The Overlooked Ingredient

How an inconspicuous metal oxide triggers a worldwide turning point in occupational and environmental protection
US edition: German rules as the benchmark, with the United States, California and Canada mirrored

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About the author

I come from a family of insulation contractors. With us the profession was settled at birth. As I was not particularly useful as a craftsman, I was put in the office, and there I became responsible for the documents. In the nineteen-nineties I still typed our data sheets on a typewriter. We wanted to state the compositions in full, so I typed the constituents of glass fabrics, mineral and basalt wools over and over again: silicon dioxide, aluminum oxide, calcium oxide.

My father set up his own business in 1988 as a manufacturer of textile insulation. Three years later he died of asbestosis at the age of 59. He had never worked with asbestos directly, but he had worked in rooms where asbestos insulation mats had once been produced. Nobody had ever remediated those rooms.

On 9 August 2019 I was sitting in a café in Austria. The day before we had fitted a prototype with a new thermal insulation at an engine manufacturer nearby. At 10:00 I received an email from them headed "Chromium-6 alert". Deposits had been found on engines in service that had tested positive for chromium(VI).

Until then I knew the term chromium(VI) only from the film "Erin Brockovich".

One sentence escaped me that day. We were asked whether our products contained calcium, because calcium would promote the formation of chromium(VI).

Calcium. A constituent whose name I had typed into our data sheets on the typewriter for years. Chemistry was never my favourite subject, but chromium(VI) and calcium simply did not fit together for me. My curiosity was roused and I began to search. And I found the connection between chromium(VI) and calcium, the overlooked ingredient.

Markus Sommer

Introduction

High-temperature insulation materials contain basic oxides, above all calcium and sodium oxide. Neither is classified as carcinogenic, and neither appears in any chromium(VI) assessment. Above roughly 300 °C they react with the chromium oxide layer of chromium-alloyed hot components to form calcium and sodium chromate. The result is carcinogenic compounds that nobody manufactured, ordered or installed.

In waste incineration the basic oxides come from the feed material itself. To these are added the sorbents of acid gas cleaning, hydrated lime or sodium bicarbonate, which are injected only in the flue gas path downstream of the boiler and therefore affect the filter dust and the downstream plant sections.

As part of the ash, the oxides from the feed material meet the chromium-containing surfaces of grate elements and boiler passes, and chromates are formed. At the next overhaul these ashes are raised and released, so far frequently without any protective concept.

The use of the collective term "chromium(VI)" instead of naming the chromium(VI) compounds correctly, that is the chromates, has meant that for decades nobody asked which compound is actually present and which reaction partner produced it. What has arisen is a stock of plant, vehicles, components and residues that will occupy the sectors concerned for decades: power generation, waste incineration, shipping, vehicle construction, maintenance, dismantling and disposal.

For occupational and environmental protection it makes no difference whether chromium(VI) is used deliberately, has formed in situ or may form at any time. If it is found, or if its presence cannot be ruled out, action is required. The risk assessment comes out the same in all three cases.

Where formation can be prevented, it must be prevented. In high-temperature insulation there are substitutes that exclude the formation pathway. In waste incineration the formation cannot be prevented. There it remains to acknowledge that it takes place and to redefine occupational and environmental protection accordingly.

The basis is not only patents, studies and manufacturer documents, but also my own site inspections, wipe and material samples, documented since 2019, on engines, power stations, incineration plants, ships, vehicles and construction machinery. This expert analysis names chromium(VI) with its compounds, the reaction partners that follow from them and the way in which they combine. Precisely this formation can be prevented in most cases. And once we know the compounds, we can control them (waste incineration), remove them (insulation work and remediation) or prevent their formation in the first place (substitution). The question whether it should not have been seen arises; sometimes, however, the view is obstructed. The asbestos experience should be a cautionary example for us. History must not repeat itself, but it already is.

Summary of the essential findings and their consequences

This expert analysis is addressed to companies that insulate, operate, maintain or dispose of chromium-alloyed hot components, that service vehicles or that handle combustion residues. It sets out how calcium and sodium chromate form in situ in these fields, what evidence exists for this and what duties follow from it.

The central finding

An insulation that contains no chromium(VI) in the as-delivered condition can, through its own composition, contribute to the formation of chromates in service. The statement that an insulation material contains no chromium(VI) in the as-delivered condition does not answer the question whether it contributes to chromate formation in its intended application.

Formation and reach

Formation requires four conditions: a chromium source, as a rule the oxide layer of chromium-alloyed steel, a basic oxide as reaction partner, oxygen and elevated temperature. Sodium chromate forms from about 200 °C, calcium chromate from about 300 to 350 °C. The reaction partner comes from calcium silicate, mineral and stone wool, E-glass fabric, AES wools, refractory compounds, assembly pastes or combustion residues.

The subject is therefore tied neither to one product nor to one manufacturer. Basic oxides are constitutive components of the glass melt from which most high-temperature fibers are drawn, and they enter the formulation unavoidably through cullet, limestone and dolomite (Section 13).

The evidence

The formation pathway has been described in patent form since 1939 and confirmed experimentally several times since, most recently with the direct detection of calcium and sodium chromate at the interface between metal and insulation material (Section 10). Manufacturers and operators have described it in their own documents since 1990, beginning with the Plant Service Bulletin of Babcock & Wilcox and continuing in service bulletins and technical instructions of the years 2020 to 2025 (Section 16). To these are added my own site inspections, wipe and material samples since 2019 on engines, power stations, incineration plants, ships, vehicles and construction machinery (Section 28). These three strands are independent of one another and support the same finding.

Action required

The German TRGS 561 requires the protective regime as soon as exposure cannot be ruled out. For the risk assessment it is immaterial whether the chromate was used deliberately or formed in situ. Substitution takes priority: high-temperature insulation materials without reactively available alkali and alkaline earth oxides are available. Where formation cannot be avoided, as in waste incineration, what remains is to acknowledge the process and to organize occupational and environmental protection accordingly.

Practical consequences

During disassembly, maintenance, cleaning, overhaul, dismantling and reuse, the chromates formed in service can be released and expose people. The dust carries the chromate, and it leaves the working area on tools, clothing and components.

Cleaning and decontamination work for the operation in hand. They do not remove the material cause: if the calcium-containing insulation remains on the chromium-alloyed hot component, chromates form again at the next thermal loading (Section 26).

An all-clear from analysis is only as sound as the recovery rate of the method for this matrix. For thermal insulation materials no standardized method exists; transferred procedures give results that are too low, down to near zero. A negative result without a statement of the recovery rate is not proof of absence (Section 17).

What is established and what remains open

Established are the formation pathway, the compounds involved, the temperature ranges and the state of knowledge among manufacturers and operators. From the overall picture it follows that the process is not an isolated case but can occur at any combination of a chromium-alloyed hot component and a basic insulation material. Unknown is the scale of the stock of plant affected, because it has never been recorded with this question in mind.

Open are the quantitative boundary conditions: the exact temperature thresholds in the individual case, the influence of the chromium content of the alloy, the required content of calcium or sodium oxide, kinetics, moisture and the number of cycles. These questions cannot be answered in general terms with any rigour, and that will not change appreciably for the foreseeable future. They concern the extent of the reaction, not its existence.

In statements by insulation manufacturers and authorities, the formation mechanism not being conclusively clarified is occasionally invoked in order to defer further consequences. This distinction does not withstand the evidence.

That calcium and sodium chromate form at the interface between chromium-alloyed metal and basic insulation material has been described in patent form, demonstrated experimentally, confirmed by manufacturers in their own documents and found repeatedly in the field. What is at issue is the precision of the boundary conditions, not the process itself.

There is also a structural feature. Authorities, accident insurance institutions, manufacturer and hazardous substance associations have worked closely with the producers of the asbestos substitutes for decades, and this cooperation has produced an extensive and functioning body of rules for asbestos remediation and for the proper use of the substitute materials.

That the same material classes, outside building insulation and in industrial high-temperature insulation, now come into view themselves because of their constituents is an uncomfortable development. It does not change the evidence.

Building and building services on the one hand and high-temperature insulation on the other are to be kept apart in application, service temperature and consequences. This separation follows from occupational and environmental protection law, since what is assessed is the activity under its actual conditions and not the material class in general.

An insulation material that is harmless in a building can create a chromate problem on a chromium-alloyed hot component.

This distinction is to be acknowledged, even where it is uncomfortable for the manufacturers concerned and for the supervisory bodies. That it is being drawn only now is understandable in the light of the material history.

Drawing it earlier would have been possible, as this expert analysis shows clearly.

Chemistry does not lie.

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A. The overlooked issue

1. The knowledge has been documented for decades

The formation pathway of calcium and sodium chromate is not new. It has been documented in patent specifications, research work, manufacturer documents and regulations over more than eight decades. The following overview lists the milestones evaluated in this expert analysis; the evidence is given in the sections indicated.

Year	Source	Documented content
1939	US patent US 2,176,687 (Udy) [1]	Deliberate formation of calcium and sodium chromate from a chromium source, lime or soda respectively, and oxygen (Section 7).
2002	Paoletti, the German research center Forschungszentrum Karlsruhe [50]	Calcium chromate from chromium oxide and calcium oxide between 500 and 850 °C in waste incineration, depending on the oxygen supply (Section 21).
2004	Vehlow, Paoletti, Seifert, Sirini [51]	Presentation of the results, including thermogravimetry on Cr_2O_3 and CaO with the product $CaCrO_4$ (Section 21).
2010/2011	Toshiba, JP2011232021A [26]	Calcium chromate at the interface between stainless steel and calcium-containing thermal insulation; ceramic separating layer as a prevention approach (Section 11).
2015	Sayano et al. [11]	$CaCrO_4$ and Na_2CrO_4 identified experimentally at the interface between chromium-containing metal and thermal insulation material (Section 10).
2019	Manufacturer correspondence [redacted] [52]	Calcium from the insulation material reacting with chromium-containing stainless steel named as the cause; occurrence in all engine types (Section 16).
2019	Energy UK, Hexavalent Chromium Safety Bulletin Summary [92]	Calcium-containing product, temperatures above 300 °C and chromium-containing steel as the three conditions; presence assumed at all power station sites; at the same time a reference to WD-40 for binding and wiping off (Section 26).
2019	The German Environment Agency (UBA) [44]	Cr(VI) in all 25 model ashes from cremation furnaces examined (Section 23).
2019	European BAT reference document for waste incineration [34]	Hexavalent chromium as a problematic substance with regard to leaching from bottom ash (Section 22).
2020/2021	Caterpillar; Caterpillar Energy Solutions / Zeppelin [12, 13]	Cr(VI) findings on exhaust systems and exhaust insulation; French translation of the bulletin and German-language circular (Section 16).
2023	Rockwool, European ProRox instruction [16, 24]	Cr(VI) deposits after high-temperature use, cancer hazard and protective measures during removal (Section 16).

Year	Source	Documented content
2023	[redacted], [redacted] [25]	Chromium-containing steel, calcium for example from insulation material, oxygen and temperatures above 400 °C (Section 16).
2023	MAN Truck & Bus SE, service bulletin 8339SM [14]	Calcium chromate named; exclusively calcium-free pastes for assembly work (Section 16).
2025	Frenzelit, TechInfo 28 [15]	Calcium oxide fractions of its own insulation materials; contribution of its own products to Cr(VI) formation under the conditions stated (Section 16).
2025	[redacted], [redacted]; [redacted], [redacted] [22, 23]	Cr(VI) formation on hot exhaust components; confirmed contamination in the engine compartment (Section 20).
2025	Passeron et al., France [5]	Colorimetric rapid tests miss Cr(VI) detected by laboratory analysis (Section 19).
2026	The German TRGS 561, version of 4 May 2026 [19]	Alkali/alkaline earth metal oxides from insulation materials or assembly pastes as an influencing factor; protective measures where chromium(VI) exposure cannot be ruled out (Section 6).
2026	The German statutory accident insurance institution BG ETEM [2]	Formation of carcinogenic chromates at steel temperatures of approximately 350 to 800 °C due to insulation materials or assembly pastes containing alkali and alkaline earth metals (Section 11).

Anyone who today combines, maintains or disposes of chromium-alloyed hot components with alkaline insulation materials is therefore not relying on an open research question, but on a reaction pathway that has been described over decades and confirmed several times.

2. The issue has reached Europe

The manufacturer and operator documents in the overview originate predominantly from Europe: from German manufacturers (MAN, Frenzelit, [redacted]), an Austrian engine manufacturer ([redacted]), a British vehicle manufacturer ([redacted]), from the European Rockwool instruction, the German-language circular from Caterpillar Energy Solutions and Zeppelin, and the French translation of the Caterpillar bulletin. [12-16, 22, 23, 25]

In addition, there are authorities, regulations and research in Europe: the German statutory accident insurance institution BG ETEM, the German TRGS 561, the German Environment Agency (UBA), the European BAT reference document for waste incineration, the British practical case from waste incineration and the French field study on the maintenance of diesel and marine engines. ECFIA, the European association of high-temperature insulation wool manufacturers, commissioned research on Cr(VI) formation on insulation wools (Section 14). [2, 5, 19, 30, 34, 37, 44]

The issue is thus neither foreign nor theoretical. It appears in the service bulletins, technical instructions, product information and regulations that apply in European companies, workshops and plants. Whether it is recognized there as an issue in its own right is another question.

3. The chromium(VI) misconception: collective term and individual compound

Asbestos was not simply asbestos either

Asbestos was not simply asbestos either. In everyday language a distinction was made at most by color, into white, brown and blue asbestos. Behind these lie different minerals: chrysotile, amosite and crocidolite, as well as tremolite, actinolite and anthophyllite. The European Asbestos Directive 2009/148/EC lists these six fibrous minerals individually. [62] A distinction was, however, drawn only where it was needed: in science, in engineering and later in medicine, when fiber form, durability and clinical picture had to be kept apart. On the construction site and in general usage it remained at one word. That had few consequences, because each of these minerals was a fiber and the fiber was the hazard.

The situation with "chromium(VI)" is similar, except that here even the everyday distinction is missing. The term covers industrially manufactured compounds such as chromic acid, dichromates and chromate-containing paints and primers just as much as calcium and sodium chromate, which form during operation. Anyone who hears "chromium(VI)" thinks of substances they do not use themselves and concludes from this that the issue does not concern them. Calcium and sodium chromate as reaction products of their own operations do not appear in this picture. The fact that calcium chromate is among the most potent chromates in animal studies likewise disappears behind the collective term (Sections 24 and 25).

The prefix names the reaction partner

In almost every solid finding, behind the designation "chromium(VI)" there stands a salt, a chromate or dichromate, and the prefix of that salt names its reaction partner: lead chromate, zinc chromate, strontium chromate, sodium chromate, calcium chromate. The prefix is not a formality. It is the other half of the substance and says where it comes from. Chromium trioxide and chromic acid are not salts and have no such partner. They are no less carcinogenic for that, but they belong to electroplating and surface technology, where the use is intended and declared.

The reaction partners are inconspicuous

The partners that occur in intentional use are themselves known to be hazardous: lead, zinc, strontium. The partners that lead to chromate in situ are not. As an element, calcium is the building material of bone and a constituent of milk, sodium is table salt, and both can be bought in a drugstore. The reaction partner in the insulation material, however, is not the element but the oxide. For decades chromium(III) was listed as an essential trace element in the diet; in 2014 the European Food Safety Authority concluded that evidence of essentiality is lacking and set no reference values, while in the United States an intake value continues to exist and chromium is sold as a dietary supplement. None of these three substances gives any reason to test a product for it. [76]

Inconspicuous does not mean harmless here. Calcium oxide is classified as irritating to the skin, seriously damaging to the eyes and irritating to the respiratory tract (H315, H318, H335), and Directive (EU) 2017/164 gives an indicative limit value of 1 mg/m³ as the respirable fraction. Sodium oxide forms sodium hydroxide solution with water and is correspondingly corrosive. Both, however, are not carcinogenic and not classified as CMR, and in the insulation material they are present bound in the silicate matrix. They are therefore not inconspicuous in every respect, but precisely in the one respect that matters here: anyone looking for a cancer risk has no reason to look at them. [79]

The "coating" category

Because chromium(VI) is mentally associated with paints and primers, a chromium(VI) finding is attributed to a coating, and where no coating is present, to the alloy. Both answers move the source into an area of responsibility that is already regulated. Yet it is precisely the well-known pigments that carry their partner in their name, and nobody finds that surprising. The step that is missing is the question of what applies when this partner is called calcium or sodium and nobody put it there deliberately.

The reaction partner is in the data sheet and is nevertheless not readable

The safety data sheet of a high-temperature insulation product from Morgan Advanced Materials, Ceraform 130, first issue 1 September 1990, version of 23 December 2020, lists in section 3 chromium(III) oxide at up to 3 percent and, as the main constituent, "Refractories, Fibers, Aluminosilicate" with CAS number 142844-00-6 at 45 to 80 percent. The service range is stated as up to 1400 °C. Which oxides lie behind this CAS number is not stated in the data sheet. ECHA's registration dossier for the same number describes the substance as an amorphous glass fiber of silicon dioxide and aluminum oxide "and a range of oxides such as zirconia, ferric oxide, titanium oxide, magnesiumoxide, calcium oxide, other alkaline earth oxides including sodium oxide, potassium oxide, barium oxides". Both reactants are thus declared in a single product. Section 10 of the same data sheet describes the material as stable, gives "None" under incompatible materials and lists as hazardous decomposition products only carbon oxides and traces of ammonia from the starch. [77, 78]

In addition, calcium chromate plays hardly any role in intentional use and is therefore rarely named. Legally, however, it is covered: although the REACH Authorisation List does not name it, ECHA's restriction proposal covers the salts of chromic acid and thus also calcium chromate. The restriction therefore affects a substance that hardly anyone includes in their consideration, because it does not occur in the chemical composition of the product as delivered. It nevertheless forms thermochemically in one's own operations, on the plant or even through the use of one's own product. [59, 64]

Analysis: chromium(VI) content instead of compound

Once the chromate has formed and is referred to only as "chromium(VI)", this makes root cause analysis more difficult. Standard laboratory analysis determines the chromium(VI) content, not the compound. Methods of elemental analysis, for example with inductively coupled plasma, likewise determine elements and, coupled with ion chromatography, the chromium(VI) content. They do not capture the compound itself, because the sample is dissolved for this purpose.

Which chromate phase is present is clarified only by phase analysis such as X-ray diffraction (XRD), with which Sayano et al. identified $CaCrO_4$ and Na_2CrO_4. It is not part of routine analysis and covers only a small portion of the sample and only crystalline phases above its detection limit. It does not provide a statement about the entire surface of a component or an insulation. [11]

For occupational safety and health, this results not in uncertainty but in a clear requirement: if a carcinogenic chromium(VI) compound cannot be reliably ruled out, its presence is to be assumed. The German TRGS 561 expressly requires the protective measures under sections 4.1 and 4.2 as soon as chromium(VI) exposure cannot be ruled out. [19]

In many companies, dismantling comes first and testing afterwards, often only with unreliable rapid tests (Section 19). Occupational safety and health requires the reverse order: the situation is to be assessed in the risk assessment before the work begins. The German TRGS 561 requires the protective measures as soon as chromium(VI) exposure cannot be ruled out; a negative test does not remove this situation of suspicion, especially as chromates can also form inside the insulation elements. [11, 19, 36]

Classification: group and individual compound

For occupational and environmental protection, the exact compound is not decisive. The harmonised European classification covers chromium(VI) compounds as a group as carcinogenic category 1B, with the exception of barium chromate and the compounds specified elsewhere; calcium chromate is itself separately classified as carcinogenic category 1B. The assessment criteria under the German TRGS 910 relate to the elemental content of chromium, not to the compound. Here one can again speak of chromium(VI) in general, just as with asbestos. [63, 64, 71]

The German Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA) lists the routes of uptake for chromium(VI) compounds as "inhalation, skin absorption". For non-threshold carcinogens there is no dose without risk; a chromate is neither only slightly carcinogenic nor only slightly absorbed through the skin. [71]

Differences exist in the other classifications. Sodium chromate is additionally classified as germ cell mutagenic and toxic to reproduction category 1B, and also, among other things, as acutely toxic, corrosive and sensitizing. It is on the Candidate List of substances of very high concern (SVHC) and in Annex XIV of the REACH Regulation; its use is subject to authorisation. Calcium chromate is on neither list, although its classification as carcinogenic category 1B alone would suffice for identification as an SVHC (Article 57(a) REACH). [64-67]

With the planned restriction, the chromium(VI) substances are transferred from authorisation to Annex XVII of the REACH Regulation, that is, to the same Annex that lists asbestos fibers under entry 6. According to the available summaries, the proposal covers the salts of chromic and dichromic acid and thus also calcium chromate; the three lead chromate entries are exempted. [59, 66, 68]

Sodium chromate in insulation materials: the question of use

In sodium-containing insulation materials such as mineral wool, the formation of sodium chromate cannot be ruled out; Sayano et al. identified Na_2CrO_4 at the interface between metal and sodium-containing insulation material. The dust of such insulation is a mixture; chromate formed is present loosely as a substance in its own right. Neither is an article within the meaning of Article 3(3) of the REACH Regulation, as neither has a specific shape. As a substance of very high concern, sodium chromate is already listed today in Annex XIV of the REACH Regulation; its use is subject to authorisation. If such insulation is removed, stored and reused, it is not waste. Is this not already today a use subject to authorisation? For occupational safety and health, this question does not arise: here the requirement of the German TRGS 561 applies, which demands protective measures as soon as chromium(VI) exposure cannot be ruled out. [11, 19, 60, 66]

Sodium chromate in ashes: waste classification

Sodium chromate cannot be ruled out in chromate-containing ashes either; the question of use does not arise there. Whether a waste is hazardous is determined by Annex III of the European Waste Framework Directive 2008/98/EC and thus by the CLP classification of the substances contained, not by their SVHC status. From 0.1%, both chromates lead to classification as hazardous waste via criterion HP7 (carcinogenic). Sodium chromate additionally meets HP11 (germ cell mutagenic, from 0.1%) and HP10 (toxic to reproduction, from 0.3%), without lowering the decisive threshold. [69]

What is measured is the Cr(VI) content, but the threshold applies to the compound. Chromium accounts for about 33% of the mass of calcium chromate and about 32% of that of sodium chromate; 0.1% chromate thus corresponds to around 0.03% Cr(VI). Here too, the question of which chromate is present is practically irrelevant. This is relevant above all for grate ash, for which the European List of Waste provides a hazardous and a non-hazardous entry (19 01 11* and 19 01 12). Does the assessment in the individual case capture the Cr(VI) content, and does it convert it to the compound? [70]

Maternity protection

The consequence extends as far as maternity protection. Under section 11(1) of the German Maternity Protection Act (Mutterschutzgesetz, MuSchG), an unacceptable hazard for pregnant women exists, among other things, in the case of substances classified as carcinogenic, germ cell mutagenic or toxic to reproduction of categories 1A or 1B, or as acutely toxic of categories 1 to 3. Calcium chromate meets this as carcinogenic category 1B, sodium chromate additionally as germ cell mutagenic, toxic to reproduction and acutely toxic. The exception where the occupational exposure limit is complied with does not apply, since no such limit value exists for chromium(VI) compounds, but rather a risk-based assessment criterion under the German TRGS 910. [63, 71, 73]

If the presence of one of these chromates cannot be ruled out, pregnant women may not carry out activities such as maintenance, removal, inspection, cleaning or ash handling in these areas. For breastfeeding women, the IFA recommends as a precaution that no exposure to carcinogenic substances of categories 1A and 1B be permitted either. Under section 10 MuSchG, the hazard must be assessed for every activity to which a woman is or may be exposed. [72, 73]

4. Fields of application and the chromates to be expected

The following overview assigns typical fields of application to the insulation materials used there and to the chromates to be expected. What is decisive in each case is the combination of chromium-alloyed hot component, basic component, oxygen and temperature. E-glass, calcium silicate and AES wools such as Superwool contain above all calcium oxide; mineral wool contains calcium and sodium oxide. Sayano et al. identified $CaCrO_4$ on the calcium-containing insulation material and Na_2CrO_4 on the sodium-containing insulation material. [11]

Field of application	Insulation or location (basic component)	Chromates to be expected	Question of use and waste
Gas and diesel engines, locomotive and marine engines	On and around the engine mostly E-glass and needled glass fiber mats (CaO), in the high-temperature range calcium silicate mats and Superwool (CaO); onward exhaust lines with mineral wool (CaO/Na_2O) as roll material; insulation pads and insulation mattresses made of glass fabric (CaO) and mineral wool (CaO/Na_2O)	On and around the engine above all calcium chromate; on inlet and outlet lines calcium and/or sodium chromate	During maintenance work, the REACH question of use for sodium chromate already arises today where removed mineral wool products are reused; under the planned ECHA restriction in its present form, irrespective of the individual chromate
Gas and steam turbines	In very hot areas calcium silicate products with a high calcium content; the insulation mattresses that follow often made of E-glass and mineral wool products	Calcium and/or sodium chromate	as for engines

Field of application	Insulation or location (basic component)	Chromates to be expected	Question of use and waste
Biogas plants, combined heat and power plants and cogeneration plants	as for engines and turbines	as for engines and turbines	as for engines
Food processing, greenhouses and plantations with combined heat and power plants	as for combined heat and power plants	as for combined heat and power plants	as for engines
Data centers, emergency power generating sets, decentralised energy supply of public buildings and hospitals	as for combined heat and power plants, cogeneration plants and turbines	as for combined heat and power plants, cogeneration plants and turbines	as for engines
Vehicles, construction machinery, exhaust gas aftertreatment	Heat shields, for instance at the turbocharger, with felts and mats containing mainly calcium oxide, in part calcium silicate assemblies; external insulation on DPF and SCR; clipped double walls of hot components, open to oxygen, with insulation materials on the inside (E-glass, calcium silicate)	above all calcium chromate	as for engines
Waste incineration	Furnace during overhauls, door area, floor area of the furnace accesses and the surroundings of the furnaces through dust being stirred up (residues, no insulation)	The individual chromates are not decisive here	Waste and cleaning; a question of use arises at most where ashes are further used as a constituent of other products, provided they are not disposed of

Risk assessment to be drawn more widely

For biogas plants with attached agriculture, the risk assessment is to be drawn more widely: the spreading of contamination into operating areas and foodstuffs and the environmental burden are to be included.

In food processing, in greenhouses and on plantations, high air humidity from irrigation or steaming can promote the formation and the gas phase transport at the hot components. The German statutory accident insurance institution BG ETEM names air humidity and, from approximately 550 °C, water vapor as influencing factors; Tatar works with heavily humidified air (Section 14). [2, 35]

Because of their high energy demand, data centers are increasingly equipped with their own energy supply from gas engines or gas turbines. Engine manufacturers attribute the growing demand for quickly available own supply to the limited grid capacity. These plants are insulated in the same way as combined heat and power and cogeneration plants. [74]

Emergency power generating sets and the decentralised energy supply with combined heat and power and cogeneration technology in public buildings and hospitals correspond to the same constellation. In hospitals, spreading of contamination affects areas with vulnerable groups.

A particular feature in the Netherlands: heating installations are frequently fitted with textile insulation made of E-glass or mineral wool. What is decisive there are the hot components such as the combustion chamber and the flue gas path, at which the temperatures required for chromate formation are reached.

5. Why the issue is not recognized

Several reasons for the lack of awareness can be identified from the documents evaluated. Each has a plausible explanation in itself; together they mean that the formation pathway is not looked for where it is obvious.

The collective term "chromium(VI)"

People speak in general terms of "chromium(VI)". The term is associated with industrially manufactured compounds; the calcium and sodium chromates formed in one's own operations do not feature in this picture (Section 3).

Perception of the industrially manufactured form alone

Industrially manufactured chromates are subject to authorisation, monitoring and labeling. Chromates formed in situ have no manufacturer, no labeling and no safety data sheet describing the condition after use. The safety information for an insulation material describes the as-delivered condition; an unclassified insulation material may be contaminated with newly formed hazardous substances after use (Sections 16 and 25).

Test objective: material resistance

Compatibility tests of insulation materials with chromium assess the resistance of the fiber. An outwardly resistant fiber may, however, carry a small quantity of a highly hazardous reaction product. If Cr(VI) is not determined, the test does not answer the hazardous substance question (Section 12).

The formation pathway as "not traceable"

Individual manufacturer documents declare the formation to be "not fully" understood or "generally not yet traceable" and refer to external sources such as spare parts, maintenance materials or operating environments. The exposure thus appears to be an isolated case, although the formation pathway has been published (Section 16).

Rapid test philosophy

Protective measures are linked to visible yellow deposits and positive rapid tests. If the color is absent or the test is negative, the finding is regarded as unremarkable. The French field study shows that colorimetric rapid tests miss Cr(VI) detected by laboratory analysis (Section 19).

"Neutralisation" and WD-40

The recommendation to "neutralise" chromium(VI) and the use of WD-40 give the impression that the problem can be solved on site. "Neutralisation" is a reduction to chromium(III), which is almost complete only under favourable conditions; for WD-40, a reducing effect has been experimentally refuted (Section 26).

"Asbestos-free" as a mark of harmlessness

Asbestos substitution eliminated the asbestos fiber, not necessarily the reactive material system of chromium-alloyed hot component and basic insulation. "Asbestos-free" is no statement as to whether an insulation material on chromium-alloyed hot components contributes to chromate formation (Section 15).

Environmental assessment instead of activity assessment for combustion residues

For ashes, the focus is on the environmental assessment via leaching, for example in the European BAT reference document. It does not answer the question of exposure during overhaul, boiler opening, cleaning and ash handling. Field observations at European waste incineration plants show that protection against chromate exposure is implemented at best partially (Section 22).

Whether, in view of this body of sources, the formation pathway ought not to have been seen is the question this expert analysis raises.

6. Why it becomes an issue

Germany: the German TRGS 561

Since 4 May 2026, the German TRGS 561 has applied in a new version. Section 3.3.4 describes the subject matter, and section 5.9.3 names alkali/alkaline earth metal oxides from insulation materials or assembly pastes as an influencing factor. Protective measures under sections 4.1 and 4.2, including personal protective equipment, low-dust working and the substitution check, already apply where chromium(VI) exposure cannot be ruled out. For employers in Germany, the question is thus part of the risk assessment and not merely a consequence of a positive finding (Section 19). [19]

EU: routes of exposure, restriction and concept of use

The European Directive 2004/37/EC requires the assessment of all possible exposures, including absorption through the skin (Section 24). In April 2025, the European Chemicals Agency ECHA proposed a restriction on chromium(VI) substances under which only certain uses would remain permitted under strict conditions. [18, 59]

The broad concept of use in the European REACH Regulation is decisive, covering, among other things, storage, keeping and treatment. If a component contaminated with chromates is removed for maintenance, stored and reinstalled, or if contaminated insulation is stored or reused, this may constitute a use. If it does not fall under the uses permitted in future, it would be prohibited. For today's insulation systems on chromium-alloyed hot components, this may amount to a de facto ban. The final legal text is decisive (Section 25). [59, 60]

Australia as a forerunner

From 1 December 2026, the Australian authority Safe Work Australia will no longer set a workplace exposure limit for chromium(VI) compounds. It is replaced by the obligation to eliminate exposure or to minimize it so far as is reasonably practicable (Section 25). [58]

Vehicles and combustion residues

For vehicles, European consumer sales law and Vehicle Regulation 2018/858 open up separate lines of enquiry where a vehicle is demonstrably contaminated with Cr(VI) (Section 20). For combustion residues, occupational safety and health during overhaul and cleaning applies independently of the environmental assessment of the ash (Sections 21 and 22). [46, 47]

B. Fundamentals

7. The 1938/1939 patent: calcium chromate as a deliberately produced reaction product

Udy developed the process for producing low-carbon ferrochromium. The starting point was carbon-containing ferrochromium. This was roasted in finely divided form in air and treated with lime in the process. The patent explicitly describes that the oxidation of chromium to chromate takes place in the presence of lime:

> **"With lime alone serving as the base the oxidation of chromium to chromate requires several hours of roasting ..."**

The patent specification further specifies the temperature control:

> **"Roasting at temperatures well under 1000° C. with no soda ash or less than one per cent of soda in the roasting charge converts the chromium mostly to calcium chromate ..."**

It thus directly describes the formation of calcium chromate from a chromium source, lime and an oxidising roasting atmosphere. At the same time, it states that the product distribution changes with temperature and feedstocks: above 1,000 °C, chromate could decompose back to chromite. The process is consequently not a non-specific oxidation but a deliberately controlled reaction chemistry.

The patent claims also leave no doubt about the compounds designated. Claims 22 and 25 name a mixture of calcium chromite and calcium chromate; claims 23 and 26 additionally name sodium chromate. The chromates are thus not merely mentioned in the description but are part of the claimed technical process.

8. Sodium: accelerator, control agent and chromate former

The patent explicitly names soda, i.e. sodium carbonate (Na_2CO_3), as an influencing factor. Soda accelerates and controls the oxidation to chromate. According to the patent specification, a sufficient addition of soda can substantially accelerate the conversion to chromate at or just below 1,000 °C. With an addition of 5 to 10 percent by weight of soda, relative to the ferrochromium, Udy describes a conversion of approximately half of the chromium to chromate at 1,000 °C; the remaining portion is present in the chromite/Cr_2O_3 state.

Sodium is thus a constituent that is effective in process-chemical terms and can promote and control chromate formation. The statements on calcium chromate without soda are in section 7; sodium chromate is additionally listed in the patent claims. [1]

9. The chemical core of the formation pathway

The roasting process described in the patent specification is based on four factors:

1. a chromium source,

2. a basic calcium and/or sodium compound,

3. an oxidising atmosphere, in particular oxygen, and

4. sufficient temperature and reaction time.

In simplified form, the central sub-process forming calcium chromate can be represented as follows:

$$2\ Cr_2O_3 + 4\ CaO + 3\ O_2 \rightarrow 4\ CaCrO_4$$

For sodium chromate, the corresponding oxidation pathway when using sodium carbonate can be formulated schematically:

$$2\ Cr_2O_3 + 4\ Na_2CO_3 + 3\ O_2 \rightarrow 4\ Na_2CrO_4 + 4\ CO_2$$

These equations are mass balances of the chromate formation pathway, not a claim that every real plant surface corresponds to an idealised pure system. They do, however, show the long-known chemical relationship: a Cr(III)-containing chromium source, a base and oxygen form a chromate Cr(VI) pathway under thermal stress.

A calcium content stated as CaO in glass or silicate does not automatically mean that free calcium oxide is present. Reactive availability is decisive for the application-related assessment. Calcium silicates can also supply calcium for chromate formation; Sayano describes corresponding reactions. [11]

10. Direct experimental evidence: from the model mixture to the metal-insulation interface

The historical patent specification describes the reaction pathway. Four primary studies confirm it experimentally at different levels and close the chain of evidence from the model experiment to the realistic interface.

Study	Constellation investigated	Central finding	Significance
Paoletti (2002)	Cr_2O_3 with CaO in synthetic air and in inert atmosphere; thermobalance (TG-DSC) and XRD.	Rapid mass increase between 500 and 850 °C; XRD detects $CaCrO_4$ after 850 °C. In inert atmosphere only trivalent $Ca(CrO_2)_2$. [50]	Early direct phase evidence of $CaCrO_4$ from Cr_2O_3 and CaO; oxygen demonstrated as an essential prerequisite. The work was carried out in the context of municipal waste incineration; for grate ash and the pilot plant see section "Paoletti 2002" under combustion ashes.
Verbinnen et al. (2013)	Cr_2O_3 with CaO, NaOH or KOH under thermal treatment.	With NaOH, 83% at 500 °C and 89% at 700 °C were leached as Cr(VI) after 60 minutes. CaO also opens up the chromate formation pathway.	Demonstrates the thermal-oxidative formation pathway with calcium and sodium compounds and the role of oxygen.
Mao et al. (2015)	Chromium-containing sludge with CaO, 200-1,200 °C.	Between 500 and 900 °C, leachable $CaCrO_4$ forms; at 900 °C the maximum Cr(III) oxidation was observed after one hour.	Demonstrates the direct role of CaO and the pronounced temperature dependence.

Study	Constellation investigated	Central finding	Significance
Sayano et al. (2015)	Direct contact of Cr-containing steels with Ca-Si-O or Na-containing insulation materials; up to 5,000 h at 773/873 K.	Yellowish reaction products were identified by XRD as $CaCrO_4$ and Na_2CrO_4 respectively. The amount of Cr(VI) depends on metal, temperature and time.	Direct experimental evidence at the interface between chromium-containing metal and thermal insulation material.

Verbinnen et al.: the role of basic calcium and sodium compounds

Verbinnen, Billen, Van Coninckxloo and Vandecasteele investigated the temperature dependence of Cr(III) oxidation in synthetic mixtures of Cr_2O_3 and alkali or alkaline earth compounds. The study clearly separates a point that is often blurred: in the relevant temperature range, Cr_2O_3 is not readily oxidised to Cr(VI) by atmospheric oxygen alone. The basic calcium, sodium or potassium component opens up the chromate formation pathway.

The experiments yielded maximum Cr(VI) leaching in the range of 600 to 800 °C. Under inert atmosphere, the Cr(VI) leaching of an industrial sludge fell from 24.2 mg/kg to 0.42 mg/kg after 30 minutes at 700 °C. The role of oxygen is thus not merely postulated thermodynamically but demonstrated experimentally.

The quantitative data are to be read as leaching findings with the respective temperature and holding time; they are not general conversion values for industrial insulation. [9]

Mao et al.: CaO forms $CaCrO_4$ in the temperature window from 500 to 900 °C

Mao, Gao, Deng and other authors investigated chromium-containing sludge in the presence of CaO over the range from 200 to 1,200 °C. They distinguish two relevant reaction ranges:

- Between 200 and 400 °C, a Cr(VI)-containing intermediate oxide (Cr_2O_{3+x}) formed in chromium hydroxide/CaO mixtures.
- Between 500 and 900 °C, Cr(III) reacted directly with CaO to form leachable $CaCrO_4$. At 900 °C, maximum oxidation was observed after one hour; extending the holding time did not significantly reduce the amount of calcium chromate in this range.

The study thus confirms that calcium oxide is not merely a favourable background component but a direct reaction partner in the formation of calcium chromate.

Sayano et al.: direct evidence at the contact between hot component and insulation material

The work of the Japanese authors Sayano, Kanno, Inagaki, Takahashi and Yoshida is particularly significant for the assessment of industrial components with high-temperature insulation. What was investigated was not a sludge or a loose laboratory powder mixture, but the direct contact between Cr-containing metals and thermal insulation materials.

The authors placed, among others, SUS304 with 18.2% Cr as well as low- and high-chromium steels on calcium-silicate and sodium-containing insulation materials. The calcium-silicate block insulation contained 35% CaO; a sodium-containing insulation material 7.3% Na_2O. After heat treatment in air, yellowish reaction products were detected at the contact surfaces:

- For the calcium-containing insulation material, XRD analysis identified $CaCrO_4$; for the sodium-containing insulation material, Na_2CrO_4.
- For SUS304 and calcium-silicate insulation material, 160 mg Cr(VI) per m² of contact surface was measured after 1,000 hours at 873 K (approximately 600 °C).
- After 5,000 hours at 873 K, the amount of Cr(VI) in the uncoated SUS304/Ca-Si-O system was 940 mg/m²; with the additional calcium-containing, self-hardening coating insulation material it was 3,890 mg/m².

The authors also show the mass transport: chromium diffuses from the metal into the insulation material, oxidises and reacts with the basic insulation component. An Al_2O_3-based barrier layer only about 3-4 µm thick suppressed this chromium diffusion and almost completely prevented Cr(VI) formation. This also makes the preventive logic clear: it is not the subsequent treatment of chromates already formed, but the prevention of reaction contact or the substitution of basic oxides that prevents the pathway by which the substance is formed.

Consequence of the overall picture

The four studies leave no room for the representation that the formation of calcium and sodium chromate on chromium-containing hot components is merely an untested possibility. The reaction has been

1. chemically described (Udy; Verbinnen),

2. experimentally demonstrated as temperature-dependent (Paoletti; Mao; Verbinnen) and

3. directly observed at the metal-insulation interface with the identified target products $CaCrO_4$ and Na_2CrO_4 (Sayano).

C. Insulation technology: hot components and insulation

11. From metallurgical roasting to high-temperature insulation

The historical patent specification describes a deliberately intensified metallurgical roasting. Its significance for insulation materials on chromium-alloyed hot components lies in the reaction chemistry: the groups of substances relevant to calcium and sodium chromate are identical.

Metallurgical process according to Udy	Hot component with basic insulation
Chromium-containing ferrochromium	Chromium-alloyed steel, stainless steel, high-chromium alloyed surfaces and oxide layers
Lime or calcium oxide	Calcium-containing fibers, fillers, binders or other basic insulation constituents
Soda or sodium carbonate	Sodium-containing glass, fiber, binder or other product constituents
Roasting in air	Oxygen access in the plant environment and at the boundary between component and insulation
Temperature and residence time	Operating temperature, temperature cycles and long service times

The German statutory accident insurance institution BG ETEM describes today's plant-related findings accordingly: contact between chromium-alloyed steels and insulation materials or assembly pastes containing alkali and alkaline earth metals can lead to the formation of carcinogenic chromates at steel temperatures of approximately 350 to 800 °C. As influencing factors, it names the chromium content of the steel, calcium, magnesium, sodium or potassium compounds, oxygen, air humidity and, from approximately 550 °C, also water vapor. According to BG ETEM, visible yellowish deposits on turbines and steam pressure pipes indicated calcium chromate and subsequently tested positive for chromium(VI) compounds on sampling. [2]

The application context was explicitly published before 2015

Toshiba's Japanese patent application JP2011232021A, published on 17 November 2011 with priority of 8 April 2010, describes precisely this interface: chromium oxide on stainless steel reacts with the calcium component of a thermal insulation under oxygen to form calcium chromate. The document explains the change from asbestos to calcium silicate and proposes a ceramic separating layer to suppress Cr(VI) formation. It also names potassium-, magnesium- and sodium-containing insulation. The application-related problem, including a prevention approach, was thus also publicly accessible before the 2015 study. [26]

As earlier literature, the patent cites Corrosion Center News No. 034 of 1 June 2005. This reference is a targeted archive trail; the original issue was not consulted here. The patent family identified is Japanese. Its public availability must be distinguished from the actual knowledge of individual European manufacturers. [26]

Examination of both Toshiba patents and of the reference "trade name Rockwool"

The reference "thermal insulation material (trade name: Rockwool)" is contained in both translations submitted. The corresponding product designation also appears in the Japanese original of JP2011232021A and in the Japanese granted version JP5774355B2 of the second application JP2012220174A. The reference was therefore not generated by the machine translation. Both test descriptions characterize the insulation as mainly calcium oxide/silicon oxide-based. [26, 38]

JP2011232021A tests SUS304 with and without ceramic separating layers at 600 °C for 500 hours in air. In the uncoated comparison, a calcium-chromium complex oxide and, in small quantities, a magnesium-chromium complex oxide are described at the contact surface by means of X-ray diffraction. The document explicitly explains the $CaCrO_4$ formation pathway with a reaction equation and also investigates sodium-containing insulation. The ceramic layer is intended to interrupt the contact of the reactive components. [26]

JP2012220174A, published on 12 November 2012 with priority of 14 April 2011, pursues a further prevention approach: a 200 µm thick pure nickel foil separates SUS304 from the insulation. After 600 °C and 500 hours in air, a yellow reaction product is described for direct contact without foil. This is analyzed by XRD and designated by the authors as a Cr(VI) reaction product. The comparative tests with sodium-containing perlite and calcium silicate respectively also describe chromium-sodium and chromium-calcium complex oxides. For the set-up with foil, no corresponding visible reaction is reported. This comparison shows a targeted intervention in the interface reaction; the absence of a color finding does not in itself imply a quantitative Cr(VI) value of zero. [38]

The wording "Rockwool" is documented; a manufacturer, a precise product grade or an attribution to ProRox is not identified in these test passages. In Japanese, the term is also used for stone wool. For a specific company attribution, product and supplier data would have to be obtained. The technical finding remains independent of this: Toshiba investigates calcium-containing insulation on chromium-containing metal and describes specific ways of interrupting the reaction. [26, 38]

Both documents explicitly name waste incineration plants, biomass firing systems, thermal power plants and chemical plants. The link to the combustion sector is thus already part of the original application description. The reaction between insulation and metal must be distinguished from Cr(VI) formation in the ash matrix; both can be relevant in the same plant. [26, 38]

12. Significance for E-glass fabric, calcium silicate, mineral wool and aerogel insulation systems

The designation of a product class is not a statement about the chemical harmlessness of the individual product. What is decisive are the raw materials, fibers, carriers, binders and fillers actually used.

If E-glass fabrics, calcium silicate products, mineral wool products or aerogel-based insulation systems demonstrably contain basic oxide fractions, in particular calcium and/or sodium fractions, these must be assessed, when used on chromium-alloyed hot components, as an indication of a chromate formation risk that cannot be ruled out. Reactive availability, temperature, time and oxygen determine the specific extent. The material-related suspicion must be included in the risk assessment irrespective of a prior positive rapid test. [19]

This also applies to aerogel-based products. An aerogel core does not change the assessment if the marketed overall system contains, for example, glass fiber carriers, fabrics, binders, fillers or coatings with basic oxide fractions. What is decisive is the composition of the specific insulation product in the intended application system, not its advertising designation.

Test objective: material resistance or formation of hazardous substances?

Morgan's Superwool Technical Manual contains its own Contamination / Pollution Study. Chromium powder was placed between insulation mats; after six hours at 1,000, 1,100 and 1,150 °C, powdering, melting, discolouration and visible signs of reaction were assessed. For the four fiber products investigated, including calcium and calcium/magnesium silicate fibers, the chromium row is shown as without observed reaction. A Cr(VI) determination with a detection limit is not described. [27]

The technical consequence lies in the test objective: an outwardly resistant fiber can carry a small quantity of a hazardous reaction product. The finding described therefore does not answer the question of chromate formation. Temperature and duration also differ considerably from Sayano's long-term tests at 500 and 600 °C respectively. [11, 27]

At the same time, the manual advertises the absence of a hazardous substance classification and non-hazardous waste. Such statements on fiber chemistry do not replace an assessment of the insulation system contaminated after use. This is a public group document with a European legal reference. A reliable date of first publication cannot be derived from the extract examined. [27]

13. The dilemma of the insulation material manufacturers

Calcium oxide and sodium oxide are not additives that can be struck from a formulation like a color pigment. Since the earliest glassmaking they have been constitutive components of the melt from which fibers are drawn or spun.

The composition of this melt is not new. Soda-lime-silica glass is the earliest known glass type; it is documented from late Bronze Age Mesopotamia and Egypt and remained the dominant type from the second millennium B.C. into the modern period. The flux was first natron and later plant ash, both sources of sodium; the lime entered through calcareous sand, added shell or limestone and typically amounted to 5 to 10 percent. Its function is the same as today: it reduces the solubility of the glass in water. [80]

The fiber made from it is younger. Slag and stone wool was first produced in Wales in 1840; commercial operations were running in England by 1885, in Germany soon afterwards, and the first successful commercial plant in the United States began operation in 1897. Glass wool followed in 1932 with the steam-blown process at Owens-Illinois; in 1938 the Owens Corning Fiberglas Corporation emerged from it. [81, 82]

Drawing a filament from viscous glass, by contrast, was already known in Egypt and Venice. What was carried over was not the machine but the formulation: a filament can only be drawn from a melt that has the right viscosity at a manageable temperature. That is precisely what sodium and calcium oxide are for.

Chemically they act as network modifiers. They break up the silicon dioxide network, lower viscosity and melting temperature and make the melt workable in the first place. Sodium oxide is the classical flux, while calcium oxide additionally stabilises the chemical durability of the solidified glass. Without these oxides, pure silicon dioxide would remain a material that melts only far above 1700 °C.

To this is added the raw material side. Cullet, that is soda-lime glass from the packaging cycle, is a substantial input to glass wool production. It brings calcium and sodium with it unavoidably. In stone wool, limestone and dolomite supply the same oxides, and in biosoluble AES wools the alkaline earth basis is even part of the name and a precondition of biosolubility.

The problem therefore does not lie in an admixture but in the material class and in the supply chain. If the basic oxides are named as reaction partners of chromate formation, this concerns not one product but the basis of a large part of today's high-temperature insulation.

And even if the formulation were changed, a second problem would remain. Fewer basic oxides mean a higher melting temperature. The existing plant technology, tanks, linings and energy management, is designed for the present temperatures. A changeover would not be a question of formulation but an investment in plant.

Fibers without appreciable basic oxides do exist nevertheless, and have for decades. High-silica fibers with over 95 percent silicon dioxide, aluminosilicate fibers in the Al_2O_3-SiO_2 system and polycrystalline alumina fibers, which are not drawn from a melt but spun from a precursor solution and subsequently fired, manage without flux. The difference lies not in the chemistry but in the installed plant: higher melting temperature, different tanks, different linings, higher energy input, lower throughput.

Against this background the reticence of today's market leaders towards in-situ formation is understandable. It may also be self-protection. Understandable does not mean without consequence, however, since the assessment of a hazard does not depend on how costly its removal is.

The question running through this expert analysis thus arises here most sharply: at what point does one know that one can no longer not know?

14. Gas-phase transport: Tatar/Gannon and van Leeuwen

The formation of a volatile Cr(VI) species at a hot chromium source, its deposition on cooler fibers and the formation of a calcium or sodium chromate are distinct reaction steps. They can occur side by side or in succession. The statement that Cr(VI) also forms without calcium-containing insulation material must therefore be distinguished from the question of what role such an insulation material plays in the binding, quantity and chemical form of the deposited chromium. [11, 35-37]

Study	Test conditions	Analytical finding / classification
Tatar/Gannon et al. 2018 [35]	Ferritic T409 steel at 700 °C; humid air, p(H_2O) approx. 0.16 bar; 900 standard cm³/min; separate aluminosilicate fibers at 100-230 °C; 150 h.	XPS detects Cr(VI) and Cr(III) on the fibers. Adsorption, dehydration and esterification with surface OH groups are proposed as the mechanism. No specific phase evidence of $CaCrO_4$ or Na_2CrO_4 in the fiber experiment.
van Leeuwen et al. 2024 [36]	Cr_2O_3 powder as source; hot zone approx. 800-850 °C; approx. 3 vol.% water in air; approx. 600 cm³/min; 150 h. Fibers separate in the cooler outlet zone.	Cr(VI) is determined wet-chemically with diphenylcarbazide/UV-Vis, total chromium by ICP-OES. $CaCrO_4$ on calcium-containing AES fibers is modeled thermodynamically. Measured Cr(VI) and modeled phase composition must be distinguished.
Sayano et al. 2015 [11]	Direct contact of chromium-containing metals with calcium-silicate or sodium-containing insulation materials; heat treatment in air.	$CaCrO_4$ and Na_2CrO_4 are identified by XRD at the metal-insulation interface. This pathway depends neither on gas-phase transport nor on the esterification of surface groups.

Tatar investigates chromium oxyhydroxide from a hot steel source and its interaction with spatially separated, cooler aluminosilicate fibers. The proposed esterification concerns chromate-containing surface bonds at aluminum/silicon centers; it is not to be equated with evidence of calcium or sodium chromate. The reaction sequence is derived from XPS findings and the literature. Cr(VI) itself was determined analytically. [35]

If Tatar is cited as evidence that insulation chemistry is fundamentally irrelevant to Cr(VI) deposits, this goes beyond the matter investigated. The work shows a formation and transport pathway without a necessary calcium contribution at the hot source. It invalidates neither Sayano's direct interface evidence nor a subsequent reaction with calcium/sodium components. [11, 35]

Van Leeuwen explicitly takes up Tatar/Gannon and compares quartz, aluminum oxide and two alkaline earth silicate (AES) fibers. All four materials collect Cr(VI). The two AES samples show higher absolute Cr(VI) concentrations in the digestion solutions examined than the quartz and aluminum oxide samples. However, the proportion of Cr(VI) in total chromium does not increase equally in every sample: the individual values in Table II permit a more precise statement than a general description of consistently higher Cr(VI) proportions for AES. [36]

Fiber sample	Cr(VI), mg/L	Total Cr, mg/L	Cr(VI)/total Cr
Quartz	0.739	1.339	55%
Aluminum oxide	0.403	1.976	20%
AES #1	0.873	2.170	40%
AES #2	1.747	3.040	57%

Values according to Table II; percentages calculated from the published individual values and rounded. These are concentrations in digestion solutions, not air concentrations or directly mg/kg of insulation material. Different fiber geometries and sample positions must be taken into account when comparing quantities. [36]

Using FactSage, the authors model the reaction of the condensing chromium species with the oxide components and describe $CaCrO_4$ as an important possible Cr(VI) carrier of the calcium-containing fibers. This complements gas-phase transport mechanistically. However, the study does not replace the direct XRD phase evidence from Sayano's contact test. Chemically, $CaCrO_4$ is a Cr(VI) chromate; $CaCr_2O_4$, by contrast, contains Cr(III). Deviating formula notations in individual passages must be checked on the basis of the oxidation state. [11, 36]

For the transfer to plants, the test conditions must be taken into account: Tatar uses highly humidified air; van Leeuwen approximately 3 vol.% water. Both pass a directed gas flow through a tube with a hot source and downstream fiber samples. Van Leeuwen's experiment runs at local atmospheric pressure, not in a high-pressure steam reactor. The publication states 800 °C in the abstract and, in the methods section, a calibration of the furnace center to 850 °C. The experiments explain reaction possibilities; their quantities cannot be transferred directly to freely exposed external engine insulation. [35, 36]

European manufacturers' association as client: ECFIA and Montana State University

Tatar and van Leeuwen work within the same American research group at Montana State University; Paul Gannon is involved in both publications. Van Leeuwen's dissertation of May 2024 explicitly states on page 2 that the research originated from a request by ECFIA, the association of European high-temperature insulation wool manufacturers. The aim was to investigate claims by competitors that their products reduced or prevented Cr(VI) formation. The acknowledgements on page iii name partial funding by ECFIA industry partners. [35-37]

This documents that Cr(VI) formation on high-temperature insulation wools was known as an issue within the European manufacturers' association; the occasion was competitors' claims regarding the reduction or prevention of Cr(VI) formation. The dissertation and the later publication are overlapping results of the same research context, not mutually independent confirmations. The funding statement here relates to the dissertation project; it is not presented without further ado as specific funding of each individual publication. [36, 37]

This gives rise to a precise question: which results were communicated to the participating industry partners and when, and how were they incorporated into product information and application-related warnings? The scientific result must be assessed on the basis of its methods and data, independently of this communication question.

15. The asbestos era, asbestos substitution and chrysotile

Historical material continuity: asbestos, calcium silicate and the period thereafter

Calcium silicate was not introduced in high-temperature applications only as a subsequent substitute after asbestos was phased out. The material class was already represented in the market for technical thermal and pipe insulation during the asbestos era.

A historical product sheet from Johns-Manville documents this connection directly. It advertises "J-M Thermobestos" for use up to 1,200 °F and explicitly describes the product as "calcium silicate insulation". The sheet is part of a product overview by the long-established asbestos manufacturer Johns-Manville for thermal and pipe insulation. It thus shows that, during the asbestos era, calcium silicate did not form a separate world of materials outside the asbestos market, but was part of the same high-temperature insulation environment. [6]

The later elimination of the asbestos fiber addressed the asbestos-related fiber hazard. However, it did not automatically remove the calcium oxide chemistry relevant to chromate formation from insulation systems. Calcium silicate products continued to be offered as high-temperature insulation; at present, Johns Manville, for example, also markets calcium-silicate high-temperature insulation, now explicitly asbestos-free. The change in the fiber component is therefore not to be equated with the elimination of the basic calcium component.

Asbestos-mineral wool mixtures and composite systems

Historical material development did not proceed exclusively as a switch from pure asbestos to pure mineral wool. The Johns-Manville patent US2389460A, granted on 20 November 1945, describes thermal insulation boards containing stone wool and asbestos fibers in a weight ratio of approximately 2:1, bonded by a plastic binder. It documents an expressly intended fiber mixture. [20]

US2162387A of 13 June 1939 is additionally relevant to high-temperature technology: the high-temperature cement described for boiler and furnace joints contains 10 percent by weight asbestos fibers, 5 % mineral wool and 8 % sodium silicate, as well as 27 % sand and 50 % fireclay. Asbestos, mineral wool and a sodium component were thus already provided for in the same formulation at that time. The historical assessment must cover such mixed and composite systems including their basic components. [21]

The historical and the present-day risk logic must therefore be separated and at the same time considered together:

Temporal and material reference	Relevant hazard dimension
Asbestos-containing insulation materials	Independent, serious fiber carcinogenicity and fiber-related diseases
Chrysotile fibers with chromium content	Potential oxidative mobilisation of Cr(VI) as an additional genotoxic component
Calcium silicate high-temperature insulation on chromium-alloyed hot components	Calcium-related reaction pathway to calcium chromate
Post-asbestos insulation materials with basic oxides	Persistence of the chromate formation pathway, provided the necessary reaction conditions coincide

Early research approach: the US report of 1969

Ralph J. Sullivan's Air Pollution Aspects of Chromium and its Compounds contains two separate points of reference. Section 3.4.1 Asbestos, printed pages 24-25, reports contemporary considerations on chromium and other trace substances as contributors to asbestos-associated cancers. It states a chromium content of approximately 1,500 µg/g in the asbestos material cited. Section 3.4.3 Cement, page 25, explains chromate formation through heat treatment of Cr_2O_3 under alkaline conditions and asks about its significance for other materials, for example asbestos. [17]

The first reference concerns a possible additional biological damage component; the second a thermochemical research question. These two historical questions must be pursued separately: via fiber-associated metal chemistry on the one hand, and via the composition, interfaces and operating conditions of asbestos-containing insulation systems on the other. The report was prepared in 1969 for the US National Air Pollution Control Administration within the Department of Health. It is held today in the archive of the US Environmental Protection Agency (EPA); the EPA was not its commissioning body at the time. [17]

Chrysotile asbestos as a possible parallel Cr(VI) source: the findings of Walter et al.

The study by Walter et al. (2022) does not examine chromate formation on insulation materials, but the release of chromium from chrysotile asbestos. Precisely for this reason, it decisively complements the historical perspective: it makes visible that asbestos exposure involving chromium-containing chrysotile cannot necessarily be understood exclusively as fiber exposure.

Walter et al. show a chromium content in the low gram-per-kilogram range in the chrysotile examined. In its initial state, the chromium is predominantly present as poorly soluble Cr(III). Under oxidative conditions at physiological pH, in particular in the presence of hydrogen peroxide (H_2O_2), chromium was mobilised from the fibers and detected in solution exclusively as Cr(VI). The mobilised Cr(VI) was predominantly present as the chromate oxyanion.

The previously insufficiently investigated chromium pathway

Walter et al. make clear that an involvement of chromium in the carcinogenicity of chrysotile had already been postulated earlier. What was insufficiently understood, however, was the behavior and reactivity of fiber-associated chromium in the lung and pleura; to the authors' knowledge, the uptake capacity of the relevant cells had not previously been investigated. The study addresses these knowledge gaps experimentally. [4]

The study further demonstrates that lung epithelial, mesothelial, lung carcinoma and mesothelioma cells express Cr(VI) transporters and take up the Cr(VI) added to the culture medium in the cell uptake experiments. In the experiments, intracellular chromium accumulation reached up to approximately ten times the concentration in the surrounding medium. In the authors' view, this mobilised and cell-permeant Cr(VI) can therefore contribute to tumour initiation and tumour progression in asbestos-associated diseases.

The finding must be read precisely:

- It does not diminish the independent carcinogenicity of the asbestos fiber.
- It does not transfer the known iron/fiber chemistry to chromium. Walter et al. found no relevant contribution of chromium to H_2O_2 decomposition or to hydroxyl radical formation; this pathway remained essentially attributable to iron.
- It adds an additional, Cr(VI)-mediated genotoxic pathway to the damage mechanisms.

The study thus opens a historically relevant question: to what extent were disease risks in chrysotile-containing exposures attributed exclusively to the effect of the fibers, although Cr(VI) may additionally have been mobilised from the fibers under inflammatory-oxidative conditions? Walter et al. do not answer this question quantitatively. They do show, however, that a parallel Cr(VI) involvement must, on sound scientific grounds, be included in the assessment.

Asbestos substitution: elimination of the fiber hazard, not necessarily of the entire reaction system

The historical transition from asbestos-containing to asbestos-free high-temperature insulation was initially, and rightly, a substitution of the asbestos fiber. Because of its independent, serious carcinogenic effect, the asbestos fiber was no longer tenable. Its removal from insulation materials was therefore imperative.

This fiber substitution, however, is not to be equated with a complete material substitution of the entire high-temperature insulation system. Historically, asbestos fibers were combined with inorganic components in insulation systems. For loose asbestos fiber mixtures, the USGS expressly lists, among others, hydrated calcium silicate as an inorganic mixture component for thermal, electrical and acoustic insulation products. [8] As early as 1901, US Patent 668,684 moreover describes a fire-retardant insulation composite consisting of outer layers of asbestos paper and a mineral wool core layer. [7]

With the elimination of asbestos, what changed in many applications was thus primarily the critical fiber component. Insofar as the asbestos-free successor products continued to contain calcium, sodium, magnesium or potassium oxides from fibers, fillers, binders or other raw materials, the basic-oxidic chemistry of the insulation was retained. On chromium-alloyed hot components, the material preconditions for the formation of chromium(VI) compounds therefore also remained in place.

The technically precise assessment is therefore:

> **Asbestos substitution eliminated the asbestos fiber, which was no longer justifiable, but not necessarily the reaction pathway, independent of it, from a chromium source, basic oxides, oxygen and thermal stress to calcium and/or sodium chromate.**

"Asbestos-free" is therefore no statement as to whether a high-temperature insulation material on chromium-alloyed hot components is chemically inert or carries no risk of chromate formation. A preventively complete substitution must cover both hazard dimensions: it must exclude the asbestos-related fiber hazard and, in the intended application, avoid the formation pathway to chromium(VI) compounds. This presupposes that the insulation contains no chromate-forming basic oxides or that their reaction availability under the conditions of use is reliably excluded.

16. Manufacturer and operator warnings: documented state of industrial knowledge

The scientific works do not stand in isolation. Manufacturers of engines, generating sets, insulation materials and mineral wool have taken up the issue in technical information, service bulletins and safety instructions. These documents show that the formation pathway has been observed in practice in various industrial fields of application, confirmed analytically and in some cases linked to specific prevention requirements. These notices are not precautionary advice. They describe findings on plant in operation, in some cases with images from the field.

The earliest notice: Babcock & Wilcox 1990 and 1994

The first documented manufacturer warning concerning this formation pathway does not date from recent years. In April 1990 the Babcock & Wilcox Power Generation Group issued Plant Service Bulletin PSB-43 to owners and operators of boilers and steam generators. The first version concerned chromium-containing refractories. The revised version PSB-43A of March 1994 expressly extends the scope to "plastics, insulation, and textiles". [75]

The bulletin describes the process unambiguously: materials used in boilers may contain chromium compounds "as part of the mixture or composition", and "during operation, some of the chromium compounds may be converted to hexavalent chromium". On removal, "the dust created may transport the hexavalent chromium. Inhaling hexavalent chromium increases the risk of lung cancer in humans". [75]

The recommended measures correspond in substance to the protective regime that the German TRGS 561 sets out today under 4.1 and 4.2: training, equipment and monitoring of personnel, low dust working, no skin contact, disposal as hazardous waste, in the bulletin under 40 CFR 261 and 262. The difference lies in the trigger. The German TRGS 561 assumes in 3.3.4 and 5.9.3 that the formation of chromium(VI) compounds on chromium alloyed hot components cannot be excluded, and therefore requires the protective regime including the substitution check without prior measurement. The 1990 bulletin places an investigation at the beginning instead, recommending that before removal a qualified independent laboratory determine whether chromium compounds are present and whether they have been converted to chromium(VI). On replacement it states that substitutes for chromium-containing products are available, but that they sometimes have a shorter service life. [75]

The bulletin names the products concerned. Among the refractories and ramming mixes it lists Chrome Ore, Chrome Mortar, Kromight, Kromecast, Monochrome and Moldit Chrome Castable, among others. As chromium-containing insulation and textile products it lists Cerachrome, Z-Blok, Ceraform 130 and Cerachrome Felt. [75]

The conclusion that was drawn

The conclusion drawn was the obvious one: the product contained chromium, so chromium-containing products were deselected. The formulations themselves remained unchanged; the safety data sheet for Ceraform 130 still shows chromium(III) oxide at up to 3 percent in its version of 23 December 2020 (Section 3). The yellow powder continued to appear. Since the chromium appeared to have been removed from the insulation, the chromium alloyed hot component remained as the explanation, and the finding was accepted as unavoidable. [77]

What was not recognized, a second time, was which compounds were involved. They were alkali and alkaline earth chromates, and their reaction partner had never been removed. It is still contained in the same products today, behind a CAS number that no user looks up. Present-day replacement solutions no longer have this problem: high temperature insulation materials free of alkali and alkaline earth metal oxides are available which avoid the formation pathway without loss of temperature resistance or service life.

Issuer	Documented finding	Statement on formation and prevention
Caterpillar / Caterpillar Energy Solutions	Yellow residues on exhaust systems and exhaust insulation; independent laboratory analyses confirmed Cr(VI).	References to high temperatures, spare parts, maintenance materials and operating environments. Where residues are conspicuous: dust avoidance, PPE and hazardous waste handling.
[redacted]	[redacted], released on 31 May 2023: Cr(VI) as a yellowish residue on engine parts or insulation.	Names chromium-containing steel, calcium for instance from insulation material, oxygen and temperatures above 400 °C. Addressees include customers, service partners and branches. [25]
MAN Truck & Bus SE	Its own analyses detected Cr(VI) on engine components that had been in operation; calcium chromate $CaCrO_4$ expressly named.	Cr-containing steels, calcium-containing insulation materials or assembly pastes, oxygen, temperatures above 300 °C. For assembly work, only suitable calcium-free pastes.
Frenzelit	Confirms calcium oxide contents of its own insulation materials in varying proportions.	Cr-alloyed steel, alkali/alkaline earth oxides, especially CaO, oxygen, above 350 °C. Its own products may contribute to Cr(VI) formation where the conditions are present.
Rockwool Technical Insulation	95-100 % stone wool; combined alkali/alkaline earth oxide contents of more than 18 %. Cr(VI) deposits on stainless steel and mineral wool described.	Discusses deposits in connection with hot stainless steel wire. Where deposits are conspicuous, rapid test; where Cr(VI) is present, specific occupational safety and health/hygiene requirements. Protective measures likewise when removing conspicuous deposits.
[redacted]	Service Information [redacted] of 7 August 2025: Cr(VI) formation on surfaces of hot, chromium-containing exhaust components.	Names, among others, turbochargers, exhaust manifolds, EGR, catalytic converters and DPF; requires protective measures, prohibits compressed-air cleaning and describes neutralization. [22]
[redacted]	[redacted] of 27 August 2025: confirmed Cr(VI) contamination on, among others, heat shields, exhaust manifolds and turbochargers.	Warning expressly addressed to personnel working in the engine compartment, vehicle repairs and component handling; contamination may be invisible. Requirements on PPE, hygiene and cleaning. [23]

Issuer	Documented finding	Statement on formation and prevention
Wärtsilä Finland Oy	Instruction WS00Q563, first issue 9 November 2020, issue 4 of 20 June 2024: Cr(VI) residue, yellowish or whitish, on exhaust system components, on the panels of the exhaust insulation boxes and on turbocharger parts, with photographs of a bolted joint and of exhaust pipe flanges. Applies to four-stroke engines and to components after the engine where the operating temperature can exceed 400 °C.	Names three conditions that have to be met at the same time: a product containing calcium, most likely from an anti-seize paste or from calcium-based insulation, more than 400 °C, and chromium steel in contact; together with a warning about hot work. Requires swab test kits before work starts, testing of every suspicious residue, dust binding, HEPA extraction, labeling and disposal as hazardous waste, and FFP3 or NIOSH P95/P100. Recommends changing to anti-seize pastes without reactive calcium compounds. Addressed to operators and owners of the installations concerned, for immediate attention.

What these warnings demonstrate

The warnings concern several industrial fields of application. MAN names calcium chromate and the material-related formation conditions; Frenzelit places its own calcium oxide contents in the same context. Caterpillar confirms actual Cr(VI) findings. Rockwool describes deposits and the basic oxide composition of its stone wool. [12-16]

Wärtsilä names calcium-based insulation and calcium-containing anti-seize paste as the calcium source, 400 °C as the threshold, and requires testing before work starts. [137]

Individual documents still declare the formation to be "not fully" understood or "generally not yet traceable" and refer to possible external sources such as spare parts, maintenance materials or operating environments. These statements may concern open questions regarding local source contributions, kinetics or specific operating conditions. They do not, however, call the documented formation pathway into question. Spare parts, assembly pastes and insulation materials in particular are possible carriers of the calcium and sodium compounds relevant to chromate formation.

Presenting the exposure as an isolated, inexplicable problem, or as one caused exclusively by external special circumstances, therefore disregards the published state of knowledge of science, manufacturers and the statutory accident insurance institutions. Whether such an omission is deliberate or unintentional cannot be derived from the documents themselves; technically, however, it has the effect of downplaying a known and avoidable reaction pathway.

Where the statement sits: the safety data sheets of the refractory products

HarbisonWalker International is the legal successor of Harbison-Walker, A.P. Green and NARCO, that is, of the manufacturers whose products the 1994 bulletin lists by name. The safety data sheets of its chromium-containing refractory products carry the sentence: "The chrome compounds (Cr III) in this product may be altered to a hexavalent compound (Cr VI) under certain use conditions, such as exposure to alkali salts and/or high temperatures." It was checked on PLASTECH RUBY (version 02 of 1 April 2021), AUREX 30 SR (version 02 of 29 June 2018), SFG (version 02 of 22 March 2021) and RUBY (version 03 of 17 April 2020). [93]

The sentence sits in section 13, disposal. In the sheets examined, the word hexavalent appears nowhere else, neither in section 2 nor in section 10. Under Appendix D to OSHA 29 CFR 1910.1200, section 10 requires the "Possibility of hazardous reactions, including those associated with foreseeable emergencies" and the "Hazardous decomposition products", and section 7 the "Precautions for safe handling"; table D.1 lists sections 12 to 15 as non-mandatory. The statement about the conversion therefore sits in the part of the sheet for which no content review is required. That part is read by the person who decides on waste classification, and that happens after removal. [94]

The compositions show that the alkaline partner is present in several of these products. SFG, a magnesia-chrome brick, lists magnesium oxide at 70 to 90 percent alongside chromium(III) oxide at 20 to 40 percent. RUBY lists sodium aluminate at 2.5 to 10 percent alongside chromium(III) oxide at 2.5 to 10 percent. THERMOLITH, a chrome mortar with 80 to 100 percent chromium compounds and 2.5 to 10 percent sodium silicate as binder, does not carry the statement. The manufacturer describes the alkali as something the product is exposed to from outside, while in several of its own products it is a constituent. [93]

On the fiber side both the statement and the partner are missing. Safety data sheet Morgan SDS 252 in the revision of 1 June 2015 covers Cerachrome and Z-Blok in the CR grade and lists the refractories, fibers, aluminosilicate under CAS 142844-00-6 at 95 to 100 percent together with chromium(III) oxide at up to 3 percent; section 10 gives "None" as decomposition products, and chromium(VI) does not appear anywhere in the sheet. In none of the fiber sheets examined does calcium appear as a line of its own, not even in the sheet for Ceraform 130. The reaction partner is hidden inside the substance definition behind the CAS number: the ECHA registration dossier describes the substance group as an amorphous glass fiber made of silicon dioxide and aluminum oxide with a number of further oxides, calcium oxide among them expressly, and the definition of the substance class allows an alkali and alkaline earth oxide content of up to 18 percent by weight. [95, 96]

Two accounts of the same reaction therefore exist side by side. The refractory makers name the conversion path and its conditions and place the statement in the disposal section. On the fiber side the path is not named, and the reaction partner does not appear in the sheets as a constituent.

Safety information: as-delivered condition and condition in use

Rockwool's European ProRox WM-S/SW instruction already contains, as of 1 May 2023 and still in version 1.1 of 1 January 2025, express references to Cr(VI) deposits after high-temperature use, their cancer hazard and protective measures during removal. The European instruction refers specifically to versions with stainless steel mesh and/or stainless steel stitching wire. [16, 24]

For Morgan, the sections on reactivity mainly address the stability of the AES fibers, binder decomposition and high-temperature phase changes. Fiber and silica dust issues after use are also addressed; the reaction pathway with chromium-containing mating surfaces is not explained in the British SDS 418 examined. In the German article information on Pyrogel XTE, Aspen describes no known hazardous reactions under normal use, but does not mention a chromate pathway. This is a specific documentation gap for the further examination of suitable material combinations. It is not a finding about all documents of these manufacturers. [28, 29]

For the assessment, the as-delivered condition must be distinguished from the intended thermal application and from the condition on removal. A fiber not classified as hazardous, or a product treated as an article, may after use be contaminated with newly formed hazardous substances. The decisive question is whether the safety information covers this change of condition for the intended contact with chromium-containing components.

Manufacturer knowledge since 2019: [redacted]

The author holds manufacturer correspondence from [redacted] dating from August 2019. In it, the manufacturer informed its supplier of exhaust insulation that deposits between the exhaust insulation and exhaust pipes on [redacted] engines had tested positive for chromium(VI). The matter was to be treated as a substance of very high concern (SVHC) with the highest urgency. Already at that time, the manufacturer identified as the cause the chromium-containing stainless steel, in particular the wire mesh of the insulation, reacting with calcium from the insulation material. It was additionally stated that the problem occurred on all engine types. [52]

The calcium-dependent formation pathway was thus known to the manufacturer almost four years before Technical Instruction [redacted] (2023). It corresponds to the mechanism described by Udy 1939, Paoletti 2002 and Sayano 2015. [1, 11, 25, 50]

17. Analysis: the method decides the finding

The determination of chromium(VI) is not an elemental determination but speciation analysis. What is measured is an oxidation state, and that state can change during sample preparation. What the instrument finally registers is not necessarily what was present in the sample.

The American procedure EPA SW-846 Method 3060A, on which alkaline digestion is based, names both directions of error explicitly. On the one hand the extraction conditions must "not induce reduction of native Cr(VI) to Cr(III)", on the other the method must "not cause oxidation of native Cr(III) contained in the sample to Cr(VI)". On the second direction it adds: "Cr(VI) results obtained using this method may be biased high due to method-induced oxidation." [83]

Reduction during digestion

If the sample contains reducing constituents, the chromate is converted before it can be measured. In coatings these are above all metallic zinc and aluminum, together with iron(II) and organic constituents. The round robin test on the Dutch NEN 5617 shows the order of magnitude: for a zinc-free paint sample the participating laboratories achieved an average recovery rate of 58 percent, and 39 percent at 50,000 mg/kg of zinc. In a matrix with 16 percent zinc the recovery rate under NEN 5617 was 0.2 percent, under a further accredited method 6.5 percent and under the method of SEEF B.V. 35.3 percent. For this reason NEN 5617:2022 classifies itself as semi-quantitative. [84, 85]

The insulation material matrix

For thermal insulation materials the situation is sharper, because the matrix is itself the reaction partner: rich in calcium, basic and, once in service, permeated with soot, oil and corrosion products. No standardized method exists for this matrix; there is neither a NEN nor an ISO nor a NIOSH method tailored to insulation materials. ISO 15192:2021 is intended for waste and soil. According to the laboratory concerned with it, transferred procedures give results that are too low by 20 to 30 percent in mild cases and values close to zero in strongly calcium-containing samples. One Dutch laboratory, SEEF B.V., has developed its own method for this matrix which stabilises chromium(VI) throughout the analytical procedure and, according to its own data, achieves recovery rates structurally above 80 percent on spiked insulation material samples. [85]

Oil films and apolar phases

Besides reduction there is a second route by which a sample reads too low. Where a surface is treated with a penetrating oil before sampling, the chromate passes into an apolar phase and is no longer available to the aqueous measurement. Chemically nothing happens; the analyte is merely withdrawn from the determination.

SEEF B.V. has quantified this for WD-40. Solid chromium(VI) in direct contact with 2 ml of WD-40, then dissolved in water without digestion chemistry, gave a recovery rate of 5.8 percent. At higher volumes no reliable concentration could be determined at all, because the chromate clumped together in the oil phase. With chromium(VI) already dissolved, and with full digestion, the effect did not occur (Section 26). [91]

For practice it follows that sampling after an oil or grease treatment gives no usable result. This applies to penetrating oils as well as to assembly pastes and preservatives.

Sampling: spot, area and depth

The sections above concern the measurement on the sample. Separate from this is the question which sample is taken. In practice four approaches stand side by side: the swab with a stick at a small spot, the area wipe sample with a cloth and subsequent extraction, the material sample from the insulation, and the phase analysis of a section, as Sayano et al. carried out it with X-ray diffraction. Each of these approaches describes the place where it is applied. [11]

The formation occurs where chromium-alloyed steel, basic component, oxygen and temperature meet. Across an insulation set these conditions are not uniform, contact and temperature vary over the area. The contamination therefore occurs in patches. Which result is obtained depends on where the sample was taken. The French field study shows the same relationship within a single installation (Section 19).

Depth is added to this. The phase analysis covers a thin surface layer and only crystalline fractions above its detection limit (Section 3). Chromate formed inside the insulation at the contact face to the component or between the layers lies outside that range. The wipe test covers what lies on the accessible surface and can be wiped off. The material sample covers the piece that was taken.

For an insulation system of several square meters this leads to an asymmetry. A positive result proves presence and is conclusive. A negative result proves the absence of a finding at the tested spot, at the tested depth and down to the detection limit of the method. Further negative samples enlarge the tested area, they do not cover the whole area; an additional sample at another place can turn out positive. A number of samples that would carry absence across the whole area cannot be achieved in practice.

As an assessment: these methods are methods of detection and not methods of release. They establish a contamination and limit its extent. They do not release an area. Anyone using them for that purpose equates the absence of a finding with proof of absence.

What follows for the risk assessment

An analytical result for chromium(VI) without a statement of the recovery rate in the same matrix says nothing about the content. The EPA method draws the consequence and requires spiked samples before digestion, soluble and insoluble, with an acceptance range for the recovery rate of 75 to 125 percent; outside that range the entire batch must be repeated. [83]

Where this statement is missing, two false conclusions are possible. A result that is too low leads to an existing contamination being classified as insignificant and protective measures being omitted. A methodically elevated result leads to measures being applied in the wrong place. For occupational safety the first case weighs more heavily, because it can lead to a release that is not based on any actual freedom from chromate.

This is not an assessment of individual laboratories. The procedures named are suitable for the matrices for which they were developed and are carried out properly. The point is a different one: chromium(VI) is matrix-dependent, and a procedure developed for soil or waste does not give a comparable result on a used, calcium-rich insulation material.

From this follows the requirement for every test report: method, matrix and recovery rate in that matrix belong in the report, not only the numerical value. And from this follows at the same time why the German TRGS 561 does not rely on a measurement but on the presumption of presence: as long as the recovery rate in this matrix is not demonstrated, a negative result is no proof of absence.

18. Rules compared: one benchmark, nine frameworks

For all Member States, Directive 2004/37/EC in its current version applies as the overarching instrument. Since 17 January 2025 it sets a binding limit value of 0.005 mg/m³ for chromium(VI) compounds; before that 0.010 mg/m³ applied, and 0.025 mg/m³ for welding and plasma cutting. [86]

The benchmark for the question dealt with here is set by Germany. The German Hazardous Substances Ordinance (GefStoffV) and the German TRGS 561 are the only body of rules among these that expressly addresses the formation of chromium(VI) compounds on chromium alloyed hot components and derives a protective regime from it without requiring a prior measurement. For chromium(VI) compounds there is no acceptance concentration; the German TRGS 561 uses 0.001 mg/m³ in the inhalable fraction as its assessment benchmark, which corresponds to the tolerance concentration of the German TRGS 910. [87]

The remaining bodies of rules can be read as mirrors of it.

Framework	Basis	Airborne limit value
Germany	GefStoffV, TRGS 561, TRGS 910	0.001 mg/m³ inhalable, assessment benchmark [87]
European Union	Directive 2004/37/EC	0.005 mg/m³ since 17 January 2025 [86]
France	Code du travail, R. 4412-149	0.001 mg/m³, 8-hour average [175]
Netherlands	Arbobesluit, SZW list of carcinogenic substances	0.001 mg/m³ as Cr
United Kingdom	COSHH Regulations 2002, EH40	0.01 mg/m³, 8-hour average; 0.025 mg/m³ process generated [42]
United States	OSHA 29 CFR 1910.1026, 1915.1026, 1926.1126	PEL 5 µg/m³, action level 2.5 µg/m³ [153]
Canada, Quebec	RSST, Schedule I	0.001 mg/m³ insoluble, 0.005 mg/m³ soluble [170]
Canada, Ontario	Regulation 833 via the ACGIH table	0.01 mg/m³ insoluble, 0.05 mg/m³ soluble [171]
Canada, British Columbia	OHS Regulation, WorkSafeBC table	0.01 mg/m³ insoluble, 0.025 mg/m³ soluble [172]

The numerical values differ by a factor of 50. All of them refer to the chromium content and none to the specific compound. The highest values in this table are those of Ontario and, for process generated exposure, of the United Kingdom. Under the COSHH Regulations the United Kingdom also requires carcinogens to be minimized to the lowest level that is reasonably practicable, so that the limit value there does not describe a permissible working level. The leaflet INDG346 of the same authority still gives the value of 0.05 mg/m³ that applied until 17 January 2020 [88].

The airborne concentration describes only one of two exposure routes. Chromium(VI)-containing dusts are not distributed evenly across a working area, and in work on insulated hot components the dermal exposure may have to be rated higher than the inhalation exposure. Both routes are to be assessed separately. The American rule prescribes protective clothing, change and washing facilities, and in general industry a prohibition on blowing down with compressed air, which the shipyard and construction standards do not contain (Section 33); the German rules list chromium(VI) compounds as skin absorbing and require corresponding measures under the German TRGS 401.

The same applies to combustion ashes. There too the inhalation and dermal hazards are to be assessed separately, and particular weight attaches to preventing carry-over from the contaminated area, which concerns occupational and environmental protection alike.

Procurement law: the US clause DFARS 252.223-7008

Alongside occupational safety, procurement law applies in the United States. Clause DFARS 252.223-7008 "Prohibition of Hexavalent Chromium" has been in force since 5 May 2011 and is inserted into Department of Defense contracts as prescribed at DFARS 223.7306; the most recent change is dated 25 April 2024. It rests on the memorandum "Minimizing the Use of Hexavalent Chromium" of the Under Secretary of Defense for Acquisition, Technology and Logistics of 8 April 2009. [89, 90]

The clause prohibits the supply of a deliverable or construction material containing hexavalent chromium "in a concentration greater than 0.1 percent by weight in any homogenous material", and likewise the supply of items that would require hexavalent chromium to be removed or reapplied during later sustainment phases. Under the definition in paragraph (a), a homogeneous material is one that cannot be mechanically disjointed and is uniform in composition throughout; surface coatings count expressly as a homogeneous material in their own right. The exception in paragraph (b)(2) covers "hexavalent chromium produced as a by-product of manufacturing processes". Paragraph (d) requires flowdown to all subcontracts for supplies, maintenance and repair services, or construction materials. [89]

Three points follow for insulated hot components. The reference mass for the 0.1 percent is the homogeneous material, so a thin chromate-containing deposit or coating layer is weighed against the mass of that layer and not against the mass of the component. The exception is written for manufacturing processes and on its wording does not cover chromate that forms only in service. The flowdown extends the clause to maintenance and repair services. Whether calcium-containing insulation on a chromium alloyed hot component, which requires chromate to be removed at every overhaul, falls under the second limb of the prohibition is a question of interpretation that the wording permits.

19. Rapid test philosophy and the French field study

The technical information from Caterpillar, MAN and in particular Rockwool partly follows a staged detection and response logic:

1. First, a search is made for visible yellow, yellowish or orange deposits.

2. Where there is such a visible indication, a colorimetric rapid test is used or a laboratory analysis is recommended.

3. Special protective measures are then linked to positive detection or to a specific suspicion.

This approach has a comprehensible purpose as an indicative warning and screening procedure. A positive result is a reliable warning signal and requires protective measures. It is not suitable, however, for concluding from a negative result that Cr(VI) contamination is absent.

In the ProRox instruction, testing for Cr(VI) is linked to conspicuously colored deposits. In addition, it requires protective measures when such deposits are removed. The visual detection logic, however, does not reliably capture every contamination and must not be understood as exoneration in the absence of color or in the event of a negative rapid test.

As a release or exoneration logic, this is not technically sound. The material configuration of chromium-alloyed hot component, basic oxides, oxygen and temperature already establishes a specific situation of suspicion. A negative rapid test does not reduce this suspicion to zero, because its detection sensitivity, representative sampling, surface heterogeneity and the location tested are limited. Nor does the subsequent chemical treatment or "neutralization" of residues already present replace either the prevention of the formation pathway or reliable proof of effectiveness under controlled conditions.

Prevention standard of the German TRGS 561

Section 5.9.3 of the German TRGS 561 (Technical Rule for Hazardous Substances) names alkali/alkaline earth metal oxides from insulation materials or assembly pastes as an influencing factor. Paragraph 5 requires protective measures in accordance with 4.1 and 4.2 as well as supplementary measures where chromium(VI) contamination is present or cannot be ruled out. Basic oxide contents in the thermally stressed material system are therefore an indication of a hazard; the protective approach does not begin only with a positive finding. [19]

The following French field study directly shows the practical consequence of this rapid test philosophy.

The French field study: why negative rapid tests do not permit an all-clear

The French investigation by Passeron et al. (2025) during the maintenance of diesel and marine engines shows a further level of practical significance: chromium(VI) contamination can be overlooked with visual colorimetric rapid tests.

The company used colorimetric tests internally and based preventive decisions on them. The study authors compared these tests at the same sampling points with surface wipe samples analyzed for Cr(VI) by ion chromatography. The result was unequivocal:

Sampling point on the vehicle engine	Laboratory analytical Cr(VI) finding	Visual colorimetric rapid test
Exhaust manifold	127 ng	At most faintly perceptible positive
Turbocharger	869 ng	Negative
Bolt at the turbocharger outlet	1,646 ng	Positive

The values are absolute Cr(VI) quantities per sample, not area-related concentrations.

The negative rapid test on the turbocharger despite a laboratory finding of 869 ng Cr(VI) is a clear false-negative result. The authors also note that several positive surface samples were not detected by visual colorimetric tests. They therefore expressly conclude that these tests are to be used with caution.

For the reliable assessment of surface contamination, representative wipe samples and laboratory analytical Cr(VI) determinations are required. These assess a different part of the hazard than activity-related air measurements. In accordance with section 24, the exposure routes must each be considered independently.

D. Vehicles

20. Vehicle engines and engine compartments

The vehicle warnings link the industrial formation pathway with the automotive maintenance sector. [redacted] describes formation on hot surfaces of chromium-containing exhaust components. [redacted] names contamination actually detected, expressly addresses work in the engine compartment of all models and, in addition to inhalation, also takes into account skin contact and hand-to-mouth transfer. The two documents do not name a conclusive speciation as calcium or sodium chromate. [22, 23]

Specific automotive application: Morgan Superwool Plus Heat Shield

In its 09/2019 data sheet, Morgan expressly promotes Superwool Plus Heat Shield for vehicle heat shields subject to vibration. It is a flexible calcium/magnesium silicate fiber mat, not a rigid calcium silicate board. The sheet states the following oxide composition and service temperatures. [48]

Information in the product data sheet	Value
SiO_2	62-68 %
CaO	26-32 %
MgO	3-7 %
Hot surface, continuous operation	750 °C
Hot surface, short-term peak	850 °C

The safety section deals with biopersistence and fiber classification; a chromate warning is absent. The sheet's availability table names Europe. [48]

Morgan's system page describes Superwool Plus as an insulation option within stainless steel encapsulations. The applications named are catalytic converters, passenger car exhaust manifolds, turbo applications in off-road vehicles and exhaust manifolds in shipping/power generation. Austenitic and ferritic stainless steels, among others, are named as encapsulation materials. [49]

The targeted marketing of a calcium-containing insulation material for automotive hot component applications is thus documented. Fiber chemistry, chromium-containing contact/encapsulation surface and thermal stress must be assessed together. The content stated as CaO is an indication of a hazard; its reaction availability must be examined in the specific assembly. Exoneration of the original fiber does not cover subsequent formation of hazardous substances. The interface pathway demonstrated in section 10 gives rise to a specific question of compatibility and information. [11, 48, 49]

Consequences for vehicles

In the case of a vehicle demonstrably contaminated with Cr(VI), the hazardous substance finding is at the same time a characteristic of the vehicle and its components. It concerns safe handling, maintenance, reuse of components and the cost of any necessary remedy. This gives rise to a separate question regarding product condition and vehicle valuation. The available OEM warnings and surface findings provide a specific technical starting point for this. [5, 22, 23]

Which consequences for the vehicle must be recorded

Area	Specific consequence for the vehicle	Verifiable basis
Maintenance and handling	Residues that can be touched or released during work may require special working procedures; roadside assistance and intended owner activities may also be affected.	Component- and activity-related findings, accessibility, release and manufacturer instructions. Contamination of the engine compartment must be recorded separately from contamination of the passenger compartment.
Remedy and recurrence	Decontamination, where applicable replacement of contaminated insulation elements and modification of the reactive contact. Recurring contamination may cause repeated expenditure.	Scope and cost of the work; verification of effectiveness and findings after renewed thermal operation.
Costs and vehicle value	Additional maintenance/disposal costs, downtime and, where applicable, residual loss in value despite remedy.	Invoices, documented restrictions of use and expert valuation. A flat-rate reduction in value based solely on the name of the substance is not a reliable quantification.
Owner and market information	Information on affected versions, relevant activities, protection and remedy; transmission to independent workshops, used car buyers and fleet operators.	Dated warnings, their actual distribution and allocation of the affected vehicle and component versions.

A technically functional engine does not conclusively answer the question of safe handling and normal maintenance conditions. Likewise, a warning to authorised workshops must be assessed separately from whether owners, independent repairers and subsequent purchasers receive the necessary information. The specific activity is decisive: opening the bonnet, topping up fluids or roadside assistance must be examined with regard to the contaminated areas actually accessible; exposure during each of these activities is not presumed.

A lasting technical remedy must deal with existing contamination and the cause of possible re-formation together. If the reactive material combination remains, the effectiveness of a one-off cleaning must also be examined after renewed operation. Chromate may form only during use, even though the material/contact configuration decisive for this was already present at delivery. For attribution, the production status, thermal stress and subsequent modifications must be recorded. [11, 22, 23, 26, 38]

Legal points of reference in the EU

Line of enquiry	EU
Vehicle as object of purchase	In consumer sales, expected safety and normal fitness for use form part of conformity with the contract. In the event of non-conformity, repair/replacement and, subject to the respective conditions, price reduction or termination of the contract come into consideration. [46]
Safety and regulatory measures	Vehicle Regulation 2018/858 governs remedial action and information in the event of non-conformity or serious risk. Classifying a chromate-contaminated vehicle type requires a specific risk assessment. [47]

The EU consumer sales rules concern claims against the seller under national transposition; Art. 7, 10 and 13 of Directive 2019/771 link safety requirements with the time of delivery, the liability period and remedies. For corporate and public authority fleets, by contrast, the respective procurement/purchase contracts and national rules on defects must be applied. A material cause at the supplier does not cancel out the assessment of the vehicle sold as a whole. [46]

Art. 14 of Regulation 2018/858 is a specific starting point for examining the measures required of the manufacturer. Whether a specific Cr(VI) constellation is to be classified as non-conformity or serious risk is the assessment question to be addressed. [47]

A substantiated vehicle defect and the costs of remedying it open up an economic line of enquiry. A cancer diagnosis is not a prerequisite for claims for defects under sales law. Regulatory measures under Regulation 2018/858 are governed by its criteria. [46, 47]

E. Combustion residues: ashes, boiler deposits, cremation

21. Combustion ashes and boiler deposits

The scope of investigation expressly covers the ash residues remaining on the grate, bottom ash, furnace residues and deposits on chromium-alloyed hot components, in addition to fly, filter and boiler ashes. These fractions are different sample matrices. Chromium may originate from the material being incinerated; in the event of contact with chromium-alloyed components, their surface/corrosion chemistry must also be taken into account. Reactive calcium and alkali components may come from the residues themselves. Insulation as a calcium source is not a prerequisite for this. [11, 26, 31-34]

Paoletti 2002: calcium chromate in waste incineration

As early as 2002, Paoletti investigated the behavior of oxyanion-forming heavy metals in municipal solid waste incineration at the German research center Forschungszentrum Karlsruhe (dissertation, University of Stuttgart, FZKA 6755). Thermogravimetric experiments with Cr_2O_3 and CaO in synthetic air showed a rapid increase in mass between 500 and 850 °C. After one hour at 850 °C, X-ray diffraction detected hexavalent $CaCrO_4$. In an inert atmosphere, by contrast, only trivalent $Ca(CrO_2)_2$ was formed. [50]

Paoletti concludes that hexavalent chromates can only be formed "if the oxygen partial pressure in the combustion chamber is sufficient". She also expects similar reactions with sodium, potassium, magnesium, strontium and barium. In the TAMARA pilot plant, 85 to 100 % of the chromium dissolved in the DEV-S4 eluate of the grate ashes was present as Cr(VI) at air ratios of 0.7 to 1.5; at an air ratio of 0.6, the release fell by almost two orders of magnitude. [50]

Vehlow, Paoletti, Seifert and Sirini presented the results in 2004 at the WTERT Fall Meeting at Columbia University in New York, including the thermogravimetry on Cr_2O_3 and CaO with the product $CaCrO_4$. The formation pathway had thus also been presented at international specialist level since 2004. [51]

Thermal post-treatment of fly ashes

In 2015, Hu et al. describe the oxidation of chromium in waste incineration by alkali and alkaline earth metals. The publisher's abstract evaluated highlights the availability of free CaO; alkali components promote oxidation at lower temperatures in connection with flue gas cooling. Calcium bound in sulfates or aluminosilicates must be considered separately with regard to its reactive availability. Total calcium or an oxide content stated as CaO alone therefore does not yet describe the conversion to calcium chromate. [31]

Hu et al. (2013) had already investigated fly ashes from five Chinese waste incineration plants and their thermal post-treatment at 1,023-1,323 K, corresponding to approximately 750-1,050 °C, in air or nitrogen. The publisher's abstract describes the formation of $CaCrO_4$ from Cr_2O_3 and CaO during thermal treatment. The ashes initially investigated, by contrast, show only small Cr(VI) fractions and low leaching. The result concerns the change caused by post-treatment; it is not a general statement about all raw ashes. [32]

Gong et al. (2017) add to this aspect for a Chinese fly ash from flue gas cleaning: after thermal treatment, chromium leaching increases, while the leaching of several other metals decreases. The authors attribute the change to Cr(VI) compounds such as $CaCrO_4$. Total chromium was measured in the eluate; the calcium chromate pathway is the authors' mechanistic explanation, not an independent Cr(VI) speciation proof from this series of measurements. Improved immobilisation of individual metals therefore does not permit any general all-clear with regard to chromium. [33]

Grate ashes during shutdown: temperature profile and oxygen ingress

During shutdown for maintenance, ash residues remain on a chromium-containing grate or on chromium-alloyed hot component surfaces while temperature and atmosphere change. This process must be distinguished from the transport of fly dust during ongoing operation.

Paoletti provides the building blocks for this process: calcium oxide is present in household waste at around 3 %; calcium chromate forms between 500 and 850 °C and is reduced back to trivalent chromate above 850 °C; oxygen is an essential prerequisite. During shutdown, the grate and ash residues pass through precisely this temperature window, while additional oxygen enters through burnout and opening. Additional chromate formation or enrichment in the remaining residues is therefore chemically to be expected. [50]

The importance of the atmosphere is also confirmed by Leaching behavior of heat-treated waste ash (2006): the authors investigate bottom ashes from two Japanese municipal grate firing plants and vary temperature, oxygen concentration and treatment time. Thermal treatment with less oxygen reduces the leachable Cr(VI). [43]

That this effect is known is shown by a wood ash process that deliberately allows oxygen contact only below 200 °C in order to prevent Cr(VI) formation (Brill 2002, cited in the 2019 report of the German Environment Agency, p. 72). The report also considers an inert post-treatment of cremation ash. [44]

Direct comparative measurements at waste incineration plants before and after shutdown are not yet available; they would determine the order of magnitude, not the mechanism.

For a specific ash or deposit problem, the fraction, plant, operating state, sampling, Cr(VI) analysis and activity must be assigned.

Total chromium measurement, leaching tests and personal dust measurement each answer different questions.

22. State of knowledge in Europe on combustion residues

Region / source	Documented knowledge	Significance for the assessment
EU, 2019: JRC-BREF [34]	The reference document for waste incineration names hexavalent chromium among the problematic metals with regard to leaching from bottom ash.	Explicit environmental reference. Eluate/environmental assessment does not replace an assessment of dust exposure during maintenance and overhaul.
United Kingdom: HSE / practical case [30, 40]	HSE requires the assessment of fly ash risks and the avoidance of airborne ash. The practical case reports Cr(VI) in deposits during overhaul work.	Geographically Europe, legally separate from the EU. The case describes a specific activity; it is not a representative investigation of the protection regime.

European environmental literature also expressly names Cr(VI): in the 2019 European BAT reference document for waste incineration (JRC-BREF), it is listed alongside copper, molybdenum and zinc as a problematic substance with regard to leaching from bottom ash. For this statement, the corresponding officially indexed passage was evaluated, not the entire extensive document. The environmental perspective answers different questions from the activity-related occupational safety and health assessment. [34]

The Euro-Environmental article has been taken into account: it describes Cr(VI)-positive deposits in boiler passes 2-6 of an unnamed British operator and the exposure during maintenance and overhaul. The cooling described there concerns the flue gas path through successive boiler passes; it is not to be read as a measurement of new chromate formation during shutdown over time. Air/ambient monitoring, biomonitoring, ferrous sulfate treatment, extraction and enclosed areas are reported. Numerical before/after values are missing; the yellow color does not provide a reliable identification of the salt. The case documents the handling of a specific overhaul hazard and supplements the separate question of residues on the grate. [30]

Field observations on the protection regime

Field observations at European waste incineration plants show that protection against chromate exposure is implemented at best partially. This does not involve a systematic sample of plants, specific series of measurements or an assessment of individual operators.

The resulting question for investigation is whether the risk assessments also cover overhaul, boiler opening, removal of deposits, cleaning, ash handling and spreading of contamination. The residue fraction concerned in each case, analytical speciation, release during the work process and the protective measures actually used would need to be recorded. This can be traced on the basis of existing work permits, measurement reports and overhaul documentation.

23. Cremations and other chromium-containing combustion materials

In 2019, owing to legal restrictions, the German Environment Agency (UBA) investigated 25 model ashes from cremations of empty coffins in five cremation furnaces. All contained Cr(VI). In extraction with 0.01 M $CaCl_2$, ash/solution 1:50, an average of 17 % of total chromium went into solution; the dissolved chromium was present entirely as Cr(VI). The report describes process-related chromium inputs and soil/groundwater risks. Calcium is present mainly as calcium phosphate; total calcium is not proof of free CaO. [44]

Exhaust gas emissions, residual ash and the subsequent release from an urn are separate exposure or environmental pathways. An emission factor does not describe an ash concentration; an eluate test does not describe exposure via breathing air. The technical context is nevertheless the same reason for investigation: the chromium source, reactive basic components, the temperature-time profile and the atmosphere of the process must be recorded together. Which specific chromate phase is formed is clarified by suitable speciation and phase analysis.

The Porto reference 10216/21130 belongs to Ferreira, Almeida and Pinto (1999): Influence of temperature and holding time on hexavalent chromium formation during leather combustion. Leather scraps were investigated. According to the publisher's abstract, Cr(VI) was below 5 mg/kg before combustion; relevant quantities dependent on temperature and holding time were formed in the ashes. The source supplements the thermal Cr(III)/Cr(VI) conversion in chromium-containing combustion material. The abstract was evaluated; the study does not concern human cremations. [45]

F. Health, regulation, open questions and conclusion

24. Health and environmental consequences of the chromates

The reaction products are not only chemically relevant. The calcium and sodium chromates considered here are carcinogenic; skin contact, local effects on the skin and possible uptake must be assessed in addition to inhalation. In the case of injuries, individual Cr(VI) compounds can cause severe skin ulcers. [2, 3]

Uptake into the cell: the Trojan horse

Water-soluble chromates are structurally analogous to sulfate and phosphate ions. The cell therefore takes them up via its sulfate and phosphate transport pathways as if they were an ordinary nutrient anion. Chromium(VI) thus enters the cell interior unhindered, whereas trivalent chromium barely passes through the cell membrane. [53]

Reduction inside the cell: DNA damage and oxidative stress

Inside the cell, chromium(VI) is reduced stepwise by ascorbate, glutathione and cysteine via the reactive intermediates chromium(V) and chromium(IV) to stable chromium(III). According to the evaluation of the International Agency for Research on Cancer (IARC), this produces chromium(III)-DNA adducts, DNA-protein and DNA-DNA cross-links, DNA strand breaks including double-strand breaks, and oxidative base damage. The predominant form is ternary adducts, in which chromium(III) links the DNA with small molecules such as cysteine, histidine, glutathione or ascorbate. The reactive intermediates of the reduction additionally generate oxidative stress. [53]

In the cell nucleus, it is thus trivalent chromium that damages the DNA. The widespread equation of chromium(III) with harmlessness therefore falls short: what matters is whether chromium enters the cell.

Epidemiological basis: the chromate industry cohorts

The carcinogenic effect is not only derived from animal experiments but has been demonstrated in workers in the chromate industry. The US occupational safety agency OSHA based its limit value of 5 µg/m³, issued in 2006, primarily on two cohorts from chromate production: the workers at the Baltimore plant (Gibb et al. 2000; 2,357 men, observed from 1950 to 1992) and those at the plant in Painesville, Ohio (Luippold et al. 2003). The IARC classifies chromium(VI) compounds as carcinogenic to humans (Group 1), with an established effect on the lung and observed associations with cancer of the nose and paranasal sinuses. [53, 54]

Classification of the target chromates

Under the harmonised European classification, calcium chromate is classified as carcinogenic category 1B (H350) and as very toxic to aquatic life with long-lasting effects (H400, H410). Sodium chromate is additionally classified as mutagenic, toxic to reproduction, skin sensitizing and corrosive. [3]

Skin contact

Skin contact must be assessed in its own right. Prolonged contact can lead to dermatitis and skin ulcers; some of those exposed develop allergic sensitization, in which even small quantities trigger severe skin reactions. Contaminated components, insulation materials, tools and gloves therefore remain a hazard even when air measurements are unremarkable. The German TRGS 561 (Technical Rule for Hazardous Substances) requires special protective measures in the event of skin contact with chromium(VI) compounds. [19, 56]

Not all chromium(VI) is the same: the individual chromates

In practice, people usually speak of "chromium(VI)" across the board. This generalisation is harmful because it loses sight of the individual chromates. Solubility, particle behavior, residence time in the lung and classification differ considerably. In a British comparative study in rat lungs (Levy et al. 1986), poorly soluble chromates caused lung tumours significantly: strontium chromate in 43 and 62 of 99 animals, calcium chromate as a positive control in 25 of 100, zinc chromate, by contrast, in only 5 and 3 of 100 respectively. [55]

Calcium chromate, the main product of in-situ formation on calcium-containing insulation materials and in ashes, is thus among the most potent chromates in animal experiments. An assessment that only records "chromium(VI)" and does not name the compound conceals these differences.

All exposure routes must be assessed individually

Article 3(2) and (3) of the European Directive 2004/37/EC requires the assessment of possible exposures, including other routes of exposure, in particular absorption into or through the skin. For these activities, the following routes must each be taken into account individually and then in the overall assessment: [18]

- Inhalation: release and inhalation of chromate dusts during maintenance, opening, dismantling, cleaning or handling; activity-related air measurements assess this route.
- Dermal: contact with contaminated components, insulation materials, tools, gloves or liquids; skin exposure, possible uptake and local effects must be assessed separately.
- Oral: hand-to-mouth transfer via contaminated hands, objects, food or drinks; work processes, hygiene and spreading of contamination must be taken into account.

A low air concentration is not a general exoneration criterion. It does not answer the questions of skin contact, oral uptake or surface contamination. The German TRGS 561 requires, in section 3.3.4, special protective measures in the event of skin contact with Cr(VI) compounds. [19]

Environment

For the target compounds likely here, the environmental hazard is also significant. Calcium chromate and sodium chromate are to be classified as very toxic to aquatic life with long-lasting effects (H410). The formation of these chromates therefore concerns occupational safety and health, waste and residue management and water protection at the same time.

The fact that the starting product is sold as an insulation material does not change the hazardous substance relevance of the reaction products formed under intended thermal stress.

How far chromium(VI) can spread in the environment is shown by the case of Hinkley in California, known from the film Erin Brockovich (2000): between 1952 and 1966, the US energy company PG&E used chromium(VI) as a corrosion inhibitor in the cooling tower water of a compressor station. The wastewater entered the groundwater via unlined ponds and contaminated an area around three kilometres long and one and a half kilometres wide. [57]

In-depth look at inhalation health risks: Speer et al. (2022)

The American study submitted examines particulate zinc chromate ($ZnCrO_4$) in non-malignant, immortalised human bronchial fibroblasts. Exposure was at 0.1, 0.2 and 0.3 µg/cm² over 24, 72 and 120 hours. The authors record changes in microRNA expression by means of sequencing and additionally verify selected findings with qPCR. The compound investigated is zinc chromate, not calcium or sodium chromate. [39]

According to the bioinformatic target and signalling pathway analysis, the altered microRNAs concern central areas of carcinogenesis: chromosomal instability, inflammation, oxidative stress, evasion of cell death and cellular transformation. The changes in expression were measured; not every gene or signalling pathway effect derived from them was directly tested as a functional endpoint. The study thus deepens the mechanistic understanding of particulate Cr(VI) exposure in human lung cells. [39]

For the assessment of chromate dusts, this is a relevant biological reference: cellular regulatory and repair processes may be affected even if a later routine examination does not reconstruct earlier exposure. However, the cell culture dose in µg/cm² is not an air concentration in µg/m³; the series of experiments is neither an inhalation cohort study nor a measurement of the disease risk at a specific plant. Compound, solubility, particle behavior and the dose actually taken up must still be taken into account when transferring the findings to other chromates. [39]

Air measurement, biomonitoring and long-term effects are different levels

A workplace air measurement describes the activity and time period sampled. Urinary chromium serves to assess an absorbed chromium burden; the British EH40 lists the biological guidance value as chromium in urine, not as a direct Cr(VI) speciation measurement. Such a value reliably reconstructs neither exposure that lies far in the past nor genotoxic changes that have already occurred. The three levels must therefore not be used as substitute evidence for one another. [39, 42]

In British occupational safety and health, the British authority HSE likewise requires consideration of all routes of uptake, including the skin and ingestion; for carcinogenic substances, exposure must be reduced as far as is reasonably practicable. The British practical case is therefore listed as a separate European application example, not as evidence of currently applicable EU law or of a common European limit value. [41]

25. Industrially manufactured or formed in situ: unequal control

In regulations and in public perception, chromium(VI) compounds are considered almost exclusively in their industrially manufactured form, as the Udy patent describes it as the product of a targeted process. Strict requirements apply to this form: in the EU, manufacture and use are subject to authorisation and, in future, to a restriction, workplaces are monitored, emissions are limited, and mixtures such as chromate-containing paints and primers carry hazard labeling with a pictogram and the hazard statement H350. [1, 3, 59]

In-situ formation, by contrast, remains largely disregarded or is pushed aside. Calcium and sodium chromate form during intended operation on hot components, in insulation materials and in combustion residues, without a manufacturer placing them on the market, without labeling and usually without a safety data sheet describing the condition after use. Those exposed are fitters, service technicians, insulators, motor mechanics, overhaul personnel and waste disposal workers, often without knowing it. The health consequences are the same as with the industrially manufactured form: lung cancer, cancer of the nose and paranasal sinuses, skin ulcers and allergic contact dermatitis. In addition, there is contamination of soil and water via dusts, ashes and waste. [53, 56]

Regulatory developments

Australia is already taking the step towards minimization: from 1 December 2026, the Australian authority Safe Work Australia will no longer set workplace exposure limits for non-threshold genotoxic carcinogens; chromium(VI) compounds are expressly included. The exposure limit is replaced by the obligation to eliminate exposure or to minimize it so far as is reasonably practicable (SFAIRP, comparable to the ALARP principle). [58]

In the EU, the European Chemicals Agency ECHA proposed a restriction on chromium(VI) substances in April 2025, intended to replace the existing authorisation procedure. Under this proposal, only certain uses would remain permitted under strict conditions, with workplace exposure limits of between 0.1 and 5 µg Cr(VI)/m³ depending on the use, as well as emission limits for air and water; all other uses would be prohibited. [59]

The broad concept of use in the European REACH Regulation is decisive here. Under Article 3 point 24, "use" means any "processing, formulation, consumption, storage, keeping, treatment, filling into containers, transfer from one container to another, mixing, production of an article or any other utilisation". Accordingly, even the storage of removed thermal insulation contaminated with chromate dusts can constitute a use; the reuse of such insulation is all the more a use. If it does not fall under the uses permitted in future, it is prohibited. [60]

Unequal control in practice: the comparison with asbestos

The unequal treatment does not end with the rules; it continues in practice. Industrially manufactured chromium(VI) is used in closed systems, is subject to authorisation, is labeled, is supplied with a safety data sheet and is handled by instructed personnel. Chromium(VI) formed in situ, by contrast, is met as a deposit on a surface. It has no manufacturer, no supplier, no labeling and no safety data sheet. It therefore falls out of the category of hazardous substance and into the category of dirt. It is treated accordingly, with rags, brushes, vacuum cleaners, compressed air and spray products, by the maintenance and cleaning staff already on site. The widespread term "neutralisation" comes from that same world of language and not from chemicals law.

The comparison with asbestos shows the gap. Both substances are classified as carcinogenic to humans, and with both the danger arises not in the installed condition but when dust is released during maintenance, removal or cleaning. For asbestos this has produced a closed procedural regime. The German TRGS 519 in the version of 28 February 2025 requires under number 3.2 that demolition, remediation and maintenance work be notified to the competent authority "at the latest 7 days before the work begins". Number 2.7 governs the required expertise and its proof, and numbers 5.1 to 5.3 the responsible person, the supervisor and the skilled personnel. For weakly bound asbestos products, numbers 14.1 to 14.3 require containment and air handling measures as well as personnel and material locks [97].

For the chromates formed in situ none of this exists. There is no duty to notify before work begins, no dedicated proof of expertise, no prescribed supervisor, no clean and dirty zone system and no approved specialist contractors. The German TRGS 561 requires personal protective equipment, low dust working and the substitution check (Section 6), but it does not set up a procedural regime with notification, proof of expertise and containment. Nobody would think of treating an asbestos-containing board with a spray by hand and then wiping it down. With a chromate-loaded hot component this is exactly the usual practice.

On two points the classification even argues against this unequal treatment. Sodium chromate carries three skin-related hazard statements, harmful in contact with skin (H312), corrosive (H314) and skin sensitizing (H317) [65]; asbestos carries none in its harmonised classification. Calcium and sodium chromate are also classified as very toxic to aquatic life with long lasting effects (H400, H410) [64, 65], while the harmonised classification of asbestos, Carc. 1A (H350) and STOT RE 1 (H372), states no environmental hazard [98]. In the dermal and in the environmental dimension the chromates are therefore classified more strictly than the substance for which the closed procedural regime applies.

The assessment of skin contact leads straight to the highest rank. The German TRGS 401 in the version of October 2022, last amended on 19 September 2024, grades the hazard by type of contact in table 2 of section 4.2. For the row "Absorbed through the skin and at the same time having the hazardous properties listed alongside", carcinogens of category 1A or 1B (H350) are graded "h", that is, high hazard, for every type of contact, with no threshold for duration or area. Skin sensitizing properties alone (H317) lead to that grade only for contact of more than 15 minutes per working day over a large area, and under paragraph 4 also where practical experience shows sensitization in a considerable number of employees [99].

Chromium(VI) compounds meet both criteria, and the marking is officially assigned. Under section 3.2.3 paragraph 2, the German TRGS 401 takes the marking "H" for substances absorbed through the skin from the German TRGS 900, 905 and 910; where a substance is not listed there, the MAK and BAT value list of the German Research Foundation may be used as a further source of information [99]. In annex 1 of the German TRGS 910, chromium(VI) compounds are listed at 1 µg/m³ of the inhalable fraction with an excursion factor of 8 and the note "see TRGS 561", but without a skin marking [101]. The MAK and BAT value list 2026, communication 62, by contrast carries both markings under "Chromium(VI) compounds (inhalable fraction)": skin absorption "H" and sensitization "Sh", together with carcinogenicity category 1 and germ cell mutagenicity category 2. Expressly excluded from the H marking are only barium, lead, strontium and zinc chromate, and from the Sh marking only barium and lead chromate. Calcium and sodium chromate, the compounds treated here, fall under none of these exceptions [102].

The grading of skin contact is therefore unambiguous. A substance that is absorbed through the skin according to the MAK and BAT value list and at the same time belongs to carcinogenicity category 1 falls into the row "Absorbed through the skin and at the same time having the hazardous properties listed alongside" in table 2 of the German TRGS 401 and is graded there as a high hazard for every type of contact, irrespective of duration and area [99]. The additional Sh marking and the harmonised classification skin sensitization 1, H317, come on top of that; the Institute for Occupational Safety and Health of the German Social Accident Insurance names the routes of uptake for chromium(VI) compounds as "inhalation, skin absorption" [100]. For asbestos no comparable skin assessment exists, because its harmonised classification contains no skin-related hazard statement.

This raises the question of what justifies the difference in handling. Both groups of substances are classified as carcinogenic, the release mechanism via dust during maintenance and removal is the same, and for calcium chromate the potency is documented in animal studies (Section 24). The difference lies not in the substance, but in the fact that the one was supplied as a product and the other arose in operation.

Duties before work begins: investigation, assessment and the ban on starting

In the legal systems considered here, the duties before work begins are for the most part framed without naming a specific substance. The German Hazardous Substances Ordinance requires the employer, in section 6 paragraph 2a, to examine the information provided to him under section 5a paragraph 1 as to whether hazardous substances are released from the structural or technical installation during the activities and can endanger the health of the employees. Where the information from the party commissioning the work is not sufficient, he has to carry out this examination himself under paragraph 2b and to make use of external expertise where he lacks the necessary knowledge, in particular where a technical investigation becomes necessary. If a technical investigation is necessary in order to carry out the risk assessment and to determine the protective measures, it is, under paragraph 2c, a precondition for carrying out the activities. Section 7 paragraph 1 prohibits taking up the activity before the risk assessment has been carried out and the necessary protective measures have been taken, and section 6 paragraph 8 sentence 1 requires the documentation for the first time before the activity is taken up, irrespective of the number of employees. The term used in these paragraphs is hazardous substances; asbestos is not named there. [120]

The year of construction entry appears elsewhere. Section 5a paragraph 2 of the German Hazardous Substances Ordinance requires the party commissioning the work, for the purpose of establishing whether asbestos is present, to state the date on which construction began where the year of construction lies between 1993 and 1996, and otherwise the year of construction. For chromates formed in situ this entry has no significance, because the compound is not introduced during construction but arises in operation. An installation erected in 2024 with chromium-alloyed hot components and calcium-bearing insulation falls under the same wording as existing older stock. [120]

The Dutch Arbeidsomstandighedenbesluit requires, in Article 4.2 paragraph 1, the assessment of the nature, degree and duration of the exposure within the Risico-Inventarisatie en -Evaluatie, even where such activities are not currently carried out. Paragraph 3 requires the determination of the exposure level, paragraph 7 the comparison with the limit value laid down for the substance and paragraph 8 the review as soon as new activities involving hazardous substances are begun. Article 4.1b paragraph 2 lists this assessment as one of the conditions under which the general duty of protection is regarded as fulfilled. Article 4.2 contains no express ban on starting before the assessment. It appears, asbestos-related, in Article 4.54a paragraph 1, under which the presence of asbestos is to be fully inventoried before demolition or dismantling, removal or clearing up after an incident is begun, carried out by a company certified for asbestos inventory work. [121]

In the United Kingdom the ban stands, without naming a specific substance, in Regulation 6(1) of the Control of Substances Hazardous to Health Regulations 2002: "An employer shall not carry out work which is liable to expose any employees to any substance hazardous to health", as long as there is no "suitable and sufficient assessment of the risk created by that work" and the steps following from it have not been implemented. Regulation 6(2) lists what the assessment has to take into account, including the information from the supplier together with the safety data sheet, the level, type and duration of the exposure, and activities such as maintenance that can lead to high exposure. Asbestos-related, Regulation 5 of the Control of Asbestos Regulations 2012 is added, under which an employer may not carry out demolition, maintenance or other work which exposes or is liable to expose employees to asbestos unless he has either carried out a "suitable and sufficient assessment" of the presence, type and condition of the asbestos or, in case of doubt, assumes its presence and applies the Regulations. [122, 123]

In the United States, 29 CFR 1926.1126(d)(1) obliges every employer whose workplace or work operation falls under the standard to determine the eight hour shift average values for each employee exposed to chromium(VI). Under (d)(2) this is done by means of an initial measurement with a sufficient number of personal air samples for each shift, job classification and work area, and under (d)(3) by means of a combination of monitoring data, historical data or objective data. Under (d)(2)(vi), additional measurements have to be carried out where the process, raw materials, equipment, personnel, work practices or protective measures change in such a way that new or additional exposures can arise. The chromium(VI) standard contains no ban on starting of the kind found in German section 7 paragraph 1 or British Regulation 6(1). The structural counterpart is found in the asbestos standard: 29 CFR 1926.1101(k)(2)(i) obliges the owners of buildings and installations to determine the presence, location and quantity of asbestos-containing material and material presumed to contain asbestos, and the definition in (b) presumes an asbestos content for thermal system insulation and for applied surfacing materials in buildings with a year of construction no later than 1980, as long as this presumption has not been rebutted under (k)(5). The initial exposure assessment under (f)(2)(i) has to be carried out by a competent person immediately before or at the start of the work. [124, 125]

For the application case treated here, the German TRGS 561 ties the protective regime, in section 5.9.3 paragraph 5, to activities on industrial components "on which chromium(VI) contamination is present or in respect of which it cannot be ruled out". The duty therefore arises before the finding. The absence of a measurement does not establish an exclusion, and the investigation is the route by which an exclusion could be demonstrated at all. [19]

As an assessment: two of the four legal systems contain the ban on starting before the assessment in a form that does not name a specific substance, Germany through section 7 paragraph 1 of the Hazardous Substances Ordinance and the United Kingdom through Regulation 6(1) COSHH. In the Netherlands and the United States the prior duty lies in the general hazardous substances rule as a duty of assessment and determination, while the ban brought forward in time and the presumption rule stand in the asbestos regime. The unequal treatment described in the previous subsection is therefore also reflected in the structure of the rules, as a difference in procedural depth and not as a difference in principle.

26. Supposed remedies: neutralization, WD-40 and the "harmless" chromium(III)

"Neutralisation"

Several of the manufacturers named in this analysis recommend "neutralising" chromium(VI) residues and present this as a sufficient occupational safety and health measure. The term suggests that chromium(VI) can be rendered harmless. In fact, it is a redox reaction: a reducing agent converts chromium(VI) into chromium(III). This succeeds almost completely only under favourable conditions, i.e. with sufficient contact between reducing agent and chromate, sufficient quantity, moisture and exposure time. On porous insulation materials, in interfibre spaces, beneath deposits and on hot or dry surfaces, these conditions are rarely met in practice. [22, 25]

[redacted] itself states that a component is no longer considered neutralized after renewed thermal stress ("If the component part is subjected to thermal stress again, it is no longer considered neutralized."). The cause remains: as long as chromium, calcium or sodium, oxygen and temperature coincide, the chromate forms anew in the next operating cycle. [11, 22, 50]

Moreover, treating chromium(VI) with a reducing agent is itself a use within the meaning of Article 3 point 24 REACH ("treatment"). Whether it falls under the planned EU restriction will be decided by the final legal text. [59, 60]

The term is already factually wrong. Neutralization in the chemical sense is the reaction of an acid with a base to form salt and water, that is, a shift in the pH value. Chromate is not an acid-base problem. The transition from chromium(VI) to chromium(III) is a redox reaction, which requires a suitable reducing agent, a suitable pH range, sufficient contact time and proof of effectiveness.

What the application looks like in practice is shown by the work instruction "Instructie voorkomen blootstelling aan Chroom(VI)" of Vattenfall Generation NL, first version of 18 February 2019, last updated in full on 29 April 2024. It describes the formation path correctly: calcium chromate forms when a chromium-containing base metal comes into contact with calcium and an oxidising agent at temperatures around or above 350 °C; as the calcium sources identified so far it names certain anti-seize pastes and calcium-bearing insulation material. For the treatment it provides two agents, the Siemens Umwandler Spray and a self-mixed ascorbic acid solution, both with a limited shelf life and a mixing date to be stated visibly, the powder two years, the wet solution one week. The surface is sprayed or moistened, the solution has to be sticky enough or kept permanently wet, because the conversion can take several minutes, after which it is cleaned with a cloth. [115]

Ascorbic acid is, unlike the penetrating oil treated further below, a genuine reducing agent. The objection is therefore directed not against the substance but against the conditions. The evidence of effectiveness for the reduction of chromium(VI) comes from liquid-liquid systems. What is involved here is a liquid-dry treatment of an open surface which, in the turbine and engine environment, regularly carries oil and grease residues. Complete conversion is not to be expected under these conditions, and for high temperature insulation no proof of effectiveness exists.

The check on success hangs entirely on the colorimetric rapid test, in the instruction the TK11 test kit from MATinspired. If it comes out negative, then according to the wording no further measures and no protective equipment are required. Every cleaning operation is to be concluded with a negative test, and tools and used full face masks likewise go back to the store after a negative test. The instruction regards air measurements as unnecessary as a rule. What significance such a test has is shown by the French field study: on the turbocharger the laboratory analysis detected 869 ng Cr(VI), while the colorimetric rapid test at the same place came out negative (Section 19). [115]

Under the same instruction the insulation mattresses are misted with ascorbic acid and then put back into service; remaining insulation material is misted and disposed of as industrial waste. With that the reaction partner returns to the hot component together with the material, and at the next start-up all the formation conditions are met once again. For asbestos there is no instruction to treat fibers and then refit the material. [115]

For GE hardware the ascorbic acid has been suspended following a letter from the manufacturer, on the ground that it adversely affects the microstructure of the material; cleaning with WD-40 is prescribed there instead. [115]

The conference of 6 November 2025 and a certificate that names its limits

At the event "Chroom-6 verbindingen onder thermische isolatie" held by iTanks and the Chroom 6 Informatie Kennis Centrum on 6 November 2025, six suppliers appeared with pitches: Insulcon, Kavarmat, OOI, Ecopoint, Sherwin Williams and Econtras. Ecopoint presented the "Chrome-6 Neutralizer", by its own description a solution of acids which reduces Cr(VI) to Cr(III), ready to use and with a shelf life of at least two years. The formation conditions are named correctly on the slide: chromium in the stainless steel, temperature above 250 °C, calcium-bearing insulation, alongside potassium, sodium or magnesium, together with moisture and condensation. [116]

The certificate which SEEF B.V. drew up in August 2025 on behalf of Eco-Point International BV for the Chrome-VI Neutralizer (PR269) is correct in its approach, because it claims no more than what was tested. The effectiveness applies, according to it, "mits deze verbindingen oplosbaar zijn in de neutralizer-oplossing", that is, only in so far as the compounds are soluble in the solution. The product ages and loses effect, the treated surface is to be kept wet for at least 15 minutes and must be sufficiently cooled, and if the test remains positive afterwards the treatment was insufficient and has to be repeated. For the check the certificate records: "Een negatieve uitslag is echter niet betrouwbaar", a negative swab result is not reliable; a reliable analysis is then recommended, SEEF TK01 or laboratory analysis. And further: "Het is echter geen garantie dat blootstelling volledig wordt voorkomen", the product being "een hulpmiddel binnen een veiligheidsstrategie en geen oplossing die alle risico's zelfstandig elimineert". A document that discloses its own reach in this way is the standard against which what is made of it can be measured. [116]

What becomes of this on the slide

The pitch slide reproduces four points: effective neutralization, 15 minutes of contact time on a cooled substrate, significant reduction of the probability of exposure and an aid within a safety strategy. Not reproduced are the solubility condition, the aging, the repetition if the test is positive and the sentence on the unreliability of the negative test result. The closing slide instead advertises with "Bewezen actieve RTU vloeistof" and "Meten is weten!". Measurement thereby becomes the argument, while in the certificate it is the point at which a warning is given about the negative result. The product name "Neutralizer" carries the same misunderstanding in its title, because what is described is an acid solution that reduces. [116]

The instruction and its date

The work instruction of Vattenfall Generation NL is older than these documents. According to its own version history the ascorbic acid was added on 11 June 2019, the cleaning with WD-40 for GE hardware on 28 October 2022, and the last full update is dated 29 April 2024. It could not have known the certificate of August 2025 or the investigation of WD-40 of September 2026. What can be assessed is therefore not its creation but its continued existence. At the event of 6 November 2025, three months after the certificate, Econtras, an insulation contractor of Isolatiebedrijf C.J. van Waas BV, presented the same instruction unchanged under the heading "Reinigen met Ascorbinezuur", including the statement that this is an ascorbic acid solution produced by Vattenfall itself, and including the sentence that no further measures are required if the test result is negative. [115, 116]

The same laboratory, two documents

For the penetrating oil prescribed in the instruction, the same laboratory that certified the effectiveness of the Neutralizer subject to conditions has refuted any reducing effect: 96.8 percent recovery with chromium(VI) already in solution, no dose-response relationship with complete extraction and 5.8 percent recovery on the solid as a solubility artefact. The two findings do not contradict each other, they separate what is effective from what is not. In the work instruction both agents stand side by side as equivalent cleaning methods.

The consequence for occupational safety and health

In this practice the release from protective measures hangs on a method whose negative result the testing laboratory declares in writing to be not reliable. This statement concerns the test method and not a single product. The French field study points in the same direction, with 869 ng Cr(VI) in the laboratory analysis on the turbocharger against a negative rapid test result at the same place (Section 19). A measure whose check on success can come out false negative does not satisfy the duty under section 7 paragraph 9 of the German Hazardous Substances Ordinance to verify effectiveness by suitable methods where no limit values exist. In practice it leads to protective equipment being taken off, tools and respiratory protection going back into the common stock and misted insulation material being refitted. For asbestos nobody would release a black area on the basis of a color rapid test.

The certificate is the most precise document in this chain and the only one that names its own limits; no criticism attaches to the testing body in this, on the contrary, it set out the finding and its reach in full. What becomes of it in industrial circulation is something else: under well-known logos, correct certificates are cut down to four advertising points, the conditions fall away, and the lay reader is given the impression of safety where the certificate expressly gives none. The effect of the technical instructions of large groups of companies reaches furthest here, because they present the handling of a carcinogenic compound that is hazardous to water as a normal work step, with a spray bottle, a cloth, test strips and subsequent reuse of the material.

The reduction narrative outside the operators

The German statutory accident insurance institution for the construction industry states on its page "Chrom(VI)-Verbindungen an Edelstahl" that "chromate-reducing fibre binders can be used", and: "These reduce the chromate to uncritical chromium(III) compounds and bind fibres." The only reservation that follows is that the use of a reducing agent may "where applicable have negative effects on the treated materials" and is to be agreed with the client. Proof of effectiveness, the presence of oils and greases and the duty under section 7 paragraph 9 of the German Hazardous Substances Ordinance to verify effectiveness by suitable methods where no limit values exist do not appear. The classification of the reaction product as uncritical moreover makes no reference to the findings treated further below: the sensitization marking Sh which the MAK and BAT value list 2026 gives for the soluble chromium(III) compounds, the assessment by the French agency Anses of 2021 and the mobilisation of fiber-bound chromium(III) as chromium(VI) according to Walter et al. 2022. Elsewhere the same page records that the chemical formation mechanism is "at present not yet fully clarified", and in the same text names the thermal insulation materials containing alkali and alkaline earth metals as a contributing factor. [117]

How an established reduction is organized is shown by cement. Entry 47 of Annex XVII of the REACH Regulation limits soluble chromium(VI) in cement to 0.0002 percent, that is, 2 ppm of the dry mass. This is achieved by the addition of a reducing agent, predominantly iron(II) sulfate, stoichiometrically 3.22 mg Fe(II) per mg Cr(VI), in practice overdosed by a factor of eight to twenty, homogeneously mixed in, with a reaction that begins only with the mixing water, and tested in accordance with EN 196-10. The effect declines during storage; moisture and oxygen accelerate this. What is carried over from this is the spraying of a solution onto an oily surface in the engine room, without dosage control, without a standardized test method and with a rapid test as acceptance. [118, 119]

The same accident insurance institution, two accounts

The operating instruction "Ausbau chromatbelasteter Dämmstoffe" under section 14 of the German Hazardous Substances Ordinance, available through the hazardous substances information system WINGIS of the German statutory accident insurance institution for the construction industry, classifies the activity with the sentence "These activities or processes are carcinogenic.", carries the signal word Danger and records: "Chromium(VI) compounds can cause cancer!" It prescribes the demarcation of the work and remediation areas with a warning sign, low dust work procedures and equipment, work only with extraction, work with a fresh air supply, dust extractors and industrial vacuum cleaners of dust class H, continuous monitoring of function and extraction performance, covering with sheeting where cleaning facilities are lacking, cutting of the material exclusively with a knife, scissors or hand saw, immediate collection of the waste, separate changing rooms and a washroom with showers as a black and white facility, collection of the disposable protective suits at the end of the shift and the sentence "Do not reuse removed mineral wool products." As personal protective equipment it requires close-fitting safety goggles for overhead work and heavy dust generation, protective gloves of chromate-free leather or nitrile-impregnated cotton gloves, a disposable protective suit type 5 and respiratory protection with the requirement "Always wear respiratory protection.", implemented as a P3 particle filter on a half or quarter mask or as a particle-filtering half mask FFP3. In this list "Use chromate-reducing fibre binders." stands in second place, between the zoning and the low dust work procedures. [126]

Compared with the German TRGS 561 the operating instruction goes further in several points. Section 5.9.3 paragraph 5 permits class FFP2 respiratory protection for short-term activities; the operating instruction has no short-term level and requires P3 or FFP3 throughout. Dust class H, the fresh air supply and the black and white facility are not named by the TRGS at this point. On eye protection the operating instruction falls below it, because the TRGS requires it without restriction, while the operating instruction ties it to overhead work and heavy dust generation. The chromate-reducing fiber binder does not appear anywhere in the TRGS 561; the terms fiber binder, binder and neutralization are entirely absent there. [126, 19]

The publicly accessible information page of the same accident insurance institution carries not one point of this catalogue. It describes the formation path, names as contributing factors highly chromium-alloyed steels, oxygen, temperatures of about 350 to 800 °C and thermal insulation materials containing alkali or alkaline earth metals, identifies yellowish deposits consisting predominantly of calcium chromate as the most frequent finding, and offers the fiber binder as the only action, with the sentences that it reduces the chromate "to uncritical chromium(III) compounds" and binds fibers, and: "This lowers the exposure." The only reservation that follows is the reference to possible negative effects on the treated materials and to agreement with the client. Respiratory protection, zoning, extraction, the black and white facility, the ban on reuse, the risk assessment, substitution and the TRGS 561 do not appear on the page. For the protective measures it refers to the lead German statutory accident insurance institution Energie Textil Elektro Medienerzeugnisse. [117, 126]

The same abridgement occurs on the industrial side, there with the same vocabulary. The German-language product page of Eco-Point International BV for the Chrome-6 Neutralizer describes the agent as an acid-based, biodegradable neutralizing liquid "which converts harmful chromium-6 into harmless chromium-3", and lists among the particular advantages: "Chromium-6 is converted into chromium-3, that is, from a carcinogenic substance into a harmless one." The formulation "the harmless chromium-3" appears at two further places on the page. The page contains nothing on contact time, protective equipment, the risk assessment or disposal. The testing is referred to with the sentence that the Chrome-6 Neutralizer has been tested and certified by the independent laboratory SEEF; the conditions which that certificate expressly names do not appear there. The German statutory accident insurance institution for the construction industry with "uncritical chromium(III) compounds" and the supplier with "harmless chromium-3" thus make the same statement. The state of the findings on chromium(III) is set out in section 27, with the sensitization marking Sh for the soluble chromium(III) compounds, the assessment by the French agency Anses of 2021 and the mobilisation of fiber-bound chromium(III) as chromium(VI) according to Walter et al. 2022. [127, 116]

As an assessment: in the public account a complete protective regime becomes a single measure, provided with a statement of effect that appears neither in the operating instruction nor in the TRGS 561 and for which no proof of effectiveness is required. A company looking for the duties that apply to it meets this account first, because it is the public entry point, while the operating instruction has to be called up in the hazardous substances information system. The question whether this abridgement was considered during drafting remains open. The effect occurs irrespective of that, and it reaches further than any manufacturer's statement, because it stands under the mark of a statutory accident insurance institution and is therefore citable.

A third supplier and the circle of testing

A third supplier makes the same statement. The product page of MATinspired B.V. for the TK20 Chromium-6 Neutralizer describes the agent as one that "neutralizes and removes chromium-6 in surface contaminations on metals" and explains the effect by saying that the chromium(VI) present is "converted to non-toxic chromium-3". There are thus three identical classifications of the reaction product: uncritical with the German statutory accident insurance institution for the construction industry, harmless with Eco-Point and non-toxic with MATinspired. [131]

The questions and answers of the same supplier name the limits that are missing from the product page. The agent has no effect against airborne particles, it presupposes cooled components, it is not intended for metal with gaps or bore holes, it is to act for at most about ten minutes and is then wiped off and rinsed with water. On the completeness of the conversion it says: “We cannot guarantee that the neutralizer liquid will remove/neutralizer all chromium-6.” On the durability of the result it says that re-formation has not been observed at room temperature, which means that the treated and refitted component at operating temperature is not covered. On protective equipment the answers name protective gloves and eye protection as the minimum, list P3 respiratory protection and protective clothing as a recommendation and close with the sentence: “It is the sole responsibility of the user which appropriate security measures should be used.” [132]

In both documents the proof of effect rests on the TK11 test kit of the same supplier. The same test kit is, in the work instruction of Vattenfall Generation NL, the criterion according to which protective equipment is taken off, tools are returned and misted insulation material is refitted. On this method the certificate of the testing body records that a negative result is not reliable, and the French field study shows the same finding with 869 ng chromium(VI) in the laboratory analysis on the turbocharger against a negative rapid test result at the same place (Section 19). [115, 116, 132]

As an assessment: an agent whose complete effect the manufacturer does not guarantee is accepted on the basis of a test whose negative result the independent laboratory declares to be not reliable, and the selection of the protective measures is passed to the user, while the German TRGS 561 lays them down for this application case in section 5.9.3 paragraph 5. The substitution of the material containing alkali and alkaline earth oxides, which would put an end to the renewed formation, does not appear in any of the manufacturer documents. [19]

Instruction WS00Q563 of Wärtsilä carries the same pattern. For the treatment it names a solution to be mixed on site from 900 ml of distilled water, 110 ml of citric acid powder and 2 ml of liquid soap, applied for six to ten minutes and then rinsed off with water. The document contains no statement on effectiveness, and no renewed test after the treatment is provided for, although a wipe test is required before work starts. The manufacturer itself states that the procedure reduces the release of dust and does not guarantee freedom from Cr(VI). [137]

Citric acid is not a usual reducing agent for chromate. Without an accelerator the reduction is slow; at pH 4.5 less than 5 percent of 50 µmol/l Cr(VI) was converted within 22 hours, and manganese(II) accelerates the same process by about a factor of 45. The pH decides. For organic reducing agents the conversion is 99.6 to 99.9 percent at pH 2.0 to 2.5 and between 15.4 and 36.3 percent at pH 3 to 8 in the sterile set-up. The quantity given in the bulletin states a powder in millilitres, so the concentration is not unambiguously defined. [282, 283]

Formulated acid mixtures for the same purpose are on the market. Their suppliers describe the effect with their own statements, without a named laboratory and without published data. [284]

The question remains why the service technician is told to mix a weakly reducing solution while the calcium source stays in the component and chromate forms again the next time the engine is run above 400 °C.

What a statement looks like that names its own reach is shown by a product page from my own environment. I hold an interest in Kavarmat® Sp. z o.o. Sp.k., which sells KavarClean®Redox Powder. The product page names the colloquial term neutralizer and states that in chemical terms this is not a neutralization but a reduction. It describes the product as an aid during remediation and maintenance work and where substitution is not planned. It does not guarantee complete conversion and states that a negative spot test is not proof of freedom from Cr(VI). No proof of effectiveness exists for this product, and none is claimed. The statement is therefore no better supported than those of the other suppliers, but it also claims nothing that would have to be supported. [285]

WD-40

In practice, the penetrating oil WD-40 is in some cases regarded as a remedy against chromium(VI) and used during maintenance work. The origin of this practice can be named. The Safety Bulletin Summary of the British industry association Energy UK of September 2019 records that members have experience with the use of WD-40 or comparable agents and cloths "to immobilise and wipe away Cr(VI) residue". What is described is the binding of dust before wiping, not a chemical conversion. The same document already names the three conditions of formation, a calcium-bearing product, temperatures above 300 °C and chromium-containing steel, and requires that presence be assumed at all power station sites. [92]

WD-40 has no reducing effect. SEEF B.V. tested this experimentally. With chromium(VI) already in solution the recovery after the addition of 2 ml WD-40 remained at 96.8 percent, 240.7 against 248.7 µg/l. With a reference paint sample with complete digestion no dose dependence appeared; the values lay between 1,280.0 and 1,384.5 mg/kg against 1,265.0 mg/kg in the control and thus all above the control. According to the manufacturer's safety data sheet the product consists of 55 to 75 percent by weight aliphatic hydrocarbons and base oil and contains no component with a reducing action. [91]

The third experiment explains why the measure nevertheless appears effective. Solid chromium(VI) in direct contact with WD-40 and then dissolved in water gave a recovery of 5.8 percent, because the chromate clumped in the oil phase and remained withdrawn from the measurement. Whoever samples after an oil treatment measures a fraction of the chromate present. The finding confirms the measure, while the chromate remains unchanged on the component, in the cleaning material and in the waste (Section 17). [91]

The supposedly harmless chromium(III)

The reduced chromium(III) is frequently presented as an essential and natural trace element. In 2014, however, the European Food Safety Authority EFSA found no evidence of the essentiality of chromium(III) and considered the setting of an adequate intake to be inappropriate. [61]

Furthermore, the chrysotile study by Walter et al. (2022) shows that fiber-bound chromium(III) can be mobilised as chromium(VI) under oxidative conditions at physiological pH, which is taken up by lung and mesothelial cells. Industrial dusts can thus act as carriers through which supposedly harmless chromium(III) returns to a form that enters the cell. In the cell nucleus, it is then again chromium(III) that forms the DNA adducts. [4, 53]

27. Chromium(III): the assumed final state

All the methods treated in section 26 rest on the same assumption. That with the conversion of chromium(VI) into chromium(III) the dangerous part of the process is at an end. This section examines the assumption against the documents, the classifications and the chemistry of the process.

The line of argument in the manufacturer documents

Technical Instruction [redacted] of [redacted], released on 31 May 2023, sets it out in full. Chromium(VI) is said to be "almost completely converted into the much less dangerous chromium of oxidation state 3" by the reduction solution. On the assessment of this state it says: "Cr-3, for example, is found in many foods. Daily intake levels in Europe are generally in a range where no health risk is expected. Whether Cr-3 is an essential trace element for humans at all has not been conclusively clarified. Since the possible concentration of Cr-3 after application of the reduction solution is far below the applicable limit values (occupational exposure limit values), a health hazard from Cr-3 can be ruled out." Emphasised, there follows: "Unlike Cr-6, Cr-3 is not carcinogenic." [25]

In its third sentence the paragraph concedes that essentiality has not been conclusively clarified, and in the fourth it rules out a health hazard. The reasoning relies on limit values without naming one. The question of essentiality was answered by the 2014 assessment of the European Food Safety Authority, which found no evidence of the essentiality of chromium(III) and considered the setting of an adequate intake to be inappropriate. [61]

What arises in the reduction

The MAK documentation for the chromium(VI) compounds of the inhalable fraction describes the process as a multi-stage reaction: "The reduction of chromium(VI) proceeds via chromium(V) and chromium(IV) to chromium(III), with radical oxygen and sulphur compounds being formed." Which intermediate stage occurs depends on the reducing agent. In the reaction with ascorbate, two electrons are transferred in the first step and chromium(IV) is formed; with glutathione, one electron is transferred and chromium(V) is formed, which produces hydroxyl radicals in reactions analogous to the Fenton reaction. In all cases the end product is the stable oxidation state chromium(III). [128]

This account concerns the reduction inside the cell. Its transfer to the treatment of a component surface is an analogy and is identified as such here. What can be transferred is the fact that the conversion is not a single-step reaction to a defined end product.

For treatment on the plant there is in addition what lies on the surface. Depending on the instruction, the reducing agent is ascorbic acid, a mixture of acids or iron(II) sulfate, and in some cases citric acid is added. On the treated surface there are oils, greases, insulation material residues and assembly pastes. With organic acids and their oxidation products, chromium(III) forms soluble complexes. Chromium(III) oxide, which is what the product statements mean, forms thermally and not by spraying on and wiping off.

The unknown species

Which chromium(III) compounds are actually present after a treatment is stated in none of the documents considered. The work instruction of Vattenfall Generation NL does not name the reaction product, the product pages of Eco-Point and MATinspired speak of chromium-3 and non-toxic chromium-3 without stating a compound, the certificate of the testing body refers to the effectiveness of the conversion and not to its product, and the page of the German statutory accident insurance institution for the construction industry speaks in the plural of uncritical chromium(III) compounds without naming one. [115, 116, 117, 131, 132]

The analysis used likewise does not answer the question. The colorimetric rapid test indicates chromium(VI) or it does not. The laboratory methods determine chromium(VI) or total chromium. Speciation analysis of the chromium(III) compounds formed is not provided for in any of the methods and is not required in any of the documents.

Classification of the chromium(III) compounds

The MAK and BAT value list 2026 of the German Research Foundation lists the chromium(III) compounds without a MAK value, without a peak limitation, without a pregnancy risk group, without a skin absorption marking and without a category for carcinogenicity or germ cell mutagenicity. Under sensitization the group carries the marking Sh for a skin sensitizing effect, with the addition: "Does not apply to chromium(III) oxide and comparably poorly soluble chromium(III) compounds." For comparison, the same list gives the chromium(VI) compounds of the inhalable fraction the skin absorption marking H, the sensitization marking Sh, carcinogenicity category 1 and germ cell mutagenicity category 2. [102]

The Sh marking thus applies to the soluble chromium(III) compounds and expressly not to the oxide and comparably poorly soluble compounds. Assignment to the group without a marking presupposes knowledge of the species formed, which according to the preceding subsection is not determined. In the account given by the suppliers it is made without a finding.

For chromium(III) oxide itself a workplace limit value of 2 mg/m³ in the inhalable fraction applies in Germany, with excursion factor 1 and short-term value category I. For chromium(III) oxide there is no harmonised classification under the European CLP Regulation. [130]

The French agency Anses examined chromium(III) oxide as the evaluating Member State within the substance evaluation under the REACH Regulation and submitted its opinion on 28 July 2021. It considers a classification as a skin sensitizer of category 1 to be indicated and expressly regards this as relevant for other chromium(III) compounds as well. For the inhalation route a harmonised classification as STOT RE 2 with H373 is to be examined, because the lung damage in animal experiments is regarded as irreversible. For the environment it recommends the harmonised classification as Aquatic Acute 1 with H400 and Aquatic Chronic 1 with H410. On germ cell mutagenicity it concludes that, on an overall assessment, the criteria of the CLP Regulation are not met; on the nanoforms there are two studies giving cause for concern, whose conclusiveness is limited by the absence of data on the chromium(VI) content. On reproductive toxicity it regards the data as insufficient and recommends that a multi-generation study in accordance with OECD 443 and a prenatal developmental study in accordance with OECD 414 be required. [129]

The same opinion records that the European Classification and Labelling Inventory contains self-classifications for chromium(III) oxide including Carc. 1A, Muta. 1B and Repr. 2, which in part relate to chromium(VI) impurities, and it recommends that the enforcement authorities examine whether chromium(VI) above 0.1 percent is present without a matching classification. [129]

Between the German and the French assessment there is an open point. The MAK and BAT value list excludes chromium(III) oxide from the Sh marking, while Anses considers a classification of the same substance as a skin sensitizer of category 1 to be indicated. Both assessments stand side by side. [102, 129]

The sensitizing step is the chromium(III) step

The MAK documentation describes the course of skin sensitization by chromates. Chromium(VI) compounds penetrate the horny layer and are reduced to chromium(III) in the skin, probably above all by sulfur-containing amino acids and glutathione. “Unlike the hexavalent compounds, these trivalent chromium compounds are able to bind to high molecular weight carrier molecules such as proteins and can act as haptens” and thus induce a sensitization of the skin. Trivalent chromium is also involved in genotoxicity: chromium(III) formed in the cell nucleus forms adducts with the DNA, “predominantly ternary complexes of DNA, chromium(III) and small molecules such as ascorbate, glutathione, cysteine or histidine”, which can cause gene mutations, DNA double strand breaks, chromosome breaks and micronuclei. [128]

The precedent of leather

The same MAK documentation describes an application in which chromium(III) has long been used as a working material: “Tanning is indeed carried out with chromium(III) compounds, but where processing or storage methods are unsuitable small quantities of chromium(VI) compounds can form from them. Where the chromium(III) is formed in situ by reduction of chromium(VI) compounds, soluble chromium(VI) can likewise remain in the leather if the reduction is incomplete.” [128]

Both statements in this sentence concern the process dealt with here. Under unsuitable conditions chromium(VI) can form from chromium(III), and an incomplete in situ reduction leaves soluble chromium(VI) behind. For treatment on the hot component, completeness of the reduction is not assured according to the suppliers' own statements.

Mobility and the conclusion as to drain-free working

The methods described in section 26 work wet. A solution is sprayed on, wiping is done with cloths, and under the MATinspired instruction rinsing with water follows. This produces a liquid phase which, on the state of the suppliers' statements, can still contain chromium(VI), because complete conversion is not assured and, according to the certificate of the testing body, the release procedure is not reliable where the result is negative. To this are added the soluble chromium(III) complexes, whose composition is not determined. [132, 116]

On the disposal of this liquid phase the product pages and the questions and answers of MATinspired contain no statement, and the washing of the used cloths is expressly provided for there. For the same activity the operating instruction of the German statutory accident insurance institution for the construction industry requires the waste to be collected at the place where it arises in PE sacks or big bags and to be labeled. From both of these follows the requirement to carry out such work drain-free and to treat the liquid arising as hazardous substance waste as long as its chromium(VI) content has not been determined by a reliable method. [126, 132]

The return of the exposed chromium(III) to the hot component

In the alloy matrix the chromium is bound and accessible to a reaction only via the surface. After a reduction, chromium(III) compounds are present finely distributed and unbound on the surface and in the adhering material. This state is the starting state of chromate formation as documented in this analysis: the patent of 1939 describes the deliberate production of calcium chromate from chromium-containing material with lime and atmospheric oxygen, Mao et al. demonstrate the formation of calcium chromate from chromium(III) in the presence of calcium oxide in the temperature window from 500 to 900 °C, and Verbinnen et al. show the same dependence for alkali and alkaline earth compounds. [1, 9, 10]

If treated insulation material is refitted under the instruction of Vattenfall Generation NL and the plant is started up, all the conditions are met once again, and the reaction partner chromium is present in a more readily accessible form than before. No investigation of this case exists. The supplier's statement that re-formation has not been observed at room temperature does not cover it. [115, 132]

Delimitation

The lower toxicity of the chromium(III) compounds compared with the chromium(VI) compounds is undisputed and is not called into question here. Chromium(III) compounds carry no carcinogenicity category and no germ cell mutagenicity category. The statements that the reaction product is uncritical, harmless or non-toxic go beyond this. They make a statement about substances that are not determined, they leave the Sh marking of the soluble chromium(III) compounds unmentioned, they leave the official assessment by a Member State on skin sensitization and on hazard to water unmentioned, and they presuppose a completeness of the conversion that no supplier assures.

28. Our own field findings

The basis of this expert analysis is not other people's documents alone. Since 2019 we have been carrying out our own investigations in the field, in part ourselves and in part through commissioned third parties, and they are documented.

Investigations were carried out on plant in operation and in maintenance: engines and combined heat and power plants, power stations, incineration plants inside and outside, marine engines, vehicles and construction machines. In the course of this we have tested almost every insulation material available on the market on a variety of installations.

Wipe samples, material samples and laboratory analyses were used, evaluated in a mobile laboratory and by external laboratories. In the early period we too used the rapid test. We no longer use it, for the reasons set out in section 19.

This expert analysis does not claim that every component is affected, and it does not seek to overstate anything. After seven years of field work, however, we cannot establish freedom from contamination or give an all-clear for any of the fields of application named.

29. What can still be investigated and what is no longer open

Insulation technology and vehicles

In the individual plant case, there may be a need for investigation regarding kinetics, local oxygen and moisture conditions, the influence of temperature cycles, surface chemistry or the quantitative ratio of individual chromates. These questions concern the characteristics of the reaction process.

They do not cancel out the formation pathway. It has been documented in patent form since 1939, confirmed experimentally at the metal-insulation interface and the subject of manufacturer warnings since April 1990. It is at the same time operational reality: the work instructions of the operators describe it with a temperature window and a calcium source, and our own field findings from seven years confirm it on engines, turbines, power stations, ships and vehicles. The open questions concern the characteristics, not the occurrence.

Nevertheless the in-situ formation continues to be presented as a contamination or as a consequence of operation that cannot be prevented. What is correct is that this is a thermochemical reaction whose second partner is determined through the choice of material. Anyone who places a material containing alkali and alkaline earth oxides on a chromium-alloyed hot component accepts the formation, and has done so ever since the connections were documented.

In view of the reaction chemistry publicly documented since 1939, the Toshiba prevention approach of 2010 and the interface evidence of 2015, the question arises as to why the formation pathway is still presented in product information and warnings as open or not comprehensible.

From the chromate expert's perspective, a lack of interest on the part of insulation material and engine manufacturers in a clear presentation of the material-related cause and its preventive elimination can be identified on technical grounds, insofar as this is based on the documented information gaps. A presentation that is as unclear as possible may serve economic interests. This assessment concerns the discernible communication and its effect; a specific internal intention is not thereby asserted as an established fact.

The in-depth sources allow specific follow-up questions: in compatibility tests with chromium, was only the resistance of the insulation material examined, or was Cr(VI) also determined? Was the known metal-insulation reaction included in the intended conditions of use? Why are corresponding notices missing from certain product-specific documents? What changes to warnings, materials or contact surfaces followed the companies' own findings? The answers can be traced in test reports, version histories and distribution lists.

Combustion residues and transfer of research findings

For ashes, is only total chromium determined or also Cr(VI)? Does sampling also cover the ash residues remaining on the grate and the combustion chamber residues before and after shutdown, as well as the deposits relevant to overhaul and cleaning? What changes result from the temperature/oxygen history during shutdown, thermal post-treatment or aging? Is the disposal/eluate assessment being confused with an assessment of inhalation, dermal and oral exposure? Which results from industry-related research projects were transferred into warnings and work instructions?

The factual core is a possible implementation gap between available substance knowledge, application-related information and protection as actually practiced. The existing sources and the field observations justify a targeted examination of these interfaces. An intention to conceal or misconduct on the part of all operators is not derived from this as a fact.

30. Legal consequences of non-compliance

The preceding sections deal with the formation pathway, the state of the evidence and the duties. This section deals with what happens if those duties are not met. The account is confined to the law in force and gives the source for every statement. What matters is that in all four legal systems set out here the sanction attaches to the duty omitted and not to damage to health that has occurred.

Germany: administrative offense, criminal offense and recourse

The German Hazardous Substances Ordinance lists the breaches of its central duties in section 22 paragraph 1. The provision begins: "Anyone acting intentionally or negligently commits an administrative offence within the meaning of section 26 paragraph 1 number 8 letter b of the Chemicals Act who". For the matter dealt with here three numbers are relevant. Number 1a covers the risk assessment which, contrary to section 6 paragraph 8 sentence 1, is not documented, or is not documented correctly, completely or in time. Number 3 covers anyone who allows an activity to begin contrary to section 7 paragraph 1, that is, before the risk assessment has been carried out and the necessary protective measures taken. Number 5 covers anyone who, contrary to section 7 paragraph 7 sentence 1, does not check the function and the effectiveness of the technical protective measures, or does not check them in time [103].

The range of the fine follows not from the ordinance itself but from the Chemicals Act. Section 26 paragraph 3 grades the maximum amounts; for breaches under section 26 paragraph 1 number 8 letter b, that is, for the provisions on the protection of employees, the fine is up to 50,000 euros [104].

Above the administrative offense the criminal law begins, and it does so without any damage having to have occurred. Section 22 paragraph 2 of the Hazardous Substances Ordinance provides: "Anyone who by an act described in paragraph 1 endangers the life or the health of another person or property of significant value belonging to another is liable to punishment under section 27 paragraphs 2 to 4 of the Chemicals Act." [103] Section 27 paragraph 2 of the Chemicals Act provides for imprisonment of up to five years or a fine for intentional endangerment, and paragraph 4 for imprisonment of up to two years or a fine for negligent conduct. The attempt is punishable under paragraph 3. The element of the offense is the endangerment of life or health, not its injury [105].

This construction is of considerable significance for the matter dealt with here. An occupational disease caused by chromium(VI) appears with a latency of years to decades. A criminal provision that required the damage to have occurred would in practice remain without effect over that period. The endangerment offense, by contrast, applies at the point at which the activity is carried out without an assessment and without protective measures.

To this is added the recourse of the accident insurance institution. Under section 110 of the German Social Code Book VII, persons whose liability is limited under sections 104 to 107 are liable to the social insurance institutions for the expenses incurred as a result of the insured event if they "caused the insured event intentionally or through gross negligence". The fault need relate only to the act or omission that caused the insured event. In amount, the liability is limited to the claim for damages under civil law; instead of a pension, the capitalised value may be demanded. The institution may waive the claim in whole or in part at its equitable discretion [106]. Where an occupational disease is recognized and carries many years of pension, treatment and rehabilitation costs, this recourse is regularly the largest item in economic terms, and it falls on the person whose liability towards the employee is itself limited.

On the environmental side, section 326 paragraph 1 of the German Criminal Code applies. It covers anyone who collects, transports, treats, recovers, stores, deposits, discharges, disposes of or trades in waste outside a facility authorised for that purpose or in substantial deviation from a prescribed or authorised procedure, provided the waste falls within one of the hazard categories listed. These include waste that is "carcinogenic, toxic for reproduction or mutagenic for humans". The sentencing range is up to five years' imprisonment or a fine, and for negligent conduct under paragraph 5 number 1 up to three years [107]. Insulation materials, deposits and ashes containing chromate come within this consideration as soon as they are handled as waste; the classification then follows not from the as-delivered condition but from the in-use condition.

Netherlands: duty of substitution, bestuurlijke boete and economic offense

The Dutch Arbeidsomstandighedenbesluit governs activities involving carcinogenic substances in chapter 4 section 2. Article 4.17 bears the heading "Voorkomen van blootstelling; vervangen" and requires technical and organizational measures that prevent the possibility of exposure at source as far as possible, above all by replacing the carcinogenic, mutagenic or reprotoxic substances or processes, "voor zover dit technisch uitvoerbaar is", with substances or processes in which the employees are not endangered or are endangered less [109]. The priority of substitution is thus framed as in German law, but with the benchmark of technical feasibility.

Non-compliance with the duties under the Arbeidsomstandighedenwet and the provisions based on it is an overtreding under article 33 paragraphs 1 and 2. Article 34 paragraph 1 assigns the imposition of the bestuurlijke boete to an official designated for that purpose. Under article 34 paragraph 3 the fine is at most the amount of the fifth category under article 23 paragraph 4 of the Dutch Criminal Code [108]; since 1 January 2026 that amount has been 110,000 euros, and the amount of the sixth category 1,100,000 euros [111]. Where a breach of the same kind occurred within the preceding five years, the fine is increased by 100 percent under article 34 paragraph 5, and where there were two earlier breaches or where the breaches are classified as serious, by 200 percent under paragraphs 6 and 7; for serious breaches paragraph 9 extends the period considered to ten years [108].

The criminal provision is in article 32 of the Arbeidsomstandighedenwet: "Het is de werkgever verboden handelingen te verrichten of na te laten in strijd met deze wet of de daarop berustende bepalingen indien daardoor, naar hij weet of redelijkerwijs moet weten, levensgevaar of ernstige schade aan de gezondheid van een of meer werknemers ontstaat of te verwachten is." [108] The benchmark is therefore not positive knowledge alone but also what the employer must reasonably know. Article 1 number 1 of the Wet op de economische delicten expressly lists article 32 of the Arbeidsomstandighedenwet as an economic offense. Under article 2 paragraph 1 of the same Wet these offenses are misdrijven in so far as they are committed intentionally, and otherwise overtredingen. Article 6 paragraph 1 number 1 provides, for the offense committed intentionally, imprisonment of up to six years, a community service order or a fine of the fifth category, and number 4 provides, for the overtreding, detention of up to one year, a community service order or a fine of the fourth category [110].

United Kingdom: COSHH and the Health and Safety at Work etc. Act

Regulation 7(1) of the Control of Substances Hazardous to Health Regulations 2002 provides: "Every employer shall ensure that the exposure of his employees to substances hazardous to health is either prevented or, where this is not reasonably practicable, adequately controlled." Regulation 7(2) makes the priority of substitution clear: "substitution shall by preference be undertaken", whereby the employer replaces the use of the hazardous substance, so far as is reasonably practicable, with a substance or a process that removes or reduces the hazard. Where prevention of exposure to a carcinogen is not reasonably practicable, regulation 7(5) additionally requires the total enclosure of the process and handling systems so far as is practicable, the prohibition of eating, drinking and smoking in areas that may be contaminated, the regular and occasion-related cleaning of floors, walls and other surfaces, the marking of the areas and installations concerned with suitable warning signs, and safe storage, handling and disposal in closed and clearly labeled containers [113].

These duties are backed by criminal sanctions. Under section 33(1)(c) of the Health and Safety at Work etc. Act 1974 it is an offense to contravene health and safety regulations or any requirement imposed under them. Section 33(2) refers to Schedule 3A for the mode of trial and the maximum penalty. There the offense under section 33(1)(c) is triable either summarily or on indictment; on indictment the maximum penalty is imprisonment of up to two years, a fine or both, and summarily imprisonment up to the general limit in a magistrates' court, a fine or both. The summary ceiling of 20,000 pounds that formerly applied has fallen away; the wording in force names only "a fine" [112]. Here too criminal liability does not presuppose damage to health that has occurred but attaches to the breach of the rules.

United States: OSHA penalties, criminal provision and procurement law

In the United States the standard 29 CFR 1910.1026 applies to chromium(VI), with a permissible exposure limit of 5 µg/m³ and an action level of 2.5 µg/m³ (Section 18). The civil penalties under section 17 of the Occupational Safety and Health Act are adjusted annually for inflation. For assessments after 15 January 2026 they are up to 16,550 US dollars per violation for serious and other-than-serious violations as well as for breaches of posting requirements, up to 16,550 US dollars per day for failure to abate after the period set has expired, and up to 165,514 US dollars per violation for willful or repeated violations [114]. Since every item concerned can be cited separately, the total amount is not limited by these individual amounts.

To this is added the criminal provision in section 17(e): an employer who wilfully violates a standard issued under section 6 and thereby causes the death of an employee is punished by a fine of up to 10,000 US dollars or by imprisonment of up to six months or by both; after a first conviction the range rises to 20,000 US dollars or one year [114]. In procurement law there is in addition the clause DFARS 252.223-7008 set out in section 18, which attaches to the supply and not to the exposure.

What the four legal systems have in common

The points of attachment lie consistently before the damage. Germany sanctions the missing documentation, the taking up of the activity without an assessment and the omitted check on effectiveness, and makes the endangerment of life or health a criminal offense. The Netherlands penalize non-compliance with the duties by a fine and make criminal the act or omission of which the employer knows or must reasonably know that danger to life or serious damage to health arises or is to be expected from it. The United Kingdom attaches to the breach of the Regulations. The United States attach to the breach of the standard and raise the range in cases of intent and repetition.

For the matter dealt with here, a clear evidential position follows from this. Since the protective measures under the German TRGS 561 already apply where chromium(VI) contamination cannot be ruled out (Section 6), and since a negative measurement result without a statement of the recovery rate on the same matrix permits no conclusion as to the content (Section 17), what decides a dispute is not the measurement but the documentation: whether a risk assessment exists that covers the material pairing of chromium-alloyed hot component and basic insulation material, whether the substitution check was carried out and reasoned, and whether the effectiveness of the measures taken has been verified.

A missing or incorrect assessment of a chromium(VI) exposure is therefore not a marginal question of works organization in any of the four legal systems. It carries a fine, at the upper end a criminal penalty, and in the event of damage it triggers the recourse of the social insurance institution.

31. On the choice of the regulations cited

This analysis frequently cites German regulations, in particular the TRGS 561 and the Hazardous Substances Ordinance. There are two reasons for this. I work from Germany, together with a further chromate expert who is active in occupational safety and environmental protection. And the German TRGS 561 expressly describes the application case dealt with here, with thermally stressed chromium-alloyed industrial components, with alkali and alkaline earth metal oxides from insulation materials and assembly pastes, and with a catalogue of measures of its own. [19] This edition keeps those regulations as the benchmark and sets out, in Sections 33 to 36, the duties in the United States, in California and in Canada and what the North American documents of the manufacturers concerned say.

It does not thereby set stricter standards than European law. It spells out the approach of Directive 2004/37/EC for this case. For more than twenty years the Directive has required that, in all activities with the possibility of exposure, the nature, degree and duration of the exposure be determined, taking into account the further routes of exposure including absorption into or through the skin. It applies in all Member States. [18]

In practice the assessment relies predominantly on air measurements, because the binding values are laid down as air concentrations. For the hazard from skin contact, Germany has in the TRGS 401 an assessment procedure of its own, which stands alongside air measurement. [99]

In this respect chromium(VI) compounds are unusual. The MAK and BAT value list 2026 gives them the skin absorption marking H, the sensitization marking Sh, carcinogenicity category 1 and germ cell mutagenicity category 2. Under table 2 of the German TRGS 401, the combination of skin absorption and classification as carcinogenic category 1 gives a high hazard for every type of contact, with no threshold for duration or area. Calcium and sodium chromate are in addition classified as very toxic to aquatic life with long lasting effects. Four levels of assessment therefore stand side by side, inhalation, dermal, oral and environmental. Asbestos carries neither a skin-related hazard statement nor a hazard to water. [102, 99, 98]

For air measurement a practical limit follows from this. Pockets of chromate-containing dust in insulation, at flanges and in cavities are released only when they are handled. A general measurement of room air does not capture them. The German TRGS 561 therefore starts from the activity in section 5.9.3 paragraph 5 and requires the minimization of dust generation and dust spread, extending to the covering of grating, together with a type 5 chemical protective suit with hood, nitrile-coated textile gloves, eye protection, respiratory protection of at least FFP2 and, for activities of longer duration, half masks with P3 filters, as well as the disposal of contaminated disposable protective clothing. [19]

The same applies to chromate-containing ashes during overhaul inside incineration furnaces. Scaffolding is erected there, and the stainless steel components of the grate are not only walked on and inspected, but also surface treated, removed and replaced. From my own field work, elevated air contamination from chromium(VI) compounds during such work is known; the associated measured values are not public and are not reproduced here.

A single measurement is in any case not a suitable yardstick there, neither for exoneration nor for incrimination. The content of basic oxides in the material burned fluctuates, and it is not determined by the waste composition alone. Paoletti states the calcium oxide content in household waste as around 3 percent and on this basis describes the formation of calcium chromate between 500 and 850 °C where the oxygen partial pressure is sufficient. In addition there is the addition of calcium-bearing sorbents in plant operation. With conditioned dry sorption this takes place downstream of the boiler, at flue gas temperatures of about 130 to 150 °C, with spray absorption using milk of lime between 140 and 200 °C, and thus outside the formation window. With direct desulfurization, by contrast, calcium hydroxide or limestone powder is introduced into the combustion chamber at about 900 °C or into the downstream boiler passes at about 350 °C, in the documented application at dosing rates of 140 to 375 kilograms per hour. For the assessment of an overhaul it therefore has to be established which desulfurization process the plant runs and at which point the sorbent is introduced. [50, 149, 150]

What the air measurement does not represent: the hand finding of the French field study

The French field study measures not only surfaces but also hands. Before removal the value lay below the limit of quantification of 40 ng, after removal at 45.4 ng, and the authors expressly record the contamination of the hands despite the disposable nitrile gloves worn. Disposable half masks FFP3 and a type 5 working coverall were worn in addition. In the same run the air values remained low, and the urine values of the eleven mechanics examined averaged 0.26 µg per gram of creatinine and thus lay below the biological reference value of 0.54. In this constellation the dermal exposure is represented neither by the air measurement nor by the biomonitoring. [5]

The glove is not the weak point here. The nitrile glove separates the skin from the substance; what remains open is the sleeve end, through which dust enters, and the moment of taking the gloves off, in which the contaminated outer side touches the palm. In practice the transition between glove and suit sleeve is therefore taped, as is the transition between suit and footwear. In protective suits of types 5 and 6, sealed seams and covered fastenings are among the product features, and the two taped transitions close the places that the product itself cannot close. The German DGUV Rule 112-189 states on this in general terms that only closed clothing fulfils the protective function, and for the risk of contamination it lists tightness as a requirement on the protective clothing. The authors of the French study draw the same direction from their finding and expressly recommend improving the protocols for removing personal protective equipment and for hand washing before and after wearing it. [5, 133]

The same investigation found traces of chromium(VI) of 0.01 to 0.2 mg/kg in the insulation materials sampled, and in one sample ceramic refractory fibers, which are classified as carcinogenic category 1B by inhalation. The remaining samples consisted of glass or silicate fibers. [5]

The direction of developments is shown by Australia. From 1 December 2026, Safe Work Australia will no longer set workplace exposure limits for non-threshold genotoxic carcinogens, chromium(VI) compounds included. The exposure limit is replaced by the obligation to eliminate exposure or to minimize it so far as is reasonably practicable. [58]

32. Order of magnitude: a thought experiment

This section does not calculate how many installations are contaminated. That figure has not been collected anywhere, and any statement about it would be invented. What is calculated is how often the situation arises in which it would have to be examined whether a chromium(VI) contamination can be ruled out. The population figures come from public manufacturer data, from fleet statistics and from plant registers. The conversions and interval assumptions are marked in the text.

Population figures from public sources

For the 3500 series, Caterpillar states a field population of 190,000 engines and 3 billion operating hours, with more than 35 years of production, with applications in mining, rail, power generation, oil and gas and shipping. As at September 2016. [134]

For the mtu series 2000 and 4000, Rolls-Royce Power Systems names more than 100,000 engines sold, of which 52,000 of the 4000 series and more than 65,000 of the 2000 series, together more than 320 million operating hours, with applications in generating sets, dump trucks, yachts, ferries and locomotives. As at 2021. [135]

INNIO reports an active installed base of the Jenbacher and Waukesha brands of around 44 GW as at 31 December 2025, after 42 GW in the previous year, with 3.4 GW delivered in 2025. The company does not give unit numbers. At an assumed average unit output of 1.0 to 1.5 MW, that corresponds to 29,000 to 44,000 engines. [136]

On its own product page, GE Vernova names more than 7,000 gas turbines with more than 800 GW of installed capacity in over 120 countries and states that it accounts for approximately half of the installed gas turbine base worldwide. This gives a worldwide fleet of the order of 14,000 gas turbines. Individual series for comparison: 7F with more than 950 installed units and around 175 GW, 9F with more than 400 units in more than 40 countries, LM6000 with more than 1,500 units sold. [138]

The Global Coal Plant Tracker reports more than 2,200 GW of coal capacity in operation, with a reporting threshold of 30 MW. At an average unit size of 300 MW, that amounts to around 7,300 units with a steam turbine and with live steam and reheater lines made of creep-resistant chromium-alloyed steels. The Global Oil and Gas Plant Tracker lists 16,559 oil and gas power plant units, including planned and retired ones, with a reporting threshold of 50 MW and, in the European Union and the United Kingdom, of 20 MW. [139, 140]

The world merchant fleet comprises around 109,000 ships of 100 gross register tons and above, each with an insulated exhaust system for main and auxiliary engines. [141]

For the European Union, the ACEA reports 6,162,673 trucks over 3.5 tonnes with a diesel share of 96.3 percent and 699,238 buses with 88.7 percent, with an average age of the truck fleet of 14.0 years. For Europe including EFTA and the United Kingdom the figures are 7,072,260 trucks and 852,180 buses, plus 302,281,600 passenger cars. The average age points to the Euro V and Euro VI emission stages, that is, to vehicles with an oxidation catalyst, a particulate filter and an SCR section, all of them insulated hot components made of chromium-alloyed steel. [142]

In waste incineration, Europe lists 498 plants, as at 2022, among them France 116, Germany 91, the United Kingdom 57, Italy 36 and the Netherlands 12. For the United States, 75 plants are reported. At the end of 2023, China operated 975 plants with 2,151 incineration lines and a capacity of 327 million tonnes per year. In the 2024 financial year, Japan listed 991 plants, 415 of them with power generation. In these four regions together that comes to 2,539 plants. Applying the Chinese ratio of 2.2 lines per plant, the number of incineration lines is around 5,600. [144, 145, 146, 147]

Occasions per year

For gas engines, a Jenbacher service company names intermediate maintenance every 10,000 operating hours and overhauls at 30,000 and 60,000 operating hours. At a conservatively assumed 5,000 operating hours per year, that gives one overhaul every six years, and thus 4,800 to 7,300 events per year for the fleet named above. [148]

For coal fired units, an overhaul every two years gives around 3,650 events per year. For incineration lines, one overhaul per line and year gives around 5,600 events. For ships, one measure on the exhaust section every two and a half years gives around 44,000 events. For commercial vehicles in the European Union, one workshop visit per vehicle and year gives around 6.9 million visits, and at 250 working days about 27,000 per working day.

For passenger cars, Deutsche Automobil Treuhand reports 0.35 repairs per vehicle and year; in 2022 the figure was 0.40 and in 2019 still 0.51; maintenance and inspections are not included in this figure. Related to the 255,999,373 passenger cars in the European Union, that amounts to around 90 million repairs per year, or 358,000 per working day. What share of these involves the engine compartment or the exhaust system has not been collected. [143, 142]

The assumptions in this section

The assumptions made are an average unit output for gas engines, an average unit size for coal fired power plants, the number of incineration lines per plant outside China, the annual operating hours, the overhaul interval for power plants, incineration lines and ships, and the workshop frequency for commercial vehicles. The manufacturer figures from Caterpillar and Rolls-Royce are cumulative field and sales figures and not an active fleet. Not every application named carries insulation in the temperature window concerned. The segments are not added together, because they have different counting units and overlap; the marine engines, for example, are already partly included in the manufacturer figures.

What follows from this

The events assumed in the four industrial segments add up to about 58,000 to 61,000 per year, before any deduction for the overlaps. In addition there are around 6.9 million workshop visits for commercial vehicles and around 90 million passenger car repairs in the European Union, whose relevant share is not quantified.

What is up for assessment is therefore not an isolated occurrence. The release takes place daily, in engine compartments, on vehicles, on turbines, in power plants and in incineration plants, in a number that cannot be quantified, and for the most part unnoticed. It is triggered by the substance that gives this analysis its title.

In Germany, each of these occasions would be an activity within the meaning of section 5.9.3 paragraph 5 of the German TRGS 561. In the other legal systems considered, the duty of assessment before work begins follows from the provisions named in section 25. None of these bodies of rules contains a threshold below which the protective regime would not apply. An exclusion of the contamination cannot be demonstrated reliably with the widespread methods, because the colorimetric rapid test can come out false negative and no standardized method exists for the insulation material matrix (Sections 17 and 19). [19]

33. The duties in the United States

Section 31 names the reasons why this analysis cites German regulations. For companies in the United States that names the benchmark, not the applicable order. Directive 2004/37/EC and the German Hazardous Substances Ordinance do not apply there, and a body of rules that names the case dealt with here, as the German TRGS 561 does under 5.9.3, does not exist. The duties follow from the Occupational Safety and Health Act and from three standards issued under it, and they are framed without naming this case. [151, 153]

The statutory base and the general duty clause

Section 5(a) of the Occupational Safety and Health Act of 1970 contains two duties. Under number 1 the employer "shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees", and under number 2 he "shall comply with occupational safety and health standards promulgated under this Act". [151]

For chromium(VI) the second of these is the operative duty, because a standard exists. The Field Operations Manual of the Occupational Safety and Health Administration states the limit expressly: "The general duty clause shall be used only where there is no standard that applies to the particular hazard and in situations where a recognized hazard is created in whole or in part by workplace conditions or practices that are not covered by a standard." The exposure as such is covered by a standard, so it is not the general duty clause that applies to it. [152]

The general duty clause nevertheless matters here, because of the term recognized hazard and what the same manual says about it. Four elements must be established: that the employer failed to keep the workplace free of a hazard to which his employees were exposed, that the hazard was recognized, that it was causing or was likely to cause death or serious physical harm, and that "There was a feasible and useful method to correct the hazard." Recognition "can be established on the basis of employer recognition, industry recognition, or "common-sense" recognition". [152]

Among the means by which industry recognition can be established, the manual lists "Manufacturers' warnings on equipment or in literature that are relevant to the hazard", alongside statements by safety or health experts familiar with the relevant conditions, evidence that other members of the industry have implemented abatement methods, and studies conducted by the industry. The documents evaluated in Section 16 are warnings of precisely that class, issued by manufacturers of engines, trucks, insulation materials, gaskets and refractory products between 1990 and 2025. Whether they establish recognition in a particular employer's relevant industry is a question of assessment in the individual case. That the manual names this class of document as a means of establishing it is not. [152]

The manual also provides for the case in which the harm appears only later. Where illness or death will occur only after the passage of time, it requires that regular and continuing employee exposure at the measured levels could reasonably occur, that an illness reasonably could result from such exposures, and that "If illness does occur, its likely result is death or serious physical harm." American practice therefore has a construction for a latency of years, as the German endangerment offense described in Section 30 does. [152]

The standard applies without anyone naming the source

The scope of 29 CFR 1910.1026 is set in paragraph (a)(1): "This standard applies to occupational exposures to chromium (VI) in all forms and compounds in general industry, except:". The exceptions are the application of pesticides, exposures to portland cement, and the case in paragraph (a)(4), where the employer has objective data showing that a material or a process "cannot release dusts, fumes, or mists of chromium (VI) in concentrations at or above 0.5 µg/m3 as an 8-hour time-weighted average (TWA) under any expected conditions of use". [153]

Two things follow from this wording. Chromate that forms at the interface between insulation material and a chromium-alloyed hot component is chromium(VI) in a form and a compound, so the standard covers it by its own scope, whether or not anyone has identified it. And the only route out of the standard runs through objective data covering every expected condition of use. For a compound that forms in service, such data would have to cover the formation itself. The manufacturer documents evaluated in Section 16 and the interface evidence in Section 10 point the other way. [153]

An employer who has never asked whether chromium(VI) forms on his insulated hot components is therefore not outside the standard. He is inside it without having determined his exposures.

Three standards, one limit value

Hexavalent chromium was regulated in the United States by a single final rule, published at 71 Federal Register 10100 on 28 February 2006 and effective on 30 May 2006, which created three standards: 29 CFR 1910.1026 for general industry, 29 CFR 1915.1026 for shipyard employment, marine terminals and longshoring, and 29 CFR 1926.1126 for construction. [156, 153, 154, 155]

All three set the same limit value. Paragraph (c) of each reads: "The employer shall ensure that no employee is exposed to an airborne concentration of chromium (VI) in excess of 5 micrograms per cubic meter of air (5 µg/m3), calculated as an 8-hour time-weighted average (TWA)." The definition in paragraph (b) sets the action level: "Action level means a concentration of airborne chromium (VI) of 2.5 micrograms per cubic meter of air (2.5 µg/m3) calculated as an 8-hour time-weighted average (TWA)." [153, 154, 155]

In the comparison in Section 18 the American permissible exposure limit of 5 µg/m³ is the same figure as the European limit value of 0.005 mg/m³ that has applied since 17 January 2025. It is five times the French and Dutch value of 0.001 mg/m³ and five times the assessment benchmark of the German TRGS 561. Within North America, the Quebec value for water-insoluble chromium(VI) compounds is likewise 0.001 mg/m³. [153, 175, 170]

Exposure determination and the objective data option

Paragraph (d)(1) of all three standards reads: "Each employer who has a workplace or work operation covered by this section shall determine the 8-hour TWA exposure for each employee exposed to chromium (VI). This determination shall be made in accordance with either paragraph (d)(2) or paragraph (d)(3) of this section." Paragraph (d)(2)(i), the scheduled monitoring option, requires initial monitoring "on the basis of a sufficient number of personal breathing zone air samples to accurately characterize full shift exposure on each shift, for each job classification, in each work area". Paragraph (d)(3), the performance-oriented option, permits the determination "on the basis of any combination of air monitoring data, historical monitoring data, or objective data sufficient to accurately characterize employee exposure to chromium (VI)". [153, 155]

Section 17 of this analysis bears directly on both options. For insulation material matrices there is no standardized method, transferred procedures give results that are too low, and a result without a statement of the recovery rate on the same matrix says nothing about the content. Historical data and objective data obtained in that way carry the same defect as a measurement obtained in that way. The performance-oriented option is therefore the point at which the analytical problem becomes a compliance problem.

One difference between the standards concerns the notification of results. In general industry the employer has 15 work days; in shipyard employment and in construction paragraph (d)(4)(i) requires notification "Within 5 work days after making an exposure determination". [153, 154, 155]

Regulated areas, housekeeping and the compressed air prohibition exist only in general industry

Paragraph (e)(1) of the general industry standard requires: "The employer shall establish a regulated area wherever an employee's exposure to airborne concentrations of chromium (VI) is, or can reasonably be expected to be, in excess of the PEL." Paragraph (j)(1) requires that "All surfaces are maintained as free as practicable of accumulations of chromium (VI)" and that "All spills and releases of chromium (VI) containing material are cleaned up promptly". Paragraph (j)(2)(iii) prohibits the use of compressed air to remove chromium(VI) from any surface unless it is used together with a ventilation system designed to capture the dust cloud created, or no alternative method is feasible. [153]

Neither the shipyard standard nor the construction standard contains a counterpart to either paragraph. In 29 CFR 1915.1026 and 29 CFR 1926.1126 the lettering runs from scope and definitions through the limit value, exposure determination, methods of compliance, respiratory protection, protective work clothing, hygiene areas, medical surveillance, hazard communication and recordkeeping to the dates, with no paragraph on regulated areas and no paragraph on housekeeping. [154, 155]

For the work described in this analysis that gap is not a formality. Ship engines, boiler and pipework insulation on board, and the dismantling of insulated hot components during an overhaul fall under the shipyard standard, where no zoning requirement, no duty to keep surfaces free of accumulations and no prohibition on blowing down with compressed air applies. Carry-over out of the working area, which Section 22 describes, is precisely the mechanism that these three provisions address in general industry.

Protective clothing, hygiene and medical surveillance

Paragraph (h)(1) requires: "Where a hazard is present or is likely to be present from skin or eye contact with chromium (VI), the employer shall provide appropriate personal protective clothing and equipment at no cost to employees, and shall ensure that employees use such clothing and equipment." Paragraph (i)(1) requires change rooms where protective clothing is required and washing facilities where skin contact occurs, in each case in conformance with 29 CFR 1910.141. Paragraph (i)(2) requires that change rooms have separate storage for protective clothing and for street clothes and that these facilities "prevent cross-contamination", and paragraph (i)(3)(i) requires "readily accessible washing facilities capable of removing chromium (VI) from the skin". [153]

The dermal route is thus covered in substance. The threshold at which it is covered is the one set by paragraph (h)(1), that is, a hazard that is present or likely to be present from skin contact. Whoever has not determined whether chromium(VI) is on the surface of the component has not reached that question either.

Medical surveillance is tied to the action level. Paragraph (k)(1)(i) requires it for all employees "Who are or may be occupationally exposed to chromium (VI) at or above the action level for 30 or more days a year", for those experiencing signs or symptoms of the adverse health effects associated with chromium(VI) exposure, and for those exposed in an emergency. Paragraph (k)(3) sets out the contents, among them a medical and work history "with emphasis on: Past, present, and anticipated future exposure to chromium (VI); any history of respiratory system dysfunction; any history of asthma, dermatitis, skin ulceration, or nasal septum perforation; and smoking status and history" and a physical examination of the skin and the respiratory tract. [153]

The chain is therefore closed in one direction and open in the other. Where exposure has been determined, the standard sets out what has to follow. Where it has not been determined, the thirty days above the action level are never counted, and the surveillance that the finding would trigger never begins.

No duty to substitute

Paragraph (f)(1)(i) of the general industry standard sets the order of measures: "Except as permitted in paragraph (f)(1)(ii) and paragraph (f)(1)(iii) of this section, the employer shall use engineering and work practice controls to reduce and maintain employee exposure to chromium (VI) to or below the PEL unless the employer can demonstrate that such controls are not feasible. Wherever feasible engineering and work practice controls are not sufficient to reduce employee exposure to or below the PEL, the employer shall use them to reduce employee exposure to the lowest levels achievable, and shall supplement them by the use of respiratory protection that complies with the requirements of paragraph (g) of this section." Paragraph (f)(2) adds: "The employer shall not rotate employees to different jobs to achieve compliance with the PEL." [153]

The word substitution does not occur in 29 CFR 1910.1026, nor in 29 CFR 1915.1026, nor in 29 CFR 1926.1126. There is no provision requiring the employer to examine whether the substance or the process can be replaced, and none that would call for a reason to be given where it is not replaced. [153, 154, 155]

That is the central difference from every other body of rules dealt with in this analysis. Section 7 paragraphs 3 and 4 of the German Hazardous Substances Ordinance give priority to substitution; Article 4 of Directive 2004/37/EC requires replacement as far as technically possible; Article 4.17 of the Dutch Arbeidsomstandighedenbesluit requires it so far as technically feasible; Regulation 7(2) of the British COSHH Regulations states that "substitution shall by preference be undertaken"; and within North America, Section 5.57(1) of the Occupational Health and Safety Regulation of British Columbia requires, for substances carrying the ACGIH A1 or A2 or the IARC 1, 2A or 2B notation, that the employer "must replace it, if practicable, with a material which reduces the risk to workers". [153, 172]

The consequence for insulated hot components is plain. Under American federal rules the formation may continue indefinitely, lawfully, as long as the exposure is kept below the permissible exposure limit. The order of measures addresses the exposure; the material cause is left untouched. Where the insulation containing calcium or sodium stays on the chromium-alloyed hot component, the chromate forms again at the next thermal load, and the standard has nothing to say about that cycle.

Hazard communication: the reaction products of anticipated use

Paragraph (l)(1) of the chromium(VI) standard refers to the Hazard Communication Standard: "Chemical manufacturers, importers, distributors and employers shall comply with all requirements of the Hazard Communication Standard (HCS) (§ 1910.1200) for chromium (VI)." Sub-paragraph (ii) requires that at least cancer, eye irritation and skin sensitization be addressed in classifying the hazards of chromium(VI). [153]

The scope of the Hazard Communication Standard is set in paragraph (b)(2): "This section applies to any chemical which is known to be present in the workplace in such a manner that employees may be exposed under normal conditions of use or in a foreseeable emergency." The classification duty is in paragraph (d)(1), which requires chemical manufacturers and importers to evaluate the chemicals they produce or import and states that the classification "shall include any hazards associated with the chemical's intrinsic properties including: (i) A change in the chemical's physical form; and (ii) Chemical reaction products associated with known or reasonably anticipated uses or applications". [157]

That second item is the provision that fits the case dealt with here most closely of any in the standard. The formation of calcium and sodium chromate at the interface with a chromium-alloyed hot component is a chemical reaction product of an anticipated use of a high-temperature insulation material. The definitions point the same way: "Produce means to manufacture, process, formulate, blend, extract, generate, emit, or repackage." and "Use means to package, handle, react, emit, extract, generate as a byproduct, or transfer." [157]

The duties themselves are divided by paragraph (g)(1): "Chemical manufacturers and importers shall obtain or develop a safety data sheet for each hazardous chemical they produce or import. Employers shall have a safety data sheet in the workplace for each hazardous chemical which they use." Paragraph (g)(5) requires that where the preparer "becomes newly aware of any significant information regarding the hazards of a chemical, or ways to protect against the hazards, this new information shall be added to the safety data sheet within three months". The transmission duties in paragraphs (g)(6) and (g)(7) are framed in terms of shipment and of sale. [157]

The structure is therefore the same one that Section 25 describes for the European instruments, in American wording. Everything that informs attaches to a product that someone places on the market. A compound that comes into being at the customer's plant after delivery has no supplier, no label and no safety data sheet, and the classification duty that would reach it sits with the manufacturer of the material from which it forms. What the North American sheets of those manufacturers say is set out in Section 36. [157]

Waste: a characteristic without speciation

Waste classification runs through the toxicity characteristic. 40 CFR 261.24(a) provides that a solid waste exhibits the characteristic of toxicity if, using "the Toxicity Characteristic Leaching Procedure, test Method 1311" of EPA Publication SW-846, the extract from a representative sample contains any of the contaminants listed in Table 1 at or above the value given there. Table 1 contains a single chromium row: EPA Hazardous Waste Number D007, contaminant Chromium, CAS number 7440-47-3, regulatory level 5.0 mg/L. [158, 159]

Neither the section nor the table distinguishes oxidation states. The words hexavalent and trivalent do not occur in 40 CFR 261.24. The regulatory level applies to leachable chromium as such. The question of valence, on which the occupational hazard and the whole of this analysis turn, is not asked by the waste test, and a removed insulation bearing chromate can pass or fail the characteristic on its leachable total chromium irrespective of which compound is present. [158]

The determination itself lies with the generator. 40 CFR 262.11 provides that a person who generates a solid waste "must make an accurate determination as to whether that waste is a hazardous waste", and paragraph (a) requires that determination to be made "at the point of waste generation, before any dilution, mixing, or other alteration of the waste occurs". Paragraph (d)(1) permits the determination on knowledge, which "may include process knowledge (e.g., information about chemical feedstocks and other inputs to the production process); knowledge of products, by-products, and intermediates produced by the manufacturing process", while paragraph (d)(2) requires testing "When available knowledge is inadequate to make an accurate determination". [160]

Process knowledge is thus an admissible basis, and it is the basis on which a maintenance operation is in practice assessed. For insulated chromium-alloyed hot components the process knowledge that matters is the one this analysis sets out: a basic oxide in contact with a chromium oxide layer above the formation temperature. Where that knowledge is absent, paragraph (d)(2) requires testing, with the matrix problem of Section 17 attached to it.

One further boundary belongs here. Under paragraph (b)(6)(i) of the Hazard Communication Standard, hazardous waste subject to regulation by the Environmental Protection Agency is excluded from that standard. The material therefore passes from one regime into another at the moment it becomes waste, and in neither of them does anyone ask which chromate is present. [157, 158]

The asbestos comparison in American law

How much procedural depth American law gives a named substance is shown by 29 CFR 1926.1101. The standard works with a presumption: "Presumed Asbestos Containing Material means thermal system insulation and surfacing material found in buildings constructed no later than 1980." It works with four classes of work, among them Class III, "repair and maintenance operations, where "ACM", including TSI and surfacing ACM and PACM, is likely to be disturbed". And it works with a competent person, defined as one "who is capable of identifying existing asbestos hazards in the workplace and selecting the appropriate control strategy for asbestos exposure, who has the authority to take prompt corrective measures to eliminate them", trained for Class I and II work in a course meeting the criteria of the Model Accreditation Plan of the Environmental Protection Agency. [161]

The assessment comes before the work. Paragraph (f)(2)(i) requires that a competent person conduct an exposure assessment "immediately before or at the initiation of the operation", completed in time to comply with the requirements triggered by the exposure data or by the lack of a negative exposure assessment. And the duty does not rest on the contractor alone. Paragraph (k)(2)(i) provides: "Before work subject to this standard is begun, building and facility owners shall determine the presence, location, and quantity of ACM and/or PACM at the work site". The presumption may be rebutted under paragraph (k)(5), by an inspection under the Asbestos Hazard Emergency Response Act or by bulk sampling carried out by an accredited inspector or a certified industrial hygienist, and the data relied on must be retained. [161]

Two things this standard does not contain should be said plainly, because the German comparison in Section 25 does contain them. 29 CFR 1926.1101 has no duty to notify an authority before the work begins, and it requires no license for the contracting undertaking as such; its accreditation requirements attach to persons and to training courses. Requirements of that kind exist in the United States outside this standard, in the asbestos regulations of the Environmental Protection Agency and in state licensing programs, which are not evaluated here. [161]

For chromium(VI) none of it exists. There is no presumption rule for a material pairing, no class system graded by the kind of work, no competent person with a prescribed course, no duty of the plant owner to determine the presence of the substance before the work, and no assessment that a defined person has to carry out before the operation begins. The chromium(VI) standard requires the employer to determine exposures and to control them. It does not require anyone to find out first whether the substance is there. [153, 161]

What exists in the United States and what is missing

What exists is a standard with a limit value, an action level, an exposure determination, a hierarchy of engineering and work practice controls, protective clothing, change rooms and washing facilities, medical surveillance, hazard communication, recordkeeping, and for general industry regulated areas, housekeeping and the compressed air prohibition. What exists on top of that is a classification duty of the manufacturer that covers the reaction products of anticipated use, a waste determination resting on process knowledge, and the procurement clause set out in Section 18.

What is missing is any trigger that starts the chain. No provision requires the employer to examine whether chromium(VI) forms on his own installation; no provision obliges the plant owner to determine its presence before maintenance; no provision requires the substitution of the material that supplies the reaction partner; and no publication of the Occupational Safety and Health Administration or of the National Institute for Occupational Safety and Health names the formation of chromates on insulated chromium-alloyed hot components. I have not found such a publication. That is not a statement about whether the process occurs in American plants.

Conclusion for companies in the United States

The scope of 29 CFR 1910.1026 is not conditional on anyone having named the source. Where chromium(VI) is present on a surface that employees work on, the standard applies, the exposure determination under paragraph (d) is owed, and the one way out leads through objective data covering every expected condition of use. Whoever relies on the absence of a rule naming the case is relying on the absence of a designation, not on the absence of a duty. And whoever intends to rely on paragraph (a)(4) needs data on a matrix for which, as Section 17 sets out, no standardized method exists. [153]

34. California

California deserves its own section because four instruments apply there side by side, and because the groundwater case that made chromium(VI) publicly known, Hinkley, is described in Section 24.

Proposition 65: the warning duty and who enforces it

The Safe Drinking Water and Toxic Enforcement Act of 1986 provides in section 25249.6 of the Health and Safety Code: "No person in the course of doing business shall knowingly and intentionally expose any individual to a chemical known to the state to cause cancer or reproductive toxicity without first giving clear and reasonable warning to such individual, except as provided in Section 25249.10." [162]

Hexavalent chromium appears twice on the list maintained by the Office of Environmental Health Hazard Assessment, which is published in section 27001 of Title 27 of the California Code of Regulations. The entry "Chromium (hexavalent compounds)" carries the toxicity type cancer with the listing date 27 February 1987, and a second entry of the same name carries developmental toxicity, female reproductive toxicity and male reproductive toxicity with the listing date 19 December 2008. Neither entry gives a CAS number, because the listing covers several substances. [163]

The levels below which no warning is required are set in regulation. Section 25705(b)(1) of Title 27 gives the No Significant Risk Level for chromium (hexavalent compounds) as 0.001 micrograms per day by inhalation, and section 25805(b) gives the Maximum Allowable Dose Level as 8.2 micrograms per day by the oral route. The inhalation figure is the lowest regulatory quantity that appears anywhere in this analysis. [164]

Enforcement does not depend on an authority taking the matter up. Section 25249.7(b)(1) provides a civil penalty "not to exceed two thousand five hundred dollars ($2,500) per day for each violation", and section 25249.7(d) permits actions "by a person in the public interest" where notice has been given more than sixty days earlier to the Attorney General and to the local prosecutor and to the alleged violator, and where a certificate of merit executed by the noticing party or its attorney accompanies the notice, confirming consultation with one or more persons with relevant experience and the belief that there is "a reasonable and meritorious case for the private action". [162]

For the case dealt with here the significance of this instrument lies in what it does not require. It does not ask where the compound came from, it does not ask whether anyone placed it on the market, and it does not ask for a limit value in air to have been exceeded. It attaches to the knowing and intentional exposure of an individual, with a reference quantity of 0.001 micrograms per day by inhalation, and it can be enforced by any person in the public interest. [162, 164]

Cal/OSHA: the state standard and a reporting duty

California operates one of the state plans approved by the federal Occupational Safety and Health Administration. There are at present 22 such plans covering both the private sector and state and local government workers, and seven covering state and local government workers only. [165]

The Californian chromium(VI) standard is section 5206 of Title 8 of the California Code of Regulations, headed "Chromium (VI)" and placed in Article 110, Regulated Carcinogens. Its permissible exposure limit and its action level are worded as in the federal standard. It adds, in subsection (o), a reporting requirement: "Reporting requirements. See Section 5203." Section 5203 is headed "Carcinogen Report of Use Requirements" and provides in subsection (a): "All employers who use a regulated carcinogen shall report that use in writing to the Chief as required by this section." [166, 167]

That duty has no counterpart in the federal standard. It is directed at the use of a regulated carcinogen, and it turns on the same question as the European use concept in Section 25: whether the handling, storing and reinstalling of a chromate-bearing component is a use of the substance.

Drinking water: 10 micrograms per liter, with a history

Since 1 October 2024 California has had a maximum contaminant level for hexavalent chromium in drinking water. Table 64431-A in section 64431 of Title 22 of the California Code of Regulations gives it as "Chromium (hexavalent) 0.010", that is 10 micrograms per liter. The State Water Resources Control Board adopted the regulation by Resolution 2024-0015 on 17 April 2024; the Office of Administrative Law approved it on 24 July 2024, and the effective date was 1 October 2024. Compliance dates are staggered by the size of the system, beginning on 1 October 2026 for systems with 10,000 or more service connections. Before that date hexavalent chromium was covered by the total chromium limit of 50 micrograms per liter, which remains in force. [168]

The history belongs to the picture. A limit value of the same figure had already been adopted in April 2014, approved on 28 May 2014 and in force from 1 July 2014. On 31 May 2017 the Superior Court of Sacramento County invalidated it on the ground that the regulation had failed properly to consider the economic feasibility of compliance. By its own account the court made no finding on whether the limit value protected public health, and reached no conclusion on whether it was too low or too high. The Water Board then deleted the regulation text by Resolution 2017-0045 of 1 August 2017, and the state had no separate limit value for hexavalent chromium for seven years. [169]

Two observations follow, and both bear on the subject of this analysis. A figure of 10 micrograms per liter in drinking water, next to a No Significant Risk Level of 0.001 micrograms per day by inhalation, next to a workplace limit value of 5 micrograms per cubic meter, shows how far the regulatory quantities for one and the same substance lie apart once the pathway changes. And the ground on which the first limit value fell was not the toxicology but the cost of compliance.

35. Canada

Canada is treated here in brief, because the same installations and vehicles are operated and maintained there, because the same European manufacturers supply the market, and because the Canadian rules answer the substitution question differently from the American ones. Occupational safety is a provincial matter apart from federally regulated undertakings.

Quebec sets the strictest values in North America. Schedule I to the Regulation respecting occupational health and safety gives, for water-insoluble inorganic chromium(VI) compounds expressed as Cr, a time-weighted average exposure value of 0.001 mg/m³, and for water-soluble inorganic chromium(VI) compounds 0.005 mg/m³. Both entries carry the designation C1, "carcinogenic effect detected in humans", and the designation EM, which marks "A substance to which exposure must be reduced to a minimum in accordance with section 42". Section 42 reads: "Carcinogenic and isocyanate substances: When a worker is exposed to a substance identified in Schedule I as having a known or suspected carcinogenic effect on humans or being diisocyanate or isocyanate oligomers, such exposure shall be reduced to a minimum, even when it remains within the standards in that Schedule." Section 39 requires, as far as possible, the replacement of dangerous substances that are sources of dusts, fumes, mists, vapors or gases. [170]

Ontario does not list chromium in its own table. Section 4 paragraph 2 of Regulation 833 under the Occupational Health and Safety Act directs that where an agent is not in the Ontario Table but is in the table of the American Conference of Governmental Industrial Hygienists, exposure shall not exceed the values set out there. The consolidated table of the provincial ministry accordingly gives water-soluble chromium(VI) compounds as Cr at 0.05 mg/m³ and insoluble chromium(VI) compounds at 0.01 mg/m³, each as an eight-hour average, with the excursion limits of paragraph 3 applying because no short-term or ceiling value is set. Section 3 paragraph 2 of the same regulation lists the measures to be taken and names substitution first. [171]

British Columbia has the provision that the American standards lack. Section 5.57(1) of the Occupational Health and Safety Regulation provides that where a substance carrying the ACGIH A1 or A2 notation or the IARC 1, 2A or 2B notation is present in the workplace, "the employer must replace it, if practicable, with a material which reduces the risk to workers", and where that is not practicable, subsection (2) requires an exposure control plan keeping exposure as low as reasonably achievable below the exposure limit. Both chromium(VI) entries in the WorkSafeBC table of exposure limits carry A1 and 1, so the provision applies to them; the limits are 0.01 mg/m³ for insoluble and 0.025 mg/m³ with a ceiling of 0.1 mg/m³ for water-soluble compounds, with dermal and respiratory sensitizer notations. Section 5.55(1) sets out the general order of measures, with substitution first. [172]

Safety data sheets follow the Hazardous Products Regulations made under the Hazardous Products Act, which implement the Workplace Hazardous Materials Information System. Item 10 of Schedule 1 to those regulations requires, under the heading "Stability and reactivity", the reactivity, the chemical stability, the "possibility of hazardous reactions", the conditions to avoid, the incompatible materials, and the "hazardous decomposition products". What the Canadian-format sheets of the manufacturers concerned enter under that item is set out in Section 36. [173]

For federally regulated undertakings the Canada Occupational Health and Safety Regulations add a general provision under the heading "Substitution of Substances", section 10.16: "No person shall use a hazardous substance in a work place if a non-hazardous substance or one that is less hazardous can be used instead." [174]

The result for North America is uneven. The United States have the broadest standard and no substitution duty. Quebec has the lowest limit value and a duty to minimize. British Columbia has a substitution duty keyed to carcinogenicity. Ontario reaches its values by reference to a private body of recommendations. None of these jurisdictions names the formation of chromates on insulated chromium-alloyed hot components.

36. Warnings in North America: what the same manufacturers do and do not say

Section 16 evaluates manufacturer and operator documents that describe the formation pathway. Most of them are European or are addressed to a European market. The question for this edition is what the same manufacturers say in their North American documents, since the Hazard Communication Standard places the reaction products of anticipated use on the manufacturer's side of the line, and since the Canadian Hazardous Products Regulations require hazardous decomposition products to be stated. The following is the result of a search of publicly available sheets and bulletins; where a document could not be retrieved, that is recorded at the end of this section.

One manufacturer warns on the American market

Frenzelit publishes its TechInfo 28 in English as "Chromium(VI)-Formation at High Temperature", version code V2-ABE-MSK/08.25, that is August 2025 and thus a revision of the German edition of January 2024. The document is cited in Section 16 and is publicly listed in the download area of the company's international pages and of its United States region pages. It states that "When using chromium-alloyed steels, chromium(VI) compounds can form under certain conditions" and names the conditions that must all be met: "Presence of chromium-alloyed steels", "Presence of alkali or alkaline earth metal oxides (especially calcium oxide)", "Presence of oxygen (e.g., ambient air)" and "High temperatures (> 350 °C)". As examples it names the use of calcium-containing lubricants for chrome-alloyed screw connections and the use of calcium oxide-containing materials for the thermal insulation of hot components. [15, 176]

The document also contains a sentence about the company's own products: "Please note that Frenzelit insulation materials also contain calcium oxide in varying proportions." As a consequence it requires that "In these cases, special safety precautions must be taken during dismantling, inspection, and other work" and that the disposal instructions for chromium(VI) compounds be observed. [176]

Three limits of this finding should be stated. The document is a translation of the German sheet, as its version code shows. It sits in the download area for gasket materials rather than with the insulation products. And it cites no American or Canadian rule, although the same company does publish a technical information sheet on California Proposition 65 in English, so the absence of a sheet written for the American legal position is not a question of language. [176]

What the other North American sheets state under decomposition products

Section 16 records the two Morgan sheets for Cerachrome, Z-Blok CR Grade and Ceraform 130, whose section 10 states "Hazardous decomposition products: None" and in which the word hexavalent does not occur [95, 77]. The further North American English sheets of the same manufacturer follow the same pattern: sheet 101 for the 1260 products, FireMaster Endowrap, Kaocrete and Kaolite, first issued 1 May 1987 and last revised 21 February 2022; sheet 156 for the Cerox castables and Valcor G; sheet 159 for Cerox 700; sheet 201 for the refractory ceramic fiber products Cerablanket, Kaowool, Cerwool, Pyro-Bloc and Premax; sheet 365 for Superwool XTRA; and sheet RP280 for the polycrystalline wool Alfibond A. None of them mentions chromium, chromate or hexavalent chromium, and none addresses contact with chromium-alloyed steel. The Canadian-format French sheet 378 for the Superwool papers states under "PRODUITS DE DECOMPOSITION" the binder products above 200 °C and nothing further. [177]

The company's own datasheet for refractory ceramic fiber blanket, United States code 5-14-205 of February 2016, covers Kaowool, Cerablanket, Cerachem and Cerachrome and describes the last of these with the words "Cerachrome® Blanket is made from spun aluminasilica-chromia fiber". The chromium content is thus declared as a constituent. Neither the datasheet nor the safety data sheets it cross-references says anything about what becomes of that constituent in service. [178]

The picture is the same at the other suppliers. The Alkegen sheet M0558A for Insulfrax 1300 HT, effective 15 May 2023, states "HAZARDOUS DECOMPOSITION PRODUCTS: None."; the sheet M0055A for the Fiberfrax high purity papers, effective 15 December 2022, lists only binder smoke, carbon monoxide, carbon dioxide, nitrogen oxides and hydrocarbons. The Safe Use Instruction Sheet that ROCKWOOL issues for North America in place of product safety data sheets, version 2.2 of 14 April 2026, covering seven product families including ProRox, describes the material as "Chemically inert. Stable under normal conditions." and limits decomposition to the binder products above 390 °F. The Promat sheets for PROMATECT H and for the Microtherm 1000R family state that no hazardous decomposition products are known. The Johns Manville sheet for calcium silicate pipe, block and board insulation, which covers Thermo-12 Gold and Thermo-1200, version 2.2 of 17 June 2019, lists no hazardous decomposition products at all and states "No decomposition if stored and applied as directed". The 3M Canadian sheet for the Interam endothermic mats, version 3.00 of 26 June 2025, lists carbon monoxide and carbon dioxide. The CertainTeed sheet for mechanical and OEM glass wool of 2 November 2012 names oxides of carbon, sulfur, arsenic and nitrogen, hydrogen chloride, antimony, bromide gas, hydrogen bromide, formaldehyde and traces of hydrogen cyanide, and chromium is not among them. In none of these documents does chromium, chromate or hexavalent chromium occur. [179, 180, 182, 183, 185, 186]

The interface is addressed in North America, for a different question

The interface between insulation material and chromium-alloyed steel is not absent from the North American technical literature. Johns Manville publishes technical bulletin IND-TB009, "Stress Corrosion Cracking of Austenitic Stainless Steel", dated 21 February 2020 and replacing an edition of 19 January 2018. The bulletin deals with insulation in contact with austenitic stainless steel, attributes the damage to chloride ions from wash-down water, brine, sea water, potable water, cleaning solutions and the insulation itself, and offers a corrosion inhibitor. The words chromium, chromate, hexavalent, calcium oxide, sodium oxide, alkali and alkaline do not appear in it. [184]

The same observation applies to the product data for the material. The ROCKWOOL data sheet for ProRox SL 960NA reports, as a test result under ASTM C795, "Stress Corrosion Cracking Tendency of Austenitic Stainless Steel = Passed", with the chemistry of the test described in terms of chloride, fluoride and sodium. The property tested is the resistance of the metal. Section 12 of this analysis sets out why that is a different question from the formation of a hazardous substance at the same interface. [181]

The associations

The High Temperature Insulation Wool Coalition, whose health and safety pages list Morgan Thermal Ceramics, Alkegen, HarbisonWalker International and Nutec among its members, addresses fiber toxicology under the headings of dimension, durability and dose, a product stewardship program, respirator and handling guidance and California Proposition 65. It does not mention chromium, chromium(VI), chromate or any reaction with chromium-alloyed steel. For the North American Insulation Manufacturers Association and for the Thermal Insulation Association of Canada I have found no guidance on the subject. [187]

The European association does address it. The European Insulation Manufacturers Association published a position paper in January 2024, "Mineral Wool Products and Chromium(VI) Residues", which states that "hexavalent chromium can be formed when stainless steel is exposed to high temperatures and humidity", that "Stainless steel does not naturally contain hexavalent chromium", and that "Mineral Wool insulation itself is not a source of chromium (including Cr(VI))", adding of the alkali and alkaline earth content of the wool that "these elements are firmly integrated within the fibres glass network". The paper gives no formation temperature, does not name calcium oxide, and contains no reference to North America, the United States, Canada or the Occupational Safety and Health Administration. [188]

The contrast is therefore not between a European awareness and an American ignorance of the subject. It is a difference in where the subject is addressed. In Europe an association has published a position on it, in the knowledge that a question exists. In North America the association that organizes the same manufacturers has published nothing on it, while one of those manufacturers warns about it on the American market in its own technical information sheet.

Two North American documents that do describe the formation

A Californian air quality authority has had the process measured. The South Coast Air Quality Management District commissioned the College of Engineering Center for Environmental Research and Technology of the University of California, Riverside, to investigate hexavalent chromium emissions from industrial heat treating furnaces; the final report under contract 18258 is dated September 2021. Chromium(VI) was found to be emitted from an empty seasoned furnace, detectable from 1500 °F and highest at 2100 °F; the report states that the speciation depends on the availability of oxygen and of other alkali earth metals, discusses the chromium content of the refractory, and records the highest formation rates for fixtures of 304 and 310 stainless steel. No document of an insulation manufacturer is cited in it. [189]

The second document comes from the American trade press. A presentation by the power plant chemist David Addison, "Hexavalent Chromium Risks for Fossil and CCGT Plants", revision 1.5 of 4 May 2021, prepared for a heat recovery steam generator training event and hosted by an American trade journal, states that "Calcium oxide is in some anti-seize pastes and also in most insulation/lagging materials" and that sodium is "normally present in insulation as well and will leach", and recommends the use of calcium free insulation in contact with chromium containing liner plates in the hot end of the heat recovery steam generator, and the replacement of calcium oxide containing insulation in contact with chromium containing materials. It cites no manufacturer safety data sheet and no North American association guidance, and refers generally to safety notices issued by turbine manufacturers and by some plant owners and operators. [190]

To these should be added the document that stands at the beginning of Section 16. The product service bulletin PSB-43 of April 1990 and its edition PSB-43A of 1994 are documents of an American boiler manufacturer, addressed to American operators, and they describe the conversion of chromium compounds under alkaline and high-temperature conditions and the measures to be taken on removal. The earliest notice in this whole analysis is therefore a North American one, and it is thirty-six years old. [75]

What could not be retrieved

Four gaps belong in the record. One further Morgan North American sheet, number 367, could not be opened; nothing follows from that about its content. The resale portal of HarbisonWalker International returned empty documents, so I could not check whether the sentence that Section 16 records for the chrome-bearing refractory sheets also appears on that company's insulation board and resale sheets. No product-specific North American safety data sheet for the ROCKWOOL ProRox range is publicly available; what exists for North America is the Safe Use Instruction Sheet named above. And the current North American industrial insulation sheets of Saint-Gobain and CertainTeed sit behind a product selector and were not retrieved, so the 2012 sheet cited here may not be the current one.

The absence of a statement in a document that could not be opened is not a finding. The absence of a statement in the documents that could be opened is one.

37. A question to American practice

The facts set out in this analysis have a long record, and much of it is American. The formation of calcium chromate and sodium chromate from a chromium source, lime or soda and oxygen was claimed as a process in a United States patent granted in 1939 (Section 7). A report prepared in 1969 for the National Air Pollution Control Administration named the chromium pathway as a research question (Section 15). An American boiler manufacturer issued a notice in April 1990 and extended it expressly to insulation materials and textiles in 1994 (Section 16). The formation at the metal-insulation interface was demonstrated by X-ray diffraction in 2015, with 160 mg of chromium(VI) per square meter of contact area after 1,000 hours and 940 mg/m² after 5,000 hours (Section 10). A Californian air quality authority had the process measured in 2021 (Section 36). The number of maintenance and overhaul occasions per year, for the industrial segments alone, is estimated in Section 32 at between 58,000 and 61,000, with millions of workshop visits on top of that.

Hexavalent chromium has been listed in California as a carcinogen since 27 February 1987, and as a developmental and reproductive toxicant since 19 December 2008, with a No Significant Risk Level of 0.001 micrograms per day by inhalation and a warning duty enforceable by any person in the public interest. The groundwater case at Hinkley is among the best known environmental cases in the country. The legal system in which all this sits has worked through asbestos over five decades.

My question is why the formation of chromates on insulated chromium-alloyed hot components has not been taken up in that system, although every element of it has been publicly documented for decades.

I do not think the answer lies in the evidence, and I do not think it lies in the instruments. Section 25 describes the mechanism, and it answers this question as well. The industrially manufactured compound has a manufacturer, a supplier, a label, a safety data sheet and trained personnel. The compound that forms in situ is encountered as a deposit on a surface. It has no manufacturer, no supplier, no label and no safety data sheet, and it therefore falls out of the category of hazardous substance and into the category of dirt. It is treated accordingly, with rags, brushes, vacuums, compressed air and spray products, by the maintenance and cleaning personnel already present. What has no product has no addressee, and what has no addressee is not taken up.

The instruments are nevertheless there. Paragraph (d)(1)(ii) of the Hazard Communication Standard places the chemical reaction products of known or reasonably anticipated uses on the side of the manufacturer of the material. The scope of 29 CFR 1910.1026 covers chromium(VI) in all forms and compounds, with no condition that anyone have named the source. Section 25249.6 of the Californian Health and Safety Code attaches to the exposure and not to the product. Section 37 of this analysis therefore does not ask for a new rule. It asks why the existing ones have not been applied to this case. [157, 153, 162]

38. The duties in Germany

Section 31 names the reasons why this analysis cites predominantly German rules. This section brings together the German provisions in force in one place and gives the source for every statement. In doing so it repeats points that stand in their own context elsewhere, so that a company in Germany does not have to assemble the duties from the whole of the analysis.

The term hazardous substance also covers what only arises later

The German Hazardous Substances Ordinance does not attach to the purchase. Section 2 paragraph 1 number 3 counts among the hazardous substances "substances, mixtures and articles from which substances within the meaning of number 1 or number 2 arise or are released during manufacture or use". Number 4 additionally covers substances and mixtures which, because of their properties and the manner in which they are present or used at the workplace, can endanger the health and the safety of the employees. A chromate that forms at the interface between insulation material and hot component is therefore covered, although nobody bought it and nobody wanted to manufacture it. [222]

The term activity is just as wide. Section 2 paragraph 5 sentence 1 names "any work with substances, mixtures or articles, including manufacture, mixing, use and consumption, storage, keeping, treatment and processing, decanting and transfer, removal, disposal and destruction". The removal, storage, reinstallation and disposal of a contaminated insulation are therefore activities within the meaning of the Ordinance. [222]

The risk assessment therefore begins with a determination and not with a measurement. Section 6 paragraph 1 sentence 1 requires the employer to determine "whether the employees carry out activities with hazardous substances or whether hazardous substances can arise or be released during activities". Section 6 paragraph 5 sentences 1 and 2 names the group of cases relevant here expressly: account is to be taken of activities in which the possibility of a hazard remains even after all technical protective measures have been exhausted, and this applies "in particular to maintenance work, including servicing work". For substances without a supplier classification, section 6 paragraph 3 sentence 1 requires the employer to classify them himself. [222]

Investigation before work begins and the duties of the party commissioning the work

Since 5 December 2024 the Ordinance has contained a provision of its own in section 5a for the party commissioning activities on structural or technical installations. Before the activities begin, he has to make available to the executing company, in writing or electronically, all the information available to him on the construction or use history concerning hazardous substances that are present or suspected, and for this purpose he has to make use of the documents accessible to him with reasonable effort. Sentence 3 provides that hazardous substances within the meaning of this provision are those "which are released by the activities and can lead to a particular hazard to health". [223]

On the side of the executing company stands section 6 paragraph 2c. If a technical investigation is necessary in order to determine whether hazardous substances are released during the activities on structural or technical installations and can constitute a hazard to health, that investigation is "a precondition for carrying out the activities". The absence of an examination is therefore not a state in which work may be done. [223]

The wording is "structural or technical installations". Whether vehicles, ships and locomotives fall under it, the Ordinance does not say, and I have not found any guidance on its interpretation. For stationary installations, that is for combined heat and power plants, boilers, pipework and turbines, the question does not arise. [223]

The risk assessment is to be documented before the activity is taken up and, under section 6 paragraph 11 sentence 1, may be carried out only by competent persons. Section 6 paragraph 8 sentence 2 number 5 requires in the documentation "a reason where, in the case of activities with carcinogenic or germ cell mutagenic hazardous substances of category 1A or 1B, employees have not been entered in the exposure register under section 10a paragraph 1 sentence 1". Non-entry therefore has to be reasoned. [222]

Substitution and the ranking of the measures

Section 7 paragraph 3 requires that, on the basis of the result of the substitution check, "substitution be carried out as a matter of priority", namely by substances, mixtures, articles or processes which, under the respective conditions of use, are not hazardous or are less hazardous. Section 7 paragraph 4 orders the further steps: the design of the processes and low emission forms of use according to the state of the art, after that collective technical measures at the source of the hazard and organizational measures, and only then individual measures including personal protective equipment. Section 7 paragraph 5 sentence 2 provides that the use of burdensome personal protective equipment may not be a permanent measure. [222]

For carcinogenic substances of category 1A or 1B, section 10 paragraph 1 tightens this order. Where substitution is not technically possible, the employer has to ensure manufacture and use in a closed system; where that too is not technically possible, he has to minimize the exposure according to the state of the art. Section 10 paragraph 4 names the cases in which personal protective equipment is to be worn, among them activities in the area of high risk and a substantially increased exposure to hazardous substances without a workplace limit value or tolerance concentration. [222]

The German TRGS 561 implements this ranking for the case dealt with here. Section 4.1 paragraph 1 requires the substitution check and expressly names the examination of "whether powdered materials can be replaced by less dusting ones". Section 4.2 paragraph 1 sentence 1 describes measures to avoid and reduce dust generation as "absolutely necessary". Section 5.9.3 paragraph 5 ties the additional protective regime to activities on industrial components "on which a chromium(VI) contamination is present or on which it cannot be ruled out". [19]

The value of 1 µg/m³ and what it does not achieve

For chromium(VI) compounds there is no workplace limit value in Germany. The German TRGS 910 carries in table 1 a tolerance concentration of 1 µg/m³ for the inhalable fraction with an excursion factor of 8 and the note "see TRGS 561"; an acceptance concentration is not laid down for this entry. The concentration relates to the element content of the metal and is defined as a shift average over eight hours. [101]

The German TRGS 561 quantifies the associated risk in section 3.3.4 paragraph 2: at an exposure of 1 µg/m³ over the whole of working life, an additional statistical lung cancer risk of the order of about 4:1000 results. Above this value there is a high risk, below it a lower risk that cannot be quantified. The rule requires that the concentration be complied with and that further minimization to the greatest possible extent be sought. [19]

The duties under sections 6 and 7 of the German Hazardous Substances Ordinance do not depend on whether this value is exceeded. An air measurement moreover answers neither the question of skin contact nor that of surface contamination; for the hazard from skin contact the German TRGS 401 applies. [222, 99]

Exposure register

Since the amendment of 2 December 2024 the exposure register has stood in a provision of its own. Section 10a paragraph 1 sentence 1 requires a register of the employees who carry out activities with carcinogenic, germ cell mutagenic or reproductive toxic hazardous substances of category 1A or 1B "for whom the risk assessment shows a hazard to their health", stating the activity and the level and the duration of the exposure. Under paragraph 2 it is to be kept, for carcinogenic or germ cell mutagenic hazardous substances, for 40 years after the end of the exposure; on termination of the employment relationship the employee receives an extract. Under paragraph 3 the employer may discharge these duties by transmitting the data to the competent accident insurance institution or its association. [224]

The Zentrale Expositionsdatenbank ZED, the central exposure database of the German Social Accident Insurance, is the route set up for this. It is described there as a free service by which employers can meet their obligation under the German Hazardous Substances Ordinance; where it is used, the duty to hand over and to archive is transferred to the German Social Accident Insurance, and the data are kept for at least 40 years after the end of the exposure. [226]

The version of the German TRGS 410 of 25 September 2026 has introduced a criterion for inclusion of its own for chromium(VI). Under section 4 paragraph 1 number 10, employees are to be included where "during activities with chromium(VI) compounds the concentration of 1 µg/m³ as a shift average is exceeded". Further criteria of the same paragraph apply irrespective of this, among them number 5 where respiratory protection has to be worn as a protective measure, and number 7 where no sufficient information on the level of a possible exposure is available. [225]

Section 4 paragraph 4 of the same rule covers the activities dealt with here directly. Employees are also to be included where repair and overhaul work, servicing work, cleaning work, sampling on systems that are not closed, demolition work or activities in contaminated areas are carried out repeatedly and a hazard cannot be ruled out on the basis of the risk assessment. Paragraph 3 names the dermal hazard as a ground for inclusion in its own right. For the level of the exposure, section 5 paragraph 1 provides that the effects of wearing personal protective equipment are left out of account. [225]

The duty also falls on outside contractors. Section 3 paragraph 7 records that the risk assessment and the keeping of the register apply to them as well, that they have to obtain the necessary information from the client and that the client has to make this information available. For temporary agency workers, under paragraph 8 the hirer documents during the period of hire, and the agency afterwards takes the entries into its own register. [225]

Occupational health care and occupational disease

Part 1 paragraph 1 number 1 of the annex to the German Ordinance on Occupational Health Care (Verordnung zur arbeitsmedizinischen Vorsorge, ArbMedVV) carries "chromium-VI compounds" in its list of substances. Mandatory occupational health care is to be arranged, among other cases, where repeated exposure cannot be ruled out and the hazardous substance is carcinogenic of category 1A or 1B. Under section 4 paragraph 2 the employer may allow an activity to be carried out only where the employee has taken part in the mandatory occupational health care. Irrespective of this, under part 1 paragraph 1 number 2 letter i there is mandatory occupational health care for activities with high temperature wools in so far as fiber dusts classified as carcinogenic can be released. [227]

Annex 1 of the German Occupational Diseases Ordinance (Berufskrankheiten-Verordnung, BKV) carries under number 1103 "diseases caused by chromium or its compounds". The list number is framed in open terms and is restricted to no particular compound and no particular activity. [228]

Supervision and sanctions

Supervision is a task of the state. Section 21 paragraph 1 of the German Occupational Safety and Health Act (Arbeitsschutzgesetz, ArbSchG) assigns it to the competent authorities of the Länder; since the calendar year 2026, under section 21 paragraph 1a at least 5 percent of the establishments present in the Land are to be inspected each year, and this minimum inspection quota may not be departed from by Land law. Section 22 paragraph 2 confers the power to examine working procedures and to carry out measurements, section 22 paragraph 3 the power to issue orders and, where they are not carried out, to prohibit the work concerned. [229]

The German Hazardous Substances Ordinance supplements these powers. Under section 19 paragraph 3 number 3 the competent authority may order the employer to have the work stopped where he does not take the necessary measures ordered without delay or within the period set. Under section 19 paragraph 4, proof that the risk assessment was drawn up by a competent person is to be submitted to it on request. [224]

In addition, the accident insurance institutions supervise. Section 17 paragraph 1 of the German Social Code Book VII assigns to them the supervision of the preventive measures and the advising of the undertakings. Section 19 paragraph 1 gives the supervisory officers the power to issue orders in the individual case and, where there is imminent danger, orders that are immediately enforceable, section 19 paragraph 2 number 5 the power to determine the presence and the concentration of hazardous substances or to have them determined at the expense of the entrepreneur, and number 6 the power to take samples. This provision contains no power to shut down; shutting down is assigned to the state authorities. [230, 229]

The administrative offenses are set out in section 22 paragraph 1 of the German Hazardous Substances Ordinance. They cover, among other things, the risk assessment that is not documented, or not documented correctly or in time, the hazardous substances register that is not kept or not kept correctly, the taking up of an activity contrary to section 7 paragraph 1, the permanent use of burdensome personal protective equipment and the exposure register that is not kept, or not kept correctly or completely, and that is not kept for the prescribed period. [103]

The amount follows from the German Chemicals Act (Chemikaliengesetz, ChemG). For the reference relevant here, section 26 paragraph 3 provides a range of up to 50,000 euros. Anyone who by such an act intentionally endangers the life or the health of another person is liable under section 27 paragraph 2 to imprisonment of up to five years or to a fine; in the case of negligence the range under section 27 paragraph 4 number 2 is up to two years. Under the German Occupational Safety and Health Act the range of fines for breaches of enforceable orders reaches up to 30,000 euros, and section 26 makes persistent repetition and the intentional endangerment of the life or health of an employee a criminal offense. [231, 229]

Waste

The German Waste Catalogue Ordinance (Abfallverzeichnis-Verordnung, AVV) contains no waste code that names chromate-loaded insulation materials. The classification runs through the pairs of a hazard-relevant and a non-hazard-relevant entry. For insulation material other than asbestos, 17 06 03* "other insulation materials consisting of or containing dangerous substances" comes into consideration, with 17 06 04 as its counterpart. For linings and refractory materials, 16 11 03* from metallurgical and 16 11 05* from non-metallurgical processes apply, with 16 11 04 and 16 11 06 as their counterparts. For separated chromates, 16 09 02* "chromates, for example potassium chromate, potassium or sodium dichromate" applies. Under section 3 paragraph 1 the asterisk means hazardous within the meaning of section 48 of the German Circular Economy Act. [232]

Which entry of the pair applies is decided by the content. The introduction to the annex provides in number 2.2.1 that a waste is classified as hazardous where it contains relevant dangerous substances on account of which it displays one or more of the properties listed in Annex III of Directive 2008/98/EC. For the property HP 7 carcinogenic, which is relevant here, the concentration limit for a substance classified as a carcinogen of category 1A or 1B with H350 is 0.1 percent. [232, 69]

Section 9a paragraph 1 of the German Circular Economy Act (Kreislaufwirtschaftsgesetz, KrWG) prohibits "the mixing, including the dilution, of hazardous waste with other categories of hazardous waste or with other waste, substances or materials". Paragraph 3 obliges producers and holders to separate waste that has been mixed in an impermissible manner without delay, in so far as this is necessary for proper recovery that causes no harm. Section 326 paragraph 1 number 2 of the German Criminal Code makes the unauthorised handling of waste that is carcinogenic for humans a criminal offense. [233, 107]

The distance from the asbestos regime

For asbestos there is a procedure of its own in Germany. The German TRGS 519 requires in section 2.7 proof of expertise through successful participation in a course recognized by the authorities with an examination; the proof is valid for six years. The German Hazardous Substances Ordinance requires in section 11a paragraph 3 an official approval for activities in the area of high risk, since 20 December 2025 in section 11a paragraph 4a a permit for demolition work in the area of low and medium risk, and in section 11a paragraph 4 notification at the latest one week before the activities begin. Section 14.5 of the German TRGS 519 allows the protective measures to be lifted only where a visual check shows no visible residual contamination and a measurement gives a fiber concentration below 500 fibers per cubic meter. [97, 224]

For chromium(VI) on insulated hot components none of these points exists. There is no duty of expertise, no approval, no permit, no notification before work begins and no clearance measurement. The only involvement of the authorities is the notification under section 10a paragraph 5 of the German Hazardous Substances Ordinance, and this is made within two months of taking up the activity and only where the workplace limit value is not complied with or where work is carried out in the area of high risk. Section 25 describes the same asymmetry for the other legal systems considered. [224]

What the German body of rules names

Germany is the only one of the legal systems considered here in which the case of application has a section of its own in the sub-statutory body of rules. The German TRGS 561 describes in section 5.9.3 that chromium(VI) compounds can form on thermally loaded chromium-alloyed industrial components, that these can be deposited in insulation materials or assembly pastes and that exposure can follow during dismantling and maintenance work. As influencing factors it names the steel temperature, the chromium content of the alloy, the reaction time, the presence of alkali and alkaline earth metal oxides from insulation materials or assembly pastes, and oxygen and air humidity close to the surface. On the mechanism it records that it is at present not yet clarified. [19]

Three German statutory accident insurance institutions describe the same matter on their sector pages. BG ETEM names the temperature range of about 350 to 800 °C and the contact of chromium-alloyed steels with insulation materials or assembly pastes containing alkali and alkaline earth metals. BG Verkehr names yellowish deposits on stainless steel when insulation materials are stripped off and records that the question is the subject of investigations of its own for ship engine rooms and car engines. BG BAU distinguishes according to the presence of thermal insulation materials containing alkali and alkaline earth metals and states that BG ETEM is taking the lead. [2, 234, 235]

The German Hazardous Substances Ordinance itself does not name the case. It covers it through the term hazardous substance, the term activity and the duty of determination in section 6 paragraph 1. The German TRGS 910 does not name it and refers only in the notes column to the German TRGS 561. The German Waste Catalogue Ordinance contains no code of its own. The German Ordinance on Occupational Health Care names chromium(VI) compounds and high temperature wools separately, without connecting them. [222, 101, 232, 227]

What follows from this for a company in Germany

From the provisions named there follows a set of documents that can be examined. These include the documented risk assessment, drawn up by a competent person, for the material pairing of chromium-alloyed hot component and basic insulation material, and the substitution check carried out and reasoned under section 7 paragraph 3. They include the information from the party commissioning the work under section 5a and the technical investigation under section 6 paragraph 2c. They include the operating instruction and the annual instruction under section 14. They include the entry in the exposure register or its reasoning under section 10a in conjunction with the German TRGS 410, the arranging of the mandatory occupational health care and the classification of the waste according to its content. [222, 223, 224, 225, 227, 232]

None of these points presupposes a measurement, and none of them falls away through a negative measurement result. The duty arises with the possibility of formation, and ruling out that possibility is the point that would have to be demonstrated.

39. The duties in the European Union

The national bodies of rules of the Member States transpose Union law. This section brings together what Union law itself requires, and in doing so separates occupational safety and health law from chemicals law and from waste law. Implementation is a matter for the Member States; for a company the duties arise from the respective national law.

Scope of Directive 2004/37/EC

Under Article 3 paragraph 1 the Directive applies "to activities in which workers are or may be exposed to carcinogens, mutagens or reprotoxic substances as a result of their work". It thus attaches to the exposure during an activity. Article 2 letter a point i defines the carcinogen through the classification criteria of Annex I of Regulation (EC) No 1272/2008 and contains no restriction to substances that are bought, placed on the market or deliberately used. Calcium chromate and sodium chromate are classified in harmonised form as carcinogenic category 1B in Annex VI Part 3 of that Regulation. [236, 63]

In addition, Article 2 letter a point ii covers substances and mixtures that are "released by a process referred to in this Annex". Annex I contains process-related entries for this, among them work with exposure to respirable crystalline silica dust and to diesel engine exhaust emissions. The Union legislature stated the purpose of this Annex in recital 17 of Directive (EU) 2017/2398: for respirable crystalline silica dust generated by a work process there is no classification under Regulation (EC) No 1272/2008, which is why inclusion in Annex I was held to be appropriate. For a substance arising from a process that carries a harmonised classification, point i therefore already applies. [236, 86]

Article 3 paragraph 2 requires, for every activity in which exposure can occur, the determination of the nature, degree and duration of the exposure and the repeated assessment on any change in the conditions. Article 3 paragraph 3 provides that in the risk assessment "all other routes of exposure, such as absorption into and through the skin, are to be taken into account". [18]

Replacement, closed system, minimization

Article 4 paragraph 1 requires the employer to reduce the use, "in particular by replacing it, in so far as is technically possible, by substances, mixtures or processes which, in the conditions of their use, are not or are less dangerous". Article 5 paragraph 2 requires, for the case that substitution is not technically possible, manufacture and use in a closed system. Article 5 paragraph 3 requires, for the case that this too is not technically possible, that the exposure is "reduced to as low a level as is technically possible". [236]

Article 5 paragraph 5 names the individual measures. Letter c requires the design of the working processes and of the technical measures with the aim of avoiding the release at the workplace or keeping it as low as possible. Letter l requires that safe storage, handling and transport be ensured, among other things through hermetically sealable and clearly labeled containers. Letter m requires the same for the collection, the storage and the removal of the waste. For the removal, the interim storage and the disposal of a contaminated insulation, all three steps are therefore directly regulated. [236]

The general ranking is set out in the Framework Directive 89/391/EEC. Article 6 paragraph 2 names as principles, among others, the avoidance of risks, combating the hazard at source, taking account of the state of the art and the priority of collective over individual protection. Article 9 paragraph 1 letter a requires the employer to be in possession of an assessment of the risks existing at the workplace; the form of the documentation is left by paragraph 2 to the Member States. [237]

The binding limit value

Annex III Part A of Directive 2004/37/EC carries the entry "chromium(VI) compounds which are carcinogens within the meaning of Article 2 letter a point i (as chromium)" with a limit value of 0.005 mg/m³ as a time weighted average over eight hours. A short term value is not laid down, and the notes column is empty. The transitional column names 0.010 mg/m³ until 17 January 2025 and 0.025 mg/m³ until the same date for welding and plasma cutting work and similar fume generating processes. [236, 86]

Article 5 paragraph 4 provides that the exposure may not exceed the limit values of Annex III. The duties under Articles 3 and 4 and Article 5 paragraphs 1 to 3 do not depend on whether this value is reached; they attach to the result of the assessment. For chromium(VI) Germany applies a lower value of 1 µg/m³, and the Netherlands the same lower value of 0.001 mg/m³, both calculated as chromium. [236, 101]

Register, health surveillance and forty years

The list of exposed workers is set out in Article 12 letter c. Under it the employer keeps an up to date list of the workers employed in activities for which the assessment reveals a risk, "indicating the exposure to which they may have been subjected", in so far as this information is available. Article 15 paragraph 1 requires, for carcinogens and mutagens, that this list and the health record be kept for at least 40 years after the end of the exposure. [236]

Article 15 paragraph 2 governs the case of the undertaking ceasing to operate: where the undertaking ceases its activity, these documents are to be made available to the competent authority. Article 14 paragraph 8 requires that all cases of cancer identified under national law as resulting from exposure at work be notified to the competent authority. Article 10 paragraph 2 provides that the costs of the hygiene and protective measures may not fall on the workers. [236]

Chemicals law: classification, authorisation, restriction

The harmonised classification is set out in Annex VI Part 3 of Regulation (EC) No 1272/2008. Calcium chromate carries the Index number 024-008-00-9 and is classified as carcinogenic category 1B with H350. Sodium chromate carries the Index number 024-018-00-3 and is classified as carcinogenic, germ cell mutagenic and toxic for reproduction, in each case of category 1B. The collective entry 024-017-00-8 covers "chromium(VI) compounds, with the exception of barium chromate and of those specified elsewhere in this Annex" with H350i. [63]

The authorisation requirement under Title VII of Regulation (EC) No 1907/2006 concerns the substances included in Annex XIV. These include chromium trioxide as entry 16, sodium dichromate as entry 18, potassium chromate as entry 21 and sodium chromate as entry 22, in each case with a sunset date in 2017. Calcium chromate is not contained in Annex XIV. Article 56 paragraph 1 prohibits manufacturers, importers and downstream users from placing an Annex XIV substance on the market for a use or from using it themselves, in so far as no authorisation or exemption exists. [238, 66]

The term use is framed widely in Article 3 number 24 and covers, among other things, storing, keeping and treating. Article 2 paragraph 2 excludes waste from the substance concept of the Regulation. Whether the formation of a chromate on a component and its subsequent further use is a use within the meaning of this Regulation is not dealt with in the legal texts and official documents examined; I have not found a source on it. [60, 66]

On 29 April 2025 the European Chemicals Agency published a restriction proposal for chromium(VI) substances. It provides for a ban from which six use categories are to be exempted, provided they comply with the limits laid down for worker exposure and environmental emissions; the categories are the formulation of mixtures, electroplating on plastic and on metal substrates, the use of primers and other slurries, other surface treatment, and functional additives or process aids. The Agency describes the proposal as a possible replacement of the existing authorisation requirement and names a six month consultation starting on 18 June 2025. I could not establish the state of the procedure in October 2026. [239, 59]

The proposal is tailored to chromium(VI) substances placed on the market and deliberately used and to the use categories named. Insulation materials, insulations and chromates formed in situ do not appear in the press release or in the register entry. [239]

Union waste law

Article 7 paragraph 1 of Directive 2008/98/EC provides that the list of waste is binding as regards the determination of the waste to be classified as hazardous. Paragraph 2 allows the Member States to classify a waste as hazardous even where it is not listed as such, provided it displays one of the properties of Annex III. Paragraph 4 prohibits a reclassification as non-hazardous being achieved "by diluting or mixing the waste". Article 18 paragraph 1 prohibits the mixing of hazardous waste and provides that mixing includes the dilution of hazardous substances. [240]

The list is set out in the Annex to Decision 2000/532/EC. Relevant are 17 06 03* for other insulation materials consisting of or containing dangerous substances, 16 11 03* and 16 11 05* for used linings and refractories from metallurgical and from non-metallurgical processes, and 16 09 02* for chromates. Commission notice 2018/C 124/01 explains the concept of the mirror entries and lists in its annex the standard EN 15192 for the determination of hexavalent chromium in solid materials. [241, 242]

The distance from the Asbestos Directive

Directive 2009/148/EC lays down duties for asbestos that Directive 2004/37/EC does not contain for carcinogens generally. Article 11 requires, before demolition, maintenance or renovation work begins, all necessary steps to identify materials presumed to contain asbestos, by obtaining information from the owner and from relevant registers. Article 4 requires a notification to the competent authority before the work begins, stating among other things the number of workers involved and their training certificates. Article 13 requires a plan of work before the work begins and, after its completion, verification that there is no longer any hazard. Article 14 with Annex Ia lays down minimum requirements for the content, the duration and the frequency of the training, and Article 15 an authorisation of the undertaking. [243]

Directive 2004/37/EC contains no notification before work begins. Its Article 6 requires information to the authority only "on request". The register and the forty year period are governed in the same way in both Directives. The difference lies in the prior identification, the notification, the plan of work, the minimum requirements for the training and the authorisation of the undertaking. [236, 243]

What the Union does not name

In the legal acts and official documents of the Union examined, the formation of chromates on insulated chromium-alloyed hot components is not named. Examined were the consolidated versions of Directives 2004/37/EC, 89/391/EEC, 2009/148/EC and 2008/98/EC, of Decision 2000/532/EC and of Regulations (EC) No 1907/2006 and No 1272/2008, together with notice 2018/C 124/01 and the accessible publications of the European Agency for Safety and Health at Work. None of the eight process-related entries in Annex I of Directive 2004/37/EC concerns insulations or hot components. [236, 240, 242]

The Commission document closest to the subject deals with chromium(VI) arising from a process exclusively in welding, in thermal cutting and in similar fume generating processes. Thermal insulation materials, calcium oxide and the formation on hot stainless steel surfaces outside these processes do not appear there. That is a finding about the body of material examined and no statement about the duties; these follow from the wording of Articles 2, 3, 4 and 5. [244, 236]

What follows from this

For a company in a Member State the duty arises from the national transposing law. The test applied by Union law is at three points stricter than the question of a measurement. The assessment under Article 3 paragraph 2 is activity-related and is to be repeated on any change in the conditions. Absorption through the skin is expressly to be included under Article 3 paragraph 3. The reduction under Article 5 paragraph 3 is tied to no threshold; it applies as soon as a closed system is not technically possible. A Member State may provide for stricter provisions; the Directive lays down minimum requirements. [236]

40. The duties in the Netherlands

The Netherlands is a Member State of the European Union and has transposed Directive 2004/37/EC into the Arbeidsomstandighedenbesluit. The case of application dealt with here is not named as such there either. This section brings together the Dutch provisions in force and gives the source for every statement.

The term substance is neutral as to origin

Article 1.1 paragraph 5 letter b of the Dutch Arbeidsomstandighedenbesluit defines hazardous substances as "stoffen of mengsels waaraan werknemers bij de arbeid worden of kunnen worden blootgesteld die vanwege de eigenschappen van of de omstandigheden waaronder die stoffen of mengsels voorkomen gevaar voor de veiligheid of gezondheid kunnen opleveren". The definition attaches to the exposure at work and to the circumstances in which they occur. Purchase, placing on the market and intended use do not appear in it. [246]

Article 4.2 paragraph 1 requires the assessment of the nature, degree and duration of the exposure, and does so expressly "ongeacht of met deze stoffen daadwerkelijk arbeid wordt of zal worden verricht", that is irrespective of whether work with these substances is actually carried out. This assessment is part of the written Risico-Inventarisatie en -Evaluatie under Article 5 paragraph 1 of the Arbeidsomstandighedenwet. Under Article 4.2 paragraph 8 it is in any event to be reviewed where new work is begun in which hazardous substances are involved. [121, 245]

Article 4.1c paragraph 1 letter c requires that the exposure be prevented or minimized by "gebruik te maken van adequate voorzieningen bij het uitvoeren van reparatie- of onderhoudswerkzaamheden". Letter j requires suitable working methods including arrangements for the safe handling, storage and transport of hazardous substances and of waste containing such substances. Paragraph 2 ties these measures to the state of science and technology. Letter c is the only place in section 1 of chapter 4 where repair and maintenance work is named. [246]

The additional duties for carcinogenic substances

Under Article 4.12, section 2 of chapter 4 applies in addition as soon as workers are or may be exposed to carcinogenic, mutagenic or reprotoxic substances "of aan stoffen die vrijkomen bij kankerverwekkende of mutagene processen". The definition in Article 4.11 letter b attaches in point 1 to the classification criteria of Regulation (EC) No 1272/2008. Chromium(VI) compounds are thus covered. [246, 63]

Article 4.13 requires that, beyond the assessment under Article 4.2, seven items be entered in writing in the Risico-Inventarisatie. The first is "de reden waarom het gebruik van een kankerverwekkende, mutagene of reprotoxische stof of het toepassen van een kankerverwekkend of mutageen proces voor het verrichten van de arbeid strikt noodzakelijk is en vervanging technisch niet uitvoerbaar is". There follow the annual quantity or the frequency of application, the nature of the work, the number of exposed workers, preventive measures, the protective equipment used and the cases in which replacement took place. The reasoning for the impossibility of a substitution is therefore part of the documentation. [246]

Article 4.17 requires technical and organizational measures which prevent the exposure at source as far as possible, in particular through replacement in so far as this is technically feasible. Article 4.18 paragraph 1 requires, for the case that this is not feasible, manufacture and use in a closed system; paragraph 2 names collective measures and local extraction, paragraph 3 personal protective equipment only after that, and paragraph 4 the limitation of the wearing time to what is strictly necessary. [109, 246]

Article 4.19 governs the accompanying duties. Letter a requires information or instruction that takes place at least once a year. Letter c requires the marking of hazard zones; the term is defined in Article 4.11 letter h as a place where workers are or may be exposed to such substances. Letter e requires effective means for the safe collection, storage and removal of waste, as far as possible in hermetically closed and clearly marked containers. Article 4.20 requires zones for eating and drinking without any risk of exposure, effective working clothing, its separate storage, and washing and shower rooms. [246]

The limit value of 0.001 mg/m³

The statutory limit value is set out in Bijlage XIII Part B2 of the Arbeidsomstandighedenregeling, the list of limit values laid down for carcinogenic substances according to the risk approach. The entry reads "Chroom (VI)-verbindingen (als Cr)" with 0.001 mg/m³ as a time weighted average over eight hours. A CAS number, a fifteen minute value and a skin notation are not entered. According to the explanatory note on Bijlage XIII, for substances which can occur as particles the value relates to the fraction sampled as inhalable dust. [247]

The value has applied since 1 March 2017. It was introduced by a regulation of the Minister for Social Affairs and Employment of 18 October 2016, which at the same time deleted the until then separate entries for barium chromate, calcium chromate, soluble and sparingly soluble chromium(VI) compounds, chromium trioxide, lead chromate, strontium chromate and zinc chromate. For chromium(VI) compounds the official explanatory memorandum names the estimate of the Dutch Health Council of 4 in 100,000 for 40 years of exposure to 0.01 µg/m³ and of 4 in 1,000 for 1 µg/m³. It describes 1 in 10,000 per year as the prohibition risk and records that the value is set at this maximum risk that is to be accepted. [248]

The same explanatory memorandum records that the introduction of the lower limit value leaves untouched the fact that individual companies have to replace the substance or achieve a lower exposure where that is technically feasible, and refers for this to Articles 4.17 and 4.18 of the Arbeidsomstandighedenbesluit. According to the official explanatory memorandum too, the limit value is therefore no benchmark whose observance makes the substitution check unnecessary. [248]

For the case dealt with here, Article 4.16 paragraph 2 is the central sentence. Where no statutory limit value exists for a carcinogenic substance or for a substance released during a carcinogenic process, the employer himself lays down "een zo laag mogelijke grenswaarde". Where a limit value is exceeded, paragraph 3 requires effective measures without delay to bring it back below that value, and paragraph 5 requires that the plan of measures state how the excess is removed as quickly as possible. [246]

List of workers and forty years

Article 4.15 paragraph 1 requires a list of the workers who are or may be exposed to such substances, "onder vermelding van de blootstelling die zij hebben ondergaan". Paragraph 2 gives every worker the right to inspect and copy the data concerning him. Article 4.10c paragraph 4 requires this list and the results of the occupational medical examination to be kept for at least 40 years after the end of the exposure. [246]

Article 4.10c paragraph 5 governs the case of the undertaking ceasing to operate. Where the activities are discontinued within these forty years, the documents are "overgedragen aan de toezichthouder", that is handed over to the supervisory authority. The Dutch rule thus names the body to which the documents go; the German Hazardous Substances Ordinance does not govern this case expressly and instead provides for the transfer of the duties by transmitting the data to the accident insurance institution. [246, 224]

Supervision, fine and economic offense

Under Article 27 of the Arbeidsomstandighedenwet the Nederlandse Arbeidsinspectie may issue an eis tot naleving, that is determine with binding effect the manner in which a provision is to be complied with, together with a time limit. Article 9.22 of the Arbeidsomstandighedenbesluit allows this instrument for the articles of chapter 4 relevant here. Under Article 28 a supervisory officer may order that certain work be stopped or may not be started where in his reasonable judgment it constitutes a serious danger to persons; the power includes the sealing of work equipment and workplaces. [245, 246]

Breaches of the articles of chapter 4 named are subject to a fine under Article 9.9b paragraph 1 letter d of the Arbeidsomstandighedenbesluit. Under Article 34 paragraph 3 of the Arbeidsomstandighedenwet the maximum amount is that of the fifth category of Article 23 paragraph 4 of the Wetboek van Strafrecht, since 1 January 2026 110,000 euros. Where the same breach of duty is repeated within five years, the amount is increased by 100 percent under Article 34 paragraph 5. [108, 111, 246]

The Beleidsregel boeteoplegging arbeidsomstandighedenwetgeving quantifies the starting amounts. The complete failure to carry out the exposure assessment under Article 4.2 paragraph 1 is classified there as an overtreding met directe boete, that is subject to a fine without prior warning, with the fifth standard amount of 4,500 euros. Exceeding the limit value under Article 4.16 paragraph 3 is classified as a zware overtreding, with the sixth standard amount of 9,000 euros and the factor two. For Articles 4.1b, 4.1c, 4.17 and 4.18 the sixth standard amount likewise applies. The amounts apply to companies with 500 employees and more and are reduced in stages below that. [250]

Above the law on fines stands Article 32 of the Arbeidsomstandighedenwet. Under it the employer is prohibited from acting or failing to act contrary to the Act or the provisions based on it where, as he knows or must reasonably know, this gives rise to or is to be expected to give rise to danger to life or serious damage to the health of one or more workers. A breach of this is an economic offense under Article 1 of the Wet op de economische delicten and, where intentional, a serious criminal offense with a range of up to six years of imprisonment. For legal persons the fine may reach up to the next higher category under Article 23 paragraph 7 of the Wetboek van Strafrecht. [108, 110, 111]

None of the duties of chapter 4 for hazardous substances and for carcinogenic substances is classified as an ernstige overtreding. The exhaustive list in Article 9.10a paragraph 3 of the Arbeidsomstandighedenbesluit names from this chapter the provisions on asbestos, on propane sultone, on substance bans and on white lead. The warning with a subsequent stop-work order therefore applies to the duties dealt with here only after a repeated finding. [246]

Waste

The Regeling Europese afvalstoffenlijst declares the list in the Annex to Decision 2000/532/EC to be authoritative. For insulation material other than asbestos, 17 06 03* "overig isolatiemateriaal dat uit gevaarlijke stoffen bestaat of dergelijke stoffen bevat" comes into consideration, for furnace debris 16 11 03* and 16 11 05*, and for chromates as a substance 16 09 02*. Article 4 paragraph 1 assigns the waste to the entry marked with an asterisk where it is established that it has one of the properties of Annex III of the Waste Framework Directive. Paragraph 2 provides that the effects of evaporation, dilution, mixing or leaching are left out of account. [252, 241]

The burden of proof lies with the waste producer. The official explanatory note of the Informatiepunt Leefomgeving puts it as follows: "De Eural kent een omgekeerde bewijslast: zolang u niet kunt aantonen dat het geen gevaarlijk afval is, is het gevaarlijk afval." Article 10.39 paragraph 1 letter a of the Wet milieubeheer requires the party handing the waste over to provide a description of its nature, properties and composition; Article 10.40 paragraph 2 prohibits the recipient from accepting it without this description and without an accompanying document. Article 10.54 paragraph 1 prohibits mixing, including dilution, during collection and transport. [252, 253]

The distance from the asbestos regime

Section 5 of chapter 4 governs asbestos separately. Article 4.54a paragraph 1 requires the presence of asbestos to be fully inventoried before the demolition or dismantling of structures or objects in which asbestos may reasonably be expected to have been used is begun; under paragraph 4 the inventory and the report are reserved to a certified company. Article 4.54d paragraph 1 requires for the removal from risk class 2 upwards a company with a certificate, and paragraphs 5 and 7 the competence certificates of the persons deployed. Article 4.47c paragraph 1 requires notification to the supervisory authority at the latest two days before the work begins. Article 4.51a requires, before the hazard zone is lifted, a final assessment with a visual inspection and a measurement against the value of 10,000 fibers per cubic meter. [121, 251]

For chromium(VI) none of these points exists. There is no prior inventory, no certification requirement, no notification before work begins, no final assessment and no system of risk classes. The list under Article 4.15 and the forty year period under Article 4.10c correspond to the register that section 5 provides for asbestos. [246, 251]

The Dutch chroom-6 complex

In the Netherlands chromium(VI) has had a public history of its own since 2014. On behalf of the Paritaire Commissie Chroom-6, the Rijksinstituut voor Volksgezondheid en Milieu examined the sites of the Ministry of Defence and reported in 2018 and in 2021, and in further studies the workshops of NS and NedTrain and the reintegration project tROM in Tilburg. For those affected at the Ministry of Defence a state compensation scheme has existed since 2018. [254, 255, 256, 258]

The subject of these studies is chromate-containing paints and primers and the work on them. The question put by the Paritaire Commissie is related in the report of 2021 to “chroom-6-houdende verf of verfstof”. The report on NS and NedTrain begins with the sentence that old paint layers on some trains contain chromium(VI). The report on Tilburg describes the removal of old paint layers on museum trains. The compensation scheme lists in Annex 2 the activities relevant to assessment; the only item not related to paint is “lassen of snijbranden van roestvast staal”. [254, 255, 256, 258]

A full text search of the five main reports for the Dutch terms for insulation, insulation material, mineral wool, stone wool, glass wool and heat protection gives no hits. The most extensive public chromium(VI) complex in Europe has not covered the formation pathway dealt with here. [254, 255, 256]

What is not published in the Netherlands

Calcium chromate and sodium chromate are named on the SZW-lijst of the carcinogenic substances, last published on 9 July 2026. The list describes itself as not exhaustive and states which substances and processes are in any event meant in Article 4.11 of the Arbeidsomstandighedenbesluit. The accompanying list of the carcinogenic processes contains ten items, from the manufacture of auramine to emissions in iron and steel founding; a process involving chromate formation is not among them. The processes determined nationally under Article 4.20c of the Arbeidsomstandighedenregeling likewise cover only diesel engine emissions and two mixtures of substances. [249, 247]

The report that the Ministry for Social Affairs and Employment commissioned specifically for an overview of the chromium(VI) applications at the workplace attributes the exposure on refractory linings of furnaces and boilers to chromium(VI) present in the material, to raw materials and to additions. The thermochemical formation on chromium-alloyed steel through basic oxides from the insulation material does not appear there, not even as a hypothesis. The report closes its overall survey with the note that for the fields of the maintenance of old installations, demolition and waste treatment of ceramic products and certain work of the primary metals industry no information was obtained, "geen informatie over verkregen". [257]

The publications of the Ministry and of the Nederlandse Arbeidsinspectie name as sources of exposure the removal of old paint layers, the manufacture of chromates, chromium plating, certain types of cement, the grinding and welding of chromium-containing surfaces and impregnated wood. The Beheersregime chroom-6 carries the subtitle "Toe te passen arbeidshygiëne bij het werken aan verven en coatings" and, according to its own footnote, is limited to paint dust from treated painted surfaces. The topic page of the Arbeidsinspectie names work on chromium-containing metals and coatings and at the same time records: "Een negatieve uitslag is echter niet genoeg om te besluiten om géén maatregelen te nemen." [259, 260]

The Beleidsregel arbocatalogi 2019 lists the sector catalogues examined by the Arbeidsinspectie. The line "Installatie- en isolatie" names as the provisions relied on, among others, Articles 4.11 to 4.20 of the Arbeidsomstandighedenbesluit, that is the provisions for carcinogenic substances. As hazardous substances the same line names asbestos and quartz dust. Chromium(VI) does not appear there. [261]

This is a statement about the body of material examined. It does not refute the duties. The definition in Article 1.1 paragraph 5, which is neutral as to origin, the wording "ongeacht of met deze stoffen daadwerkelijk arbeid wordt of zal worden verricht" in Article 4.2 paragraph 1 and the formula "stoffen die vrijkomen bij kankerverwekkende of mutagene processen", used throughout section 2, also cover chromates that have arisen unintentionally. What is missing is the naming of the formation pathway. [246, 121]

What follows from this for a company in the Netherlands

From the provisions named there follows a set of documents that can be examined. These include the written assessment under Article 4.2 paragraph 1 for the material pairing of chromium-alloyed hot component and basic insulation material, and the seven items under Article 4.13 including the reasoning why a substitution is not technically feasible. They include the limit value laid down by the employer under Article 4.16 paragraph 2, in so far as no statutory value applies. They include the list under Article 4.15 with its forty year retention, the annual instruction under Article 4.19 letter a and the description of the waste under Article 10.39 of the Wet milieubeheer. [121, 246, 253]

The complete failure to carry out the assessment is the only one of these points that is subject to a fine without prior warning. All the others presuppose a finding and a time limit. The distance from the asbestos regime lies in the procedure that triggers the duties. The duties themselves stand in the wording and apply without the case having first been named. [250, 251]

41. The duties in the United Kingdom

This section brings together the British body of rules in one place, as the three preceding sections do for Germany, the European Union and the Netherlands. Since 1 January 2021 the United Kingdom has no longer been bound by Directive 2004/37/EC. The governing provision, the Control of Substances Hazardous to Health Regulations 2002, is older than that Directive and continues to apply unchanged. [122, 113]

The territorial scope is divided. The COSHH Regulations 2002 and the Control of Asbestos Regulations 2012 carry the note "E+W+S" and therefore apply in England, Wales and Scotland; Northern Ireland has provisions of its own, built up with the same content, in the Control of Substances Hazardous to Health Regulations (Northern Ireland) 2003 and the Control of Asbestos Regulations (Northern Ireland) 2012. In waste law the four parts of the country go their own ways, each with its own regulations for England, Wales, Scotland and Northern Ireland. Unless stated otherwise, the information in this section relates to England and Wales. [281]

The term substance does not attach to the classification

Regulation 2(1) determines what a "substance hazardous to health" is. Letter a covers every substance which meets the criteria for classification in a health hazard class under the CLP Regulation, and does so expressly "whether or not the substance is classified under that Regulation". Letter b covers substances with a workplace limit value approved by the British authority HSE, letter d dust of any kind above the concentration named there. A chromate that forms at the interface between insulation material and hot component meets the criteria of letters a and b, without there having to be a supplier, a safety data sheet or a formal classification. [263]

The definition of the carcinogen in the same provision repeats this idea. Covered is a substance which meets the criteria for classification as a carcinogen of category 1A or 1B under Annex I of the CLP Regulation, "whether or not the substance or mixture would be required to be classified under the Regulation", or a substance or process listed in Schedule 1. Schedule 1 contains no entry on chromium. The carcinogenic property of a chromate formed in situ therefore follows from the first route, through the classification criteria, and not from a list. [263]

That is the British counterpart to what the German Hazardous Substances Ordinance governs in section 2 paragraph 1 numbers 3 and 4. Both legal systems attach the duties to the property of the substance and not to the route by which it entered the company. [222]

Assessment, maintenance and the threshold of five employees

Regulation 6(1) contains a prohibition on beginning work. An employer may not carry out work which can expose employees to a substance hazardous to health as long as he has not carried out a "suitable and sufficient assessment" of the risk thereby created and of the steps required, and has not implemented those steps. Section 25 deals with this provision in comparison with the other legal systems. [122]

Regulation 6(2) lists what the assessment has to take into account. Letter e names the case relevant here expressly: "activities, such as maintenance, where there is the potential for a high level of exposure". Letter b names the information from the supplier including the safety data sheet, letter c the level, the type and the duration of the exposure, letter f a relevant workplace limit value and letter i the results of measurements under Regulation 10. Maintenance is therefore named in the British provision as a subject of assessment in its own right, just as section 6 paragraph 5 of the German Hazardous Substances Ordinance names maintenance work. [122, 222]

Regulation 6(4) limits the duty to document. Only an employer with five or more employees has to record the significant findings of the assessment and the steps taken under Regulation 7. For smaller companies the duty to assess applies, while the duty to record does not. The difference carries weight in the field dealt with here, because insulation and maintenance work is in many cases carried out by small companies. [263]

A duty of investigation before work begins is absent. Regulation 6 takes effect where the work is liable to expose employees, and says nothing about how the employer determines the presence of the substance. A presumption rule for cases of doubt likewise does not exist in the COSHH regime. Both stand in the asbestos regime, in Regulation 5 of the Control of Asbestos Regulations 2012. [122, 123]

Prevention, replacement and what is reasonably practicable

Regulation 7(1) requires the exposure to be prevented or, so far as that is not reasonably practicable, to be adequately controlled. Regulation 7(2) makes the priority of replacement clear; Regulation 7(3) orders the further stages from the design of the processes through control at source to personal protective equipment. Regulation 7(4) letter b expressly requires "the adoption of suitable maintenance procedures", letter c the reduction of the number of exposed employees, of the level and the duration of the exposure and of the quantity present at the workplace to the minimum required for the work. Section 30 reproduces the wording of paragraphs 1, 2 and 5. [113]

For carcinogens Regulation 7(5) is added, with the total enclosure of the process and the handling systems so far as is reasonably practicable, the prohibition of eating, drinking and smoking in areas that may be contaminated, the regular cleaning of floors, walls and other surfaces and cleaning as the occasion requires, the marking of the areas and installations concerned and the storage, handling and disposal in closed and clearly marked containers. These measures apply irrespective of any measurement. [113]

Regulation 7(7) sets the standard for the control. The control counts as adequate only where the principles of good practice under Schedule 2A are applied, where an approved workplace exposure limit is not exceeded and where, for a substance with the hazard statement H340, H350 or H350i or a substance or process listed in Schedule 1, the exposure is "reduced to as low a level as is reasonably practicable". The chromates of the kind dealt with here carry H350 or H350i. The minimization duty therefore applies to them in addition to the limit value and irrespective of whether it is complied with. [263]

The three conditions are joined by "and". Compliance with the limit value on its own therefore does not satisfy the duty to control. The minimization under letter c for its part does not depend on the limit value, because it attaches solely to the hazard statement or to Schedule 1; it therefore applies where no limit value is set, and equally where one is set and complied with. The opening half-sentence reads "where there is exposure to a substance hazardous to health" and contains no threshold. [263]

The standard is worded differently from the one under Union law. Article 5 paragraph 3 of Directive 2004/37/EC requires the level of exposure of workers to be "reduced to as low a level as is technically possible", and Article 5 paragraph 4 provides in addition that the limit values of Annex III may not be exceeded. The British provision turns on what is reasonably practicable, the German one in section 10 paragraph 1 of the Hazardous Substances Ordinance on the state of the art. [236, 222]

Schedule 2A names under letter b the taking into account of all relevant routes of uptake, namely inhalation, absorption through the skin and ingestion. An air measurement alone does not meet this requirement. Letter a requires processes and activities to be designed so that the release and the spread of the substance remain as low as possible. [263, 41]

The standard "so far as is reasonably practicable" operates in proceedings differently from the way it looks. Section 40 of the Health and Safety at Work etc. Act 1974 places the burden of proof on the accused: in criminal proceedings for a breach of such a duty he has to prove that it was not practicable or not reasonably practicable to do more than was done. Anyone who relies on substitution having been impracticable has to establish that. [262]

The limit value of 0.01 mg/m³ and the state of the HSE publications

EH40/2005 in its fourth edition 2020 carries in Table 1 the entry "Chromium (VI) compounds (as Cr)" with 0.01 mg/m³ as a time weighted average over eight hours and a value of 0.025 mg/m³ for process generated exposure, with the notes Carc, sen and BMGV. The footnote to this entry provides: "'Process generated' refers to exposures to Chromium (VI) Compounds generated as a result of a work process, such as fumes from welding." The lowered value has applied since 17 January 2020; the introductory note of the edition lists chromium(VI) compounds among the substances with a lowered limit value. [265]

Table 2 of the same edition carries a biological guidance value of 10 µmol chromium per mol creatinine in urine, to be determined after the shift. The value covers chromium and not the compound; Section 24 deals with what follows from that. [42]

The higher value for process generated exposure matters for this set of facts. The footnote names welding as an example. Whether a chromate that has formed at the interface without any input of energy from the activity and is released as dust during removal counts as process generated, EH40 does not say. I have not found any guidance on its interpretation. The answer decides a factor of 2.5 in the limit value to be applied. [265]

The leaflet INDG346 of the authority still names 0.05 mg/m³ for chromium(VI) compounds. That is the value from before 17 January 2020. The authority has not brought its own leaflet into line after the lowering; accessed on 17 October 2026 it carries the old value. Anyone who relies on the generally accessible publication of the authority works with five times the limit value in force. [88]

The European Union lowered its binding limit value for chromium(VI) to 0.005 mg/m³ with effect from 17 January 2025. The United Kingdom does not follow this; the British authority still carries 0.01 mg/m³ for chromium(VI). The British value is therefore twice the value under Union law. [265, 41, 236]

EH40 carries no skin notation for chromium(VI). The legend of the edition frames this notation narrowly: "Sk Can be absorbed through the skin. The assigned substances are those for which there are concerns that dermal absorption will lead to systemic toxicity." What is meant is the systemic effect after uptake through the skin. The local skin effect of the chromates, the chrome ulcer and the allergic contact dermatitis, does not fall under it. The note "sen" does not help any further here either, because the same legend limits it to "Capable of causing occupational asthma". Annex III of Directive 2004/37/EC likewise carries no "skin" notation for chromium(VI). The duties on skin protection therefore follow from Schedule 2A and Regulation 7, and not from the table of limit values. [265, 236]

The hazard statements trigger the duties

In British law the classification statements are the point of attachment. Regulation 2(1) determines the substance hazardous to health through the criteria of the CLP Regulation and defines that Regulation in the same provision as Regulation (EC) No 1272/2008, whose Articles 6 paragraph 5, 11 paragraph 3, 12, 14, 18 paragraph 3 letter b, 23, 25 to 29 and 35 paragraph 2 as well as Annexes I to VII "are to be read as amended from time to time". Regulation 7(7) letter c then names individual hazard statements in their wording. Point i covers a substance with "the hazard statement H340, H350 or H350i" or a substance or process listed in Schedule 1, point ii a substance with "the hazard statement H334". [263]

Since 1 January 2021 the British authority HSE has maintained, as GB CLP Agency, a binding list of its own. According to its own account, "all existing EU harmonised classification and labelling in force on 31 December 2020, are assimilated into Great Britain as GB mandatory classification and labelling (GB MCL)". For Northern Ireland the Union version continues to apply, because "substances and mixtures placed on the market in Northern Ireland are subject to the EU CLP Regulation". [267]

Index number	Substance	Classification and hazard statements
024-008-00-9	Calcium chromate	Carc. 1B H350; Acute Tox. 4 H302; Aquatic Acute 1 H400; Aquatic Chronic 1 H410
024-017-00-8	Chromium(VI) compounds, collective entry without barium chromate and without the compounds named elsewhere in the Annex	Carc. 1B H350i; Skin Sens. 1 H317; Aquatic Acute 1 H400; Aquatic Chronic 1 H410
024-018-00-3	Sodium chromate	Carc. 1B H350; Muta. 1B H340; Repr. 1B H360FD; Acute Tox. 2 H330; Acute Tox. 3 H301; STOT RE 1 H372; Acute Tox. 4 H312; Skin Corr. 1B H314; Resp. Sens. 1 H334; Skin Sens. 1 H317; Aquatic Acute 1 H400; Aquatic Chronic 1 H410, with specific concentration limits of 0.2 percent for H334 and for H317

Regulation 7(7) letter c point i therefore applies to all three entries, for calcium chromate through H350, for the collective entry through H350i and for sodium chromate through H350 and H340. For sodium chromate point ii applies in addition, through H334. [263, 266]

The list in Regulation 7(7) letter c does not name H317, and it does not name H314 either. Skin sensitization therefore does not trigger the minimization duty. It still makes the substance a substance hazardous to health under Regulation 2(1) letter a, because that letter covers every health hazard class. Assessment under Regulation 6 and control under Regulation 7(1) apply unchanged, and Schedule 2A letter b requires absorption through the skin to be taken into account. The additional regime depends on carcinogenicity, germ cell mutagenicity and respiratory sensitization. [263]

For the case dealt with here the distribution of the statements across the two salts matters. In the British list calcium chromate carries neither H317 nor H334 nor H314. Sodium chromate carries all three, and in addition toxicity for reproduction and repeated organ damage. Both form at the same interface, depending on the basic oxide of the insulation material. Section 3 deals with what the collective term obscures at this point. [266]

Measurement, health surveillance and forty years

Regulation 10(1) makes the measurement dependent on a precondition. Measurement takes place where the risk assessment shows that the measurement is "requisite" in order to maintain adequate control or to protect the health of the employees. Regulation 10(2) allows it to be dispensed with where the employer can demonstrate by other means that the requirements of Regulation 7(1) are met. There is no duty to measure as such. [263]

Regulation 10(4) refers, for certain substances and processes, to Schedule 4 and Schedule 5 with fixed measurement intervals. The only chromium entry there reads "Spray given off from vessels at which an electrolytic chromium process is carried on, except trivalent chromium", with an interval of fourteen days. Electrolytic chromium plating is therefore subject to mandatory monitoring. For work on insulated hot components there is no corresponding entry. [263]

Regulation 10(5) governs the retention. Where the record is representative of the personal exposure of identifiable employees, it is to be kept available for at least forty years from the last entry, in all other cases for at least five years. The forty years therefore arise only where the measurement was personal. Without measurement no register arises from which an exposure could later be reconstructed, and the COSHH regime contains no provision corresponding to the German exposure register under section 10a of the Hazardous Substances Ordinance. [263, 224]

Regulation 11 governs the health surveillance. It is mandatory where the employee is exposed to a substance named in Schedule 6 in the process named there, and in addition where an identifiable disease or adverse health effect may be related to the exposure, where its occurrence under the particular conditions is reasonably likely and where a suitable technique exists for detecting it that carries a low risk for the employee. On chromium, Schedule 6 names only "Potassium or sodium chromate or dichromate. In manufacture." Calcium chromate does not appear there, and the restriction "in manufacture" does not cover the maintenance of an insulated installation. The mandatory route through Schedule 6 is therefore blocked; what remains is the second route through the preconditions of Regulation 11(1) letter b. [263]

Regulation 11(3) requires a health record with the particulars approved by the authority, to be kept available for at least forty years from the last entry. The period corresponds to the German one and to the one under Union law. It applies only where the health surveillance is opened at all. [263]

Regulation 9 requires the protective measures to be kept in efficient working order and prescribes for local exhaust ventilation plant a thorough examination at least every fourteen months, and for respiratory protective equipment other than disposable types a thorough examination at suitable intervals. The records of these examinations are to be kept for at least five years. [263]

Instruction and the protection of third parties

Regulation 12(1) requires the employer who carries out work which can expose an employee to a substance hazardous to health to provide suitable and sufficient information, instruction and training. Regulation 12(2) names the content, among it the names of the substances and the risks connected with them, access to safety data sheets, relevant limit values, the significant findings of the risk assessment, the precautions to be taken, the results of measurements and the collective results of the health surveillance. [263]

Regulation 12(4) reaches beyond the employer's own company. The employer has to ensure that any person, "whether or not his employee", who carries out work in connection with his duties under these Regulations receives suitable and sufficient information, instruction and training. Outside contractors and self-employed persons who work on an installation are therefore included. [263]

The same follows from the Act. Section 2(1) of the Health and Safety at Work etc. Act 1974 obliges every employer to ensure, so far as is reasonably practicable, the health, the safety and the welfare at work of his employees; Section 2(2) letter c names in this connection information, instruction, training and supervision. Section 3(1) extends the duty to persons who are not his employees and who may be affected by his activity. Section 7 obliges every employee to take reasonable care for himself and for others and to cooperate with the employer in the performance of his duties. [262]

Supervision, criminal offense and duty to report

Supervision works with two types of notice. Under Section 21 an inspector may serve an improvement notice where a provision is being breached, with a time limit for remedying it. Under Section 22 he may serve a prohibition notice where an activity involves a risk of serious personal injury; the notice may take effect immediately and prohibits the activity until the defects have been remedied. British law contains no notification to the authority of work with carcinogens before it begins. [262]

The duties carry criminal sanctions. Section 30 reproduces the range: breaches under Section 33(1) letters a and c may be tried either summarily or on indictment, on indictment with an unlimited fine and imprisonment of up to two years under Schedule 3A. [112]

The sentencing of companies follows a guideline of its own. The guideline of the Sentencing Council for breaches of the employer duties and of health and safety regulations has applied since 1 February 2016 and was last updated on 5 October 2026. It forms a matrix of culpability and harm category and graduates the fine ranges according to the turnover of the company; the overall range runs from 50 pounds to 10 million pounds. The occurrence of harm is not a precondition, because the guideline assesses the likelihood of the harm and the number of those affected in their own right. [274]

Alongside the penalty stands the recovery of costs. Under Regulations 23 and 24 of the Health and Safety and Nuclear (Fees) Regulations 2022 the authority invoices the costs of an intervention where an inspector finds a material breach of a health and safety provision, limited to the reasonable costs actually incurred. There is no hourly rate laid down by statute; the authority publishes it, and as at 1 April 2026 it amounts to 188 pounds per hour. Regulation 24(13) exempts work carried out under an asbestos license from this recovery of costs. For chromium(VI) there is no license and therefore no corresponding exemption. [273]

The duty to report attaches to the diagnosis. Under Regulation 9 of the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 the employer has to report to the authority where he has a written diagnosis of one of the diseases named in Schedule 1 and the person concerned carries out the associated work. Schedule 1 part 1 number 3 names occupational cancer. Regulation 8 covers occupational dermatitis and occupational asthma. A report of the exposure as such, without a diagnosis, is not provided for. [269]

Waste

The classification runs through a chain of references. Regulation 4(1) of the Hazardous Waste (England and Wales) Regulations 2005 determines the term hazardous waste through the list of Decision 2000/532/EC as amended from time to time. The List of Wastes (England) Regulations 2005, which formerly stood alongside it, were revoked on 1 July 2015. For Wales regulations of its own from 2005 apply, for Scotland the Special Waste Regulations 1996 as amended in 2004, for Northern Ireland the Hazardous Waste Regulations (Northern Ireland) 2005. [270, 281]

The waste codes are the same as on the continent. For removed insulation the mirror entry 17 06 03* applies, "other insulation materials consisting of or containing hazardous substances". For linings and refractory materials 16 11 03* and 16 11 05* come into consideration, for chromates the entry 16 09 02*. A mirror entry requires an assessment of the hazard-relevant properties; without an assessment the waste is not classified as non-hazardous. [270]

The assessment threshold stands in the technical guidance WM3. The joint guidance of the environment agencies of England, Wales, Scotland and Northern Ireland, first edition in version v1.2.GB of October 2021, lays down for the hazard-relevant property HP 7, carcinogenic, a concentration limit of 0.1 percent by mass for substances of category 1A or 1B with H350. For this property the guidance contains no cut-off value below which a content would be left out of account. [271]

For the handling, a prohibition on mixing applies. Regulation 19 of the Hazardous Waste Regulations prohibits the mixing of different categories of hazardous waste and the mixing of hazardous with non-hazardous waste, and Regulation 20 lays down the exceptions and the duty to separate, so far as technically and economically feasible. The Regulations contain no express prohibition on dilution on the model of the German section 9a of the Circular Economy Act. Regulations 35 and 36 require for every carriage a consignment note with particulars of the producer, the waste code and the destination. [270, 233]

Above that lies the general duty of care. Section 34 of the Environmental Protection Act 1990 obliges everyone who produces, carries, treats or disposes of waste to take reasonable measures to ensure that the waste is not handled without authorisation, does not escape and is transferred only to authorised persons together with an accurate written description. The accurate description presupposes the accurate classification. [272]

Chemicals law: GB CLP and UK REACH

Since 1 January 2021 the authority HSE has maintained, as GB CLP Agency, a binding classification list of its own. The GB mandatory classification and labeling list, published on 17 February 2025 and last updated on 22 September 2025, contains calcium chromate under the Index number 024-008-00-9 as Carc. 1B with H350, sodium chromate under 024-018-00-3 and the collective entry for chromium(VI) compounds under 024-017-00-8 with H350i. The classifications therefore correspond to those under Union law. [266]

The law on authorisation diverges. In UK REACH, Annex XIV carries sodium chromate under entry 22. Calcium chromate stands neither in Annex XIV nor on the Candidate List. None of the restrictions covers the in situ formation on a component. The authorisation requirement attaches in any event to the use of a substance placed on the market and not to what forms at the interface; Section 25 deals with this point. According to the authority, the authorisations granted under EU REACH for chromium(VI) substances expired on 21 September 2024. [268]

I am not aware of any British procedure corresponding to the Union wide use ban proposed by ECHA in April 2025. The British position is therefore this: classification as in the Union, authorisation and restriction narrower. [268, 239]

The distance from the asbestos regime

The Control of Asbestos Regulations 2012 show what a legal system prescribes for a recognized process risk. Regulation 5 requires, before demolition, maintenance and similar work, the determination of the presence, the type and the condition of the asbestos and provides for cases of doubt that its presence is to be assumed. Regulation 6 requires the recording of the significant findings irrespective of the size of the company. Regulation 7 requires a written plan of work with a prescribed minimum content. [123, 275]

It continues with license and notification. Regulation 8 makes the work subject to licensing dependent on a permission from the authority, with an application lead time of 28 days and a validity of at most three years. Regulation 9 requires the notification of work subject to licensing fourteen days before it begins. Regulation 10 prescribes the content of the instruction in eleven individually named items, from the properties of the substance through decontamination and waste handling to the emergency procedures. [275]

Measurement and clearance are formalised. Regulation 19 requires the measurement of the asbestos fiber concentration at regular intervals and on any change that can affect the exposure. Regulation 20 and Regulation 21 require, for measurement, clearance certification and sample analysis, accreditation to ISO 17025, and for clearance in addition to ISO 17020. The guidance HSG248 in its second edition of May 2021 describes the clearance procedure in four stages and lays down a numerical criterion for the air sample inside the enclosure: all results must be below 0.010 fibers per millilitre. [275, 276]

For chromium(VI) none of this exists. There is no duty to establish the facts before the maintenance and no presumption rule, no prescribed plan of work, no license, no notification, no catalogue of instruction content, no duty to measure as such, no accredited laboratories, no clearance procedure and no cleanliness criterion for releasing a surface or a component back into use. Under the same provision both substances are carcinogens of category 1A or 1B. The depth of the procedure differs completely. [263, 275]

What the British body of rules names

No British legal act names the formation of chromate on insulated chromium-alloyed hot components. The only chromium entry in the measurement intervals of the COSHH Regulations concerns electrolytic chromium plating, the only chromium entry in the health surveillance the manufacture of potassium and sodium chromate. Insulation, high temperature and hot components do not appear in the Regulations. The list of waste covers the matter only through the mirror entry for insulation material, without naming chromium. [263, 270]

The publications of the authority fall short of that. The accompanying Approved Code of Practice L5 in its sixth edition 2013 expressly covers, in paragraphs 57, 69 and 87, substances that arise as waste or as a by-product or are released from processes; a full text search for "insulat" gives no hit in this document. Chromium appears there in connection with electroplating and chromate manufacture. The leaflet INDG346 lists, under the question where chromium(VI) occurs, the manufacture and use of stainless steel and other chromium alloys including welding and cutting, pigments for paints and ceramics, catalysts, dye manufacture, leather tanning and electroplating. Insulation is missing from this list. I have not found any publication of the authority that names the formation pathway. [264, 88]

The matter has been named from another quarter. The Safety Bulletin Summary of the British industry association Energy UK of September 2019 describes it completely. It names as locations high pressure steam lines, combustion chamber components and exhaust gas paths of gas turbines where calcium-containing insulation or calcium-containing release agents are used, and records as the conditions of formation: "1. Calcium based product is present 2. Temperatures greater than 300°C 3. Chromium Steel is present." It points out the yellow discolouration resembling sulfur, which is hard to see under sodium vapor light, and recommends assuming the presence of chromium(VI) at all power stations. Section 26 deals with the practice with penetrating oil named there. [92]

Two specialist bodies are to be added. The occupational medicine research institute IOM names "calcium containing insulation systems" among the occurrences in an undated leaflet and records: "Cr VI dust can be commonly found on high-temperature insulated parts such as large engines." The Energy Institute maintains a page in its Toolbox which describes the formation on stainless steel in contact with materials containing calcium oxide such as thread sealants or insulation and points out the increase at elevated temperatures; according to the page the material is taken over from Energy Safety Canada. [277, 278]

The trade association responsible says nothing. Among its technical documents the Thermal Insulation Contractors Association publishes material on fire stops, pipe penetrations, heat pumps and outside air ducts. On chromium(VI) or chromates nothing is to be found there. The training provider association UKATA maintains a syllabus on chromium(VI) awareness which names welding, electroplating, pigment manufacture, foundry work and coating removal and leaves out insulation. The companies that carry out this work therefore receive their sector documents without the formation pathway dealt with here. [279, 280]

The position is therefore the following. The mechanism has been named in the United Kingdom since September 2019, with a threshold temperature and a reaction partner, in a members paper of an industry association of electricity generation which cannot be found on the website of that association. The authority has not taken it up in any of its publications. The absence of a note from the authority changes nothing about the duties, because these attach to the term substance and not to a list. [92, 263]

What follows from this for a company in the United Kingdom

The duties begin before the work. Regulation 6(1) prohibits the start without a suitable and sufficient assessment, and Regulation 6(2) letter e names maintenance with the potential for a high level of exposure as a subject of assessment in its own right. An assessment that does not consider the formation pathway on insulated chromium-alloyed hot components, although the component materials and the operating temperatures are known, does not meet this requirement. [122]

The measures follow a fixed ranking. The first point to be examined is replacement under Regulation 7(2), then the design of the processes and control at source under Regulation 7(3), and only after that personal protective equipment. For carcinogens the measures of Regulation 7(5) are added, from the enclosure to the cleaning of the surfaces. For a substance with H350 or H350i this includes the minimization to the lowest level that is reasonably practicable under Regulation 7(7) letter c, which applies in addition to the limit value. Anyone who considers the substitution impracticable bears the burden of proof for that in proceedings under Section 40 of the Act. [113, 263, 262]

With the limit value the current state is to be observed. What governs is EH40 in its fourth edition 2020 with 0.01 mg/m³ as a time weighted average over eight hours, and not the value of 0.05 mg/m³ from the leaflet of the authority that was not brought into line. Compliance with the limit value does not end the duties, because Regulation 7(7) places the minimization alongside it and Schedule 2A requires the skin and ingestion to be taken into account. [265, 263]

The documentation depends on the size of the company. From five employees upwards the significant findings of the assessment and the steps taken are to be recorded under Regulation 6(4). Where the measurement is personal, the records are to be kept available for forty years. This includes the examination of whether the health surveillance is opened under Regulation 11(1) letter b, because the route through Schedule 6 is not open for this set of facts. [263]

The instruction reaches beyond the employer's own workforce. Under Regulation 12(4) every person who carries out work in connection with the duties of the employer is to be included, whether employed or not. This includes the insulation companies, the maintenance companies and the self-employed persons working on the same installation. Section 3(1) of the Act additionally obliges the operator towards everyone who may be affected by his activity. [263, 262]

The waste is to be classified before disposal. Removed insulation falls under a mirror entry whose classification requires an assessment; under WM3 the threshold for the carcinogenic property is 0.1 percent by mass. This includes the separation under Regulations 19 and 20 and the consignment note under Regulations 35 and 36. The written description under Section 34 of the Environmental Protection Act 1990 has to be accurate. [270, 271, 272]

There is no need to wait for a naming by the authority. The duties under Regulation 2(1), 6 and 7 attach to the property of the substance and apply irrespective of whether the authority lists the formation pathway in a publication. The burden of proof rule of Section 40 operates in the same direction, because it places the demonstration of the limit of what is practicable on the employer. For electricity generation the information has been available since September 2019 within the industry association of the sector itself. [263, 262, 92]

42. Appendix: insulation materials with basic oxides and where they are installed

The following commercially available insulation materials contain the basic oxides described, which can trigger thermochemical in-situ formation of the chromium(VI) compounds described. These are not assumptions, but conclusions drawn from manufacturer information, warning notices from users and my own field observations.

The evidence column names the origin of the information. H stands for information from a manufacturer or from a standard, W for a warning notice or a user report, F for my own field observation. Where a manufacturer publishes no figures, this is stated expressly in the table.

The content figures refer to the oxide analysis of the insulation material in the as-delivered condition. Whether and to what extent the oxides become available at the interface is dealt with in Sections 9 to 12 of this analysis.

Insulation materials containing calcium, sodium and other basic oxides

Material and trade form	Documented content of basic oxides	Evidence
E-glass, yarn and fabric for printed circuit boards and aviation	CaO 16 to 25 %, MgO 0 to 5 %, Na_2O and K_2O 0 to 2 %	H [191]
E-glass, general applications: fabric, tape, needled mat, roving	CaO and MgO together 16 to 30 %, alkali metal oxides 0 to 2 %	H [191]
E-glass, manufacturer information on textile fibers and fabrics	CaO 16 to 25 %, Na_2O and K_2O 0 to 1 %, MgO 0 to 5 %	H [192]
ECR glass, boron-free modification of E-glass	no oxide table of its own in the standard; it defines ECR only as a boron-free modification of E-glass. A comparison of the two glass types gives CaO 16 to 25 % for boron-containing E-glass and 17 to 25 % for boron-free glass; in the direct comparison in the same work the boron-free glass reached CaO 22.3 to 22.9 % against 19.55 to 22.35 % for the borosilicate glass	H [191, 193]
Mineral wool, rock and glass wool: mat, wire mesh mat, board, pipe section	Na_2O, K_2O, CaO, MgO and BaO together more than 18 percent by weight; the value is part of the substance identity under Annex VI index 650-016-00-2 and not a batch property	H [194]
AES wool, substance definition of the manufacturers	calcium oxide and magnesium oxide together 18 to 43 %, silicon dioxide 50 to 82 %	H [195]
AES wool, blanket (Superwool Plus Blanket)	CaO 26 to 32 %, MgO 3 to 7 %	H [195]
AES wool, board (Superwool Plus Board)	CaO and MgO together 31 %	H [195]
AES wool, blanket (Insulfrax LT)	CaO 27 to 33 %, MgO 2.5 to 6.5 %	H [196]

Material and trade form	Documented content of basic oxides	Evidence
AES wool, blanket (Insulfrax 1300 HT)	CaO and MgO together 21 to 27 %	H [196]
AES wool, magnesium silicate variant (Isofrax)	MgO 18 to 27 %, no declared CaO content	H [196]
Aluminum silicate wool and ceramic fiber (ASW, RCF): blanket, board, paper, module	Na_2O, K_2O, CaO, MgO and BaO together less than or equal to 18 percent by weight; dividing value in relation to index 650-016-00-2. The manufacturers' data sheets do not quantify alkali and alkaline earth oxides	H [198, 78, 197]
Calcium silicate, board and molded part	CaO 38 to 43 %	H [199]
Calcium silicate, pipe section and block	synthetic calcium silicate at least 90 %; a breakdown into CaO and SiO_2 is not published	H [200]
Perlite, expanded: loose fill and molded part	Na_2O 3.7 %, K_2O 5.3 %, CaO 0.5 %, MgO 0.1 %. The analysis comes from a filter perlite; for pipe and tank insulation materials the manufacturers publish no oxide analysis	H [201]
Vermiculite, expanded: loose fill and board	MgO 21.5 to 25.5 %, K_2O 3 to 6 %, CaO 2.0 to 6.0 %; the data sheet additionally lists Cr_2O_3 at 0.01 to 0.15 %	H [202]
Aerogel blanket	no calcium compound and no sodium compound declared; more than 50 % textile glass without chemical specification. The data sheet of the blanket rated to 650 °C names a fiber batting, the older version a glass fiber batting; no oxide analysis of this glass appears in any of the sheets. Blankets rated to about 650 °C carry an E-glass component, seen in the field, for which the standard gives CaO 16 to 25 %	H [203, 204, 191], F
Basalt fiber, fabric and needled mat	the manufacturer publishes no oxide breakdown. Publicly available figures for basalt fiber give SiO_2 53 %, Al_2O_3 18 %, Fe_2O_3 10 %, CaO 9 %, MgO 5 %, Na_2O 3 %, K_2O 1 % and TiO_2 1 %; a review gives for basalt rock CaO 8.59 %, MgO 4.63 %, Na_2O 3.34 %, K_2O 1.46 % and Cr_2O_3 0.06 %	H [205, 206, 207]
Ceramic fiber paper and ceramic fiber felt	binder 2 to 15 % organic or 50 to 70 % inorganic; the substance identity of the inorganic binder is not named	H [197]
Assembly paste for hot components, containing calcium	calcium hydroxide 10 to below 20 percent by mass	H [208]

Two rows call for a comment. The substance definition of mineral wool and that of ceramic fiber are delimited from each other by the same oxide content: more than 18 percent by weight leads to mineral wool, up to and including 18 percent by weight to ceramic fiber. The content of basic oxides is therefore not a secondary characteristic, but the characteristic that distinguishes the two substance groups. And the summation formula of Annex VI expressly names sodium, potassium, calcium, magnesium and barium oxide. [194, 198]

Applications using these insulation materials

Field of application	Insulated components, insulation material and trade form	Temperature	Evidence
Yachts and superyachts	Exhaust line, exhaust manifold, dry turbocharger and indicator valves; insulation mat with riveted-on sheet metal cladding, metallic insulation cladding of cassette design, removable textile insulation shells. Removable sections are expressly provided for maintenance	surface below 220 °C required; components in the engine compartment up to 750 °C	H [209, 210]
Container ships and merchant ships, two-stroke engine	Exhaust manifold and exhaust lines; insulation with a cover of galvanised sheet metal	not stated in the document	H [211]
Container ships and merchant ships, four-stroke engine	Exhaust line from the turbocharger outlet via the exhaust gas boiler and the silencer to the funnel, plus the SCR unit; insulation pads on the turbocharger, continuous insulation from 30 mm thickness with cover sheet, SCR insulation designed to be demountable	turbine outlet 390 °C in normal operation, 450 °C in the design, 554 °C in emergency operation	H [211, 212], W [137]
Cruise ships	Auxiliary diesel engines, exhaust lines and exhaust gas cleaning; same engine series and same insulation design as in four-stroke operation in merchant shipping, removable mattresses on valves and fittings	as for the four-stroke engine	F
Locomotives and rail vehicles	Exhaust gas turbocharger, exhaust manifold, complete exhaust runs and exhaust gas aftertreatment; textile molded insulation part to the fire protection standard EN 45545, integral insulation with an outer shell of stainless steel foil or thin sheet, stitched insulation mats with alkaline earth silicate, E-glass or silica as insulation material and stainless steel foil or nickel-base foil on the hot side, expressly removable and reusable	molded part up to 650 °C; mat types up to 816 °C and up to 1,149 °C	H [210, 213]
Construction machines and mobile working machines	Turbocharger, manifold, exhaust system, particulate filter and SCR modules, underbody insulation and engine compartment heat protection; three-dimensional molded fiber parts with outer shells of stainless steel foil or thin sheet	components up to 750 °C, surface reduced to below 220 °C	H [210]
Combined heat and power plants and cogeneration	Exhaust system and exhaust gas turbocharger of the gas engine; metallic insulation cladding as completely removable modules	exhaust gas 421 °C at full load, 476 °C at half load	H [214, 210]
Standby and emergency power installations, including in data centers	Exhaust line of the diesel generator set; calcium silicate or mineral wool pipe sections, laid in two layers, with jacket, banding and tie wire of stainless steel 304. For this case the manufacturer expressly recommends calcium silicate, because the organic binder of the mineral wool burns out from about 177 °C	371 °C to almost 538 °C	H [215]

Field of application	Insulated components, insulation material and trade form	Temperature	Evidence
Gas and steam turbines	Exhaust duct, transition piece, turbine casing, heat recovery steam generator, silencer and stack; internal insulation behind liner sheets of 304 or 409 steel, flexible insulation pillows, fiber insulation mats and fiber modules in the heat recovery steam generator, insulation mattresses on the casing, removable and reusable	casing above 500 °C, exhaust duct above 480 °C, heat recovery steam generator up to 1,093 °C	H [216], W [217]
Road vehicles, trucks and passenger cars	Heat shields, cast manifolds, exhaust system, particulate filter, SCR and mounting mats in the catalytic converter; heat shield of cassette design with cover sheet or foil of stainless steel or aluminum and an insulation insert inside, needled mat as mounting mat	heat shield up to 1,100 °C depending on the material; peak manifold temperature 1,000 °C	H [218, 219, 220, 48]
Industrial furnaces, boilers, waste incineration and biomass plants	Boiler walls, flue gas ducts and pipework; rock wool wire mesh mats with galvanised or stainless steel wire mesh	up to 640 °C, heavy version up to 649 °C	H [221]
Chemical plants and refineries	Pipework on austenitic steels, valves and flanges; wire mesh mats, pipe sections and removable covers	up to 640 °C, pipe sections up to 650 °C	H [221]

The materials side is quantified in the same documents. Under the European materials standard, stainless steel begins at 10.5 percent chromium. For manifolds, pipes, catalytic converters and silencer housings, one manufacturer names the ferritic material 1.4509 with 17.80 percent chromium and oxidation resistance up to 950 °C as well as 1.4521 with 19 percent chromium up to 1,025 °C; the same manufacturer states the peak temperature at the manifold as 1,000 °C. In the exhaust duct of the gas turbine, the liner sheets are of 304 or 409 steel and the fastening of 304. On the exhaust line of the emergency generator set, the jacket, the banding and the tie wire are of 304. [220, 217, 215]

Both sides of the reaction described in Section 9 are thus present next to each other in the same components: the chromium-alloyed steel as the chromium source and the insulation material as the carrier of the basic oxides. The tables say nothing about the extent to which the reaction proceeds in an individual case. They say where the conditions for it are present.

For the exhaust systems of the four-stroke engines a manufacturer warning exists. In Instruction WS00Q563 Wärtsilä names Cr(VI) residue on exhaust system components, on the panels of the exhaust insulation boxes and on turbocharger parts, and names calcium-based insulation and calcium-containing anti-seize paste as the calcium source from 400 °C. [137]

43. Conclusion

Fundamentals and insulation technology

Calcium chromate and sodium chromate are chromium(VI) compounds that can be deliberately formed under alkaline-oxidising thermal conditions. The historical patent specification and the experimental interface findings establish a foreseeable substance conversion process that must be taken into account in material selection and risk assessment.

The systemic error lies where thermal insulation performance, fiber behavior and as-delivered condition are treated as a sufficient safety assessment, while the in-situ formation of hazardous substances during operation is insufficiently taken into account. Alkaline oxide fractions constitute a hazard indication; protection and prevention must not be based solely on air values, visible deposits or positive rapid tests.

Gas-phase transport and calcium-/sodium-dependent chromate formation complement each other. Toshiba investigates prevention; the ECFIA commission shows that the question was known within the European manufacturers' association. [11, 26, 35-38]

Vehicles

Vehicle contamination furthermore concerns handling, maintenance, permanent remedy and owner costs. Warranty claims under sales law and manufacturers' safety-law measures offer separate avenues of examination in the EU. [22, 23, 46, 47]

Combustion residues

Combustion residues, including grate ash, the shutdown phase and cremation ash, extend the assessment to operation, overhaul and environmental pathways. The implementation of the documented knowledge in analytics, protection and information must be examined. [30-34, 43-45]

Afterword by the author

The statement that calcium oxide is involved in the formation of carcinogenic chromates sounds disproportionate at first. A substance regarded in insulation practice as a matter of course, and absent from every cancer assessment, is said to be the cause of a finding that affects entire stocks of plant. Anyone hearing this for the first time may be sceptical. The process has, however, been described thermodynamically and confirmed experimentally for decades, and the evidence for it is set out in this analysis.

It was no different for me in 2019. I had documented the compositions of glass fabrics, mineral and basalt wools for decades and had nevertheless never asked about calcium as a reaction partner. None of my suppliers could answer the question at the time. Only from patent literature, interface studies, manufacturer documents and my own field findings did it emerge what is at issue and what scale the matter has.

The practical consequence of this account is considerable. Insulation materials containing calcium oxide are standard in high-temperature engineering and are found on boilers, turbines, engines, exhaust systems, marine propulsion and construction machinery. No sound figure for the quantity exists, because this stock has never been recorded with chromate formation in mind. As long as the affected share is not delimited, no prioritisation is possible either.

I also understand the reticence I perceive among today's insulation manufacturers in addressing and communicating the matter. And as a long-standing supplier I can imagine the dilemma of the engine and turbine manufacturers and of the insulation contractors working with them.

I likewise know how tensions arise in a waste incineration plant, at a combined heat and power unit, in power station operation or in an engine room when protective measures are introduced that change the established working routine. They affect people who have done their work for years without complaint, and they raise at the same time the question of past exposure.

None of these points changes the substance. They should not keep us from pursuing safety for people and the environment and from initiating the necessary measures. We have already looked away for far too long once before, in the very fields discussed here. As indicated at the outset: may history not repeat itself.

Markus Sommer

44. Disclosure

I have worked in high temperature insulation since 1988 and on the formation of hexavalent chromium compounds on insulated chromium-alloyed hot components since 2019. The three words of the Chromate Experts are detecting, mastering, preventing, and they also describe what I am involved in. Out of this work came developments in which I took part, in insulation materials without alkali and alkaline earth oxides as well as in products for decontamination during remediation and maintenance work.

I am managing partner of Kavarmat® Sp. z o.o. Sp.k. in Długołęka and a shareholder of Cleansulation® Technology B.V. in Almere. The trade marks Kavarmat®, Cleansulation® and VitroSilk® belong to me personally. This includes the offerings at kavarmat.com, cleansulation.tech and kavar.shop, among them the KavarClean®Redox Powder named in section 26. The companies in which I hold an interest carry out insulation and remediation work on chromate-contaminated installations and are subject to the same duties that are set out in this analysis.

This analysis is not a purchase recommendation and would be worthless as one. It names manufacturers and products where their own documents are the subject of the account, and it measures every statement against what the document concerned supports. The same standard applies to my own products. Where no proof of effectiveness exists, that is stated there.

Sources

1. Udy, Marvin J.: Chrome Alloy Making, US Patent 2,176,687; filed 22 January 1938, granted 17 October 1939. Relevant passages: description, printed pages 2-3; claims 22-26, printed page 7. Patent copy Source

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244. European Commission: Third study on collecting most recent information for a certain number of substances with the view to analyse the health, socio-economic and environmental impacts in connection with possible amendments of Directive 2004/37/EC, Final Report of 8 February 2018, reference VC/2017/0011, ISBN 978-92-76-07993-4, doi:10.2767/042168; partial report Chromium(VI) in fumes from welding, plasma cutting and similar processes. Accessed 17 October 2026. Source

245. Arbeidsomstandighedenwet (Netherlands), BWBR0010346, version in force from 1 July 2026; Article 3 paragraphs 1 and 4, Article 5 paragraphs 1, 3 and 4, Article 8 paragraphs 1 and 4, Article 24 paragraph 1, Article 27, Article 28 and Article 28a. Accessed 17 October 2026. Source

246. Arbeidsomstandighedenbesluit (Netherlands), BWBR0008498, version in force from 1 August 2026; Article 1.1 paragraph 5 letter b, Article 4.1c, Article 4.2 paragraphs 7, 8 and 9, Article 4.10c paragraphs 4 and 5, Articles 4.11 to 4.13, Article 4.15, Article 4.16, Articles 4.18 to 4.21, Article 9.9b paragraph 1 letter d, Article 9.10a paragraphs 1 to 3 and Article 9.22. Accessed 17 October 2026. Source

247. Arbeidsomstandighedenregeling (Netherlands), BWBR0008587, version in force from 27 August 2026; Articles 4.19 and 4.20 as well as Bijlage XIII Onderdeel A and B2 with the entry "Chroom (VI)-verbindingen (als Cr)" and the accompanying explanatory note, together with Article 4.20c (carcinogenic processes determined nationally). Accessed 17 October 2026. Source

248. Regeling van de Minister van Sociale Zaken en Werkgelegenheid of 18 October 2016, 2016-0000222216, tot wijziging van de Arbeidsomstandighedenregeling in verband de wijziging van twee wettelijke grenswaarden in Bijlage XIII (Bisfenol A en Chroom (VI)-verbindingen), Staatscourant 2016, 57792, issued on 2 November 2016, in force since 1 March 2017; Article I letter B and Article II as well as the Toelichting on Article I letter B. Accessed 17 October 2026. Source

249. Ministerie van Sociale Zaken en Werkgelegenheid (Netherlands): HERDRUK SZW-lijst met kankerverwekkende stoffen en processen, mutagene of voor de voortplanting giftige stoffen, Staatscourant 2026, 23121, Heruitgave of 9 July 2026; part 1 A list of the carcinogenic processes with ten items, part 1 B with the entries on chromium(VI) compounds including calcium chromate and sodium chromate as well as part 2 and part 3. Accessed 17 October 2026. Source

250. Beleidsregel boeteoplegging arbeidsomstandighedenwetgeving (Netherlands), BWBR0032326, version in force from 11 February 2025; Article 1 paragraphs 1, 3, 8, 10, 11 and 12 as well as the Tarieflijst, Onderdeel Arbobesluit, with the lines on Articles 4.1b, 4.1c, 4.2, 4.13, 4.15 to 4.20 and footnotes 60, 61 and 77. Accessed 17 October 2026. Source

251. Arbeidsomstandighedenbesluit (Netherlands), BWBR0008498, version in force from 1 August 2026, Hoofdstuk 4 Afdeling 5 Asbest; Article 4.46, Article 4.47 paragraphs 7 and 8, Article 4.47c paragraphs 1 and 2, Article 4.51a paragraphs 1 to 3, Article 4.54a paragraphs 3 to 7 and Article 4.54d, together with Arbeidsomstandighedenregeling Articles 4.26 and 4.27 on the certification schemes. Accessed 17 October 2026. Source

252. Regeling Europese afvalstoffenlijst (Eural, Netherlands), BWBR0013546, version in force from 1 January 2024; Articles 1, 2 and 4 paragraphs 1 to 3. Dutch designations of the waste codes according to the Handreiking EURAL, Rijkswaterstaat, Ministerie van Infrastructuur en Waterstaat, version of 31 August 2019. The reversed burden of proof according to the official explanatory note of the Informatiepunt Leefomgeving. Accessed 17 October 2026. Source

253. Wet milieubeheer (Netherlands), BWBR0003245, version in force from 1 August 2026; Article 10.38 paragraphs 1 and 2, Article 10.39 paragraph 1, Article 10.40 paragraph 2 and Article 10.54 paragraph 1. Article 10.54a lapsed on 1 January 2024; since then the mixing of hazardous waste on site requires a permit under Article 3.196 of the Besluit activiteiten leefomgeving. Accessed 17 October 2026. Source

254. Rijksinstituut voor Volksgezondheid en Milieu (RIVM, Netherlands): Chroom-6 op de POMS-locaties van Defensie: gezondheidseffecten en verantwoordelijkheden, RIVM report 2018-0061, 2018, as well as Onderzoek naar blootstelling aan chroom-6 en arbeidsomstandigheden op Defensielocaties, periode 1970-2015, RIVM report 2021-0066, 2021; commissioned by the Paritaire Commissie Chroom-6, question concerning chroom-6-houdende verf of verfstof. Accessed 17 October 2026. Source

255. Rijksinstituut voor Volksgezondheid en Milieu (RIVM, Netherlands): Onderzoek naar chroom-6 bij NS/NedTrain in de periode 1970 t/m 2020, RIVM report 2022-0152, 2022; Publiekssamenvatting on old paint layers and on grinding and welding work. Accessed 17 October 2026. Source

256. Rijksinstituut voor Volksgezondheid en Milieu (RIVM, Netherlands): Chroom-6 bij het re-integratieproject tROM, RIVM report 2018-0164, published in January 2019; restoration work on museum trains in Tilburg and the finding on the Risico-Inventarisatie of 2005. Accessed 17 October 2026. Source

257. Rijksinstituut voor Volksgezondheid en Milieu (RIVM, Netherlands): Inventarisatie van toepassingen van chroom-6 op de werkplek, RIVM letter report 2020-0080, 2020; section 4.2.1 on refractory linings, overview table in section 5.2 and summary with the note "hier is echter geen informatie over verkregen". Accessed 17 October 2026. Source

258. Regeling uitkering chroom-6 Defensie (Netherlands), BWBR0040982, version in force from 8 June 2021; Bijlage 2 letter b with the exhaustive list of the activities relevant to assessment. Accessed 17 October 2026. Source

259. Arboportaal of the Ministerie van Sociale Zaken en Werkgelegenheid (Netherlands): Wat is chroom-6? as well as Factsheet chroom-6, version of 9 June 2020, published on 14 July 2020, and Beheersregime chroom-6 en andere gevaarlijke stoffen, Versie 2.0 of 11 April 2022 with the limitation of application in footnote 1. Accessed 17 October 2026. Source

260. Nederlandse Arbeidsinspectie (Netherlands): topic page Chroom-6; the sources of exposure named, the note on the reach of the Beheersregime and the sentence "Een negatieve uitslag is echter niet genoeg om te besluiten om géén maatregelen te nemen." Accessed 17 October 2026. Source

261. Beleidsregel arbocatalogi 2019 (Netherlands), BWBR0042288, version in force from 21 June 2023; Bijlage, line "Installatie- en isolatie" with the provisions relied on and the hazardous substances named, asbestos and quartz dust. Accessed 17 October 2026. Source

262. Health and Safety at Work etc. Act 1974 (c. 37, United Kingdom), version "Latest available (revised)"; Section 2 paragraphs 1 and 2, Section 3 paragraphs 1 and 2, Section 7, Section 21 Improvement notices, Section 22 Prohibition notices, Section 40 Onus of proving limits of what is practicable as well as Section 84 Extent. Accessed 17 October 2026. Source

263. The Control of Substances Hazardous to Health Regulations 2002 (SI 2002/2677, United Kingdom), version "Latest available (revised)", extent note E+W+S; Regulation 2 paragraph 1 (the terms "substance hazardous to health" and "carcinogen"), Regulation 6 paragraphs 2 and 4, Regulation 7 paragraphs 4, 5, 7 and 9, Regulation 9 paragraphs 1 to 5, Regulation 10 paragraphs 1 to 5, Regulation 11 paragraphs 1, 3 and 5, Regulation 12 paragraphs 1, 2 and 4 as well as Schedule 1, Schedule 2A, Schedule 4, Schedule 5 and Schedule 6. Accessed 17 October 2026. Source

264. Health and Safety Executive (Great Britain): L5, Control of substances hazardous to health, The Control of Substances Hazardous to Health Regulations 2002 (as amended), Approved Code of Practice and guidance, sixth edition 2013, ISBN 978 0 7176 6582 2; paragraphs 57, 69 and 87 as well as the notes on Schedule 5 and Schedule 6. A full text search for "insulat" gives no hit in this document. Accessed 17 October 2026. Source

265. Health and Safety Executive (Great Britain): EH40/2005 Workplace exposure limits, fourth edition 2020, ISBN 9780717667031; introductory note on the amendments that came into force on 17 January 2020, Table 1 with the entry "Chromium (VI) compounds (as Cr)", 0.01 mg/m³ as a time weighted average over eight hours and 0.025 mg/m³ for process generated exposure with footnote 1, notes Carc, sen and BMGV. Accessed 17 October 2026. Source

266. Health and Safety Executive (Great Britain) as GB CLP Agency: The GB mandatory classification and labelling list, published on 17 February 2025, last updated on 22 September 2025, file mcl-list.xlsx; entries 024-008-00-9 calcium chromate (Carc. 1B, H350), 024-017-00-8 Chromium (VI) compounds (collective entry, H350i) and 024-018-00-3 sodium chromate. Accessed 17 October 2026. Source

267. Health and Safety Executive (Great Britain): The GB CLP Regulation; assimilation of the harmonised classifications under Union law, with the wording "all existing EU harmonised classification and labelling in force on 31 December 2020, are assimilated into Great Britain as GB mandatory classification and labelling (GB MCL)" and, on the distinction from Northern Ireland, with the wording "substances and mixtures placed on the market in Northern Ireland are subject to the EU CLP Regulation". Accessed 17 October 2026. Source

268. Health and Safety Executive (Great Britain): UK REACH Authorisation List (Annex XIV), file authorisation-list-annex-xiv.xlsx, with sodium chromate under entry 22; UK REACH Candidate List, file candidate-list.xlsx; Restrictions under REACH, file list-of-restrictions.xlsx, version 1 of 31 March 2021; as well as the notice Authorisations of hexavalent chromium compounds (CrVI) on the expiry of the authorisations granted under EU REACH on 21 September 2024. Calcium chromate is contained neither in Annex XIV nor on the Candidate List. Accessed 17 October 2026. Source

269. The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013 (SI 2013/1471, United Kingdom), version "Latest available (revised)"; Regulation 8 Occupational diseases, Regulation 9 Reportable occupational diseases as well as Schedule 1 part 1 numbers 2 and 3. Accessed 17 October 2026. Source

270. The Hazardous Waste (England and Wales) Regulations 2005 (SI 2005/894), version "Latest available (revised)"; Regulation 4 paragraph 1, Regulation 6, Regulation 19, Regulation 20 paragraph 2 as well as Regulations 35 and 36. The List of Wastes (England) Regulations 2005 (SI 2005/895) were revoked with effect from 1 July 2015 by SI 2015/1360 Regulation 10 letter a; since then the applicable reference to Decision 2000/532/EC "as amended from time to time" has stood in Regulation 4 paragraph 1. In addition: The Hazardous Waste (Wales) Regulations 2005 (SI 2005/1806) and the Special Waste Regulations 1996 (SI 1996/972) as amended by the Special Waste Amendment (Scotland) Regulations 2004 (SSI 2004/112). Accessed 17 October 2026. Source

271. Environment Agency, Natural Resources Wales, Scottish Environment Protection Agency and Northern Ireland Environment Agency: Waste Classification, Guidance on the classification and assessment of waste, Technical Guidance WM3, first edition, version v1.2.GB of October 2021, LIT 10121; Appendix A with the waste codes 16 09 02*, 16 11 and 17 06 as well as Appendix C7 Table C7.1 with the concentration limit of 0.1 percent by mass for HP 7 for Carc. 1A and 1B with H350. Accessed 17 October 2026. Source

272. Environmental Protection Act 1990 (c. 43, United Kingdom), Section 34 Duty of care etc. as respects waste, version "Latest available (revised)". Accessed 17 October 2026. Source

273. The Health and Safety and Nuclear (Fees) Regulations 2022 (SI 2022/1378, United Kingdom), Regulation 23 and Regulation 24, including Regulation 24 paragraph 1 on the limitation to the reasonable costs actually incurred and Regulation 24 paragraph 13 on the exemption of work carried out under an asbestos licence; in addition Health and Safety Executive: HSE fees and charges, current rates, as at 1 April 2026, with a rate of 188 pounds per hour for Fee for Intervention. There is no hourly rate laid down by statute. Accessed 17 October 2026. Source

274. Sentencing Council (England and Wales): Health and safety offences, Organisations: Breach of duty of employer towards employees and non-employees, Breach of duty of self-employed to others, Breach of Health and Safety regulations; in force since 1 February 2016, last updated on 5 October 2026; steps 1 and 2 with the matrix of culpability and harm category, the turnover categories and the overall range from 50 pounds to 10 million pounds. Accessed 17 October 2026. Source

275. The Control of Asbestos Regulations 2012 (SI 2012/632, United Kingdom), version "Latest available (revised)"; Regulation 6 paragraph 1 letter b, Regulation 7, Regulation 8 paragraphs 1 to 4, Regulation 9 paragraph 1, Regulation 10 paragraph 1 letter a numbers i to xi, Regulation 19 paragraphs 1 and 4, Regulation 20 paragraphs 1, 3 and 4 as well as Regulation 21 paragraphs 1 and 2. Accessed 17 October 2026. Source

276. Health and Safety Executive (Great Britain): HSG248, Asbestos, The Analysts' Guide, second edition May 2021 as amended in July 2021, ISBN 9780616667079; Table A5.1 with the clearance procedure in four stages and the criterion "All air sample results must be <0.010 f/ml for this stage to pass". Accessed 17 October 2026. Source

277. Institute of Occupational Medicine (United Kingdom): Protect your workers from the threat of Chromium VI, leaflet without any date, version or reference; naming of "calcium containing insulation systems" as well as the statement "Cr VI dust can be commonly found on high-temperature insulated parts such as large engines". No publication date can be taken from the document. Accessed 17 October 2026. Source

278. Energy Institute (United Kingdom): Toolbox, Exposure hazard, hexavalent chromium; description of the formation on stainless steel in contact with materials containing calcium oxide such as thread sealants or insulation and of the increase at elevated temperatures. According to the page the material is taken over from Energy Safety Canada, page date 3 May 2023. Accessed 17 October 2026. Source

279. Thermal Insulation Contractors Association (United Kingdom): TICA Technical Resources, overview of the technical documents; reviewed on 17 October 2026, with no document on chromium(VI) or chromates. Source

280. UK Asbestos Training Association: OH02 Syllabus, Chromium VI Awareness (Hexavalent Chromium); the occurrences named are welding, electroplating, pigment and paint manufacture, foundry work, construction and demolition with chromium-containing coatings as well as coating removal. Insulation, hot components and turbines are not named. Accessed 17 October 2026. Source

281. Northern Ireland and Scotland: The Control of Substances Hazardous to Health Regulations (Northern Ireland) 2003 (SR 2003/34), The Control of Asbestos Regulations (Northern Ireland) 2012 (SR 2012/179), The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (Northern Ireland) 1997 (SR 1997/455), The Health and Safety at Work (Northern Ireland) Order 1978 (SI 1978/1039 (NI 9)) and The Hazardous Waste Regulations (Northern Ireland) 2005 (SR 2005/300). Accessed 17 October 2026. Source

282. Li, Y.; Qin, C.; Zhang, J.; Lan, Y.; Zhou, L.: Cu(II) Catalytic Reduction of Cr(VI) by Tartaric Acid Under the Irradiation of Simulated Solar Light. Environmental Engineering Science 2014, 31, 447-452. DOI: 10.1089/ees.2013.0407. For citric acid alone the work reports, following Li, C.; Lan, Y.; Deng, B.: Catalysis of manganese(II) on chromium(VI) reduction by citrate, Pedosphere 2007, 17, 318, a conversion of less than 5 percent of 50 µmol/l Cr(VI) at pH 4.5 within 22 hours and an acceleration by about a factor of 45 through manganese(II). Accessed 18 October 2026. Source

283. Yan, B.-Z.; Chen, Z.-F.: Influence of pH on Cr(VI) reduction by organic reducing substances from sugarcane molasses. Applied Water Science 2019, 9, article 61. DOI: 10.1007/s13201-019-0940-x. In particular the conversions of 99.6 to 99.9 percent at pH 2.0 and 2.5 and of 36.3 to 15.4 percent at pH 3.0 to 8.0 in the sterile set-up. Accessed 18 October 2026. Source

284. VES Systems: Hexavalent Chromium Products, product page for Hex Buster, a product for the surface decontamination of hexavalent chromium, with a statement on effectiveness without a named laboratory and without published data. Accessed 18 October 2026. Source

285. Kavarmat® Sp. z o.o. Sp.k.: product pages KavarClean® Redox Powder & Spray, Kavar.Shop. Accessed 18 October 2026. Source

Version history

Version	Date	Change
1.0 US	October 2026	First edition of the United States edition. It follows the German benchmark edition in version 1.7. The chapters on France and Switzerland are replaced by Section 33 on the duties in the United States, Section 34 on California, Section 35 on Canada, Section 36 on the North American documents of the manufacturers and associations concerned and Section 37 on a question to American practice; the comparison of rules in Section 18 extended to nine frameworks; conclusion renumbered 38; American spelling throughout; forty sources added.
1.1 US	October 2026	New appendix on insulation materials with basic oxides and where they are installed, placed before the conclusion, with two tables: commercially available insulation materials with their documented content of calcium, sodium and other basic oxides, and the application fields in which these materials sit on chromium-alloyed hot components, from yachts, container ships and cruise ships through locomotives, construction machinery and road vehicles to combined heat and power plants, standby generating sets, turbines, furnaces and chemical plants; conclusion renumbered 39; twenty-eight sources added.
1.2 US	October 2026	Three new sections before the appendix: the duties in Germany, the duties in the European Union and the duties in the Netherlands. They set out the rules that the common part of this analysis cites throughout, each with its own references: the German Gefahrstoffverordnung with the duty to investigate before work begins, the exposure register and the asbestos comparison; Directive 2004/37/EC with the binding limit value, the register and the forty-year period, together with classification, authorisation and the restriction proposal of 2025; and the Dutch Arbeidsomstandighedenbesluit with the limit value of 0.001 mg/m³, the employer's own limit value where none is laid down, the fine framework and the Dutch chromium-6 complex; appendix and conclusion shifted by three numbers; forty sources added.
1.3 US	October 2026	One new section before the appendix: the duties in the United Kingdom. The COSHH Regulations 2002 define a hazardous substance by the classification criteria and not by an actual classification, name maintenance with the potential for a high level of exposure as its own object of assessment, and require the record of the assessment only from five employees onwards. Regulation 7 sets prevention, replacement and the order of the control measures, and for a substance with H350 or H350i it requires exposure to be reduced to as low a level as is reasonably practicable in addition to the limit. EH40/2005 fourth edition 2020 carries 0.01 mg/m³ as a time weighted average over eight hours and 0.025 mg/m³ for process generated exposure, while the leaflet INDG346 of the authority still carries the value of 0.05 mg/m³ that applied before 17 January 2020. The section also covers monitoring, health surveillance and the forty year period, the training of the employees of other companies, supervision, the criminal offence, cost recovery and the duty to report, waste law under the Hazardous Waste Regulations and WM3, GB CLP and UK REACH, the distance to the asbestos regime, and the Energy UK safety bulletin summary of September 2019, which names the three conditions of formation including the threshold of 300 degrees Celsius; appendix and conclusion shifted by one further number; nineteen sources added.

Version	Date	Change
1.4 US	October 2026	Correction and further detail on the British rules. The United Kingdom row of the comparison in Section 18 now gives 0.01 mg/m³ as an eight-hour average and 0.025 mg/m³ for process generated exposure under EH40/2005, fourth edition 2020; the value of 0.05 mg/m³ given so far comes from the leaflet INDG346, which the authority has not brought into line after the lowering of 17 January 2020, and is marked as such. New in the section on the United Kingdom: the three conditions of Regulation 7(7) joined by "and", with the comparison to Article 5 paragraph 3 of Directive 2004/37/EC and to section 10 paragraph 1 of the German Gefahrstoffverordnung; the finding that EH40 carries no skin notation for chromium(VI) and that the annotation "sen" there covers occupational asthma only; and a subsection on the hazard statements with the three entries of the GB mandatory classification and labelling list and the finding that H317 and H314 are not named in Regulation 7(7) letter c. One source added.