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Development of a new methodology for evaluation of spontaneous fire risk potential and rating of underground coal mine panels in bord and pillar method of mining in India

This is an innovative user-fhendly prediction model developed for evaluation of spontaneous fire risk potential and rating of underground coal mine panels in bord and pillar workings. It is based on qualitative effect of fire risk parameters on underground panels, and to some extent dependent on experience of the user. Here, major fire risk parameters associated with spontaneous heating of panels are short-listed and divided into three broad groups in accordance with the nature of their contribution. The paper describes vividly the procedure for estimation of fire risk rating of individual groups using separate objective type models developed for this purpose and then it evaluates the overall fire risk potential and rating of the concerned panel by combining the fire risk ratings of all the three groups. This model may be applied to a panel where extraction is carried out using any of the techniques: (i) depillaring with formation of small pillars as final operation, (ii) extraction by broadening of galleries, (iii) depillaring with hydraulic sand stowing, and (iv) depillaring with caving. The model is tested with the field data collected from different collieries spreading across the country and the laboratory data for critical assessment of fitness. Some results showing the validity of the model are also cited here.

Introduction

Spontaneous heating is often found to be the cause of fire in underground coal mine panels. The initiation of spontaneous heating depends not only on the spontaneous susceptibility of the coal but also on the extraneous conditions created due to mining. Spontaneous heating of coal is a typical physico-chemical process involving absorption, adsorption and finally oxidation of coal with the oxygen present in the surrounding air. If conditions favour, a part of the generated heat is accumulated within the loose coal or coal fines and manifested by self-heating. When it exceeds the critical temperature, the oxidation becomes self-accelerating and leads to open fire.

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Loose coal in large quantity in goaf or in worked out area, excessive cracks and fissures due to stress relief (intensive mining), partial extraction, multi-section workings, caving under shallow cover, large size panel, inadequate size of barrier pillars, fractured parting, loose coal in crushed pillars, loose coal on the floor in running panels, coal fines in cracks, inadequate heat flow by convection etc. are all extraneous conditions that make the underground mining environment favourable to spontaneous heating. Besides, poor stowing rate, ineffective and delayed stowing, extraction beyond the incubation period, inadequate monitoring of gob atmosphere, delaying in removal of fresh loose coal with pyrite etc. are the unwarranted factors that make the situation further critical.

Therefore, it is a problem with the mine authorities how to evaluate the fire risk involved in an actual underground mining operation. There are some fire risk evaluation models available in literature such as the models of Feng and others (Feng et al. [1]), Atkinson and his group (In: Singh et al. [2]), and Olpinski and his students (In: Banerjee [3]). These models are either theoretical in nature or they do not possess necessary guidelines for the users. These are not in use in India. So, we felt the necessity of a genuine fire risk prediction model for underground coal mine panels. Since most of the mines in India are worked by bord and pillar method of mining, the prediction model was designed keeping this method in view so that maximum number of mines could be covered.

The methodology used in the model is innovative. The model is user-friendly, and to some extent dependent on experience of the user. It relies upon qualitative effect of the fire risk parameters on underground panels. The author feels that apart from the present application, this methodology may also be applied to similar problems in mining and in other fields of science and technology.

As for its publication, the model was published in national and international journals either in part or in totality at different stages of development. The model published in the paper Roy [4] may be applied to the panels that undergo depillaring with hydro pneumatic (or hydraulic) sand stowing, whereas the model in Roy [5] is for the panels extracted by depillaring with caving. However, the prediction model Roy [6] is a complete model that may be applied to a panel undergoing any of the depillaring techniques: depillaring with formation of small pillars as final operation or by broadening of galleries, depillaring with hydraulic sand stowing, and depillaring with caving. If we look into the papers Roy [4, 7], it may be also observed that in every next paper the model was improved either by incorporating new fire risk aspects that were left unnoticed or with more clarity.

In February 2002, a meeting of mine fire experts from national coal mine companies, premier R&D and academic institutes, and administrative bodies for mines was held at this Institute under the chairmanship of the Director-General of Mine Safety (DGMS) for discussion on the original model (Roy [4, 6]). Though the model received huge appreciation at the meeting, some officials from the DGMS felt necessity of a broader scale for more accurate and distinctive fire risk rating of panels. A lot of efforts were given to achieve this objective, and finally the impediment was removed in 2004. In the improved version (Roy [7]), the three-point fire risk rating scale was replaced with a twenty-seven-point scale.

In this paper most of the fire provocative causes in Tables 7 and 8 are improved version of the previous ones given in earlier papers (Roy [4, 7]). The section with sub-heading 'Identification of dominating groups in respect of their role in spontaneous heating and development of a broad fire risk rating scale for panels', which is the most important part of this model, has also been rewritten for more clarity of the logic. The model has been revised once again to make it more realistic and understandable to the users.

Major fire risk parameters, groups of parameters, and building modules

The causative factors that play a major role in bringing about spontaneous fire in underground panels are: spontaneous heating susceptibility of the coal; loss of coal after extraction/accumulation of loose coal in the panel; effective surface area of the reacting mass; availability of air for the process of oxidation; and accumulation of residual heat in the system.

If we look into the manifestations of the major fire risk parameters involved in underground panel fires, every single parameter may be found to have a number of possibilities. Let us call these possibilities 'fire risk aspects' of the parameter. Any underground mining scene in bord and pillar workings can be well described using the following parameters when considered along with corresponding fire risk aspects, each parameter being related to at least one of the above five causative factors:

- System of depillaring (depillaring with caving/hydraulic sand stowing/formation of small pillars as final operation, etc.)
- state of extraction (at the time of observation whether the extraction work in the panel is complete or is ongoing)
- seam thickness
- parting (nature of parting, closeness of two consecutive seams, etc.)
- nature of extraction (single-/multi-lift extraction)
- scope of accumulation of loose coal/coal fines (existence of coal in the roof, frequency of roof fall, existence of crushed/cracked pillars, etc.)
- state of consolidation of coal mass (cracks in pillar/barrier/ isolation stopping, etc.)
- size of panel (pillar size, and number of pillars)
- heat dissipation by conduction
- geological disturbances that facilitate leakage of air into a panel (fault, dyke etc.)
- leakage of air from surface or other sources (subsidence, cracks and fissures on surface in case of shallow overburden), ventilation in undesired route outside a panel, etc.
- ventilation of panel during extraction of coal (status of ventilation, undesired exposure of the depillared area to ventilating air, etc.)
- incubation period of coal
- category of coal in respect of proneness to spontaneous heating (crossing point temperature)
- wetness of mines
- existence of pyrite band in coal seam
- existence of inferior coal band
- particle size distribution in coal fines
- gassiness of coal seam and
- hot spots (adjoining fire, hot springs, etc. to distinguish from contact fire)

In view of their nature of contribution to spontaneous heating in underground panels, the above parameters have been divided into three broad groups, viz; (i) panel specifics, (ii) environment, and (iii) coal and seam characteristics. These groups have specific role in underground fire. To evaluate the fire risk rating of each group, separate objective type model has been developed using respective constituting parameters. These models, referred to as building modules, have been selectively used later to form the desired prediction model for evaluation of fire risk potential/rating of panels. We will use either the above parameters directly or their mining manifestations in the building modules given hereafter.

Fire risk rating technique used in building modules of the groups 'panel specifics' and 'coal and seam characteristics'.

The objective of the building module of the group 'panel specifics' is to make an estimation of the possible amount of loose coal/coal fines that may be present on the floor or in the crushed/cracked pillars or elsewhere in a panel. The parameters of this group have more than one fire risk aspect. Accordingly, a set of suitable digits such as (0,1,2), (1,2,4,5) etc. is assigned to every individual parameter where an elementary digit corresponds to a particular fire risk aspect of the parameter. The lowest digit stands for the aspect that has least risk of spontaneous heating, while the highest one corresponds to the aspect that has maximum risk. In a case study, an appropriate fire risk aspect along with the assigned digit is chosen from the list given with every individual parameter. We call the assigned digit 'fire risk number of the parameter [1] and is denoted by N_i ("i" stands for the ith parameter). However, it is to be remembered that this fire risk numbering technique is purely subjective and based on the professional experience of the author. When the fire risk numbers of all the parameters are added, we call the total number (ΣN_i) 'fire risk number of the module'. For the group 'panel specifics', it may vary up to 10. A qualifying value of 0.1 is then attached to every unit of the fire risk number of the module, and hence the quantity ($0.1 * \Sigma N_i$) may attain a maximum value 1.0. We call it 'fire risk value of the module'. Similarly, in case of the group 'coal and seam characteristics', total fire risk number of the module may vary up to 25. When it is multiplied by 0.04 (weight factor), the maximum fire risk value that the module can attain is 1.0. The fire risk rating of these groups is done, thereafter, as per the range of the fire risk value given at the end of Modules 1a and 3.

Panel specifics

The parameters such as system of depillaring, state of extraction, nature of extraction, seam thickness, parting, scope of accumulation of loose coal/coal fines, state of consolidation of coal mass, size of panel, and heat dissipation by conduction are part of this group. The compulsions such as non-availability of stowing material, necessity of higher production etc. often dominate the selection of the system of depillaring. However, this group of parameters has three modules. Module 1a is applicable to the panels where depillaring is done with formation of small pillars as final operation or coal is extracted by broadening the galleries, and is given in Annexure 1. Two other modules, applicable to (i) depillaring with hydraulic sand stowing (Module 1b) and (ii) depillaring with caving (Module 1c), are also given in Annexures 2 and 3 respectively.

Environment

The parameters such as geological disturbances, leakage of air from surface or other sources, ventilation of a panel during extraction of coal, and incubation period of coal constitute the group 'environment'. The following modules (2a, 2b and 2c in Annexure 7) may be used for collection of field data related to these constituting parameters.

Characterization of environment of unsealed panels

A list of fire provocative causes (Module 2ab) for unsealed panels has been prepared by combining Modules 2a and 2b. Each of the causes is characterised by one of the three fire risk ratings: Low(e), high(e), and very high(e) in accordance with its contribution to spontaneous heating, where 'e' signifies environment. A similar list was given in the original model of the author (Roy [4, 6]), but in that list the effect of incubation period did not find its due importance that it deserved. The improved list (Annexure 7 of Roy [7]) was free from this shortcoming. However, we have improved this list further with some more clarifications.

Characterization of environment of sealed panels

The following module has been prepared combining Module 2a with 2c (Annexure 8). The fire provocative causes enlisted in Module 2ac are applicable to sealed panels only. Though a similar list was given in the earlier publications of the author (Roy [4, 7]), the list in Annexure 8 has been written afresh with more clarity.

Coal and seam characteristics

The parameters falling in this group are independent of mining environment. The constituting parameters are: category of coal in respect of proneness to spontaneous heating (crossing point temperature), wetness of mines, existence of pyrite band in coal seam, existence of inferior coal band in seam, particle size distribution in coal fines, and gassiness of seam. The building module of this group (Module 3) is presented in Annexure 9.

Estimation of fire risk potential of mine panels

As per the nature of the constituting parameters, all the three groups of parameters discussed above have got their own role in underground panel fires. The fire risk potential of underground panels may be estimated by combining

- the fire risk rating of the group 'environment' (obtained by using Module 2ab or 2ac),
- the fire risk rating of the group 'coal and seam characteristics' (obtained by using Module 3), and
- the fire risk rating of the group 'panel specifics' (obtained by using Module 1a or 1b or 1c)

Identification of dominating groups in respect of their role in spontaneous heating and development of a broad fire risk rating scale for panels

In the original model (Roy [4, 6]), the fire risk rating of underground panels was evaluated as an average of the fire risk ratings of the individual groups of parameters, where each group was given equal weight. However, we realised later that this idea was not fully justified. One group may be predominant over other two groups or may be dominated by these groups or it may dominate one group, but may be dominated by the remaining group in coal-air reaction. So, with due emphasis on the dominating nature of individual groups, we will establish a broad scale for more appropriate evaluation of fire risk rating of panels.

First, we will identify the dominating group between 'coal and seam characteristics' and 'panel specifics'. To do so, let us start with a query: In an environment of adequate air which of the combinations high(c),very high(p) or very high(c), low(p) has higher fire risk potential?

Coal and air are two main ingredients in coal oxidation where characteristics of coal in respect of proneness to spontaneous heating is an indicator of oxygen consumption rate of coal. Therefore, in a broad sense we can identify the group 'panel specifics' with the amount of coal (loose or otherwise) that exists in a panel, the group 'environment' with the availability of air, and the group 'coal and seam characteristics' with the oxygen consumption capacity of the reacting loose coal/coal fines in a panel. Here, only the qualitative aspects of these factors are considered.

In the combination high(c),very high(p), the fire risk rating of the group 'panel specifics' is found to be 'very high(p)', whereas in very high(c), low(p) this rating is 'low(p)'. It means that in the first case the panel may have much higher amount of coal than the amount estimated in the second case. Therefore, in the first case, there may be a large number of air pockets in the accumulated coal, while in the second case the air pockets may be only a few in number. However, out of them only one or a few air pockets may take active part in initiation of spontaneous heating.

Again, in the combination of high(c),very high(p), the fire risk rating of the group 'coal and seam characteristics' is 'high(c)' and in very high(c), low(p) this rating is 'very high(c)'. So, in the first case the oxygen consumption capacity is less than the consumption capacity estimated in the second case, the environment being the same in both cases. This inference may also be verified in laboratory with the help of U-index data (ml/hr/g, symbols having standard meaning) of coal categorization in respect of proneness to spontaneous heating. In the second case higher amount of residual heat will be left at the place of reaction, after a part of the generated heat is dissipated by convection and other means. Therefore, initiation of spontaneous heating will start earlier in the second case than the first case. If appropriate remedial measures are not taken, it may lead to spontaneous fire and spread around.

Hence, we find that the combination very high(c), low(p) has higher fire risk potential than that of the combination high(c), very high(p) if the 'environment' is kept unchanged. Similarly, the combination high(c),low(p) has higher fire risk potential than the combination low(c), very high(p).

So, the group 'coal and seam characteristics' may be considered to be dominating over the group 'panel specifics'. A heap of loose coal with higher proneness to spontaneous heating having only a few air pockets is more dangerous in air than a heap of loose coal with lesser proneness to spontaneous heating having large number of air pockets. After identification of the dominating group between 'coal and seam characteristics', and 'panel specifics, we will look into the dominating nature of the combination of the groups 'environment', 'coal and seam characteristics', and 'panel specifics. Here also we will start with a query: Which of the combinations high(e), very high(c), very high(p) or very high(e), low(c),l ow(p) has higher fire risk potential? We will try to find out the answer to this query for unsealed and sealed panels separately.

An unsealed panel with fire risk potential 'high(e), very high(c), very high(p)' may be found to possess one of the following situations:

(i) The coal has very high proneness to spontaneous heating. There is sufficient coal (loose coal on the floor/loose coal in crushed stooks/coal fines in cracks of coal mass) in the goaf/worked out area of the depillaring panel, and it is affected by a leakage of air. The depillaring time is significantly less than the incubation period of the coal. [Deduced from Module 3, Module 1(a/b/c), and Module 2ab (cause no.2)]

(ii) The coal has very high proneness to spontaneous heating. There is sufficient coal (apparently no loose coal or coal fines) in the goaf/worked out area of the depillaring panel, and it is affected by a leakage of air. The depillaring time either has exceeded or is close to the incubation period of the coal. [Deduced from Module 3, Module 1(a/b/c), and Module 2ab (cause no.3)]

(iii) The coal has very high proneness to spontaneous heating. There is sufficient coal (apparently no loose coal or coal fines) in the panel. It is a completely depillared unsealed panel left exposed to the ventilating air or is at close proximity to a ventilation route. [Deduced from Module 3, Module 1(a/b/c), and Module 2ab (cause no.4)]

Similarly an unsealed panel with fire risk potential 'very high(e), low(c), low(p)' may also have one of the following situations:

(I) The coal has low proneness to spontaneous heating. There is a necessary amount of coal (loose coal on the floor/loose coal in crushed stooks/coal fines in cracks of coal mass) in the goaf/worked out area of the depillaring panel, and it is affected by a leakage of air. The depillaring time either has exceeded or is close to the incubation period of the coal. [Deduced from Module 3, Module 1(a/b/c), and Module 2ab (cause no.1)]

(II) The coal has low proneness to spontaneous heating. There is a necessary amount of coal (loose coal on the floor/loose coal in crushed stooks/coal fines in cracks of coal mass) in the working area of the running panel or elsewhere, it is unattended, and the ventilation is insufficient (sluggish ventilation). [Deduced from Module 3, Module 1(a/b/c), and Module 2ab (cause no.6)]

The necessary requirements for initiation of spontaneous heating in an unsealed panel are: (a) availability of air, (b) availability of loose coal/coal fines, and (c) completion of incubation period of the coal (in case of normal ventilation). Analysing the situations [nos.(i)—(iii)] that may arise in an unsealed panel with fire risk potential 'high(e), very high(c), very high(p) we find that these situations do not readily fulfil all the three above requirements. In all these situations, except the requirement (a), other two requirements (b) and (c) do not hold simultaneously. Either there is uncertainty of loose coal/ coal fines in the panel or the depillaring time is significantly less than the incubation period of the coal. Whereas the situation [no.(I)] with fire risk potential 'very high(e), low(c), low(p)' readily fulfils all the necessary requirements (a), (b), and (c) for initiation of spontaneous heating. The situation no.(II) is a case of sluggish ventilation where loose coal or coal fines is present in the panel. Here, the rate of accumulation of residual heat, and, so the rise of temperature of the reacting coal is faster than those in normal ventilation. In such a situation, initiation of spontaneous heating may take place even before completion of incubation period. Therefore, in case of an unsealed panel the combination 'very high(e), low(c), low(p)' has higher fire risk potential, and hence higher fire risk rating than those of the combination 'high(e), very high(c), very high(p)'.

[Anyway, we must remember that the situations [nos. (i)—(iii)] and [nos.(I)-(II)] of the unsealed panel may not be the only ones, there may be some more situations akin to them]

Now, in case of a sealed panel with fire risk potential 'high(e), very high(c), very high(p)', one can find the panel possessing the situation as given below:

(i) The coal has very high proneness to spontaneous heating. There is sufficient coal (loose coal/coal fines existed at the time of sealing or accumulation of this kind of material is highly probable after the sealing because of roof fall, crushing of stooks, etc.) in the panel. The panel is subjected to substantial pressure difference due to presence of an air source outside the panel, but the leakage could not be confirmed by quantity measurement. [Deduced from Module 3, Module 1(a/b/c), and Module 2ac (cause no.2)]

Further, a sealed panel with fire risk potential 'very high(e), low(c), low(p)' may have the situation given as:

(I) The coal has low proneness to spontaneous heating. There is a necessary amount of coal (loose coal/coal fines existed at the time of sealing or accumulation of this kind of material is highly probable after the sealing due to roof fall, crushing of stooks, etc.) in the panel. There is a leakage of air into the sealed panel confirmed by quantity measurement. [Deduced from Module 3, Module 1(a/b/c), and Module 2ac (cause no.1)]

The necessary requirements for initiation of spontaneous heating in a sealed panel are: (a) availability of air, and (b) availability of loose coal/coal fines. The situation [no.(i)] with fire risk potential 'high(e), very high(c), very high(p)' has sufficient coal (loose coal or coal fines as explained before), but one main ingredient - air is not available in the panel even though it has undergone a threat of air leakage. Hence, the situation [no.(i)] does not readily fulfil the necessary requirements to initiate spontaneous heating in the panel. Again, the situation [no.(I)] arising in a sealed panel with fire risk potential 'very high(e), low(c), low(p)' implies that there is a necessary amount of coal (loose coal or coal fines as explained before) in the panel and also that there is a leakage of air confirmed by quantity measurement. So, in this case the requirements for initiation of spontaneous heating in the sealed panel are readily fulfilled. Therefore, the combination 'very high(e), low(c), low(p)' has higher fire risk potential, and so higher fire risk rating than those of the combination 'high(e), very high(c), very high(p)'. [We should remember that the situations [nos.(i) &(I)] of a sealed panel, may not be the only ones, some more situations, akin to them, may also exist]

Similarly, we can establish that the combination 'high(e), low(c), low(p)' has higher fire risk potential and rating than those of the combination 'low(e), very high(c), very high(p)' for both unsealed and sealed panels. The fire risk ratings of other combinations, given in Annexure 10, are obvious. Thus, in accordance with the contribution to spontaneous heating the aforementioned groups of parameters can be arranged in the following sequential order from most dominating group to least dominating group: 'Environment', 'coal and seam characteristics', and 'panel specifics'. In each combination, the fire risk rating of the group 'environment' is placed first, the fire risk rating of the group 'coal and seam characteristics' in second, and then the fire risk rating of the group 'panel specifics' is placed. It may be found in Annexure 10 that there are altogether twenty-seven combinations arranged in ascending order of their rating.

Advantage of the twenty-seven-point fire risk rating scale over the three-point scale

The three-point fire risk rating scale for panels used in the original prediction model (Roy [4, 6]) had three ratings: Low, high and very high. The panels with rating low were 'safe' panels and the panels with rating high or very high were 'unsafe' panels. However, there is another kind of panels, we call them 'vulnerable' panels. Their fire risk rating may lie between the ratings of 'safe' and 'unsafe' panels. We could not conceive this kind of panels during development of the original model, but we have incorporated them in the improved version. For more details let us look into the following definitions:

Safe panels

These are non-fire panels and they do not have the chance of catching fire under the prevailing conditions. One of the two main ingredients of fire, either air or loose coal in necessary amount is not available in this kind of panels. In case, both the ingredients are available, it is the weathered coal that keeps the panel safe.

Unsafe panels

These are fire panels having symptoms of fire or there is a chance of catching fire at any point of time depending on the thermo-chemical status of the coal. These panels possess both air and loose coal (blasted or fallen or otherwise) in necessary amount (if not enough) for coal oxidation, and the incubation period of the coal either has elapsed or about to be elapsed unless it is a sealed panel.

Vulnerable panels

In this kind of panels there may be uncertainty of the availability of either loose coal in necessary amount or air for coal oxidation, and in case of availability of both the ingredients, the reaction time may be significantly less than the incubation period of the coal unless it is a sealed panel.

When the fire risk rating of a panel is in the range 1-9 of the twenty-seven-point scale, the panel may be predicted to be 'safe'. When it is in the range 10-18, the panel may be called 'vulnerable'. The panel is 'unsafe', if it is in the range 19-27. In each of these ranges, there are nine divisions with increasing rating. So, for its precise fire risk rating, a panel of a particular kind may be placed at one of these nine divisions depending on the fire risk ratings of the groups 'coal and seam characteristics' and 'panel specifics'. This advantage, however, was not present in the original prediction model Roy [4, 6].

Efficacy of the model

The presented model has been tested with field data of more than 30 panels in 12 different seams belonging to 11 collieries of BCCL, CCL, ECL, MCL, SECL and WCL under Coal India Limited. We were interested in unsafe panels with symptoms of fire, not in unsafe panels with a chance of possible fire break out to avoid controversy and to satisfy the readers. We did not include those unsafe panels, where remedial measures were taken before catching fire. However, out of these 30 panels 14 were fire panels and 16 were non-fire panels. The rating of all the 14 fire panels was found to fall in the range 19-27, while the rating of the remaining 16 non-fire panels was in the range 1-18, of course, a few of them fell in the range 10-18. That means all the prediction results of the given model agreed with the observed status of the panels (some of these test results are given in Annexure 11).

As reported in the paper Roy [6] the original model fell short of making an appropriate prediction on the fire risk status of a panel (Part-panel-6 in Annexure 5 of Roy [6]) during field test. This was one of the specific kind of depillaring panels with caving where the loose coal in the goaf was left exposed to a leakage of air. For evaluation of the fire risk rating of the panel, earlier we used the fire provocative cause (SI. no.1 in Annexure 2 of Roy[6]): "When there is a substantial leakage of air into a depillaring panel (there is loose coal affected by the leakage), then fire risk rating-»Very high (e)" and the fire risk rating of the panel was evaluated as 'high'. So, the panel should have been a fire panel, but in reality it was not so.

Subsequently, we modified the aforementioned fire provocative cause by incorporating the effect of incubation period of coal (SI. no.2 in Annexure 7) and used it for evaluation of fire risk rating of the above panel. It was a small panel with 11 pillars (35m x 35m) and the depillaring time was significantly less than the incubation period (7 to 9 months). So, when we applied the modified fire provocative cause, the fire risk rating of the panel became 10 (Annexure 11) that fell in the range 10-18 of the twenty-seven-point scale. So, it was a vulnerable panel, not a fire panel as predicted by the original model (Roy [6]). The prediction result obtained by using the improved model, thus, matched the observed status of the panel. This is an example how we could remove the shortcoming of a fire provocative cause in Module 2ab of the original model (Roy [6]) by recognising due importance of incubation period of coal in spontaneous heating.

Concluding remarks

(i) The prediction model presented here is very useful in bord-and-pillar mining. The colliery managers who keep proper information of underground panels, and also of the irregularities that may affect the safety of panels such as accumulation of loose coal, existence of unconsolidated coal mass, leakage of air from outside a panel, improper supply of air facilitating accumulation of heat in vulnerable areas of a panel etc., are probably the most suitable persons for best use of this model, and to take necessary remedial measures beforehand to reduce the fire risk potential of the endangered panel in accordance with the demand of the situation.

(ii) We often come across the collieries where two or more depillaring techniques are used for extraction of coal in bord-and-pillar mining, and the panels with caving are found to have more fire problems than the panels that followed other depillaring techniques such as hydraulic sand stowing, broadening of galleries, etc., though the coal and seam characteristics are same. The reasons may be that the panels with caving have more loose coal in the goaf than the amount of loose coal left by other depillaring techniques. The given prediction model is in conformity with this aspect also, and may be verified through critical analysis of Modules 1c and 2ab.

(iii) Under each parameter in Modules 1(a, b, c) and 3, there is a list of distinct fire risk aspects with assigned fire risk number. Even though we had exercised an utmost care during development of these modules so that no major fire risk aspect of any parameter was left out, if a user finds a particular aspect is missing he is free to choose judiciously an equivalent aspect with assigned fire risk number from the list to overcome this problem.

It may also be noted that there are some methods of underground mining other than bord and pillar method where this prediction model can be used with some minor modifications. However, we would prefer to leave this academic exercise to the interested persons working in the field.

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ANNEXURE I

MODULE 1A: BUILDING MODULE OF THE GROUP 'PANEL SPECIFICS'

(Applicable to depillaring with formation of small pillars as final operation or to extraction by broadening of galleries)

Parameters		Fire risk numbers of individual parameter (N_i)
STATE OF EXTRACTION		(1,2,3)
(With the assumption that there is no coal in roof, unless stated otherwise)		
(i)	Developed panel (extraction not started)	(1)
(ii)	Depillaring panel	(2)
(iii)	Extraction not completed, loose coal may or may not exist in the working area, panel sealed temporarily due to heating	(3)
(iv)	Extraction incomplete, loose coal lying on the floor, area left unattended	(3)
(v)	Entirely depillared panel (extraction complete)	(2)
(vi)	Entirely depillared/depillaring panel, huge coal left in pillars due to complicated mining conditions	(3)
NATURE OF EXTRACTION		(0,1)
(Developed/completely depillared/depillaring panel)		
(i)	Extraction in single lift (Seam thickness is not enough for more than one section)	(0)
(ii)	Extraction may be carried out in more than one lift (Panel does not have an upper section)	(0)
(iii)	Extraction may be carried out in more than one lift (Panel has an upper section, virgin or otherwise)	(1)
EXISTENCE OF COAL IN ROOF		(0,1)
(Developed/completely depillared/depillaring panel)		
(Coal in upper seam separated by a narrow parting may be taken into account)		

[In case of a developed panel, coal left in roof during development is measured/in case of a completely depillared panel, coal left in roof after depillaring is measured/in case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel)]

(i)	Less than 1.5m coal in roof	(0)
(ii)	It has 1.5m or more coal in roof	(1)

[It has been observed that if there is a layer of coal of width less than 1.5m (on a rough estimation) in the roof and if there is a roof fall of the entire coal, after falling the coal mass becomes fragmented and forms a heap with lesser thickness. Heat generated by oxidation in this kind of coal heaps is found to be dissipated easily]

FREQUENCY OF ROOF FALL (0,1)

(Developed/completely depillared/depillaring panel)

[In case of a developed panel, coal left in roof during development is measured/in case of a completely depillared panel, coal left in roof after depillaring is measured/in case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel)]

(i)	No roof fall/occasional roof fall/frequent roof fall (Panel has less than 1.5m coal in roof)	(0)
(ii)	No roof fall/occasional roof fall (Panel has 1.5m or more coal in roof)	(0)
(iii)	Frequent roof fall (Panel has 1.5m or more coal in roof) Not heavy roof fall; max. height of roof fall is less than 1.5m (as understood from roof fall history of the area)	(0)
(iv)	Frequent roof fall (Panel has 1.5m or more coal in roof) Heavy roof fall; max. height of roof fall is sometimes 1.5m or more (as understood from roof fall history of the area)	(1)

EXISTENCE OF CRUSHED/CRACKED PILLARS, ACCUMULATION OF LOOSE COAL DUE TO SCALING OF PILLARS ETC. (0,1)

(Developed/completely depillared/depillaring panel)

(It may be due to heavy overburden, intensive mining etc.)

(i)	Such a situation does not exist	(0)
(ii)	This kind of situation exists	(1)

SIZE OF PANEL (0,1,2)

(Developed/completely depillared/depillaring panel)

(Ideally, a panel consists of a number of pillars that can be extracted within the incubation period supposedly without facing any fire hazard. However, in India the following situation may be taken by default.)

Sealed/unsealed panel

(i)	up to 30 pillars	(0)
(ii)	31 to 50 pillars	(1)
(iii)	above 50 pillars	(2)

HEAT DISSIPATION BY CONDUCTION (0,1)

(Developed/completely depillared/depillaring panel)

(i)	Coal exists neither in the roof nor in the floor	(0)
(ii)	Coal exists either in the roof or in the floor	(0)
(iii)	Coal exists in the roof, as well as, in the floor	(1)

(Panel may or may not have an upper section)

[The coal of thickness 1.5m or more is only taken into account. Here the words 'coal exists' means that there exists 1.5m or more coal (in the roof or in the floor)]

Therefore, the total fire risk number of Module 1a = SN,

The corresponding fire risk value of Module 1a = ΣN_j *0.1

Hence, the fire risk rating of Module 1a ⟶ low (p)/high (p)/very high (p), depending on the fire risk value as given below :

Low (p),	for fire risk value up to 0.4
High (p),	for fire risk value from 0.5 to 0.7
Very high (p),	for fire risk value from 0.8 to 1.0

Note 1: It is to be kept in mind that the parameters - (i) existence of coal in roof, (ii) nature of extraction, and (iii) frequency of roof fall, indicate whether there is a possibility of accumulation of loose coal on the floor of a panel or elsewhere due to roof fall.

Note 2: It has been observed from the field data that the thermal conductivity of in-situ rock is in average 5 to 10 times more than the thermal conductivity of adjoining in-situ coal in India

MODULE 1B: BUILDING MODULE OF THE GROUP 'PANEL SPECIFICS'
(Applicable to depillaring with hydraulic sand stowing)

Parameters		Fire risk numbers of individual parameter (N_i)
STATE OF EXTRACTION		(0,2,3)
(With the assumption that there is no coal in roof, unless stated otherwise)		
(i)	Entirely depillared and fully stowed panel (extraction complete)	(0)
(ii)	Entirely depillared panel, void area partially stowed (extraction complete)	(2)
(iii)	Depillaring panel	(2)
(iv)	Extraction not completed, loose coal may or may not exist in the working area, panel sealed temporarily due to heating	(3)
(v)	Extraction incomplete, loose coal lying on the floor, area left unattended	(3)
NATURE OF EXTRACTION		(0,1)
(Completely depillared/depillaring panel)		
(i)	Extraction in single lift (Seam thickness is not enough for more than one section)	(0)
(ii)	Extraction may be carried out in more than one lift (Panel does not have an upper section)	(0)
(iii)	Extraction may be carried out in more than one lift (Panel has an upper section, virgin or otherwise)	(1)
EXISTENCE OF COAL IN ROOF		(0,1)
(Completely depillared/depillaring panel)		
(Coal in upper seam separated by a narrow parting may be taken into account)		
[In case of a depillaring panel, coal left in roof is measured either in the developed or in the unstowed depillared area (as prevailing in the major portion of the panel)/in case of a completely depillared and fully stowed panel, this factor need not be considered]		
(i)	Less than 1.5m coal in roof	(0)
(ii)	It has 1.5m or more coal in roof	(1)
(iii)	Completely depillared and fully stowed panel	(0)
FREQUENCY OF ROOF FALL		(0,1)
(Completely depillared/depillaring panel)		
[In case of a depillaring panel, coal left in roof is measured either in the developed or in the unstowed depillared area (as prevailing in the major portion of the panel)/in case of a completely depillared and fully stowed panel, this factor need not be considered]		
(i)	No roof fall/occasional roof fall/frequent roof fall (Panel has less than 1.5m coal in roof)	(0)
(ii)	No roof fall/occasional roof fall (Panel has 1.5m or more coal in roof)	(0)
(iii)	Frequent roof fall (Panel has 1.5m or more coal in roof) Not heavy roof fall; max. height of roof fall is less than 1.5m (as understood from roof fall history of the area)	(0)
(iv)	Frequent roof fall (Panel has 1.5m or more coal in roof) Heavy roof fall; max. height of roof fall is sometimes 1.5m or more (as understood from roof fall history of the area)	(1)
EXISTENCE OF CRUSHED/CRACKED PILLARS IN THE DEVELOPED AREA OF A DEPILLARINQ PANEL		(0,1)
(It may be due to heavy overburden, intensive mining etc.)		
(i)	Such a pillar does not exist	(0)
(ii)	This kind of pillar exists	(1)
SIZE OF PANEL		(0,1,2)
(Ideally, a panel consists of a number of pillars that can be extracted within the incubation period supposedly without facing any fire hazard. However, in India the following situation may be taken here by default.)		
Unsealed depillaring panel		
(i)	up to 30 pillars	(0)
(ii)	31 to 50 pillars	(1)
(iii)	above 50 pillars	(2)

Completely/partially depillared, stowed and sealed panel

(i)	up to 50 pillars	(0)
(ii)	above 50 pillars	(1)

HEAT DISSIPATION BY CONDUCTION (0,1)
(Completely depillared/depillaring panel)

(i)	Fully stowed panel with or without coal in roof	(0)
(ii)	Coal exists neither in the roof nor in the floor	(0)
(iii)	Coal does not exist in the roof, but may exist in the floor	(0)
(iv)	Coal exists in the roof, it may or may not exist in the floor (Panel may or may not have an upper section)	(1)

[The coal of thickness 1.5m or more is only taken into account. Here the words 'coa exists' means that there exists 1.5m or more coal (in the roof or in the floor)]

The fire risk rating of Module 1 b may be obtained in the same way as in the case of Moduk 1a.

ANNEXURE 3

MODULE 1C: BUILDING MODULE OF THE GROUP 'PANEL SPECIFICS'
(Applicable to depillaring with caving)

Parameters		Fire risk numbers of individual parameter (Ni)
STATE OF EXTRACTION (With the assumption that there is no coal in roof, unless stated otherwise)		(3,4)
(i)	Depillaring panel	(3)
(ii)	Extraction not completed, loose coal may or may not exist in the working area, panel sealed temporarily due to heating	(4)
(iii)	Extraction incomplete, loose coal lying on the floor, area left unattended	(4)
(iv)	Entirely depillared panel (extraction complete)	(4)
(v)	Entirely depillared/depillaring panel, huge coal left in pillars due to complicated mining conditions	(4)
NATURE OF EXTRACTION (Completely depillared/depillaring panel)		(0,1)
(i)	Extraction in single lift (Seam thickness is not enough for more than one section)	(0)
(ii)	Extraction may be carried out in more than one lift (Panel does not have an upper section)	(0)
(iii)	Extraction may be carried out in more than one lift (Panel has an upper section, virgin or otherwise)	(1)
EXISTENCE OF COAL IN ROOF (Completely depillared/depillaring panel) (Coal in upper seam separated by a narrow parting may be taken into account) [In case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel)/in case of a completely depillared panel, coal left in roof after depillaring is measured]		(0,1)
(i)	Less than 1.5 m coal in roof	(0)
(ii)	It has 1.5m or more coal in roof	(1)
SIZE OF PANEL (Completely depillared/depillaring panel) (Ideally, a panel consists of a number of pillars that can be extracted within the incubation period supposedly without facing any fire hazard. However, in India the following situation may be taken by default.)		(0,1,2)
Unsealed/sealed panel		
(i)	up to 30 pillars	(0)
(ii)	31 to 50 pillars	(1)
(iii)	above 50 pillars	(2)
HEAT DISSIPATION BY CONDUCTION (Completely depillared/depillaring panel)		(0,1,2)

[In case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel)/in case of a completely depillared panel, coal left in roof after depillaring is measured]

(i) Coal exists neither in the roof nor in the floor (0)

(ii) Coal does not exist in the roof, but may exist in the floor (0)

(iii) Coal exists in the roof, it may or may not exist in the floor (1)
(Panel does not have an upper section)

(iv) Coal exists in the roof, it may or may not exist in the floor (2)
(Panel has an upper section, virgin or otherwise)

[The coal of thickness 1.5m or more is only taken into account. Here the words 'coal exists' means that there exists 1.5m or more coal (in the roof or in the floor)]

(In extraction by depillaring with caving more coal in roof implies more loose coal on the floor as a result of roof fall. Here, the generated heat due to oxidation will be more, and hence the residual heat will also be more under the prevailing atmospheric conditions)

The fire risk rating of Module 1c may be obtained in the same way as in the case of Module 1a.

ANNEXURE 4

MODULE 2A: MODULE FOR COLLECTION OF FIELD DATA RELATED TO THE FIRE RISK PARAMETERS - GEOLOGICAL DISTURBANCES, AND LEAKAGE OF AIR FROM SURFACE/THROUGH PARTING

(Applicable to both unsealed and sealed panels)

- Surface cover (overburden above the selected panel)
- Subsidence/cracks and fissures on the surface of overburden (shallow width)
- Geological disturbances affecting the panel (presence of geological fault, dyke etc. in coal seam within the panel area)
- Leakage of air from surface
- Leakage of air through parting during depillaring
  [in view of the nature of extraction, status of the parting between the working section/seam and the upper section/seam (in case such a situation exists), and intensity of mining etc.]
- Quantity balance for evaluation of leakage with inference

ANNEXURE 5

MODULE 2B: MODULE FOR COLLECTION OF FIELD DATA RELATED TO THE FIRE RISK PARAMETERS - VENTILATION DURING EXTRACTION, AND INCUBATION PERIOD OF COAL

(Applicable to unsealed panels only)

- Ventilation status during depillaring (normal/sluggish)
- Depillaring panel, loose coal lying on the floor is exposed to the ventilating air, and panel is unattended (selective mining in haphazard sequence)
- Depillared area of a depillaring (or completely depillared but unsealed) panel is exposed to the ventilating air, while working in the nearby area outside or inside the panel
- Completely depillared but unsealed panel is situated at close proximity to a ventilation route
- Whether the work for preparatory isolation stopping was carried out during depillaring
- Incubation period and depillaring time of the panel
  (It is to be kept in mind that the incubation period of a panel reopened after a fire problem, should not be the same as in case of a new panel)

Note 3: In case of a panel temporarily sealed due to symptoms of fire, some of the residual heat may remain trapped within the oxidised coal. When reopened, this kind of trapped heat may lead to further heating.

ANNEXURE 6

MODULE 2C: MODULE FOR COLLECTION OF FIELD DATA RELATED TO THE FIRE RISK PARAMETERS - LEAKAGE FROM UNDERGROUND THROUGH BARRIER PILLARS, ISOLATION STOPPING, PANEL BARRIER ETC.

(Applicable to sealed panels only)

- Whether barrier pillars/panel barrier punctured during depillaring
- Whether the adjoining gallery of the sealed panel is used as a ventilation route creating huge pressure difference across the barrier pillars, isolation stopping, etc.
- Whether the sealed panel is endangered due to presence of unsealed air source at close proximity of the panel
- Existence of cracks and fissures in the barrier pillars, isolation stopping, etc. (may be due to intensive mining, heavy overburden, etc.)
- Quantity balance for evaluation of leakage into a sealed panel with inference

ANNEXURE 7

MODULE 2AB: FIRE PROVOCATIVE ENVIRONMENT AND CHARACTERIZATION OF THE RELEVANT CAUSES
(GUIDELINES FOR CHARACTERISING ENVIRONMENT OF UNSEALED PANELS)

1. When there is at least the necessary amount of coal (loose coal on the floor/loose coal in crushed stooks/coal fines in cracks of coal mass) in the goaf/worked out area of a depillaring panel that can support spontaneous heating, it is affected by a leakage of air (confirmed by observation/quantity measurement), and the depillaring time either has exceeded or is close to the incubation period, then fire risk rating ⟶ Very high (e)
2. When there is at least the necessary amount of coal (loose coal on the floor/loose coal in crushed stooks/coal fines in cracks of coal mass) in the goaf/worked out area of a depillaring panel that can support spontaneous heating, it is affected by a leakage of air (confirmed by observation/quantity measurement), and the depillaring time is significantly less than the incubation period, then fire risk rating ⟶ High (e)
3. When there is at least the necessary amount of coal (apparently no loose coal or coal fines) in the goaf/worked out area of a depillaring panel that can support spontaneous heating if accumulated on the floor or elsewhere, it is affected by a leakage of air (confirmed by observation/quantity measurement), and the depillaring time either has exceeded or is close to the incubation period, then fire risk rating ⟶ High (e)
4. When a completely depillared unsealed panel having at least the necessary amount of coal (apparently no loose coal or coal fines) that can support spontaneous heating if accumulated on the floor or elsewhere, is left exposed to the ventilating air or is at close proximity to a ventilation route, then fire risk rating ⟶ High (e)
   (This fire provocative cause carries an implied sense that the depillaring time of the running panel either has exceeded or is close to the incubation period)
5. When there is at least the necessary amount of coal (loose coal on the floor/loose coal in crushed stooks/coal fines in cracks of coal mass) in the goaf/worked out area of a depillaring panel that can support spontaneous heating, it is affected by a leakage of air (confirmed by observation/quantity measurement), and depillaring is carrying out with intermittent sealing and reopening of the panel due to heating, then fire risk rating ⟶ Very high (e)
6. When there is at least the necessary amount of coal (loose coal on the floor/loose coal in crushed stooks/coal fines in cracks of coal mass) in the working area of a running panel or elsewhere that can support spontaneous heating, it is unattended (may be due to selective mining in haphazard sequence), and the ventilation is insufficient (sluggish ventilation), then fire risk rating ⟶ Very high (e)
   (This kind of situation may help accumulation of more residual heat in loose coal/coal fines than in normal cases, and lead to early heating)
7. When an unsealed panel is free from any of the above fire provocative causes, then fire risk rating ⟶ Low (e)
8. When the goaf/worked out area of a depillaring panel does not have the necessary amount of coal to support spontaneous heating even though the area is affected by the ventilating air or leakage, then fire risk rating ⟶ Low (e)
9. When there is a leakage of air into an unsealed panel with weathered coal (ineffective to further oxidation), then fire risk rating ⟶ Low (e)

Note 4: Here we have followed a qualitative definition of incubation period of coal given as: it is the time elapsed between the start of the coal winning operations in a panel and first sign of recognized heating (Mukherjee et al. [8]). In India, the incubation period is understood more as a qualitative index rather than quantitative. It depends on the experience of the person engaged in determination of the parameter.

Note 5: There are some exceptional cases of spontaneous heating of loose coal when it is kept exposed to the ventilating air or leakage - in such cases the time requirement for initiation of heating is significantly less than the incubation period of the coal. These are very much colliery-specific incidents. There may be a few reasons that cause early heating; one of them is the existence of pyrite bands in coal seam. When there is a roof fall along with the pyrite bands, the material generates a huge amount of heat in moist atmosphere leading to spontaneous heating. The occurrence of this kind of incidents may be ascertained from the fire history of the colliery, and some of the fire provocative causes given in Table 7 could be suitably modified to include these incidents.

ANNEXURE 8

MODULE 2AC: FIRE PROVOCATIVE ENVIRONMENT AND CHARACTERIZATION OF THE RELEVANT CAUSES
(Guidelines for characterising environment of sealed panels)

1. When there is at least the necessary amount of coal (loose coal/coal fines existed in the panel at the time of sealing or it is highly probable that the panel acquired this kind of material after the sealing due to roof fall, crushing of stooks etc.) in a sealed panel that can support spontaneous heating, and it is affected by a leakage of air (confirmed by observation/quantity measurement) from outside the panel, then fire risk rating ⟶ Very high (e)
2. When there is at least the necessary amount of coal (loose coal/coal fines existed in the panel at the time of sealing or it is highly probable that the panel acquired this kind of material after the sealing due to roof fall, crushing of stooks etc.) in a sealed panel that can support spontaneous heating, and the panel is subjected to a substantial pressure difference due to presence of an outside air source, and the leakage could not be confirmed by quantity measurement, then fire risk rating ⟶ High (e)
3. When a sealed panel is free from any of the above fire provocative causes, then fire risk rating ⟶ Low (e)
4. When a sealed panel does not have the necessary amount of coal to support spontaneous heating even though it is affected by a leakage of air, then fire risk rating ⟶ Low (e)
5. When there is a leakage of air into a sealed panel with weathered coal (ineffective to further oxidation), then fire risk rating ⟶ Low (e)

Note 6: The statement 'a panel with necessary amount of coal that can support spontaneous heating' has different meaning for different systems of depillaring. In case of caving, the panel may not have coal in the roof, but the coal left in the stooks can support spontaneous heating. In case of partial stowing with sand it is different. Here the coal in stooks may not be able to support heating. In this case, a panel with necessary coal means that it has got an appropriate amount of coal in the roof also which in the long run may accumulate on the floor or elsewhere due to fall. In case of other systems of depillaring, some sort of realistic inference has to be made. However, the estimation of loose coal inside a sealed panel is purely subjective and may be left to the person assigned for the job.

MODULE 3: BUILDING MODULE OF THE GROUP 'COAL AND SEAM CHARACTERISTICS'
(Independent of mining environment)

Parameters	Fire risk numbers of individual parameter (N_j)
CROSSING POINT TEMPERATURE (CPT)	(0,1,2,3,4,5,6,7,8,9)
[Following specifications may be used for determination of CPT: Flow rate of oxygen = 80ml/min, rate of heating of glycerine bath = 1°C/min, amount of coal sample (kept at 60% RH before use) = 20g, and average particle size of coal sample = - BS72 + BS200]	
(i) CPT is less than 110°C	(9)
(ii) 110°C or more but less than 120°C	(8)
(iii) 120°C or more but less than 130°C	(7)
(iv) 130°C or more but less than 140°C	(6)
(v) 140°C or more but less than 150°C	(5)
(vi) 150°C or more but less than 160°C	(4)
(vii) 160°C or more but less than 170°C	(3)
(viii) 170°C or more but less than 180°C	(2)
(ix) 180°C or more but less than 190°C	(1)
(x) 190°Cor above	(0)
WETNESS OF MINES	(0,1,2)
(In case of the floor as well as both sides of galleries being fully wet, the mine/panel is taken to be wet. Otherwise, it is considered dry. Partial wetness just lies between these two states. It is also to be kept in mind that during depillaring with hydraulic sand stowing a running panel becomes wet. However, the experience of the user may be helpful in proper assessment of this parameter.)	
(i) Dry mine	(0)
(ii) Partially wet mine	(1)
(iii) Wet mine	(2)
EXISTENCE OF PVRITE BAND IN COAL SEAM	(0,1,2,3,4,5,6)
Dry coal	
(i) No pyrite band exists	(0)
(ii) Pyrite bands exist and total thickness: Less than 0.25m	(1)
(iii) Total thickness: 0.25m or more but less than 0.5m	(2)
(iv) Total thickness: 0.5m or more but less than 0.75m	(3)
(v) Total thickness: 0.75m or above	(4)
Wet coal	
(i) No pyrite band exists	(0)
(ii) Pyrite bands exist and total thickness: Less than 0.25m	(3)
(iii) Total thickness: 0.25m or more but less than 0.5m	(4)
(iv) Total thickness: 0.5m or more but less than 0.75m	(5)
(v) Total thickness: 0.75m or above	(6)
EXISTENCE OF INFERIOR COAL BAND IN SEAM	(0,1)
(It resists dissipation of heat from the loose coal)	
(i) It does not exist in the seam	(0)
(ii) There exists this kind of band	(1)
PARTICLE SIZE DISTRIBUTION IN COAL FINES	(0,1,2,3)
(Sampling from the heap of loose coal is done following a technique called 'cone and quartering')	
(i) -BS40+BS72 size fraction is > -BS72 size fraction + a margin of 50% of this size fraction	(0)
(ii) -BS40+BS72 size fraction is < -BS72 size fraction + a margin of 50% of this size fraction & > -BS72 size fraction + a margin of 25% of this size fraction	(1)
(iii) -BS40+BS72 size fraction is < -BS72 size fraction + a margin of 25% of this size fraction & > -BS72 size fraction	(2)
(iv) -BS40+BS72 size fraction is < -BS72 size fraction	(3)

[A size fraction is expressed in weight percentage (wt.%)]

GASSINESS OF COAL SEAM (1,2,4)

(i) Gassy seam of degree I (1)

(ii) Degree II (2)

(iii) Degree III (4)

(For details please see Note 10)

Therefore, the total fire risk number of Module 3 = ΣN_i

The corresponding fire risk value of Module 3 = $\Sigma N_j * 0.04$

Hence, the fire risk rating of Module 3 ⟶ Low(c)/High(c)/Very high(c), depending on the fire risk value as given below:

Low (c),	for fire risk value up to 0.44
High (c),	for fire risk value from 0.48 to 0.64
Very high (c),	for fire risk value from 0.68 to 1.00

Note 7: This module has been developed on the basis of field data, experimental data produced at laboratory, and the literature on coal and Indian coal mines. The parameter 'inherent moisture content of the coal' given in the original model (Roy[6]) has not been included in the improved version of the model as the effect of this parameter may be observed in CPT of coal (Banerjee[3]). Instead, we have introduced here a new parameter 'inferior coal band in seam'.

Note 8: On the basis of the data collected from different collieries, the specifications of the parameter 'particle size distribution in coal fines' given in the original model have been modified in this improved version. Here we have taken a little liberal view.

Note 9: It is to be noted that if a coal seam does not contain pyrite band, band of inferior coal, as well as if it is not a degree-III mine, then fire risk rating of the group 'coal and seam characteristics' can never be very high.

Note 10: All coal seams in India are now treated as gassy and they are classified into three degrees of gassiness as defined in Reg. 2 (12A, 12B, and 12C) of Coal Mines Regulations, 1957. These are given below:

12A: "Gassy seam of the first degree" means a coal seam or part thereof lying within the precincts of a mine not being an opencast working whether or not inflammable gas is actually detected in the general body of air at any place in its working below-ground, or when the percentage of the inflammable gas, if and when detected, in such general body of air does not exceed 0.1 and the rate of emission of such gas does not exceed one cubic meter per tonne of coal produced.

12B: "Gassy seam of the second degree" means a coal seam or part thereof lying within the precincts of a mine not being an opencast working in which the percentage of inflammable gas in the general body of air at any place in the working of the seam is more than 0.1 or the rate of emission of inflammable gas per tonne of coal produced exceeds one cubic meter.

12C: "Gassy seam of the third degree" means a coal seam or part thereof lying within the precincts of a mine not being an opencast working in which the rate of emission of inflammable gas per tonne of coal produced exceeds ten cubic meter.

12D: "general body of air" means the general atmosphere in a seam and includes the atmosphere in the roof cavities but does not include general atmosphere in the sealed off area or in any borehole drilled in coal or in the adjacent strata.

ANNEXURE 10

FIRE RISK RATING SCALE FOR UNDERGROUND PANELS IN BORD AND PILLAR MINING

	Fire risk potential of panels (combination of the fire risk ratings of three broad groups arranged in decreasing order of domination)	Fire risk rating of panels (in ascending order) (Evaluated)		Fire risk potential of panels (combination of the fire risk ratings of three broad groups arranged in decreasing order of domination)	Fire risk rating of panels (in ascending order) (Evaluated)
(i)	Low(e), low(c), low(p)	(1)	(xv)	High(e), high(c), very high(p)	(15)
(ii)	Low(e), low(c), high(p)	(2)	(xvi)	High(e), very high(c), low(p)	(16)
(iii)	Low(e), low(c), very high(p)	(3)	(xvii)	High(e), very high(c), high(p)	(17)
(iv)	Low(e), high(c), low(p)	(4)	(xviii)	High(e), very high(c), very high(p)	(18)
(v)	Low(e), high(c), high(p)	(5)	(xix)	Very high(e), low(c), low(p)	(19)
(vi)	Low(e), high(c), very high(p)	(6)	(xx)	Very high(e), low(c), high(p)	(20)
(vii)	Low(e), very high(c), low(p)	(7)	(xxi)	Very high(e), low(c), very high(p)	(21)
(viii)	Low(e), very high(c), high(p)	(8)	(xxii)	Veryhigh(e), high(c), low(p)	(22)
(ix)	Low(e), very high(c), very high(p)	(9)	(xxiii)	Very high(e), high(c), high(p)	(23)
(x)	High(e), low(c), low(p)	(10)	(xxiv)	Very high(e), high(c), very high(p)	(24)
(xi)	High(e), low(c), high(p)	(11)	(xxv)	Very high(e), very high(c), low(p)	(25)
(xii)	High(e), low(c), very high(p)	(12)	(xxvi)	Very high(e), very high(c), high(p)	(26)
(xiii)	High(e), high(c), low(p)	(13)	(xxvii)	Very high(e), very high(c), very high(p)	(27)
(xiv)	High(e), high(c), high(p)	(14)			

Note 11: Though the second column of Table 10 gives the fire risk potential of a panel, for more intimate understanding the fire risk values of the groups 'coal and seam characteristics' and 'panel specifics' should also be kept in mind.

ANNEXURE II

PREDICTION RESULTS AND OBSERVED STATUS OF SOME PANELS

	Panel/colliery/ subsidiary of CIL/ seam/system of extraction'	Fire risk rating of the group 'environment'	Fire risk rating of the groups of parameters: Fire risk rating of the group 'coal and seam characteristics' (Table 9)	Fire risk rating of the group 'panel specifics'	Fire risk potential of the panel obtained by using the prediction model)	Fire risk rating of the panel (Table 10)	Observed status of the panel
1.	Panel-39/ Chirimiri colliery /SECL/Seam-3 (bottom section) /depillaring with caving	Very high (Fire provocative cause no.1) (Table 7)	Low (Fire risk value: 0.2)	High (Fire risk value: 0.7) (Table 3)	Very high(e) low(c), high(p)	20	Fire in depillaring panel (Unsafe)
2.	Panel-7/ Samla colliery/ ECL/Samla/ depillaring with hydraulic sand stowing	Low (Fire provocative cause no.7) (Table 7)	Low (Fire risk value: 0.44)	Low (Fire risk value: 0.4 (Table 2)	Low(e), low(c), low(p)	1	Non-fire depillaring panel (Safe)
3.	Panel-5/ Methani colliery/ECL/ Burradhemo/ depillaring with caving	Very high (Fire provocative cause no. 1) (Table 8)	Low (Fire risk value: 0.4)	Low (Fire risk value: 0.4) (Table 3)	Very high(e), low(c), low(p)	19	Fire in sealed panel (Unsafe)
4.	Part-panel-6/ Methani colliery/ ECL/ Burradhemo/ depillaring with caving	High (Fire provocative cause no.2) (Table 7)	Low (Fire risk value: 0.4)	Low (Fire risk value: 0.4) (Table 3)	High(e), low(c), low(p)	10	Non-fire depillaring panel (Vulnerable)