MODERN WORK PROTECTION WITH THE SHOTCRETE CONSTRUCTION METHOD UNDER OVERPRESSURE

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The shotcreting method currently accounts for 90% of all urban traffic tunnels in the Federal Republic of Germany erected in the mining method of construction. Pressurized shotcreting has gained considerable importance in inner-urban tunnel construction during the past years. Examples in our country are encountered principally in the construction of the Munich subway system.

Driving underground cavities is accomplished under difficult working conditions and involves great health and accident hazards (Figure 1). The causes being:

- High dust development in shotcreting, rock excavating and conveying operations,
- poor air and visibility conditions,
- unfavourable climatic conditions,
- narrow, largely closed spaces,
- long handling distances for excavated and construction materials in long-extended, cramped spaces,
- frequently unforeseeable irregularities of the rock,
- piecework as well as schedule and cost pressure,
- parallelism of various operations performed in most closely restricted space.

The same health and accident hazards also apply for the workers engaged in shotcreting under overpressure.

The Compressed Air Ordinance stipulates that working chambers must be kept free from odours, as well as harmful gases, vapours and dusts (Figure 2).

Working methods involving intensive dust development, such as e.g. tunnelling with road headers without dust exhaust systems, are prohibited for work in compressed air just like the employment of internal combustion engines. Adherence to the maximum workplace concentration and technical standard concentration values for harmful substances in the breathing air must be assured. This can only be accomplished by means of constant control measurements of the inhaled air.

The technological problems had been solved. Concerning problems of labour medicine, studies were made to provide information on whether harmful mineral dust under overpressure constitutes a greater health hazard than atmospheric pressure.

The Medical Institute for Environmental Hygiene at the Düsseldorf University (Prof. Schlipköter) was thereupon commissioned by TBG to conduct appropriate animal experiments. In these preliminary studies it was found that the inhalation of dust containing quartz at an overpressure of 1.5 bar for a period of 6 months leads to increased typical quartz-induced lesions of mediastinal lymph nodes.

Further on it could be observed in the test of pulmonary function that for compressed air workers the flow-volume curve decreases significantly with increasing dust concentration:

> The test results indicate that with the measured high dust concentrations late damages to the respiratory tracts are possible.

More results on this deterioration of the pulmonary function tested after 1 working day and after 2 years will be published shortly in British JOURNAL OF OCCUPATIONAL HEALTH by Prof. Dr. Kessel, collaborator of Prof. Fruhmann, Munich University.

In view of these alarming findings, the following three institutions had been commissioned to perform further-going studies on primates under conditions similar to those prevailing at construction sites parallel to human medicine tests of compressed air workers at Munich subway construction sites:

- Med. Institute for Environmental Hygiene at the Düsseldorf University (Prof. Schlipköter)
- Institute for Surgical Research at the Munich University (Prof. Brendel)
- Institute and O.P.D. for Occupational Medicine of the Munich University (Prof. Fruhmann).

Interim results of these medical tests will be presented subsequently by Dr. Rosenbruch, Düsseldorf University and Dr. Krombach, Munich University. The Studiengesellschaft für unterirdische Verkehrsanlagen, STUVA, Köln, has assumed the technical management of the test programme and the medicine tests of compressed air workers were carried out by Munich University, Prof. Fruhmann.

Maximum workplace concentration values constitute a basis for assessing the questionableness or harmlessness of con-

No.	Work sector	Number of accidents	severe	fatal
1	Thrust-boring equipment	39	21	—
2+3	Tunnelling machines	17	6	1
4+5	Excavation work	8	3	—
6	Drilling and blasting	20	10	1
7	Falling stone, collapsing material	57	25	1
8	Sheeting, stabilization	27	13	—
9	Shotcreting work	76	10	—
10	Finishing (concrete + formwork)	32	13	—
11	Lining segments	11	6	—
12	Loading, mucking	16	8	—
13	(Underground) tracklaying	4	1	—
14	Materials handling	51	24	1
15	Welding + electr. work	11	3	—
16	Fitting	22	8	—
17	Toxic gases + vapours	7	5	—
18+19	Shaft construction + miscellaneous	31	14	1
	Total	425	173	5
	≙	(100 %)	(41 %)	(1.5%)

Figure 1. Accident analysis—tunneling, 2 years comparison.

centrations of noncarcinogenic working media appearing in the air at the workplace in the form of gas, vapour or suspended matter. Maximum workplace concentration values are scientifically founded, but apply only to pure substances. Since pollutant mixtures are the rule at the workplace, an orientation aid will be needed for the safety measures to be taken in modern work protection. This requires a pragmatic and generally applicable valuation concept. The Committee for Harmful Substances established by the Minister of Labour and Social Order in the Federal Republic of Germany has been engaged for some time in the valuation of pollutant mixtures in the air at the workplace with significant cooperation of the industrial insurance societies.

Re § 4 General requirements

1. **Keep working chambers clean and free from odours as well as harmful gases, vapours and dusts**
2. **Ventilation**

   Supply 0.5 m^3/minute of fresh air per worker into the working chambers

Figure 2. Compressed air ordinance.

The valuation index of a substance mixture is the totalized value of pollutant indices J_i with the individual J_i being the quotient resulting from the concentration C_i established for the individual pollutant in the air at the workplace and the associated maximum workplace concentration (here MAK) value (Figure 3).

$$I = \frac{C_1}{MAK_1} + \frac{C_2}{MAK_2} + \ldots \frac{C_n}{MAK_n}$$

The valuation process is limited to those components of a substance mixture, for which parallel biological action can be supposed or not excluded with appropriate concentration in the breathing air. Since in compressed air work usually a lower air exchange and thus also a lower pollutant dilution occur than in tunnelling work under atmospheric pressure, particularly stringent requirements must be imposed on the quality of the breathing air. This is true all the more for pressurized shotcreting. Shotcrete dust normally must be classified under the category of siliciferous fine dust (Figure 4).

Therefore shotcrete dust is hazardous to health under two aspects:

- The dust may contain fine mineral dusts containing in some cases considerable amounts of quartz, which are added with the sand, the accelerating agents and the filler, and

$$I = \frac{C_1}{MAK_1} + \frac{C_2}{MAK_2} + \ldots \frac{C_n}{MAK_n}$$

$$= \sum_{i=1}^{n} \frac{C_i}{MAK_i} = \sum_{i=1} I_i$$

I ... Evaluation index

C ... Average concentration

MAK .. Maximum workplace concentration

I ... Totalized value

$I \leq 1$ Limiting value for substance mixture

Figure 3. Evaluation of substance mixtures in the air at the workplace.

- due to their high alkalinity with a pH-value around 13, all accelerating agents must be regarded as caustic substances (Figure 5).

Additional dust sources, such as excavation and transportation e.g. contribute correspondingly to the silicon content of the total amount of fine dust.

The research project on shotcreting under overpressure is intended to clarify whether the current pollutant limits provide adequate health protection also for work under overpressure or whether more stringent requirements are necessary for the quality of the breathing air. We must make every effort to counter in time a silicosis hazard such as former generations experienced in mining, the consequences of which are still felt today.

As a rule following technical dust-combatting measures may contribute to the desired result (Figure 6).

1. Use of a liquid setting accelerator.
2. In case of powdered accelerators, selection of the one with the lowest possible respirable fine content and the lowest possible amount of quartz in the fine content. Accelerators without quartz are to be preferred.
3. Selection of sand without quartz, wherever possible, with a low respirable fine portion.
4. Fillers without quartz.
5. Addition and portioning of powdered accelerators in a closed system.
6. Addition of an adhesive to reduce dust.
7. For the shotcreting equipment:

Quartz content (% by weight)	Max. workplace concentration (mg/m^3)	Reference concentration
Q < 1	6.0	General dust limit (fine dust limit)
$1 \leq Q \leq 3.75$	4.0	Fine dust containing quartz
Q > 3.75	0.15	Fine quartz dust

Figure 4. Maximum workplace concentration limits for inert and siliciferous fine dust.

- selection of a low-dust shotcrete method
- lowest possible delivery lengths
- selection of the proper jet type, regular machine maintenance
- selection of a favourable hose diameter
- prewetting when adding adhesive
- proper inherent moisture of the design mix.

At some workplaces, such as e.g. the spray jet, technical dust protection measures alone will not be made available and also used.

The development of a dust protection helmet which combines protection of respiration, head, eye and face and also hearing was the result of a research project undertaken by the Tiefbau-Berufsgenosen-schaft.

Pressurized shotcreting is feasible only in combination with modern work protection.

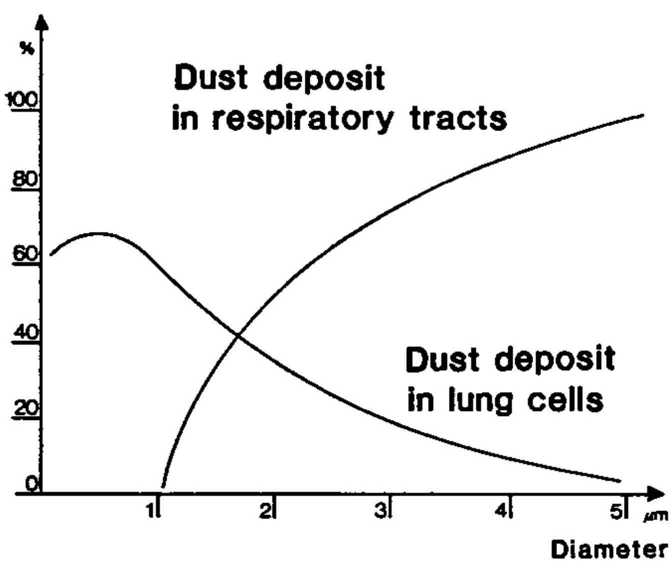

Figure 5. Schematic representation of dust deposit in the lung and in the respiratory tracts (acc. Winkler).

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