THE DESIGN PROCESS OF A MODERN MINER'S HELMET WITH INTEGRATION OF SAFETY NEEDS

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ABSTRACT

This paper presents the design process of a modern helmet for miners that would be ideal for all workers who risk their lives every day in underground and surface mines to supply us the materials we need for our everyday life. The dangers that the miners face throughout their work time are chronologically explained, as well as the necessary preventive measures and the security measures needed for the achieved. Compared to the classic mining helmet only an impact protection and a lamp holding bracket is provided, the design of the helmet presented in this paper is based on the method of integrating the needs of the miner. Through the available technology today pretty much everything is possible, so it is truly sad because significant improvements have been made in the mining branch while the protection of the miners is still at a bare minimum.

The exterior of the helmet is simple, with curved lines and is used to its maximum in order to integrate all the proper functions without ruining the esthetics. The interior of the helmet is designed to withstand an impact without allowing injury to happen. Besides the integrated functions such as the air filters and the option for attaching oxygen tanks, the helmet is still comfortable and it does not present a burden to be worn throughout the work.

Keywords: miner helmet, design process, protection at work, safety design.

1. DANGERS IN MINING

Miners are constantly exposed to dangers during their everyday work. The dangers are various and they differ according to the fact is the miner working in an underground or in a surface mine, the region in which the miner operates as well as the available technology (machines and tools) used in the process. Unfortunately, besides the significant improvement in the available technology, human health and security has remained on a basic level. For their protection miners are still using basic helmets, sometimes with build-in masks, and not a thing more for their further protection has been accepted.

1.1. Dangerous air articles

The most abundant compound in the Earth's core is the free crystal silica which presents the most often air dust with which miners are in contact. The most probable form of the silica is quartz and it can be found as cristobalite and tridymite. The contents of silica in different types of ores vary, but even that is not a real indicator of the level of free silica that can be present in the air. It is not unusual to have presence of 30% of free silica dioxide in the ore and 10% in the air, or vice versa. Sand can contain up to 100% silica dioxide and granite can contain up to 40%.

After a longer exposure of a human organism to silica, silicosis might occur, which is a typical pneumoconiosis which is developed in years and without trace. Exposure to silica is often connected with increased risk of tuberculosis, lung cancer as well as some auto immune illnesses like sclerodermas, systematic lupus erythematosus and rheumatic arthritis.

Dust from coal presents a significant danger in the underground and surface mines. The composition of the dust varies depending on the type of coal that is excavated. The dust is created during explosions, drilling, cutting and transportation of the coal. The dust from coal can result in pneumoconiosis and it contributes to development of chronic illnesses like bronchitis and lung emphysema [1].

1.2. Dangerous gases and fumes

Most common toxic gasses that are present in the mines are methane and sulfurous dioxide (Table 1). The presence of these gasses results in deficit of oxygen. Methane is highly flammable. Most explosions in coal mines are result of ignited methane and are followed by even stronger explosions of the coal dust. Throughout the history of coal mining, fires and explosions have been the main cause for death of thousands of miners.

Table 1: The most toxic gases and their impact on health

Gas	*Used name*	*Impact on health*
Methane (CH_4)	Explosive gas	Suffocation
Carbon monoxide (CO)	White suffocate	Chemical suffocation
Hydrogen sulfate (H_2S)	Lazy suffocate	Nose irritation, eyes and throat; obstruction of the respiratory system
Lack of oxygen	Black suffocate	Anoxia
Explosion of product	Consistent suffocate	Irritation of the respiratory system
Exhaust from engines	Exhaust gas	Irritation of the respiratory system; lung cancer

1.3. Physical dangers

Noise is very much present in mining. It is created by the operation of the powerful machines, air-conditioning systems, explosions and transportation of ore. Exposure to noise in underground mines is significantly higher compared to surface mines. Noise can be reduced by using conventional means for noise control of the mining machines and with use of hearing protection equipment [1].

Ionizing radiation is dangerous in mining as well as in other industries. A free radon might be released from the ore by detonation or it might enter a mine through underground streams. A radon and decomposing products emit non-ionizing radiation, some of them having enough energy to cause cancer cells to lungs.

Heat presents danger in mines as well. In underground mines, main source of heat is the ore itself. The temperature of the ore is increased by 1°C for every 100m depth. Other sources of heat stress are the physical activity of the miners, circulation of air, surrounding temperature and moisture of air, as well as the heat generated by the mining equipment. The temperature can reach around 40°C in the deep mines (deeper than 1.000 m). Mains sources of heat in surface mines are the physical activity, proximity to hot engines, air temperature, moisture and sunlight. Reduction the heat stress can be achieved by introducing cooling devices, limiting the physical activity and providing adequate quantities of drinking water, protection from the sunlight and appropriate ventilation.

Drills can cause significant **vibrations** that can result in damage to the nerves in miner's hands – vibration white finger. This symptom is noticed for the first time in mines in Japan, India and Canada.

2. PREVENTIVE MEASURES FOR PROTECTION

Head protection of the miner is necessary due to the potential for head injuries caused by mechanical or electrical nature, low temperature, heat radiation, dirt, radioactive radiation, wet and other. For protecting the miner's head from mechanical injuries a helmet is used. Protective helmets must comply with the following requirements: to be durable on deformation and penetration, to be able to absorb impact and to be easy for maintenance. Depending on the use, they are produced from leather, phenol epoxy, polyamide, polyethylene, polyester etc. Helmets can be in form of a hat or a cap.

Plastic helmets are not suitable for high temperatures, but on the other hand are very light. Helmets from aluminium are more durable, easy for maintenance, deflect heat, but are permanently deformed on impact. Negative side of the aluminium helmets is the fact that they are conducting electricity.

For head protection from electrical current helmets made from materials that have the appropriate resilience are made.

For head protection only from heat radiation hoods from asbestos are used, or a combination of asbestos and aluminium foil. These hoods are often combined with a face protector and protection for neck and shoulders. For protecting the eyes of the miner cobalt glass is used. If in the mines beside the mechanical injures, danger from high temperature is present, then the protective helmets are made from thermo resistant material.

In a case where beside the mechanical injuries, the miner's work is followed by low temperatures, the protective helmets should have additional parts that can be placed underneath the helmet. These parts are made out of cotton or wool fabrics, or leather with fur. If in the working conditions the protection from cold is primary, and there is no present possibility for mechanical injuries, then caps lined with fur are used.

Figure. 1: Standard protection for miners (Source: Environmental Protection Agency).

In wet working conditions, where beside the danger of mechanical injuries, there are possibilities for wetting the miner's head, then helmets made from water resilient materials are used. In working conditions where rotating parts of machines can tangle upon the worker's hair, protective caps, hoods, nets and scarfs are used.

Dirt and dust in the working environment can cause various skin conditions to the head of the miner. In order to prevent this, appropriate caps made from thick cotton fabric are used. They have to be easy to maintain. In working conditions where radioactive radiation is present, the whole body of the miner is exposed to it, so specific protection equipment only for the head is not available. The protection comes in a form of an overall suit composed of protection for the body, head and face [3].

For protecting the eyes, in general various types of protective glasses are used. If danger to the face is present, the eyes protection equipment is always made in such a way that it covers the whole face.

Depending on the factors for eyes damage, different types of eye googles are produced, like: protective glasses with transparent glass – used in operations where danger of injuries to the eyes are possible from flying small particles, for example when filing, grinding, stirring etc.

When there is a danger to the eyes present from flying particles from the front and from the side, glasses with side protection are used. This is the case in operations like grinding, milling, wood grating or similar activities.

For protecting the eyes from eroding materials (ammonia, formaldehyde etc.) transparent triplex glasses with leak-proof frames are used.

For workers that operate with welding machines, in order to protect their head, neck and eyes of the direct and indirect effect of the ultraviolet and heat radiation, as well as from the flying particles special shields are used. They can be hand held or head mounted.

The protection of the hearing organs of miners is necessary due to the fact that the damage from noise is significant to the hearing organs and through them to the complete nerve system. Noise is defined as any non-desired sound with high intensity that causes uncomfortable hearing reaction. Noise today is produced as a result of the fast technological development of the industrial production, motor transportation and noise producing activities [5].

If the noise is constant during the working period, the working capability of the miner is decreased, the hearing organs are getting damaged and in certain level the nerve system is ruined. Due to that, the protection of the hearing is essential.

For those workplaces where noise that cannot be reduced with technical means below the allowed limit is present, workers must use appropriate protection equipment, like:

- cotton for protection from noise level up to 75 dB
- ear plugs for protection for noise level up to 85 dB
- ear protection equipment for noise level up to 105 dB

Ear plugs cannot reduce the average value of the audibility for more than 15 dB. Also, the protection equipment should not irritate the ears and must provide that the noise will not surpass the allowed limit [1].

Beside the regular conditions that apply to all protective equipment (not to irritate skin, not to transfer paint and to be easy to maintain), the noise protective equipment should:

- to damp noise efficiently
- to be comfortable
- their use should not result in physiologic or pathologic changes to the ear canal
- to only allow to pass sounds with low frequency

The ear plug is usually made in a form of an unformed or formed plug. The unformed plug is made out of material (bee wax, cotton or similar plastic material), formed according the ear canal of the user. The formed plug is made out of material that is not irritating for the skin, not easily fumbles and is bad in transmitting the sound oscillations. These plugs have pre-defined shape [6].

The ear protective equipment is consistent of two shells with elastic semi-circle holder. The shell is consisted of cushion and body of the shell, and the elastic semi-circle holder is consisted of two elastic strips formed according the shape of the head. The force with which the ear protective equipment is pushing upon the head should not be bigger than 10N (approx. 1kp) and the weight of the equipment should not be bigger than 0.4 kg [4].

Protection of the respiratory system. By breathing an exchange of gases is done between the organism and the environment. The goal of the respiratory system is to supply the necessary level of oxygen and to throw out carbon dioxide (CO_2) which if present in increased level can cause suffocation and death.

Workers that work in polluted environment where fog, smoke, dust or anything similar is present (when concentration level is above allowed), appropriate equipment for protection of the worker breathing organs must be used.

For protection of the respiratory system from rough and inert dust, i.e. fine industrial dust that consist silica dioxide (SiO2), suitable protective equipment foresees respirators with appropriate design and protective capability [7].

For protection of the organs from dangerous gases, fog, smoke or dust in high concentration i.e. when in the environment the level of oxygen is less than 16% the use of masks in various shapes and design and isolation equipment with oxygen are used [5].

Figure. 2: Modern protection equipment for miners (Source: http://inside.mines.edu/Mining-Edgar-Mine).

A gas mask is used for protection of the respiratory system, the face and eyes of those workers that operate in working conditions where the level of oxygen is at least 16%.

The protective equipment for the respiratory system should not obstruct normal breathing during use and it must be adjusted for quick and easy installation. The selection of the equipment is done based on the type and time of containment of the workers in the room.

The respiratory system protective equipment might be divided according the type of pollutants and the type of operation.

According the type of the pollutant the equipment is divided in respirators for purification of the air from aerosols, protective masks for protection from gasses and fumes with filters for purification of air and isolation materials that are used in case of lack of oxygen.

According the operation, the equipment is divided in: equipment based on filtration and protective equipment based on isolation.

The protective equipment based on filtration purifies the air of the environment (for example protective mask, respirator for purification). These protective devices include:

- Equipment for protection from aerosols (mechanical filters) which include respirators for aerosols
- Equipment for protection from gases and fumes which include protective masks, cartridges with active filling and self-saver for carbon monoxide (CO)
- Equipment for combined protection from gases and aerosols which include protective mask with active filling and filters for aerosols.

The equipment based on isolation is used in case of decreased concentration of oxygen under the allowed level.

This includes:

- Tube mask with pot or without pot for supply with clean air from a distant environment
- Tube mask with attachment for compressed air used only if central line for compressed air supply is available (from a central compressor or a tank).

Isolation devices with open or closed system that supply the user with clean air from a tank, where the exhaled air is released in the atmosphere (in open system) or released in to a chemical cartridge where certain amount of oxygen is missing (closed system). The recirculated air is again brought to the respiratory system [6].

3. DEVELOPMENT OF CONCEPT DESIGN

After conducting thorough research and analysis of the danger with which are miners faced daily, two concept designs that fulfill all demands have been developed.

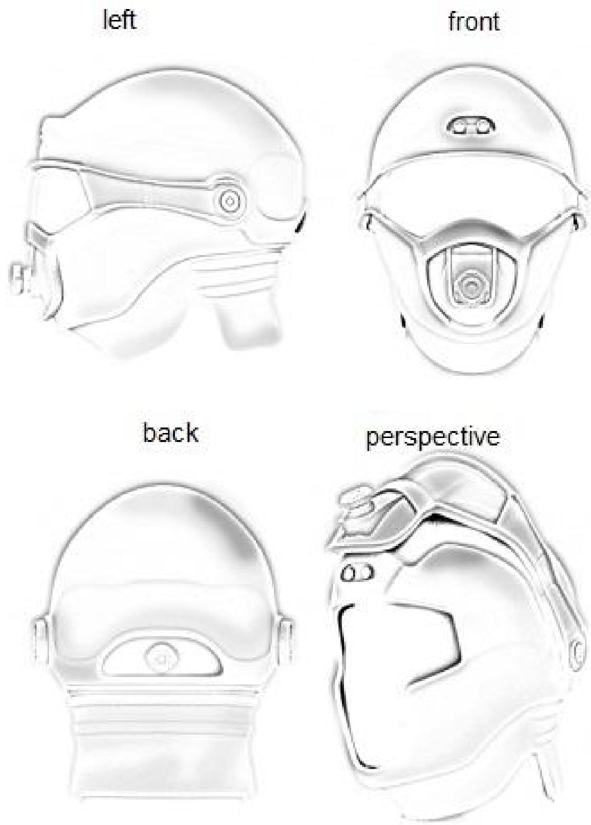

Figure. 3: Side, front, back and perspective view of the first concept design.

The first concept design (Fig. 3) has integrated protection for eyes, protective mask with air filter and a complete protection of the head and the neck. Also, on the front upper part of the helmet two LED lights are fitted powered by lithium batteries fitted in the middle part of the helmet's layers.

Figure. 4: Real-look render of the concept design 1 of a miner's helmet.

On the back of the helmet an opening is positioned for supplying fresh air for breathing, filtered through the air filter fitted on this side of the helmet. The elegant design resembles the design of military fighter jet helmets. Organic forms have been used in this concept design enabling complete integration of the functions in the available space without deranging the look or to result in difficulties in use of the helmet.

Figure 4 presents a real-look render of the helmet where the Head-Up Display is presented at the eyes mask where the miner can receive important information about the temperature, air pollution, gas leakage or other information. All this is made available by the sensor located in the helmet's sides. The central processing unit processes the sensor's data and sends the information to the OLED display positioned between the layers of protective glass. This display as well as the CPU, are powered by the same lithium batteries integrated in the helmet [2].

In Figure 5 both sides of the mask are presented where the sensors are located which measure specific parameters in real time. The sensors and the display are powered by 2 batteries located in the back end of the helmet with total nominal power of 12.000 mAh. The battery capacity is sufficient to provide constant operation of the helmet with all its features for 72 hours. The helmet has sensors for:

- Temperature
- Altitude and pressure
- Air humidity
- Detection of poisonous gases in the air
- GPS chip
- Radio transmission for communication

The face mask can be adjusted by a simple push of a button which releases the mechanism and allows the mask to be translated to the front and rotated upwards above the helmet (Fig. 4.) This function provides the helmet with the ability to be used in underground mines as well as in surface mines where most of the time a face protection is not necessary. When positioned above the helmet, the display and sensors are not in function.

Figure. 5: Face mask with included sensors attached on the sides

In the helmet 2 LED lights are fitted with total power of 12W powered by a separate lithium battery positioned behind behind them. The capacity of this battery is 3.000 mAh, which is sufficient for constant operation of the lights for more than 140h. The lights are turned on by a simple switch positioned on their front. By rotating this switch 15 degrees clockwise the lights are turned on.

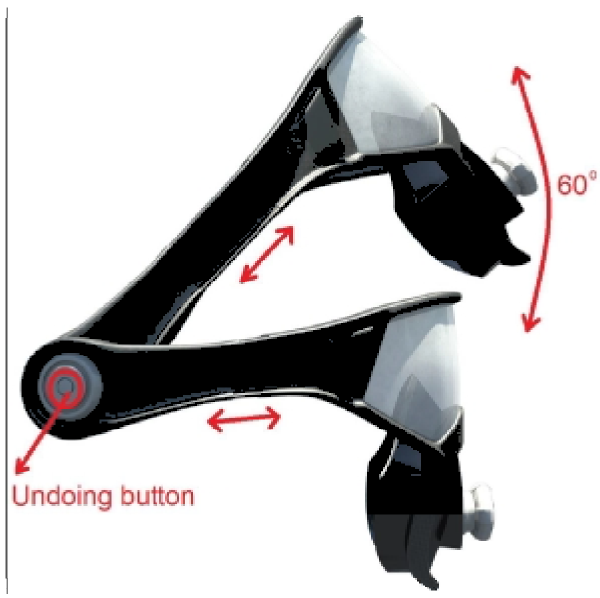

Figure. 6: The face mask is adjustable depending the needs of the miner (for underground or surface mines).

The face mask can be adjusted by a simple click to the undoing button allowing for the mask to be moved forward and rotated above the helmet (Fig. 6). This provides the helmet to be used underground as well as in surface mines or other areas where the face mask is not necessary. When the mask is released, the sensors and display are not in function.

In the helmet 2 LED lights are fitted with total power of 12W powered by a separate lithium battery positioned behind behind them. The capacity of this battery is 3.000 mAh, which is sufficient for constant operation of the lights for more than 140h. the lights are turned on by a simple switch positioned on their front. By rotating this switch 15 degrees clockwise the lights are turned on.

Figure. 7: LED lights fitted in the front part of the helmet.

All functions and sensors in the helmet are powered by lithium batteries placed in the back side of the helmet. The batteries are rechargeable and a standard 12V socket for the charger is positioned on the back side (Fig. 8). The batteries can be sully charged in less than 3hours.

Figure. 8: Socket for battery charger build-in the helmet.

With the use of this concept design of the helmet it is foreseen to be used racks where after use of the helmets the miners will place them and connect them to chargers for their next use (Fig. 7).

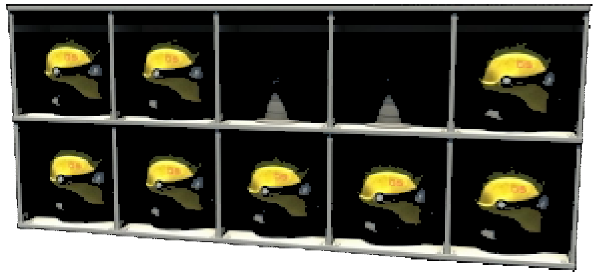

Figure. 9: Racks for helmets with integrated chargers and pedestals.

At the section view presented in Figure 10 the interior of the helmet is presented together with the protective basket for the head of the miner. The protective basket is attached with elastic bolts which have the function to absorb the impact. The basket is made of plastic, and the lower part is lined with polyurethane in order to increase the absorption capability from impacts, but also to make it more comfortable for wearing.

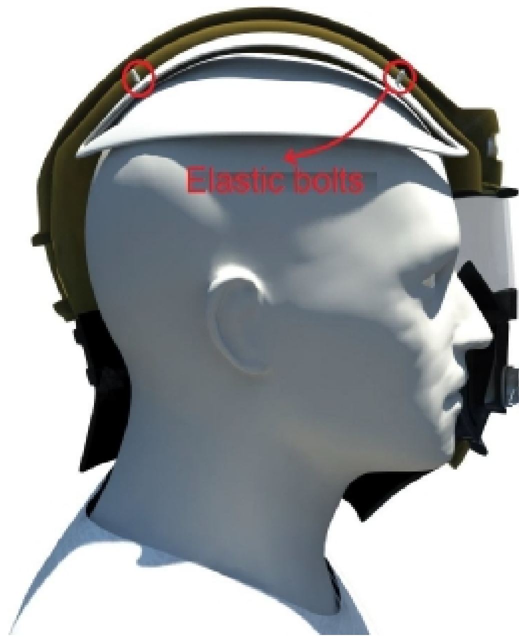

Figure. 10: Section view of the helmet.

The second concept design has more futuristic look with moreover the same functions as the first concept design (Fig. 11). With this concept design the focus is placed on the functions for air-conditioning and air filtration.

Figure. 11: Side, front, back and perspective view of the second concept design.

At the front part of the helmet a fixed mask made of three-layered protective glass with integrated display is placed. This concept has a non-detachable mask. In order for the mask to be removed, it has to be completely undone from the helmet and removed in such a way. Also, this concept has an integrated camera at the front of the helmet connected wirelessly to the headquarters of the mine where a real time video feed can be monitored in order to follow the movement and operation of the miner.

Figure. 12: Photorealistic render of the second concept design of the helmet.

Figure 12 presents the helmet of the miner while wearing. Also, the Head-Up Display can be seen at the front mask for protection of the eyes and face where the miner can receive information about the temperature around him/her, information for any leaks of poisonous gasses and other relevant information which will further facilitate the miner's operation.

On Figure 13 the sensors placed on the both sides of the helmet are shown. These sensors collect data that is processed by the CPU and display information in real time to the protective glass and the integrated display. The sensors are powered by two batteries placed on the back of the helmet with total capacity of 12.000 mAh. With this capacity the helmet can operate constantly for 72 hours with all functions activated.

Figure. 13: Sensors and clamps for detaching the face mask from the helmet.

The helmet has the following sensors integrated:

- Sensor for temperature
- Sensor for altitude and pressure
- Sensor for humidity
- Sensor for detection of poisonous gasses in the air
- Integrated GPS sensor
- Integrated radio frequency sensor

The OLED display integrated in this concept design is a bit different from the one in the previous concept because it is occupying bigger area in the user's field of view. In order to be safe, the display is integrated in a three-layered protective glass resistant to impact and breaking, scratches and heat.

The camera placed in the front part of the helmet enables to monitor the worker's operation with the ability to get further instructions from the headquarters that is monitoring the process. The connection is made available through a wireless protocol.

The second concept design has an engineering design that does not allow an easy detachment of the face mask. Nevertheless, this option is still made available by unclamping the pads placed on the lower and upper part of the face mask and with that it is completely removed from the helmet (Fig. 13). By detaching the face mask the functions of the sensors and the display are suspended until it is again mounted to the helmet.

Figure 14 presents the six LED lights placed on both sides of the helmet. These lights are with total power of 36W (6W each LED) powered by two lithium batteries placed behind them. The capacity of the batteries is 6.000 mAh (2 x 3.000 mAh) which enables the lights to be used for more than 120 hours. The lights are turned on with a switch in a form of buttons placed on the side of the lights (Fig. 14). This design enables the lights to be turned on separately on each side.

Figure. 14: LED lights placed on both sides of the helmet.

All functions and sensors are powered by lithium batteries integrated in the sides and in the back of the helmet. The batteries after certain period of use are charged through the socket placed on the back of the helmet. Batteries are fully charged in six hours. For storing and charging of the helmets the same rack is used as presented in the first concept design.

Figure. 15: Active carbon filter integrated in the front part of the helmet.

Compared to the first concept design, here a special filter is used (Fig. 15) that is an active carbon filtration process. That means that the breathing air is filtered through a several layers' carbon material. This material does not allow tiny particles to pass through and thus protecting the miner from breathing in particles with size smaller than 10 Nano meters.

Figure. 16: Air circulation system for fresh air supply.

With the integrated system for air circulation, the helmet is constantly supplied with fresh air and a stable temperature level is maintained. As show in Figure 16, the system is placed in the back side of the helmet and it is consisted of an electric fan with metal hoses integrated in the helmet supplying the air.

On the section view presented in Figure 17 the head inlay with polyurethane is displayed. This inlay also does not hold on the moisture. Compared to the first concept design, in the concept the protection used in this engineering design is similar to the helmets for motorcycle drivers. With the polyurethane inlay instead of protective basket an additional protection and absorption from strong impacts is provided without causing significant injures.

The only negative side is that air circulation through the helmet inlay is not possible. This system for protection in combination with the system for air circulation will not result in difficulties while use.

Figure. 17: Head inlay with polyurethane.

4. CONCLUSION

The conducted research shows that the regular miner's helmet is simply not enough for maximum protection of the user. Aa result of that the miner is forced to use additional equipment such as light, radio transmitter, batteries, air filter, protective mask for eyes and other body parts that only make the operation more difficult. The safety of the miners is neglected regardless the development in technology and in the mining industry.

Concept designs have been developed for modern miner's helmet using the method of integrating the needs of the users. A concept of a helmet is created that will satisfy all protection measures necessary for protecting the miners. During the design process of the helmets, the anthropological measures and ergonomic methods defined for the potential group of users have been used.

The production costs and the selling price of the concept helmets is higher than the regular miner's helmet but as concluded in the description of the concept designs they are completely integrated with all necessary protective equipment for miners.

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