SIDE STUDY 20250101.01 CHROMATES IN THE WORKPLACE – ADDITIONAL OBSERVATIONS

Supplementary observations to the main study 20250101 – Chromates in the workplace

Gesundheitsrisiken durch Chrom (VI)-Expositionen bei Arbeiten mit (erd-) alkalimetallhaltigen Hochtemperaturisolierungen und -systemen in der gängigen Praxis unter Anwendung anerkannter Mess- und (labortechnischen) Analysemethoden (Gesamtstaub und Hintergrundkonzentration (E-Staub) untersucht

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Revision: 1.0

Further observations on chromium (VI) formation by the use of alkali and/or alkaline earth metal containing insulation materials on chromium-containing metal hot parts on a gas engine

Summary

This side study to the main study given in the cover page, whose structure and structure is largely retained here and only makes necessary changes to the individual chapters, reports on further observations and analyses made during the implementation of the main study, as well as the information collected here on further mechanisms of chromate formation when using alkaline and/or alkaline earth metal containing high-temperature insulation products on a Gas engine.

The observations show significant presence of carcinogenic and chronically environmentally harmful chromium (VI) compounds in areas of so-called "insulation cassettes" (Fig. 1), which consist of a chromium-containing housing, which includes insulation mats in the sandwich structure, and in some places, especially in bending and bending areas, includes "oxygen-open" areas (Fig. 2), on which fibers of the insulation mats are visible. These areas were tested **both according to the rapid test procedure "ST01"** and **tested positive for chromate presence with the test kit method "TK01" (Fig. 3).**

Since the rapid test method presented positive chromium (VI) results, the results obtained were verified with the test kit procedure in order to exclude "false-positive" test results.

Here, too, the observations show the possible carry-over risks of harmful substances and their effects on the environment and health.

Fig.1 Insulation cassette

Fig.2 Bending areas

Fig. 3 Cr6-positive (TK01)

1. Introduction

1.1 Introduction and Objective

The handling of chromate-contaminated insulation elements, textile or (partially) metallic, represents a considerable challenge for occupational health and safety and environmental protection.

Chromium (VI) compounds (chromates) are known to be carcinogenic hazardous substances because they are deposited in the respiratory tract and can cause cell damage due to their high oxidizing power. Even low concentrations in the air are considered harmful to health, as they significantly increase the risk of **lung cancer and other toxic effects on the organism**.

For chromates in the workplace, particularly narrow and low limit values or so-called exposure-risk relationships apply, such as the statistical risk of developing cancer with regular exposure between acceptance (4:10,000) and tolerance risk (4:1,000).

There is no safe threshold for chromates in the workplace. Any inhalation or dermal exposure potentially poses a risk, which underlines the high danger of chromium (VI) compounds.

Since hexavalent chromium compounds are also classified as **chronically harmful to the environment with long-term consequences**, the question of disposal as hazardous waste in accordance with regulations **and subject to labelling also arises**.

Materials that have been proven to contain chromium (VI) cannot **be disposed of with regular industrial waste**, but are subject to **separate disposal regulations** in accordance with the Hazardous Substances Ordinance (GefStoffV), the Waste Directory Ordinance (AVV) and TRGS 910.

As part of the main study, observations and resulting tests were made that detect chromates even in places that even the expert would not necessarily expect to be contaminated:

- The long-standing assumption that the risk of chromate formation exists wherever alkaline or alkaline earth metal-containing insulation materials come into contact with hot, chromium-containing surfaces is being confirmed more and more. This certainty also helps to **determine the risk as part of the risk assessment**.

- Since chromium (VI) compounds are considered to be skin-absorbent, there is a so-called "dermal risk" if contaminated components have to be handled. These components can also cause turbulence of the chromate-containing deposits when moved, which then also leads to an inhalation risk that has not yet been calculated.

    - ➢ The main study showed the exceedances of limit values caused by the mere handling of a small number of contaminated insulation elements.

The aim of this observational study is to point out hidden and unexpected hazards from hexavalent chromium compounds in contact with the skin, but also to **the exposure of carcinogenic and chronically harmful substances to the environment when working with engine components** , and shows once again that both the personnel entrusted with this work and persons entrusted with other work, some of whom happen to be in the working environment described, are exposed to dangerous health risks. Normally, the components would be dismantled without special protective clothing, deposited in the work area to promote dust and placed unprotected. Draught or artificial ventilation can then lead to inhalable chromium (VI) compounds being released, but also inhaled.

On the basis of these findings**,** a package of measures is to be developed **that protects people and the environment in accordance with existing occupational safety regulations** and creates a **reliable and reliable recommendation for action to correctly assess the hazard posed by CMR substances**.

1.2 Reaction mechanism and chemical basis

[no change from main study]

The use of thermal insulation containing (earth) alkaline metals in the high-temperature range (up to 650°C) can lead to the formation of chromium (VI) compounds. The process takes place in several stages:

- Even at normal humidity, the calcium oxides contained in the insulation materials react with water to form calcium hydroxide: $CaO + H_2O \rightarrow Ca(OH)_2$
- The resulting calcium hydroxide forms an alkaline solution as a strong base, which chemically attacks the passive layer of the stainless steel.

  This results in:

  - Local damage to the protective layer
  - Formation of stress cracks
  - Pitting corrosion, albeit on a small scaleThese impairments of the alloy release, among other things, chromium(III) oxide (Cr_2O_3) from the passive layer.

- Under the prevailing conditions (increased temperature, oxygen supply), the released chromium (III) is then oxidized to chromium (VI).

The processes described are further intensified by various factors such as abrasion, aging or wear of the insulation materials, as this continuously creates new reactive surfaces.

The overall reaction to the formation of calcium chromate can be summarized as follows:

$$2\,Cr_2O_3 + 4\,CaO + 3\,O_2 = 4\,CaCrO_4$$

1.2.1 Problem

For a long time, the problem of chromium (VI) formation caused by insulation materials containing calcium in particular was underestimated or deliberately downplayed by the industry.

For decades, the insulation industry has been using materials that were originally developed as asbestos substitutes, without initially recognizing their potential to form chromates, especially calcium chromate.

In the 1970s and 1980s, the formation of chromates due to the presence of (earth) alkali metal-containing compounds in high-temperature contact with chromium-containing hot parts was not the focus of companies and developers.

Yellowish deposits that occurred during the deinstallation of insulation were incorrectly classified as harmless sulfur formations.

Parallel to the textile insulation described in the main study, however, partial metal insulation has also been and is being used in engine and turbine technology, in that mainly stainless steel jackets determine the shape and the stainless steel elements are either connected to the selected insulation material (stainless steel jacket), or a cassette shape is chosen that has a metallic inner jacket and a metallic outer jacket.

The cassettes provide a reliable and stable shielding of hot areas, even though the metal jackets often have a slightly higher outside temperature than textile or flexible insulation systems due to the formation of thermal bridges.

The main study investigated in particular the release of chromates when handling textile, separable and thus flexible insulating elements.

In this observational study, the focus was on alkali or alkaline earth metal containing insulation mats, which are integrated into metal jackets (insulation cassettes).

In the case of insulation cassettes, there are several types of insulation material integration.

Often, only a metal outer sheath is chosen and the insulation material in mat form is connected to the inner sheath without further contact protection against the hot part and is then mounted around or on the hot part.

In the case of the engine examined, the insulation cassettes were elaborately and purposefully manufactured.

However, due to the manufacturing process, some bending and bending areas were manufactured in such a way that the insulating material was visible at certain points, which in turn means that the insulating material can be described as "oxygen-open" at these points.

This property ("oxygen-open") has long been seen by the authors as a potential trigger of chromate formation, because it is precisely at these points that the thermochemical basis for the chemical equation mentioned under 1.2

$$\mathbf{2\,Cr_2O_3 + 4\,CaO + 3\,O_2 = 4\,CaCrO_4}$$

are given.

The scope of service work resulting from the main study meant that some of the cassettes described had to be opened and dismantled.

This step opened up the opportunity for the testing personnel to test the inside of such cassettes for chromium (VI) compounds, because in the presence of hot parts containing chromium, physically connected to alkaline and/or alkaline earth metals, especially calcium-containing insulation materials, in **combination with the high system temperatures and in the presence of additional oxygen, (calcium) chromate formation can no longer be ruled out**!

1.3 Health and environmental risks

1.3.1 Health risks and clinical pictures

Chromium (VI) compounds are classified as carcinogenic hazardous substances.

The body's own reduction from chromium (VI) to chromium (III) produces **reactive intermediates that can cause DNA double-strand breaks, which explains the high carcinogenic potential of these compounds**.

Specific cancers include:

- **Bronchial carcinoma (lung cancer)**
- **Sinus cancer**
- **Laryngeal cancer (laryngeal carcinoma)**
- In case of high exposure, also:
  Stomach cancer caused by swallowed chromium-containing nasal secretions

In addition to the carcinogenic effects, **the following acute and chronic diseases** can occur:

- **Respiratory diseases:**
- **Chronic bronchitis**
- **Nasal mucosal inflammation**
- **Nasal septum perforation ("chrome hole")**
- **Bronchial asthma**
- **Skin:**
- **"Chromium eczema" (toxic or allergic contact eczema)**
- **Chrome ulcers**
- **Sensitization with lifelong chromium allergy**
- **Systemic effects:**
- **Kidney damage**
- **Liver damage**
- **Damage to the hematopoietic system**

Even low concentrations in the air are considered harmful to health and can trigger these diseases. The risk increases with the duration and intensity of exposure.

1.3.2 Skin absorption and dermal risks

Chromium (VI) compounds are classified as skin resorptive. They can penetrate the skin barrier and be absorbed into the body through the skin. **Therefore, any skin contact with chromium (VI) compounds must be strictly avoided**. This requires appropriate personal protective equipment, in particular suitable protective gloves and protective clothing.

1.3.3 Environmental hazard

Chromium (VI) compounds are classified as hazardous to water with long-term harmful consequences for aquatic ecosystems. They can **enter the food chain via groundwater** and

accumulate in organisms. The **high mobility of chromates** in the soil leads to a large-scale distribution, which **can cause** lasting damage to flora and fauna.**Particularly problematic is the long persistence in the environment, which can lead to a permanent burden on ecosystems.**

1.4 Regulatory framework

1.4.1 Germany (TRGS 910)

- Tolerance value: 1 µg/m³
- Acceptance value: 0.1 µg/m³
- Between acceptance and tolerance value:
    - Obligation to implement a detailed concept of measures
    - Regular exposure measurements
    - Documentation of all protective measures
    - Health monitoring of employees
    - Training and instruction
    - Preparation of special operating instructions
    - Minimization requirement according to the state of the art
    - Obligation to regularly review substitution options

1.4.2 Netherlands (SER standard)

- Tolerance limit: 1 µg/m³
- Below the tolerance limit:
- Commitment to further minimise exposure
- Application of the ALARA principle (As Low As Reasonably Achievable)
- Implementation of an Actieplan Kankerverwekkende Stoff (AKS)
- Regular occupational hygiene measurements
- Registration of exposed employees
- Medical monitoring

1.4.3 United Kingdom (COSHH)

- Limit value: 5 µg/m³
- Recommendations from 1 µg/m³
- Principle ALARP (As Low As Reasonably Practicable) for CMR substances

1.4.4 France (VLEP)

- Limit value: 1 µg/m³
- Below the limit value:
    - Principe ALARA (As Low As Reasonably Achievable)
    - Obligation de moyens (obligation to provide funds)
    - Documentation des expositions professionnelles, surveillance médicale renforcée (SMR), plan de prévention spécifique,
    - Formation et information des travailleurs, Évaluation régulière des risques

2. Methodology

		
Fig.4 Positive swab tests (ST01)	Fig.5 Wipe test sample (TK01)	Fig.6 Wipe test result (TK01)

2.1 Framework conditions and basics of the study

The measurements and analyses were carried out as part of cyclical service work on a gas engine from MWM.

Like other motors from various manufacturers, the engine is equipped with so-called "insulation cassettes", which consist of a metallic outer jacket, an internal insulation material and a metallic inner jacket.

On some bending edges, the insulating material is visible ("oxygen-open").

The insulation cassettes were loosened and then dismantled.

Chromium (VI) rapid tests using the SEEF Swabtest ST01 showed a first "chromium (VI)-positive" result (Fig.4), especially at the open points, which necessitated a detailed examination by means of the mobile chromium (VI) laboratory "SEEF Chromium (VI)-Testkit TK01".

To verify the positive swab test ST01, a so-called "wipe test" was carried out, in which open fiber areas of the insulation and parts of the inner jacket were wiped with an analysis cloth (10 x 10 cm) and used as the carrier of the sample (Fig. 5).

After completion of the mobile laboratory analysis, the correctness of the positive chromium (VI) detection (ST01) was confirmed (Fig.6)

The study was important because it is a type of engine that is used in large numbers worldwide and is regularly serviced as part of overhauls.

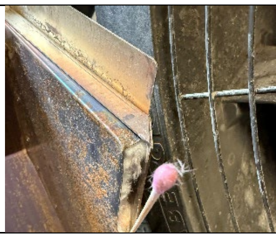
Supplementary framework conditions:

Work situation:

- Room temperature: 22°C ± 2°C
- Relative humidity: 45% ± 5%

Working environment:

- 40 foot container
- No forced ventilation, engine was not in operation
- Electric lighting
- Two access doors (3 × 3 meters)

		
Fig.7 Insulation cassette, rear	Fig.8 Insulation cassette, front	Fig.9 Insulation cassette, inside

Condition of the insulation cassette:

- Age of insulation: approx. 4500 operating hours
- The insulation cassettes were in a normal undamaged condition (Figs. 7 -9)
- Released insulating materials (see main study) also settled on the cassettes throughout the engine area, but due to the very precise geometries, no fiber penetration from the outside to the inside could be detected.

2.2 Measurement methods and implementation

		
Fig.10 Enclosure	Fig.11 Dust collection	Fig.12 Material sample

2.2.1 Wipe Test and Analysis

See 2.1

The coloristic test procedure confirms the "true-positive" swab tests, so the presence of chromates is considered to be proven.

During service work, parts of the cassettes must be removed and stored, a direct dermal contamination cannot be ruled out, nor can an inhalation background concentration of e-dust when handling the cassettes (disassembly, storage); there is a risk of carryover

3.4 Assessment of carryover risks

3.4.1 Direct working environment

The immediate working environment represents the main exposure area where the highest chromium (VI) concentrations occur in the form of background exposures due to mechanical processing and manipulation of the insulation cassettes.

The release takes place both through direct work processes and **through secondary whirling**, whereby **the handling of the cassettes in particular represent critical moments**.

The contamination of tools, work equipment and personal protective equipment leads to a constant expansion of the contaminated area.

Primary dust release:

- Handling of the insulation cassettes
- Cleaning work on contaminated surfaces

Secondary dust swirling:

- Movements of maintenance personnel
- Air flows through ventilation
- Vibrations caused by running units
- Vibrations during tool use

Contamination spread through work equipment:

- Tools and Measuring Instruments
- Cleaning equipment and materials
- Mobile work aids (ladders, platforms)
- Personal protective equipment

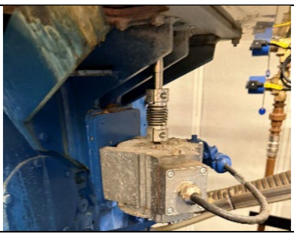
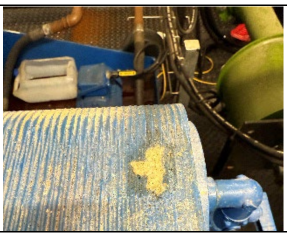
		

Fig.20 Fibre dust environment	Fig.21 Fiber dust environment	Fig.22 Fiber dust environment

3.4.2 Extended Workspace

The spread of chromium (VI) contamination beyond the immediate working area occurs through various carryover mechanisms, whereby **in particular personal transmissions and technical propagation routes (Figs. 20-22, 23-25) play a central role.**

Inadequate demarcations between contaminated and clean areas as well as inadequate decontamination processes lead to a steady expansion of contaminated zones.

The risk therefore also extends to persons who are not directly involved in the maintenance work.

Personal abduction:

- **Contaminated workwear**
- **Footwear with adhering dust**
- **Movement patterns of personnel between different work areas**
- **Insufficient decontamination when leaving the work area**

Technical transmission paths:

- Ventilation systems and air flows
- Transport routes of tools and materials
- Cable and wire routing
- Maintenance Accesses and Bushings

Organizational factors:

- Lack of demarcation of black-and-white areas
- Inadequate cleaning concepts
- Lack of access restrictions
- Unmarked contamination zones

3.4.3 Environmental impact

The environmental effects of chromium (VI) contamination can be seen both in the immediate vicinity through dust deposits and surface contamination and in long-term impairment of soil and groundwater. The high persistence of chromium (VI) compounds in combination with their mobility leads to a large-scale distribution and accumulation in different environmental compartments. A particular problem is the **professional disposal of contaminated materials** , which **requires special concepts and measures**.

Immediate environmental contamination:

- **Deposition of dusts on external surfaces**
- Entry into rainwater drains
- **Contamination of soil surfaces**
- **Spread via building openings**

Long-term environmental impacts:

- **Accumulation in soil layers**
- **Migration into groundwater**
- **Inclusion in the food chain**
- **Persistence of chromium (VI) compounds**

Disposal problems:

- **Contaminated PPE and cleaning materials (Fig. 23)**
- **Contaminated insulation residues due to other contaminated insulation parts (Fig. 27)**
- **Contaminated tools and aids**
- **Contaminated packaging materials**
- **Soil dust**

		
Fig.23 Contaminated PPE	Fig.27 Remains of insulation	Fig.28 Contaminated tools

3.4.4 Special risk factors

The carryover of chromium (VI) compounds is influenced by a variety of external and internal factors that can **significantly increase the spread of contamination**. **Weather influences**, **work organisation aspects** and **structural conditions form a complex interplay** that promotes the **spread of contamination**. **The combination of these factors requires a holistic view and specific countermeasures for each work situation**.

Weather influences:

- Wind turbulence through open gates/windows
- Thermal flows due to temperature differences
- Moisture effect on dust particles
- Weather-related changes in air flow

Work organization:

- Time pressure during maintenance work
- Parallel activities
- Shift handovers
- Emergency situations

Structural conditions:

- Complex plant geometry
- Hard-to-reach areas
- Inadequate seals
- Penetrations and openings

3.4.5 Metrological recording of carry-over

The **systematic recording and quantification of the carryover processes** requires a **comprehensive measurement program** that **includes both stationary and personal measurements**. The **combination of different measurement strategies** enables the **identification of critical spread paths** and the **evaluation of the effectiveness of protective measures**.

Stationary measurements:

- Fixed point measurements at defined intervals
- Continuous monitoring of critical areas
- Long-term measurements to capture trends
- Gradient measurements for propagation characteristics

Personal measurements:

- Exposure measurements on personnel
- Contamination measurements on PPE
- Wipe samples of workwear
- Measurement of surface contamination at discharge points

3.4.6 Economic impact

The **carry-over of chromium (VI) compounds** causes **considerable direct and indirect costs**, ranging from **immediate expenditure on protective measures** to **long-term follow-up costs** .

A holistic economic view must also take into account potential liability risks and damage to the company's image.

Direct costs:

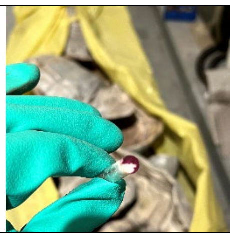
- Increased cleaning effort
- Additional PPE Requirements
- Special disposal
- Decontamination measures

Indirect costs:

- Occupational health monitoring
- Documentation and verification
- Training
- Quality assurance

Long-term costs:

- Remedial
- Liability
- Image damage
- Insurance aspects

		
Fig.29 Decontamination	Fig.30 Decontamination	Fig.31 Disposal

4. Discussion

4.1 Evaluation of the measurement results

4.1.1 Total dust analysis (see main study; here: exposure to other insulation)

- **The chromium (VI) concentrations in the direct working environment are 2.33-6.99 µg/m³, well above all national and international limit values**
- **Even with the most conservative assumption (10% e-dust), the tolerance value is exceeded by more than twice**
- **The potential seven-fold exceedance in the 30% assumption (inhalable fraction) is particularly critical**
- **The high total load of 47 ppm in the dust indicates intensive chromate formation on the hot part surfaces and inner surfaces of the insulating elements**
- **Dust releases and deposits must therefore be considered as chromium (VI) contaminated**

4.1.2 Background exposure (see main study; here: exposure to other insulation)

- **The measured background concentrations (0.526-0.556 µg/m³) are above the acceptable value**
- **Uninvolved persons are also exposed to relevant exposure**
- **Vertical distribution shows effective dispersion of dusts throughout the work area**
- **The danger extends to the entire container area**

4.1.3 Assessment of limit value exceedances

- **Systematic exceedance of all national limit values**
- **Particular relevance of the EU-wide minimization obligation**
- **Immediate need for action for technical protection measures**
- **Necessity of immediate organizational measures**

4.2 Comparison with other studies/warnings

(Natural) scientific and technical studies on chromate formation are available

Manufacturers are now warning against the formation of calcium chromate in combination with calcium-containing high-temperature insulation

4.2.1 Similar Exposure Scenarios

- **Comparable load patterns during insulation work on high-temperature systems**
- **Consistent observations on dust dispersion**
- **Similar carryover problems**
- **Confirmation of the relevance of the problem**

4.2.2 Additional findings

- High concentrations in the present case
- Strong spread in the work area
- Intensive chromate formation
- Significant exceedances of limit values

4.2.3 New findings

- Detailed recording of the vertical distribution
- Quantification of Background Exposure by Filter Pump
- Systematic recording of the routes of dispersal

4.2.4 Historical development of the problem

The current study confirms that **the chromate problem also has its origin in the historical development of insulation materials**.

At first glance, the materials used appeared to be suitable for thermal insulation, as only factors such as temperature resistance and thermal conductivity were examined when reviewing the data sheets.

Insulation fiber products, however, naturally react by "fraying"; this exposes the base core (glass core) of the insulation products, which then leads to the release of the (earth) alkaline metal oxides, which are responsible for the high oxidation of the chromium (III) compounds to hexavalent chromium compounds; Figures 32-34 show a global problem with calcium-containing insulation materials from different sectors.

		
Fig.32 Cr6-positive - mineral wool	Fig.33 Cr6-positive "Microtherm"	Fig.34 Cr6-positive "Superwool"

4.3 Methodological limitations

4.3.1 Measurement-related limitations

- Limited number of measurement points or swab tests
- Time-limited measurement period

4.3.2 Analytical uncertainties

- Assumptions about the e-dust fraction, but realistic estimate
- Simplified modelling of the spread, but based on many years of experience
- Influence of environmental conditions

4.3.3 Transferability of results

- Specific container situation
- Special climatic conditions
- Limited number of measurement situations

4.4 Significance for practice

4.4.1 Relevance to occupational health and safety

- Immediate need for action in comparable work
- Need for extended protection concepts
- Revision of existing work instructions
- Adaptation of risk assessments

4.4.2 Technical consequences

- Development of improved containment systems
- Optimisation of extraction technology
- Adaptation of working procedures
- Development of special tools

4.4.3 Organizational impact

- Implementation of stricter access restrictions
- Introduction of extended documentation obligations
- Intensification of employee training
- Strengthening occupational health surveillance

4.4.4 Economic aspects

- Increased costs for protective measures
- Extended working hours due to protective measures
- Additional documentation costs
- Increased disposal costs

4.5 Future research needs

4.5.1 Metrological aspects

- Development of improved measurement methods
- Continuous monitoring systems
- Optimized sampling strategies
- Automated measurement methods

4.5.2 Analytical development

- Improved E-Dust Determination
- More precise dispersion models
- Validation of measurement methods
- Standardization of analytical methods

4.5.3 Prevention strategies

- Alternative insulation materials
- Optimized working procedures
- Improved protection concepts
- Innovative decontamination methods

4.5.4 Long-term studies

- Chronic exposure effects
- Carry-over into the environment
- Persistence of contamination
- Costs

5. Recommendations for action

The area of recommendations for action outlines the prescribed measures to be applied if contact with so-called "CMR substances" (carcinogenic, mutagenic and reprotoxic substances) by employees cannot be excluded and is mainly implemented in national regulations by EU Directive 2004/37/EC.

The following points are derived from the German Hazardous Substances Ordinance (GefStoffV) and various Technical Guidelines for Hazardous Substances (TRGS).

The list clearly shows the immense influence that the presence of hexavalent chromium compounds will have on previous work processes.

If the findings from this study are understood, the entire energy-generating industry is facing a true paradigm shift.

It should be noted that all measures only take into account the control of the contamination that has already taken place in order to control the demonstrably existing risk to humans and the environment and to prevent further damage.

In the long term, the so-called "minimisation requirement" must be applied, i.e . **hazardous substances must be replaced by substances that are less dangerous or, at best, not dangerous at all** (substitution (5.2.1)).

Since chromates are not present before the thermally insulated systems are commissioned, but only during and after commissioning, the priority in the long term is to replace the source of chromate formation, i.e. the calcium-containing insulation. Calcium-free insulation systems are already available and have better properties than the current state of the art.

Another approach would be the use of hot parts that do not contain chromium, but such a change could only be made in new buildings as part of further developments in engine technology.

From today's perspective, the only option for the thousands and thousands of plants already in operation is the removal of today's insulation materials, a deep cleaning of the plant (decontamination) and the subsequent application of said (earth) alkaline metal oxide-free insulation.

Even if these new insulation systems are somewhat more expensive to purchase for the first time and the decontamination and disposal of the old thermal insulation also generates short-term additional costs, these expenses - even if not planned - are still likely to be cheaper than permanently continuing to operate the affected systems after the measures listed below.

In this respect, history will repeat itself, as it is already known from the times of asbestos removal. For the complete package of measures, their planning, implementation and monitoring, it is recommended to be supervised by expert safety officers who also have the necessary contacts to external companies that are necessary for the implementation of the measures.

5.1 Immediate measures

5.1.1 Technical measures

Enclosure and extraction

- Installation of fully enclosed workspaces
- Negative pressure maintenance with at least 20 Pascal
- Multi-stage filter systems with HEPA H13/H14
- Air exchange rate > 10 times per hour
- Separate supply and exhaust air ducting

Dust minimization

- Use of low-dust dismantling processes
- Humidification of the work areas where possible
- Special tools for gentle work
- Dust extraction directly at the point of origin
- Regular surface cleaning

Workplace design

- Setting up black and white areas
- Professional decontamination sluices
- Separate material transport routes
- Marking of contaminated areas
- Specially equipped cleaning zones

5.1.2 Organisational measures

Access restrictions

- Access only for trained personnel
- Documentation of all persons present
- Time limitation of working hours
- Rotation principle for exposed activities
- Coordination of parallel work

Workflows

- Detailed work instructions
- Risk assessment for every step of the process
- Determination of emergency procedures
- Regular workplace monitoring
- Documentation of all activities

Hygiene measures

- Strict separation of work and private clothing
- Regular change of protective clothing
- Shower facilities after work
- Ban on eating/drinking in the work area
- Regular cleaning of the work areas

5.1.3 Personal protective equipment

Respiratory

- Blower Assisted Full Face Masks
- P3 filter for suspended solids
- Regular maintenance and testing
- Individual adjustment, leak fit test before each use

Protective clothing

- Disposable Protective Suits Category III Type 5/6
- Chemical-resistant gloves
- Special safety shoes with overcoats
- Safety goggles with side protection
- Head and neck protection

Accessories

- Communications
- Personal Measuring Devices
- Emergency equipment
- Cleaning material
- First aid kit

5.2 Long-term measures

5.2.1 Substitution

Alternative materials

- Development of chrome-free insulation solutions
- Use of Cleansulation products
- Innovative fastening systems
- Improved coating technologies
- Mechanically more stable constructions

Design changes

- Optimization of insulation geometries
- Improved accessibility for maintenance
- Modular design
- Integrated monitoring systems
- Temperature-optimized design

Process adjustments

- Revision of maintenance intervals
- Preventive replacement of endangered parts
- Optimization of operating parameters
- Adaptation of cleaning procedures
- Development of special tools

5.2.2 Monitoring

Metrological monitoring

- Continuous air measurements
- Regular wipe tests
- Personal dosimetry
- Biomonitoring
- Material analyses

Documentation

- Digital maintenance management
- Complete exposure documentation
- Recording of material changes
- Logging of incidents, long-term archiving of all data

Quality assurance

- Regular audits
- Certification of processes
- Review of protective measures
- Validation of measurement methods
- Documentation control

5.2.3 Qualification

Basic training

- Hazard potential of chromium(VI)
- Occupational health and safety measures
- Emergency behavior
- Documentation obligations
- Legal basis

Hands-on training

- Handling of PPE
- Decontamination process
- Sampling techniques
- Cleaning methods
- Emergency drills

Further education

- Regular refresher courses
- Updates on new regulations
- Exchange of experience
- Best Practice Workshops
- Certified training courses

5.2.4 Prevention

Health care

- Regular occupational medical examinations
- Biomonitoring programs
- Psychological support
- Ergonomic workplace design
- Occupational health management

Environmental protection

- Disposal concepts
- Emission minimization
- Resources
- Recycling strategies
- Environmental monitoring

Economy

- Cost assessment of the measures
- Investment
- Insurance aspects
- Liability minimization
- Image protection

6. Conclusions

The present side study on chromium (VI) exposure when working with chromate-contaminated insulation cassettes on gas engines and other energy-generating equipment leads to several fundamental conclusions:

6.1 Exposure risks

The measured values determined from a mix of different insulation materials and systems prove a systematic and significant exceedance of the applicable occupational exposure limits:

- **The measured chromium (VI) concentrations of 2.33-6.99 µg/m³ in the direct working area exceed many national limit values several times over**
- **Even the background pollution (0.526-0.556 µg/m³) is above the acceptable values**
- **The hazard affects not only directly exposed employees, but also people in the extended work environment**
- **The vertical distribution of the load shows an effective spread of the contaminated dusts throughout the entire work area**

6.2 Systemic problems

The study reveals fundamental weaknesses in previous practice:

- **The historical development of insulation materials has led to an inherent problem**
- **The combination of calcium-containing insulation materials with chromium-containing components creates ideal conditions for chromate formation**
- **Mechanical stress and aging increase the formation and subsequent release of chromates**
- **Existing protection concepts are inadequate for the identified hazards**

6.3 Risks of carry-over

The study shows multiple ways of carry-over:

- **Primary dust release due to direct work on the insulation**
- **Secondary contamination through stirring up and distribution**
- **Carry-over via tools, work equipment and personal protective equipment**
- **Spread via ventilation systems and structural openings**

6.4 Economic implications

The necessary measures have a significant economic impact:

- **Direct investment in protective equipment and technical facilities**
- **Increased personnel and time required for maintenance work**
- **Additional costs for monitoring and documentation**
- **Long-term expenditure on substitution and prevention**

6.5 Paradigm shift needed

The results illustrate the need for a fundamental rethink:

- **Previous practices are no longer up-to-date and legally questionable**
- **Immediate technical and organizational measures are essential**
- **There is no alternative to long-term substitution of chromate-forming materials**
- **Holistic prevention strategies must be developed**

7. Recommendations

Based on the study results, the following recommendations are made:

7.1 Strategic orientation

The industry should take a coordinated approach:

- **Development of a common strategy to address the chromate problem**
- **Establish industry standards for non-chromate-forming insulation solutions**
- **Establishment of competence networks for the exchange of experience**
- **Coordinated research and development initiatives**

7.2 Technical innovation

Focus on future-proof solutions:

- **Accelerated development of (earth) alkaline metal-free or low-alkaline metal insulation materials**
- Optimization of processing and assembly techniques
- **Integration of monitoring systems into new plant concepts**
- **Improving decontamination and cleaning technologies**

7.3 Organizational realignment

Adaptation of operational structures:

- **Implementation of systematic risk assessments**
- **Establishment of professional training and qualification programs**
- **Establishment of effective documentation and verification systems**
- **Development of specific emergency and intervention plans**

7.4 Regulatory measures

Recommendations for the regulatory framework:

- **Tightening monitoring and control**
- **Standardization of measurement methods and documentation**
- **Harmonization of international limit values and standards**
- **Development of specific guidelines for the industry**

7.5 Preventive strategies

Long-term prevention approaches:

- **Systematic substitution of chromate-forming materials (insulation, seals, pastes)**
- **Implementation of preventive maintenance concepts**
- **Development of improved occupational health and safety strategies**
- **Establishment of continuous improvement processes**

7.6 Need for research

Identified research interests:

- **Further development of measurement technology and analysis methods**
- **Investigation of long-term effects and chronic effects**
- **Optimization of decontamination and cleaning methods**
- **Development of innovative protection concepts**

7.7 Economic aspects

Recommendations for cost optimization:

- **Development of cost-effective protective measures**
- **Optimization of workflows and processes**
- **Use of synergy effects during implementation**

- **Consideration of life cycle costs in investments**

These recommendations are to be understood as guidelines for the future development of the industry and should serve as a basis for the development of specific action plans.

8. Bibliography (Sources/Reference)

See document "Safety for people and the environment" of 06.12.2024

9. Test and measurement methodology (total dust analysis)


9.1 Chromium (VI) Swab Test ST01


9.2 Cr(VI) Test Kit TK01


9.3 Cr(VI) Laboratory Analysis

9.1"Chromium (VI) Rapid Tests"

In all previous investigations and investigations, so-called "rapid tests" have been used for the initial detection and identification of chromium (VI) compounds.

In this procedure, a test tip soaked in DPC described below is wiped or dabbed over a surface to be tested in order to induce a colorimetric reaction in the presence of chromium (VI).

The operation of the rapid tests, which are offered by different companies (e.g. product "HexChecks" (Figure Engineering Ltd. USA) or product "TK11" (MATInspired NL)), is based on a "colorimetric method"; the test procedure uses a chemical reaction with 1,5-diphenylcarbazide (DPC), which oxidizes to 1,5-diphenylcarbazone in the presence of chromium (VI) and produces a violet to pink coloration.

The intensity of the color is proportional to the chromium (VI) concentration and can be evaluated visually or with a colorimeter.

The test results are quite reliable, **false positive results are very rare, but false negative results are, because it can happen that dusts and deposits, but also oily surfaces, can prevent the reaction between chromium (VI) and the DPC from taking place during the swab**.

Since 2023, the Dutch company "SEEF B.V." has been offering a rapid test system "Chromate Speedtest" specially developed for chromate-contaminated thermal insulation, which is also designed according to the above-mentioned methods, but is somewhat less sensitive to dust deposits, but still cannot prevent them completely.

Field tests have shown that the **swab tests have a "true positive" hit rate of over 99%** and a **"false negative" rate of less than 50%,** so it was decided to keep this test method in the future.

It is advantageous to mention in the selection of test methods that SEEF has developed a mobile laboratory for relatively simple but deeper Cr6 analysis, which can also be used stationary and offers a relatively fast laboratory-like test for material samples.

9.2 "Mobile laboratory" Cr(VI) test kit TK01 (SEEF B.V.)

The TK01 Chromium-6 test kit enables fast and reliable on-site analysis of chromium-6 and has been developed for the measurement of calcium chromate in insulation, assembly pastes, lubricants and stainless steel parts, among other things.
The analysis takes place within 45 minutes and allows the simultaneous analysis of 6 samples. The patented process prevents the reduction of chromium-6 to chromium-3 during the analysis process and at the same time minimizes interference from zinc and aluminum.

Smaller material samples or so-called wipe swabs are pre-treated with certain chemical substances and heated in test tubes, so that an almost 100% safe colorimetry can be performed.

In practice, further tests according to this procedure could, for example, heavily dust-covered or otherwise soiled areas be detected as positive and thus chromate-containing despite a negative rapid test.

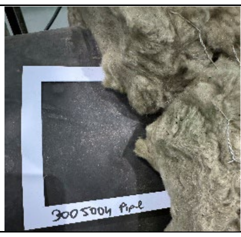
9.3 Laboratory analysis (wipe test | Material samples) (SEEF B.V.)

In the so-called "wiping test", a spatially defined area of 10 x 10 cm is wiped diagonally and horizontally with a cloth in order to absorb the surface dust and bind it in the cloth.

Subsequently, if the cloth is not examined using the mobile laboratory method, it is sent to the laboratory for analysis of the chromium (VI) load for the tested area. A few days later, the exact contamination in ppm | mg/kg in writing; the wipe sample is also tested for other heavy metals.

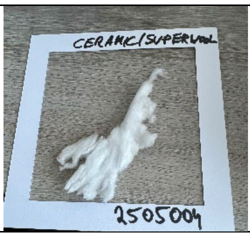
In the case of material samples, samples of fibre dust or other deposits are sent to the laboratory and then analysed and evaluated according to the same procedure, as in the wipe test.

9.3 Wipe Test



9.3 Wipe Test

9.3 Wipe Test Analysis with TK01

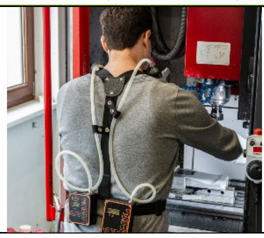


9.3 Material sample

9.3 Material sample

9.3 Material Sample Analysis with

10. Test and measurement methodology (background loading)

		
10.1 Sampling Device	10.1 Pumping head	10.1 Measuring principle

10.1"Sampling Device SG 10-2 (GSA)"

The **SG10-2 sampling device** incl. charger for **the personal** and **stationary** sampling of hazardous substances up to 12 l/min in accordance with EN 481.

The **SG10-2 sampling device** was developed for the measurement of hazardous substances, especially when **high volume flows** are required.

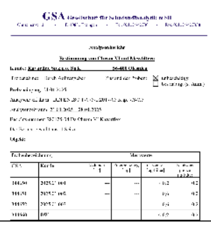
The SG10-2 offers a volume flow of 1-12 l/min and thus enables significantly shorter measurement times.

The various sampling heads licensed by IFA allow the measurement of inhalable dust (**E-dust, total dust**) and/or the alveolar dust fraction (A-dust, fine dust).

For the determination of chromium (VI) compounds in the air we breathe, a volume flow rate of 10 l/min is preset.

The measurements were carried out on base bearings of the DGUV (German Social Accident Insurance) in accordance with Information 213-505 as a recognised measurement method for determining the concentration of hexavalent chromium in the air in working areas.

A few days after the filter dissolved in the analysis solution has been sent, the result is given in micrograms/filters, followed by conversion and evaluation (total amount of air, derived from this micrograms/cubic meter).

		
10.2 Resolved filter in solution	10.2 Analysis Solution	10.2 Certificate of Analysis

11. Outlook and further investigations

11.1 Status of this study

This side study builds on the findings of the basic reference study (20250101) on the chromium (VI) problem in high-temperature insulation. It forms the scientific and methodological basis for all further investigations. The observations from this side study 20250101.01 broaden the observation perspective. Future and past measurements and empirical values are used as a supplementary data collection, with the established methods and parameters of the main study serving as standard.

11.2 Representativeness and transferability

It should be expressly pointed out that the MWM engine examined happened to be the first unit to be analyzed using state-of-the-art measurement technology. It is noteworthy that this engine has a relatively small amount of textile insulation compared to other manufacturers. The insulation cassettes examined are professional and of high quality, but do not take into account the formation of chromates. Many other engine manufacturers use significantly more textile insulation technology and significantly inferior cassettes, which could potentially lead to even higher loads.

11.3 Extended findings

The significant chromium (VI) concentrations detected in removable metal cassettes are produced according to the clear thermochemical pattern in areas where calcium-containing insulation materials with air supply ("oxygen-open") have been installed. This observation once again supports the theoretical considerations on the formation mechanism of chromates in a practical way.

11.4 Automotive sector

Initial preliminary investigations have also detected chromates in the engine compartment of various car models (especially Mercedes and Audi). Further dedicated studies are currently being prepared for this purpose. The possible implications of these findings for the automotive sector are the subject of ongoing investigations.

11.5 Social relevance

The scope of the problem becomes particularly clear when one considers the diverse areas of application of the motors concerned. Aggregates of the type studied can be found in, among others:

- Hospitals (emergency generators)
- Public buildings
- Liners
- Power plants
- Industrial plants

This underlines the need for further systematic investigations and preventive measures.

11.6 Outlook

The available findings mark only the beginning of a comprehensive inventory. The identified exposure risks and their potential impact on occupational safety and public health require further detailed investigations. Based on the methods and standards developed here, further application areas and scenarios are systematically analyzed.

The results of this study suggest that a cross-industry reassessment of the use of calcium-containing high-temperature insulation is urgently needed. The protection of exposed workers and the development of safe alternatives should be in the foreground.

11.7 Further documentation

This side study and all subsequent evaluations will be carried out on the basis of the main study and differ in notes on 2.1 (working situation and environment, condition of the insulation), 2.2 (measurement methods and implementation), as well as 2.2.2 (total dust analysis), as well as the measurement results; all other information can be treated and interpreted in the same context, albeit with minor variations.