Eliminating Exposure to Silica Dust: Possibilities in the Design Phase of Buildings[1]

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Samenvatting

Vrijwel alle steenachtige materialen bevatten kwarts. Het bewerken van deze materialen met elektrisch verspanend gereedschap leidt tot inademing van respirabel kristallijn kwartsstof, waarbij de wettelijke grenswaarde van 0,075 mg/m^3 vele malen kan worden overschreden. Beheersmaatregelen zoals plaatselijke afzuiging of watertoevoer kunnen de blootstelling met 90% of meer verlagen. Maar ook dan wordt de grenswaarde vaak nog overschreden, vooral bij taken met hoge blootstelling zoals voegen, zagen, of slopen. Elimineren of verkleinen van de bron is daarom nodig. Vaak kan een vrij eenvoudige aanpassing in het ontwerp de blootstelling aan kwartsstof in de bouwfase verminderen of zelfs elimineren. Echter, preventie van blootstelling aan kwartsstof in de ontwerpfase heeft tot nu toe weinig aandacht in de literatuur gehad. Het doel van dit artikel is een aantal voorbeelden van ontwerpoplossingen te presenteren waarmee kwartsstofemissie op de bouwplaats wordt verminderd of voorkomen en daarmee in de eerste fase van het bouwproces aandacht te vragen voor arbeidsomstandigheden.

Twee arbeidshygiënisten hebben voorbeelden van bouwsystemen en bouwdetails verzameld waarbij emissie van kwarts optrad. De voorbeelden zijn besproken met twee bouwkundigen met het verzoek alternatieven met lagere of geen kwartsemissie voor te stellen. Zo zijn 19 voorbeelden van relatief eenvoudige aanpassingen verzameld. De voorbeelden maken duidelijk dat in de ontwerpfase meerdere bronnen van kwartblootstelling in de uitvoeringsfase kunnen worden geëlimineerd.

Summary

Nearly all stony materials contain silica. Tooling silica containing materials with electric tools leads to high silica exposure. The occupational exposure limit (OEL) for respirable crystalline silica (0.075 mg/m^3 in the Netherlands) can be exceeded many times. Engineering control measures like local exhaust ventilation or water supply may reduce exposure by more than 90%. But even then the limit value is very often exceeded, especially for jobs with high exposure like tuck pointing, sawing, or demolition. Elimination or reduction of the source to prevent exposure is therefore necessary. Often a relatively simple modification of the design may lower, or even eliminate, exposure to dust later on. However, prevention of silica dust in the design phase has received little attention in the literature so far. The purpose of this paper is to present a number of design solutions to prevent or reduce dust emission at the construction site, and in this way to ask attention for working conditions in the earliest possible phase of the building process.

Two occupational hygienists have collected examples of construction systems or construction details that lead to tasks with dust exposure. These examples are discussed with two construction engineers with the request to propose an alternative leading to less or no dust exposure. In this way 19 examples of relatively simple design modifications are collected. These examples show that it is indeed possible to eliminate several sources of silica exposure in the design phase.

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Introduction

Nearly all stony materials contain silica. Examples of silica containing materials are concrete, brick, lime sandstone, concrete stone and many kinds of natural stone. Silica content may vary from about 2% in gypsum blocks up to over 80% in lime sandstone (Lumens and Spee, 2001). When these materials are processed mechanically, e.g. by cutting, sawing, grinding or polishing, respirable crystalline silica dust is released.

The Dutch occupational exposure limit (OEL) for respirable crystalline quartz form of silica is 0.075 mg/m^3. Within the European Union there is an indicative occupational exposure limit value (IOELV) of 0.05 mg/m^3 and the ACGIH TLV is 0.025 mg/m^3. When processing silica containing materials with electric tools, these OELs can be exceeded many times. Task based measurements show that short term exposures up to 400 times the Dutch OEL are not exceptional (Lumens and Spee, 2001; Flanagan *et al*., 2003; Flanagan *et al*., 2006; Flynn and Susi, 2003; Rappaport *et al*., 2003). Also full shift exposures often exceed the OEL. Tjoe Nij *et al* (2003) have measured exposures up to 10 times the Dutch OEL.

The purpose of this paper is to present a number of design solutions to prevent or reduce dust emission at the construction site, and in this way to ask attention for working conditions in the earliest possible phase of the building process.

Exposure to silica dust may lead to silicosis. This is a fibrotic disease caused by the inhalation, retention and pulmonary reaction to crystalline silica. Epidemiologic studies have firmly established that silicosis is also a risk factor for developing Tuberculosis (Parker and Wagner, 2008; NIOSH 2002). The International Agency for Research on Cancer considers respirable crystalline silica a confirmed human carcinogen (IARC, 1984, 1997).

Tjoe Nij *et al*. (2003) investigated the prevalence of silicosis among construction workers with high silica exposure by means of roentgen photography. Abnormalities of ILO category 1/0 or higher where observed among 10% of 1339 construction workers. From this population, 79 persons were further examined with high resolution computer tomography (HRCT). Rounded opacities where observed among 13 persons (16%), and pleural abnormalities among 29 persons (37%).

Several authors have studied the effect of control measures on silica exposure (Flynn and Susi, 2003; Echt *et al*., 2003; Croteau *et al*., 2002; Collingwood and Heitbrink, 2007; Akbar-Khanzadeh *et al*., 2007). These authors report reductions varying from 90% up to 99.8% for various types of processes when applying water supply and/or local exhaust ventilation. However, the exposure limit of (then) 0.05 mg/m^3 was still exceeded in these cases. These examples show that, although control measures may spectacularly reduce exposure, meeting the limit value is very often not achieved, especially for jobs with high exposure like tuck pointing, sawing, or demolition. Control measures are sensitive to maintenance and proper use and, as pointed out, are for the construction industry often not sufficient. Beaudry *et al*. (2013) have summarised all white and grey literature they could find and concluded that no control measure was able to reduce silica exposure below the Canadian limit value (0.1 mg/m^3). Upon measurement at construction sites, van Deurssen et al. (2014) found only a 50% exposure reduction from a number of control measures. Elimination or reduction of the source to prevent exposure is not influenced by behaviour of maintenance and is therefore considered best occupational hygiene practice. This approach is established in the European Directive 98/24/EC on the protection of workers from the risks related to chemical agents at work (EEC, 1998).

Decisions taken in the design phase, often affect exposure to dust in the construction phase. Often a relatively simple modification of the design may lower, or even eliminate, exposure to dust later on. Schulte et al (2008) emphasize the importance of prevention through design in the construction industry. Currently, the NIOSH National Occupational Research Agenda (NORA), contains several initiatives to eliminate health and safety hazards in the construction industry through design. These should lead to results within several years. Before these initiatives, prevention of silica dust in the design phase has received little attention in the literature. A literature search revealed that some authors have drawn attention to hazardous substances in the design phase in general, but without mentioning specific substances (Hecker and Gambatese, 2003; Weinstein *et al*., 2005). The British Health and Safety Executive (HSE) has analysed causes of construction accidents and states: "While health could not be considered in this analysis it is the view of the Author that the case for improvement, through designer intervention, in workforce health is implicit in these findings" (Bennnett, 2004). To our best knowledge, there is no publication in the occupational hygiene literature specifically about reduction of silica in the design phase. However, several authors have drawn attention to safety matters in the design phase. This may be connected to the clear relationship between safe design and deadly accidents. Estimations of numbers of victims due to unsafe design vary from 42 to 60% of all deadly accidents in the construction industry (Bennett, 2004; Gambatese *et al*., 2005; Behm, 2005; Frijters ans Swuste, 2008). HSE concludes that at least 1 in 6 of all accidents are at least partially the responsibility of the lead designer (Benett, 2004). For long term effects, like silicosis, this relationship is much less clear.

Methods

Data collection

In a series of projects silica dust measurements were performed at a large number of construction sites. During these projects two occupational hygienists (ML and TS) have collected examples of construction systems or construction details that lead to tasks with dust exposure. These examples were presented to two construction engineers (AF and DS) with the request to propose possible changes in the design phase of the construction plan to eliminate or reduce exposure.

Design analysis
Design analysis is a descriptive analysis of the design process, to find an answer to the question: “what is produced and by which means?” (Swuste et al., 1997) It uses a hierarchic classification of production items developed in the field of the systematic design of installations. The basis is the production function, which divides a production process into its core activities. After this comes the production principle, describing the principles to carry out the function, and finally the production form, the actual design of the principle. Changing or eliminating the production function is the most fundamental way to alter a process, and often creates the opportunity to eliminate an exposure generating task completely. Therefore, elimination of the production function was the primary level to search for solutions to prevent silica dust. The production function is in all cases: ‘removing material’. The production principle may be sawing, drilling, grit blasting, and others.

A construction can be divided in construction elements. The Dutch Construction Documentation (Nederlandse Bouw Documentatie, NBD) divides the design process into elements, based on the Swedish SfB code, and mentions materials connected to these elements. In this paper the NBD system is followed in the description of the design elements (NBD, 2004).

Results

Table 1 and 2 show an overview of activities creating dust, the expected respirable sicila concentrations, and the alternatives.

Carcass construction: structural framework in poured concrete

Building with poured concrete leads to dust exposure when tooling the hardened concrete. Holes must be drilled to fasten steel rods, needed to connect parts of the construction. Vertical connections use the existing reinforcement rods. But this is not possible for horizontal connections, because these are perpendicular to the mould. Rods are then often mounted in the hardened

Table 1 alternatives for silica generating activities: construction work

Construction part	Activity	Expected silica concentration (mg/m³)	Alternative
Carcass	Drilling for connection of reinforcement rods	up to 0.2	Anchor bushing
	Grit blasting to make pebbles visible	Up to 25 (outside respirator) Up to 2 (inside respirator)	Leave columns smooth
			Use retardant and wash out with water
Roof	Sawing roof tiles	Up to 120	Design dormers in accordance to tile size
			Shift building block to avoid angle ridge and valley gutter
Outer wall	Sawing bricks to create patterns	0.22	Use prefab half and quarter bricks
	Sawing bricks slantwise to create a non-rectangular corner		Use prefabricated slantwise baked bricks
	Tuck pointing	Up to 0.56	Use glue instead of cement joints
Interior wall	Sawing last layer to size	Up to 0.2	Match block height to wall height
	Cut blocks around lintel		Match door frame to height to storey height
Floor	Application of dry mortar for top flooring		Compacting concrete floor with rotating disc equipment (avoid laying of sand/cement top flooring
	Sanding of top flooring		“

Table 2 alternatives for silica generating activities: installation work

Activity	Expected exposure (mg/m³)	Alternative
Drilling through floors	Up to 0.3	Shaft for pipes and cables
		Boxing-out openings
		Accessories for cut-outs
Fixing	0.11 – 0.21	Cast anchor bolts, anchor rails etc. in concrete
Recess milling	up to 6.9	Hollow cable bricks or hollow concrete stones
		Integrate cable for light switch into hollow doorpost
		Infrared remote controlled light switch
		Wall sockets on cable gutters

concrete, by drilling holes and gluing steel rods (‘chemical anchors’). Van Marle *et al*. (2002) have measured the exposure to respirable silica when drilling holes in concrete with an 8 mm spiral drill. Exposure varied from 0.111 to 0.213 mg/m^3 over a 120 – 225 min period. The production function ‘removing material’ and the production principle ‘drilling’ can be eliminated by using anchor bushing, as shown in Figure 1.
These can be embedded in the concrete. Anchor bushing can be connected to the reinforcement steel, leading to a very reliable connection. For the same purpose there is an other device called ‘keybox’, a casing that houses pre-bent bars that can be straightened after the mould is removed.

Figure 1 Anchor bushes, to be embedded in the concrete

Carcass construction: columns with infilling

Figure 2 shows a load-bearing structure built of columns and a brick infilling. The architect had determined that the pebbles in the concrete had to be visible. This was achieved by grit blasting of the hardened concrete. Exposure to respirable crystalline silica during dry blasting of concrete may be up to 25 mg/m^3 outside the supplied air respirator and 0.2 mg/m^3 inside the respirator (Golla and Heitbrink, 2004).
Figure 3 shows a comparable construction, a load-bearing construction built of columns and a concrete stone infilling. Here the columns are left smooth, avoiding grit blasting and thus the corresponding dust exposure. The production function ‘removing material’ is thus eliminated. With an adapted concrete covering, the pebbles could also have been made visible with a retardant and washing out the concrete immediately after demoulding.

Figure 2 Grit blasted columns
Figure 3 Columns left smooth

Roofs

Dormers are often mounted in inclined roofs. Designing these in accordance with the size of the roof tiles prevents the sawing of tiles for infilling. Task based exposure measurements when sawing roof tiles, as shown in Figure 4, showed respirable silica exposures varying from 2,9 to 120 mg/m^3 (28 – 160 times the Dutch occupational exposure limit) (Boeckhout et al., 2010).
A lively design is made by staggering the outer wall and the roof. In Figure 5 this is achieved in the roof with a valley gutter and an angle ridge. Many roof tiles must be sawn for this construction. The production function ‘removing material’ and the production principle ‘sawing’ can be eliminated by shifting the entire building part, as shown in Figure 6**.** This avoids edging of the roof, and thus sawing of roof tiles.

Figure 4 Sawing roof tiles

Figure 5 Valley gutter and angle ridge construction
Figure 6 Shifting the whole building part avoids sawing of roof tiles

Outer walls

For some details in the outer walls much sawing work must be done. One Measurement during dry sawing in brick and lime-sandstone showed an exposure of 0,22 mg/m^3(Huizer *et al*., 2006). Figure 7 shows a building built of bricks in two colours with straight lines. A double baked brick is chosen, which cannot be cut to size with a bricklayers’ bolster. The only method is to cut these

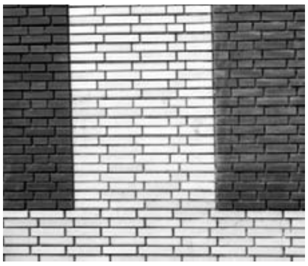 

Figure 7 Two colors of brick in one building
Figure 8 Dust settled on sawn bricks

 

Figure 9 Tuck pointing
Figure 10 Glued bricks with small joints

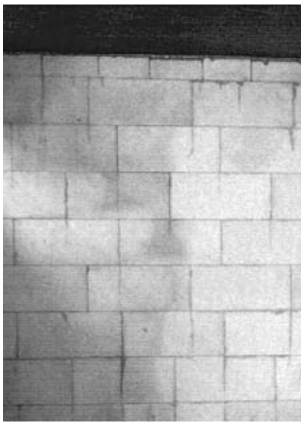 

Figure 11 Blocks do not match the storey height
Figure 12 Blocks matching the storey height avoids sawing

 

Figure 13 Door opening with a lintel
Figure 14 Door frames matching the storey height avoids sawing work

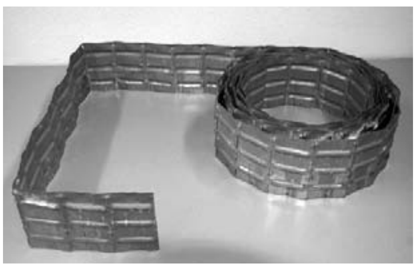

Figure 15 Accessory to create a floor opening

bricks with a diamond saw. And although this was done with water supply, dust remains on the brick (Figure 8). When processing the bricks this dust is released to the air. Designing details in standard size bricks (whole, half, quarter brick) prevents this.
For non-rectangular corners in repeating structures the stone can be factory-made, as can be seen in Figure 3. This is not only more aesthetic, but also prevents slantwise sawing of bricks.
Figure 9 shows tuck pointing for renovation, which is a notorious source of dust (Tjoe Nij *et al*., 2003; Collingwood and Heitbrink, 2007). Tjoe Nij *et al* measured exposures to silica dust up to 0.56 mg/m^3. Joints can be avoided by using glue instead of cement, as shown in Figure 10.
The very thin joint is not affected by weather influences and thus will not deteriorate. It must be kept in mind however, that the building will get a different appearance.

Interior walls

Figure 11 shows an interior wall built from blocks. The storey height does not match with the height of the blocks, which means that the last layer must be sawn to size. Sawing of lime-sandstone blocks with a circular saw in a test situation showed silica concentrations from 0.023 to 0.197 mg/m^3 (West et al., 2009). In Figure 12 the storey height matches with that of the blocks, thus avoiding sawing to size.
Figure 13 shows a door opening with a lintel. Around the lintel many bricks must be cut to size. In Figure 14 the door frame matches the storey height, thus avoiding a lintel.
Other methods to eliminate silica are the use of silica-free materials, e.g. gypsum blocks instead of lime-sandstone or cellular concrete, or walls built from plaster board on a Metalstud® or wooden frame.

Floors

A concrete floor is commonly covered with a top flooring. In case of a sand/cement flooring, first a thin layer of dry mortar is spread out on the damp floor surface. After hardening, the floor must be sanded to remove the thin upper layer of the top flooring because otherwise adhesives do not stick. Spreading of dry cement as well as sanding are sources of dust. For these activities no measurement results are available, but they both generate a considerable amount of visible dust. Both can be avoided by compacting the floor with rotating disc equipment. The concrete surface is mechanically compacted and smoothened. The floor finishing (e.g. carpeting, parquetry) can be applied directly on the concrete floor and the floor needs no sanding and the production function 'removing material' is eliminated.

Installation work

Clever design can avoid much dust in the realisation phase. This is also true for the installation phase. Fixing and ductwork can be designed in such a way that drilling, cutting and sawing are avoided or at least diminished.

Figure 16 Accessory to create openings for ductwork

Figure 17 Anchor rail (demonstration model)

Figure 18 Infrared switch

Figure 19 Retention wall

Figure 20 Cable gutter

Drilling

Dry drilling leads to silica exposures up to 0.3 mg/m^3 (Huizer *et al*., 2006). The application of water can decrease this exposure to 0.05 mg/m^3. The most rigorous solution is to work with a shaft to avoid drilling holes for separate pipes and cables. Many accessories for boxing out the opening are available, e.g. the one shown in Figure 15.

If this solution is not possible or not wanted, there are many accessories available on the market to realise cut-outs in concrete floors. Figure 16 shows an accessory to spare holes for central heating ductwork.

The accessory is mounted on the mould to get the openings for the tubes at the right place and at the right distance. Many of these accessories are available, for all kinds of pipe work.

Fixing

Alternatives for fixing by drilling and plugging are anchor rails and anchor bushes, as shown in Figure 17.

Apart from the advantage that drilling is avoided, the fixing is much more secure. The accessories are fixed at the reinforcement steel and so are fixed in the construction. Another advantage of anchor rails is the flexibility for mounting of ductwork. By embedding these at regular distances in the concrete floor, electricity cables, air conditioning ducts and water supply can be fixed at any point. This is a tremendous advantage when e.g. an office building is refurbished, when often an entirely new system is installed. A wrench and a screwdriver are sufficient to remove the old system and to install a new one.

Of course electricity cables and water supply can be embedded in the concrete floor as well, but then the lay-out of the building cannot be modified afterwards.

Cutting for cables and pipes

Vertical cables and water supply are often concealed in the wall by cutting or milling a recess. Measurements during recess milling showed exposure to a maximum of 6.9 mg/m^3 (Lumens and Spee, 2001). Closest to this practice is the use of hollow cable bricks or concrete stones. A vertical opening is created in this way, through which a tube can be put in place. These stones are especially developed for two-sided exposed masonry, but of course they can be used if the wall is plastered as well. A comparable solution is to integrate the cables to the light switch in a hollow doorpost. For concrete constructions, designing the details of the utility installation at an early stage make it possible to embed water pipes, cables et cetera in the concrete.

A more sophisticated solution for the central power point is an infrared remote control, as shown in Figure 18.

This looks like an ordinary light switch, but in fact it generates an infrared signal. The remote control can be mounted everywhere, which is a great advantage.

Power sockets can be mounted in hollow walls like

Metalstud® and plaster board, instead of mounting them in the solid (spine) wall. If the socket must be mounted at the place of the solid wall for some reason, a retention wall can be used, as in Figure 19.
There are many cable gutter systems especially designed for exposed work, which are commonly used at places where flexible cable and ductwork is wanted. An example is shown in Figure 20.

But nowadays systems are integrated neatly into the skirt board, and even applicable in dwellings.

Discussion

There appear to be many possibilities to eliminate generation of dust during construction. or, in terms of design analysis: to eliminate the production function 'removing material'. The examples in this paper are by no means exhaustive. All examples have proven themselves in practice, but the designer does not decide spontaneously to prescribe them in his specifications. Safety can teach us some lessons about the reasons.
In theory, designers are aware of the interest of safety in design. The American Society of Civil Engineers states in Policy Statement Number 350 that engineers shall have responsibility for "recognizing that safety and constructability are important considerations when preparing construction plans and specifications" (citation from Gambatese et al., 2005) On the other hand, when ranking the priorities of project criteria, construction safety scores 5.7 on a scale from one to six, where one is the highest priority and six the lowest. This means that 95% of all designers in Gambatese's study ranks construction safety last, after quality, end-user safety, cost, schedule and aesthetics. A literature study in the same paper for the reasons why construction safety gets so little attention yielded the following reasons:

1. insufficient requirements for designers to give attention to safety in design
2. the employer (i.e. the construction company) is responsible for safety
3. liability concerns among designers if a recommendation leads to an accident
4. narrow specialization of construction and design
5. limited availability of tools, guidelines and procedures in safety in design
6. limited collaboration among the parties in the design phase
7. limited education on construction workers safety and safety in design.

Some of these reasons will also apply to paying attention to silica in design. Reason 4, 5 and 7, all about lack of knowledge of the subject, apply to silica. Architects and construction engineers in The Netherlands are not educated to recognise hazardous substances in the construction process, which means that attention for this subject is hardly to be expected. One of the authors has attended a number of construction team meetings. The team consisted of an architect, a construction engineer and a structural engineer and the project was renovation and partial rebuilding of an old building. The three persons involved considered dust no more than a nuisance, and did not realise that dust may contain hazardous substances. The Dutch labour inspectorate states in one of her documents: "In the construction industry, those who really decide about the production process in the design phase (architect, technical designer) are often not very familiar with prevention of occupational risks and with the working conditions in the construction phase". And also: "The sector is characterized by insufficient structures for consultation between designers, future users and builders during the programming and design phases of the building" *(http://nl.test.osha.europa.eu/euweek/PDFdownloads/arborisicosinbranchebouw.pdf)* (reason 6). On the other hand, designers have a legal obligation to account for the influence of their decisions on the working conditions at the construction site. This is established in the European directive 92/57/EEG for temporary or mobile construction sites, which is incorporated in the member states legislation by 31 December, 1993 (EEC, 1992). For large, complicated and/or hazardous projects the designer must render a safety and health plan for the design phase to the builder. The hazards of silica dust, being a carcinogenic substance, should of course be described in this plan. This means that reason 1 and 2 of Gambete's literature study are not true. It is not the lack of rules, but the lack of knowledge which is crucial. Of course the health and safety of the construction workers at the building site are the responsibility of the employer, but before that the designer is definitely responsible for taking health and safety hazards into account. However, there are so many rules for designer concerning quality, aesthetics, end-user safety, energy consumption and many more, that health and safety in the design phase may easily be forgotten. One of the authors (DS) was involved in a project with special attention for design analysis. During an entire project constructing a utility building exposure specialists have cooperated with and advised both the architects and the construction company on ways to decrease silica dust exposure. The experience from this project was: "It was distressing to see that architects and advisers are hardly or not aware of their influence on the safety and health of construction workers" (Spekkink, 2010).
Involving a working conditions specialist from the beginning of the design process would avoid many hazardous situation in the construction phase. Currently, occupational hygienists are involved in the construction phase, which is too late to really change design principles and leads often to less wanted solutions like personal protection. The occupational hygienist does not need to have knowledge of designing and engineering. Just pointing to building systems, building methods or construction details that lead to high dust exposure may let the designer think of a solution. The designer

and the occupational hygienist together can then assess the solution. In this way, the designers feeling of responsibility will increase without the occupational hygienist taking over the designers job. Hopefully, this leads to maximum safety in design without affecting the creative freedom of the designer.
It would also be good to catalogue solutions at a central place, to make them available to everybody, whether designer or occupational hygienist. Illustrations would help to overcome confusions due to country-specific terminology and differences in building systems.

Conclusions

Exposure to respirable crystalline silica during the construction process is a serious health hazard and needs urgently to be lowered. Technical measures like water supply or local exhaust ventilation often work insufficiently. There are many possibilities to prevent or reduce dust exposure in the design phase. The designer has not sufficient knowledge of working practices at the building site to lower health risks for workers in the realisation phase and often does not even consider this his/her task. Input of an occupational hygienist in the design phase may improve this.

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