History Repeats Itself

Chromium(VI) in High-Temperature Insulation and the Parallels to Asbestos

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Foreword

In 1988 my father started his own business making textile insulation. Three years later he died of asbestosis at the age of 59. He never worked with asbestos directly, but he did work in rooms where asbestos insulation mats had once been made and which nobody had ever cleaned up.

Since 2019 I have been studying the formation of chromium(VI) compounds on insulated hot components, and the longer I work on it, the more often I come across patterns I know from the history of asbestos. A material is considered safe. Warnings appear early and are doubted or dismissed as irrelevant. The hazard becomes most apparent during maintenance and removal, and its consequences often show only decades later.

After "The Overlooked Ingredient" and "The Overlooked Use Ban", this is my third work on the subject. The first two establish the facts chemically and legally, and their sources are available at www.cr6.info. This one describes what these facts are currently setting off at the companies that build and operate equipment and among the people who maintain it. One chapter is devoted to the authorities in charge of oversight, another to what the issue means beyond Europe. The comparison with asbestos runs through every chapter.

Since when has not knowing no longer been an option?

1. The Findings

High-temperature insulation materials contain basic oxides, above all calcium oxide and sodium oxide, which are not themselves classified as carcinogenic. Above about 300 °C they can react with the chromium oxide layer of chromium-alloyed hot components to form calcium chromate and sodium chromate, two carcinogenic chromium(VI) compounds. In the as-delivered condition there is no chromate. It can only form during operation at the interface between insulation and component, and it can form again after cleaning.

Contrary to a widespread belief in the market, chromium(VI) cannot be neutralized. At most it can be reduced to chromium(III) compounds, and even that works most reliably in the laboratory and only to a limited extent on technical equipment. The laboratory reports that are often cited as certified proof of effectiveness describe these limits themselves. They are rarely read, because anyone looking for such a product understandably hopes for a solution that spares him the prescribed measures. Whoever points out the limits is quickly regarded as the black sheep, and that is one of the milder labels attached to my name.

Whether and where chromate forms depends on the conditions on site. The German TRGS 561 lists among the influencing factors the temperature, the chromium content of the alloy, oxides from insulation materials or assembly pastes, oxygen and moisture. The fact that no chromate has appeared on a piece of equipment so far is therefore no guarantee that formation will not start tomorrow. Any installation can be affected where chromium-alloyed steel, a basic-oxide insulation material, oxygen and temperature come together, that is, gas and diesel engines, combined heat and power units, gas and steam turbines, power plant piping, boilers, marine engines, vehicles, locomotives, aircraft engines and construction machinery. Mineral wool, calcium silicate, E-glass products and AES wools contain these oxides, and they are the standard of today's high-temperature insulation.

Release

Once chromate has formed, it is released as soon as the insulation is opened, during maintenance, overhaul, cleaning, removal and dismantling. It is then present as a powder and as chromate-containing dust and leaves the work area on tools, clothing, gloves and removed components. Releases are also possible during normal operation. There is a constant temperature gradient between the hot component and the cooler surroundings. The air in the porous insulation heats up, expands and escapes at joints, seams and fastenings, on cooling the insulation draws in ambient air again, and the vibration of the machine adds to this. These air movements can carry chromate dust that has formed to the outside.

Air measurements do not capture this dust reliably, because it does not distribute evenly in the room, so an unremarkable air measurement can easily lead to a wrong assessment. Whatever is released and stirred up settles somewhere later, often where nobody expects it, and dust in a room cannot be controlled. Wipe samples have detected chromates on light switches and cable trays as well, in areas that have no direct connection to the insulation. What settles on equipment ends up on the floor, and from there clothing and above all footwear carry the particles out of the work area, into other parts of the plant and finally home. With asbestos, too, family members fell ill who had never worked on a plant, for example because they shook out and washed the work clothes. This is not scaremongering. Taken by themselves the quantities are small, but harm to health and the environment does not require large quantities. How many particles already hide behind a microgram that is barely visible to the eye, also in comparison with asbestos, is shown in the section "Just a Little Dust" in the chapter on the workers.

In many cases asbestos was also inconspicuous in its installed state and became dangerous when it was worked on, damaged or removed. The chromates under the insulation behave in a similar way. The hazard lies in the installed base, and it affects primarily the people who work on the equipment, less those who operate it.

What Remained After the Asbestos Phase-Out

On the job site people spoke of asbestos without distinguishing between chrysotile, amosite and crocidolite. This had few consequences, because each of these minerals was a fiber. The term "chromium(VI)" works in a similar way, but with one decisive difference. Whoever hears it thinks of chromic acid, electroplating and chromate primers, that is, of substances he does not use himself. Calcium and sodium chromate as reaction products of one's own operation do not appear in this picture, and so for decades the collective term has prevented anyone from asking about the reaction partner.

The phase-out of asbestos was imperative and right. What was replaced was the fiber, while the basic-oxide chemistry of the insulation systems remained. Calcium silicate already belonged to the same market in the asbestos era, Johns-Manville explicitly advertised its product Thermobestos as "calcium silicate insulation," and mineral wool was already being installed mixed with asbestos in the 1940s. On chromium-alloyed hot components the conditions for chromate formation therefore remained in place. "Asbestos-free" says nothing about whether an insulation material contributes to chromate formation.

With the replacement of asbestos insulation materials, a standard emerged in insulation technology that is still in place today. Engine and energy technology has since advanced many times over, but at the end the engine component is still covered by an insulation element whose technical origin lies in the 1970s and which has hardly changed since. I have worked in high-temperature insulation since 1988 and have experienced this development from the inside. High-temperature insulation technology is a particularly innovation-averse field, in which nobody questioned any longer what had been accepted as the solution after asbestos. Asbestos, too, was the undisputed standard of thermal insulation for decades, as long as it served its technical purpose.

2. The Manufacturers

Engine, turbine and insulation manufacturers know how chromate forms. Since November 2020, Wärtsilä, Caterpillar, Rolls-Royce, MAN, Mercedes-Benz, Proventia, Frenzelit and Rockwool have issued their own communications on the subject. Since May 31, 2023, INNIO Jenbacher has governed work on its gas engines in Technical Instruction TA 2300-0025 "Application of the Cr-6 reduction solution," which is addressed to customers, sales and service partners, and MAN has detected calcium chromate on engine components that had been in service in its own analyses.

With asbestos, the first reliable indications were available decades before the ban, and with chromates it is no different. In 1939 Udy's US patent describes the deliberate production of calcium chromate from a chromium source, lime and atmospheric oxygen. In April 1990 Babcock & Wilcox warned boiler operators in Plant Service Bulletin PSB-43 about chromium(VI) from chromium-containing refractory material, and in 1994 the company extended the warning to other chromium-containing materials, including insulation materials and textiles. In a 2010 patent application Toshiba described precisely the interface between stainless steel and calcium-containing thermal insulation and proposed a separating layer as a remedy, and in 2015 Japanese researchers directly detected calcium and sodium chromate at this interface.

The warnings were doubted, dismissed as irrelevant or attributed to other causes. Because of their color, yellow dusts and residues were taken for sulfur, and where that did not fit, they were blamed on a coating or the alloy. When chromium-containing insulation products were phased out in 1994, the reaction partner calcium remained in the replacement products. The yellow powder kept appearing and was now considered unavoidable.

Today's manufacturer communications govern occupational safety at the moment the work is done. They prescribe protective equipment, prohibit compressed air and brushes and in some cases recommend treatment with reduction solutions. Wärtsilä requires calcium-free assembly pastes, Proventia recommends them. No leading manufacturer has so far announced the same step for the insulation material itself. The question suggests itself whether handling is being regulated while the material stays, because a change of insulation material would raise questions about all the equipment already delivered. The asbestos industry paved this path. When the health consequences could no longer be disputed, it promoted the controlled use of chrysotile for decades, and protective measures were meant to keep the material usable. That the manufacturers had known about the health consequences since the 1930s was later shown in the United States by the documents presented in the asbestos litigation.

Each company cultivates its own perception of the problem. Where rapid tests are provided for, they are presented as reliable, although they are only conditionally dependable and their informative value is correspondingly limited. Chemically, too, the assessment is limited. The cotton-swab rapid tests are designed for an area of one square centimeter, and an area that has been swabbed once cannot be used for a second test, because its surface has then been chemically treated. A negative result therefore does not rule out chromium(VI) contamination. A French field study found 869 ng of chromium(VI) in the laboratory on the turbocharger of an engine, while the rapid test at the same spot remained negative. Much remains half-hearted, and that too is familiar from the asbestos era, when limit values and measurements made handling appear manageable.

For the manufacturers this raises questions they should ask themselves, namely whether their notices reach everyone who works on the equipment, including independent workshops, reconditioners and recyclers, whether their safety information describes the condition of the product after use or only the as-delivered condition, and which insulation material they are shipping today with new equipment whose service life extends far beyond the coming use ban.

3. The Operators

On the operators' side, chromate formation can in principle affect any installation that was fitted with the replacement insulation materials after the asbestos phase-out, provided that temperature, material and operating conditions coincide. The industry relied on these materials. Whether, in view of the warnings since 1990, one should not have seen what one was relying on is the question that arises.

Thousands of installations have been delivered and are in operation, and new ones are being fitted with the same insulation materials in these very weeks. Order books are full, deadlines are tight, and service personnel have been working on these installations for years without being informed about chromate formation or protected against it. Whoever takes the steps that are actually necessary under these circumstances raises questions that reach far beyond today, for example since when the facts have been known, which employees should have been entered in an exposure register, whether occupational medical care was offered, and what happens to the installations already at customer sites and to the spare parts in stock.

These questions are asked in the minds of those responsible long before they are spoken anywhere, and it stands to reason that they delay the first step. Whoever changes nothing has nothing to explain, or so it seems, and that too is familiar from the history of asbestos. The calculation does not work, however. In Germany, the Netherlands, the United Kingdom and the United States, fines and penalties attach to the failure to carry out a risk assessment and to missing protective measures, not to health damage that has occurred. Every further maintenance job without an assessment is another such case, and in Germany the accident insurer can also take recourse if an insured event was caused by gross negligence. The question of since when one knew becomes harder to answer with every year.

Doing nothing is also a decision. It is made anew at every maintenance job, and each time somebody opens an insulation without protection, under which chromate may have formed. The first step ends this state, and the later it comes, the longer the stretch for which the company has to account.

The biggest economic question concerns the installed base. In Germany the operator is the client commissioning the work on his installation and, under Section 5a of the German Hazardous Substances Ordinance, must provide the contractor before the work begins with all information available to him about hazardous substances that are present or suspected. The model operating instructions of the German BG BAU require that removed mineral wool products not be reused, and an insulation element that has to be disposed of after the first maintenance does not reach the service life for which it was procured. Building owners know this situation from the history of asbestos. Asbestos in existing buildings was known long before remediation got under way, and the remediation of the building stock continues to this day. The obligation of the client under Section 5a was introduced in 2024 mainly with a view to this asbestos stock. It applies equally to insulated hot components.

4. The Workers

The risk is borne by the people who open the insulation. For them, the yellow powder on exhaust manifolds, turbochargers and flanges has been part of everyday work for years. It was taken for sulfur, removed with rags and sprays, and the insulation was put back on. Many are only now learning that they have been working with carcinogenic chromates, and they ask themselves how often and for how long.

With asbestos, the consequences appeared first among insulators. In 1964 Irving Selikoff demonstrated clusters of lung cancer and mesothelioma among the members of the insulators' union in New York and New Jersey. But it also struck those who merely worked nearby, like my father. With chromium(VI), as with asbestos, years to decades pass between exposure and disease, and whoever opens an insulation without protection today will not notice the consequences tomorrow.

For asbestos there is a closed procedure. Throughout the EU, asbestos work must be notified to the authority in advance, and personnel must be specially trained. In Germany a certificate of competence is also required, areas are sealed off, and protective measures end only after a clearance measurement, and in the Netherlands only certified companies may remove asbestos. For the chromates on insulated hot components none of this exists. Cleaning is done with rags, sprays and test strips by the existing maintenance staff, although the chromates carry classifications that asbestos does not have. Under Annex VI of the CLP Regulation, calcium and sodium chromate are classified as very toxic to aquatic life with long-lasting effects, and sodium chromate additionally as corrosive to skin and as a skin sensitizer. The difference in treatment is explained by the fact that asbestos was delivered as a product, whereas the chromate can only form during operation.

The subordinate role of personal protective equipment has been anchored in EU law since 1989 and has long been national law in the member states. The new Directive (EU) 2026/2450 of October 21, 2026, lays it down explicitly for carcinogens and names respiratory protection specifically. What is new is the wearers' right to regular breaks in an area free of contamination risk, whose length and frequency follow from the risk assessment, and the member states must transpose it into national law by November 20, 2028. Anyone who works a whole shift in a full-face mask and protective suit needs these breaks and a place where he can take them without contamination. The regulatory analysis "Personal Protective Equipment as a Last Resort" in the compendium of The Chromate Experts reproduces the provisions verbatim.

Throughout the EU, workers are entitled to information and instruction on the hazardous substances they work with, and anyone exposed to carcinogens belongs in the exposure register, which is kept for at least forty years after exposure ends. In Germany, operating instructions are added and, for anyone who may be repeatedly exposed to chromium(VI), mandatory occupational medical care. This applies equally to contractors and temporary workers, and in Germany diseases caused by chromium or its compounds are listed as occupational disease no. 1103. Anyone who finds dust or residues on insulated equipment should know that color is not a reliable sign, because chromium(VI) can also be present without visible yellow dust.

With asbestos, fiber counts and contaminated areas were far greater than what happens today on insulated hot components. Chromium(VI), however, brings other properties. It does not form fibers, the contamination is usually invisible, and in addition to the inhalation hazard there is skin contact and the hazard to the environment. In the asbestos field there is the saying that a single fiber can kill. I do not apply it to chromium(VI) particles, but what is true about it is that for carcinogens without a threshold, nobody can seriously state above which inhaled quantity a disease develops and below which it does not.

The law therefore works with risks. The German TRGS 910 sets a tolerable concentration of 1 µg/m³ for chromium(VI) compounds, expressed as chromium in the inhalable fraction (DGUV). It corresponds to the

tolerable risk of 4 in 1,000, arithmetically four additional cancer cases among 1,000 workers who are exposed to this concentration every working day for 40 years. The binding occupational exposure limit of the European Union under Directive 2004/37/EC has been 5 µg/m³ since January 18, 2025, five times as high (Annex III).

"Just a Little Dust"

Whoever is alarmed at 100,000 asbestos fibers per cubic meter and considers the little bit of yellow dust on the exhaust manifold harmless is comparing a number with an impression. Asbestos is counted in fibers, chromium(VI) is measured by weight, and the two only become comparable through conversion.

A typical asbestos fiber is about 10 µm long and 0.5 µm thick and, at the density of chrysotile, weighs around 5 picograms, that is, 5 trillionths of a gram. 100,000 such fibers together weigh about 0.5 µg, depending on the length and thickness of the fibers 0.04 to 4 µg. It is precisely these 100,000 fibers per cubic meter that the German TRGS 910 sets for asbestos at the tolerable risk of 4 in 1,000, and for chromium(VI) at the same risk 1 µg/m³. The two values look completely different, but they describe the same cancer risk and are of the same order of magnitude by weight.

Counted the other way round, the little bit of dust looks different. 1 µg of chromium(VI) as calcium chromate in particles of 1 µm diameter amounts to around 1.8 million particles, and at the same risk 100,000 asbestos fibers are thus matched by around 1.8 million chromate particles. The quantity a worker inhales is also small. At around 10 m³ of breathing air per shift, at the tolerable concentration this is about 10 µg of chromium(VI) per day, a good 2 mg over a working year of 220 shifts and just under 90 mg over 40 working years, less than a tenth of a gram. With this quantity over a working life, TRGS 910 calculates four additional cancer cases among 1,000 workers. The French field study found 869 ng of chromium(VI) on the turbocharger of a single engine. Distributed in one cubic meter of air, that would come close to the tolerable concentration.

This equivalence is not reflected in the limit values. Under Directive (EU) 2023/2668, a limit value of 10,000 fibers per cubic meter applies to asbestos until December 20, 2029. By that date the member states switch fiber counting to electron microscopy, and until then counting is done with phase-contrast microscopy where possible. From December 21, 2029, either the same value applies including thin fibers below 0.2 µm, or a value of 2,000 fibers per cubic meter (WHO). That is about 0.05 and 0.01 µg/m³. The binding European limit value for chromium(VI) is 5 µg/m³ and thus, by weight, one hundred to five hundred times higher. The calculation compares masses and particle numbers, it says nothing about the mechanisms of action of the two substances.

5. Oversight

After the asbestos phase-out, insulation manufacturers, authorities and accident insurers worked hand in hand for many years. This was intended and is built into German law. Under Section 20 of the German Hazardous Substances Ordinance, the Committee on Hazardous Substances, which drafts the TRGS, is to include employers, trade unions, state authorities, statutory accident insurance and science. What came out of this cooperation deserves respect, because it considerably reduced the hazard from fibers.

The replacement fibers were examined jointly and classified within the regulations, and from this emerged the classification and exoneration criteria by which man-made mineral fibers are assessed to this day. The European classification groups as mineral wool those silicate fibers with a content of more than 18 percent of sodium, potassium, calcium, magnesium and barium oxides. Under Note Q, the classification as carcinogenic does not apply if the fibers are broken down quickly enough in the biopersistence test (Directive 97/69/EC of December 5, 1997). In Germany the carcinogenicity index was decisive for a long time, the sum of the oxides of sodium, potassium, boron, calcium, magnesium and barium minus twice the aluminum oxide content. From a value of 40, a vitreous fiber was not classified as carcinogenic (TRGS 905). Since June 1, 2000, mineral wools that have not been exonerated may no longer be manufactured or used in Germany for thermal and acoustic insulation, fire protection and technical insulation in building construction, and exonerated products generally carry the RAL quality mark of the Gütegemeinschaft Mineralwolle (Gewerbeaufsicht Niedersachsen).

For high-temperature insulation this leads to an uncomfortable finding. The carcinogenicity index rises with the content of basic oxides, because these dissolve the fiber faster in the body, and the more calcium and sodium oxide a vitreous fiber contains, the more likely it is to be exonerated. On chromium-alloyed hot components, precisely these oxides are the reaction partner for chromate formation. With the same 1997 directive, aluminosilicate wool, which contains at most 18 percent of these oxides, was classified as carcinogenic, and in 2010 it was added to the candidate list of substances of very high concern. As an alternative, manufacturers offer alkaline earth silicate wools that are exempted under Note Q. In all cases, what was assessed was the fiber in its as-delivered condition and its behavior in the lung. What the same fiber forms after years at several hundred degrees on chromium-alloyed steel was not part of the assessment.

The supervisory authorities now recognize in-situ formation. Since May 4, 2026, the German TRGS 561 has dealt with it in a section of its own and requires the protective regime as soon as chromium(VI) contamination cannot be ruled out, and the German statutory accident insurance institutions BG BAU, BG ETEM and BG Verkehr explicitly name the affected areas. The next step is far more difficult. Whoever recognizes the hazard potential of chromate formation must in the same breath point to the products that for many years were treated, largely jointly, as the recognized state of the art, and psychologically that is a tough nut to crack.

In procedural law, such a situation is described as bias. It does not require misconduct, the justified appearance of a lack of impartiality is sufficient. The European Court of Human Rights therefore also examines impartiality under Article 6 of the European Convention on Human Rights by its outward appearance. Whether a body can reassess without bias a substance it helped to classify is a fair question. In the high-temperature field, regulators and insulation manufacturers will in any case have to part ways.

With asbestos, too, handling was regulated first. In Germany, asbestosis was recognized as an occupational disease as early as 1936, and asbestos was banned on October 31, 1993 (German Environment Agency). In between lay 57 years in which handling was regulated. As its first limit value, asbestos received a technical guidance concentration in 1971 (Bavarian Environment Agency). It denoted the concentration “that can be achieved according to the state of the art” and, in the wording of TRGS 102, could “not completely exclude” a health risk. The

yardstick was what was technically achievable, and the regulations called the substance itself into question only at the end.

6. The Global Dimension

Hundreds of thousands of installations with insulated hot components are in operation worldwide, and if vehicles are included, there are far more. The insulation materials in question are standard everywhere. Engines, turbines and exhaust systems from European manufacturers run on every continent, ships are maintained in whichever ports they happen to call at, construction machinery and commercial vehicles in workshops all over the world. The International Agency for Research on Cancer of the World Health Organization classifies chromium(VI) compounds as carcinogenic to humans, Group 1, in the very same Volume 100C in which it also evaluates asbestos (IARC, Monograph 100C). This hazard is a property of the substance and does not depend on the country in which someone comes into contact with it. The only difference is how countries protect their workers and the environment from it.

What this means for the existing stock of insulated installations, ships and vehicles cannot be quantified, because this stock has never been recorded with chromate formation in mind. For gas engines, coal-fired power plants, waste incineration lines and ships alone, public inventory figures and cautious assumptions about maintenance intervals yield a rough estimate of 58,000 to 61,000 maintenance events per year, before deducting overlaps, at which the insulation is opened (derivation of the order of magnitude). On top of this come millions of workshop visits by commercial vehicles. The rules that cover the issue, on the other hand, apply in only a few places. TRGS 561 is a German rule, the REACH Regulation applies in the European Economic Area, and the manufacturers nevertheless deliver one and the same product to all markets.

Asbestos has shown how long a worldwide phase-out takes. Germany banned asbestos in 1993, the European Union in 2005, the United States chrysotile only in 2024, and in many countries asbestos is still used today. Canada mined and exported chrysotile until its last mines closed in the early 2010s, while buildings were being remediated at home. In the United States, the asbestos lawsuits drove major manufacturers into bankruptcy. Johns-Manville filed for bankruptcy in 1982, and to this day trust funds compensate those who fell ill. Whoever supplies worldwide is also subject to legal systems in which liability for damage to health is structured this way.

One difference from asbestos weighs heavily here. Asbestos was delivered as a product, and where it was banned, delivery ended. Chromate can form anew during operation on any installation fitted with a basic-oxide insulation material, and as long as these insulation materials are supplied, the stock keeps growing.

Power Plants and Combined Heat and Power Units

The Global Integrated Power Tracker of Global Energy Monitor lists 116,095 power units worldwide (Carbon Brief, July 2024). These include wind, solar and hydropower plants without insulated hot components, the rest are coal, gas, oil, bioenergy, nuclear and geothermal plants with insulated steam and exhaust lines. In the United States the Department of Energy records almost 4,400 sites with combined heat and power (US Department of Energy), and in Germany more than 10,000 combined heat and power units are in operation. They supply hospitals, residential districts, greenhouses, wastewater treatment plants and biogas plants, and their exhaust line is opened at every major overhaul. The German statutory accident insurance institutions explicitly name combined heat and power units among the affected areas.

In June 2026 INNIO went public on Nasdaq. The principal shareholder sold 90 million shares for around 2.4 billion US dollars, and INNIO itself received no proceeds from the offering (Börsen-Zeitung, June 4, 2026). The final

prospectus of June 3, 2026, does not mention the chromate issue. Chromium, chromates and carcinogenic substances do not appear in it, and it refers to hazardous substances, occupational safety and personal protective equipment only in general terms (prospectus filed with the US Securities and Exchange Commission). The prospectus describes design and manufacturing defects as a possibility that "could cause a large field recall," it relates hazards from hazardous substances to "our current or former facilities," and the term product liability does not appear. It puts the installed base of the company's own gas engines at around 44 gigawatts as of December 31, 2025, and points out that engines in the global fleet can reach a service life of more than 20 years. Technical Instruction TA 2300-0025 on Cr-6 reduction had been in place for three years at that time. In 2021 a US federal court of appeals ruled that risk factors describing a risk only as a possibility can be misleading if the risk has already materialized (In re Alphabet, Ninth Circuit). This raises the question of whether chromate formation on the company's own engines belonged in the IPO prospectus.

Data Centers

We are in a phase that is very hungry for energy. Hardly a day goes by without engine and turbine manufacturers reporting new orders, above all for data centers. Wärtsilä is supplying gas engine power plants of 412 megawatts and 282 megawatts for data centers in the United States. Siemens Energy quotes delivery dates in 2030 and 2031 for gas turbines ordered today (Börsen-Zeitung, June 11, 2026). According to an industry overview in Turbomachinery Magazine from July 2026, new turbine capacity at GE Vernova, Siemens Energy and Mitsubishi Power will not be available before the end of 2028, and Baker Hughes is sold out with its NovaLT turbines until 2028. Rolls-Royce Power Systems increased its order intake in 2025 by 21 percent to 7.14 billion euros, driven above all by power supply for data centers and by the defense business, and is expanding its plants in Friedrichshafen and Mankato (release of February 27, 2026). In October 2025 INNIO received the largest order in its history from VoltaGrid, 2.3 gigawatts of Jenbacher capacity for data centers (release of October 21, 2025).

For the data centers, power plants are being built at a new density. Wärtsilä's 412-megawatt project comprises 40 gas engines of the 34SG type, 2 gigawatts with Caterpillar engines of the G3500 series are planned for the Monarch campus in West Virginia, PROENERGY is supplying Crusoe with 13 gas turbine sets totaling 650 megawatts, and INNIO has signed a framework agreement with Rehlko for 1.25 gigawatts of Jenbacher capacity (Power Engineering). Around 11,600 data centers are in operation worldwide (Voronoi, June 2026), and more and more of them generate their power on site because grid expansion cannot keep pace. A site with 40 engines has 40 insulated exhaust lines that are maintained on the same schedule.

As they have been for decades, these machines are fitted with insulation materials that contain basic oxides. Each of them is maintained over its entire service life, and the insulation is opened at every maintenance. What is delivered in these years makes up the installed base that will still be worked on long after the coming use ban. This, too, has a parallel. In Germany, asbestos was installed above all in buildings from the 1960s and 1970s (German Environment Agency), and worldwide consumption only declined at the end of the 1970s (USGS). What was installed in the years of greatest demand still keeps remediation busy today.

Boilers and Incineration Plants

In recent months boilers have come into focus. Often it is the cover mat on a chromium-containing casing or the calcium-containing sealing rope on the chromium-alloyed door to the combustion chamber where chromate can form. The sealing ropes on boiler and furnace doors used to be made of asbestos. Here too it was the fiber that was replaced, and its replacement can today itself be the reaction partner.

In waste incineration plants a second formation pathway is added that has nothing to do with the insulation. The chromium enters the combustion with the waste, can be oxidized to chromate there and ends up in the

ashes. Francesca Paoletti examined this formation pathway in her Karlsruhe dissertation (FZKA 6755, 2002). For the worker who cleans a boiler or opens its insulation, it is the same dust. More than 3,100 waste incineration plants are in operation worldwide (ecoprog, March 2026).

Ships and Yachts

On January 1, 2025, the merchant fleet comprised around 112,500 ships of 100 gross tonnage and above (UNCTAD), and in addition there are yachts, ferries and government vessels. Measurements and investigations in recent months show chromate contamination in almost every examined engine room of ships, in particular also on yachts and superyachts. In some cases the dust has spread over the entire engine room and is accessible there through skin contact. The measurements also show that the chromates are carried out of the engine rooms, because chromate deposits were detected on floors, desks and office chairs in cabins and on the bridge. On a ship, the crew lives where it works.

At the same time, suppliers of exhaust aftertreatment systems for ships and yachts are issuing warnings. In Information Bulletin 2/2025 "Hexavalent Chromium (Cr(VI)) Awareness and Safety Guidance," the Finnish company Proventia Oy describes the formation of calcium chromate on stainless steel exhaust systems in contact with calcium-containing insulation mats and assembly pastes above 300 °C. In a "Chromium (VI) Precautionary Notice," the Swiss company HUG Engineering AG alerts its customers to chromate formation on insulated stainless steel exhaust systems, and its service technicians can carry out a rapid test before starting work and postpone maintenance if contamination is confirmed.

With asbestos, too, ships were a focal point. Since January 1, 2011, the International Convention for the Safety of Life at Sea has prohibited the new installation of asbestos-containing materials on all ships without exception (IMO), and the stock on board still keeps shipping companies busy today.

Vehicles and Rail Vehicles

According to the last published overall survey by the manufacturers' association OICA, more than 1.2 billion motor vehicles were in use worldwide (OICA). Every heat shield is high-temperature insulation, and at exhaust manifolds, turbochargers and exhaust aftertreatment, chromium-alloyed steel and insulation meet. Not every small car is fitted with heat shields made of glass fiber needle mats. For vans and trucks, especially those with exhaust aftertreatment, I assume that it is more than half. In the European Union, with around 31 million vans and 6.2 million trucks (ACEA), that is more than 18 million vehicles, not counting buses, construction machinery and agricultural machinery. On passenger cars from three manufacturers on two continents, I have detected **chromium(VI)** also on cold, freely accessible surfaces of the engine compartment away from the hot components. The German BG Verkehr explicitly names vehicles among the affected areas, and they are serviced in dealer workshops and independent garages all over the world.

The same applies to rail vehicles. In North America alone, around 37,700 locomotives were in service at the end of 2024, most of them diesel-electric (Railway Age via Rolling Stock World), and diesel railcars and shunting locomotives run on every continent. Rail vehicles, too, had to undergo extensive remediation after the asbestos phase-out.

Aviation

Aircraft engines, too, are encased in insulation materials that contain basic oxides. In June 2025 the global commercial fleet comprised 35,550 aircraft, of which 30,300 were in active service (IATA). In aviation, chromates have been known for decades from corrosion-protection primers that are used deliberately. Formation on engine insulation is independent of this and a source of its own, which can be exposed at every overhaul in the engine

shops. This is exactly where the collective term mentioned in the findings takes effect, because whoever hears chromium(VI) in aviation thinks of the primer.

Retired Components

When its use ends, a component has not left the world. Diesel particulate filters are cleaned and reconditioned. The Danish manufacturer Dinex offers operators of truck and bus fleets an exchange in which the used filter is sent back, reconditioned and delivered again as a "reconditioned unit" with type approval (Dinex, November 2025). A component on which chromate may have formed thus goes back into operation, and it is precisely this reinstallation that the chapter "The Law Catches Up" describes as use.

Catalytic converters and SCR units are opened and decanned to recover the precious metals. In the European Union around 6.5 million vehicles reach the end of their life every year (European Parliament), and their exhaust systems pass through further hands as scrap metal or used parts. Whether the manufacturers' notices reach those who dismantle, sort or reinstall them is the question from the chapter on the manufacturers. With asbestos, too, the hazard was not confined to the large installations. Brake linings and clutch discs were changed thousands of times in workshops, and abrasion dust and old parts went their own way, unregulated, for a long time.

7. The Dilemma of Engine and Insulation Manufacturers

Every installation delivered remains in the field, and with it the insulation with which it left the factory. A manufacturer that switches today to an insulation material without basic oxides thereby answers a question for the new installations and leaves it open for the old ones. The operators of the installations already delivered will want to know why their installation still runs with the old material, whether it will be retrofitted and who pays for that. The INNIO prospectus describes what a design defect can trigger, namely a large field recall. With engines that run for more than 20 years, this question reaches far into the future.

Added to this is a burden the manufacturers have imposed on themselves. They report on sustainability, occupational safety and health. Under the European reporting standards this also includes workers in the value chain (ESRS S2), that is, the service technicians, workshops and reconditioners who open the insulation. The circular economy, too, has a downside here. Programs such as Cat Reman or the mtu Reman Technology Centres of Rolls-Royce Power Systems in Germany and the United States take back used engines and components, recondition them and put them back into service (Caterpillar, Rolls-Royce). Whether they take into account that chromate may have formed on these components is a question for the programs themselves.

Power generation itself keeps advancing. Each generation of engines and turbines brings more output and higher efficiency, emission limits are getting tighter, and exhaust aftertreatment requires the heat to stay in the exhaust gas until it reaches the catalyst. Insulation has thus become part of emission control. The insulation element itself has hardly taken part in this development. Highly optimized machines still carry a material concept from the 1970s that has since been assessed mainly with regard to fiber issues. Everything by which the performance of an installation is measured gets optimized, and nobody measures the insulation as long as it holds the heat.

The irony is that an insulation material in its as-delivered condition can meet all applicable requirements and still contribute to the formation of chromium(VI) compounds under operating conditions. The insulation materials are exonerated, and they were exonerated because of their content of basic oxides, that is, because of precisely the constituent that forms chromate on chromium-alloyed steel. The safety data sheets describe the

as-delivered condition completely and correctly. Every manufacturer communication on chromate formation is compliance as well, and each one documents at the same time since when the company has known about the formation pathway. The more conscientiously a company warns, the more precisely it documents its state of knowledge, and as long as the insulation material stays, every warning lengthens the stretch for which it has to account.

The insulation manufacturers are caught in an ingredient trap. In their products the basic oxides are not an impurity. Stone wool is melted from basaltic rock and additives that bring calcium and magnesium oxide with them, glass wool needs sodium oxide as a flux, and calcium silicate carries the substance in its very name. The biosolubility on which exoneration is based depends on the same oxides. Whoever removes them leaves his product family and the basis of its classification. The engine manufacturers will therefore hardly find the replacement at their current supplier.

A new line of business makes the question more pressing. The insulation manufacturers take back mineral wool and return it to production. ROCKWOOL operates a take-back system called Rockcycle in 25 countries and collects stone wool from construction, renovation and demolition sites. In several plants, clean stone wool goes directly back into production without being melted again (ROCKWOOL). In Germany, ISOVER returns offcuts from new insulation materials via its EASY-ECO service, whereas demolition waste with waste code 17 06 03* may not be recycled (ISOVER, July 2025). In the Netherlands, Renewi's acceptance point for Rockcycle does not accept stone wool with chemical contamination (Renewi, 2025). Whether mineral wool from industrial high-temperature insulation is also returned cannot be seen from the documents. The exclusions only work if someone knows about the contamination, and chromate contamination cannot be seen in the wool. What happens to the chromate when contaminated wool goes back into production is not addressed in any of the documents.

At the same time, the hamster wheel keeps turning faster. Order books are full, delivery dates extend to 2030, and every week installations with the same insulation material leave the factories. A changeover requires testing, approvals and new supply chains, and it takes time that nobody believes they have with this order situation. Yet every installation delivered enlarges the installed base that a later changeover will call into question. The longer one waits, the more expensive the step becomes, and the greater the incentive to postpone it further.

The momentum for it has been there. The first manufacturer communications date from November 2020, the German TRGS 561 followed in May 2026, and INNIO's IPO in June 2026. Each of these moments would have lent itself to a changeover that could have been presented as progress. Whoever switches today still does so of their own accord. After a decision on Annex XVII, they will do it because they have to. Whoever switches first also sets the benchmark against which the others are measured. The asbestos manufacturers missed the moment at which they could have shaped the phase-out themselves, and in the end it was shaped by legislators and courts.

8. The Law Catches Up

The regulations have begun to capture the facts. The German TRGS 561 has done so since May 2026, and Directive (EU) 2026/2450 explicitly classifies personal protective equipment for carcinogens as a last resort. For sodium chromate, a stricter rule has applied for years. Since September 21, 2017, it may no longer be used in the European Union without authorization, and it can form wherever mineral wool lies on chromium-alloyed hot components, because mineral wool contains sodium oxide. As long as the installation is running, the insulation is an article. Once it is opened, chromate-containing dust and fibers are present in free form, and storing, handling and reinstalling them are uses within the meaning of the REACH Regulation. Nobody has applied for an authorization for this. The manufacturers' notices begin three years after the sunset date, and none of them mentions Annex XIV. The manufacturers must face the question of whether they should have seen this connection. The details are set out in the work "The Overlooked Use Ban".

A chromium(VI) finding by itself does not say which chromate compounds are present in detail. For the operator, this is no reason to regard the continued use of chromate-contaminated insulation as unproblematic. Regardless of the outcome of the European restriction procedure, occupational safety requirements already apply today, and the formation pathway belongs in the substitution assessment.

In April 2025 the European Chemicals Agency proposed restricting almost all chromium(VI) compounds under Annex XVII of the REACH Regulation. This is the same annex in which asbestos fibers are listed under entry 6. Only a closed list of industrial uses is to remain permitted, and the maintenance of insulated hot components is not on it. The agency's report expects entry into force in 2028. Since the procedure is in its final stages and most of it has been defined, I consider a decision in the first half of 2027 realistic, and with the planned transition period of 18 months the deadline then ends in the second half of 2028. Insulation installed today will then still be in the installation.

9. Today's Decision

The substitution obligation under Article 4 of European Directive 2004/37/EC does not depend on the restriction procedure. It applies today, it is linked to the classification as carcinogenic, and it applies equally to calcium and sodium chromate. Directive (EU) 2026/2450 also makes it explicitly clear that personal protective equipment comes into consideration only after substitution, technical and organizational measures, and thereby gives the priority measures, above all substitution, even greater weight. What is substituted is the material that can lead to the formation of the carcinogenic chromium(VI) compounds, that is, the insulation material containing alkali and alkaline earth metal oxides. The chromate that has formed cannot itself be replaced, because nobody uses it on purpose.

High-temperature insulation materials without alkali and alkaline earth metal oxides are available. They avoid the formation pathway without falling short in temperature resistance and service life. The history of asbestos ended in Annex XVII of the REACH Regulation, under entry 6, and chromium(VI) compounds are on their way into the same annex. Whether history repeats itself in high-temperature insulation all the way there will be decided before then, in the procurement decisions being made today.

The sources for all statements in this brochure are set out in the expert analyses "The Overlooked Ingredient" and "The Overlooked Use Ban" at www.cr6.info and, for Directive (EU) 2026/2450, in the regulatory analysis "Personal Protective Equipment as a Last Resort".

Version history

Version	Date	Change
0.1	November 2026	First version (draft for review)
0.2	November 2026	Chapter "The Global Dimension" restructured: power plants and combined heat and power units, data centers, boilers and incineration plants, ships and yachts, vehicles and rail vehicles, aviation, retired components
0.3	November 2026	New chapter "The Dilemma of Engine and Insulation Manufacturers"
0.4	November 2026	Editorial corrections: timeline of the restriction procedure, as-delivered condition of insulation materials, derivation of maintenance events, examined engine rooms, page breaks; first English edition
1.0	November 2026	First published version