 <b>programme</b> 46:1 <b>progress</b> 103:14 <b>progresses</b> 96:3 <b>progressing</b> 96:8 113:21 <b>progression</b> 77:15 95:20 103:2 <b>properties</b> 1:13 10:12,20 15:12,24 17:16 20:10 24:9 36:13 37:6 38:7 39:2 64:13 69:2 70:18 71:23 72:15 <b>property</b> 19:21 <b>proportion</b> 59:15 105:4 <b>proportions</b> 13:17 15:9 <b>proposition</b> 10:16 <b>propylene</b> 72:10 <b>protected</b> 74:7 86:9 <b>protection</b> 69:8	<b>protective</b> 27:20 63:25 86:16 <b>proved</b> 77:4 <b>provide</b> 5:19 7:15 7:21 8:25 9:17 53:7 100:14 109:25 <b>provided</b> 2:18 3:1,2 6:14 13:15 37:2 39:19 55:2 56:3 56:13 58:5 59:22 62:13 64:13 77:2 83:14,16 88:22 91:14 106:8 <b>provides</b> 22:21 25:16 79:15 <b>providing</b> 69:3 76:17 89:13 <b>public</b> 6:5 39:16 77:2 100:11 105:22 <b>publication</b> 3:20 <b>publicly</b> 6:23 <b>pulsing</b> 88:3 <b>pure</b> 25:10 63:24 <b>purlboard</b> 45:18,22 60:8,16,19,21,24 <b>purpose</b> 99:20 <b>purposes</b> 5:18 64:14 <b>put</b> 21:25 <b>PVC</b> 71:8,10,12 <b>PVCu</b> 71:11 <b>pyrolyse</b> 31:23 66:2 66:19 <b>pyrolysis</b> 12:2,3 13:8 14:15,19,22 14:24 15:1,1,2,4 18:18,21,23 19:6 19:7,8,10 20:22 21:5,6 22:13,16 23:7 27:3,25 29:12,14 30:17 31:18 32:1,4,22 32:23 33:6,18
---	--	--	---	---

65:17,21 66:4,20 67:2	39:15 54:19 58:23 60:6 64:15 72:1	<b>reality</b> 11:12 12:23 19:18 21:24 45:12 50:14	<b>regarding</b> 25:20 72:14 84:7	<b>releases</b> 11:21 13:18
<b>Q</b>	<b>ranked</b> 20:5	<b>reasonably</b> 33:22	<b>regards</b> 8:12 17:3 20:5 26:7 37:21 50:2 57:19 63:3 65:12 72:22 89:18	<b>releasing</b> 66:25 68:5
<b>quantifies</b> 20:2	<b>rapid</b> 8:2 18:23 23:9 28:17 32:12	<b>reasons</b> 12:16 24:11 28:8 76:24 105:19	<b>region</b> 28:23,24 30:17 31:16,22 32:3,22 42:17 83:3,19 92:22	<b>relevance</b> 36:20 71:9
<b>quantify</b> 19:2 21:17	<b>rapidly</b> 5:16 7:24 11:20 18:17,22 22:13 23:17 28:25 31:25 67:10 71:1 74:5 86:8 96:16 113:23	<b>recall</b> 95:9	<b>regular</b> 93:7	<b>relevant</b> 1:12 3:6 4:12 8:23 26:4 31:14 36:4 37:16 37:20 40:1 43:17 64:16 76:18 80:1 84:13 103:7
<b>quantities</b> 21:6 26:13 67:17 70:6 70:21	<b>rarely</b> 41:19	<b>Recalling</b> 98:22	<b>regulation</b> 89:10,20	<b>relied</b> 113:10
<b>quantity</b> 27:25	<b>rate</b> 14:24,25 15:1 15:4 16:13 17:15 18:6 23:11 24:15 24:22 25:20 26:18 26:19,23,23,23 27:2,7,19,23,25 28:2,5,10,16,24 30:13,15,16 31:18 31:25 32:1,5,18 32:23 33:18,19 37:21 38:5 66:11 67:1,2,5,8 98:21	<b>received</b> 19:16 98:16	<b>Regulations</b> 8:13 89:11,20	<b>remain</b> 97:15
<b>question</b> 76:19 90:16,24	<b>rates</b> 31:21	<b>receives</b> 72:8	<b>regulatory</b> 8:10 20:1 64:21 90:14	<b>remains</b> 103:4
<b>questions</b> 90:7,25	<b>re-entrant</b> 97:11	<b>recladding</b> 47:12	<b>reinforced</b> 42:1 46:6 47:14 48:7 48:12 49:8 55:21 60:13 61:23 62:6 85:4	<b>remarks</b> 9:16 40:14 80:12 91:19
<b>quickly</b> 26:21 34:25 73:25 85:16	<b>re-visit</b> 9:15 84:8 85:16	<b>recognise</b> 106:1	<b>reiterate</b> 63:17 99:2	<b>remember</b> 45:6 69:1
<b>quite</b> 69:17 72:19 75:7 109:18 111:12	<b>reached</b> 78:4 97:23 98:13,25 107:8,14 107:16,19,21 108:1,4 112:12,24	<b>recorded</b> 81:8	<b>reiterating</b> 68:14	<b>Remembering</b> 51:15
<b>R</b>	<b>reaches</b> 21:5 98:18	<b>recording</b> 80:6 102:3	<b>relate</b> 15:18 36:9	<b>remind</b> 57:22 68:3 102:17
<b>radiant</b> 21:9 23:4	<b>react</b> 12:4,11 13:18 26:10	<b>red</b> 26:11 82:23,24 83:2 101:4,4	<b>related</b> 5:8	<b>reminding</b> 89:17
<b>radiate</b> 13:19	<b>reaction</b> 11:17,18 11:20 13:18,20 14:22 57:7 64:4 66:8	<b>reduced</b> 37:13 46:21	<b>relates</b> 73:25	<b>remit</b> 5:7
<b>radiation</b> 13:23 14:4,7 21:19 22:11	<b>reactivity</b> 25:11	<b>reduces</b> 27:24 67:1	<b>relating</b> 26:7	<b>remove</b> 23:3
<b>ragged</b> 41:23	<b>read</b> 3:9 114:19	<b>reducing</b> 69:14	<b>relation</b> 36:15 63:19 86:23 103:9	<b>removed</b> 41:22 45:10 46:1 48:23 57:13,16 62:2 84:15 85:1 92:2
<b>rail</b> 52:23	<b>readily</b> 12:18 16:16 16:22	<b>reductions</b> 71:22	<b>relative</b> 8:20 19:20	<b>removing</b> 31:6
<b>rails</b> 46:4,19 48:25 50:21 51:2,8 52:19 55:20	<b>ready</b> 38:24 76:12	<b>refer</b> 40:7,15,18,21 41:2,9,18,25 54:4 94:19	<b>relatively</b> 16:11 35:6 65:3 66:11	<b>repeat</b> 3:8 75:21 76:9
<b>rainscreen</b> 40:21 40:23 41:22 46:10 46:12,14 49:5,9 50:22 51:1,7,9 52:21,22 54:5 55:2 56:9,12,18 56:20 62:1 67:18 67:20 68:9 69:13 85:14 86:19 87:10 87:22 97:7 100:21 103:3 104:7,12,14 105:5 110:12		<b>reference</b> 38:2 108:19	<b>release</b> 14:11 26:18 26:23,23 27:2,7 27:18,19 28:2,5 28:10,16 38:5 67:8	<b>repeated</b> 65:3
<b>raise</b> 80:13		<b>referenced</b> 6:24 109:3	<b>released</b> 13:7 22:14 22:17 24:16,19,21 24:23,24 25:17,21 26:20,21,24 28:12 29:13 33:7 67:4 73:24 74:12	<b>repeating</b> 92:8
<b>range</b> 6:15 10:14 10:21 20:13 39:12		<b>references</b> 107:10		<b>repetition</b> 43:24
		<b>referred</b> 12:2 71:11		<b>repetitive</b> 54:25
		<b>referring</b> 33:13 41:25 46:16 49:9 79:1		<b>replay</b> 80:11
		<b>refers</b> 10:9 14:10		<b>replies</b> 81:2
		<b>refurbishment</b> 39:7 44:6 45:2,25 46:3 48:5 50:24 59:21 61:5,22 63:4 64:6 72:25 85:3		<b>report</b> 2:19,21 3:1 3:2,4 4:8,11,25 5:7,11,18 6:25 7:15 39:15 52:7 55:13 70:19 72:9 72:16 77:12 79:7

79:15 88:23 91:8 103:19 109:3 110:11 <b>reported</b> 77:17 <b>Reporting</b> 4:4 <b>represent</b> 21:21 104:2 <b>represented</b> 82:23 <b>represents</b> 18:9 59:2 <b>required</b> 17:25 29:7 <b>requires</b> 14:16 <b>research</b> 3:15 <b>residents</b> 7:14 <b>resist</b> 89:23 <b>resistance</b> 86:12 <b>resistant</b> 85:25 <b>resolidified</b> 104:18 <b>resolution</b> 109:19 <b>respect</b> 6:1 53:11 63:12 74:13 <b>respective</b> 54:24 74:17 <b>respond</b> 39:4 <b>responds</b> 9:10 <b>response</b> 7:13 8:5 16:4,12 <b>rest</b> 38:12 <b>result</b> 11:13 14:24 19:5 28:17 69:20 71:17,24 103:11 <b>resulted</b> 4:19 73:7 100:24 105:13 <b>resulting</b> 23:18 32:21 38:5 <b>results</b> 11:17 20:6 25:13 31:20 32:11 <b>resume</b> 38:18 75:11 75:15 114:17 <b>retardants</b> 69:20 70:17 <b>return</b> 26:17 27:11 27:17 54:18 57:20 <b>returned</b> 65:15	<b>reveals</b> 56:17 <b>review</b> 106:20 <b>reviewed</b> 4:25 77:6 79:9 <b>Reynobond</b> 53:23 54:1,4 55:24 56:2 57:1 67:18 68:13 73:14 86:19 <b>right</b> 1:11 22:22,23 23:4 33:11,13,21 42:14 43:2 48:20 48:22 50:13,14 53:9 75:9 83:15 85:6 98:17 102:3 111:4 <b>right-hand</b> 22:8,10 22:11 27:22 45:9 88:10 110:20 <b>rigid</b> 68:25 70:9 71:10,12 <b>rise</b> 13:10 30:21 31:19 75:15 <b>rising</b> 33:12 <b>risk</b> 61:2 <b>rivulets</b> 35:15 <b>role</b> 3:14 8:17 <b>roles</b> 8:21 10:6 15:13 19:2 <b>roll</b> 62:11 <b>roof</b> 55:21 73:11 78:3 98:18 <b>rooftop</b> 97:24 <b>room</b> 42:11,15 71:12 <b>Rory</b> 6:20 <b>route</b> 85:22,23 93:1 <b>routes</b> 50:2 77:7 84:20 <b>RS5000</b> 54:19 58:11,22 <b>RS5080</b> 54:11,18 59:2 <b>RS5100</b> 58:12 <b>rubber</b> 49:11,25 61:20 62:8,11	72:11,12,12,15 85:8 86:11 <b>run</b> 37:19 53:8 <b>running</b> 41:19 73:9 <b>runs</b> 102:18 <hr/> <b>S</b> <hr/> <b>safety</b> 3:20 4:3,4 20:19 90:4 <b>sample</b> 22:18 34:25 35:4,9,11,17 <b>samples</b> 39:17 63:23 <b>sandwich</b> 60:22 <b>says</b> 80:18 <b>scale</b> 44:3 <b>scenario</b> 22:3 <b>scene</b> 79:22 <b>schematic</b> 83:16 <b>schematically</b> 27:9 <b>school</b> 3:11 <b>science</b> 8:25 9:1,20 9:22 11:4,6 28:21 36:3 38:9 <b>scientific</b> 1:11 3:20 5:8,15 21:17 34:21 35:22 64:8 <b>scope</b> 30:2 44:15 89:15 <b>SCOSS</b> 4:3 <b>Scotland</b> 3:12 <b>screen</b> 33:25 <b>sealant</b> 47:3,25 48:9 <b>second</b> 5:21 7:21 9:7 17:22 21:16 35:8 39:5 80:14 83:11 90:18 92:24 100:11 101:19 <b>seconds</b> 22:2,18,25 35:2 80:7,7 <b>section</b> 3:1,4 37:2 39:12 40:18,23 42:6 46:8 49:18 50:6 51:18,18	52:3 53:3 55:1 63:6 74:23 97:10 97:11,16 102:6 107:4 <b>sections</b> 40:20,24 41:2,3,5,10 43:17 45:11 51:13,14,15 58:16 59:16,19 60:20 62:15,18 91:2,22 95:7 100:23 104:11,20 <b>see</b> 17:10 22:5,14 30:12 32:7 33:3,6 35:2,9 37:20 41:23 44:20 46:21 48:11 50:11 53:6 57:14,24 59:4 62:5 80:19 82:15 85:2,7 87:6 96:6 96:10,24 98:10 99:4 100:22 101:11 102:4 104:4 110:10 111:7,12 <b>seen</b> 32:6 45:13 52:17 67:17 82:18 <b>segment</b> 35:2,8,16 81:8 <b>segments</b> 35:1 <b>selected</b> 64:7 <b>self-accelerating</b> 32:11 <b>self-sustaining</b> 14:12 <b>sense</b> 11:10,10 26:1 <b>senses</b> 26:6 <b>sentence</b> 89:21 <b>separate</b> 41:16 <b>separated</b> 53:25 104:13 <b>sequence</b> 11:13 22:3 32:13 33:1 44:24 88:22 91:9 91:10,17 98:11 106:10	<b>series</b> 29:6 36:25 50:25 97:1 100:10 101:2 103:21 108:16 <b>serve</b> 5:18 <b>service</b> 6:10 8:5 39:18 40:5 56:4 56:14 58:5 62:14 71:25 77:3 91:14 100:12 103:12,18 103:22 106:9 <b>service's</b> 99:6 <b>services</b> 5:2 7:14 <b>set</b> 1:15 4:8,11 5:21 24:25 25:5 26:22 73:19 <b>seventh</b> 96:25 <b>severity</b> 21:14 <b>shaded</b> 83:2 <b>shavings</b> 16:20,22 17:6 <b>sheet</b> 34:16,18,22 45:23 49:11 62:5 62:12 101:16 <b>sheets</b> 53:24 56:10 62:20 <b>short</b> 23:18 31:10 32:13,15 33:1 38:21 65:4 75:18 83:5 91:25 92:12 100:13 101:20 113:22 <b>shortly</b> 45:20 <b>show</b> 18:3 22:4,24 29:20 31:10 33:22 44:12 47:10 51:24 52:3 53:2 82:20 95:22 96:1 98:2 102:9 103:21,24 104:7 110:24 <b>showed</b> 22:1 38:1 48:25 67:25 82:3 85:17 101:17 112:8 <b>showing</b> 42:7 48:7
---	--	---	--	---

48:19 56:17,18 94:14 101:5 108:17,25 110:3 <b>shown</b> 9:15 12:20 14:3,7,7,8 17:5 22:3,8,17 23:2 26:8 27:10,22 32:13 33:1 40:12 40:20 41:3 42:6 42:17 44:19 45:14 45:16,22 46:16,20 47:2,20 49:1,14 49:15 50:9,18,21 50:25 51:1,18,20 52:2,4,13,19 53:4 53:23 54:12,15,17 55:6,11 57:2,3 59:12,22,24 60:3 60:11,21 61:10,13 61:15 62:16,23 66:12 68:11,22 72:11 80:11,17 82:22 91:19 95:25 98:12 106:25 107:11,13,18 109:20 110:6 113:20 <b>shows</b> 2:3 26:2 31:10 32:15 33:10 34:16 40:3 44:24 45:4,8 52:12 56:2 56:11 58:3,15 61:10,17 62:11 76:3,5 82:13 87:12 88:1,8 91:17 92:9 93:10 96:25 98:21 101:1 101:3,7,10,19,22 102:11 104:25 107:12 108:22 109:4,12,19 110:8 110:11 112:8,17 <b>side</b> 22:8,10,12 45:8,9 48:13 61:12,16 62:3	80:9 81:4,16 85:13 87:18 98:15 105:1 108:3 <b>side-by-side</b> 17:5 <b>sides</b> 35:9 54:15 60:18 <b>sight</b> 14:5 82:24 101:5 <b>significance</b> 88:15 <b>significant</b> 8:16 26:6,12 57:19 67:16 68:19 71:22 72:3 87:16 90:12 105:4 114:1 <b>significantly</b> 31:5 35:17 37:25 97:19 <b>silent</b> 96:10 <b>silicone</b> 47:3,25 48:8 <b>similar</b> 26:14 33:9 36:23 54:5 62:25 68:12 90:21 100:1 <b>similarities</b> 101:15 <b>similarity</b> 101:25 <b>simple</b> 11:12 31:12 65:3 <b>simply</b> 47:9 64:14 71:11 <b>simulates</b> 85:22 <b>single</b> 11:12 36:9 48:18 49:4 52:19 53:19 62:12 63:24 91:9 106:11,13 <b>sir</b> 1:3 2:11,13 5:13 12:21 28:18 38:8 38:14,17,23 53:10 68:7 74:24 75:6,9 75:14,20 76:10,12 79:7 91:16 102:17 114:12,16 <b>sit</b> 47:13 <b>site</b> 6:11 104:22 <b>sits</b> 1:10 54:16 <b>situation</b> 17:18 21:2	<b>sixth</b> 96:4 <b>size</b> 31:17 33:22 46:22 78:6 <b>sketch</b> 45:4 48:13 48:21 52:12 <b>sketches</b> 43:16,19 44:2,12 57:23 <b>skin</b> 57:16 <b>skins</b> 104:15 <b>slab</b> 45:14 <b>slabs</b> 41:25 46:6 <b>slice</b> 45:6 47:15,19 50:8,11 52:12,15 58:2 60:15 61:14 61:16 62:9 <b>slices</b> 57:23 <b>slide</b> 34:16 37:18 44:24 45:4 48:14 52:14 59:25 61:17 83:14,15 88:14 107:12 <b>slides</b> 87:21 <b>slightly</b> 89:1 94:3 97:17 109:11 111:8 112:4 <b>slow</b> 18:13 <b>slower</b> 30:25 32:23 37:12 <b>slowly</b> 26:21 33:4 78:5 89:5 <b>small</b> 12:6 35:6 43:7 47:2 49:18 51:3 59:6,15,15 70:5,20 81:21 92:21 95:8 101:3 102:7 110:14 111:3 <b>small-scale</b> 39:19 <b>smaller</b> 32:21,22,22 49:24 62:24 <b>smoke</b> 8:6 11:16 12:7 77:10 80:5 80:15,19,24,25 81:1,3,21 92:17 94:8	<b>smooth</b> 61:18 <b>soften</b> 65:25 71:21 <b>softening</b> 31:5 <b>sold</b> 55:25 <b>solid</b> 11:23 12:3,6 12:14 13:2,6 14:10,15,20,25 15:19 16:20 17:14 18:7,20 21:1,4,25 22:5 23:2 27:4 29:11 33:20 37:8 66:3,22,24 <b>solidified</b> 104:1,9 <b>solids</b> 12:12,18 74:15 <b>somewhat</b> 99:25 <b>soot</b> 12:8 13:21,24 <b>sorry</b> 49:19 69:16 <b>source</b> 11:14 14:17 15:10 17:14 18:8 21:9 23:4 28:6,8 67:6 110:24 <b>sources</b> 28:5 39:12 100:9 <b>south</b> 40:12 78:14 94:8 98:8 106:10 108:3,5 109:19,22 113:9,17 <b>southeast</b> 107:22 109:16 113:11,13 113:15 <b>southwards</b> 78:11 97:19 <b>southwest</b> 42:21 78:21 108:13 113:4 <b>spaced</b> 55:18,20 <b>spandrel</b> 40:18,23 46:6 50:6,12,13 50:19,22 51:13,18 58:16 59:16 60:13 60:19 95:7 97:10 97:16 100:23 102:6 107:4 <b>spandrels</b> 40:15	55:3 58:24 <b>spans</b> 52:25 <b>speak</b> 84:2 <b>special</b> 30:8 33:8 <b>specialist</b> 6:18 <b>specific</b> 5:6 8:18 17:24 18:5 20:15 42:5 47:5 49:18 55:12 58:11 59:1 60:3 63:9 64:9 70:18 72:14 77:11 80:21 91:22 99:20 105:19 108:16 <b>specifically</b> 6:19 42:6,23 44:21 79:7 <b>specified</b> 20:3 <b>speed</b> 9:5 <b>spend</b> 91:22 <b>spent</b> 36:2 <b>spray</b> 51:3 59:5 88:3 <b>sprayed</b> 82:18 <b>spraying</b> 94:11 96:15 <b>spread</b> 1:12,17,24 2:1,3,23 5:16,22 7:8,22,24 8:3,5,19 9:3,6,13,19,24,25 10:1,19,22,25 11:2 12:23 24:7 24:10,17 28:18,18 28:21,22,25 29:2 29:4,7,16,18,18 29:19,21,25 30:1 30:6,8,9,10,13,15 30:19,20,21,24 31:1,6,8,11,15,18 32:12,16,18,19,23 32:24,25 33:8,9 33:10,14,15,17 34:3,8 35:25 36:6 36:8,13,16 37:4,8 37:11,16,22,25 38:4,4 50:2 66:5
---	---	--	--	---

69:8,11,15,16 70:13 71:17 72:6 72:22 73:15 74:3 74:5 75:2,24 76:1 76:3,15,19,21,22 76:23,24 77:7,9 77:22,24 78:1,3,5 78:7,8,9,11,13,16 78:17,19,25 79:1 79:4,8,10,16 80:1 80:11 82:9 84:5,7 84:20 86:1,8,23 87:13 88:25 89:6 89:17,18,23 90:3 90:8,10 91:1,3,3,4 91:6,7,18 93:1 95:20,24 97:9 98:3,5,6,22,23,24 99:11,17,19,21,21 99:23 100:2,3,5,6 100:14 102:10,21 103:4,11 105:10 105:12,13,16,21 105:24 106:1,2,5 106:15,16,17,22 107:3,7,15 108:2 108:6,8,10,12,14 108:17 109:1,8,9 109:15,16,21 110:1,3 111:11,13 111:14,18,25 112:7,9,18 113:6 113:8,17,19,25 114:1,2,7 <b>spreading</b> 33:11 96:16 97:17,19 99:12 102:12,15 107:23 110:23 113:5,23 <b>spreads</b> 29:19,22 29:24 31:24 101:13 107:4 110:17 112:3,17 <b>square</b> 21:15,20 22:3,7	<b>stabilised</b> 92:3 <b>stage</b> 6:2 38:10 54:1 63:15 64:18 97:15 114:8 <b>stages</b> 87:1 <b>stamp</b> 95:1 <b>stamps</b> 83:7 91:14 <b>standardised</b> 20:6 <b>Standing</b> 4:3 <b>stands</b> 47:4 55:24 57:10 71:11 <b>start</b> 25:7 82:2 108:20 110:7 <b>started</b> 7:8 78:5 <b>starting</b> 44:25 <b>starts</b> 98:15 <b>state</b> 65:25 <b>stated</b> 18:18 89:3 <b>statement</b> 63:17 <b>statements</b> 79:17 79:19 81:7 96:17 105:3 <b>states</b> 80:8 89:21 <b>statutory</b> 89:17 <b>stays</b> 16:11 <b>steady</b> 27:7 33:20 66:11 <b>Steve</b> 94:23 <b>stiffness</b> 86:3 <b>stills</b> 88:5 <b>stop</b> 23:8 114:17 <b>stopped</b> 103:2 <b>stored</b> 25:15 <b>streaks</b> 35:14 <b>strength</b> 86:2 <b>strictly</b> 69:22 89:14 <b>strike</b> 96:7 <b>strip</b> 48:2 49:20 61:9 <b>strong</b> 18:20 28:7 64:11 <b>strongly</b> 14:22 21:2 23:12,14 29:2 65:22 66:8 <b>structural</b> 3:22,23	4:3,4,6 42:1 <b>structure</b> 45:13 62:7 70:10 <b>structured</b> 8:24 <b>structures</b> 3:11 <b>studied</b> 72:17 <b>study</b> 64:15 <b>studying</b> 90:8 <b>subject</b> 11:5 64:23 114:4 <b>submitted</b> 6:5 <b>submitting</b> 39:14 <b>subsequent</b> 5:12 17:11 77:20 80:14 88:10 95:15 106:16 <b>subsequently</b> 67:3 <b>subset</b> 7:16 <b>substance</b> 85:9 <b>substantial</b> 55:7 <b>substantially</b> 36:12 <b>sufficient</b> 13:15 21:6 28:22 29:10 55:16 67:5 <b>sufficiently</b> 34:9 106:18 <b>suggest</b> 24:6 103:10 105:3 <b>suggested</b> 25:3 <b>suggesting</b> 93:3 <b>suggests</b> 96:12 110:22 <b>suitability</b> 20:5 <b>summarise</b> 72:20 <b>summary</b> 9:17 38:8 39:11 83:24 105:11 <b>supplied</b> 29:11 <b>supply</b> 14:17 <b>support</b> 50:22 69:7 70:13 103:4 <b>supported</b> 55:20 <b>supporting</b> 46:4 <b>sure</b> 75:8,13 85:18 <b>surely</b> 106:2	<b>surface</b> 16:10 17:1 17:14 18:6,10,14 18:15,22 21:4,12 22:12 27:21 29:1 31:20,21 50:11 52:15,17 56:5,8 57:17 58:8 61:19 71:2 74:1,2 93:18 100:7 <b>surfaces</b> 23:17 56:21 70:14 74:6 86:21 <b>surprising</b> 35:21 <b>surround</b> 58:1 84:9 88:19 <b>surrounding</b> 12:11 13:13,13 15:25 22:20 28:3 <b>surroundings</b> 16:6 <b>survivors</b> 4:21 5:1 <b>sustain</b> 15:3 21:7 28:15 29:7 33:7 67:5 <b>sustained</b> 20:21 22:24 <b>swinging</b> 43:1 <b>sympathies</b> 5:2 <b>synthetic</b> 23:20 26:15 27:5 31:1 34:5 65:1,6 67:22 68:24 70:8 71:8 71:16 72:11 73:4 <b>system</b> 9:9 26:13 29:3 31:7 39:7 42:4 46:3,14 51:4 53:15 54:24 56:24 61:6 67:16 68:20 69:12 72:25 73:4 74:19 95:11 102:22 <b>systems</b> 8:2,11,21 10:7 20:16 90:15 90:20	<b>take</b> 3:9 47:15 50:8 75:2,3,4 <b>taken</b> 39:17 51:16 55:8 56:3,12 58:3 58:16 61:18 62:12 82:1 85:22 86:25 97:8 100:12 110:5 110:20 111:10,16 111:23 112:11,16 112:22 <b>tape</b> 51:5 <b>task</b> 6:6 7:21 <b>technical</b> 3:19 5:6 10:5 11:3,8 15:18 35:22 64:8,11,22 64:24 69:21 72:20 <b>tell</b> 52:2 <b>tells</b> 54:9 <b>temperature</b> 16:4,8 17:14 18:1,7,10 18:15 19:6 21:4,5 22:12 30:18 68:2 71:4,13,25 72:2 74:1 <b>temperature-dep...</b> 14:23 18:19 <b>temperatures</b> 14:23 19:9,10 71:21 86:3 <b>tend</b> 19:13 <b>tends</b> 69:6 <b>term</b> 40:15 65:6 <b>terminology</b> 11:8 15:18 36:4 39:22 39:25 40:18 46:14 64:24 69:17 <b>terms</b> 3:9 5:15 10:2 20:14 21:10 57:6 63:1 76:15 <b>test</b> 10:14 20:7 34:21 64:12 <b>tested</b> 23:25 <b>testing</b> 6:11 20:12 21:21 36:19 39:19 57:3 64:18 72:17
--	--	---	---	--

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**T**


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<b>tests</b> 10:21 20:4,6 21:8	62:16 86:5,10	<b>tip</b> 52:7,13,16,23 53:2 94:5 102:19	54:23 55:3,23 56:3,12 57:1,9 58:4,17,23 59:9 59:11 60:9 61:18 62:13,15 63:5,12 64:6 65:13 67:13 67:19 68:9,20 70:7,22,24 71:10 72:4,16,23,25 74:19,21 76:3,7 76:16,22 77:19,25 78:10,12 79:23 84:11 86:16,25 87:5 89:14 90:2,8 90:12,20 95:21 99:13,19,24,25 101:2,8 103:19 105:14 106:8,12 107:9,12 108:13 108:22 109:5,12 109:19 113:12	<b>twice</b> 83:9 <b>two</b> 5:18 9:21 14:1 17:3 29:23 42:14 45:11 46:7 50:15 50:19 51:15 53:24 56:25 57:6 58:21 58:24 59:17 62:20 65:8,11 80:12 90:7 96:8 99:5 100:9
<b>Thank</b> 2:11,13,14 4:14,16 38:14,19 38:25 74:24,25 75:16 76:10,11 114:12,15,16,20	<b>thickness</b> 16:18 46:9 50:17,20 52:21 58:13,25 62:21,22	<b>tips</b> 102:16	70:7,22,24 71:10 72:4,16,23,25 74:19,21 76:3,7 76:16,22 77:19,25 78:10,12 79:23 84:11 86:16,25 87:5 89:14 90:2,8 90:12,20 95:21 99:13,19,24,25 101:2,8 103:19 105:14 106:8,12 107:9,12 108:13 108:22 109:5,12 109:19 113:12	<b>type</b> 46:15 47:5 <b>types</b> 65:9 <b>typical</b> 56:11,17 71:24 <b>typically</b> 14:3 21:14,21 28:17 31:25 67:9 71:3
<b>Thanks</b> 76:13	<b>thin</b> 15:22 16:2,16 16:22 48:2 54:14 61:8	<b>today</b> 1:10 3:9 5:23 11:7 13:1 30:4 37:2 38:13 39:6 50:4 55:16 72:19 79:14 84:3 85:5 90:17,24 101:18 114:11,14	107:9,12 108:13 108:22 109:5,12 109:19 113:12	
<b>thereof</b> 97:7 105:7	<b>things</b> 11:6	<b>today's</b> 1:4 66:13	<b>tragic</b> 4:19 5:4	<b>U</b>
<b>Therma</b> 60:5	<b>think</b> 3:22 19:13 21:13 38:17 72:21	<b>tomorrow</b> 114:18	<b>transcript</b> 79:18	<b>U</b> 71:11
<b>thermal</b> 12:1,13 13:23 14:14 15:12 15:25 16:18 17:19 17:21 18:4,8,12 18:15,21,24 21:12 21:18 22:11 23:12 23:15,16,19 25:15 30:14 38:7 39:2 46:7 49:4 51:10 69:1,3,5,10 70:11 70:25 73:25 74:4 79:20 82:1,13,21 83:5,22 87:1,25 88:7,20 96:18	<b>third</b> 9:12 17:24 35:16 76:14 81:8 93:10 102:2	<b>top</b> 32:8 46:2 48:11 48:14 51:23 53:9 55:6 58:19 60:22 78:4,10,12,14 79:2 96:2 98:5,7,9 98:10,18,25 101:11,14 106:23 107:2,8,16 108:24 109:1,8,9,15,16 109:22 110:23 111:4,4,11,18,25 112:1,10,13,24 113:14,17,20	<b>transcripts</b> 79:18 80:17	<b>UK</b> 4:2 10:15 36:22 64:20 89:10,20 90:13,23
<b>thermally</b> 13:6 15:22,22 16:2,7 16:16,17,22,24 17:13 22:5 23:12 65:20	<b>thought</b> 29:5	<b>top-left</b> 92:15	<b>transfer</b> 14:2,10 16:5,13 17:21 18:3 23:5 25:22 27:24 30:14 31:15 31:21 32:18 33:15 67:1	<b>unable</b> 99:8
<b>thermoplastic</b> 65:9 65:14,24 66:7,10 66:15 67:23 71:1 71:9	<b>three</b> 8:24 18:4 35:1 37:18 41:15 42:10 58:12 91:2 94:2 96:8	<b>top-right</b> 45:15 59:25	<b>transferred</b> 16:9 28:13,23	<b>unburned</b> 14:9 103:6 104:10
<b>thermoplastics</b> 66:5 67:15 74:9	<b>Thursday</b> 114:22	<b>topic</b> 11:7 89:3	<b>transfers</b> 38:6	<b>unburnt</b> 28:23 31:16,22 32:18 38:6
<b>thermosetting</b> 27:16 65:9,19 66:18 67:8,15 68:24 70:8 74:8 86:7	<b>TIC</b> 79:21	<b>topics</b> 8:8	<b>translucent</b> 57:3	<b>uncontrolled</b> 11:17
<b>thick</b> 15:22 16:7,17 16:24 17:13 22:5 23:12 34:19 49:5 56:5,6,7 59:3,23 60:1,18 61:19	<b>tilting</b> 42:25	<b>tops</b> 106:24 107:14	<b>transported</b> 13:9 13:11	<b>undamaged</b> 59:19 102:24
	<b>timber</b> 22:12 45:17 48:16,17	<b>torch</b> 34:23,23	<b>trauma</b> 4:21	<b>undergo</b> 65:17,21 66:3
	<b>time</b> 13:1 20:14 21:13 23:13 26:24 36:2 53:15 69:7 70:13 72:16 75:7 75:12 79:4 83:7 83:11,17 91:14,22 93:4,25 95:1,1 96:23 98:12 101:23 107:7,23 108:14	<b>total</b> 24:18,20,24 68:4 73:21 74:11	<b>triangular</b> 111:3	<b>undergoes</b> 13:8
	<b>time-dependent</b> 21:2	<b>totally</b> 105:24	<b>trigger</b> 1:20 75:22	<b>underneath</b> 41:24
	<b>timeline</b> 77:15 106:4,6,15 107:6	<b>touch</b> 6:1	<b>true</b> 4:9	<b>understand</b> 5:14 9:2,24 10:24 13:4 18:25 19:1 37:15 77:12 94:22
	<b>timelines</b> 9:18	<b>tower</b> 1:15,18 2:8 4:17 5:6,15,20 6:11 8:2,12 9:23 10:25 15:16 19:4 19:17 20:17 24:7 26:8,13 36:1,6,24 39:8,13,18 42:20 43:18 44:5 51:23 52:4 53:3,15	<b>try</b> 64:22 74:17	<b>understanding</b> 1:16 5:19 8:18 10:6 11:1 15:16 24:5 26:10 36:5 39:3 74:20 77:4
	<b>timer</b> 83:8		<b>turn</b> 19:11 28:21	
	<b>times</b> 23:18,21 106:17 107:14		<b>turned</b> 96:3	
	<b>timings</b> 110:1		<b>turning</b> 43:1,9	
	<b>tiny</b> 13:21			

80:1 90:10 105:18 <b>understood</b> 10:2 16:19 43:20 <b>undertaken</b> 6:12 7:5 57:4 103:17 <b>unfolded</b> 7:10 76:6 <b>unfolding</b> 2:5 <b>unfortunately</b> 34:2 109:18 <b>unglazed</b> 41:10 <b>uniform</b> 33:22 <b>uniformly</b> 16:3 <b>unimportant</b> 12:15 <b>uninterrupted</b> 52:24 53:8 91:21 <b>unit</b> 17:23 24:21 25:10 26:24 81:18 81:19 92:16,19 <b>units</b> 21:15,17 41:11 46:18 62:19 65:3 <b>University</b> 3:12,17 6:13,19 39:20 57:4 <b>unpick</b> 74:17 <b>unpicking</b> 10:6 <b>unplasticised</b> 47:4 71:12 <b>unprotected</b> 70:14 <b>unsuccessful</b> 96:15 <b>unusual</b> 99:25 105:16 <b>uploads</b> 77:3 <b>upper</b> 25:16 71:25 94:5 106:10,12 <b>uPVC</b> 46:25 47:4 47:24 48:2 49:14 49:20 61:4,6,11 61:12,17 71:11,14 71:21,25 72:5 84:14 85:1,24 <b>upward</b> 30:5,19,20 31:11,15 32:12,19 37:8 38:3 76:22 91:2,6,7 96:15	98:23 99:16 100:3 105:25 114:3 <b>upwards</b> 29:24 41:1,12 77:24 97:9 <b>use</b> 9:16 12:22 19:16 31:12 39:23 40:16,18 43:16 54:6 69:19 70:16 77:1 89:24 <b>useful</b> 36:14,25 43:24 63:18 89:16 <b>usually</b> 106:22 <hr/> <b>V</b> <hr/> <b>value</b> 27:8 31:13 67:10 70:19 <b>values</b> 21:20 24:2,3 26:14 64:13 <b>vantage</b> 93:11 94:3 95:16 <b>vapour</b> 12:6 13:21 <b>variability</b> 26:1 44:9 <b>variable</b> 24:14 <b>variation</b> 44:6 <b>varied</b> 49:22 <b>varies</b> 69:18 70:15 <b>various</b> 6:12 9:8 19:2 43:13 44:20 45:2 53:14 56:11 74:14 85:17 89:14 <b>ventilated</b> 46:13,14 52:22 56:20 <b>versus</b> 16:20 <b>vertex</b> 95:6 97:10 <b>vertical</b> 34:3,6 35:14 42:19 44:19 45:6 46:22 51:13 51:19 53:5,7 57:23 60:15 61:12 61:14 66:12 73:8 73:13 78:5 91:7 91:17 95:10 97:13 98:3,22 99:16	102:21 103:11 105:10,25,25 <b>vertically</b> 31:11 32:16 34:16 41:19 45:11 55:18 77:24 90:3 95:21 96:8 100:3 108:15 <b>victims</b> 5:1 <b>video</b> 2:1 6:4 9:15 17:9 22:4,15,19 23:1 31:10 32:6 32:13,14,15 33:1 33:2,5,10,23 34:13,15 35:7,13 35:19 37:23 76:1 77:1 79:18 80:11 81:8,10,12,13,14 82:4,11,13 83:8 83:10,12,13 86:25 87:2,4,6,11,14,15 87:16,24 88:1,4 91:17,18,21,24,25 92:3,6,7 93:3,5 98:10 100:13 101:16,16 102:1 103:10 109:2 110:7,16,24,25 111:2,6 <b>videos</b> 1:23 2:4 17:5 37:19 75:24 76:4 91:8,11,15 95:15,22 96:1,25 98:11 100:10,17 105:21 <b>view</b> 49:1 50:25 72:3 84:18 85:2 101:4 113:13 <b>viewed</b> 47:18,19 82:16 87:19 105:24 <b>views</b> 92:4 <b>violate</b> 36:17 63:20 <b>virtually</b> 25:14 27:8 <b>viscosity</b> 34:8	<b>visible</b> 11:16 12:7 20:24 31:24 34:12 34:24 41:21 47:2 47:25 57:11 58:6 58:9,18 81:15,22 82:15 84:13 85:6 88:20 92:13,17 96:20 110:9,20 <b>visual</b> 91:13 94:13 94:20 99:6 100:14 <b>visually</b> 29:15 <b>void</b> 46:13 49:8 51:8,19,22 52:24 53:1 95:10 102:18 <b>voids</b> 46:16 51:4,24 52:3 53:2,5,8 <b>volume</b> 17:23 32:22 72:19 <b>volumes</b> 59:6 68:19 <hr/> <b>W</b> <hr/> <b>walk</b> 89:5 <b>wall</b> 42:9 45:15,19 48:10 60:19 88:8 97:16 <b>walls</b> 89:22,23 <b>wanted</b> 47:9 80:13 <b>warning</b> 75:22 76:9 <b>warnings</b> 1:20 <b>warranted</b> 44:1 <b>wasn't</b> 105:7 <b>water</b> 12:5 13:21 82:18 88:3,6,11 93:22 94:11,14,16 94:18 95:13 103:13,18 <b>way</b> 3:2 51:23 53:9 85:21 86:18 <b>ways</b> 27:1 54:7 73:18 <b>we'll</b> 75:10,14,14 96:6 114:17,17 <b>we're</b> 101:6 <b>weatherproofing</b> 49:11 61:21 85:9	86:11 <b>weave</b> 58:20 <b>web</b> 6:23 <b>website</b> 77:3 <b>Wednesday</b> 1:1 4:18 <b>week</b> 1:10 <b>weeks</b> 80:12 <b>welcome</b> 1:4 <b>west</b> 40:3,10 52:3 53:3 78:19 101:1 101:7,13,24 102:12 105:1 106:12 108:6,9,10 112:6,7,9,13 <b>whereabouts</b> 80:24 <b>whilst</b> 67:24 73:15 89:13 <b>white</b> 41:12 <b>white-coloured</b> 34:17 <b>wide</b> 88:8 <b>wider</b> 7:2 <b>window</b> 24:9 41:2,5 41:7,9,11 42:13 42:15,17,23,24 43:6,14,15 44:8 44:17,23 45:5,17 46:18,22,25 47:17 47:20,24 48:3,5,6 48:17,21 49:2,7 49:14,19,20 50:7 50:24 51:17,25 57:25 58:1,2 59:20 60:10,12 61:4,12,13,15,16 61:22 62:10,17,18 62:24 70:24 72:5 72:8 80:20 81:3 81:16,17,21,22 83:21 84:9,9,10 84:13,14,19,22,25 85:1,3,6,18,19,24 87:7,18 88:12,16 88:19 92:10,13,14
---	--	--	--	---

92:15,16,22 93:7 93:8,9,17,19 96:15 102:5 105:6 <b>windowpane</b> 42:24 43:8 45:10 92:18 <b>windows</b> 1:14 40:17 41:6,13,15 42:9,14,19 45:15 45:21,22 46:1,17 47:13 48:18,23,24 59:21 61:4 97:20 104:20 <b>windowsill</b> 47:21 61:11 <b>windowsills</b> 104:21 <b>wish</b> 52:8 <b>withdrawn</b> 34:25 <b>witness</b> 3:14 5:5 79:17,19 81:6 96:17 105:3 <b>witnessed</b> 76:5 <b>witnessing</b> 2:5 <b>wonder</b> 38:15 <b>wood</b> 11:24 13:2,3 13:4,6,8 14:9,11 16:19,20,21,21,24 17:6,6,11 22:1,6,9 23:2,5,5 25:8 26:12 27:15 <b>wooden</b> 12:20 20:23 <b>word</b> 19:15 54:6,8 54:8 63:13 <b>work</b> 7:3,4 8:14 30:3 44:15 55:14 64:17 89:15 114:13 <b>Working</b> 85:21 <b>worldwide</b> 6:23 <b>worth</b> 20:13 40:25 41:11 68:14 <b>would've</b> 56:19 85:22 110:13 <b>writing</b> 46:16 72:16 <b>written</b> 2:18	<hr/> <b>X</b> <hr/> <hr/> <b>Y</b> <hr/> <b>year</b> 77:13 <b>yellow</b> 13:25 41:10 41:24 42:3 48:3 52:8 55:4 57:24 58:6,18 61:14 62:5,8,19 67:21 68:23 83:19 <b>yes/no</b> 10:16 <b>yesterday</b> 79:11 82:4 83:4,6 84:1 <hr/> <b>Z</b> <hr/> <b>zone</b> 31:17 32:21 37:10 109:2 111:3 <b>zones</b> 103:1 <b>zoom</b> 42:16,22 <b>zooming</b> 42:5 <hr/> <b>0</b> <hr/> <b>0.5-millimetre</b> 56:5 56:7 <b>01.14.12</b> 82:7 <b>01.14.16</b> 99:7 <b>01.15.28</b> 88:1 <b>01.15.53</b> 94:15 <hr/> <b>1</b> <hr/> <b>1</b> 5:7,11,12,18 6:25 7:6,13,15 8:14 9:20 18:1,2 30:2 38:13 39:14 52:7 55:13 62:16 66:13 68:1 70:19 72:9 72:16 77:12 79:15 88:23 89:15,21 91:8 93:3 101:17 103:19 106:6 108:22 109:3 110:11 <b>1-millimetre</b> 86:10 <b>1,000</b> 21:16 <b>1.05</b> 81:10 <b>1.08</b> 92:9	<b>1.09</b> 77:23 87:5 89:1 92:24 <b>1.12</b> 93:10 94:1,17 <b>1.15</b> 94:4 99:4 <b>1.16</b> 95:2 <b>1.19</b> 95:2 <b>1.21</b> 99:10 <b>1.22</b> 96:4 <b>1.22.19</b> 96:5 <b>1.24</b> 97:1 <b>1.26</b> 97:21 <b>1.29</b> 78:4 97:22 98:4,17 107:16 108:23 109:5 111:10 <b>1.36</b> 78:8 98:4 <b>1.4</b> 3:4 <b>1.56</b> 107:19 108:23 109:6,13 111:10 <b>1.6</b> 3:1 <b>10</b> 99:13 112:11 114:18 <b>10.00</b> 1:2 114:23 <b>100</b> 49:5 50:18 52:20 58:13 <b>105</b> 72:2 86:3 <b>11</b> 81:11 112:16 <b>11.00</b> 38:20 <b>11.10</b> 38:18 <b>11.15</b> 38:22 <b>12</b> 112:22 <b>12.11</b> 75:17 <b>12.54</b> 77:17 98:15 <b>12.54.29</b> 80:6 <b>13</b> 60:17 84:10,16 113:2 <b>130</b> 68:2 <b>135</b> 68:2 <b>14</b> 4:18 5:16 77:5 77:18 <b>15</b> 22:18,25 77:20 <b>16</b> 1:17 24:7 42:10 42:13 43:15 72:7 76:20 77:18,21 78:1 79:20,21	80:2,4 82:3,15,22 83:17 84:5,12 87:3,7,19,25 88:3 91:3,6,7,18 92:10 96:9,14,19 97:3 99:5,7 104:25 <b>18</b> 71:20 <b>19</b> 96:10 <hr/> <b>2</b> <hr/> <b>2</b> 2:19 55:15 62:21 63:6 74:23 75:11 75:15 95:9 109:4 <b>2-minute-and-48...</b> 110:16 <b>2.00</b> 75:19 <b>2.23</b> 107:21 109:5 109:13,20 111:16 <b>2.25</b> 78:13 <b>2.48</b> 101:9 108:1,2 109:20 111:16,23 112:11 <b>2.49</b> 78:20 <b>20</b> 1:1 78:2 <b>2010</b> 89:11,20 <b>2012</b> 45:25 <b>2016</b> 45:25 <b>2017</b> 4:18 5:16 40:6 55:8 77:5,18 103:23 104:25 <b>2018</b> 1:1 2:19 114:22 <b>21</b> 11:19 25:13 114:22 <b>23</b> 97:23 <b>230</b> 71:5 <b>25</b> 40:6 55:8 62:22 91:8 103:23 <b>25-millimetre</b> 59:23 60:1 86:5 <b>26</b> 69:24 <hr/> <b>3</b> <hr/> <b>3</b> 34:19 35:8 42:20 75:2 78:24 109:12 111:1	<b>3-millimetre</b> 56:6 <b>3.11</b> 101:9 108:4 111:23 <b>3.15</b> 114:21 <b>3.20</b> 101:21 108:6 112:16,22 <b>3.33</b> 101:21 108:8 <b>3.48</b> 108:10 112:11 112:16,22,23 113:2 <hr/> <b>4</b> <hr/> <b>4</b> 41:1,12 51:22 53:9 73:10 77:18 78:3,24 95:14 107:13 109:18 <b>4.09</b> 78:22 102:11 108:12 113:2,3 <b>40</b> 71:6 <b>46</b> 68:6 71:7 <hr/> <b>5</b> <hr/> <b>5</b> 82:7 99:13 106:19 110:5 <b>50</b> 21:20 22:2,7 72:1 <b>52</b> 80:7 <b>55</b> 80:7 <hr/> <b>6</b> <hr/> <b>6</b> 35:16 94:6 95:4 97:17 110:5 <b>60</b> 69:25 <hr/> <b>7</b> <hr/> <b>7</b> 94:6 95:4 111:10 <b>71</b> 4:20 <b>75</b> 72:2 <hr/> <b>8</b> <hr/> <b>8</b> 111:16 <b>80</b> 46:9 50:20 58:25 59:2,3 <hr/> <b>9</b> <hr/> <b>9</b> 111:23 112:8
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<p><b>9.5</b> 61:19 <b>999</b> 2:9 76:8 79:17 80:3 81:11 98:16 <b>9th</b> 98:2</p>				
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