

**QUEENSLAND COAL MINING BOARD OF INQUIRY**

*Coal Mining Safety and Health Act 1999*

*Establishment of a Board of Inquiry Notice (No 01) 2020*

Before:

Mr Terry Martin SC,  
Chairperson and Board Member

Mr Andrew Clough,  
Board Member

At Court 17, Brisbane Magistrates Court  
363 George Street, Brisbane QLD

On Monday, 29 March 2021 at 10am  
(Day 23)

1 THE CHAIRPERSON: Yes, Mr Rice?

2

3 MR RICE: Mr Martin, I call Dr Ting Ren, who is appearing  
4 remotely. Hopefully he will be on the screen.

5

6 THE CHAIRPERSON: Professor, are you there? Can you hear  
7 me?

8

9 DR REN: Good morning, yes, I can.

10

11 <TING REN, affirmed: [10am]

12

13 <EXAMINATION BY MR RICE:

14

15 MR RICE: Q. Dr Ren, I want to ask you some questions to  
16 begin with. Can you see me and hear me okay?

17 A. I can only see the wording here "Queensland Coal  
18 Mining Board of Inquiry". I don't see the other - I cannot  
19 see, you actually.

20

21 Q. Let's see if we can arrange that. That's preferable.

22 A. Yes, I can see the courtroom now. Yes.

23

24 Q. Is your name Ting Ren?

25 A. Correct.

26

27 Q. Dr Ren, you're an associate professor at the  
28 University of Wollongong where you're situated today; is  
29 that right?

30 A. Correct.

31

32 Q. And you're attached to the School of Civil, Mining and  
33 Environmental Engineering?

34 A. Yes.

35

36 Q. Have you had that position since 2009?

37 A. That's correct.

38

39 Q. I just want to ask you a few more details about your  
40 background. You were tertiary educated in the United  
41 Kingdom; correct?

42 A. Yes.

43

44 Q. You gained your Masters in Mining Engineering in 1988?

45 A. Yes.

46

47 Q. And then a doctorate in the same field in 1992?

- 1 A. Correct.  
2
- 3 Q. And you worked in the UK until 2003 as a mining  
4 engineer and also a senior research fellow?  
5 A. That's correct.  
6
- 7 Q. You came to Australia and worked for a number of  
8 years, I think until 2009, with CSIRO?  
9 A. That's correct, yes, six years.  
10
- 11 Q. And you worked there in various capacities - as  
12 a research scientist and a senior research engineer, also  
13 a ventilation engineer?  
14 A. Yes.  
15
- 16 Q. You're the co-editor of the International Journal of  
17 Mining Science and Technology?  
18 A. That's correct.  
19
- 20 Q. And you've published many papers and technical reports  
21 in your field of expertise?  
22 A. Yes.  
23
- 24 Q. Relevant to today's topic, you've participated,  
25 I think some years ago, in a number of ACARP projects that  
26 considered the application of inertisation to active goafs  
27 and, in particular, the two projects in 2005 and 2010;  
28 correct?  
29 A. Yes.  
30
- 31 Q. And have you retained since then a professional  
32 interest in that subject?  
33 A. Yes, I do.  
34
- 35 Q. Let's start with something basic. We know that an  
36 active goaf contains both methane and oxygen to varying  
37 degrees and that that's a situation to be managed. Would  
38 you tell us, to begin with, what inertisation involves?  
39 A. In my view, the active goaf inertisation basically  
40 refers to the action of creating an inert atmosphere in  
41 goaf areas and in underground coal mines by means of  
42 injecting inert materials such as inert gas to deplete or  
43 reduce oxygen concentrations to a low level that would  
44 effectively suppress or contain the onset of active coal  
45 oxidation or spontaneous heating or potentially a gas  
46 explosion situation.  
47

1           In addition to the use of inert materials, such as  
2 inert gas, this process could involve a combination of  
3 other actions, for example, ventilation controls, pressure  
4 balancing, seals, injection of other materials, depending,  
5 like foams, slurries, things like that, to minimise oxygen  
6 ingress into the goaf area.  
7

8           Q.    We might discuss some of those as we go along. In  
9 terms of reduction of oxygen levels, is there an objective  
10 in terms of a percentage to be ideally achieved?

11          A.    I think for any spon com from mines or longwalls or  
12 whatever you call it, the goaf inertisation basically - it  
13 is used for operating longwalls. The aim is to drop the  
14 gas, the oxygen level, to a certain level to contain the  
15 onset of spon com. And for gassy mines with high gas  
16 emissions, methane - for example, during the longwall  
17 seal-off operations - the inertisation will help to  
18 minimise the risk of gas explosion by rendering a potential  
19 explosive goaf atmosphere.  
20

21          Q.    Can we start with the 2005 project and just speak  
22 about the content of that for a while, and then later on  
23 you can bring us more up to date. Okay?

24          A.    Yes.

25  
26          Q.    There was quite a lot of time and money spent on that  
27 2005 project; am I right?

28          A.    Yes, that's true.  
29

30          Q.    It spanned over a two-year period?

31          A.    Yes.  
32

33          Q.    According to the abstract from the report, the program  
34 was one to develop and demonstrate effective proactive  
35 inertisation strategies. Can I ask you, what was the  
36 impetus behind a project of that expense and magnitude?

37          A.    I think at that time in Australia we had done quite  
38 a lot of goaf inertisation already. It was coming to the  
39 point that we need to further optimise the inertisation  
40 strategy, and, as a result, I think ACARP supported that  
41 project. I can't remember the exact amount of the money,  
42 but it's quite substantial, say something like \$450,000.  
43

44          Q.    To that point, had there been use made of inertisation  
45 beyond its more established use in sealing operations?

46          A.    Prior to this project, there was another ACARP project  
47 with the aim of optimising the process of seal-off

1 operations by injecting some nitrogen into the goaf to  
2 speed up the process of inertising the goaf, and therefore  
3 you reduce the danger of gas explosion. Yes, there was  
4 some study already before this project, but for a different  
5 purpose.

6  
7 Q. Again, the abstract of the report refers to some  
8 frequency of goaf heatings and also production losses that  
9 can emanate from adverse incidents. Was that part of the  
10 figuring behind the conduct of that project?

11 A. Correct.

12  
13 Q. The report, I think, makes mention that there have  
14 been developments by way of increased awareness of  
15 spontaneous heating hazards, some improvement in gas  
16 monitoring systems, and perhaps, since then, some greater  
17 understanding of gas flow mechanics. If you accept that  
18 there have been improvements in those areas, is there still  
19 a case for the wider use of active goaf inertisation?

20 A. Yes, I believe so. At the time, I think, although the  
21 industry has been practising inertisation for quite some  
22 years, and I think there's a general need of improved  
23 knowledge of the science behind this process, exactly what  
24 is happening in the goaf and what happens to the inert gas  
25 that you inject, and there's a common perception that  
26 there's a need to better understand this process, and  
27 therefore we are able to improve the practice in industry.  
28 I think that's probably the major driver behind that  
29 project.

30  
31 Q. I was wondering if you could comment on the scope of  
32 application of this process of active inertisation. Is it,  
33 for example, one that has potential for use in all  
34 underground coal mines or only some or only where some  
35 features are present? Could you comment on that?

36 A. Yes, sure. I think by referring to that study or that  
37 project, ACARP project, I think there's two particular key  
38 outcomes from that project. The first one is perhaps the  
39 scenario that when the proactive inertisation should be  
40 introduced to reduce or contain the risk of spon com in the  
41 longwall goaf, and that would include, for example, if the  
42 longwall is extracting a seam that is highly liable to  
43 spon com or you are mining a particular section with severe  
44 geological disturbances, for example, faults or dykes, you  
45 might expect a bit of delay of your longwall advance, or  
46 you may experience a situation that the longwall stops for  
47 a prolonged period - it might be because of tailgate or

1 face collapse or other reasons, for example, equipment  
2 failures; or in certain situations, you might have abnormal  
3 CO readings or other gas ratios that indicate something is  
4 perhaps happening, or perhaps you're passing an adjacent  
5 goaf that in the past has a history of caving and you take  
6 some precautions. That's the situation.

7  
8 Q. In the area of mining that we're particularly  
9 concerned with, which is the Goonyella Middle seam -  
10 I don't know if you have any familiarity with that. Do  
11 you?

12 A. I'm not into that, honestly.

13  
14 Q. It so happens that in the ordinary course of mining in  
15 this seam, the conventional practice is to leave a beam of  
16 coal in the roof, which then caves into the goaf, and,  
17 similarly, there may be a section of floor which is not  
18 mined, in other words, it's not stone to stone, as it were;  
19 there's some coal which is left behind from the process of  
20 mining which then forms part of the goaf. In that  
21 circumstance, there is a spontaneous combustion hazard to  
22 be managed. Is that a scenario to which this active  
23 inertisation may be potentially applicable?

24 A. I think that's correct, because I think it's quite  
25 common practice in underground coal mining operations,  
26 sometimes you leave roof coals or floor coals, and  
27 sometimes you may have a thin seam above your face, and in  
28 the process of mining, all these coals will be left in the  
29 goaf, and therefore you would have the fuel or the sources  
30 for spon com.

31  
32 I think most of the mines, when they're doing the goaf  
33 inertisation, it's not only just the coal they're mining  
34 but also, as you say, some of the roof coals are left,  
35 maybe some of the carboniferous materials are close to the  
36 roof that need to be left behind simply because they're not  
37 good quality, or maybe a very adjacent thin seam that is  
38 liable to spon com - these are the situations that you  
39 would I think consider the use of active goaf inertisation.

40  
41 Q. Would you see it, in that scenario, as being something  
42 which is applicable to be done as a matter of course or  
43 only in response to a particular developing issue of  
44 spontaneous combustion?

45 A. I would say the first option, I think. It's action or  
46 response that, if you have your mine in that sort of  
47 situation, then you should actively consider active goaf

1 inertisation.

2

3 Q. Could we just come back to the 2005 report, and  
4 perhaps you might explain something of the methodology  
5 involved there. There were, for example, field studies  
6 involving two mines. Can you give us some idea of the  
7 scope of those?

8

9 THE CHAIRPERSON: Sorry, Mr Rice, just before the  
10 professor goes on, I think this topic started with his  
11 saying that there were two key issues that came out of it,  
12 and I thought that he dealt with number one. I was just  
13 curious about what was number two. That was all.

14

15 MR RICE: Q. Would you mind commenting on that, Dr Ren?

16 A. Yes, I think the second outcome from that project is  
17 very much relevant to the last question. Basically from  
18 that project, the second aspect is we produced a set of  
19 recommended guidelines for active inertisation, and that  
20 included, like, the location, the injection rate and how  
21 you operate this process. This actually involves a lot of  
22 details, for example, when and where you should inject the  
23 nitrogen and at what sort of a rate and what are the  
24 controls or systems you should have in place to support  
25 that process.

26

27 Q. Let's develop that, then. You mentioned a set of  
28 recommended guidelines. Do you want to take them one by  
29 one?

30 A. Yes. I think the first thing is the recommendation  
31 would be an onsite nitrogen generation unit should be  
32 available. If you are mining a seam that is highly liable  
33 to spon com, you need to have really good knowledge of your  
34 goaf gas flow dynamics, including, for example, what's the  
35 gas conditions: you've got compactions, your ventilation,  
36 gas composition and also the likely critical oxygen zones  
37 in your goaf. We recommended at that time that the inert  
38 gas flow should be a minimum of 0.5 cubic metres per second  
39 or 500 litres per second, but I think the recent field  
40 experience and study indicated that this may be not  
41 sufficient, in particular for some longwall panels  
42 exceeding 350 metres wide and you're running 2000 metres  
43 long. That sort of inert gas rate may need to be increased  
44 to a minimum, say, 1.5 metres per second, but dependent on  
45 the field conditions.

46

47 Q. Does that equate to 1500 litres per second?

1 A. That's right, 1500 litres per second, and that's  
2 probably a minimum for some of the high-production longwall  
3 faces. It depends. I mean, we did some studies recently,  
4 and it was indicated that that should be the minimum flow  
5 rate that the site should provide.  
6

7 Q. That creates a requirement for a certain  
8 infrastructure by way of a means of producing and applying  
9 nitrogen at that rate. Is there infrastructure available  
10 to achieve that desired flow?

11 A. I think currently most onsite nitrogen generators will  
12 be able to provide 5000 litres per second flow rate, but  
13 there are mine sites that do have prepared - they can  
14 double that, and I believe that the infrastructure could be  
15 upgraded to provide that sort of flow rate. It's a matter  
16 of costing, obviously, but I think that is achievable.  
17

18 The other recommendations, I think as we go - I can go  
19 through, for example, where we should inject the inert gas,  
20 and we're suggesting a deep injection is better than a  
21 shallow one. The shallow injection, say, within 50 metres  
22 behind the face, you will not achieve the inertisation  
23 effect. You had better do it, say, at least 250 to  
24 400 metres behind the face.  
25

26 Q. Was that a conclusion that came out of this report,  
27 that inertisation near to the face was not effective?

28 A. Absolutely, absolutely. And also that has been  
29 supported as well by some of the field data.  
30

31 Q. Why is that so?

32 A. If you see the field data and some of the numerical  
33 modelling that we did in the past, basically if you inject  
34 the nitrogen too close to the face, basically it's diluted  
35 with the high ingress of your ventilation leakage, so  
36 therefore it's not going to get into the places where it  
37 should be, in other words, the critical zones, and most of  
38 the injected nitrogen will just go with the leakage of  
39 airflow and report to the tailgate.  
40

41 Q. You mentioned, I think, the more desirable point of  
42 injection was some 200 metres behind the face. How was  
43 that conclusion arrived at?

44 A. That conclusion is based on several things. One is  
45 some of the field data and secondly we did lots and lots of  
46 extensive numerical modelling using computational fluid  
47 dynamics, and also that suggestion is also based on some of



1 the site validations and most recent applications, for  
2 example, in some of the mines in Australia.

3

4 Q. I might just put up a diagram from that report and you  
5 might be able to speak to it. It's relevant to what you've  
6 just been speaking about. Mr Operator, could we have  
7 document BOI.036.001.0001 and at page .0011. Can you see  
8 that page, Dr Ren?

9 A. Yes, I can.

10

11 Q. You would be well familiar with it, I'm sure?

12 A. Yes, yes.

13

14 Q. Perhaps, Mr Operator, if it's possible to enlarge the  
15 diagram that appears on that page?

16 A. Better.

17

18 Q. In figure (c), we see, do we, the results of gas  
19 injection 200 metres behind the face?

20 A. Yes.

21

22 Q. And from the looks of the colouration, the great  
23 majority of the goaf appears to involve oxygen at least  
24 well under 5 per cent?

25 A. Yes.

26

27 Q. Towards the right of the diagram, we see the  
28 colouration reflects the presence of oxygen?

29 A. Yes.

30

31 Q. And I suppose the yellow line, if I can call it that,  
32 represents a demarcation of about 12 per cent?

33 A. Yes.

34

35 Q. Tell me, does this activity of inertisation to achieve  
36 that kind of result affect the extent of the goaf fringe,  
37 which at some point in its zone will contain an explosive  
38 mixture?

39 A. Well, if you see from the top of this model, the top  
40 picture basically shows a typical Australian longwall,  
41 you've got a maingate and a tailgate, and the modelling  
42 shows the oxygen ingress patterns, which indicate the red,  
43 the light red, the orangey colour, and then develop into  
44 the deeper goaf, which is the blue colour, and that shows  
45 where the goaf gas is sitting. In this case, it's methane.  
46 Obviously on the top of that picture, close to the  
47 tailgate, you will see, as we expected, the goaf gas is

1 going to report and converge to the tailgate.  
2

3 The purpose for this study is basically trying to  
4 understand that if we do inject inert gas behind your  
5 longwall face, at different locations, the best  
6 inertisation effect you could achieve.  
7

8 The second diagram actually shows that if you inject  
9 the inert gas at something like 30 metres behind the face,  
10 which was quite common practice in the past, and you see  
11 that it's not working as it should be, and much of the  
12 injected gas or the inert gas will be either diluted with  
13 the leakage and then it drifts to the tailgate, or some of  
14 the things have actually been pushed and mixed and diffused  
15 with the ventilation leakage into the goaf, and it's not  
16 doing the expected job, which is to inertise the goaf area.  
17

18 But obviously if you compare (a) and (b), there are  
19 slight changes of the tailgate colours in terms of the  
20 oxygen level and perhaps also the gas concentration, but  
21 not that significant.  
22

23 The bottom one basically shows that if you do the  
24 inertisation - everything we assume is the same; there's no  
25 change of other ventilation or other parameters - and if  
26 you do a deep injection, in this case 200 metres, of the  
27 same inert gas, you have much better effectiveness of goaf  
28 inertisation.  
29

30 But if you look on the tailgate corner side, there are  
31 some changes of the gas levels, but I wouldn't say there's  
32 a significant impact, really, on the tailgate gas  
33 emissions, because most of the inert gas that we injected  
34 at the deep holes will be staying further in the goaf areas  
35 and to replace the oxygen that would otherwise penetrate.  
36 So in that regard, I don't think the strategy here would  
37 impact that much on the tailgate, in particular the  
38 tailgate corner, on the gas accumulation, but it depends,  
39 you know, what sort of gas emissions that you have in the  
40 goaf and other parameters as well.  
41

42 Q. Is it possible to estimate the size, in diagram (c),  
43 of the oxygen zone, if I can call it that, which is below  
44 12 per cent, in terms of distance?

45 A. Yes, from the modelling, yes, you can. Actually,  
46 these three diagrams illustrate some very important  
47 concepts. From the top one, from the red into the blue,

1 there is a band of orange colour, and that is the area that  
2 we call the critical zone, and that's where the spon com is  
3 likely to occur and the coal oxidation is likely to occur.  
4

5 So the purpose, actually, is trying to narrow down  
6 this area, and therefore you minimise the oxidation  
7 process. By doing so, if you see figure (c), actually,  
8 that band, that orange sort of colour, light red, has been  
9 significantly narrowed. That also means that if you have  
10 coal left in the goaf, either from the roof or from the  
11 floor, then you have a very limited time to be exposed to  
12 sufficient oxygen for oxidation or potentially spontaneous  
13 combustion, and that's the whole purpose of an optimised  
14 goaf inertisation strategy.  
15

16 Q. Diagram (c) reflects the modelled result of injection  
17 at 200 metres behind the face. Can I ask you first of all,  
18 are we speaking about injection on the maingate side or the  
19 tailgate side or both?

20 A. The model here is modelling a situation of injecting  
21 from the maingate side.  
22

23 Q. And why is that?

24 A. This is because from the first diagram here, (a), we  
25 understand - if you see, and we can from the modelling and  
26 also from the field data - we know the majority of the  
27 oxygen ingress takes place on the maingate side, and also  
28 the critical oxidation zones are mostly aligned next to the  
29 maingate rib side. That's why we're doing this from the  
30 maingate side.  
31

32 But if, for example, the longwall orientation has  
33 changed and you have different goaf gas regimes, for  
34 example, that oxygen penetration pattern may change, and  
35 you could have, perhaps, on the tailgate side, a deep  
36 oxygen ingress pattern, and in that regard you might have  
37 to, say, do injection on the tailgate side or on both  
38 sides.  
39

40 Q. The next question, perhaps, is the method of delivery  
41 of the gas to the goaf. What is the point of delivery and  
42 the method of delivery?

43 A. I'm not an infrastructure engineer, but my  
44 observations normally are you have an oxygen-generating  
45 system on the surface, you have compressors, you have  
46 pipelines, and typically the main pipeline will be 6 inches  
47 and then you could pipe it all the way to the back or the

1 starting-off line by either a borehole or a drop hole  
2 somewhere and all the way to the gateroad, and then you can  
3 couple it with - my observation is I think it's 4 inch  
4 pipes, and these can be distributed to different  
5 cut-throughs. Obviously you're going to seal that, each of  
6 the cut-throughs, seals that would have pipes pre-installed  
7 for the purpose of inertisation.

8

9 Q. Pre-installation of pipes, I think you're referring  
10 to, on the maingate side?

11 A. I think for most of the mines, if they mine a pit that  
12 is spon com liable, when they're doing the goaf seals, they  
13 would pre-lay a pipe for goaf inertisation.

14

15 Q. With the gas to be delivered from the surface via  
16 a generator at that location?

17 A. That's true, yes. Most of the oxygen will be  
18 delivered from a nitrogen-generation plant located on the  
19 surface.

20

21 Q. You're telling us, I infer, that that kind of  
22 infrastructure is available to be applied in that way?

23 A. To my knowledge, yes. Most mines, if they're  
24 operating a pit that is mining coal that is liable to  
25 spon com, they would have such facilities on the surface.

26

27 Q. Is it correct to say that to some degree at least,  
28 mines that operate in the fashion I described earlier,  
29 where reasonably significant amounts of coal are left in  
30 the roof and the floor and then form part of the goaf - are  
31 they the kinds of mines that carry a spontaneous combustion  
32 hazard to be managed?

33 A. I would believe so, but it very much depends on the  
34 coal they're mining and the coal left behind, and if the  
35 coal left behind has a very high propensity to spon com,  
36 then that will be the case.

37

38 Q. In your answers to date I think you've spoken about  
39 the use of nitrogen for this purpose. Are there other  
40 options?

41 A. In Australia, basically the most popular one obviously  
42 is using nitrogen. We do in some mines use the Tomlinson  
43 boiler, and that delivers 80 per cent of nitrogen and  
44 perhaps 12 per cent of CO<sub>2</sub>. You could also use CO<sub>2</sub>, for  
45 example, but in Australia, in most cases, most of the mine  
46 sites would prefer to use nitrogen because the system is  
47 simple, it offers a continuity of inert gas supply, and

1 there's lots of operational experience there already.

2  
3 Q. What about the fluid properties of nitrogen compared  
4 with other options, like perhaps carbon dioxide?

5 A. Well, if you say nitrogen, which is almost the same,  
6 you know, density because the majority is nitrogen, that  
7 means the flowability of nitrogen is almost the same as  
8 air. So that means that in a goaf space, nitrogen can flow  
9 to any places that it can.

10  
11 But in comparison with CO<sub>2</sub>, carbon dioxide, because  
12 CO<sub>2</sub> is a heavy gas, it tends to stay on the floor, and so  
13 the flow - in some of the cases, the CO<sub>2</sub> will not be able  
14 to cover some of the areas, for example, that you want to  
15 cover. In particular, for example, if you have roof coal  
16 left or a band of carboniferous material or thick goaf left  
17 in the goaf, and if you inject CO<sub>2</sub> from a higher elevation,  
18 it's probably very difficult for CO<sub>2</sub> to cover these areas,  
19 and therefore you could have a spon com risk.

20  
21 Q. As I read it, one of the points of emphasis from the  
22 2005 report was that the success or failure of inertisation  
23 operations depends on mine-specific design. Did I read  
24 that correctly?

25 A. That's right.

26  
27 Q. Is that because there's a range of variables  
28 associated with all mines, really, including ventilation  
29 layout, airflow intake, degree of gas flow emissions, and  
30 probably several other factors as well?

31 A. Yes. I think if we assume that a mine site has the  
32 inertisation system available - there are many factors,  
33 actually, affecting the design of the inertisation  
34 strategy. The first one obviously is ventilation. Are you  
35 using two gateroads or three gateroads? Is there a bleeder  
36 system or perimeter road? The location of the shaft - is  
37 it forcing ventilation or exhausting? All these impact on  
38 the goaf, the oxygen ingress into the goaf. And also the  
39 mining method - your cutting head, for example, you  
40 mentioned, you could be leaving coals, roof coals or floor  
41 coals.

42  
43 The other factor is the gas composition. In this  
44 case, the diagram that we illustrated is methane. But if  
45 you're mining a seam that is CO<sub>2</sub> dominant, the distribution  
46 pattern of the goaf gas may be different and may change,  
47 because CO<sub>2</sub> is heavy and will tend to go to the lower

1 location, and therefore at higher locations you would have  
2 more oxygen ingress. Obviously with other systems that  
3 you're running, gas drainage systems, in particular goaf  
4 drainage, you have different goaf hole locations, operating  
5 parameters - all these things will impact on the design of  
6 an effective inertisation system.

7  
8 Q. It raises a question, perhaps, if there are quite  
9 a range of variables which are involved in the development  
10 of a strategy for an effective program of inertisation, who  
11 then would undertake the necessary analysis to devise the  
12 optimum strategy?

13 A. I think the optimum strategy would have to be specific  
14 and it has to be an integrated effort, I would say - people  
15 working on site, the ventilation officers, mining  
16 engineers, because they know the pit better. But also  
17 I think there are some really qualified people that could  
18 provide some advice in terms of the design of the system  
19 and how to better understand the goaf flow dynamics, what  
20 are the key factors that will be impacting on a particular  
21 pit. I would say it will be teamwork, but it mainly depend  
22 on who is operating the site.

23  
24 Q. It may be difficult to generalise, but I was wondering  
25 if the necessary expertise is likely to exist on site or  
26 whether outside assistance is likely to be called for to  
27 advance a desirable strategy?

28 A. I think goaf inertisation practice has been used in  
29 Australia for quite many years, and there is plenty of  
30 knowledge and experience on site. Certainly to my  
31 understanding there's quite many people in the industry  
32 that have quite a lot of knowledge in terms of goaf  
33 inertisation, what sort of system is working or not.

34  
35 But I think it is always useful to have a third  
36 person, for example, seek some additional advice from some  
37 specialists in this area. That would help them provide  
38 a design for sufficient, effective inertisation design or  
39 system.

40  
41 Q. This report was published in 2005, and I think since  
42 then you and Dr Balusu have also published a conference  
43 paper in 2009 on a similar subject, or at least derived  
44 from the ACARP project?

45 A. Yes.

46  
47 Q. Could you perhaps bring us up to date, then, since the

1 2005 project, since your conference presentation in 2009,  
2 as to the take-up of proactive inertisation in the  
3 industry?

4 A. I think since the last project we mentioned and this  
5 hearing, quite many of the outcomes from that project have  
6 been adopted or at least considered to a certain extent by  
7 people on site when they are designing their inertisation  
8 system. Obviously it has been quite some years and there  
9 are changes in the mining conditions. For example,  
10 I believe in Queensland there's lots of high-production  
11 mines, they are operating not only a spon com pit but also  
12 high gas emissions.

13  
14 So in facing the challenge of spon com, you deal with  
15 spon com on one hand, and on the other hand you have to  
16 deal with very high gas emissions. So there are studies,  
17 field trials still going on, for example, at the University  
18 of Wollongong we continue to do some modelling studies  
19 trying to better understand other parameters in the  
20 equation, for example, high gas emissions or larger  
21 longwalls, what sort of inertisation strategies you could  
22 perhaps adopt on the basis of previous studies and things  
23 like that.

24  
25 We also look at the impact of goaf gas compositions -  
26 for example, there are pits that are operating in CO<sub>2</sub>  
27 dominant goaf gas, but the seam is also liable to spon com,  
28 and what we're going to do in that sort of situation. We  
29 are also adopting other techniques, for example, tracer gas  
30 studies, to help this process.

31  
32 The work is still going. Obviously there are still  
33 unknowns. There's still a need for the advance of science  
34 and knowledge, and that will be needed for designing a more  
35 effective inertisation strategy, in particular for the  
36 current high-production longwall panels.

37  
38 Q. Tell me, to your knowledge, are there any mines that  
39 adopt continuous inertisation of their longwalls as  
40 a routine practice?

41 A. Yes.

42  
43 Q. Or is it more still in response to specific developing  
44 issues?

45 A. To my knowledge, there are mines that are using this  
46 goaf inertisation as an ongoing and continued control  
47 process. So it's not just on and off. It is a continuous

1 injection of inert gas into goaf areas.

2

3 Q. You've probably touched on this already, but I was  
4 going to ask you if you wouldn't mind perhaps commenting on  
5 the advantages of doing that?

6 A. The obvious advantage is prevention. I think we have  
7 a saying, "prevention is better than cure". By taking that  
8 strategy, in particular working with a spon com management  
9 plan, you have the opportunity to suppress or contain  
10 a potential heating risk. I think that's the practical  
11 purpose, because people onsite know that if you don't do  
12 that, there's high likelihood, you know, certain levels of  
13 coal oxidation or spon com could occur, and by taking that  
14 preventive strategy you could avoid a potential disastrous  
15 situation.

16

17 Q. Tell me, you've described a method of delivery of gas  
18 to the goaf, is there any interruption involved to  
19 production in the kind of method of delivery that you  
20 describe? In other words, does this process impact on  
21 production or not?

22 A. I'm not aware of any sort of significant interruption  
23 to the production process, because the delivery of  
24 inertisation is very much independent of your production  
25 system. You know, the gas is generated on the surface and  
26 in most cases the gas is delivered with pipelines and drop  
27 holes or boreholes from behind the longwall, and then it is  
28 piped to the goaf seals. So I would say practically it's  
29 very much independent of your production system, but there  
30 will be some link. You know, there will be certain  
31 interactions in certain areas, but I wouldn't say there  
32 would be significant interruption by doing so.

33

34 Q. Moving forward to the 2010 project, it apparently had  
35 the object of looking into the feasibility of foam  
36 applications in underground mines to improve the  
37 effectiveness of proactive inertisation. Do I understand  
38 that correctly?

39 A. Yes.

40

41 Q. Was that to do with assisting with control of  
42 particular issues, such as fires or heatings, or was its  
43 application to be considered more widely as part of the  
44 proactive inertisation strategy?

45 A. I think the purpose of that project is basically to  
46 develop a foaming technology that would facilitate the goaf  
47 inertisation process, in other words, it's to enhance the



1 effect of inertisation rather than --

2

3 Q. How?

4 A. The purpose for that project is basically developing  
5 a foam technology that can be pumped at some distance, you  
6 know, through the seals, and to place a foam plug that will  
7 essentially increase the resistance of air leakage close to  
8 the tailgate side, and therefore you minimise the oxygen  
9 ingress and also perhaps the air leakage momentum.  
10 Therefore, if you do inertisation inbye the foam injection  
11 site, the inert gas will stay there for longer and  
12 therefore replace or minimise the oxygen ingress.

13

14 I don't think that the technology developed at that  
15 time is for the purpose of suppressing the heating or for  
16 other purpose. That's not the case.

17

18 Q. Was its potential utility, then, as you described, to  
19 assist by way of forming a plug at different points; was  
20 that the main objective?

21 A. That's correct, and we did a trial on site, and it  
22 demonstrated that it is possible to offer some kind of  
23 increased resistance to air leakage, but the problem is the  
24 stability of foams. In that particular site, I believe the  
25 air leakage from the maingate into the goaf is pretty  
26 strong, and the foam only lasted a few hours before  
27 basically the bubbles of the foam disappeared.

28

29 Q. What would be the strategic location of the kind of  
30 foam plug that you've spoken about? Where would it be  
31 deployed?

32 A. In that trial, the foams were injected from the first  
33 and second cut-through behind the longwall, and in that  
34 case we observed that because of the velocity of the  
35 leakage, it is having a significant impact on the stability  
36 of the foam. I think the lesson from that trial or that  
37 study is the location - if you do use foam in the future,  
38 the location is also very important. As I just mentioned,  
39 if you do gas inertisation, you would do deep injection  
40 rather than shallow, and I would suggest that the foam plug  
41 would be the one maybe just next outbye to the injection  
42 point of your inertisation, but not too close to the face,  
43 because the foam will just not stay there.

44

45 Q. You mentioned a question mark about the stability of  
46 the foam. Is the technology sufficiently advanced for it  
47 to be able to be used in the way that you just described in

1 your last answer?

2 A. I'm not aware of that. I do believe that there are  
3 some researches still going, I think it's driven by a  
4 company, but I do not have knowledge of its latest  
5 development.

6  
7 Q. Could you tell us whether you have any knowledge,  
8 since this project was done in 2010, of the use of foams by  
9 mines as an adjunct to a gas inertisation program?

10 A. If we're talking about foams, it might be in  
11 a different sort of forum, put it that way. To my  
12 knowledge, there are mines that are using a foam plug, so  
13 basically it will be fly ash, nitrogen or water, and they  
14 can pump it in from a surface borehole to a particular  
15 location, therefore not only you produce some sort of plug  
16 but also the extent and the stability of the plug will be  
17 extended to a level that the conventional foams would not  
18 reach - I mean, the height, the shape of the plug.

19  
20 I think, to my knowledge, there is an ongoing ACARP  
21 project supporting the further development of this  
22 technology, but I haven't seen the final report yet of this  
23 project. I believe it's still going.

24  
25 Q. Can we turn to the overseas experience of proactive  
26 inertisation of active goafs. Can you give us some  
27 perspective on the nature and extent of its use overseas?

28 A. I think goaf inertisation using nitrogen has been  
29 reported, I would say, in the early 1950s. I think the  
30 first one using pure nitrogen would be in the Czech  
31 Republic.

32  
33 I think since then, nitrogen has been used routinely  
34 for firefighting, to my knowledge. In the UK, for example,  
35 in some of the pits - I've been there many times. In the  
36 Domain colliery, for example, they have been using nitrogen  
37 for the prevention of spon com. And in other countries  
38 when they have this mine industry, like in Germany,  
39 certainly other countries, like Poland and Czech Republic,  
40 they have been using this technique for quite many years,  
41 and even today, and they are still using this. Countries  
42 like the US, South Africa, definitely in China, they are  
43 still using goaf inertisation based on either nitrogen or  
44 other means or materials.

45  
46 Q. I was just looking to get some perspective, bearing in  
47 mind the delineation, perhaps, between its continuous use

1 across a longwall as opposed to its strategic use to deal  
2 with heating incidents and fire incidents. Bearing that  
3 delineation in mind, would you like to comment further?

4 A. Yes, most early actions will be responsive.  
5 Basically, "Okay, we have a heating incidence", you know,  
6 "This is happening, we've got to do something", and that's  
7 how this nitrogen is deployed.

8  
9 But more recently, to my knowledge, the inertisation  
10 has been used by several countries, including the Czech  
11 Republic and Poland, and they do use it as an ongoing and  
12 continuous inertisation strategy to control spon com and  
13 heating in their longwalls.

14  
15 Q. I suppose we should be careful to draw comparisons  
16 with mining conditions in other places, but are there  
17 conditions in those other countries that make its  
18 continuous use more advantageous than in Australia; in  
19 other words, is a comparison apt?

20 A. I wouldn't say that. You know, mining conditions in  
21 other countries are different. For example, in Poland or  
22 the Czech Republic they are mining in greater depths,  
23 overburdens and gassy, lot more complicated geological  
24 conditions, and their ventilation system or longwall system  
25 is perhaps quite different from others. That can impact on  
26 the use, for example, of the inertisation system.

27  
28 So there is experience and knowledge that we could  
29 perhaps learn from other countries, but Australia is very  
30 different in terms of the mining system that we're using,  
31 in particular ventilation systems that we're using, in  
32 comparison with other countries.

33  
34 Q. You've set out in your report a range of methods that  
35 you're aware have been deployed overseas, including a mud  
36 slurry, foams of various kinds. Is it the case that  
37 nitrogen is still the option of general choice?

38 A. Yes. These means, as I mentioned, the slurries or  
39 gels, and sometimes they use these things in combination.  
40 I know these things are being used and applied in quite  
41 many mines in China. They use so-called three-phase foams.  
42 Basically they have fly ash, they have foam, they have  
43 nitrogen. They also combine with, like, other slurries and  
44 fly ash, even sometimes, like, clay, and in combination  
45 with inert gas.

46  
47 The purpose for that is by using other means, in

1 particular like the slurries or fly ash, they will be able  
2 to seal or minimise the oxygen risk - oxygen ingress to  
3 a particular heating site, and therefore by injecting inert  
4 gas, they would have a better impact on the potential  
5 heating.  
6

7 Q. In your report, you've noted various of the  
8 spontaneous combustion indicators that are used by way of  
9 monitoring that particular hazard, and you've made mention  
10 that at least a couple of those would be affected by use of  
11 nitrogen for inertisation purposes, in particular I think  
12 Graham's ratio and Trickett's ratio?

13 A. Yes.  
14

15 Q. Can I ask you about the effect of inertisation on  
16 those spontaneous combustion indicators. It has been said  
17 here that all of the various indicators that you've listed  
18 have some flaw or other and that they all have different  
19 flaws. Do you agree with that?

20 A. I would say so, yes.  
21

22 Q. Arising from that, there is a proposition that given  
23 the flawed nature of the various indicators, more is  
24 better, as it were, and that it would be desirable, in the  
25 interests of spontaneous combustion monitoring, to retain  
26 the full suite of indicators rather than reduce their  
27 number as a consequence of this inertisation. Do you have  
28 a comment about that?

29 A. That is correct. I think throughout these hearings  
30 I believe the experts from Simtars have already provided  
31 much information on the different gas indicators and things  
32 like that. I don't think that I can add a lot more  
33 evidence in this regard, but what I can say is there are  
34 a number of well-documented, let's say, spon com ratios or  
35 indicators or whatever you call them, that we can use for  
36 monitoring and assessing the progress of heating.  
37

38 The standard indicators for spon com, like CO,  
39 hydrogen or ethylene or different trigger levels at  
40 different mines, they should be still applicable. So  
41 obviously when you do the goaf inertisation, you will  
42 disturb the process, the nature of the forming of the goaf  
43 atmosphere. You introduce contaminations to some of the  
44 parameters that you mentioned, the GR and also the  
45 Trickett's ratio, because both GR and the Trickett's ratio  
46 need to calculate the oxygen deficiency, to detect oxygen  
47 in the oxidation, and this is actually the measure of

1 oxygen consumption.

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These ratios are based on two assumptions. The first one is that the supply of air has no contamination. That means the air supply should be 21 per cent of oxygen, 79 per cent of nitrogen. The second assumption is that no nitrogen has been consumed or added to the process.

So the drawback for these ratios is that accuracy will be doubtful if the oxygen that has been consumed is very small or the oxygen deficiency is less than 0.2 per cent. This is actually very common for any gas indicators that - if you need to use the oxygen deficiency.

Having said that, the GR is still the most widely used indicators for detecting heating events. In my opinion, these drawbacks can be overcome, for example, by establishing a normal range for a particular mine, and that will be the case, and according to the textbook, if normal is less than 0.5 per cent, then if there's any per cent deviations from this normal range, that could be an indicator of heating.

The other point that I want to make here is that it is critical that you have a comprehensive picture of your goaf environment, and this can only be achieved by taking samples, ideally continuous sampling, from multiple points. And if you're injecting inert gas from a particular cut-through, I wouldn't suggest you take a sample from that cut-through, because obviously the injected nitrogen could give you a false reading. But gas readings from your adjacent cut-throughs, say, 100 metres away or 50 metres away, should still give you a good indication of what's happening.

As I said and perhaps also as an expert already provided, the most important part is not to look at a particular value at a particular point; it's the trending. It's the trending of different gas ratios, different indicators that will give you the best estimate of what is happening.

Q. Just on the impact that the inertisation would have on the use of Graham's ratio and Trickett's ratio, the disturbance of those indicators by use of proactive inertisation - does that factor, in your view, outweigh the benefits of proactive inertisation?

1 A. I wouldn't say so. I mean, as I said, that GR is  
2 still a very powerful tool we can use. Obviously you  
3 wouldn't take a sample for the GR calculation or the other  
4 ratios that you will take the sample calculation from the  
5 point of the inertisation, but the adjacent sampling  
6 locations will give you perhaps a better indication of  
7 what's happening.

8  
9 Q. You touched on the prospect of getting a false reading  
10 by doing gas monitoring at a point adjacent to the point of  
11 injection. One proposition is that the use of nitrogen  
12 injection for inertisation purposes might actually serve to  
13 mask a spontaneous combustion event. For example, if there  
14 was an injection of nitrogen at one particular point and  
15 there was nearby gas monitoring, it might give a false  
16 picture of the overall position across the goaf. Is there  
17 a method of dealing with that?

18 A. I wouldn't think so, but there's a potential error  
19 there, but this can be overcome, as I say, that you should  
20 be taking samples from various locations, I would suggest,  
21 you know, five or six sampling points behind the longwall,  
22 next to the injection point - some distance from the  
23 injection point, and that will give you a better picture of  
24 what's happening rather than just depending on a reading  
25 from an injection location.

26  
27 But also, in addition to the GR ratios, the other gas  
28 indicators as I mentioned in the report, like CO, hydrogen,  
29 ethylene, all these things, all these gases, will still  
30 remain good if this event is happening. So the  
31 interpretation of the goaf readings must take into  
32 consideration not only the GR but also other gas ratios.

33  
34 Q. Is it a matter of strategic location of the gas  
35 monitoring points?

36 A. Yes, that is very important.

37  
38 Q. Another proposition has been put that a robust  
39 spontaneous combustion management system doesn't need  
40 proactive inertisation. Do you have any comment about  
41 that?

42 A. I would say a robust spon com management plan should  
43 include an active goaf inertisation system in place,  
44 because if you run a pit that is liable to spon com, you do  
45 all the monitoring, you do all the controls, you try to  
46 minimise the risk, but there's always the chance that you  
47 could be going through particular locations, you know,

1 slowing down your advance or retreat, you have roof  
2 failures and things like that, and that could cause  
3 potential risk, and that is the time that the active goaf  
4 inertisation should kick in, you know, to contain any  
5 potential heating events.  
6

7 So I would say a robust spon com management plan  
8 should consider the use of, or at least perhaps an integral  
9 part of that system should include a proactive inertisation  
10 system. That's my view.  
11

12 Q. There's one other topic I wanted to just broach with  
13 you. It concerns the interaction between inertisation and  
14 goaf drainage. I'm talking about post-drainage. What are  
15 the implications for the conduct of a post-drainage program  
16 of the use of proactive inertisation?

17 A. Are you talking about the gas inertisation of goaf  
18 drainage?  
19

20 Q. Well, how would they interact with each other? Would  
21 there be an adverse or positive impact on the effectiveness  
22 of goaf drainage through the use of such a program?

23 A. I think the key issue lies in the compromise between  
24 the goaf drainage and the goaf inertisation. As  
25 I mentioned, the primary objective of goaf inertisation is  
26 to reduce oxygen ingress into the goaf by filling up  
27 whatever spaces or voids that would otherwise be occupied  
28 by oxygen or goaf gas, such as methane.  
29

30 Goaf drainage I believe aims to capture seamgas or  
31 methane as much as is needed to reduce the gas emissions  
32 reporting to your longwall and to the tailgate, but must  
33 avoid sucking excessive air or oxygen into the goaf area  
34 and perhaps also the drainage pipelines, or consequently  
35 you run the risk of a spon com, of forming an explosive  
36 atmosphere.  
37

38 Those issues can be addressed by better understanding  
39 the goaf gas flow dynamics and the knowledge of the goaf  
40 gas distribution patterns - what sort of goaf gas you're  
41 mining, is it methane or CO<sub>2</sub>, where is the gas coming from,  
42 what sort of rate; and by, as I mentioned, optimum design  
43 of the goaf hole locations and structures, so where the  
44 goaf holes are located; your elevations; you have  
45 a perforated section, how long would that be; and also how  
46 you operate the goaf holes in such a way that you could  
47 find a balance between the goaf inertisation and gas

1 drainage.

2

3

4 But, having said that, in particular for very gassy  
5 mines, in some way the goaf inertisation could assist the  
6 methane drainage process or goaf drainage process by  
7 chasing out the oxygen and feeding perhaps part of the  
8 inert gas that you injected in to the drainage system, and  
9 so therefore it's a win:win situation - you contain the  
10 spon com and in the meantime you improve the capture  
11 efficiency. I believe that the research is still going,  
12 supported by ACARP. I'm looking forward to the outcome  
13 from this project as well.

13

14 Q. You may be aware that Dr Balusu has advanced a theory,  
15 subject to some further research, that the displacement of  
16 oxygen through the inertisation process might actually  
17 assist post-drainage. Is that the kind of concept that  
18 you've just been referring to?

19

20 A. That's correct, and I'm aware of Dr Rao Balusu's  
21 research and I do believe that, as I demonstrated,  
22 actually, in the slides, I think the first two slides  
23 showed the longwall goaf gas accumulation patterns, so  
24 basically we have - when you're injecting the inert gas, it  
25 will take over the space, whatever is going to be occupied  
26 either by oxygen or methane. So in that way, if we could  
27 increase the inert gas flow, it will be able to take much  
28 space that would otherwise be occupied by oxygen and also  
29 in a way that it would help maximising the goaf gas capture  
30 of goaf gas from the system.

30

31 Q. In your last answer, you referred to some slides.  
32 I think you may have been referring to the first couple of  
33 figures depicted in your 2005 report; am I right about  
34 that?

35

36 A. That's right, yes. That's the diagram, yes.

36

37 MR RICE: We haven't gone to those, because your  
38 explanations have perhaps been sufficient, but we can all  
39 go to that report and look at them if we need to. Those  
40 are my questions, Mr Martin.

41

42

43 THE CHAIRPERSON: Thank you. Mr Holt?

43

44

44 <EXAMINATION BY MR HOLT:

45

46

46 MR HOLT: Q. Dr Ren, can you hear and see me okay?

47

47 A. Yes, I can hear you, yes. I can see you as well.



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Q. My name is Saul Holt. I'm one of the barristers for the Anglo group of companies, just so you know where my questions are coming from.

A. Yes.

Q. Thank you. I'd just like to go back to the 2005 ACARP report which you took us through earlier. You explained that that report involved numerical modelling and the outputs of numerical modelling?

A. Yes.

Q. In addition, and importantly, it also included calibrating that numerical modelling to field data from a number of coal mines?

A. Yes.

Q. And obviously enough being able to calibrate model results to actual field data is critically important for any model?

A. Absolutely.

Q. If we could pull up, please, Mr Operator - and I hope this works, Dr Ren, for you to see it also - the ACARP report, which is BOI.036.001.0001, and might we go, please, to .0017, Mr Operator. If we can just call out the third paragraph down, that commences "The authors ", we can see there an acknowledgment to the management and staff of collieries of Anglo Coal Australia and Xstrata?

A. Yes.

Q. And it was from those sources that much of the field data and the work that could be done in field studies was obtained?

A. Yes.

Q. Thank you. Could we come out of then, please, Mr Operator, and call up the paragraph just prior to that. As well as that access to field data, people from Anglo Coal Australia were also acknowledged for their valuable contributions, support and interest in proactive inertisation research?

A. That is true.

Q. You would be aware also, I imagine, and I'll come to it in a moment, of the ongoing collaborative work between Dr Balusu from CSIRO and Anglo Australia also on this

1 particular issue and the research and development of it?

2 A. I am not aware of that.

3

4 Q. I'll come to something which might assist with that in  
5 a moment. You were being asked some questions by our  
6 learned friend Mr Rice about, in particular, where the  
7 expertise lies in relation to inertisation, and you noted  
8 that inertisation has been going on for a while, and so  
9 there will be quite a degree of site-specific expertise?

10 A. That's correct.

11

12 Q. I imagine you would also expect, particularly for  
13 a coal miner such as Anglo, that they would have  
14 centralised expertise also to assist the individual,  
15 separate coal mines with these kinds of issues?

16 A. Well, I'm not sure of that. I don't think I can  
17 comment on that, but I'm pretty sure there's quite some  
18 people, and I know in Anglo Coal they have quite good  
19 knowledge and experience in this regard.

20

21 Q. And Dr Bharath Belle you would be familiar with,  
22 I imagine, who has done quite a lot of work with Dr Balusu  
23 also?

24 A. I know Dr Bharath Belle.

25

26 Q. On that question that Mr Rice was asking you about  
27 toward the end about the relationship between goaf gas  
28 drainage and inertisation strategies, you referred to the  
29 fact that this is an ongoing, important developing field of  
30 knowledge?

31 A. I do believe so, yes, yes.

32

33 Q. And you are working in that field and Dr Balusu is  
34 also working in that field?

35 A. Well, I know that I am doing something, some research  
36 in this field, but I can't speak for Dr Rao Balusu --

37

38 Q. But I think a moment ago you indicated in an answer to  
39 Mr Rice's questions that you were aware of some of his  
40 research in this area?

41 A. That's right, yes. That's right.

42

43 Q. And particularly are you aware of a 2018 piece of  
44 collaborative work between Anglo American and CSIRO called  
45 "Development of goaf gas drainage and inertisation  
46 strategies in 1.0 kilometre and 3.0 kilometre long panels"?

47 A. I have seen a paper and a report, I believe - I think

1 it's a paper published by Dr Rao Balusu and his colleagues.

2

3 Q. And also including - and you might have to accept this  
4 from me - Dr Bharath Belle from Anglo also in  
5 a collaborative project between those two organisations?

6 A. Yes, that's correct.

7

8 Q. Thank you very much. In that sense, you were being  
9 asked some questions about overseas experience with  
10 continuous proactive inertisation. Are you aware that  
11 continuous proactive inertisation has been practised at the  
12 Grosvenor coal mine through its longwall development right  
13 through from 101?

14 A. Say it again, please? I missed that question.

15

16 Q. I'm sorry. Are you aware that continuous proactive  
17 inertisation has been practised at the Grosvenor coal mine  
18 right through from its first longwall panel?

19 A. No, I am not aware of that. I'm not in contact with  
20 any people in that mine.

21

22 Q. No, I understand. Thank you. In any event, moving  
23 out from the specific to the general, part of the  
24 development of thinking around continuous proactive  
25 inertisation is around the use, for example, of multi-point  
26 injection strategies; that's right, isn't it?

27 A. Yes, ideally, I think injection from multiple points,  
28 at least two, is better than a single point.

29

30 Q. Indeed, in fact a sophisticated inertisation strategy  
31 would see, effectively, a nitrogen - if that was your  
32 chosen gas - pipeline with multiple injection points that  
33 can be ramped up or ramped down as circumstances require?

34 A. That's correct.

35

36 Q. In addition, another way in which those who are at the  
37 forefront of thinking about goaf inertisation are operating  
38 is moving from direct injection into the goaf into what are  
39 called balance chambers; you would be familiar with some of  
40 that advancing technology and work?

41 A. I wouldn't say I'm familiar with that. I'm aware of  
42 the application of that balance chamber.

43

44 Q. Can we then, just on a final topic, please go back to  
45 .0005 of that same document, Mr Operator, and the abstract.  
46 Might we call up the first paragraph, please. Dr Ren, when  
47 I put documents up like this, are you seeing them okay?

1 I obviously can't see your screen.

2 A. Yes, okay, pretty clear. That's good. No problem.

3

4 Q. If you need them in any other format or size, please  
5 just ask.

6 A. Sure, no problem.

7

8 Q. What's noted there in the abstract from the second  
9 sentence is:

10

11 *Review of oxygen ingress patterns into*  
12 *longwall goaf at various mines has shown*  
13 *that in some cases the oxygen concentration*  
14 *in the goaf was well over 17% even at 300 m*  
15 *to 400 m behind the longwall face.*

16

17 A. Yes. That is correct. That is dependent on some of  
18 the sites. Obviously the review, the report, is based on  
19 some observations, some data from the longwall face, and  
20 the data tells us that even at 300, 400 metres behind the  
21 longwall, you could have a gas reading of oxygen that is  
22 greater than 17 per cent.

23

24 Q. And that was part of - not all of, but part of - the  
25 motivation for this increased research and development and  
26 deployment of goaf inertisation strategies in order to try  
27 to reduce those oxygen concentrations in the goaf for the  
28 purposes of managing spontaneous combustion and ignition  
29 risks?

30 A. Correct.

31

32 Q. I have the benefit of another paper that you've  
33 written. I just want to read something which I think  
34 should be pretty straightforward, but if it's an issue,  
35 please let me know. I'll just read what you've said:

36

37 *The specific objective of inert gas*  
38 *injection operations is to reduce the goaf*  
39 *oxygen levels below the safe limit of*  
40 *8 per cent (ie with a factor of safety of*  
41 *1.5 on the explosive nose limit of*  
42 *12 per cent) before methane concentration*  
43 *reaches the lower explosive limit of*  
44 *5 per cent.*

45

46 I'll break that down, but in essence what's being said is  
47 that the specific objective of inert gas injection is to

1 reduce goaf oxygen levels below 8 per cent, which gives  
2 a factor of safety of 1.5 on the explosive nose limit of  
3 12 per cent. Would you agree with that?

4 A. Yes, but that is for different purpose. The purpose  
5 of injection for this active longwall is to suppress the  
6 onset of spon com.

7  
8 Q. Yes.

9 A. That data that you mentioned reference to is referring  
10 to the seal-off operation.

11  
12 Q. Yes.

13 A. So when you finish off a longwall, you're going to  
14 seal that off, and that purpose for injecting inert gas is  
15 not for suppressing, say, the onset of spon com; rather  
16 than - it is the purpose to render an explosive atmosphere.  
17 That's why we say --

18  
19 Q. I understand that. Thank you. Can you explain what  
20 the explosive nose limit of 12 per cent is in relation to  
21 oxygen?

22 A. Well, I think in the public hearing in the past  
23 few days - and I've been watching this - so the nose point  
24 is basically you have this Coward's triangle, and that's  
25 the point of 12 per cent oxygen, and above that you have  
26 a sample, you could be drifting - say, a sample between 5  
27 to 14 or 15 per cent of methane, you could drift into the  
28 explosive atmosphere, and therefore you run the risk of an  
29 explosion.

30  
31 Q. That's why, albeit in a different context, and  
32 I understand that, you describe 8 per cent as giving a 1.5  
33 factor of safety --

34 A. A safety factor.

35  
36 Q. -- to that 12 per cent?

37 A. That's right.

38  
39 MR HOLT: I'm conscious of the time. I have only a few  
40 minutes.

41  
42 THE CHAIRPERSON: Carry on.

43  
44 MR HOLT: Thank you, Mr Martin.

45  
46 Q. Could we pull up that figure that we were looking at  
47 before of the three longwalls, which is B0I.036.002.0001 at

1 0004. That's the specific page, Mr Operator. Could we  
2 call out the colourful diagram. I just want to be clear  
3 about a couple of things you were talking about, Dr Ren, if  
4 I can. The top figure we can see there is the base model,  
5 and of course there will be variations in individual  
6 longwalls --

7 A. Yes

8

9 Q. -- but that's designed to represent the situation in  
10 the absence of inertisation?

11 A. Correct.

12

13 Q. What we can see there is that classical sort of  
14 air-wash zone shape down towards the maingate where there's  
15 more oxygen in the sort of semi circle shape as it comes  
16 around to the left?

17 A. Yes. On the maingate side, the oxygen.

18

19 Q. I understand. The point that you were making is that  
20 part of the strategy here of inertisation is to reduce that  
21 orangey zone effectively where you're in that problematic  
22 range of oxygen concentrations?

23 A. For the purpose of suppressing oxidation and spon com,  
24 yes, correct.

25

26 Q. But the point is that on any of these renderings -  
27 that is, on the second or the third - we still see, of  
28 course, the high level of oxygen close to the face, and the  
29 idea is simply to limit the length or the width of the zone  
30 which is problematic to as small as it's possible to do so?

31 A. That is correct.

32

33 Q. And with the added benefit in the third rendering  
34 towards the bottom, where we see the 220 metres behind the  
35 face injection represented there by the green arrow --

36 A. Yes.

37

38 Q. -- the effect is also to drop the oxygen  
39 concentrations down well into the blue zone for the  
40 majority or almost all of that goafed area?

41 A. Yes.

42

43 MR HOLT: Thank you, Mr Martin.

44

45 THE CHAIRPERSON: Thank you. Mr Crawshaw?

46

47 MR CRAWSHAW: No questions, thanks, Mr Chair.

1  
2 THE CHAIRPERSON: Ms Grant?  
3  
4 MS GRANT: No questions, thank you, Mr Martin.  
5  
6 THE CHAIRPERSON: Mr Trost?  
7  
8 MR TROST: No questions, Mr Martin.  
9  
10 THE CHAIRPERSON: Mr O'Brien?  
11  
12 MR O'BRIEN: No, thank you.  
13  
14 THE CHAIRPERSON: Ms Holliday, do you have questions?  
15  
16 MS HOLLIDAY: Yes, I do.  
17  
18 THE CHAIRPERSON: All right, we might take the morning  
19 break, then.  
20  
21 Professor, we're just going to have the morning break.  
22 We'll be about 15 minutes, if that's all right.  
23  
24 THE WITNESS: Yes, sure, no problem.  
25  
26 **SHORT ADJOURNMENT**  
27  
28 THE CHAIRPERSON: Yes, professor, are you there?  
29  
30 THE WITNESS: Yes, I'm here.  
31  
32 THE CHAIRPERSON: Good, thank you.  
33  
34 **<EXAMINATION BY MS HOLLIDAY:**  
35  
36 MS HOLLIDAY: Q. Dr Ren, my name is Deborah Holliday.  
37 I'm appearing for Resources Safety & Health Queensland.  
38 I just have a couple of questions for you. In an answer to  
39 Mr Rice earlier this morning, you indicated that you were  
40 aware that there were mines that are using proactive goaf  
41 inertisation as a continuing control process?  
42 A. Yes.  
43  
44 Q. Can you assist with whether those mines are, firstly,  
45 in Australia?  
46 A. Yes, some of the mines are in Australia, some  
47 overseas. When I say the mines in Australia, I believe

1 some of the mines are in New South Wales and in Queensland  
2 as well.

3

4 Q. In relation to those mines that are using proactive  
5 goaf inertisation continuously as a control process rather  
6 than as reactory, are they high production rate mines with  
7 high gas emissions?

8 A. Yes, some of the pits are. To my knowledge, some of  
9 the mines, the pits, for example, producing 5 million  
10 tonnes of coal are pretty gassy, yielding not only methane,  
11 in some cases CO<sub>2</sub> as well.

12

13 Q. You indicated in response to another question by  
14 Mr Rice that there needed to be more research done in  
15 relation to how your theoretical approach to active goaf  
16 inertisation could be practically implemented, particularly  
17 in high production rate mines.

18 A. That's correct.

19

20 Q. So you still stand by that as a statement?

21 A. Yes.

22

23 Q. Indeed, that is because of the intricacies and nuances  
24 that exist when there are advancing longwalls in high  
25 production rate mines?

26 A. Because we are operating in a changing mining  
27 environment, and we're getting deeper, it's getting gassy,  
28 our longwall mines are getting perhaps bigger and highly  
29 productive, that actually presents a lot more challenges,  
30 for example, ventilation, dealing with gas, and of course  
31 spon com. That can, to some extent, change the goaf  
32 atmosphere or the goaf gas dynamics, and therefore we will  
33 need further studies to better understand exactly what is  
34 happening and so that we can do a better job in containing  
35 the potential heating or gas events.

36

37 Q. Would you agree that that further research should also  
38 include as to how traditional spon com indicators can be  
39 better understood with proactive inertisation?

40 A. I do believe so, and as was mentioned I think also by  
41 some of the experts in these public hearings, there are  
42 limitations for all the gas indicators, and it has always  
43 been an ongoing study in how, in particular, a set of gas  
44 indicators can be improved to improve their reliability.

45

46 In the case of inertisation, you introduce additional  
47 alien gas, such as nitrogen or CO<sub>2</sub>, and this actually



1 disturbs the natural formation of the seamgas, and as  
2 I mentioned and also the other experts mentioned in this  
3 hearing, it could cause other issues with some of the gas  
4 indicators. So I do believe that further research is  
5 needed to study the impact of inertisation on these gas  
6 indicators or ratios.

7  
8 Q. In response to one of the questions asked by the  
9 Board, you ran through in your brief response how ethylene,  
10 for example, could still be used. But there's the  
11 difficulty with ethylene, isn't there, that whilst it's  
12 a good indicator of an advanced heating, if it's present,  
13 it nonetheless means that it can't be used to detect  
14 a heating?

15 A. Well, if you detect ethylene, in most cases we would  
16 say the heating has developed to an advanced stage, and  
17 sometimes I would say some of the online monitoring systems  
18 will not be able to give you a timely response or reading,  
19 and we sometimes rely on bag samples.

20  
21 It is an important parameter, but, as we said, we  
22 would not wait until you detected the occurrence of ethane  
23 or ethylene or other unsaturated hydrocarbon gases; we'd  
24 rather focus on other parameters, other indicators, and try  
25 to contain the heating before it advanced to that stage.

26  
27 Q. Any mine that's currently using proactive goaf  
28 inertisation would have to make sure, wouldn't they, that  
29 their TARPs take into account the fact that they are using  
30 the inertisation?

31 A. Yes, they have to. They have to consider the impact  
32 of potential inertisation on all these TARP systems that  
33 they're using, and that's why they have TARPs for different  
34 locations, for example, the goaf stream or the returns, the  
35 intake, the goaf seals, the gas drainage plants and things  
36 like that. So there are considerations built in the TARP  
37 systems to address these issues.

38  
39 Q. You expect that to be the case. You can't comment  
40 specifically on, for example, Grosvenor mine, as to whether  
41 they did or they didn't?

42 A. No, I have no idea. I would expect a mine operated by  
43 Anglo Coal, they would have done such a thing in their  
44 system, but I am not aware of the exact system, things like  
45 that.

46  
47 MS HOLLIDAY: I have no other questions, thank you,

1 Mr Martin.

2

3 THE CHAIRPERSON: Thank you. Mr Rice?

4

5 MR RICE: Nothing from me, Mr Martin.

6

7 THE CHAIRPERSON: Yes, Mr Clough?

8

9 MR CLOUGH: Good morning, Professor Ren. Andrew Clough  
10 here.

11 A. Good morning.

12

13 Q. I do have a couple of questions. The first question -  
14 I understand that your studies were primarily directed at  
15 controlling or preventing the development of spontaneous  
16 combustion. However, I wonder if you have any comment on  
17 the other effect, which is the impact on the total volume  
18 of explosive gas mixture sitting in the goaf, whether or  
19 not the proactive inertisation - one of the other potential  
20 benefits is it will actually reduce the size of the zones  
21 within the goaf that contain an explosive gas mixture?

22 A. I think that will be the add-on bonus for goaf  
23 inertisation. You are injecting inert gas into the  
24 atmosphere of the goaf, and that inert gas, if you're using  
25 nitrogen, is ready to diffuse and mix with the goaf gas or  
26 oxygen. In that manner, if you provide sufficient inert  
27 gas in that environment, then you will be able to render  
28 the goaf atmosphere out of the explosive range in addition  
29 to containing spon com.

30

31 Q. The second question is in relation to the importance  
32 of other measures to reduce oxygen ingress into the goaf.  
33 Correct me if I have this wrong, but I was left with the  
34 impression that unless you do other things to try to  
35 prevent oxygen getting into the goaf, then you may actually  
36 compromise the ability of the inert gas to reach its  
37 maximum effectiveness. In particular, I wanted to ask  
38 about the maingate corner of the longwall as a source of  
39 oxygen getting into the goaf and any comments you might  
40 have on the importance of managing that part of the  
41 longwall face?

42 A. If we talk about the injection rate of inert gas,  
43 nowadays lots of mines are perhaps pumping nitrogen at  
44 a rate of 500 litres per second or, you know, maximum  
45 1500 litres per second, and that in comparison with your  
46 ventilation or your ventilation leakage into the goaf is  
47 pretty small. So in that regard, it is very important to

1 take whatever controls, in particular like ventilation  
2 controls, the seals, your mine layout, to minimise oxygen  
3 ingress into the goaf area.  
4

5 Now, coming back to the maingate corner, if you see  
6 most of the longwalls, we run quite high ventilation to the  
7 face, so when the ventilation is entering the longwall  
8 through the maingate corners, it has very high momentum, so  
9 therefore a part of that ventilation will tend to penetrate  
10 into the goaf. If that happens, it will compromise to  
11 a great extent the inertisation effect. To minimise that  
12 sort of impact, we will need to minimise the oxygen ingress  
13 from that point by - for example, in most cases, we would  
14 have a goaf curtain. I have seen most of the mines will  
15 have these things in place.  
16

17 Further to that, I would suggest it's not only just  
18 a curtain next to the first chock and second chock, maybe  
19 extending that a bit further along the longwall face,  
20 I would say maybe to the fourth or fifth longwall chocks,  
21 to maximise the impact of stopping oxygen or air ingress  
22 into that position.  
23

24 This could be also combined with other techniques, for  
25 example, a plug you could drop in or put in through  
26 a cut-through just outbye of your injection point. All  
27 these things will come together, and that will help you to  
28 have the inertisation system work better and more  
29 effective.  
30

31 Q. The next question is on similar lines, but it's in  
32 relation to goaf drainage. What I'm seeing is that the  
33 management of the goafs is an integrated approach. Do you  
34 have any comment on the importance of making sure that you  
35 extract as much gas as possible with pre-drainage versus  
36 relying on post-drainage and that impact on the  
37 effectiveness of inertisation?

38 A. Yes, if you're operating any mine or longwall panels  
39 that extract a seam that's pretty gassy, we are trying to  
40 pre-drain the gas from not only the seam that you're going  
41 to mine but also adjacent seams, for example, in the roof,  
42 in the floor, to reduce the gas content below the  
43 threshold - in most cases, we're talking about outburst.  
44 Then whatever is left in the seam will have to be dealt  
45 with by post-drainage.  
46

47 So there is a balance there. For the post-drainage,

1 you try to drain as much as you need; I wouldn't say as  
2 much as you "can", because you don't want to drain too  
3 much, and then you run the risk of introducing significant  
4 oxygen or air into the goaf and therefore you bring in  
5 another risk, your spon com and potentially an explosive  
6 atmosphere somewhere.  
7

8 So, as you say, it's an integrated strategy. It's  
9 a compromise. The design has to make sure that the two  
10 systems work together and offer the best benefit of  
11 ensuring that you control the gas emission reporting to  
12 your ventilation systems but also with due consideration of  
13 oxygen ingress and therefore spon com risk.  
14

15 Q. I have a final question. It's in two parts. The  
16 first question is, if you can ensure or you're quite  
17 confident that you have less than 5 per cent oxygen within  
18 your goaf, would this not be a better indicator to measure,  
19 rather than Graham's ratio, because Graham's ratio assumes  
20 you've got an oxygen flow through your goaf. So if you had  
21 the choice of not having oxygen in your goaf versus having  
22 oxygen in your goaf, is it really such an issue that you  
23 lose Graham's ratio in those two scenarios?

24 A. Well, I would never suggest that you're just looking  
25 only at a particular ratio, such as Graham's ratio. We  
26 always need to look at other gases together. For example,  
27 you mentioned oxygen. You know, an oxygen level of less  
28 than 5 per cent is something that we consider in the goaf,  
29 in terms of spon com, is a pretty safe level, because there  
30 were some tests done before that if you ran at an oxygen  
31 level of less than 7 per cent or even 5 per cent, then the  
32 coal will be pretty dead, there's very a low oxidation  
33 rate.  
34

35 I wouldn't say the GR ratio is - that you don't need  
36 to look at that, but it's just another factor or another  
37 parameter into the equation. By looking at not only just  
38 the GR but also other gas indicators, certainly your oxygen  
39 level would give you a confidence, perhaps better idea or  
40 knowledge of what is happening in the goaf area.  
41

42 Q. The second part of that question: based on your  
43 recommendations of injecting nitrogen on the maingate side  
44 of the goaf through the seals some couple of hundred metres  
45 behind the face, running concurrently with gas drainage  
46 with goaf wells, would not the goaf wells themselves be one  
47 of the best sampling points for actually determining the

1 oxygen content in your goaf? They're on the tailgate side  
2 of the goaf. You're injecting on the maingate. So if you  
3 were controlling your goaf wells so that you had less than  
4 5 per cent oxygen, that would be a very good indicator that  
5 you've actually to a large extent controlled the majority  
6 of your goaf in terms of oxygen content. Is that a fair  
7 enough proposition?

8 A. I would say so, but certainly you've got to monitor  
9 what is coming out from your drainage holes and certainly  
10 the oxygen levels, and your oxygen level will definitely  
11 tell you what is happening and perhaps how effective that  
12 inertisation is.

13  
14 But also bear in mind that the oxygen could be coming  
15 from your tailgate side as well, because your goaf hole  
16 could be located quite close to your tailgate side, and if  
17 it's just next to a seal, depending on the goaf gas  
18 compositions, there are possibilities that oxygen could be  
19 penetrating from the tailgate side or maybe through some  
20 seals close to the tailgate or from the adjacent - the  
21 goaf. That's all possible, but certainly monitoring oxygen  
22 levels in your drainage system would give you a very good  
23 indication of what is happening in that particular location  
24 of the goaf.

25  
26 MR CLOUGH: That's very helpful. Thank you very much.  
27 I have no more questions.

28  
29 THE CHAIRPERSON: Mr Rice, might Professor Ren be excused?

30  
31 MR RICE: Yes.

32  
33 THE CHAIRPERSON: Professor, thank you for your evidence  
34 today. You are excused.

35  
36 **<THE WITNESS WITHDREW**

37  
38 MR RICE: The next witness was scheduled for tomorrow,  
39 Mr Martin, which raises another subject.

40  
41 THE CHAIRPERSON: Ladies and gentlemen, as no doubt you've  
42 heard, it seems that there will be a COVID lockdown  
43 certainly in this area from 5pm today, which will interfere  
44 with the hearings for tomorrow and Wednesday.

45  
46 Consequently those witnesses will be rescheduled for  
47 next week, which will be hopefully Tuesday and Wednesday,

1 but no doubt counsel assisting will be in touch further  
2 this afternoon.  
3

4 In any event, parties will be notified by letter or  
5 email of rescheduling, and the public will be notified via  
6 the website of any rescheduling that has been arranged.  
7

8 However, the Board is still very keen to receive  
9 written submissions as soon as possible. A list of issues  
10 to be addressed in submissions will be provided to the  
11 parties today. As I mentioned I think last week, these  
12 submissions will be required by 5pm on 9 April 2021.  
13 A somewhat extended period will be allowed in respect of  
14 topics which will be the subject of hearings next week, but  
15 hopefully they can be met.  
16

17 Mr Holt, how are you travelling?  
18

19 MR HOLT: Up until the COVID lockdown, we weren't going to  
20 seek an extension or anything of that kind, but what you  
21 have indicated in terms of some leeway potentially on  
22 topics where the evidence will address that, I suspect we  
23 will deal with any issues, and if we have any other  
24 concerns, we will raise them immediately.  
25

26 THE CHAIRPERSON: Thank you. And Ms Holliday?  
27

28 MS HOLLIDAY: Similarly.  
29

30 THE CHAIRPERSON: Thank you for that. It's much  
31 appreciated.  
32

33 Is there anything else at this stage?  
34

35 MR RICE: No, Mr Martin, not at this stage.  
36

37 THE CHAIRPERSON: So we adjourn until 10am next Tuesday.  
38 Thank you.  
39

40 **AT 12.12PM THE BOARD OF INQUIRY WAS ADJOURNED**  
41 **TO TUESDAY, 6 APRIL 2021 AT 10AM**  
42  
43  
44  
45  
46  
47

|   |   |  |   |  |
|---|---|--|---|--|
| <b>\$</b>   | <b>3</b>  | 2035:37, 2044:44,<br>2048:20, 2054:11,<br>2055:7, 2055:24  | 2053:1  | <b>appreciated</b> <sup>[1]</sup> - 2068:31  |
| <b>\$450,000</b> <sup>[1]</sup> - 2034:42   | <b>3.0</b> <sup>[1]</sup> - 2056:46   | <b>accept</b> <sup>[2]</sup> - 2035:17,<br>2057:3  | <b>advanced</b> <sup>[5]</sup> - 2047:46,<br>2054:14, 2063:12,<br>2063:16, 2063:25  | <b>approach</b> <sup>[2]</sup> - 2062:15,<br>2065:33   |
| <b>0</b>  | <b>30</b> <sup>[1]</sup> - 2040:9   | <b>access</b> <sup>[1]</sup> - 2055:39   | <b>advancing</b> <sup>[2]</sup> - 2057:40,<br>2062:24   | <b>April</b> <sup>[1]</sup> - 2068:12  |
| <b>0.2</b> <sup>[1]</sup> - 2051:11   | <b>300</b> <sup>[2]</sup> - 2058:14, 2058:20  | <b>accounting</b> <sup>[2]</sup> - 2034:33,<br>2051:19   | <b>advantage</b> <sup>[1]</sup> - 2046:6  | <b>APRIL</b> <sup>[1]</sup> - 2068:41  |
| <b>0.5</b> <sup>[2]</sup> - 2037:38, 2051:20  | <b>350</b> <sup>[1]</sup> - 2037:42   | <b>account</b> <sup>[1]</sup> - 2063:29  | <b>advantageous</b> <sup>[1]</sup> -<br>2049:18   | <b>apt</b> <sup>[1]</sup> - 2049:19  |
| <b>0004</b> <sup>[1]</sup> - 2060:1   | <b>363</b> <sup>[1]</sup> - 2031:37   | <b>accumulation</b> <sup>[2]</sup> -<br>2040:38, 2054:22   | <b>advantages</b> <sup>[1]</sup> - 2046:5   | <b>area</b> <sup>[12]</sup> - 2034:6, 2036:8,<br>2040:16, 2041:1,<br>2041:6, 2044:37,<br>2053:33, 2056:40,<br>2060:40, 2065:3,<br>2066:40, 2067:43                                 |
| <b>0005</b> <sup>[1]</sup> - 2057:45  | <b>4</b>  | <b>accuracy</b> <sup>[1]</sup> - 2051:9  | <b>adverse</b> <sup>[2]</sup> - 2035:9,<br>2053:21  | <b>areas</b> <sup>[7]</sup> - 2033:41,<br>2035:18, 2040:34,<br>2043:14, 2043:18,<br>2046:1, 2046:31  |
| <b>0011</b> <sup>[1]</sup> - 2039:7   | <b>4</b> <sup>[1]</sup> - 2042:3  | <b>achievable</b> <sup>[1]</sup> - 2038:16   | <b>advice</b> <sup>[2]</sup> - 2044:18,<br>2044:36  | <b>arising</b> <sup>[1]</sup> - 2050:22  |
| <b>0017</b> <sup>[1]</sup> - 2055:26  | <b>400</b> <sup>[3]</sup> - 2038:24, 2058:15,<br>2058:20  | <b>achieve</b> <sup>[4]</sup> - 2038:10,<br>2038:22, 2039:35,<br>2040:6  | <b>affected</b> <sup>[1]</sup> - 2039:36  | <b>arrange</b> <sup>[1]</sup> - 2032:21  |
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