PURPOSEFULNESS OF IMPROVING THE BOREHOLE FIRE EXTINGUISHING METHOD AND PREVENTION OF UNDERGROUND FIRES WITH DIFFICULT ACCESS

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Summary. The paper presents experiences acquired in a difficult fire-fighting operation, during which the borehole fire extinguishing method was successfully used for quenching a dangerous fire with difficult access. The method consisted in extinguishing the fire by supplying packing material through boreholes made during the fire-fighting operation. The operation was conducted for 5 weeks without stopping production on the longwall. The cavities in the longwall caused by extraction were in direct contact with the fire-enveloped area. The paper specifies positive aspects of the borehole method of extinguishing fire as well as its deficiencies in need to be perfected further. It was found necessary that in order to improve its effectiveness mine rescue services had to be provided with modern and dependable drilling machines and equipment, it was necessary to improve underground drilling technology in difficult geological and exploitation conditions, systematically maintain well-trained teams of rescue workers specialized in drilling, extend the range of using packing material in mines and increase operating dependability of installations, get better knowledge of properties of packing materials in connection with the planned objective of backfilling (e.g. flooding the fire focus, making sealing stoppers, goaf stowing, etc.)

I. Introduction

In spite of big efforts made by the mines and mine rescue services, underground fires are still a great hazard to the mining staff, mine property and the deposit. The intensive fire prevention programme implemented in Polish mining industry has in consequence given a decreasing number of these dangerous events [9, Table 1, Drg. 1]. However, in connection with large concentration and intensification of mining works the costs of conducting necessary fire-fighting operations are increasing considerably.

Table 1. Statistical data pertaining to fire hazards in Polish coal mines during the last 10 years

	Years 1993 ÷ 2002										Total
	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	
Number of fires	15	12	9	9	6	7	6	3	1	7	75
Fire rate indicator	0.12	0.09	0.07	0.07	0.04	0.06	0.06	0.03	0.01	0.07	0.06
Number of endogenous fires	10	7	9	7	4	5	3	2	1	4	52
Percent share [%]	66	58	100	78	67	71	50	67	100	57	70
Number of exogenous fires	5	5	-	2	2	2	3	1	-	3	23
Percent share[%]	34	42	0	22	33	29	50	33	0	43	30

Causes of exogenous fires											
Electrical defects	1	1	-	-	2	1	-	-	-	-	22
Mechanical defects	2	2	-	-	-	-	-	-	-	-	4
Starting fires	2	1	-	2	-	-	2	-	-	3	10
Causes unknown	-	1	-	-	-	1	1	1	-	-	4
Total costs of all fires [mln PLN]	16,57	24,10	6,98	11,75	22,58	11,00	22,84	18,35	10,00	52,08	
Average cost of one fire [mln PLN]	1,18	2,00	0,78	1,31	3,76	1,57	3,81	6,12	10,00	7,44	

During the last 10 years, i.e. from 1993 to 2001 the total number of fires was systematically decreasing from 15 in 1993 to 1 in 2001. The so called fire rate determined as a quotient of the number of existing fires per 100 million tons of mined coal in a given year also kept falling systematically. Unfortunately, in 2002 there were 7 fires. There is a heated discussion being conducted in Poland and intensive scientific studies aimed at explaining such considerable increase in the number of all fires in the year 2002. We have so far had two dangerous fires in mines with a high methane concentration till the end of July 2003.

The data presented in Table 1 shows a smaller share of exogenous fires – approximately 30%. However, endogenous fires are still a big danger – 70%. The problem of suitable prevention and fighting these fires therefore requires the working out of more effective methods of fighting them. This applies to suitable mining technologies, which reduce the risk of such fires being formed, improving methods of their early detection, efficient extinguishing methods, particularly in inaccessible goafs.

The practice of extinguishing fires in coal mines occurring during recent years shows that apart from the well-known active, passive and combined extinguishing methods [2, 5], the so called borehole method was successfully used in several fire-fighting operations. The method consists in feeding through boreholes to the centre of the fire or to the fire enveloped area, a stowing mixture that should quench the fire or seal off that area. However, success of this operation depends on many factors, such as:

- possibly accurate location of the fire centre in goafs or in workings with difficult access,
- accurate planning and execution of boreholes leading to the fire centre, goafs or to threatened workings,
- maintaining boreholes in rock mass frequently disturbed by working or with geological displacements,

- efficiency and reliability of stowing mixture feeding technology through the drilled boreholes.

The borehole method has also been successfully used in preventive works, especially during liquidation of endogenous fire hazard in goafs.

2. Fire detection circumstances, initial stage of the operation

During the night shift of 16th to 17th April, 2001, on a holiday, the inspection team making the round stated at the mouth of the drift C5E (Drg. 2) the smell of hydrocarbons and with the indicator tubes a concentration of carbon monoxide in excess of the admissible level of 26 ppm. The fact was immediately reported to the mine control room. A mining officer from the ventilation division was directed to the endangered working on level 550 m, whereas a nearby mine rescue team was directed to the drift C6E (Drg. 2) on level 650 m. Further measurements carried out at the mouth of drift C5E confirmed the existence of CO concentration value of 50 ÷ 60 ppm. It was decided that a fire-fighting operation was to be started. The earlier mentioned inspection team making the round was detained in the roadway W52S/III and was ordered to perform the task of first guard of the smoky zone. The rescue team from the roadway W64S and drift C6E (Drg. 2) started penetrating the workings of the endangered area. A high concentration of CO was found in the niche before the sealing dam TI 479 (Drg. 2, 3, 5) cutting off the workings in seam 405/3 in the vicinity of the drift C6E support pillar and in the flow round current in drift C6E starting from this dam.

This information allowed to locate the centre of the fire initially in closed down workings of the 405/3 seam or in the dammed goafs of that seam north of the drift C6E (Drg. 2, 3, 5). The zone endangered with fire smoke, marked out in conformity with the binding principles, included workings with air current at the mouth in the line of drifts C6E, C5E and C4E on levels 650, 550 and 450 respectively and from level 550 m upcast shaft of the neighbouring "Szczygłowice" Mine. The zone was secured with 6 required posts.

3. Characteristic of seam 405/3 and threatened mine area

The seam 405/3 with thickness of 3.5 ÷ 4.0 m and slope of 15° ÷ 20° in part of the "Knurów" mining area, in the panel between drift lines B and C was mined since 1982 (Drg. 2, 3). Mining was carried out with the longitudinal longwall system with roof caving in 8 longwalls. The goafs in this seam spread over the depth of approx. 450 m to about 850 m. During the analysed period longwall No. 29, leading from the drift line C to line B (Drg. 2, 3),

was in operation. The direction of previous longwall running was the opposite, that is from line B to line C.

Seam 405/3 belongs to Category II of methane hazard, 1st degree of water hazard, Class B of coal dust explosive conditions and it is a non-rock burst seam. The coal in longwall 14 panel (lot above longwall 29) has been included in group I of liability to spontaneous ignition, whereas in longwall 29 panel to Group III.

The previous longwall 14 with seam 405/3 (Drg. 2, 3) was a sub-level longwall with access from level 650 m drift C6E made by means of sloping belt conveyors I and II. After longwall 14 lot had been excavated the needless workings were sealed off with complex sealing dams (brickwork and frame dam as well as stopping made of mineral binding material).

Then the longwall 29, in the part of seam 405/3, 200 m in length and total life of face 1150 m, could be made accessible from the side of the B8E drift on new level of 850 m. Development of the lot was also conducted from the side of the C6E drift level 650 m by making a haulage incline I (Drg. 2, 3, 5) to the corner of the longwall 20 raise and top road 29a. This incline made reinforcement of longwall 29 much easier. However, the driving of incline I involved the cutting of old workings i.e. haulage roadways I and II (Drg. 2, 3, 5) twice. The roadway crossings formed were secured by making sealing frame dams.

Starting of the longwall 29 took place in July 2000. It was fitted with 24/47Oz Pioma support, KSW-500 cutter-loader, PSZ 850 "Nowomag" longwall conveyor. The longwall achieved a high rate of advance over 100 m/month and considerably high output 4200 ÷ 4500 t/d. This formed about 40% of the daily output of the mine. Transport of mined rock from the bottom road 29b was directed to a higher level of the mine by means of belt conveyors.

After starting longwall 29. the haulage incline I was closed by stowing the entire crossing with road from the drift C6E side with ash dust. At a later date the whole incline in seam 405/3 up to the level 550 m was also backfilled. It was then that "U type" system ventilation of longwall 29 was made possible Dr. 2, 3). Intake air to the longwall was conducted along the bottom road 29b from drift B8E level 850 m. The return air was directed along the top road 29a to the ventilation passages in seam 406/1 and to level 550 m to drift B5E, and then by means of ventilation passages to shaft V of the neighbouring "Szczygłowice" mine. The delivery of air in the longwall, due to the fairly difficult thermal working conditions, amounted to approximately 1300 m^3/min. The methane-bearing capacity was small up to 5 m^3Ch_4/min. There was no carbon monoxide in the flow round current,

concentration of that gas in the cave-in did not exceed 5 ppm. Until the fire had broken out the longwall achieved 840 m advance of face, whereas the remaining life was 310 m.

The fireproof protection prepared for longwall 29 provided feeding a mixture of ash dust and water to the goafs in the longwall. This type of stowing was being effected from the side of the C6E drift. Till the day of the fire approximately 650 m^3 of mixture had been pumped into the goafs.

Above the goafs in seam 405/3 there are dammed goafs of non-methane seams 405/1, 404/5 and 404/2 at the vertical distance of 44 m, 47 m and 85 m respectively from seam 405/3. Under the goafs of seam 405/3 up to the level of 650 m there are dammed goafs in seam 406/1 and 406/3 at a distance of 14 m and 43 m. The seams in this part of the deposit have been classified respectively as Category III and Category I of methane hazard. No works had been conducted in the seams between drifts B and C during the analysed period.

4. Planned lines of defence as well as active and passive extinguishing of fire

During development of the fire there was a quick increase of fire gas concentration behind dam TI 479, in the flow round current of air from that dam in drift C6E level 650 m and in the entire zone (Drg. 2, 3). After several hours a high concentration of gases was also found behind dam TI 736, which sealed off the workings in seam 406/1 from the C6E drift side. It was observed that gases were permeating through the rock mass around the dams. Later on gases were being liberated into the flow round current also from the north wall, roof and floor of drift C6E in the neighbouring seams. The rock mass around the drift C6E was considerably loosened. During previous months, certain sections of the working had to be rebuilt. On the second day of the operation the stream of evolving carbon monoxide, determined on the basis of taken measurements, among other things, in the upcast shaft V of KWK "Szczygłowice" mine, reached the value of approximately 600 l_{CO}/min (Drg. 4). This proved that the fire was developing very fast.

Analysis of the order of appearance of fire gases and increase of their concentration behind the sealing dams TI 479 (Drg. 2, 5 - from two control pipes, that is from the sealed off haulage incline I and from the access gallery to the goafs of longwall 14), behind TI 736 – seam 406/1 level 650 m, TI 541 – seam 406/1 level 550 m and TI 195 – seam 405/3 level 550 m allowed to specify the most probable place, where the fire formed in the support pillar of drift C6E in the area of the corner of the longwall 14 raise and haulage incline I (Drg. 5). The results of tests of air penetration through the goafs using tracer gas SF_6 [1] were also used in this range. Most probably this was a fissure fire in this corner, which after a certain time took

over the whole crossing together with haulage incline I and sloping roadways I and II (Drg. 5). The distance of this spot from the closest active working in the mine – drift C6E – was about 95 m.

The existing situation, due to inaccessibility to the fire centre, contact with goafs of the active longwall 29 in seam 405/3, directions of air and fire gas penetration through the goafs and damming of the working, showed that it would be very difficult to get the fire under control. The fire-fighting operation plan, prepared in conformity with general principles [2, 5] anticipated the alternative use of three Line of Defence. Implementation of the consecutive line depended on the success or lack of progress in quenching the fire.

Defence Line I assumed the ambitious plan of active extinguishing of fire with the borehole method by pumping stowing mixture into the fire enveloped area i.e. behind the sealing dams and to goafs through the boreholes drilled during the operation, as well as maximal sealing of the rock mass around the sealing dams and drift C6E. This plan assumed ending the operation without forming a fire field, saving longwall 29 and maintaining its production whilst conducting the operation. This was a very important matter for the mine given the fact that longwall 29 had 40% share in the total output of the mine.

Defence Line II, which would have been put into effect had there been no progress in active extinguishing of the fire according to Line I assumptions, assumed the necessity of forming a fire field with inlet dams built on bottom roads 29a and 29b of longwall 29 seam 405/3 (Drg. 2, 3) and existing outlet dams of drifts C6E, C5E and C4E on levels 650, 55 and 450 m respectively. The high-yield longwall 29 would have had to be closed in this field, thereby causing great economic losses to the mine, in its production potential and in its output. Materials and places for making fire dams were prepared during the operation.

Defence Line III would have been effected in the event, if it were impossible to get the danger under control in compliance with assumptions of Line II. Great difficulties were expected with sealing the dams next to drift C6E and rock mass around the drift. Such difficulties could not be excluded, therefore the necessity of closing the drift C6E on the section between seams 403/1 and 406/3 (Drg. 2) was additionally assumed. This section was also included in the fire field. In the event of having to implement the Defence Line III the mine losses would have been greater still. Material and places for making fire dams additionally in drift C6E during the operation were also prepared.

5. Assumptions of Defence Line I aimed at extinguishing the fire with the borehole method

In compliance with principles of a difficult fire-fighting operation, in order to obtain quick knowledge of how the fire gas concentration was shaping, the chromatography emergency unit of the CSRG (Central Mine Rescue Station) in Bytom was called on the second day of the operation. Three observation lines were installed. Independent air samples were also being taken by mine service staff and measurements were made with individual equipment.

As already mentioned, the assumptions of **Defence Line I** planned active extinguishing of inaccessible fire without the necessity of forming a fire field. With regard to sealing off the space around the fire on the side of fire gas outlet during the operation, it was possible to additionally seal the outlet dams next to the drifts C6E level 650 m, C5E level 550 m and C4E level 450 m (Drg. 2, 3), sealing the rock mass around these drifts and stowing with ash dust closed down workings, through which fire gases from the fire centre migrated to active workings in the sub-network of the upcast shaft V "Szczygłowice". Sealing off the fire outlet was put into effect according to Items a) and b) of the following general specification of works.

The seal from the side of the air inflow to the fire enveloped area (closing of inlet), in Defence Line I was very problematic, because the air migrated probably to the fire through goafs of the active longwall 29. That is why Line I plan assumed the pumping of ash dust mixture and water into these goafs, and in the final stage of the operation also sand and heavy foam. It was expected that this stowing will not be fully effective due to its considerable volume and unfavourable space configuration of the goafs with a decline of several degrees towards the longwall 29. This could cause a substantial inflow of water to the bottom road 29b and make longwall advance difficult (Drg. 3) In order to further reduce air penetration through the goafs the difference of aerodynamic potential between the longwall and drift C6E was reduced. Moreover, sealing stoppages (Items c, d of the general scope of works) were built along the line of caving in the bottom road following the advance of the longwall.

It was possible to actively affect the fire during the extinguishing process by making boreholes to the workings affected by fire and to drifts, pumping a dust and water mixture as well as water, and in the final stage of the operation additionally sand and heavy foam (items e, f, g of the general scope of works).

Therefore, in order to fight the fire in conformity with the assumptions contained in **Defence Line I,** it was necessary to:

a) start works connected with sealing dams, walls around these dams located next to the drift C6E level 650 m, and later also sealing off dams next to drifts C5E lelevl 550 m and C4E level 450 m (Drg. 2),
b) start works connected with sealing rock mass around the drift C6E level 650 m, and later also around drifts C5E level 550 m and C4E item 450 m (Drg. 2, 3, 5),
c) reduce the difference in aerodynamic potential between longwall 29 and drift C6E in order to limit the migration of air from the longwall through the goafs to the fire enveloped area, simultaneously preventing the migration of fire gases from the fire to the longwall 29,
d) with the advance of longwall 29, build stoppages restricting the flow of air to the goafs in bottom roads along the line of caving,
e) start works involved with drilling long boreholes to goafs in seam 405/3, to certain closed workings in the area and behind chosen sealing dams,
f) start works connected with pumping a mixture of ash dust and water behind the sealing dams and through the boreholes made to goafs and closed workings,
g) increase the intensity of pumping water from the bottom road 29b of the longwall 29, due to the flow of water through the goafs to this roadway. This flow resulted from the unfavourable arrangement of goafs for stowing with a decline of several degree towards the longwall 29 (Drg. 3),
h) secure a suitable supply of materials and equipment,
i) conduct works involved with the possibility of performing the assumptions of Defence Line II and III.

The presented assumptions of Defence Line I required the provision of appropriate staff, equipment and means as well as suitable organization of all works.

6. Active extinguishing with the use of packing material fed through boreholes

For the first two days of the fire-fighting operation, advance of the longwall 29 in seam 405/3 was stopped. This resulted from the necessity of recognizing the possible fire gas hazard, adjustment of the network to reduce air penetration through the goafs, elaboration of additional automatic safety measures (additional monitoring of air composition). Upon elaboration and implementation of longwall 29 operating principles in the vicinity of an active fire, the longwall was again put in operation and achieved a slightly lower output than before.

Works connected with additional sealing of dams and rock mass around the dams in the outlet zone from the fire area were conducted on 5 dams to the north of drift C6E level

650 m (Drg. 2), with two dams to the north of drift C5E level 550 m and one dam to the north of drift C4E level 450 m. The construction of certain sealing dams in non-methane seams required reinforcing in order to fulfil explosion-proof requirements. This was the consequence of methane appearing behind these dams during the operation. There were two cases of explosive methane-air mixture appearing. This gas penetrated the goafs and fissures in rock mass from the goafs of the methane seam 405/3 to the goafs of the methane-free seams 405/1 and 404/5.

In the drift C6E wall cementing and narrowing of the roadway was made on a length of about 220 m as well as casting of floor on a distance of approx. 150 m. The north wall of the drift and sealing dams were controlled each day with an infrared camera. In the drift C5E cementing of walls and roadway narrowing was needed on a length of about 65 m. In drift C4E identical works had to be performed on one dam on a length of approx. 25 m.

During the foregoing sealing works different chemical and mineral agents were used, depending on the requirement and supplies. Their consumption was as follows: mariflex 78.8 Mg, durafoam 189.6 Mg, tekblend 56 Mg, geolit 3 Mg, geoset 10.5 Mg, wilkit 13.7 Mg. In order to reduce air penetration to the fire area approximately 9,000 m^3 of dust and water mixture was pumped into the longwall 29 goafs, and somewhere round 800 Mg of sand during the last days of the operation.

As the theory and practice of extinguishing underground fires shows [2, 5] closing off the outlet or inlet only to the extensive fire area does not lead to extinguishing of fire. That is why in the situation, which occurred in the fire-enveloped pillar, to the north of the drift C6E, especially with a leaky inlet, it was necessary to make an attempt at extinguishing the fire by using the active method. As we have already mentioned, the plan of Defence Line I assumed the application of the borehole method by making several long boreholes (up to 135 m) to the goafs and closed workings, and pumping of a dust-water mixture through the boreholees. The mine's own rescue units as well as specialist units of the CSRG (Central Mine Rescue Station) in Bytom and ZOK Jastrzębie were engaged in making these boreholes.

In the first phase of the operation it was planned to make two boreholes (Drg. 5) of 143 mm diameter at least to longwall 14 goafs, i.e. from the drift C6E borehole I 92 m long and from drift C5E borehole 8 of 135 m long. The influence range of these boreholes in the goafs should have interrelated, thus stopping the fire from spreading in the initial phase and then to its extinguishing. This interrelation of borehole influence was also necessary due to the fact that the location of the fire centre was not fully certain and also in view of the possibility of its displacement during the operation.

Borehole I, which had been planned from drift C6E to the access road crossing to longwall 14 goafs, was not made due to the jamming of drill conduit during drilling. The planned function of this borehole was later taken over by borehole 4, 62.5 m long, made from the drift C6E to the access road crossing to the longwall 14 and sloping road I (Drg. 5). As it turned out later this borehole became the most important borehole during the entire operation. More or less 13,000 m^3 of mixture was fed to longwall 14 goafs and sloping road I through this borehole. The batching was repeated a number of times and the borehole "accepted".

Borehole 8 and parallel borehole 8a about 135 m in length, drilled from the drift C5E to the upper corner of longwall 14 was not made due to drilling tooth failure. Drilling of parallel borehole 8b, through which water was still fed, was completed during the last days of the operation.

On 4^{th} day of the operation fire gases together with hydrogen (approx. 0.9% H_2) appeared behind the sealing dam TI 195 in seam 405/3 – area of drift C5E to the north at a higher level of the mine 550 m (Drg. 2). This meant that these gases penetrated the goafs of panels excavated in the years 1986 – 1991 to a higher level and the possibility of the fire shifting to the support pillar. In order to remove this danger borehole 11 with a length of 117 m (Drg. 3) was made from drift C5E to goafs in seam 405/3. This borehole was often blocked when water was being fed, thereby requiring enlarged drilling. In practice it only accepted water – more or less 800 m^3. The reason for this could be considerable bonding of the caving rubble from 1991.

Other boreholes drilled during the operation served to fill the workings that had already been closed down in that area with a dust and water mixture. During the operation it was acknowledged that their stowing would bring a favourable effect because air and fire gas migration was eliminated and the possibility of fire spreading any further was eliminated. In sum 23 boreholes had been planned, the drilling of 22 boreholes was taken up, the drilling of 10 boreholes was abandoned due to the fact that drilling conduits jammed during the process, other equipment defects occurred or the planned working was not reached through the borehole. Great difficulties appeared during the drilling of long boreholes, which ran through the area of the working boundary of several seams. During the fire extinguishing process a total of 8 boreholes was used effectively. Beside the already mentioned ones, the following boreholes were used:

- borehole 6b – 20 m long from drift C5E to the incline in seam 404/5 – filling of incline from level 550 m to 650 m,

- borehole 3b – 25 m long from drift C5E to the incline in seam 406/1 - filling of incline from level 550 m to 650 m,
- borehole 5 – 23 m long from drift C6E to sloping road I in seam 405/3,
- borehole 17 – 26 m long from drift c6E to incline in seam 404/5,
- borehole 18a – 87 m long from drift c6E to the haulage incline I in seam 405/3.

In sum, approximately 51,200 m^3 of dust and water mixture and approximately 800 Mg sand was fed to the goafs and workings through the boreholes and pipes in the sealing dams during the fire-fighting operation. In the final stage of the operation, in order to speed up the cooling of the haulage incline I and sloping roads in seam 405/3 area C6E to the north, heavy foam deteor – 3670 I and roteor – 3060 I was fed to the workings.

During the most difficult stage of the operation area more or less 720 l_{co}/min of carbon monoxide (Drg. 4) was liberated in the fire-enveloped area. Concentrations of fire gases during this time behind the most difficult dams were as follows (Table 2):

Table 2. Chosen fire gas concentrations behind certain fire and sealing dams

Sealing dam	Seam, area	Date of Analysis	O_2 %	CO_2 %	CO %	CH_4 %	H_2 %	C_xH_y %
TI 479a	405/3 road to longwall 14	24.04.01	5,21	9,6	2,45	4,36	1,54	0,07
TI 479	405/3 haulage incline I	24.04.01	4,29	9,54	2,58	5,24	1,20	0,07
TI 736	406/1 C6E to N	24.04.01	5,59	10,17	3,00	4,19	3,77	0,08
TI 541	406/1 C5E to N	24.04.01	4,68	11,33	1,64	4,04	2,44	0,07
TI 195	405/3 C5E to N	24.04.01	3,68	10,61	1,13	3,80	0.50	0,05

During the conducted works CO liberation from the fire-enveloped area (Drg. 4) periodically dropped and then increased. The same applied to gas concentrations behind the sealing dams. This proved the active effect on the fire and unfortunately of its repeated temporary increased burning intensity. During the last two weeks of the operation, after a stagnation period, there was a clear falling trend of CO flow produced by the fire (Drg. 4). Also concentrations of other fire gases started dropping. Tests of composition and reduction dynamics of these concentrations confirmed the possibility of active extinguishing of the fire.

In 5th week of the operation detailed tests of air composition with the use of modern chromatographic methods were carried out. These tests confirmed that the burning process had finished and that now it passed into the cooling stage of the still hot coal substance [3]. Mine analyses also confirmed a drop in the rate of fires behind sealing dams and in the flow round currents to admissible values. These facts authorized the Manager of the Fire-Fighting Operation to call it off on 21st May, 2001. Conviction that the fire had been extinguished, in result of carried out tests, allowed to finish the operation without forming a fire field. After almost five weeks of difficult operation, the assumptions of Defence Line I were successfully implemented, and the inaccessible fire was quenched actively by using the borehole method, practically maintaining untouched the course of the longwall 29 in seam 405/3.

During the culminating period of work intensity in the operation underground 11 units had been working at the same time during one shift. In sum, at certain moments there were 200 people engaged in connection with the operation. The Operation Manager made use of the opinions of the WUG (Superior Mining Office) Commission Working Team and detailed analyses of fire gas concentrations carried out by GIG (Chief Mining Institute).

Further works in the said area connected with the final sealing of workings and goafs, control of air propagation and distribution of aerodynamic potential in the ventilation network as well as tidying up the active workings were conducted within the framework of preventive works.

7. Difficulties during the Operation

The long five week period of conducting the fire-fighting operation was caused by inaccessibility of the fire in sealed off workings of the support pillar of drift C6E touching on the line of caving, vast heterogeneity of rock mass resulting also from the excavation of several seams in the area, application of the difficult to implement Defence Line I as well as unforeseeable events such as defects of equipments, installations, and certain unavoidable organizational errors. The experiences obtained in this range are worthy of attention, as they enrich the theory and practice of fighting underground fires.

A great difficulty during the operation was the small effectiveness of drilling of planned boreholes. As mentioned earlier the drilling of 22 boreholes had been started. This large number of boreholes resulted from the necessity of doubling the boreholes, during the drilling of which different failures appeared or the borehole failed to reached the planned spot. There were cases when three attempts had to be made to finish the borehole drilling. This applied to boreholes of different lengths, in particular the longest ones. Approximately 36% of

the started boreholes were used more or less effectively during the operation. Very often there appeared difficulties during drilling or in maintaining the already drilled borehole, which cut through working boundaries. Nevertheless, the usefulness of this borehole method in fighting inaccessible fires in certain cases, shows the purposefulness of improving the technology of emergency drilling, especially in rock mass dislocated by natural factors and mining.

The installation already existing in the mine was used during the fire-fighting operation to feed the stowing mixture; it had low flow capacity and unfortunately high failure frequency, especially of its underground elements. This high failure frequency and low availability of the installation also considerably contributed to the extension of the operation. As already mentioned, till then the installation was used for locating wastes in closed down workings and in fire prevention. It is a well-known fact that in many mines with typical hydraulic packing material (sand and water), the extinguishing of fires with such packing is a well-tested and effective element of fire-fighting practice. The effective use of the fire quenching method by using power wastes and post-flotation wastes during the foregoing operation proves its usefulness. However, due to certain drawbacks, the methods needs to be perfected.

Behind two sealing dams in non-methane seams, the methane and air mixture (without fire gases) obtained parameters, which indicated to the possibility of an explosion. This hard to foresee circumstance was the consequence of methane penetrating through the cracked rock mass from goafs of the methane seam 405/3 to the goafs of non-methane seams 405/1 and 404/5 located in the vertical distance of 44 and 47 m. This held up the basic operation trend for several shifts. The explosive methane-air mixtures formed were being fought by systematic feeding of stowing material behind the dams with the purpose of filling the goafs and cracks in rock mass between these seams.

Moreover, insufficient delivery of the pump feeding water from the bottom road of longwall 29, in spite of two pumps type PSZ 125 being operated, installed on this road, was a serious impediment during the operation. On several occasions after stowing the water flowed out of longwall 29 goafs to roadway 29b, thus obstructing the longwall operation. Then the filling with stowing material of longwall 29 goafs had to be stopped.

8. Final remarks, statements and conclusions

The course of the five-week difficult fire-fighting operation, during which by using passive and active methods (borehole method), the inaccessible fire in the line of the support pillar of drift C6E and goafs was successfully extinguished without the necessity of creating a

fire field, proves that the assumptions accepted in Defence Line I were well-grounded. This was made possible by additional sealing of the fire outlet area, partial sealing of the inlet area and actively by pumping the ash dust mixture to goafs and closed workings through the drilled boreholes during the operation. With small interruptions the operation did not interfere with the advance of the active longwall, so important for the output of the mine. Production in the longwall was safely conducted in the neighbourhood of the fire-enveloped area during the operation. Extinguishing of the fire with the use of the borehole method without forming a fire field, allowed the panel to be excavated till the end of its planned.

The course of the fire-fighting operation justifies the following statements and conclusions to be made:

1. Beside hydraulic packing (sand and water) in mines that do not have such installations, it is helpful to use installations for locating power and post-flotation wastes in fire-fighting operations and in fire prevention. The use of such an installation considerably contributed to extinguishing of the fire in seam 405/3.
2. It is necessary to improve the technology of locating power and flotation wastes in order to decrease operating failure frequency and to increase availability so very needed in fire-fighting operations.
3. Extinguishing of inaccessible fire with the use of boreholes drilled during the operation brought positive effects. However, due to the large uncertainty of its performance, especially of long boreholes in rock mass with natural dislocations and those caused by mining, it is necessary to improve the technology of such emergency drilling.
4. Mine rescue services should be equipped on a central level with modern drilling equipment low in failure frequency, useful in preventive works and during extinguishing of underground fires with the borehole method.
5. Specialised units of drillers - mine rescue workers should be maintained and trained on a current basis with the purpose of effective drilling of boreholes needed in fire prevention and during quenching of inaccessible underground fires.
6. It is necessary to intensify the testing of different stowing materials with added mineral and resin components in order to obtain the necessary properties with regard to sealing, filling of workings, strength, permeability, bonding time, etc.

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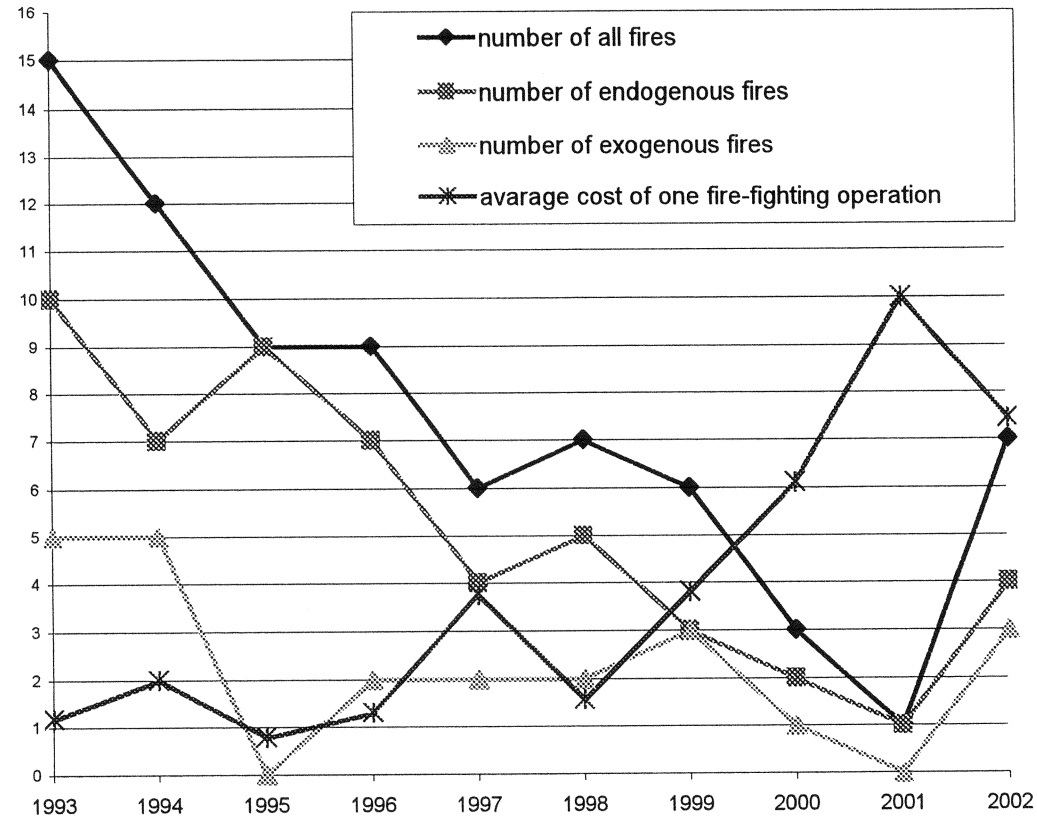
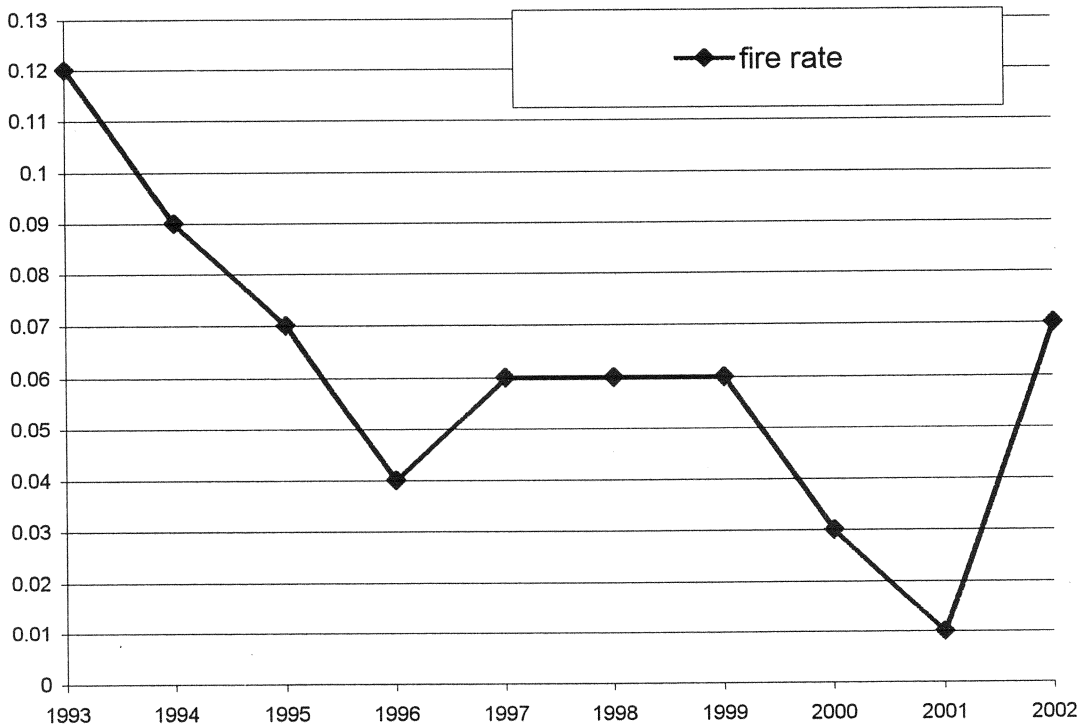
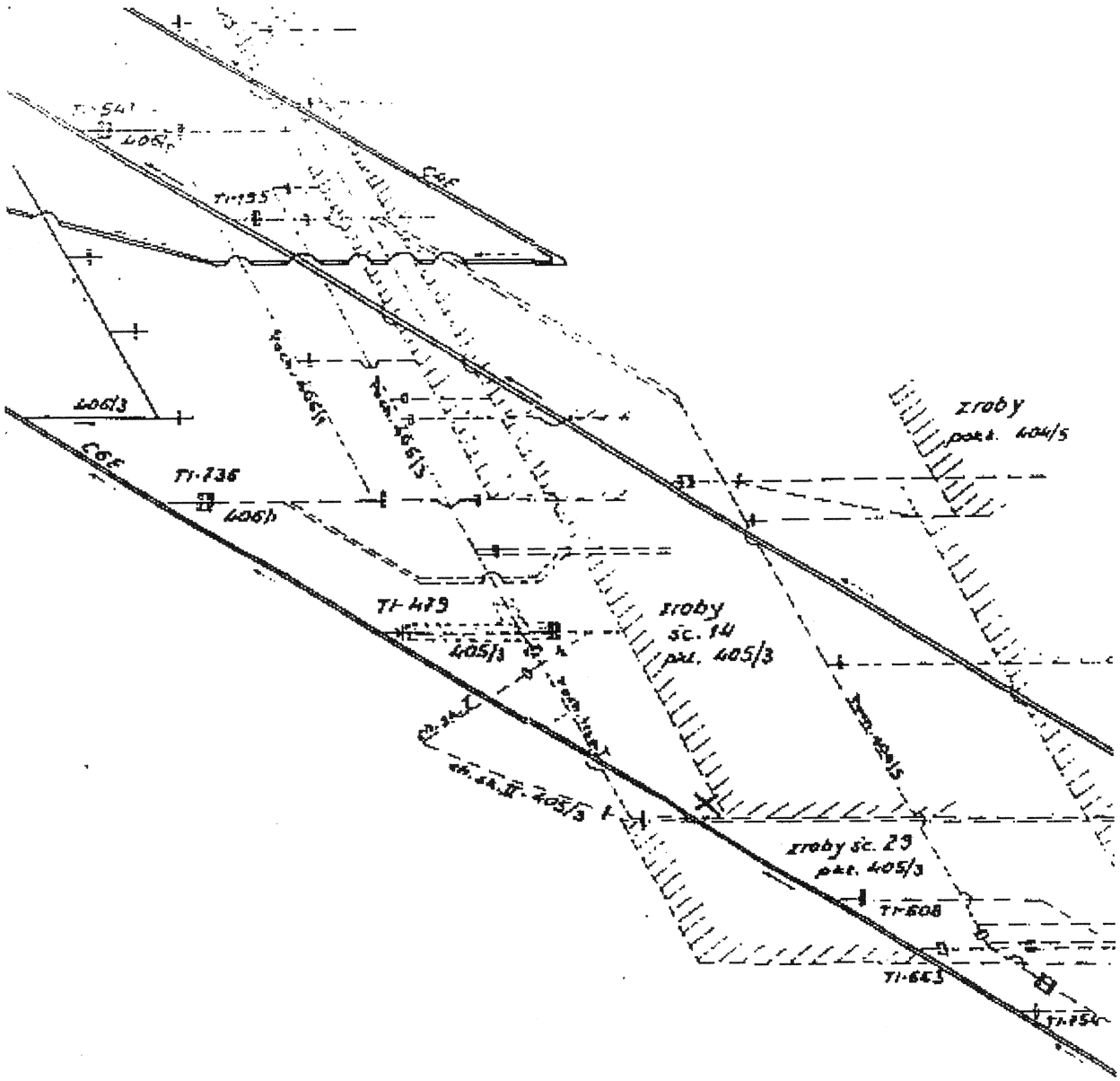


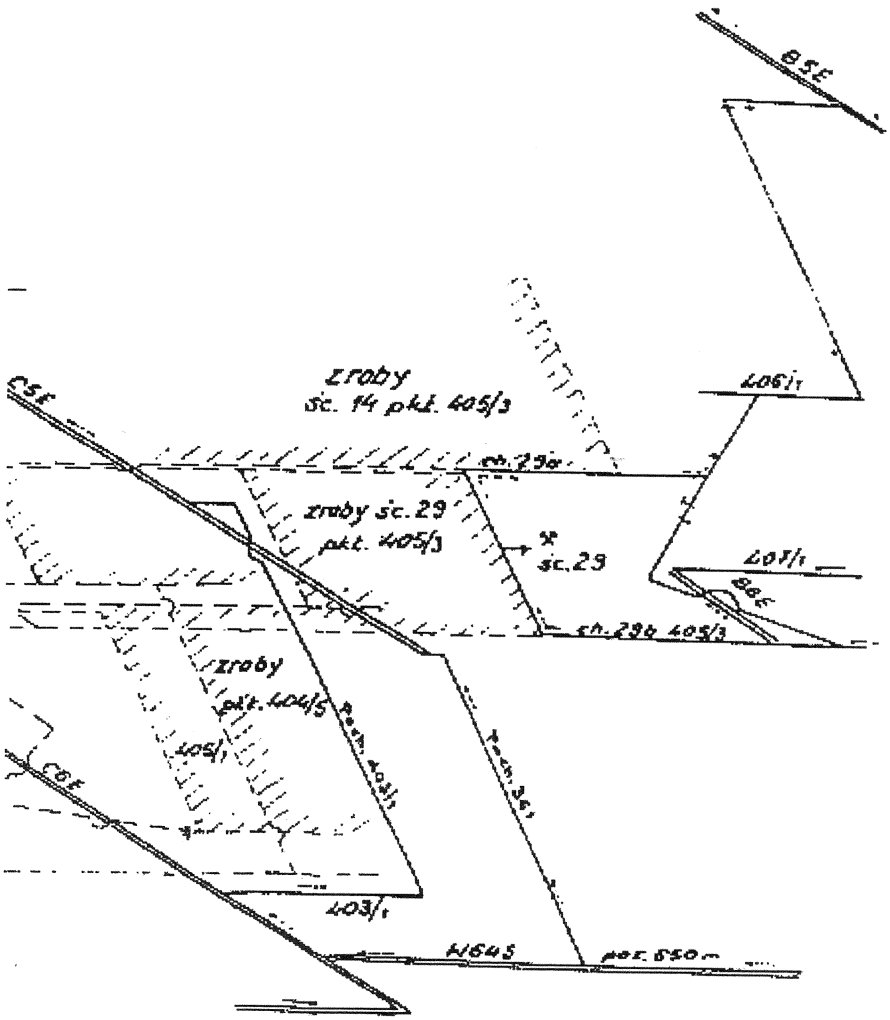
Drg. 1a. Number of all fires, exogenous and endogenous, avarage coas of one operation during the period of the last 10 years in Poland



Drg. 1b. Fire rate during of the period of the last 10 years in Poland



Drg. 2. Fragment of spatial diagram of KWK "Knurów" Coal Mine - lines of drifts B and C x probable place of fire formation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sc. 14 pkt. 405/3
CSE
ch. 29a
zroby sc. 29
pkt. 405/3
sc. 29
407/1
BSE
ch. 29b 405/3
zroby
pkt. 404/3
405/1
Tech. 403
Tech. 36
CSE
403/1
N645
max. 650 m