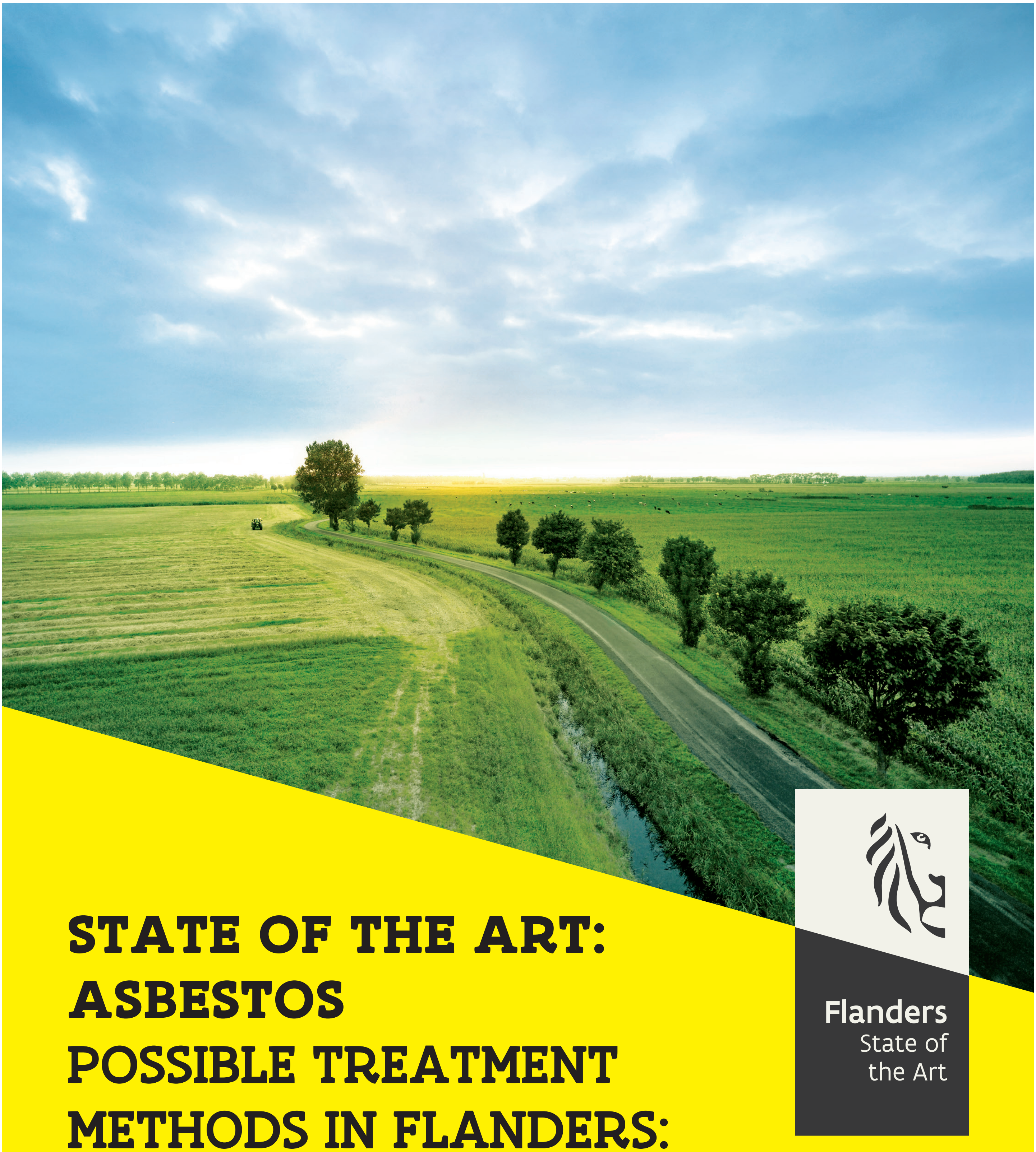

STATE OF THE ART: ASBESTOS

POSSIBLE TREATMENT METHODS IN FLANDERS: CONSTRAINTS AND OPPORTUNITIES

[3.03.2016]

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STATE OF THE ART ASBESTOS

Possible treatment methods in Flanders:
constraints and opportunities
3.03.2016

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In Flanders the current policy for non-friable asbestos is double-bagging, labelling and landfilling, while friable asbestos has to be cemented before disposal. As such, the problem by landfilling all asbestos waste is not eliminated but merely postponed to future generations. Furthermore, the technique requires a lot of space, the need for desposal spacelinked with the current policy for treating ACW in Flanders, is conflicting with the idea of sustainable land use and recycling and closing material cycles. Based on this study, two promising techniques were selected that could be studied in more detail, resulting in a possible implementation in Flanders: plasma-torch vitrification and denaturation.

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EXECUTIVE SUMMARY

‘Asbestos’ is a group of six naturally-occurring, fibrous silicate minerals. Due to specific properties linked to these minerals, asbestos has been widely used in various commercial products and industrial processes. As a result of several medical studies that concluded that there exists a direct link between certain diseases and the exposure to asbestos, policies regarding asbestos in several countries all over the world were seriously modified, as is the case in Belgium. Here, the Decree of 23 October 2001 implements an overall ban on all types of asbestos, starting from 01/01/2005. This was preceded by the Royal Decree of 03/02/1998 prohibiting all asbestos applications, including asbestos cement. In addition, several countries also introduced specific regulations regarding safe removal and disposal of asbestos and asbestos containing materials (ACMs) and concerning the protection of employees against the risks associated with exposure to asbestos. Flemish regulations on environmental protection (VLAREM) and waste management (VLAREA, now VLAREMA) have changed in order to comply with these new regulations with respect to asbestos. As a result, these asbestos containing wastes (ACWs) need to be disposed of under stricter disposal conditions.

The current amount of ACMs in and around buildings in Flanders is estimated to be 3.7 million tons, more specifically, 1.9 million tons in buildings and 1.8 million tons in utility pipelines. On the 24th of October, 2014, the Flemish government gave their consent to implement an accelerated phasing-out plan for obtaining an asbestos-safe Flanders by 2040. OVAM got the task of presenting a final phasing-out plan by 2018, within the scope of a new start-up phase. At the moment, a feasibility study is in progress, conducted by OVAM, in order to establish a plan for phasing out the remaining asbestos in Flanders. The study started in 2013 and is expected to end in 2018.

In Flanders the current policy for non-friable asbestos is double-bagging, labelling and landfilling, while friable asbestos has to be cemented before disposal. Although this technique for friable asbestos stabilizes the material by encapsulating the asbestos fibers with cement, leading to the removal of the direct danger, it does not offer a permanent solution to the asbestos problem. In both non-friable asbestos waste and the cemented friable asbestos, the harmful asbestos fibers are still present and can still become airborne again when the cement weathers, breaks … As such, the problem by landfilling all asbestos waste is not eliminated but merely postponed to future generations. Furthermore, the technique requires a lot of space, which means it does not offer a solution for the increasing shortage of available space in Flanders. In other words, the need for disposal space linked with the current policy for treating ACW in Flanders, is conflicting with the idea of sustainable land use and recycling and closing material cycles. As such, the necessity of the development of alternative, more innovative and sustainable treatment techniques is evident. In the meantime, technologies for mining of the deposited ACW in the monolandfills can be developed.

Several countries are investing in research to develop more sustainable treatment methods that destroy the fiber structure of asbestos by using either mechanical, thermal or chemical principles or even a combination of these principles. By destroying the fiber structure, the material becomes inert and free of asbestos, enabling its re-use as secondary materials so they do not have to be landfilled. However, in Flanders, this research is not yet advanced enough for large-scale installations. Next to stabilization methods, substantial research has already been done, and is still in process, concerning crystallochemical treatment methods. This type of treatment methods destroys the hazardous fiber structure rendering the material inert, asbestos-free, and

often enabling its reuse. This report studies various existing methods for asbestos disposal. Based on this research, two promising techniques were selected that could be studied in more detail, resulting in a possible implementation in Flanders: plasma-torch vitrification and denaturation.

Both techniques are thermal methods where the ACW is heated to extreme temperatures. As a result, the asbestos fibers are completely destroyed after which the resulting end-product can be crushed and used as a secondary resource. Inertam in France has successfully established a plant where ACW is treated using a plasma-torch developed by Europlasma Group. This technique operates at temperature of >1.600°C and the resulting end-product can be used in low-grade building applications. At the moment, the installation of Inertam is licensed to treat 8.000 tons/year at €1.000-2.500/ton. Denaturation, on the other hand, operates at lower temperatures than vitrification, more specifically 1.100°C, resulting in the end-product known as 'beststof', with possible applications as a substitute for cement or as a filler for cement. Twee "R" Recycling Groep BV has already undertaken several steps in order to set up a plant that treats non-friable asbestos-containing-material with the denaturation method. Here the denaturation will be carried out in a long tunnel furnace of 180 meters, with a residence time of 75 hours for the ACW. It is estimated that the capacity of the installation will be 100.000 tons/year at a price rate of €175/ton. A similar technique has been used in Italy for the treatment of both friable and non-friable chrysotile (MODYAM).

Based on the present study, the two selected techniques are both considered to be proven methods, albeit with some differences. Vitrification is proven as a full-scale installation but the 'proven'-state of denaturation technique is still not entirely clear since the quality of the end-product (whether or not it is entirely asbestos-free) often remains a point of discussion. However, since this technique is in fact in use in several countries (e.g. Italy), it is given the status of 'proven' in this study.

Both methods offer a permanent solution for the asbestos problem, due to the total destruction of the asbestos fibers at elevated temperatures. In addition, the end-products do not need to be landfilled but instead they can be used as secondary resources in various applications. These advantages provide solutions for the deficiencies linked to the current stabilization processes. In a next step, further extensive research should be done, focused on both vitrification and denaturation, to determine which of these two techniques is the Best Available Technique to apply in Flanders.

As an intermediary step the asbestos can be landfilled in 'temporary storage facilities' so it can be treated once the necessary techniques are developed and more suitable regulations are in place. Besides temporary storage, also the asbestos already stored in mono landfills can be subject to treatment. Measures that can be taken at this moment are directly linked with the concept of Enhanced Landfill Mining (ELFM). The landfilled asbestos/ACW in 'temporary storage facilities' can be retrieved once the necessary techniques are fully developed and available to treat this waste stream. These temporary storage facilities can be organized as such so that this specific waste stream can be retrieved without been mixed with other waste streams. In other words, by dividing a landfill site in compartments, asbestos/ACW can be stored separately, making it easily accessible in the future so ELFM can be applied.

SAMENVATTING

De term ‘asbest’ definieert een groep van zes natuurlijk voorkomende, vezelachtige silicaat mineralen. Asbest werd in het verleden op grote schaal toegepast in allerlei materialen zoals cementgolfplaten, dak- en gevelleien, bloembakken en isolatiematerialen wegens de voordelige eigenschappen (sterk, slijtvast, eenvoudige verwerking, onbrandbaar). Wanneer de asbestvezels uit deze materialen vrijkomen, bijvoorbeeld door een verkeerde behandeling of verwering, kan dit leiden tot gezondheidsrisico’s. Het is immers bewezen dat het inademen van de asbestvezels schadelijk kan zijn voor de gezondheid. Het Koninklijk Besluit (KB) van 1998 en het Decreet van 23 oktober 2001 voerde een algemeen verbod in van alle types van asbest tegen 01/01/2005. Daarnaast werd er in verschillende Europese landen een regelgeving ingevoerd met betrekking tot het veilig verwijderen en afvoeren van asbest en asbesthoudende materialen en tot de bescherming van werknemers tegen de risico’s die gepaard gaan met de blootstelling aan asbest. Vlaamse regelgevingen met betrekking tot milieubescherming (VLAREM) en afvalbeheer (VLAREMA) werden aangepast naar deze nieuwe regelgeving.

Met de beslissing van de Vlaamse regering van 24 oktober 2014 voor een versneld asbestafbouwbeleid tegen 2040, kreeg OVAM de opdracht middels een doorstartfase uiterlijk 2018 een finaal asbestafbouwplan voor te leggen. Dit plan ambieert gefaseerd uiterlijk 2040 alle risicovolle, asbesthoudende materialen uit het Vlaamse gebouwenpatrimonium uit te faseren, de aanwezigheid van asbest in de leefomgeving te reduceren, milieu- en gezondheidsrisico’s te verminderen en selectieve sloop, renovatie en stedelijke herontwikkeling te faciliteren.

De studie “Inventarisatiestudie asbesthoudende materiaalstromen in Vlaanderen (Ecorem, 2013)” inventariseerde en groepeerde de nog relevante asbesthoudende materiaalstromen in Vlaanderen. Volgens een theoretische benadering raamde de studie de resterende omvang van deze asbesthoudende materiaalstromen op circa 3,7 miljoen ton; in het bijzonder asbestproductieafval, asbesttoepassingen in en rondom gebouwen en nutsleidingen.

De huidige techniek in Vlaanderen omvat het storten van het asbesthoudend afval (niet-hechtgebonden na cementering) onder specifieke voorwaarden op stortplaatsen die gevaarlijk afval mogen accepteren. Volgens de huidige trends in het bergen van afval zal de beschikbare stortcapaciteit binnen enkele jaren moeten worden uitgebreid. Dit gaat ten koste van onze beschikbare ruimte. Bovendien schuiven we met het storten het asbestafvalprobleem, de potentiële risico's en de beheerskosten enkel maar door naar toekomstige generaties.

In functie van een circulaire economie wil OVAM binnen een duurzame materiaal- én ruimtegebruik ook voor asbestafval inzetten op het realiseren van materiaalkringlopen. In het bijzonder verankerd binnen de realisatie van een versneld asbestafbouwbeleid tot een asbestveilig Vlaanderen tegen 2040.

Verschillende Europese en niet-Europese landen investeren in onderzoek naar technieken, of passen reeds varianten toe, waarbij de vezelstructuur van asbest vernietigd wordt op basis van mechanische, thermische of chemische principes, of zelfs een combinatie van deze principes. Door de vezelstructuur te vernietigen, wordt het materiaal inert en bruikbaar als asbestvrije, secundaire grondstof, zodat het niet moet worden gestort.

OVAM liet een state-of-the-art studie uitvoeren om het potentieel van deze technieken te onderzoeken en de implementeerbaarheid in Vlaanderen-België te kunnen inschatten.

De twee potentiele technieken vitrificatie en denaturatie berusten op het principe van de thermische behandeling. Hierbij wordt de gevaarlijke asbestvezelstructuur door gecontroleerde, stapsgewijze verhitting onder hoge temperaturen (1100 – 1600 °C), vernietigd en resteert een inert, asbestvrij materiaal. Dit nieuwe materiaal is veilig en kan opnieuw ingezet worden als asbestvrije, secundaire grondstof. Bij vitrificatie wordt het asbesthoudend materiaal tot 1 600°C verhit met behulp van plasmatechnologie. Bij denaturatie wordt gewerkt met temperaturen tot 1 100°C. Het eindproduct ‘beststof’ kent mogelijke toepassing ter vervanging of als vulmiddel van cement.

In de realisatie van een volwaardige, duurzaam alternatief voor het huidige stortbeleid zijn een aantal randvoorwaarden cruciaal voor het welslagen. Aanvullend onderzoek is noodzakelijk om alle randvoorwaarden met betrekking tot o.a. procestechniek, regelgeving – certificering, veiligheid, rendabiliteit, bouwtechnisch kwaliteitseisen, afzetmarkt, enz. uit te klaren.

Flankerend hieraan kan asbesthoudende afval gestort worden in de daartoe bestemde stortplaatsen als 'tijdelijke opslag', in apart voorziene compartimenten. Zodra BBT-verwerkingstechnieken als volwaardig alternatief beschikbaar zijn, kan ingezameld asbestafval rechtstreeks verwerkt worden tot nieuwe grondstof en kan potentieel ook het reeds gestorte asbestafval volgens het concept van ‘Enhanced Landfill Mining’ ELFM ontgonnen en verwerkt worden).

1 INTRODUCTION

1.1 ASBESTOS: GENERAL INFORMATION AND DEFINITIONS

Asbestos is a generic term for a group of six naturally-occurring, fibrous silicate minerals that have been widely used in commercial products (USDHHS, 2001). This commercial usage is due to the fact that this group of minerals have specific properties such as, for example, high tensile strength, flexibility, heat resistance and they are chemically inert (or nearly so), which means that they do not evaporate, dissolve, burn or undergo significant reactions with most chemicals. This made them the ideal components in many manufactured products and industrial processes. Common commercial products are e.g. plaster, roofing, fire proofing, thermal (pip) insulation, chemical insulation, asbestos cement, etc.

Asbestos minerals form under special physical conditions that promote the growth of fibers that are loosely bonded in a parallel array (fiber bundles) or matted masses. The individual fibrils, which are readily separated from the bundles of fibers, are finely acicular, rod-like crystals. Deposits of fibrous minerals are generally found in veins, in which the fibers are at right angles to the walls of the vein. In the general mineralogical definition, fiber size is not specified. Naturally Occurring Asbestos (NOA) is the term applied for the natural geological occurrence of any of the six types of asbestos minerals.

Fibers are defined by the US ATDSR[1] , as well as in EU directives, as those particles of asbestos minerals that have lengths exceeding 5 µm and length-width ratios larger than 3:1. It should be noted that other agencies use different definitions of asbestos fibers for counting purposes. For example, the US Environmental Protection Agency defines a fiber as any particle with an aspect ratio exceeding 5:1.

Asbestos minerals are grouped into two groups or classes: serpentine asbestos and amphibole asbestos. It should be noted that serpentine and amphibole minerals also occur in non-fibrous/non-asbestiform forms. In fact, most amphibole and serpentine minerals in the earth's crust are of non-fibrous forms and are therefore not asbestiform. Fibrous forms may occur together with non-fibrous forms in the same deposits. Non-asbestiform amphiboles may occur in many diverse forms, including flattened prismatic and elongated crystals and cleavage fragments. When large pieces of non-fibrous amphibole minerals are crushed, as may occur during mining and milling of ores, microscopic fragments can be formed that have the appearance of fibers but are generally shorter and have smaller length-width ratios (i.e., particle length <5 µm and a length-width ratio <3:1). These fragments are thus most of the time not considered as fibers by health regulatory agencies. However, some cleavage fragments may fall within the dimensional definition of a fiber and can be counted as an asbestos fiber in air samples or biological samples, unless evidence is provided that the particles are non-asbestiform.

Regulatory or health agencies such as the European Union, WHO, ILO, U.S., EPA and OSHA only focus on the risks that are associated with the asbestiform type of the above mentioned minerals.

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[1] Agency for Toxic Substances and Disease Registry: agency of the US Department of Health and Human Services

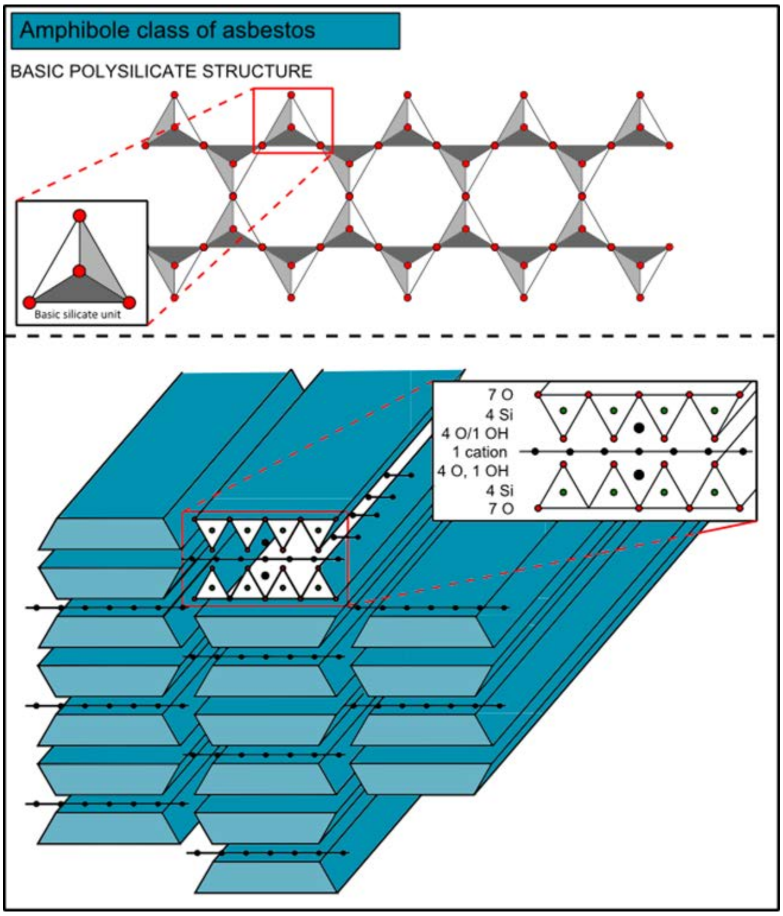

Figure 1: Basic polysilicate structures of asbestos: Amphibole group (adapted from Hurlburt & Klein, 1977)

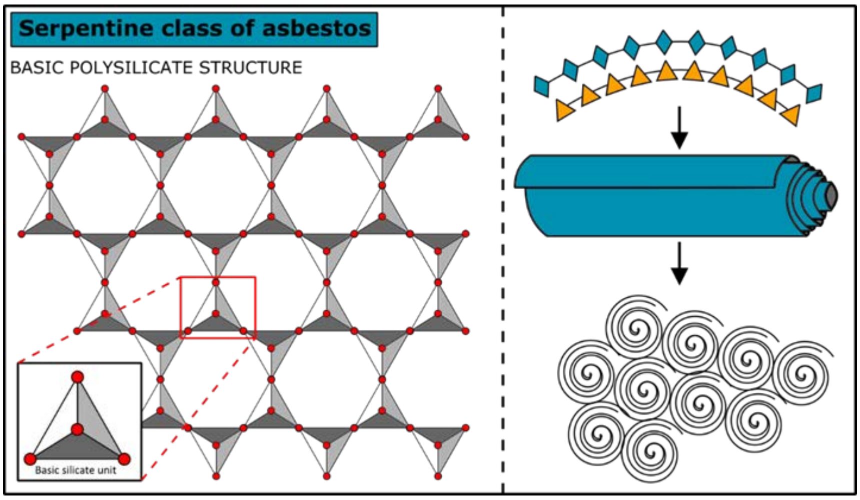

Figure 2: Basic polysilicate structures of asbestos: Serpentine group (adapted from Hurlburt and Klein, 1977)

For the **amphibole class** of asbestos, the polymeric structure consists of a linear double chain (Si_8O_{22}; **Figure 2**). These chains crystallize into long, thin straight fibers, which are the characteristic structure of this type of asbestos. Five types of asbestiform amphiboles can be distinguished (**Table 1**), which have following specific properties:

- greater hardness than serpentine-type asbestos;
- smooth fibers;
- relatively rigid;
- thicker and more pronounced needle-structure than serpentine-type asbestos;
- more brittle than serpentine-type asbestos.

For the **serpentine class**, the polymeric form is an extended sheet (**Figure 2**). This extended sheet tends to wrap around itself, forming a tubular fiber structure. These fibers are usually curved (“serpentine”), in contrast with the straight morphometry of the amphiboles. The long crystalline serpentine fibers are capable of being woven. This class contains only one asbestiform mineral, namely chrysotile. Further specifications can be found in **Table 1**.

Asbestos Type	Synonyms	Chemical Formula
Amphibole Group		
Amosite	Brown asbestos Fibrous cummingtonite / grunerite Mysorite	$(Fe^{2+})_2)(Fe^{2+},Mg)_5Si_8O_{22}(OH)_2$
Tremolite*	Silicic acid Calcium magnesium salt (8:4)	$Ca_2(Mg_5)Si_8O_{22}(OH)_2$
Actinolite*	/	$Ca_2(Mg,Fe^{2+})_5Si_8O_{22}(OH)_2$
Anthophyllite	Ferroanthophyllite Azbolen asbestos	$Mg_7Si_8O_{22}(OH)_2$
Crocidolite	Blue asbestos Riebeckite	$Na_2(Fe^{2+}, Mg)_3Fe^{3+}Si_8O_{22}(OH)_2$
Serpentine Group		
Chrysotile	White asbestos	$Mg_3Si_2O_5(OH)_4$

* Tremolite and Actinolite form a continuous mineral series in which Mg and Fe(II) can freely substitute with each other while retaining the same 3D crystal structure. Tremolite contains little or no iron, while actinolite contains iron (Jolicoeur et al., 1992).

Table 1: List of common synonyms and chemical formulas for the six individual asbestos minerals

The term “crocidolite” and “amosite” are varietal or trade names rather than formal mineral names. However, they are common in the literature regarding the regulation and health effects of asbestos. Chrysotile was and still is the most commonly used type of asbestos and probably accounts for 90 to 95% of the worldwide historic production. Crocidolite and amosite together cover up the second biggest part of the world’s historic production. Small amounts of anthophyllite-asbestos, tremolite-asbestos and actinolite-asbestos have also been produced (Ross, 1981).

Asbestos fibers are chemically inert (or nearly so). They do not evaporate, dissolve, burn or undergo significant reactions with most chemicals. In acid and neutral aqueous media, magnesium is lost from the outer brucite layer of chrysotile. Amphibole fibers are more resistant to attack by alkalis (WHO, 1998).

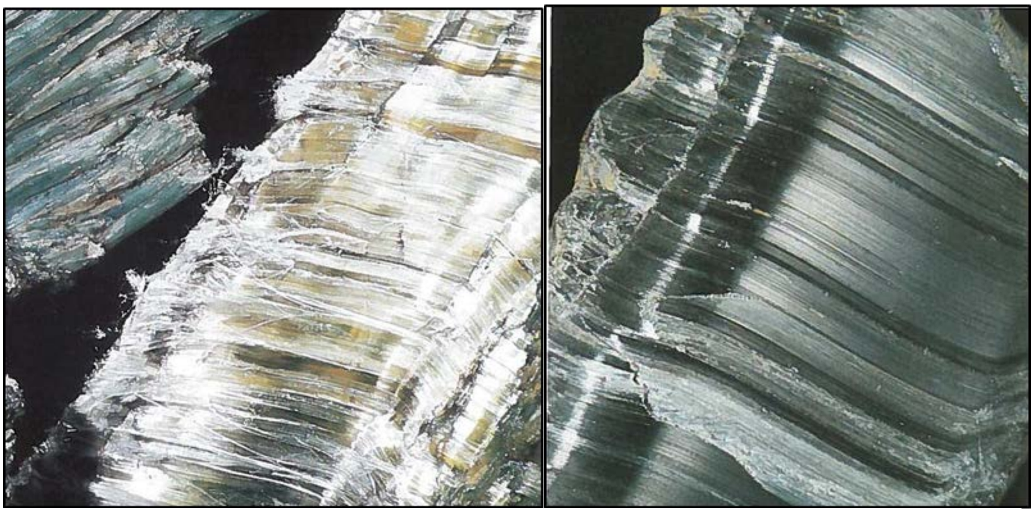

Figure 3: Illustrations of chrysotile/white asbestos (left) and crocidolite/blue asbestos (right) (From: Minerals of the World, by Rudolf Dud'A & Lubos Reijl)

1.2 HEALTH RISKS RELATED TO ASBESTOS

1.2.1 General information and literature

Medical studies have shown that there is an association between certain diseases and asbestos exposure. Initial concern over the health effects of asbestos arose from studies involving employees working in asbestos related industries . Much of the medical data on asbestos related diseases come from these studies. These studies were focused on workers in the asbestos industries[2] and showed that these workers were exposed to all six of the asbestiform minerals. Since these initial studies on industrial asbestos exposure, other research has been carried out, focusing in turn on the non-occupational exposure to asbestos minerals and on the potential health effects of other mineral fibers as well.

At present, the main illnesses known to be caused by airborne asbestos are:
- nonmalignant lung and pleural disorder, including interstitial pulmonary fibrosis (asbestosis), pleural plaques, pleural thickening and pleural effusions;
- pleural and peritoneal mesothelioma;
- lung cancer.

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[2] CAMUS, M., SIEMIATYECKI, J. & MEEK, B. (1998). Non-occupational exposure to chrysotile asbestos and the risk of lung cancer. New England Journal of Medicine, 338(22), 1565-1571.

While the processes by which the asbestos minerals cause these diseases have been studied, no general consensus has been reached by the medical community regarding the exact mechanism, or combination of mechanisms, by which these minerals cause these diseases. There is also no general consensus among the medical community about the potency of different fiber sizes, relative potency of different asbestos species and potential health effects of cleavage fragments versus fibers. Some of these issues are controversial and contribute to the overall complexity of the asbestos issue. It is however widely recognized that asbestos is a human carcinogen and that all six of the asbestos types are considered to be potentially dangerous.

Asbestos fibers may enter the body after inhalation or oral exposure. The deposition and fate of the fiber largely depends on its size and shape. Human and animal studies indicate that when asbestos fibers are inhaled, thick fibers (diameter > 2-5 µm) are deposited in the upper airways, whereas thinner fibers are carried deeper into the alveolar regions of the lung[3]. Fibers that are deposited in the respiratory tract may be removed (e.g. by swallowing and mucociliary transport) but can also be retained in the lung. Very few of the long fibers are likely to move through the lungs and be distributed in tissues other than the mesothelium. Fiber width can be seen as a key determinant of the access of fibers to the lung and pleural cavity and thus of fiber toxicity.

Longer fibers that are retained in the lung may undergo a number of processes including translocation, dissolution, fragmentation, splitting or protein encapsulation. Fibers that are encapsulated in protein can form a so-called "asbestos body" (the term "ferruginous body" is used when the nature of the core fiber is not known).

Fibers that are retained in the lung or mesothelium for a long period of time are capable of producing chronic inflammation and fibrotic and tumorigenic effects. Fibers that enter the gastrointestinal tract, either by ingestion or mucociliary transport from the lungs, are mostly excreted in the feces, although a small fraction of the fibers may become lodged in cells or penetrate the gastrointestinal lining and enter other tissues. A small number of fibers may reach the lymph system or be transported to the pleura and peritoneum. Dissolution of fibers by alveolar macrophages is also thought to play a role in eliminating asbestos fibers from the lung, especially for chrysotile fibers.

Some fibers are not cleared from the lung, which leads to a gradual accumulation. There is evidence in animals that long fibers are retained in the lungs for longer periods than short fibers[4] but analysis of autopsied human lung or parietal tissue for retained fibers often show higher numbers of short (< 5µm) fibers than long fibers[5].

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[3] USDHHS (2001). Toxicological profile for asbestos. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, GA.

[4] COIN, P.G., ROGGLI, V.L. & BRODI, A.R. (1992). Deposition, clearance and translocation of chrysotile asbestos from peripheral and central regions of the rat lung. Environmental Research, 58, 97-116.

[5] SEBASTIEN, P., JANSON, X., GAUDICHET, A., HIRSCH, A. & BIGNON, J. (1980). Asbestos retention in human respiratory tissues: comparative measurements in lung parenchyma and in parietal pleura. IARCH Scientific Publications, 30, 237-246.

There is also evidence that amphibole fibers are retained for longer periods than chrysotile fibers[6]. The pparent longer retention of amphibole fibers in lung tissue has been proposed as a partial explanation of why amphibole asbestos appears to be more potent in producing mesothelioma than chrysotile (Mossman et al., 1990).

The main determinants of asbestos toxicity include exposure concentration, duration and frequency, and fiber dimensions and durability. Long and thin fibers are expected to reach the lower airways and alveolar regions of the lung, to be retained in the lung longer and to be more toxic than short and wide fibers or particles. Wide particles are expected to be deposited in the upper respiratory tract and not to reach the lung and pleura, which are the sites of asbestos induced toxicity. Short, thin fibers, however, may also play a role in asbestos pathogenesis. Fibers of amphibole asbestos such as tremolite asbestos, actinolite asbestos and crocidolite asbestos are reported to be retained longer in the lower respiratory tract than chrysotile fibers of similar dimension[7].

Although it is generally agreed that fibers of amphibole asbestos are retained longer in the lower respiratory tract than chrysotile fibers, there is no general consensus on the fact that amphiboles should be more carcinogenic than chrysotile. Most international organizations state that exposure to any asbestos type can increase the likelihood of lung cancer, mesothelioma and nonmalignant lung and pleural disorders.

1.2.2 Exposure

Although asbestos is neither volatile nor soluble, small fibers or clumps of fibers may occur in suspension in **air and water**. These fibers are stable and do not undergo significant degradation in the environment. Large fibers are removed from air and water by gravitational settling at a rate dependent upon their size but small fibers may remain suspended for long periods of time.

No estimate of the amounts of asbestos released in the air from natural sources is available. Asbestos is more likely to be released to the atmosphere when asbestos deposits are disturbed, as is the case in mining operations. In Canada, over 95% of asbestos is mined in open-mining operations that involve drilling and blasting and this produces more air emissions than underground mining operations[8] .

The general population is exposed to low levels of asbestos, primarily by inhalation. Small quantities of asbestos fibers are ubiquitous in air. They may arise from **natural sources** (e.g., **weathering** of asbestos containing minerals), from **weathering of building materials**, from **windblown soil**, from hazardous **waste sites** where asbestos is not properly stored and from deterioration of **automobile clutches and brakes** or

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[6] ALBIN, M., POOLEY, F.D., STROMBERG, U., ATTEWELL, R., MITHA, R., JOHANSSON, L. & WELINDER, H. (1994). Retention Patterns of Asbestos Fibers in Lung Tissue among asbestos cement workers. Occupational and Environmental Medicine, 51, 250-211.

[7] USDHHS (2001). Toxicological profile for asbestos. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry, Atlanta, GA.

[8] SEBASTIEN, P., AWAD, L., BIGNON, J., PETIT, G. & BARRIS, Y.I. (1984). Ferruginous bodies in sputum as an indication of exposure to airborne mineral fibers in the mesothelioma villages of Cappadocia. Archives of Environmental Health, 39, 18-23.

breakdown of asbestos-containing (mainly chrysotile) materials, such as insulation. Tremolite asbestos is a contaminant in some vermiculite and talc. These sources would also contribute to asbestos levels in air. Soils may be contaminated with asbestos by the weathering of natural asbestos deposits or by land-based disposal of waste asbestos materials.

Higher exposure levels may result when asbestos is released from **asbestos-containing building materials** such as insulation, ceiling tiles and floor tiles that are in poor condition or disturbed. In general, levels of asbestos in air inside and outside buildings with undisturbed asbestos-containing materials are low but indoor levels may be somewhat higher than outside levels.

In most cases, the exposure to asbestos of the general population has been found to be very low. The concentrations of asbestos fibers in outdoor air are highly variable, ranging from below 0.1 ng/m3 (equivalent to $3x10^{-6}$ f/mL) in rural areas to over 100 ng/m^3 ($3x10^{-3}$ f/mL) near specific industrial sources such as asbestos mines. Typical concentrations are $1x10^{-5}$ f/mL in rural areas and up to an order of magnitude higher in urban areas. In the vicinity of an asbestos mine or factory, levels may reach 0.01 f/mL or higher. The concentration of fibers indoors is also highly variable, depending on the amount and condition of asbestos-containing materials in the building. Typical concentrations range from 1 to 200 ng/m^3 ($3x10^{-5}$ to $6x10^{-3}$ f/mL) (Nicholson 1987). For a human exposed for a lifetime (70 years), this range of exposure corresponds to cumulative doses of approximately 0.002–0.4 f-yr/mL. Children may be exposed to asbestos in the same ways that adults are exposed outside the workplace, namely from asbestos in air, especially near emission sources or in buildings with deteriorating asbestos-containing material (ACM). Since children are more apt to play in dirt, they may be exposed to higher levels of asbestos if the dirt they are playing in contains asbestos and they inhale the dust.

Fibers in **water** arise mainly by **erosion of natural deposits** of asbestos or waste piles or by corrosion of fibers from **pipes** made with asbestos-containing cement and disintegration of asbestos roofing materials. Waste water from asbestos-related industries may also carry significant amounts of asbestos fibers (EPA, 1976). Asbestos concentrations in most water supplies are less than 1 million fibers per liter (MFL), but may exceed 100 MFL in some cases.

The relationship between **workplace exposure** to airborne asbestos fibers and respiratory diseases is one of the most widely studied subjects of modern epidemiology. It was not until the early 1960s that researchers firmly established an epidemiologic correlation between worker excess exposure to asbestos fibers and respiratory cancer diseases. This finding triggered a significant research effort to unravel important issues such as the influence of fiber size, shape, crystal structure and chemical composition, the relationship between exposure levels and diseases, the consequences of exposure to asbestos fibers in different types of industries or from different types of products and the development of technologies to reduce worker exposure. The research efforts resulted in a consensus in some areas, although controversy still remains in other areas.

Asbestos fibers are nonvolatile and insoluble, so their natural tendency is to settle out of air and water and deposit in soil or sediment. However, some fibers are sufficiently small that they remain in suspension in both air and water and can be transported over long distances. For example, fibers with aerodynamic diameters of 0.1–1 µm can be carried thousands of kilometers in air and transport of fibers over 75 miles has been reported in the water of Lake Superior (EPA). Adsorptive interactions between the fibers and natural organic contaminants may favor coagulation and precipitation of the fibers.

Studies generally indicate the strong effects of non-occupational exposure like domestic exposure, environmental exposure from industrial pollution (mines, mills, factories, etc.), environmental exposure from asbestos in soil, etc. on human health.

According to Goldberg (2001)[9], non-occupational circumstances of exposure include domestic exposure to asbestos contaminated materials, environmental exposure from industrial pollution, environmental exposure from asbestos in the soil and environmental non-occupational exposure in buildings.

The conditions in which environmental and/or domestic exposure occurs, are the presence of tremolite- and chrysotile-bearing rocks (serpentinites, ophiolites) and soils and/or the local use of white soil. The existence of a dry or Mediterranean climate probably also plays a role. These conditions can be used as a preliminary basis for the identification of geographical areas at risk[10] (Dumortier et al., 1998).

The epidemiological studies that are focused on environmental exposure all indicate the existence of a strong effect of non-occupational exposures (domestic, industrial and natural). There appeared to be no difference between men and women, nor any apparent effect of age at first exposure. **Regarding the fiber types it could be concluded that in most of the cases amphiboles (crocidolite, tremolite) play an important role**. **However, chrysotile is almost always present in lung samples of the cancer cases.**

This co-exposure of chrysotile was also reported by Dumortier et al. (1998)[11]. The main type of asbestos fiber in broncheoalveolar lavage fluid (BALF) reported in Turkey was tremolite. Together with tremolite, elevated concentrations of chrysotile were detected in a small number of Turkish cases showing that for some cases environmental co-exposure to chrysotile also occurs. Elevated amounts of chrysotile were observed in cases with ongoing or recent exposures, but data accumulated over the past 25 year demonstrate that it is difficult to relate chrysotile lung burden to estimated exposure owing to its faster clearance rate compared with amphiboles. Churg and Wright (1994)[12] estimated that the preferential clearance of chrysotile, leading to its lower biopersistence when compared with amphiboles, must occur and be completed within weeks to months of exposure.

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[9] GOLDBERG, M.S., PARENT, M.E., SIEMIATYCKI, J., DESY, M., NADON, L., RICHARDSON, L., LAKHANI, R., LATREILLE, B. & VALOIS, M.F. (2001). A case-control study in the relationship between the risk of colon cancer in men and exposures to occupational agents. American Journal of Industrial Medicine, 39(6), 531-546.

[10] DUMORTIER, P., COPLU, L., DE MAERTELAER V., BARIS, E.I. & DE VUYST, P. (1998). Assessment of environmental asbestos exposure in Turkey by bronchoalveolar lavage. American Journal of Respiratory Critical Care Medicines, 158, 1815-1824.

[11] Idem supra.

[12] CHURG, A. & WRIGHT, J.L. (1994). Persistence of natural mineral fibers in human lungs: an overview. Environmental Health Perspectives Supplement, 102(5), 229-233.

1.2.3 Main Illnesses

1.2.3.1 Benign pleural disease

The most common asbestos-related abnormalities are pleural plaques. They are discretely elevated grey-white areas of connective tissue, rich in collagen and situated in the parietal pleura of the chest wall, diaphragm, and pericardium or towards mediastinum. Asbestos and erionite fibers are the only established causative agents for typical pleural plaques and the latency time from the onset of exposure to the occurrence of pleural plaques is several decades. **In some instances pleural plaques are found in endemic areas after environmental exposure to asbestos from the soil, but outside these areas, 80-90% of pleural plaques are attributable to occupational asbestos exposure.** Pleural plaques do not cause pulmonary function impairment, but they are frequently identifiable in the chest X-ray of exposed individuals and even more frequently in computed tomographies or autopsies. Pleural plaques can be caused by low exposure to asbestos which makes them a reliable marker of some level of past exposure to asbestos but they are not considered to indicate an important risk of lung cancer (International group of experts, 1997).

Additional observations, adding to the evidence that long-term environmental exposure to airborne **tremolite fibers** can lead to development of nonmalignant changes in the lung and pleura, include:

- High prevalence's of pleural calcification among residents of villages in Greece, Turkey, and Corsica where whitewashes containing tremolite asbestos have been used domestically or where there are abundant surface deposits rich in tremolite asbestos[13].
- Progressive pulmonary fibrogenic reactions in the lungs of rats and mice after exposure to tremolite asbestos by inhalation or intratracheal instillation[14].

1.2.3.2 Asbestosis

Asbestosis refers to a diffuse pulmonary fibrosis caused by inhalation of asbestos fibers. The traditional criteria for asbestosis included:

- History of exposure to asbestos and a sufficient latency time between the onset of exposure and the occurrence of the disease (usually more than 15 years);
- Pulmonary fibrosis in the chest X-ray;
- A restrictive pattern of pulmonary function impairment[15].

Neither the clinical features nor the architectural tissue abnormalities of asbestosis sufficiently differ from those of other causes of interstitial fibrosis to allow confident diagnosis without a history of significant

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[13] BAZAS, T. (1987). Pleural effects of tremolite in north-west Greece. Lancet, 1(8548), 1490-1491. DUMORTIER, P., BROUCKE, I. & DE VUYST, P. (2001). Pseudoasbestos bodies and fibers in bronchoalveolar lavage of refractory ceramic fiber users. American Journal of Respiratory and Critical Care Medicine, 164, 499-503. PETO, J., DECLARI, A., LA VECCHIA, C., LEVI, F. & NEGRI, E. (1999). The European mesothelioma epidemic. British Journal of Cancer, 79 (3/4), 666-672.

[14] DAVIS, J.M., ADDISON, J., BOLTON, R.E., DONALDSON, K., JONES, A.D. & MILLER, B.G. (1985). Inhalation studies on the effects of tremolite and brucite dust in rats. Carcinogenesis, 6(5), 667-674.

[15] AMERICAN THORACIC SOCIETY (1986). The diagnosis of nonmalignant diseases related to asbestos. The American Review of Respiratory Diseases, 134, 363-368.

asbestos exposure or detection of asbestos fibers or bodies in lung tissue greatly in excess of that commonly seen in the general population[16].

The risk of asbestosis is linearly related to the cumulative exposure but in case of a low level of asbestos exposure, radiological, pathological and clinical evidence of lung fibrosis is generally absent. This suggests the existence of a threshold below which asbestosis will not occur. The value commonly proposed for cumulative exposure is 25 fiber-years per cubic centimetre[17].

1.2.3.3 Mesothelioma

Mesothelioma is a cancer which is most commonly found in the pleura, less frequently in the peritoneum and occasionally also in the pericardium or tunica vaginalis testis. Mesothelioma used to be a rare tumor. The background incidence is assumed to be as low as 1-2 per million[18]. During the recent decades, however, its incidence has increased steeply in the industrialized countries and was around 10-25 per million in the early 1990s in most Western European countries[19]. **The great majority (about 80% in men) of mesotheliomas are caused by asbestos and most of them are due to occupational exposure but cases in which mesothelioma is caused by environmental exposure or exposure through a family members' work have also been reported.** Most patients have been exposed for the first 30 or more years before the diagnosis[20].

The only established causative agents for mesothelioma are asbestos and erionite fibers. Dose-response analyses indicate that even relatively low exposures increase the risk[21] and there is no safe level of exposure. Of all the asbestos fibers, crocidolite fibers are the most potent followed by amosite, tremolite and anthophyllite[22]. There is still scientific disagreement on the contribution of chrysotile to overall mesothelioma incidence. Some authors have concluded that, although less potent than crocidolite and amosite, chrysotile could still be the main cause of mesothelioma world-wide due to its wider use. Others have argued that very few mesotheliomas are caused by pure chrysotile[23]. Decisive evidence is difficult to reach as most workers have been exposed both chrysotile and amphiboles.

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[16] INTERNATIONAL GROUP OF EXPERTS (reporter TOSSAVAINEN, A.) (1997). Asbestos, asbestosis and cancer: the Helsinki criteria for diagnosis and attribution. Scandinavian Journal of Work, Environment and Health, 23(4), 311-316.

[17] BOFFETTA, P. (1998). Health effects of asbestos exposure in humans: a quantitative assessment. La Medicina del Lavoro, 89, 471-480.

[18] Idem supra.

[19] PETO, J., DECLARI, A., LA VECCHIA, C., LEVI, F. & NEGRI, E. (1999). The European mesothelioma epidemic. British Journal of Cancer, 79 (3/4), 666-672.

[20] CAMUS, M., SIEMIATYECKI, J. & MEEK, B. (1998). Non-occupational exposure to chrysotile asbestos and the risk of lung cancer. New England Journal of Medicine, 338(22), 1565-1571.

[21] IWATSUBO, Y., PAIRON, J.C., BOUTIN, C., MENARD, O., MASSIN, N., CAILLAUD, D., ORLOWSKI, E., GALATEAU-SALLE, F., BIGNON, J. & BROCHARD, P. (1998). Pleural Mesothelioma: Dose-response relation at low levels of asbestos exposure in a French population-based case-control study. American Journal of Epidemiology, 148(2), 133-142.

[22] BOFFETTA, P. (1998). Health effects of asbestos exposure in humans: a quantitative assessment. La Medicina del Lavoro, 89, 471-480.

[23] McDONALD, J.C., McDONALD, A.D. (1997). Chrysotile, tremolite and carcinogenicity. The Annals of Occupational Hygiene, 41(6), 699-705.

Mesothelioma is one of the most numerous entities in most occupational disease compensation schemes but it is also known to be heavily underdiagnosed as an occupational disease. The bulk of the mesothelioma epidemic does not result from the asbestos production industry, but from the downstream use of asbestos products in construction sites, shipyards and other industries[24]. Indirect bystander exposures in such occupations are the most difficult challenge in mapping the exposure history of a mesothelioma patient.

Additional evidence indicates a causal relationship between long-term exposure to airborne tremolite asbestos and mesothelioma which is a rare fatal cancer accounting for 2, 87 deaths per million within the U.S. white male general population in 1996[25]. The evidence includes elevated prevalences of mesothelioma deaths (of about 1/100 to 2/100) among groups of Libby, Montana, vermiculite workers[26], among residents of Greek, Turkish and New Caledonian villages that used tremolite-asbestos whitewashes on interior walls and in regions of northeastern Corsica that have abundant surface deposits of tremolite asbestos[27]. Strong supporting evidence comes from animal studies showing increased incidences of pleural tumors resembling human mesotheliomas in rats and hamsters[28].

1.2.3.4 Lung cancer

Lung cancer is numerically the most important cancer in the world. Tobacco smoke is by far the most important cause of lung cancer but several work-related factors also contribute to the global lung cancer burden. **Of the work-related causes of lung cancer, exposure to asbestos is the most important, accounting for about one half of the occupational lung cancer burden[29]**.

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[24] PETO, J., DECLARI, A., LA VECCHIA, C., LEVI, F. & NEGRI, E. (1999). The European mesothelioma epidemic. British Journal of Cancer, 79 (3/4), 666-672.

[25] NIOSH (1999). Work-related lung disease surveillance report 1999; Washington, DC: U.S. Department of Health and Human Services, National Institute for Occupational Safety and Health.

[26] AMANDUS, H.E. & WHEELER, R. (1987). The mortality of vermiculite miners and millers exposed to tremolite-actinolite: part III. Radiographic findings. American Journal of Industrial Medicine, 11, 27-37.

[27] CONSTANTOPOULOS, S.H., THEODORACOPOULOS, P., DASCALOPOULOS, G., SARATZIS, K. & SIDERIS, K. (1991). Metsovo lung outside Metsovo: endemic pleural calcifications in the ophiolite belts in Greece. Chest, 99, 1158-1570. SCHNEIDER, J., RODELSPERGER, K., BRUCKEL, B., KAYSER, K. & WOITOWITZ, H.-J. (1998). Environmental exposure to tremolite asbestos: pleural mesothelioma in two Turkish workers in Germany. Reviews on Environmental Health, 13(4), 213-220.
LUCE, D., BILLON-GALLAND, M.A., BUGEL, I., GOLDBERG, P., GOLDBER, M., SALOMON, C., NICOLAU, J., QUENEL, P., FEVOTTE, J. & BROCHARD, P. (2001). Environmental exposure to tremolite and respiratory cancer in New Caledonia (South Pacific). Poster presentation, 2001 Asbestos Health Effects Conference. Sponsored by U.S. Environmental Protection Agency, May 24-25, 2001. San Fransico, CA.
MAGEE, F., WRIGHT, J.L., CHAN, N., LAWSON, L.M.D. & CHURG, A.M.D. (1986). Malignant mesothelioma caused by childhood exposure to long-fiber low aspect ratio tremolite. American Journal of Industrial Medicine, 9, 529-533.

[28] Wagner, J.C., CHAMBERLAIN, M., BROWN, R.C., BERRY, G., POOLEY, F.D., DAVIES, R. & GRIFFITHS, D.M. (1982). *Biological effects of tremolite*. British Journal of Cancer, 45, 352-360.
DAVIS, J.M., ADDISON, J., BOLTON, R.E., DONALDSON, K., JONES, A.D. & MILLER, B.G. (1985). *Inhalation studies on the effects of tremolite and brucite dust in rats*. Carcinogenesis, 6(5), 667-674.

[29] NURMINEN M. & KARJALAINEN, A. (2001). Epidemiologic estimate of the proportion of fatalities related to occupational factors in Finland. Scandinavian Journal Work Environmental Health, 27, 161-213.

Most lung cancers among asbestos-exposed workers occur in smokers or ex-smokers and a multiplicative model of interaction between smoking and exposure to asbestos has been introduced although a review of studies in the interaction between asbestos and tobacco revealed a somewhat variable pattern of interaction ranging from supramultipicative to less than additive[30].

There is very little data on the dose-response at low levels of exposure (Health Effects Institute, 1991). A question closely related to the dose-response relationship is how much the risk is increased among those exposed individuals that do not have asbestosis. Several recent studies indicate that there is an increased risk of lung cancer among such individuals, although the risk is not as high in comparison to those with asbestosis (who have a relatively high exposure)[31]. Asbestos increases the risk for lung cancer of all sites and all histological types, but the increase may be slightly greater for lower lobe cancers and adenocarcinomas than for upper lobe cancers and squamous cell carcinomas.

Additional evidence indicates that repeated exposure to airborne tremolite asbestos can lead to increased risk for the development of lung cancer. This includes observations of statistically significantly increased rates of mortality from lung cancer in groups of Libby Montana vermiculite workers compared with rates for the general population[32], statistically significant relationships between cumulative fiber exposure measures and prevalence of lung or respiratory cancer among Libby vermiculite workers, and increased incidences of lung tumors in rats exposed to tremolite asbestos by inhalation or intratracheal instillation[33]. The weight of the human evidence for tremolite asbestos-induced lung cancer is limited by the inability to adjust for likely confounding factors from smoking in the Libby vermiculite workers.

Most concern exists for the airborne asbestos and for breathing in the tiny fibers. The fibers that are most dangerous to human health are those fibers that are longer than 5 µm and especially those longer than 10 µm, with a length-width ratio of 5:1. The tremolite-actinolite fibers may also be more chemically reactive, making them even more toxic to people’s lungs. Although people can also be exposed to asbestos by ingestion (eating, drinking) or possibly on the skin, these are not major exposure routes and do not pose nearly as great a risk as inhalation (EPA, 2000).

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[30] VAINIO, H. & BOFFETTA, P. (1994). Mechanisms of the combined effect of asbestos and smoking in the etiology of lung cancer. Scandinavian Journal Of Work, Environment and Health, 20, 234-242.

[31] INTERNATIONAL GROUP OF EXPERTS (reporter TOSSAVAINEN, A.) (1997). Asbestos, asbestosis and cancer: the Helsinki criteria for diagnosis and attribution. Scandinavian Journal of Work, Environment and Health, 23(4), 311-316.

[32] AMANDUS, H.E. & WHEELER, R. (1987). The mortality of vermiculite miners and millers exposed to tremolite-actinolite: part III. Radiographic findings. American Journal of Industrial Medicine, 11, 27-37.

[33] DAVIS, J.M., ADDISON, J., BOLTON, R.E., DONALDSON, K., JONES, A.D. & MILLER, B.G. (1985). Inhalation studies on the effects of tremolite and brucite dust in rats. Carcinogenesis, 6(5), 667-674.

2 POLICY

As a result of the medical discoveries, stricter regulations concerning asbestos were being implemented, which resulted in an overall ban on the production, usage, launching and selling of asbestos containing materials in various countries.

2.1 BELGIUM

From the end of the 1970s, the use of certain asbestos materials was gradually restricted (use of sprayed asbestos, for example has been banned since 1/1/1980). On August 28, 1986, it was stated that, if technically possible, asbestos should be replaced by materials less hazardous for human health. In 1998, a Royal Decree (Decree of February 3, 1998) was passed, forbidding a very large number of asbestos applications. This Royal Decree was replaced by the Decree of October 23, 2001 (published in the Official Gazette of November 30, 2001), imposing an overall ban on asbestos starting from 1/1/2002. This decree includes a ban on the production, usage, launching and selling of asbestos or asbestos containing materials (ACMs). Currently, this prohibition is included in Annex XVII of the REACH European regulation. The use of chrysotile asbestos, however, was still allowed for specific industrial applications until 1/1/2005. On January 3d, 2006, another Royal Decree was passed, stating that all employees must be protected against the risks associated with the exposure to asbestos. This decree was translated from the European Guidelines. Furthermore, all employees that have become ill due to asbestos exposure, have a right to claim a compensation. This compensation is paid by the 'Asbestos Fund', which is part of the fund of occupational diseases. A summary is given in **Table 2**.

Reference	Regulation
End of the 1970s: RD(*): 15/09/1978	Use of certain asbestos materials started to get banned
RD: 28/08/1986	If technically possible, asbestos should be replaced by materials less hazardous for human health
MD(**): 22/12/1993	Companies are obligated to establish an asbestos inventory containing following information: What types of asbestos-products are present What is the condition of these products Which measures are taken to prevent the exposure of the employees to these products
RD: 03/02/1998	Prohibition on the use of a very large number of asbestos applications
RD: 23/10/2001	Decree, replacing the Royal Decree: Overall ban production, usage, launching and selling of most types of asbestos or ACM's
01/01/2005: Extension RD: 23/10/2001	Chrysotile is inserted in the Decree of 23/10/2001
RD: 03/01/2006	Protection of employees against the risks to exposure to asbestos
RD: 28/03/2007	Regulating the recognition and certification of specialized and recognized companies for asbestos removal

(*RD = Royal Decree; **MD = Ministerial Decree)
Table 2: Evolution of asbestos policy in Belgium

Federal legislation regarding asbestos is mainly focused on the protection of the employees and can be found in the Codex 'Welfare at Work' and in the General Regulations for Labor (ARAB).

2.1.1 Flanders

The basis of the Flemish legislation are decrees, which have to be approved officially by the Flemish Parliament. The principles that are defined by these decrees are carried out by Implementation Decisions, which are approved by the Flemish Government. This system also applies for the Flemish environmental legislation. Important environmental decrees with accompanying Implementation Decisions are listed in **Table 3**. The purpose/goal of each of these couples is also provided.

Decree	Implementation Decision	Purpose
Decree on environmental permits = Decree of 28/06/1985 concerning environmental permits	VLAREM I = Flemish regulation concerning environmental permits VLAREM II = General and sectoral regulations concerning environmental hygiene	Setting up: - Classification list of situations in which an environmental permit is necessary - Procedures on how to applicate for these permits - Conditions and norms for installations/depots/… for which environmental permits have been obtained
Materials Decree = Decree of 23/12/2011 concerning the prevention and management of waste	VLAREMA = Flemish regulation concerning prevention and management of waste	Detailed prescription on: - Categories of (special) waste - Raw materials - Legal and selective collection - Transport - Obligation to keep an up-to-date register - Extensive responsibility of the producer - Waste with obligation to accept
Soil Decree = Decree of 27/10/2006 concerning soil remediation and protection	VLAREBO = Flemish regulation concerning soil remediation and protection	Listing of: - Procedures in case of land transfer - Procedures of remediation of contaminated soils - Parameters indicating at what point anexploratory soil survey is necessary

Table 3: Overview of the Flemish environmental legislation

Subsequently, there is VLAREL which is a decision of the Flemish Government on 19/11/2010 establishing the Flemish regulation concerning recognitions with respect to the environment. This legislation adds to the above decrees and implementation decisions by taking care of a wide variety of categories of recognitions, e.g. laboratories, procedures for analyses and sampling, experts, etc. Some adjustments were added on 01/03/2013.

It is within this framework that the Flemish regulations on environmental protection and waste management with regard to asbestos is formulated. Due to the European Directive of 2001/573/EG, which gives a new European Waste List (= EURAL, replacing the European Waste Catalogue and the Hazardous Waste List), these regulations concerning asbestos have been changed considerably. The European Directive determines which materials are considered to be waste and these regulations have been implemented in Flanders by the Implementation Decisions given in **Table 3**.

The management of asbestos containing materials and wastes is regulated by the Materials Decree of December 23, 2011 and by VLAREMA (Decision of the Flemish Government of 17 February 2012 establishing the Flemish regulation on the sustainable management of material cycles and waste).
VLAREM implemented the EU Directive 87/217/EEG regarding the provisions of the necessary measures to prevent or reduce the emissions of asbestos at the source. Furthermore, VLAREM determined the requirements for pre-treatment of hazardous asbestos waste for acceptation at a category 1 disposal site, which are disposal sites for hazardous waste. The necessary measures need to be taken in order to ensure that no asbestos fibers are released in the environment, meaning that the ACMs should be packed sufficiently and free fibers should be immobilized in a cement-matrix.

VLAREMA gives, among others, the general conditions concerning the management of material cycles and waste. Within this framework, asbestos is addressed in, in the first place, the classification for special wastes (Section 4.1), secondly in the list of wastes that need to be collected separately (Section 4.3) and thirdly, within the chapter that deals with the specific criteria for the delimitation of the waste phase (Article 2.3.2.1). Furthermore the list of wastes is added in its addendum (Addendum 2.1). A more detailed overview on these sections and addendum of VLAREMA can be found in Annex I.

VLAREBO (December 14, 2007, Order of the Flemish Government establishing the Flemish Regulations concerning soil remediation and soil protection) and the Rules of Procedure (Ministerial Decree of 25 July 2011 on the approval of the Rules of Procedure for recycled aggregates) regulate the presence of asbestos in soil, excavations and construction and demolition waste. Asbestos itself is only covered in addendum I of VLAREBO that gives an overview of all the high-risk establishments of which the exploitation has begun before 01/06/2015. The paragraphs specifically applicable for asbestos are given in Annex I.

Furthermore, the Flemish Government has tried to raise the awareness with respect to asbestos, by means of, for example, organizing awareness campaigns with the aim of informing citizens about the risks of asbestos, organizing training sessions for professionals and ensuring the administrative processing.

Up to 1986, producers of asbestos had their own disposal sites and in the best case scenarios the ACW ended up in those landfills together with the rest of the demolition waste. Since 1986 however, a large evolution concerning the removal and destruction of asbestos was present in Flanders. In 1986, obligations were made in the ARAB concerning the demolition and removal of friable asbestos, stating that all ACW containing free fibers have to be double bagged and provided with clear labels.

Furthermore, the Public Waste Agency of Flanders (OVAM) stated following disposal rules for the different categories of landfills in Flanders:

- Category 1: Landfill for hazardous waste. Friable and non-friable asbestos waste can be deposited.
- Category 2: Mono landfill for hazardous waste consisting of asbestos cement or other asbestos-containing building materials in which asbestos is present in bonded form. Friable asbestos cannot be deposited.
- Category 3: Licensed landfill for inert waste. Friable asbestos cannot be deposited.

The present criteria for double bagged, friable ACW is that it has to be cemented and subsequently packed and labelled. At the present time, Rematt TV. is the only provider for this service in Flanders. However, after this treatment, the cemented ACW still has to be disposed of at the designated landfills.

In general, the policy used in Flanders since 1986, is that all the ACW is landfilled according to the conditions determined by VLAREM. Alternative processing techniques, other than landfilling, are currently not used due to insufficient proof for certain technologies. Furthermore, these techniques are also very expensive, especially in comparison with the current prices for treatment and disposal of ACWs. The new policy should support the technological research concerning the destruction of ACWs. On the 24th of October, 2014, the Flemish Government gave their consent on the implementation of an accelerated phasing-out policy in order to achieve an asbestos-safe Flanders by 2040. The study phase prior to this decision consisted of four aspects:

- Research on the exemption and dispersion of eroded asbestos-containing roofing and wall cladding;
- An inventory study of asbestos-containing materials in Flanders;
- Market- and stakeholders consultation with on the one hand the policymakers, enforcers, local governments, etc. and on the other hand, sectors such as education, agriculture, private, etc.;
- Exploratory feasibility study and cost-benefit analyses.

OVAM got the assignment to submit a final phasing-out strategy by 2018 in the form of a roadmap to achieve an asbestos-safe Flanders by 2040.

2.2 EUROPE

Europe has already undertaken several steps to, in the first place, prohibit the use of asbestos; secondly, to set strict standards for the protection of workers that are exposed to asbestos; and thirdly, to encourage research regarding new methods of processing, either by stabilization or by rendering them harmless by destroying the fiber-structure. An overview of specific EU regulations concerning asbestos are given in **Table 4**.

Date	Regulation	Specifications
19 September 1983	EU Directive 83/477/EEG	Respectively amended by 91/382/EEC, 98/24/EC, 2003/18/EC and 2007/30/EC Concerning the protection of employees against the risks of exposure to asbestos at the working place
19 March 1987	EU Directive 87/217/EEG	Concerning the prevention and reduction of contamination of the environment with asbestos. Stating that Member States must take measures to reduce the emissions of asbestos, using the best available technology. These measures relate to air and water emissions and the disposal of asbestos waste. These measures are related to air and water emissions and the disposal of asbestos waste.
26 July 1999	EU Directive 1999/77/EG	Regarding the restriction of the merchandising and usage of certain hazardous materials and products (asbestos).
23 July 2001	EU 2001/573/EG	Amending Commission Decision 2000/532/EC as regards the list of wastes
16 January 2001	2001/118/EG	Amending Decision 2000/532/EC as regards the list of wastes
22 January 2001	2001/119/EG	Regarding modifications of Decision 2000/532/EG to replace Decision 94/3/EG concerning the establishment of a list of wastes
30 November 2009	2009/148/EC	Regarding exposure to asbestos at work Aims to protect workers' health from risk of asbestos exposure, lays down limit values and specific requirements.

Table 4: Specific EU regulations

Furthermore, the EU has also enacted the **REACH Regulation** (EC), a broad and ambitious European regulation on the registration, evaluation, authorization and restriction of chemicals to ensure a high level of protection of human health and environment. More specific to the asbestos issue, Article No. **1907/2006 of the REACH Regulation** prohibits the placing on the market, the supply and use of asbestos fibers of any type and of products containing asbestos fibers. The restriction conditions for asbestos fibers can be found in entry no. 6 of Annex XVII of the REACH Regulation, recently amended by Regulation (EC) No. 552/2009. The **EU Waste Framework Directive** (2008/98/EC) provides a general framework for hazardous and non-hazardous wastes. This Directive contains definitions for waste, recovery and final disposal. And in 2000 and 2001 the European Commission established a new European list of waste (EURAL; **Table 4**). This list replaced those from January 1, 2001 the European Waste Catalogue (EAC) and the List of Hazardous waste Materials. Both lists were integrated into one overview. In this list, hazardous materials are indicated with asterisk (*) after the respective EURAL code. Asbestos waste that has to be considered as hazardous, include:

- EURAL code 06 07 01*: asbestos waste from electrolysis;
- EURAL code 06 13 04*: wastes from asbestos processing;
- EURAL code 10 13 09*: wastes from the manufacturing of asbestos cement with asbestos;
- EURAL code 15 01 11*: metal packaging containing a dangerous solid porous matrix (*e.g.* asbestos), including empty pressure containers;
- EURAL code 16 01 11*: asbestos containing brake pads;
- EURAL code 16 02 12*: discarded equipment containing free asbestos fibers;

- EURAL code 17 06 03*: other isolation materials containing dangerous materials or similar substances;
- EURAL code 17 06 01*: asbestos containing isolation materials;
- EURAL code 17 06 05*: asbestos containing building materials.

The codes above are part of the group of hazardous materials which means that the prescribed limits defined by the CLP-regulation (Classification, Labelling and Packaging) need to be followed in case these waste streams are encountered. However, in case of there are indications pointing to the presence of asbestos (e.g. the prefix “asbestos-containing”), the government can establish its own limits and definitions. The asbestos-containing waste streams mentioned by the EURAL-codes in the list above, are always considered to be dangerous and certain rules need to be applied. Waste is considered to be “asbestos-containing waste” when the calculated asbestos content exceeds the limit of 100 mg/kg DS. This value is a standard that is calculated as followed: 10x the concentration of non-friable asbestos added by the concentration of friable asbestos.

In general, the waste materials listed by EURAL with a general reference of containing hazardous materials need to be classified as an hazardous waste materials if it contains an asbestos concentration equal to or exceeding 1000 ppm or 0,1%. If however, the waste materials listed by EURAL have a specific reference to the presence of asbestos, they have to be classified as being an hazardous waste material if it contains an asbestos concentration starting from 100 ppm or 0,01%. These specific materials are listed by the above EURAL codes.

On the 30th of January, 2013, the **European Parliament** conducted a session concerning the asbestos related threats to the health on the workplace and the prospects regarding the abolition of all known forms of asbestos (2012/2065(INI)). During this session an intermediate evaluation of the European Strategy of 2007-2012 for health and safety on the workplace was conducted as well as the reviewing of several reports, studies, *etc.* published over the past years. As a result, some conclusions were drawn in terms of health, research, society, economy and regulations. Some examples of these conclusions are given below.

In the first place, concerning the health issue, **all types of asbestos are considered to be dangerous and the risks of exposure to asbestos have been proven**. The inhalation of asbestos fibers increases the risk of cancer and the most adverse consequences express themselves several years (approximately 10 years) after the exposure. Furthermore, there is no theoretical evidence that there is a lower boundary beneath which exposure to asbestos is not harmful. Therefore, it is concluded that the exposure to asbestos is a threat to the population in general, causing, according to the World Health Organization (WHO), around 20.000-30.000 cases of asbestos-related illnesses every year. Yet, at the same time it has been observed that there are still unacceptable differences between the different systems of the Member States concerning the recognition of asbestos-related illnesses.

Furthermore, it is concluded that the **storage of asbestos is no longer considered to be the safest method** to indefinitely end the release of asbestos fibers in the environment (mainly into the air and groundwater). These storage facilities are only a temporary solution since asbestos fibers hardly perish through time. As such the problem is simply shifted to future generations. It is therefore **preferred to start the development of installations that aim at rendering the material inert and free of asbestos.**

And finally, despite the fact that the use, import, *etc*. of asbestos is prohibited, it has been determined that these activities are still present. This is thought to be partly due to the present insufficient surveillance methods of the market; the still very limited expertise leading to shortcomings concerning education, prevention and surveillance; and because there is still no known register about the position and the amount of asbestos that is still present in buildings, roads, etc.

Based on these findings and conclusions, several **proposals** were made to improve the policy concerning the asbestos issue. These proposals dealt with the following points:

- the detection and registration of asbestos;
- the support of the associations of the victims of asbestos;
- the guarantee for decent qualifications and schooling;
- the elaboration a decent program for the removal of asbestos;
- the recognition of asbestos-related diseases;
- the elaboration of strategies to achieve a global ban on asbestos.

For the detection and registration of asbestos, a model needs to be produced, applied, supported and supervised and the owners of public and/or industrial buildings need to be obligated to participate in this model. In order to analyze possibilities and different action plans for the safe removal of asbestos, cost-benefit analyses and impact assessments must be carried out by the EU as well. Furthermore, the installation of plants for the treatment of ACW and for rendering it inert and asbestos-free in the EU needs to be promoted as a way to gradually decrease, and ultimately end, the storage of this waste in dumping sites. To achieve the latter, the EU needs to **stimulate and support the research and technologies** with respect to:

- Finding environmentally friendly alternatives for asbestos.
- Developing and enforcing procedures to prevent asbestos from going airborne again and/or to render the material free of asbestos fibers and inert, *i.e.* disarming active asbestos fibers by destroying the crystal structure and thus converting them to a material that does not form a threat to public health.

It is stated that in order to achieve these goals, the EU needs to consult and work together with social partners and other interested parties to create action plans on European, national and regional level for the management and removal of asbestos and to apply them together.

Although these EU legislations cover all member states, it appears that the national legislation in individual countries can often vary significantly. In what follows, a couple of examples are given of the asbestos policy in three European countries: France, The Netherlands, Germany and Poland. The first three countries are being described because of their position as neighboring countries and a short description of Poland is given because of the fact that Poland was the first country in the EU that set up a plan of action for achieving an asbestos-free country.

2.2.1 France

In France, asbestos has been recognized as an occupational disease since 1945, leading to the prohibition of, among others, spraying glues with more than 1% asbestos fibers in houses and the use of amphibole type of asbestos. In 1974, a peak of imported asbestos was noticed, followed by a slow decrease since then. In December 1992, a legislation was passed, stating that asbestos could only be disposed in special waste centers reserved for industrial wastes and in 1996, a general ban was established for the manufacturing, importation and selling of asbestos and ACMs. Furthermore, this legislation mandated the requirement for all asbestos waste to be stabilized, starting from March 30, 1998.

As ACW is also considered to be a hazardous waste, its disposal is strictly regulated under two regimes:

- ACW linked to inert materials and soils containing naturally occurring asbestos is processed in storage facilities for non-hazardous waste.
- Other ACW follows a stricter procedure and must be processed by thermal decomposition in facilities for hazardous waste disposal.

2.2.2 The Netherlands

In 1930, it was admitted for the first time that asbestos can be dangerous and this resulted in, among others, the official recognition of asbestos in 1949 as being a cause for several occupational diseases. This eventually led to the asbestos policy in the Netherlands present nowadays. In general, this policy consist of a ban on the manipulation, processing or stockpiling of asbestos or asbestos containing materials. This started with a prohibition of the use of sprayed asbestos and on brown and blue asbestos, followed by another prohibition in January 1st, 1993, that stated that asbestos could no longer be used in roads, buildings and roofs and that it can no longer be sold, imported, processed, *etc*. Eventually in 1998, a general ban for asbestos was formulated. In 2005, a decision was made concerning the removal of asbestos and in 2024, a general prohibition on asbestos-containing roofs will be enforced, meaning that all roofs containing asbestos have to be replaced. It is expected that this prohibition will lead to a shift from the current attention on asbestos-containing sewage pipes to roofs due to the fact that in the Netherlands, only approved remediation companies are authorized to remove asbestos and there are approximately 300 of such companies present in the Netherlands. Furthermore, employees suffering from asbestos-related diseases have the right to a compensation. Eventually, by 2040, The Netherlands aim to have no more new victims as a result of exposure to asbestos.

In the second National Waste Management Plan (‘Landelijk Afvalbeheerplan’ LAP 2), applicable from 2009 to 2021, a statement is included concerning (timing of) the **declaration of a landfill ban**. This states that when a treatment method for non-combustible and non-recyclable materials is developed, other than landfilling, it would be appropriate to add this waste stream to the landfill bans in the Decree on landfills and bans Waste materials (‘Besluit Stortplaatsen en Stortverboden Afvalstoffen’ Bssa), as such supporting any new processing technique. However, before this landfill ban is enforced, the treatment process has to meet with following **conditions**:

- The **pressure on the environment** of the new processing technique has to be lower than the environmental pressure present when landfilling the waste stream.
- There has to be a **market** for the end product.
- The new technique must work properly and **be able to process at least 75%** of the amount that is released on an annual basis.
- The new technique must cost no more than 150% of the equivalent landfilling tariff.

The latter condition has been changed recently, due to the abolishment of the **landfill tax** in 2013. This led to the fact that alternative processing techniques could no longer compete with landfilling. Therefore, the previously stated 150% is changed to a **fixed-price of €175**. Although in 2014, the landfill tax (not only for asbestos but for all hazardous waste) was introduced again, this condition with a fixed-price remained.

At the moment, the only option for the treatment of asbestos in the Netherlands is landfilling. This means that all asbestos needs to be disposed of in a controlled manner on specialized landfills since asbestos is a hazardous waste material. Since the re-introduction of the landfill tax in 2014, the landfilling of asbestos costs €50/ton (at a minimum) and on top of that there are special asbestos-taxes of €13/ton.

2.2.3 Germany

The first measurements against asbestos were implemented in Germany in 1940. The Ministry of Labor ('Reichsarbeitministerium') and the Imperial Insurance Authority ('Reichsversicherungsamt') implemented a directive aimed at protecting workers against the exposure to asbestos dust in companies that use asbestos. Following this directive, several guidelines, regulations, safeguards, etc. were introduced to address and manage the dangers posed by asbestos in the workplace. This resulted in 1993 to the acknowledgement that the controlled handling of asbestos products cannot be guaranteed over their entire life-time, leading to a ban on manufacturing, sale and use of asbestos products in West-Germany.

In 1982 a first catalogue was published on substitute materials for asbestos. This recognition of asbestos substitutes initiated several innovative efforts of the industry to find safe, non-hazardous substitutes. As a result to these studies, the withdrawal of the use of asbestos products that was introduced in 1990 was eventually finalized in 1995, when an overall ban. The suspected economic consequences did not materialize. Instead of that, Germany took on a pioneering role regarding producers of asbestos substitute products. As a consequence, they had a competitive advantage on the international market.

In Germany, as a result to the council decision No. 573 of the 27th of July, 2007 which classifies all ACW as being hazardous (including construction ACW that is embedded in the binder matrix, e.g. asbestos cement), ACW is normally disposed of permanently in special landfill sites or sections thereof. Attempts at large scale asbestos fiber destruction with concurrent cement matrix recycling have been unsuccessful.

2.2.4 Poland

In Poland, asbestos was widely used as a building material throughout the 20th century but now the link between asbestos exposure and several illnesses, including a severe form of lung cancer, is considered to be a proven fact. As a result, Poland banned the import, production and trading of asbestos and ACMs in 1997. This solves the problem of occupational exposure by employees, but the large quantities of asbestos present in the communal environment remains a problem. On top of this ban, Poland aimed to achieve an asbestos free country by 2032, making it the first country in the EU that has a plan of action for achieving an asbestos-free country. However, due to a lack of progress, studies have been done to re-evaluate this statement which led to the conclusion that 2032 is no longer plausible and that, at this progress rate, Poland would reach its ambitious goal by 2080 at the earliest. As a result to this study, the Polish Government has announced an update to their policy by 2015.

At the moment, deposition on landfills is the sole, legally permitted method for the disposal of ACW in Poland (Poland – The 2010 National Waste Management Plan; Warsaw, December 2006). In 2006, 26 such landfills were operating throughout Poland:

- hazardous waste landfills;
- separated silos on the landfill sites for waste other than hazardous and inert waste.

3 INVENTORY OF ASBESTOS CEMENT BUILDING MATERIALS[34]

3.1 TYPES OF ASBESTOS MATERIAL

In general, a distinction is made between two types of asbestos containing materials, namely friable and non-friable materials.

- Friable materials can be crumbled, pulverized or reduced to powder under hand pressure, for example spray-applied insulation (on walls and ceilings), blown-in insulation, fireproofing materials and pipe insulation.
- Non-friable materials cannot be pulverized under hand pressure, for example asbestos cement.

Chrysotile is resistant to alkaline attack and for this reason was mainly used for asbestos cement products; joints and packing products; friction materials; floor tiles and coverings; and for fillers and reinforcement in felts, mastics, coatings, etc. Amosite was predominantly used for fire resistant boards and some asbestos cement pipes. Crocidolite was extensively used in insulation materials in chemical and gas works, in power stations, in thermal and sound proofing materials in railway rolling stock and in sprayed coatings, due to its resistance to attack by mineral acids.

Distinction between asbestos containing materials and materials free of asbestos is not always very obvious. Absolute certainty can only be given by means of analytical techniques. There are however some general rules which can be used to make a distinction between asbestos containing and asbestos-free products, such as, for example:

- Asbestos containing materials often show a very weathered look due to their age.
- Unpainted asbestos-containing plates sometimes show very typical flower-like prints.
- Asbestos-containing plates often have a layered structure.
- Asbestos-containing plates feel harder and more brittle and sound clearer than asbestos-free plates.
- The “Burn Test”: a noncombustible fiber will often be an asbestos fiber and when held in a flame, it will only start to glow and will remain unaffected when the flame is removed.

3.2 FLANDERS

The current situation of asbestos in Flanders was calculated in a report for OVAM (Inventarisation study of asbestos material streams in Flanders. OVAM, 2013). The quantity of asbestos in public buildings, schools, houses, offices, farms, landfills and soil was defined for both friable and non-friable materials. Following data is a review of the report of 2013, based on the most recent publication of OVAM at the ISWA Congress, Antwerp, September 2015. It is clear that most asbestos containing materials are currently still present in the soil, in the form of utility lines in Flanders.

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[34] This chapter is based on Ecorem. *Inventarisation study of asbestos material streams in Flanders.* OVAM, 2013.

In and around buildings	Amount of ACW
Schools	15.000 ton
Residential	910.000 ton
Agriculture	245.000 ton
Companies	724.000 ton
Public	6.000 ton
Utility lines	1.800.000 ton
TOTAL	3.7 million ton

Table 5: Amount of ACW in and around buildings

Based on the production numbers, the current amount of asbestos containing materials in and around buildings in Flanders is estimated to be **3.7 million tons.**

The policy goal of OVAM is to have an asbestos-safe or asbestos-free Flanders by 2040. The approach to reach this goal is to set prohibited milestones, in order to increase the scale of asbestos removal. Good inventarisation of asbestos in and around buildings stay crucial to have an accurate view on the amount of future ACW. Integrated renovation policy can stimulate the phasing out of asbestos in the environment. Linked to this, organizational and financial support, is to be given to ensure the implementation.

3.3 BELGIUM

For Belgium, 2.079.689 tons asbestos fibers were used for the production of non-friable materials. About 86.653 tons were processed in friable materials. Especially in Flanders, there was a production of asbestos materials. Wallonia imported their asbestos from Flanders.

In the Netherlands, approximately 70.000 tons of asbestos containing material are released every year. In total, there would be another 4 million ton of asbestos containing material with approximately 4% pure asbestos. In Germany, it was estimated that some 24 million tons of asbestos cement was applied in the production of asbestos cement plates. Over a period of 50 year, there will be a yearly disposal of 450.000 tons of asbestos cement.

4 TREATMENT OF ASBESTOS-CONTAINING WASTE (ACW)

4.1 INTRODUCTION

Numerous industrial and experimental facilities have been set up, particularly in the last ten years, as a result of studies and research on treating asbestos-containing waste (ACW) to stabilize it and to enable its reuse. Some of the processes reduce the hazard of ACW by imprisoning it in a cement of resinoid matrix. Other processes modify the fibrous structure of asbestos and transform it into an inert and asbestos-free substance. These are called respectively stabilization and crystallochemical processes. An overview of both these processes is given in **Table 6**.

Treatment Class	Principle	Technique	Fate
Stabilization Processes	Physical	Double-bagging	Landfill
		Encapsulation	Landfill
Crystallochemical processes	Thermal	Vitrification	landfill, building, roadway, tiles
		Ceramitization	landfill, building, roadway, tiles
		Pyroceramitization/Glass Ceramitization	Glass ceramic materials
		Pyrolithic Lithization	Building
	Chemical	Chemical Attack	Landfill
		Mechanochemical Attack	Additives for cement, catalyst

Table 6: Overview of the different treatments for asbestos contaminated waste (based on Bruno et al., 2013)

As mentioned before, a distinction is made between friable and non-friable asbestos containing materials. Examples of materials of these two types are given below.

- Friable materials: spray-applied insulation (on walls and ceilings), blown-in insulation, fireproofing materials and pipe insulation, etc.
- Non-friable materials: asbestos cement, floor tiles and other types of flooring, pipelines, roof plates and other types of roofing, etc.

For these two types of ACW, often different treatment methods are necessary. For example, as already mentioned, in Flanders non-friable ACW does not need further treatment besides double bagging and labelling while friable ACW needs to undergo treatment in order to stabilize the asbestos fibers and as such neutralizing the threat. Many of the treatment methods that are listed in **Table 6** and that will be further explained in the following chapters, are not equipped to handle every type of ACW. A suitable pre-treatment procedure could provide a solution here. An obvious example of one of these procedures is the crushing of non-friable ACW, resulting in a reduction in size and as such making it more manageable for various methods. Another example is the design of a fitting pre-treatment procedure for friable ACW so they can be treated by treatment techniques that are only equipped to handle non-friable material. A possibility is to subject friable ACW to the process of encapsulation in a cement matrix, as such transforming it into a non-friable material and as a result making it treatable with methods such as denaturation. Next to these reasons, the pre-treatment of ACW can be necessary to reduce the health risks related with the distribution of asbestos fibers to a minimum.

Table 7 gives an overview of possible pre-treatment methods for different types of hazardous asbestos waste.

Type of Asbestos Waste	Possible pre-treatment Methods
Waste materials containing free asbestos fibers (spray applied insulation, asbestos dust…)	Grind into pieces of max 1cm
	Immobilization by means of cement
	Packing in sealed plastic bags, tagged with asbestos labels
Synthetic waste products and contaminated packing materials	Compressing to a minimal density of 400kg/m³
	Packing in sealed plastic bags, tagged with asbestos labels
Unbreakable materials covered with asbestos containing materials	Packing in sealed plastic bags, tagged with asbestos labels

Table 7: Overview of the different pre-treatment methods for different types of asbestos waste

Several countries all over the world are doing extensive research for alternative methods for the treatment of asbestos and ACW. This research, in some cases, has already led to small- or large-scale pilot installations or even full-scale operational treatment-plants.
In what follows, an overview will be given of different treatment techniques. For each technique, examples will be given of countries/companies/… that have done research is this technique, either on laboratory, pilot or full-scale. Any references to specific companies are given purely from an informative point of view, to illustrate which techniques have already been tested extensively and which techniques are used in full scale installations. Additionally, an assessment will be made, where possible, giving quantifications and identification of all costs and benefits for the discussed treatment method.

Key elements required for the cost/ benefits analysis are the price range for accepting ACW vs. the cost for investment and operation. Obviously, for different reasons, this data is not yet available for all options and techniques described above, due to the fact that many of these treatment systems have only been tested on laboratory scale hence these methods haven't been applied on full scale for the time being. All prices given in following sections are given purely as an indication for the price range of a specific technique in a specific country. These price-settings vary for each country and need to be reviewed for Flanders if a technique is selected for application.

Given the fact that only a couple of full scale installations are in operation, one can see the available data is mostly considered as confidential. Where no data is available, a more general overview is given for this technique.

4.2 STABILIZATION PROCESSES

4.2.1 Physical

4.2.1.1 Encapsulation and double-bagging (and landfilling)

4.2.1.1.1 General

A relatively simple way to encapsulate and thus immobilize unbound asbestos fibers, is to capture the fibers in a concrete matrix.

In practice, the asbestos is delivered to the treatment facility in containers. These containers contain bags with asbestos. These bags are opened and distributed manually on a belt conveyer. Metal and plastic parts are sorted out of the asbestos manually. A magnetic belt will remove the remaining metal. After this the waste is transported to a first crusher.

After the first crusher, the waste is transported to two other crushers to reduce the size of the waste to maximum 1 cm³. The in size reduced waste is then stored in a storage bunker. From the storage bunker, the waste is transported to the mixing unit. Here the asbestos is mixed with cement and other additives and distributed into volumes of 1 m³. After these blocks are dried, they can be landfilled.

It is often required that the asbestos-bonded cement be double-bagged or double wrapped in plastic bags or big bags, taped and provided with clear indication of the content of the bags before it is landfilled.

The stabilization process of cementation reduces the hazard of non-friable asbestos/ACW by imprisoning the fibers in a cement or resinoid matrix. This is a relatively simple way to immobilize the unbound asbestos fibers and thus removing the direct threat. Although, it does not eliminate the characteristics of the fiber, as such it merely dilutes the problem. At the same time, this technique increases both the volume and the mass (+150%) of materials that need to be dumped. Furthermore, this technique does not result in a re-usable end-product. The only place the blocks of asbestos-cement are used is in the landfills themselves for various infrastructure-related needs. For all these reasons, this technique will be very expensive in the long run since it does not solve anything.

4.2.1.1.2 Example: Flanders

In Flanders, the current treatment technique for non-friable asbestos is double-bagging, labelling and landfilling, while friable asbestos has to be immobilized (by cementation) cemented before disposal. This policy exists and gets implemented in Flanders since 1986 and is put in practice by the treatment facility of Rematt since 1993.

In Flanders, the only enterprise that has the technical know-how and the environmental licenses to carry out this treatment is Rematt. However, the immobilization is not suitable for all types of ACWs. Therefore, at Rematt, the installation is also used for compacting the contaminated waste in bales and for packing non-shreddable waste and then transporting these bales and packages to dumping sites. Rematt’s installation is fixed, thus the process is always done under the same conditions and there are little unknown factors that can affect the production process and the level of asbestos emissions in the surrounding air. Otherwise, the disadvantage of this fixed installation is that the ACW has to be transported twice: first to the installation and then, after processing, to the appropriate landfill (Ecolas, 2000).

Rematt is licensed to process a maximum of 15.000 ton/year of ACW and 400 ton/year of friable asbestos and this up until October 2021. Table 8 gives an overview of the division of this capacity per type of asbestos containing waste (ACW) that is accepted by Rematt.

ACW	Total amount (ton)	Friable Asbestos (ton)
Contaminated soil	12.000	80
ACW for immobilization	1.500	250
ACW for compaction	1.000	2,5
ACW for packing	50	0,05
ACW for external export	400	80

Table 8: Overview of the division of the capacity per type of ACW for REMATT (Emis Vito: Techniekfiche Conditionering & Immobilisatie, retrieved 2015)

The ACW for export contains the ACW coming from Brussels that are transported to Inertam for processing. This fraction of the ACW is handled by Recona, which is a sister company of Rematt, and they compact the ACW for transportation.

The average price rate at which Rematt processes the friable ACW, is €1.100/ton. This price rate includes the cost of both the cementation of the friable ACW and the dumping of the end-product. This does not include, however, the cost of the removal of the asbestos from the buildings/constructions that are to be demolished.

4.2.1.1.3 Financial & economic parameters

4.2.1.1.3.1 Landfilling

In Flanders, the dumping of different types of asbestos is allowed on licensed landfills. In 2014, there were several landfills in which ACW could be dumped (Tarieven en capaciteiten voor storten en verbranden; OVAM, 2014):

- Category 3, for asbestos cement:
  - Nv De Kock in Huldenburg, until August, 2015
  - Nv Scheerders-Van Kerckhove in Sint-Niklaas, until January 26, 2026
- Category 2, for asbestos cement and other ACW:
  - IMOG in Moen
  - Vanheede Landfill Solutions
- Category 1, for asbestos cement and other ACW:
  - Nv OVMB in Gent, until December 21, 2021
  - Nv Indaver in Antwerp, until 2020
  - Nv Indaver In Doel, until 2021
  - Nv REMO milieubeheer in Houthalen-Helchteren, until September 11, 2017

In 2006, the **environmental taxes** on landfilling ACW was €11,14/ton. However, the government abolished these taxes in 2007, reducing them to **€0/ton**, thus stimulating the legal collection of ACW.
The normal costs linked with dumping of ACW however remained. Based on numbers from 2014, these costs were:

– Category 1: (OVAM, 2014)
  - €48/ton (weighted average) for asbestos cement waste
– Category 2: €60/ton (OVAM, 2014):
  - €38/ton (weighted average) for other asbestos containing waste

The tariff for the last category is rather low since this category is made up of a large amount of remediation waste, giving a distorted picture.

4.2.1.1.3.2 Encapsulation and double bagging

Stabilization, double bagging and dumping of the ACW (non-friable) according the specification set by the VLAREM regulation, is the only treatment method in Flanders at this moment. Friable asbestos, is first immobilized by cementation, before it is double bagged and landfilled. This asbestos waste stream is only a small proportion in comparison with the amount of non-friable asbestos in Flanders. As mentioned before, alternative processing techniques are currently not an issue. This is mainly due to the fact that too few of these alternative techniques are adequately proven.

TV Rematt is the only company in Belgium that is allowed to process both friable and non-friable asbestos. They have a license that allows the acceptance and processing of 15.000 tons of ACW and 400 tons of friable asbestos per year, until 2021. Rematt immobilizes the ACW and friable asbestos in a cement matrix, double bags the asbestos cement and after which the processed waste is being landfilled on a category 1 landfill. In order to be able to carry out this entire process of immobilizing, bagging and dumping, Rematt asks an **average price of €1.100/ton of asbestos** that they have to process). This price varies depending on, for example:

– the total amount that is delivered, e.g.:
  - <50 ton: €1.125
  - 50 to 100 ton: €1.050
  - ≥100 ton: € 990
– the state in which it is delivered, since Rematt has very strict regulations concerning for example the size/dimensions of the bags and/or the containers, whether or not the material was spilled, presence of non-asbestos material, *etc*., hence the following additional costs:
  - Cleaning of containers in case of damaged/non-air tight bags: €160
  - Repacking of objects that are to large: €15/piece
  - Presence of large pieces of metal that block the shredder: €250/blocking
  - Etc.

4.3 CRYSTALLOCHEMICAL PROCESSES

Treatment	Principle	Final Destination
Vitrification	Melting with plasma torch or standard furnace	Landfill Applications for buildings and roadways
Ceramitization	Melting with standard furnace, with or without additives	Landfill Applications for buildings, roadways and tiles
Pyroceramitization/ Glass ceramitization	Melting and crystallization, Glass ceramic materials, inert	Landfill Applications for buildings, roadways and tiles
Pyrolyses furnace	Melting in furnaces to produce expanded clay	Building industry
Chemical attack	Dissolution in acid or bases	Landfill
Mechanochemical attack	Structural destruction by mechanical energy	Cement applications Catalyst
Denaturation	Heating to 1000°C for destruction of fiber structure	Secondary material in several industries

Table 9: Overview of the different crystallochemical processes (based on Plescia et al., 2003)

These crystallochemical techniques (**Table 9**) can be complemented by different pre-treatment methods (e.g. shredding to increase the surface, compression, spreading…).Different pre-treatment methods can be used for different goals, e.g. to accelerate the process or to make a certain crystallochemical method applicable.

4.3.1 Thermal

Two parameters of importance with thermal treatment methods of ACW are time and temperature. The range of the temperatures used varies for each of the methods described below and subsequently so does the cost linked to each of these techniques. The generally high temperature that are necessary for the processing of asbestos in these techniques result in high energy needs. These high energy needs drive up the costs.

The temperature depends on what the goal of the technique is and how it wants to achieve it. For processes such as vitrification, the ACW is vitrified and due to the high glass transition temperatures of these materials, these techniques need high process temperatures up to 1.600°C to ensure a harmless end-product that is completely vitrified. Other techniques aim at altering the asbestos fiber structure by eliminating the OH-groups. This also result in an asbestos-free material and can be achieved at lower temperature ranges of up to 1.100°C. Furthermore, the range of decomposition temperature of each asbestos-type varies (no data for actinolite; Seymour et.al, 1983):

- $T_{decomposition}$ (chrysotile) = 800-850°C
- $T_{decomposition}$ (crocidolite) = 400-900°C
- $T_{decomposition}$ (tremolite) = 1.040°C
- $T_{decomposition}$ (amosite) = 600-900°C

- $T_{decomposition}$ (anthophylite) = 950°C

With this in mind, some companies target specific asbestos minerals with their treatments to keep the required temperature, and as such the cost, low, while other companies target all asbestos minerals, using the upper temperature limit to ensure total destruction of all asbestos-types.

The second important parameter is the residence time of the ACW. This is the time during which the ACW has to be treated in order to ensure complete destruction of the asbestos fibers. Within the described techniques this parameter ranges from minutes to several hours or even days. Consequently, the cost to process ACW increases with longer residence times.

Furthermore, the infrastructure necessary for these techniques, e.g. furnaces, plasma torches, etc., is very expensive and often not readily available. This limited availability leads to transport of the ACW over larger distances, which in turn may lead to, not only a larger environmental risk, but also a **higher logistical cost**. This parameter of availability of infrastructure and transport may be less applicable in Flanders than it is in the U.S. of in France in terms of distance but in terms of environmental and social issues, this should be taken into account in order to minimize the risk at environmental and social problems.

A total of four thermal techniques will be described and several countries can be given as examples. However only three of these techniques, namely vitrification, ceramitization and denaturation, will be described from a financial point of view, because no financial information can be found for the fourth technique (pyrolysis furnace).

4.3.1.1 Vitrification

4.3.1.1.1 General

Vitrification is the transformation of a substance into glass (Jacobs et.al, 2003; Varshneya, 2006). When used on asbestos or asbestos containing waste, it can serve as an alternative to immobilization in a cement matrix. During this treatment, the material is heated to extreme temperatures (~1100-1600°C). At these temperatures, it is possible to completely destroy the hazardous fiber structure, transforming it into an inert, asbestos-free, vitrified end-product that can be re-used (Jacobs et.al, 2003).

A number of different technologies can be employed to achieve vitrification of asbestos waste. Some of the more common examples are:

- **Vitrification with a plasma gun**. This is probably the most common technique and it is proven to be a successful commercial technology for the treatment of hazardous waste. The application of the technique for the treatment of ACW was further developed by Inertam in France (Europlasma Group).
- **Vitrification in conventional ovens**. This is done with or without fluxes, respectively at temperatures of 1150-1200°C and >1400°C.
- **Vitrification with an electrical furnace**. This is an electric melting process used to treat hazardous and radioactive wastes through Joule heating, at temperatures ranging between 1300 and 2000°C (Geomelt Vitrification Process).

Vitrification processes require that the raw material remains reasonably constant both in chemical and physical properties. For this reason, the melting of asbestos to glass requires tight control over raw material input, including control over the particle size of the raw material. This degree of control is very expensive and difficult to achieve and maintain in asbestos waste due to the presence of other materials such as fiberglass, calcium silicates, water-soluble silicates, portland cements, clays, calcium sulfate (gypsum), silica, lime, oxychloric-bonded dolomites and a variety of other components used within insulating materials and building products. Asbestos content by weight may vary from 5% or less to almost 100% of these composite materials.

In order to control the vitrification process, the amount of asbestos waste entering the process must either be kept low, relative to the amount of glass formers required or the type of waste entering the vitrification process needs to be controlled to preclude wide variation in raw material chemistry. While some very limited separation of materials may be carried out as part of the asbestos abatement process, it is both impracticable and undesirable to be separating materials at the scale required to maintain chemical and physical properties. Therefore control of the process would normally be achieved through limiting the asbestos material feed rate and thus increasing processing costs.

Vitrification processes present a number of technical challenges associated with extreme temperatures and control of the rate of corrosion of the carbon electrodes. The aggressive atmosphere presented by molten silicates also significantly increases both the capital and maintenance costs of this equipment.

Several of the vitrification methods have been patented leading to specific processes for different companies. A few examples are described below, based on the different technologies listed earlier.

4.3.1.1.1.1 Vitrification with a plasma gun (JACOBS ET.AL, 2003)

This technique uses a plasma gun to heat the waste to extreme temperatures. When the waste enters the torch, the temperature can rise up to 1600°C. At these high temperatures, it is possible to transform the ACW into an inert and asbestos-free vitrified product. The asbestos fibers are hence completely destroyed in this process. After this, the vitrified material is cooled down in metal molds. The resultant glass can be crushed and re-used in low-grade construction applications, such as road building. Another advantage of the treatment is that it leads to both a mass and volume reduction of respectively 40% and 60%. The exhaust gasses produced in the process are first treated by an afterburner. Then the gasses are cooled down and purified in a bicarbonate scrubber. At the end, the exhaust gasses also pass through a fabric filter.

The plasma gun or torch that is used in the treatment process of ACWs was developed and built by Aerospatiale for space and military applications. Now, it is used commercially for applications such as hazardous waste treatment. In 2001, this technical expertise was reinforced by Inertam (Europlasma Group) resulting in a treatment process for ACW through vitrification by plasma technology.

The plasma torch is generated by an electrical arch between two electrodes. This will generate very high temperatures. This type of plasma gun used for the treatment of ACWs is of the tubular type (developed by Aerospatiale) and the most important characteristics of the torch are:
- Produced thermal power: 1.700 kW;
- Maximum electric power: 2.000 kW;

- Maximum current: 950 A;
- Maximum voltage: 2.200 V;
- Plasma gas: air;
- Efficiency of the torch: > 80 %.

A schematic overview of a plasma torch is given in **Figure 4**.

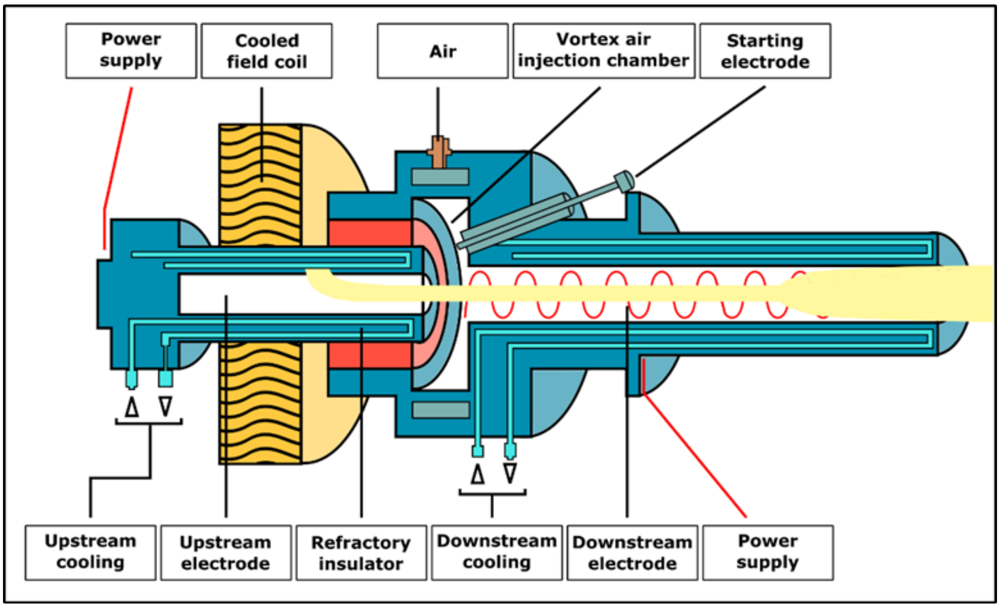

Figure 4: Schematic overview of a plasma torch (Inertam)

The plasma torch is directed at a relatively small area to achieve the required temperature and therefore the efficiency of heating is relatively low. Concentration of the heating area also means that output of the plant is limited and that heat losses are proportionately higher due to the very large temperature difference between the melted material and the surrounding environment and the limited size of the heated area.

The Europlasma Group has developed and patented a gas plasma technology for plasma-torch vitrification. This process is, at the moment, the only method for converting ACMs that has been successfully converted from lab-scale into a fixed large-scale industrial plant. This industrial plant was opened in 1999 in Morcenx, France by Inertam of the Europlasma Group (**Figure 5**). The end-product of this vitrification process is a chemically stable material named Cofalit and is non-hazardous. It resembles obsidian glass and can be used in road foundations and as a substitute of quartz and basalt in building materials.

The Europlasma-technology for the treatment of ACMs has also been successfully licensed in Japan and the UK by Tectonics Limited and it is expected to have a wider distribution in the future. Furthermore, in the past, Inertam's industrial plant processed all the ACW coming out of Brussels Region, since the vitrification process was designated as the required pre-treatment. Since July 1st, 2008, this is no longer an obligation.

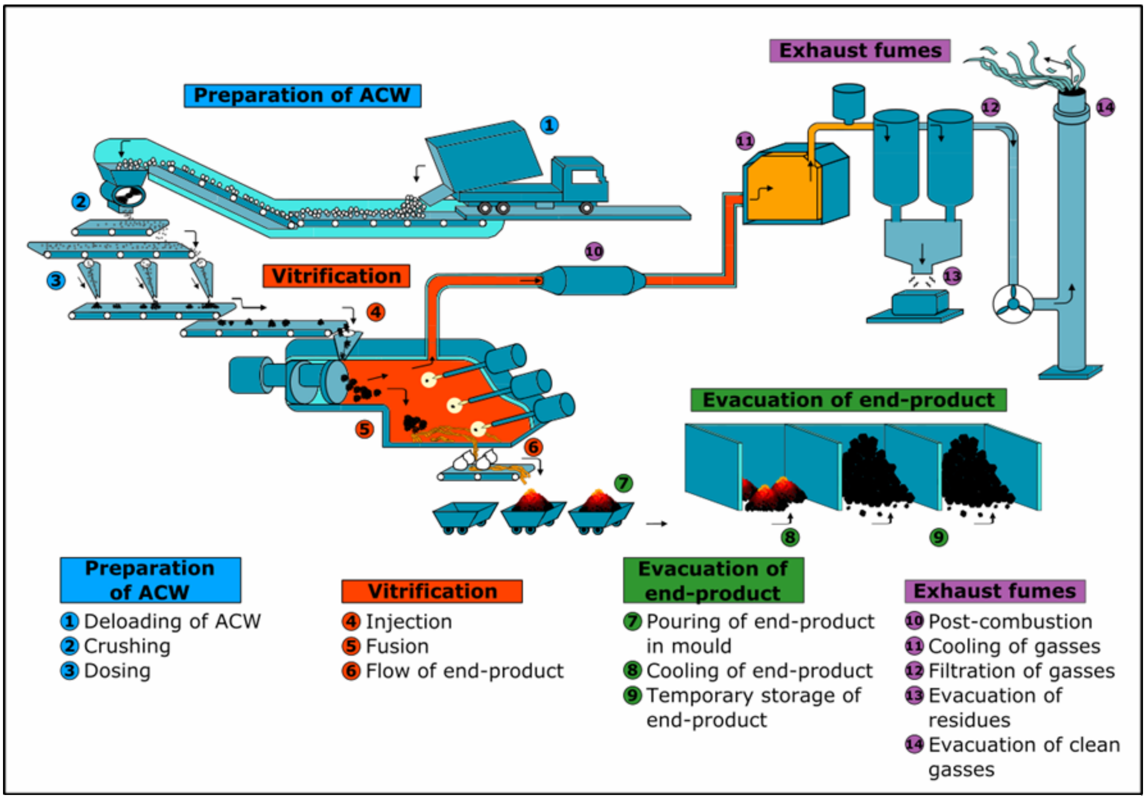

Figure 5: Schematic overview of the operation of the Inertam's plant

4.3.1.1.1.2 Vitrification in conventional ovens

Another example of a vitrification technique is **vitrification in conventional ovens**, with or without fluxes. The fluxes mentioned can play a key role in the vitrification of materials since it is used to lower the high melting point of glass formers. Without fluxes, the fusion is achieved by working at temperatures above 1400°C, where all the components of the mixture melt to produce a vitreous slag. Conversely, with the use of fluxes, the melting temperatures is lowered and the process is performed at temperatures close to 1150-1200°C, again producing a harmless and useless vitreous slag.

4.3.1.1.1.3 Vitrification with an electrical furnace *(FINUCANE ET.AL, 2008; KURION INC, 2015)*

Vitrification has been chosen by the EPA as the best "demonstrated available technology" for high level nuclear waste, which is far more hazardous than toxic wastes. However, due to the volume of toxic wastes as compared to high level nuclear waste, it is too expensive to do extensive pre-treatments to toxic waste or low level nuclear waste. Thus, there is a need to develop a robust vitrification process which can accommodate asbestos materials, infectious waste ash, toxic materials and low level radioactive waste.

In general, vitrification with an electric furnace is an electric melting process used to treat hazardous and radioactive wastes through Joule heating. In **Figure 6** an example is given of an electric furnace, explaining the functioning of the furnace.

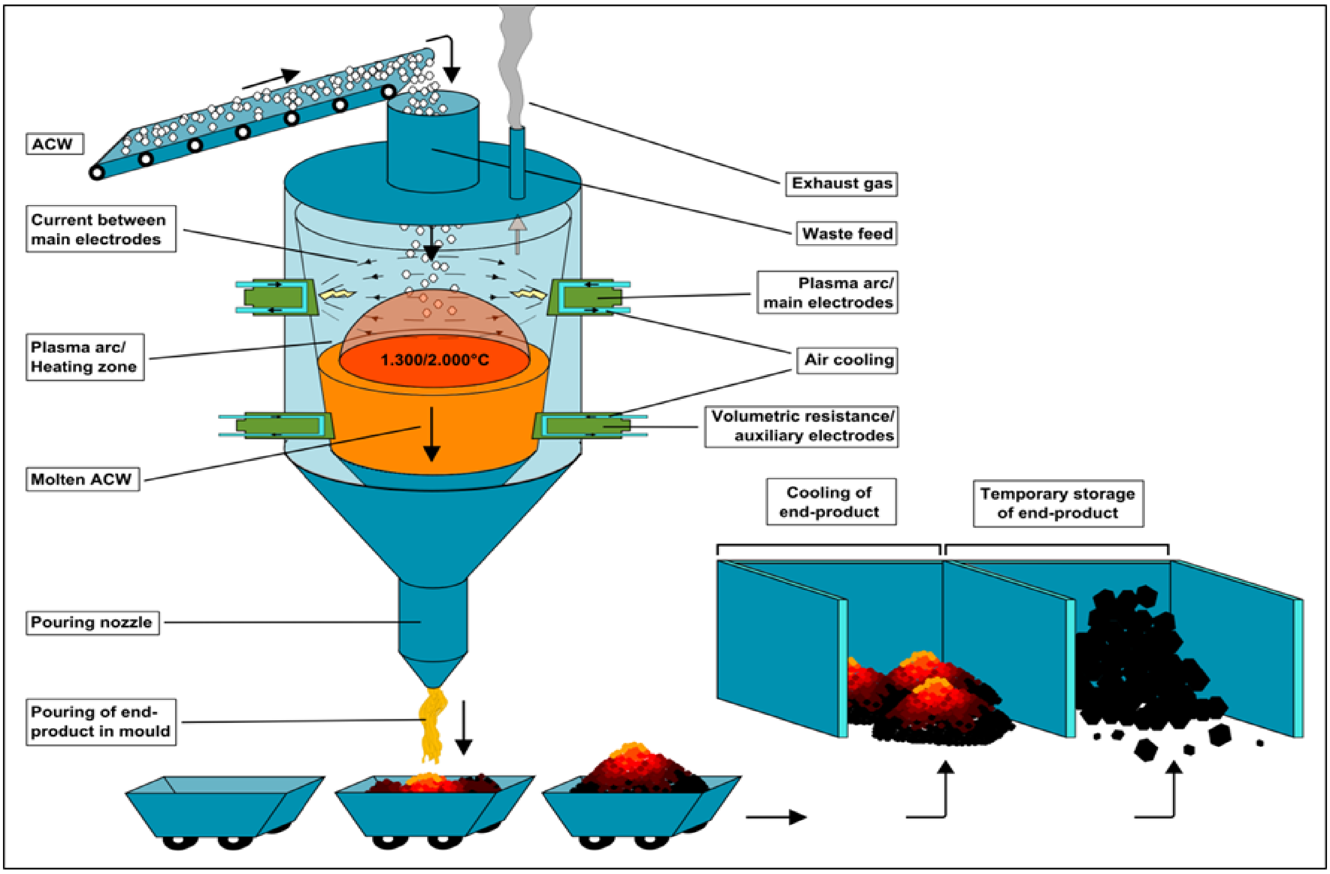

Figure 6: Example of an electrical furnace in the vitrification process

The treatment results in the destruction, removal or permanent immobilization of contaminants. This process has been successfully used on a commercial basis to treat a wide range of hazardous and radioactive wastes (e.g. chlorinated organic wastes including dioxins, pesticides and polychlorinated biphenyls). The melting temperature typically ranges from 1300-2000°C depending on the materials being treated and on the process configuration being used. Silica (SiO_2) or alumina (Al_2O_3) may be added to the waste in order to increase the melting rate at the desired temperature. Primary attributes for the process in its various configurations include the following examples:

- Soil provides the source of glass formers for the processing media (molten soil) and to form the resulting glass product.

- The process can treat contaminated soils or non-soil wastes can be added to soil for treatment.
- Treatment rates of up to 100 tons per day.
- No organic contaminants remain in the glass product due to the inability of organics to exist in the melt at such high temperatures.
- The destruction and removal efficiency (DRE) for organic contaminants achieved during commercial operations is greater than 99.9999%. This DRE includes the percentage destroyed by the melt (typically 90 to 99.9%) and the percentage destroyed and/or removed from the off-gas stream by the off-gas treatment equipment.
- The process can accommodate relatively high concentrations of heavy metals and radionuclides resulting in permanent immobilization within the vitrified product.
- Most metals and radionuclides are retained in the melt, with typical melt retention efficiencies (REs) of 99.99% or better for the non-volatile species.
- The degree of retention in the melt of semi-volatile heavy metals such as lead, cadmium and arsenic is quite high and generally around 80 to 90%. In some electric furnace treatment configurations, cesium has been processed with processes resulting in REs of 99.9% or more.
- The electric furnace process can accommodate complex mixtures of contaminant types as well as debris such as concrete, bitumen, bricks, steel, wood, plastic and automobile tires.
- Off-gases that evolve from the melt are collected in a steel containment hood and directed to an off-gas treatment system.
- The off-gas treatment steps vary depending on project requirements but generally consist of particulate filtration, quenching, wet scrubbing, a second stage of particulate filtration, and carbon adsorption and/or thermal oxidation. Additional treatment steps can be added to meet project-specific requirements.

The resulting product normally consists of a mixture of glass and crystalline materials and also often has the appearance of volcanic obsidian as well. The end-product is typically ten times stronger than concrete, 10 to 100 times more durable and extremely leach resistant. The latter is considered to be due to a high concentration (60-90%) of glass formers (SiO_2 and Al_2O_3) and due to the ability to treat most soils and wastes without temperature-lowering additives such as sodium. As such, this vitrified product readily satisfies the requirement of the US Environmental Protection Agency's (EPA) Toxicity Characteristic Leaching Procedure (TCLP).

4.3.1.1.2 Examples: France

Inertam (http://www.inertam.com/) in France has successfully established a plant where ACW is being stabilized. It uses the **Europlasma technology**, which is a plasma-torch **vitrification method**. The process is designed to render any type of solid waste or residue by vitrification. It is particularly appropriate for powdered or particulate materials, containing *e.g*. metals (particularly heavy metals such as mercury, cadmium, lead, *etc*.) as well as their salts and asbestos; and generally speaking, it is well designed for rendering inert any powdered or particulate material containing heavy metals or other toxic substances that must be destroyed, transformed or trapped for recycling or storage under present or future legislation regarding the treatment and elimination of said toxic waste.

At the moment, the plant is licensed to process 8.000 ton/year and their actual capacity lies around 7.000 ton/year at a price rate ranging between €1.000-2.500/ton. The amount of energy used is dependent on the composition of the ACW and ranges between 500 and 1.300 kWh/ton, with an average of consumption of 1.000 and 1.300 kWh/ton (Jacobs et.al, 2003).

4.3.1.1.3 Financial & Economic parameters

At Inertam (France), a subsidiary company of Europlasma, this end-product is called Cofalit and can be used as a substitute for quartz and basalt in building materials. **Cofalit** can therefore be **sold for €10/ton (transportation costs excluded)**. The amount of produced Cofalit varies between 4.000 and 6.000 ton/year (Jacobs et.al, 2003).

In Morcenx, France, Inertam has been processing ACW since 1995, using an installation for vitrification. This is the only operational installation in Europe for processing ACW that uses this kind of treatment. The installation of Inertam is capable of processing all types of ACW, both friable and non-friable. The processability of the material is dependent on the caloric value of the ACW and the amount of asbestos present. On a yearly basis, the installation is licensed to process 8.000 ton of ACW and their actual capacity lies around 7.000ton/year. **They process the ACW at a price range of €1.000-2.500/ton with the average price lying around €1.500/ton, not including transportation costs**. This average price varies according to the conformability of the ACW. For example, an extra cost is charged when the packing of the ACW is not as it has to be and when contaminants are present that complicate the process. Although this technique has an advantage with respect to cementation because it is a long term solution since it destroys the asbestos fibers, the high energy needs of 2.400kWh/ton ACW, or 8.64 GJ/ton, results in a **processing cost that is about 35% higher compared to cementation**. This energy consumption is linked to the composition of the ACW, with the main factors being the caloric value and the water content.

4.3.1.2 Ceramitization

4.3.1.2.1 General

It is well known that asbestos materials are unstable at high temperatures. Chrysotile, for example, has a tendency to lose the hydroxyl groups at 500-600°C and to be transformed into a different inert mineral phase, forsterite, which recrystallizes at 820°C. However, heating materials to these temperatures has the disadvantage that it is extremely energy consuming and expensive due to the very high temperatures that are required for this process. The application of the ceramitization method makes it possible to obtain inert and asbestos-free materials from ACW, whether pre-ground or processed as such, and this in furnaces at temperatures ranging between 800-950°C. These lower temperatures reduce energy consumption and make the method economically more competitive. Furthermore, if heating is preceded by the compaction of the material, the consequent disorientation of the crystals allows the final product to be used as electrical insulation or refractory material. This technique has been tested on laboratory scale. One of the pioneering ceramitization processes of ACMs is the CORDIAM project (Abruzzese et al., 1998).

In this process for producing ceramic-type materials by processing asbestos-containing waste, pre-ground asbestos-containing waste is mixed with clay, thus obtaining a mixture which is fired at temperatures between 800-950°C (**Figure 8**). This firing process leads to the complete elimination of the asbestos fibers and to the conversion of the mixture into ceramic materials whose characteristics depend on the parameters of the mixture and of the asbestos-containing waste materials.

A variation on the ceramitization process is vitro-ceramitization (Plescia et.al, 2003). With this technique, the waste is melted at higher temperatures ranging between 1300 and 1400°C, together with particular additives such as blast furnace slag or industrial sludge, thus forming a mixture with a high metal content. The slag thus derived is crystallized at a controlled temperature. In this manner, one obtains products with very high mechanical strength, particularly suitable as coating and protective surfaces in the building, mechanical and chemical industries.

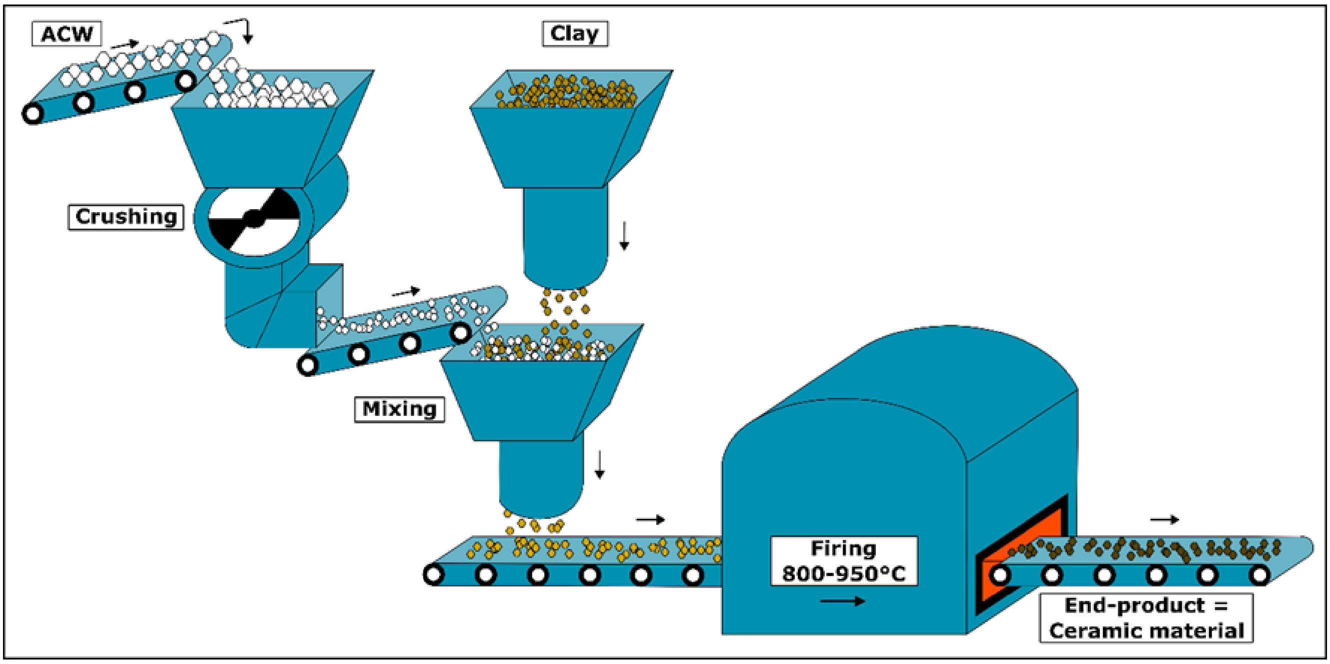

Figure 7: Process scheme for the ceramitization process

4.3.1.2.2 Financial & economic paramaters

Many patents exist describing different stages, conditions, ways *etc*. to carry out this process of ceramitization, for example, the earlier mentioned CORDIAM process described by Abruzzese et al. (1998) or the patent by Balducci G. et.al (2013; EP 2428254 B1). However, no specific financial and/or financial data has been found concerning ceramitization.

Overall, the same general assumptions can be made concerning the cost of this type of treatment, namely:

- High temperatures that are linked with thermal techniques are linked with high energy needs and thus resulting in high cost;
- Expensive equipment; and
- Higher logistical cost due to expensive equipment and thus low availability of the necessary installation leading to larger transport distances.

However, in comparison with the vitrification technique, the **needed temperatures in the ceramitization method are significantly lower** (respectively 1.600°C and 800-950°C). This lower temperature range leads to

reduced energy consumptions, making the process of ceramitization **more competitive from an economical point of view**.

4.3.1.3 Pyrolysis furnace *(JACOBS ET.AL, 2003; THAM)*

4.3.1.3.1 General

The word pyrolysis is a combination of the Greek word "*pyro*" which means fire and "*lysis*" which means separating. It is a thermochemical process that includes the decomposition of organic materials at elevated temperatures. The process differs from other thermochemical processes in that way that it happens in absence of oxygen or any other halogens. The process involves the change of both the chemical composition and the physical phase and this change is considered to be irreversible.

This method contains a processing system that is capable of heating and as such destroying ACW using normal waste (Municipal Solid Waste = MSW) as fuel. The system itself consists of following elements (**Figure 9;** Park et.al, 2012):

1. an asbestos preprocessing device configured to crush incoming asbestos containing waste (ACW), mix an additive to the ACW (alkali- or silica-additive to assist in the melting), pelletize the crushed ACW and discharge the pelletized ACW at a pressure lower than atmospheric pressure;
2. a pyrolysis furnace configured to pyrolyze incoming municipal solid waste (MSW) and discharge pyrolyzed gas and pyrolyzed solids; and
3. a melting furnace configured to melt the pyrolyzed solids and discharge melting exhaust gas and slag.

The melting furnace melts the pelletized ACW resulting from the asbestos preprocessing device along with the pyrolyzed solids and discharges the melting exhaust gas and slag. The temperatures in this melting furnace can range from 1300°C to 1600°C.

This thermochemical process results in the melting of the ACW or in other words, in the destruction of the hazardous fiber structure of asbestos, rendering it harmless.

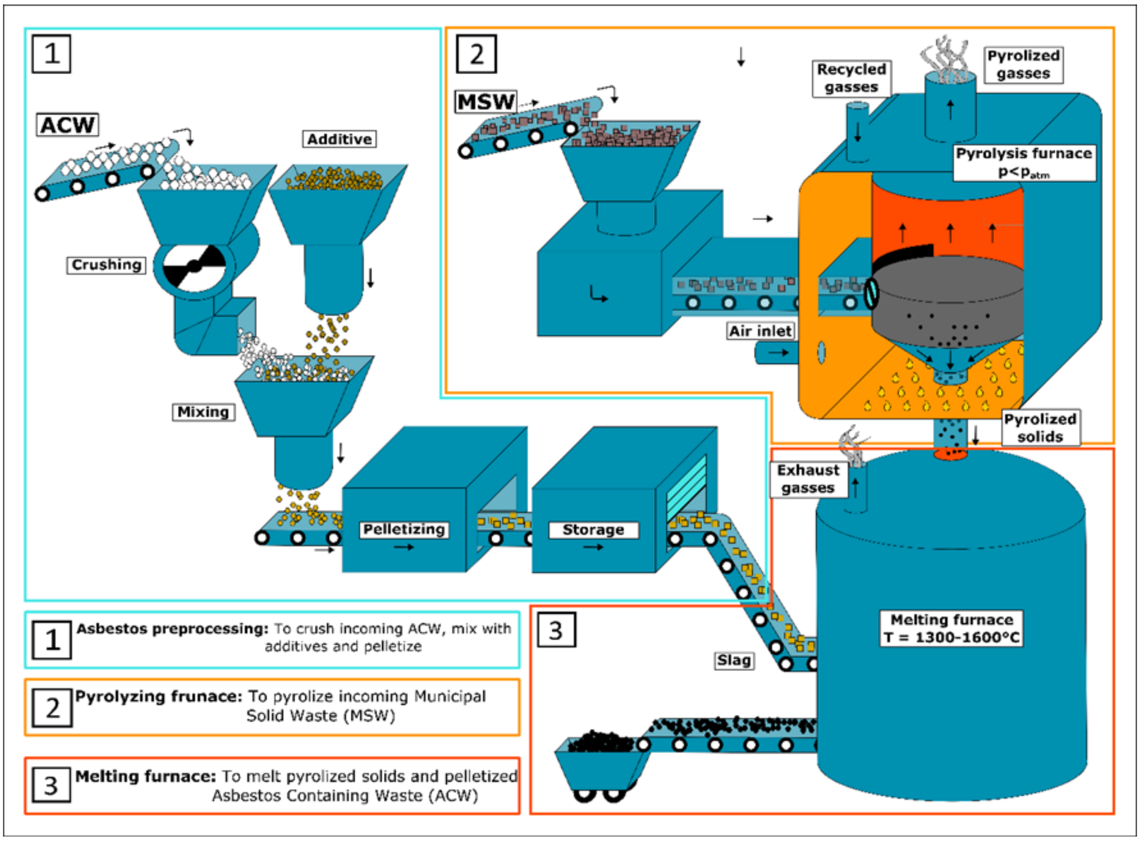

Figure 8: Treatment of ACW in a melting furnace fueled by pyrolized MSW

4.3.1.4 Denaturation

4.3.1.4.1 General

Denaturation is a process where the asbestos is heated to a temperature of approximately 1000°C after which the hazardous fiber structure is altered in a non-hazardous structure. After the denaturation, the remaining product is grinded to an end-product that can serve as a secondary material in several industries. This process of denaturation is patented in at least 23 countries (e.g. Bauer & Bauer, 2003).

An example of one of these countries is the Netherlands. In the Netherlands, plans have been made by Twee “R” Recycling Groep BV (Asbest Denaturering Zwolle BV) for the construction of a plant for the processing of the hazardous ACW (Site: www.puinrecycling.nl). The process of denaturation, following the technique of Twee “R” Recycling Groep BV, will be carried out in a long tunnel furnace of 180 meters. The concept of this tunnel furnace is to a certain degree comparable to a normal stone furnace, albeit that the build-up in temperature and the maximum temperature (1100°C) differ. The residence time of the material is about 75 hours and the reason for this long residence time is that in the first place the cooling-stage is very important and secondly because the heating has to be done gradually to avoid steam explosions due to rapid removal of fluids from the material. Furthermore, only non-friable asbestos material will be processed in this installation, which is approximately 90% of the Dutch market. This is in the first place for the safety of the operations and secondly, for the desirability of the obtained end-product. Asbestos-containing soil, for example, will not be processed because it gives a totally different end-product (soil).

Twee “R” Recycling Groep BV came to this technique through the cooperation with a German entrepreneur. Together with this entrepreneur, the technique was tested for the first time at the level of a pilot installation, with positive outcomes as a result. After this, not only the technique has been tested in several more settings, also the end-product has been analyzed by several institutions.

The installation is shown in Fout! Verwijzingsbron niet gevonden. and will work as followed:

- The ACW arrives at the plant in big bags which are transferred to a wagon, after which the wagon enters the tunnel furnace. The reason for this approach is to limit any direct contact with the asbestos-containing material. This is further ensured by unloading the big bags by means of a crane instead of just dumping them and by only accepting big bags of certain dimensions. Big bags that are too large will tear when they are lifted by the crane. Furthermore, the dimensions of the wagons that carry the ACW are made in such a way that there is a nearly seamless transition between the edges of the wagons and the walls of the tunnel furnace, ensuring limited wastage.
- In the front section of the tunnel, the big bags will be burned, leading to the exposure of the material.
- After this, a drying area is implemented, where hot air will cause an increase in temperature up to 300°C, resulting in the vaporization of the water that is present in the material.
- Next are the heating area and the fire area. In these areas, heating of the material takes place, from the topside, resulting in temperatures of up to 1100°C. These temperatures lead to the denaturation of the asbestos and as such, rendering it harmless. In theory, white asbestos or chrysotile denatures at a temperature of 400°C and colored asbestos (blue and brown asbestos) at temperatures of 800°C. However, since the big bags remain closed before/while sending them into the furnace, there is no way to guarantee that the right type of asbestos is being denatured. As a result, a standard procedure is developed, involving temperatures of 1100°C, to ensure that all the material is sufficiently heated in order to destroy all the asbestos down to the core. By heating the asbestos to these temperatures, the OH-groups that make up the fiber structure are removed. What remains is a shell/shadow of the former fiber, which is very weak and brittle. Due to this shadow, many laboratories initially stated that the asbestos fibers are still present, However, as soon as this ‘fiber’ is touched, it falls apart, leading to the discussion ‘is the end-product asbestos or not?’.
- The last area in the tunnel furnace is the cooling zone, where the denatured material is cooled down gradually.

Finally, the material will be crushed to achieve a non-hazardous end-product that can be used as a substitute for cement and as filling material in the cement and asphalt industry.

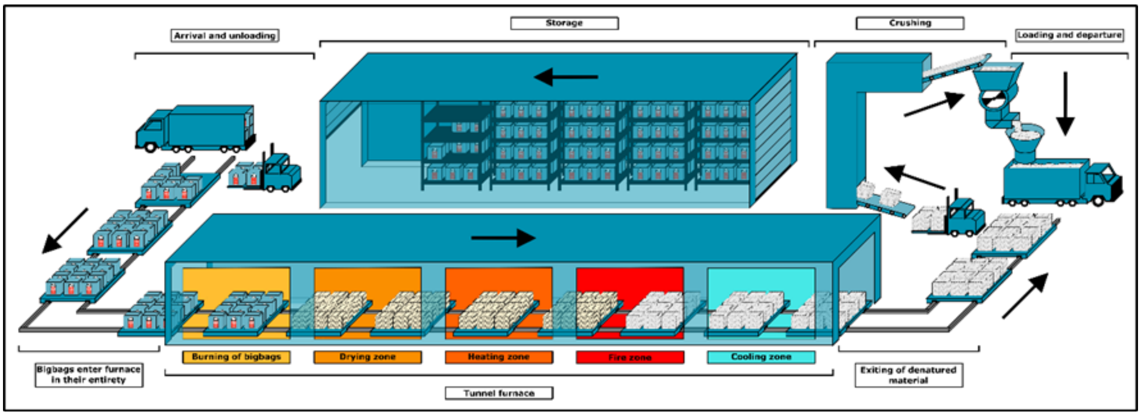

Figure 9: Schematic overview of the proposed installation of Twee "R" Recycling Group

Because it is a continuous, closed tunnel furnace and because the ACW enters it in big bags, the first time the material comes in direct contact with its surroundings, is when it leaves the furnace after 75 hours, as a completely harmless material. This material looks more or less the same as the initial material but now the asbestos-crystals are amorphous, brittle and harmless. The asbestos-free material on these wagons is crushed using a crusher (Ø0.2), resulting in the end-product: “Beststof”, which can be used as substitute for cement, cement filler…

The fuel that will be used for this process is (initially) natural gas. The two main reasons for this are:

1. There is no bio-gasification present in the area; and
2. Concerning technical authorization, this will be the fastest way to get the process realized (in the Netherlands).

An alternative to denaturation in (tunnel) furnaces, is denaturation by means of micro-wave heating. Detoxification by the micro wave method needs a lower processing temperatures than other thermal methods. This lower temperature is seen as a consequence of the microwave penetration depth in the waste material and the increased intensity of the microwave electric field in gaps between the asbestos fibers. This results in a rapid heating of the asbestos fibers inside the debris and thus resulting in the lower processing temperature. In this method the asbestos minerals are directly exposed to an electromagnetic field of high frequency between 20 and 300MHz to assure dielectric heating.

4.3.1.4.2 Examples

4.3.1.4.2.1 The Netherlands

The installation/procedure designed by Twee “R” Recycling Groep BV (Asbest Denaturering Zwolle BV) has been tested in several settings, e.g. in Germany, in England (in a periodical furnace) and in Belgium (Beersel). The end-product itself has also been tested by several laboratories, such as INTRON (SGS), ENCI (Heidelberg), TNO… During the processing, it is planned that from each wagon a sample will be taken from the core for analyses, to ensure that the material has been completely denatured.

Twee “R” Recycling Groep BV has already undergone several steps in order to set up the plant, described above. A short overview is given below:

1. A German entrepreneur from Hockenheim has developed a technique to process asbestos. Together with Twee “R” Recycling Groep BV, he planned to upgrade the technique for widespread use. Initially, a small pilot installation was set up to assess and validate the technique. These tests were done on several types of ACW. However, the collaboration came to an end when the German partner made some dishonest decisions. This eventually led to a trial in 2004, in which the court decided to grant all the patents concerning the established and tested treatment process to Twee “R” Recycling Groep BV.
2. A collaboration between Heijmans and Twee “R” Recycling Groep BV (ACD Moerdijk). This collaboration applied the necessary permits for the plant, which were all granted. However, in 2008, Heijmans had to withdraw from the collaboration due to financial problems.
3. Twee “R” Recycling Groep BV decided to continue on its own and had to deal with the next setback: the constructor of the tunnel furnace went bankrupt. Since the design and construction of this furnace is crucial in the process, finding a substitute was crucial. Furthermore, banks were quite reluctant and weary of the project. They were interested in financing but were waiting for the certainty that the government would implement the landfill ban once the plant was set up.
4. Twee “R” Recycling Groep BV found another financer: Infestos (D-Nature). They are currently applying for new permits, although there is still some uncertainty about the sites (Almelo or Zwolle). The government already informally gave their consent and agreed to introduce a landfill ban once the plant is build, provided that all the conditions are met. They also received a subsidy for the second time from Life+, which is a European program that finances projects that contribute to the development and proper implementation of environmental policy and legislation.

Considering the current situation, Twee “R” Recycling Groep BV and Infestos expect that it will take another two to two and a half years, until the plant is built and operational.

4.3.1.4.2.2 Poland (Eco-innovation Observation & Greenevo)

The **MTT-technology** is a patented asbestos containing waste treatment applied by the Polish company **ATON (**Site**:** www.aton.com.pl). MTT stands for **Microwave Thermal Treatment** and it can be used not only for the destruction of the asbestos fiber in asbestos-containing waste but also for the treatment of hazardous medical waste, laboratory waste, biological waste, etc.

For the treatment, the ACW is mixed with an agent that facilitates the heating of the material. After this the ACW is positioned in a microwave reactor where the material will be zapped by a compact microwave at a temperature of ~**1.000°C**. In other words, the material is heated by beams of focused polarized electromagnetic radiation in a microwave band and this temperature is maintained for a certain period of time to ensure the structural transformation. Once cooled, the end-product is completely harmless.

4.3.1.4.2.3 Germany

The **MCT-process**, certified in Germany, is a **thermal process** where the complete removal of molecular water is accomplished by means of dry heating the crushed ACW. By removing this molecular water, the hazardous fiber structure of asbestos is completely destroyed, thus eliminating potential hazards. Furthermore, a reactivation of the hydraulic component takes place, leading to a regeneration of Ca_3SiO_2 . The regeneration of

this element results in the fact that the end-product (**EURASCONIT**) of this treatment can be used as a hydraulic binder, which is the substance responsible for the fact that cement hardens with the addition of water. The process consists of three large stages:
- The **crushing** of the material to improve the thermal transfer
- The **heating** of the crushed material to **1.350°C**

Maintaining a sufficiently **long dwelling period** to ensure the total destruction of the asbestos.

Another example of ACW in Germany by means of a thermal method thought out by the company AsbestEx-System GmbH (http://asbestex.com.au/). They had an installation for the treatment of asbestos that consisted of a rotary kiln with temperatures ranging from 800 to 1.200°C. The resulting end-product consisted of harmless magnesium silicates and oxides and there was a certainty of 95% that a maximum of 0,1% asbestos could still be present. The end-product could be used in road construction. At the moment, the company does not exist anymore.

4.3.1.4.2.4 Italy

In Italy, another effective asbestos abatement process has been developed, called MODYAM (Site: www.Asperico.it). With this process, the asbestos is put in a special oven where it is heated and turned into forsterite (Mg_2SiO_4). It is a moderately high temperature process that can be used for both friable and non-friable asbestos. The MODYAM process is an effective asbestos abatement process. The material obtained by the process of asbestos abatement/transformation is a reusable "filler". The processes in which it can be used are fillers for use in:
- Construction mortar;
- Asphalt;
- Road beds;
- Cement production.

Laboratory tests provide evidence that the filler can be used in the processes indicated and that is not eco-toxic.

The technique is similar to the denaturation process used in the Netherlands. It also uses a continuous tunnel furnace, albeit one with a smaller capacity, and it also uses relatively low temperatures. This is because their patent is primarily meant for the treatment of chrysotile which does not need high temperatures to denature.

The company behind the MODYAM process is ASPIRECO. They are the only company in Italy who have an authorization to treat asbestos and in Regione Lombardia and this at a capacity of 40.000 tons/year through the MODYAM process. ASPIRECO has already used this process in a mobile plant while helping with the reclamation of an illegal dump at Arborea in the province of Oristano in Sardinia. More than 2.000 tons of asbestos were successful treated during the remediation. ASPIRECO has also wants authorization to install a permanent plant, both in Lombardy and in Sardinia.

4.3.1.4.3 Financial & Economic parameters

With denaturation, the asbestos is heated to a temperature of 1.000°C after which the hazardous fiber structure is altered in a non-hazardous structure. After the denaturation, the remaining product is ground into an end-product that can be used as a secondary material in several industries.

Although this process of denaturation is patented in over 23 countries, very little financial and economic information can be found concerning this treatment. It is assumed that this is because at this moment, no full scale installation exists. However, the company 'Twee "R" Recycling Groep BV' in Zwolle, the Netherlands (Asbestos Denaturing Zwolle) is planning to build a full scale installation for the denaturation of asbestos that will have a **capacity of 100.000 tons/year**. This capacity will meet the current quantity of asbestos/ACW that is present in the Netherlands (80.000 tons/year). Furthermore, it is stated that the cost at which the asbestos/ACW can/will be processed will be more or less the same as dumping asbestos cement in landfills, namely **€175/ton in average**. The installation will be placed on a site of 2,2 hectare and it is said that the **total investment cost will be around 23 million euros**. This investment will include among others, a tunnel furnace with a length of 180 meters. When the installation is fully operational, it will generate approximately 20 jobs.

The installation of AsbestEx-System GmbH could treat ACW at a price range of about €520/ton.

4.3.2 Chemical

4.3.2.1 Chemical treatment with acids or bases

4.3.2.1.1 General

With respect to acid and/or base treatments, various methods have been developed which envisage the use of both organic and mineral solutions to transform ACW to obtain secondary materials that are recyclable and often reusable in the ceramics industry. In particular, the effects of mineral acids, such as hydrofluoric, hydrochloric and sulphuric acid have been studied, as well as those of organic acids such as formic and oxalic acid.

The waste is often first wetted with water which may contain a surface activity reducing agent. This is done to enhance the dissolution rate of the asbestos.

In some countries, pilot installations are/were operational for the physical-chemical treatment of asbestos waste, turning it into an inert raw material, free of asbestos. An example is the **TreSeNeRie-procedure** in the Netherlands supported by SITA Ecoservice, WATCO and Holland Innovation Team. In this process, the asbestos fibers are transformed into harmless silicates by using a **NaOH-solution**, with NaOH being a **strong base**. This way the fiber-structure is destroyed and the end-product is a harmless grey substance that can be used in cement. The TreSeNeRie-procedure is in fact a combination of a chemical and thermal treatment since the dissolution of the asbestos/ACW by NaOH happens at temperatures of 200°C and at an elevated pressure. However, this treatment never went further than pilot installations because, among others, it could not be scaled up to industrial level installations since the process needs a very high liquid-solid ratio, meaning that a lot of NaOH is needed for a full scale installation. This was considered to be unfeasible from an economic point of view and SITA decided to end the process (Pers.Comm. H. Snellink, March 2008, SITA Ecoservice).

Another example is the method of treatment developed by Solvay Umweltchemie in Hannover. They processed the asbestos/ACW by dissolving it into a **hydrogen fluoride solution (HF),** which is a **strong acid**. During the dissolution, a chemical reaction takes place in which the silicon from the asbestos is converted to hexa-fluorosilicate and fluoride, thus destroying the fiber structure permanently. The end-product is chemically stable and non-toxic which means that it can be dumped or used for the manufacturing of paver stones. In addition to this end-product, the remaining acidic solution can be neutralized by adding calcium hydroxide. Advantages of the pilot installation that was set up by Solvay were:

- It was transportable, which means that the asbestos could be processed at the site where it was extracted.
- It causes a complete destruction of the fiber structure, giving a permanent solution.
- It lowers the amount of volume that needs to be dumped considerably.

However, disadvantages such as the fact that HF is a very corrosive and aggressive acid (Ecolas, 2000) eventually led to the abandonment of this method of processing by Solvay.

Another type of chemical treatment is carbonation of asbestos containing waste. Here, instead of adding an acid or a base, CO_2 is added leading to significant changes of the morphological structures of the minerals (Greeshma, G. et.al, 2013; Trapasso, F. et.al, 2012). Significant research is being conducted on the carbonation of magnesium silicate minerals that have similar chemical compositions as some of the asbestos-type minerals (e.g. chrysotile). These studies look to treat ACM by converting it into non-hazardous, readily disposable or even re-usable carbonates by utilizing carbonation. However, there are still many uncertainties linked with this treatment method (specifically for asbestos) and the research specifically for the treatment of asbestos has not gone further than research phase.

4.3.2.1.2 Examples: Solvay and SITA (OVAM, November 2008)

Many pilot projects have been performed by several companies to process the ACW at the construction sites and as such eliminate the packing and transport phase. However, none of these projects reached the appropriate norm of efficiency and environmental conditions. Two examples of such pilot projects are a **chemical method developed by Solvay** and the **vitrification process**.

At the moment, the process that has had the most successes for destroying asbestos fibers is the vitrification process. This process had been successfully applied by Inertam in France. However, due to the high investment associated with the equipment necessary for this method and due to the large amount of energy needed, since this process works at temperatures of 1.200-1.500°C, the vitrification process also did not withhold in Flanders.

SOLVAY and SITA are two examples of companies that used chemical treatments for processing asbestos containing waste, each respectively using an acid and a base to dissolve the ACM.

- A hydrogen fluoride solution (HF) can be used, which is a strong acid. Solvay Umweltchemie (Hannover) is an example of a company that has done research on this method. Solvay produced a method to process the asbestos fibers by dissolving them in hydrofluoric acid and as such, destroy them and render them harmless. In other words, the chemical reaction that takes place during this dissolution results in the destruction of the fiber structure and the creation of a chemically stable and non-toxic end-product, usable in for example the manufacturing of paver stones. The acidic solution could then be quenched so that the end-product is non-toxic and chemically stable. However, the disadvantage of having to work with a very corrosive and toxic acid was considered too big and the method never passed the trial period.

- The TreSeNeRie-procedure is supported by SITA Ecoservice, WATCO and Holland Innovation Team, in the Netherlands.
- Another chemical technique is when the ACM is treated by making use of a strong base (NaOH-solution), at elevated pressures and temperatures of 200°C. An example is The TreSeNeRie-procedure, supported by SITA Ecoservice, WATCO and Holland Innovation Team, in the Netherlands. The dissolution also results in the destruction of the fiber structure, leading to a harmless end-product that can be used in cement. In a first stage, it was proven that this procedure was effective on a scale of approximately 30 liters. In a second stage, a pilot installation was tested on a scale of 500 liters which also proved to be successful. However, further upscaling was found to be economically unfeasible due to the high liquid/solid ratio or in other words the need for high amounts of NaOH.

4.3.2.1.3 Financial & economic paramaters

There is no certainty, once landfilling ACW is prohibited in the Netherlands, that all the generated ACW would end up at the chemical treatment installation. Due to the open border principle, it could also be exported, for example to France, to undergo vitrification. **The Dutch government did mention that this alternative procedure could be accepted if the cost of processing did not exceed the price range of dumping by more than 50-100 euros. However, this statement combined with the high NaOH-consumption, resulted in the fact that the technique became too expensive.**

In general, it can be concluded that the application is this chemical treatment **on a large scale implies the necessity of large amounts of the reagent used to dissolve the ACM**. This not only causes a large environmental risk but is generally also **very expensive**. Furthermore, this technique produces **large amounts of waste products which represents a further cost**.

4.3.3 Combination

4.3.3.1 Thermochemical treatment

4.3.3.1.1 General

Thermochemical conversion is a thermal process in which the ACW will be converted into harmless mineral substances through pyrolysis. This process takes place at a temperature of approximately 1200°C and has a duration of about 20 minutes. The chemical component of the process consists in the expulsion of hydroxides, which results in the destruction of the fiber structure of asbestos and as such, rendering it harmless.
A patented process using this combination of chemical treatment and heat to cause demineralization of asbestos and other silicate materials is the Thermochemical Conversion Technology (TCCT), developed by ARI Technologies, Inc. (Site: http://www.ariglobaltech.com/; Downey & Timmons, 2005).

The demineralization process accomplishes several goals, including:

- Conversion of asbestos minerals into non-asbestos minerals without melting
- Destruction of organic compounds through pyrolysis and/or oxidation
- Immobilization of metals and radionuclides.

The process involves shredding and then mixing ACM with proprietary fluxing agents (e.g. borax) and heating the fluxed mixture. The size reduction of the ACM and the presence of fluxing agents at elevated temperatures (approx. 1200 to 1250°C) results in a more rapid demineralization (20 minutes) of asbestos fibers. The presence of the fluxing agents means that the conversion takes place more rapidly than would otherwise be the case, in *e.g.* denaturation, due to the refractory nature of asbestos and at a much lower temperature than that required for vitrification. As the conversion is achieved at temperatures significantly below the melting point of asbestos, the energy input is much lower than that of vitrification and the capital cost of materials capable of withstanding molten silicates is avoided.

The process also results in the destruction of organics including polychlorinated biphenyls (PCBs) to 99.9999% efficiency. Toxic metals and radionuclides are stabilized in the sintered product through molecular bonding that exhibits excellent chemical durability and surpasses US Environmental Protection Agency (EPA) and Department of Energy (DOE) leaching standards.

The inert, free of asbestos, non-hazardous, non-toxic end-product resembles coarse sand/gravel that can be used in low-grade construction applications, although due to its brittle nature it is not suitable for use in high burden applications. Another advantage is that the technique results in both a mass and volume reduction. The volume reduction has an average of 73% and ranges from ~50% for asbestos cement products to >90% for friable asbestos. This reduction is achieved through the removal of OH^+-groups, reduction of pore space and an increase in density. The average mass reduction is about 30-50%. This is primarily achieved through the removal of OH^+-groups but also from the destruction of plastics and organic compounds. Additives in the form of fluxing agents form <1% of the weight of the feedstock.

The processing equipment consists of four primary systems including feed preparation, rotary hearth converter, off-gas treatment and product removal. The system is modular and can be modified independently of other systems to accommodate a variety of feed materials. Each of these four systems is described below:

- The **feed system** consists of waste handling conveyors, a shredder, mixer, hopper and feed mechanism which compresses the ACM into a brick and simultaneously pushes the compressed ACM onto the rotary hearth
- The **rotary hearth** is a flat circular oven that rotates. The rotary hearth can be fired directly using natural gas, propane or kerosene or can be electrically heated. Waste to be processed is pushed onto the hearth and is then removed after one rotation
- The **off-gas processing system** can be designed to accommodate a variety of wastes as well as asbestos and consists of secondary thermal oxidizer, quench cooler, caustic scrubber and High Efficiency Particulate Air (HEPA) filtration
- The treated product is scraped off the hearth and dropped into a water bath to cool. The **product handling system** removes the treated product from the water bath using an auger. The auger transfers the treated product into holding bins to await verification testing

The process accepts all material normally placed within asbestos waste bags. This included binders, cement coatings, sealants and paints, chicken wire, expanded metal, Personal Protective Equipment (PPE), polyethylene tenting material etc. Furthermore, potential worker exposure is limited at all times. Abated asbestos is typically wet when removed and contained within double, 1000 gauge, polyethylene bags. These bags are loaded complete onto the process conveyor where all processes are within enclosed areas served by a separate HEPA filtered extract system.

The entire process is illustrated in **Figure 11**.

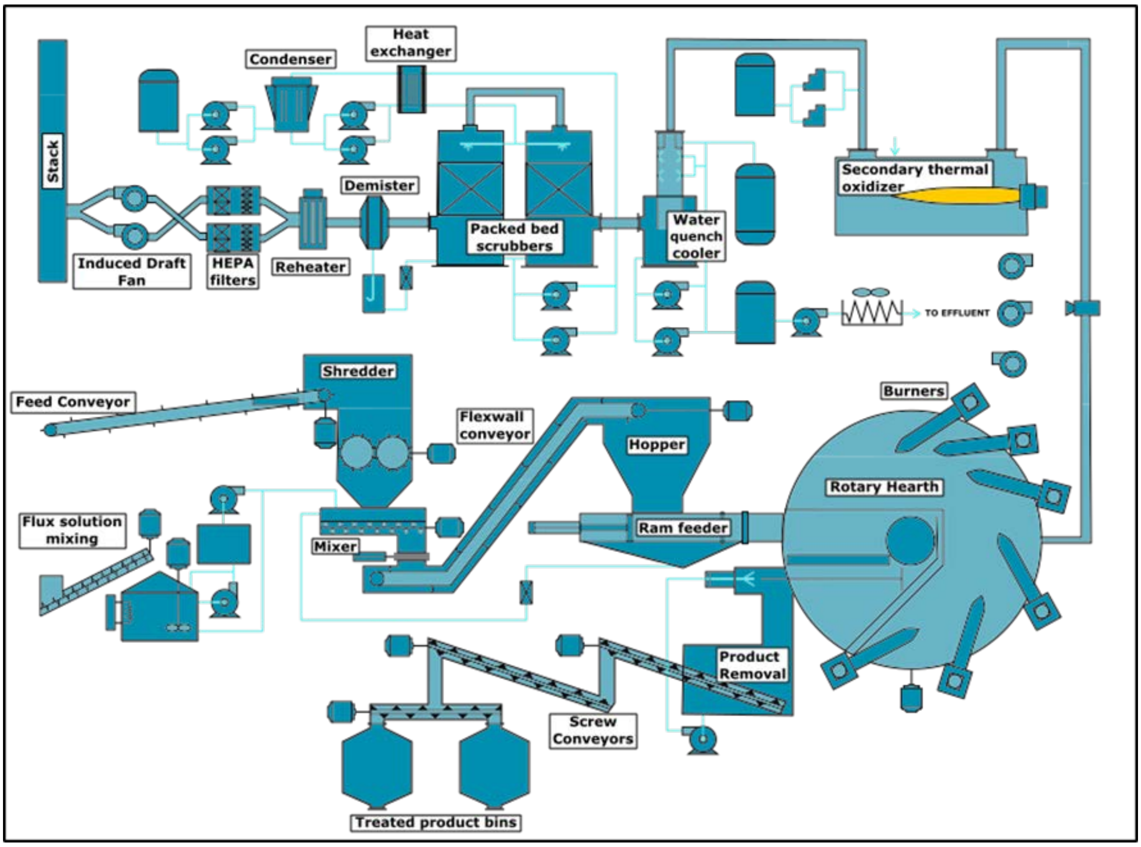

Figure 10: Schematic overview of the process of thermochemical treatment (ARI Technologies)

The operation of the plant typically follows the following sequence:

1 All waste arrives at the plant either double bagged or wrapped.
2 The waste is moved into an air-locked material handling area, maintained at negative pressure to prevent the asbestos fibers from escaping and ventilated using HEPA filters.
3 After being weighed, the bags of ACW are loaded onto the process conveyor that drops them into a shredder where they are reduced to <2 inch (50mm) diameter particles (**Figure 10)**.
4 The shredded material is dropped into a mixer where the fluxing solution is added (**Figure 10)**.
5 The mixed material is then transported to the feed hopper via an enclosed conveyor (**Figure 10)**.
6 From the bottom of the hopper, a feeding mechanism compresses the ACM into a brick and pushes it into the rotary hearth (**Figure 10)**.
7 After one rotation of the hearth (currently about 20 minutes), the converted ACM is removed from the hearth to a water bath for cooling (**Figure 10)**.
8 The treated product is transferred by auger from the water bath to holding bins (**Figure 10)**.

9 The off-gases are routed through a secondary thermal oxidizing unit for the destruction of residual organic compounds that may be present in the gas (**Figure 10)**.
10 The off-gases are then routed through an off-gas treatment system consisting of quench-coolers, caustic scrubbers and HEPA filtration before exhaust to atmosphere (**Figure 10)**.

When the off-gas is treated, it is sampled which takes place from the stack to ensure compliance with discharge authorization. Samples are also taken from the converted product. These samples are analyzed using a Transmission Electron Microscopy (TEM) to confirm absence of asbestos fibers.

Continual development of the technology has resulted in **increased capacity** achieved by reducing the residence time in the rotary hearth. Tests carried out by the developer of the technology have proved that complete asbestos destruction can be achieved with residence times as low as 10 minutes. These developments when applied to commercial scale plant should allow residence time to be safely reduced from the current 20 minutes to 12-15 minutes with a resultant increase in plant output.

A Value Engineering (VE) study concluded that TCCT offered an attractive proven solution which could be used to process both contaminated and non-contaminated wastes as well as a number of other waste streams at a cost which compares favorably with landfill disposal. However, it was noted that further work was required to investigate regulatory issues, potential siting and fuel types to confirm some of the assumptions made.

The TCCT process has successfully received approval from the US EPA both to convert asbestos and to destroy PCB’s. Following receipt of these approvals, second generation modular units have been constructed which are smaller in size with higher processing capabilities. Asbestos conversion has been carried out successfully for the US DOE (Savannah River), US Navy and US Army. The Savannah River work was subject to independent verification by the US DOE National Energy Technology Laboratory (NETL).

4.3.3.1.2 Examples: UNITED STATES

A patented technology in the US, similar to the MCT-process in Germany, is the **ARI-Technology** (Site: http://www.ariglobaltech.com/). As mentioned before, this is an EPA-approved process that uses a **combination of chemical and thermal treatment**. It uses a fluxing solution, mixing it with the asbestos waste. The presence of this fluxing agent at elevated temperatures **(~1.200-1.250°C**) results in a very rapid demineralization (~20 minutes) of the asbestos fibers. The ACW also (as is the case with the MCT-process) has to be crushed before it can be treated, to improve the thermal transfer.

A Pollution Prevention and Control (PPC) permit would be required from the Environment Agency (EA) before TCCT could be employed in the UK. Although the issuing of permits in the US will assist any application and initial discussions with the EA have been positive, this stage could still take many months to achieve. Plans for a similar TCCT plant in Ireland were announced over 2 years ago and according to our information, following a great deal of background work, a formal application for a permit has recently been made to the Irish Environmental Protection Agency (EPA). A successful outcome to this application could assist any other applications within the EU as they all fall under EU Directive 96/61 for IPPC as outlined earlier. The second draft reference document for BAT for the Waste Treatment Industries currently identifies TCCT as BAT for the processing of asbestos. Inclusion of this technology as BAT in the formal issue of this document should lend further support to any PPC application. Processing of any radiological contaminated material would be subject to a separate permit application under the Radioactive Substances Act 1993.

4.3.3.1.3 Financial & economic parameters

In this treatment, the ACW is transformed to harmless minerals by expelling the OH-groups and thus destroying the asbestos fiber-structure. This is done by reducing the ACW in size, adding e.g. borax and subsequently heating it to **temperatures up to 1.200°C** in a time frame of 20 minutes. This technique can be applied to all types of ACW, both friable and non-friable.

An example of a company that has an installation that uses this treatment method is ARI-Technologies. The installation is located in Tacoma, Washington (U.S.) and is licensed to process ACW. It can process up to 18 tons/day and it is certified by EPA (U.S. Environmental Protection Agency) as an alternative to landfilling ACW in the U.S. However the installation is currently not used as it is searching for the necessary investors. It has had two successful test processing-runs: the first one in 2002, processing 10 tons of ACW and the second one in 2007, processing 59 tons. Although, based on the results of these two test-runs, the treatment has been proven successful, the continuity of the technique has not yet been proven. Furthermore, it is proven that smaller installations are less efficient than larger installation. The installation tested in Tacoma is therefore considered as the smallest system that is commercially feasible.

The high temperatures used in this technique lead to high energy usage of 5,68 GJ/ton. This is a lower energy level than required for the vitrification technique of *e.g*. Inertam which leads to a **lower processing cost ranging between €270-370/ton, respectively for a 45 tons/day and 27 tons/day installations**. **This range is obtained by considering that an installation capable of processing 27 tons ACW/day represents a capital expenditure of 3,87 million euros while a plant capable of 45 tons ACW/day costs 5,16 million euros**. This can be written off in 10 years given 300 production days per year and taking into account other costs, such as wages, fuel cost, maintenance cost, operating costs and 15% profit margin, the range of €270-370/ton is achieved, divided as follows:

- Work: 35-45%
- Investment: 25%
- Fuel: 20-25%
- Others: 10-15%, e.g. operating, maintenance (water, electricity, filters, reagents, protection…)

Other additional costs, for example, are the replacement of the refractory material in the furnaces every 5 years. This is done during the yearly maintenance of the installation, takes about 2 weeks and costs 65.000 euros.

This processing cost together with the price rate of **€120-130/ton for transport**, leads to a **total price range of €390-500/ton.** This does not take into account any taxes. This price range is not only lower than the vitrification technique but also lower than the cementation by Rematt TV. At the moment, the only treatment for asbestos cement and other non-friable asbestos cheaper than this in Europe is storing the asbestos in landfills.

It is expected that an enhancement of the process of 25-30% can be achieved by adding energy-rich, appropriate waste streams. This means that in total, when this is accomplished, the technique needs 50% less energy than the vitrification technique of Inertam and so leading to an even lower processing cost.

4.3.3.2 Mechanochemical treatment

4.3.3.2.1 General

With a mechanochemical treatment, it is possible to transform asbestos into an amorphous material with a complete modification of its fibrous morphology, rendering it harmless. This process can be likened to a cold vitrification process (Plescia et al., 2003), insofar that it also results in the transformation of asbestos into amorphous and thus harmless material. In general, during this process, one creates a structural destruction by using mechanical energy.

Mechanochemical technology covers a wide range of important reactions in industrial processes (Plescia et al., 2003):

- Intensification of dissolution and of leaching processes;
- Faster decomposition and synthesis;
- Preparation of substances with new properties;
- Control of mineral properties during preparation of raw materials;
- Improvement in sintering properties of different compounds.

Part of the mechanical energy transferred to solid systems is converted into heat and part is utilized to cause fractures, compression and slips at macro-, meso- and microscopic levels, which affect the crystalline structure of solids including asbestos minerals (Plescia et al., 2003).
Ideally, the process follows a certain sequence (Lin & Nadiv, 1975):

- Plastic deformation;
- Increase in internal stress;
- Micro plastic deformation;
- Fracture.

These four events lead to the formation of new/fresh surfaces that are unchanged by the surrounding environment and can therefore emit or receive ions. As a result, new chemical reactions and structural changes can take place. Also, during these mechanochemical transformations a lot of energy is released. One of the reactions that can take place as a result of this process is the total transformation of a crystalline structure into new phases with a lower degree of crystallinity or even further, leading to the formation of amorphous phases.

To date, the most widely applied processes for treating ACW are thermal, *i.e*. those that are based on artificial reproduction of the temperature conditions necessary for the mineralogical transformation of asbestos minerals. Based on the use of increasingly advanced furnaces, these technologies often meet numerous difficulties arising from the following factors (Plescia et al., 2003):

- Input of ACW of extremely varied composition and morphology;
- Size of industrial plants;

- Pollution treatment and emission abatement systems;
- Necessity of a careful evaluation of environmental impact; and
- Problems in recycling of the by-products.

On the contrary, mechanochemical treatment of ACW can be carried out in small plants, that are transportable and easy to use and can therefore be seen as a fast and economic process for asbestos treatment. Gas and dust pollutions from mechanochemical reactors are extremely limited, because this technology works in a close and limited environment and does not use thermal equipment.

According to Plescia et al. (2003), a mechanochemical treatment could, based on these advantages, successfully be applied in the treatment of ACW on industrial scale. Beyond its technical advantages on an industrial scale, mechanochemical treatment is also extremely interesting from an economic point of view, especially considering European Directive 1999/3/CE of 24/4/99, which calls for the mandatory treatment of all types of waste material before its disposal. This technology is already in use in several countries, albeit with focus on eliminating organic molecules. The use of mechanochemical treatment to treat inorganic wastes, such as ACWs, is new.

4.3.3.2.2 Examples: CANADA

In Canada, a treatment process has been developed by **ABCOV** and is an EPA-approved, non-thermal, simple **chemical-physical process**. It accomplishes the total destruction of all forms of asbestos (both friable and non-friable) within just two hours by means of **high-speed dispersion and mixing the asbestos and/or ACW with proprietary ABCOV chemicals**. This can be done in a fixed-base or mobile, modular system and results in a 50% volume-reduced, free-of-asbestos, and inert sand material, which can either be recycled or sent to an ordinary, sanitary landfill.

4.3.3.2.3 Financial & economic parameters

With a mechanochemical treatment, it is possible to transform asbestos into an amorphous material with a complete modification of its fibrous morphology, rendering it harmless. This process can be likened to a cold vitrification process (Plescia et al., 2003), insofar that it also results in the transformation of asbestos into amorphous and thus harmless material. In general, this process consists in structural destruction using mechanical energy.

Different parameters have already been studied that have to be taken into account in the case of full-scale, industrial applications of the process, such as the type of mill, the oxidation conditions inside the bowl, the quantity of material used in tests and the different hardness and compression strengths of the minerals in the mixture. Beyond these studies, several advantages with respect to thermal techniques (which are, to date, the most widely applied processes for ACW treatment) have been formulated, these have been described in *Chapter 7*.

These studies and the establishment of the advantages with respect to thermal, and in some cases also chemical, techniques, lead to the **conclusion of Plescia et al. (2003) that this treatment could be successfully applied to ACW on an industrial scale**. However, despite these statements, **no specific financial and/or economic data could be found concerning the mechanochemical treatment of ACW**.

4.3.3.3 Combination Acid-Thermal

4.3.3.3.1 General

This process couples a thermal treatment with an acid treatment in which the asbestos containing material, in a broken-down form, is subjected to the action, not of a common acidic chemical reagent, but rather of an acidic industrial waste product, i.e. milk whey, which, besides creating an acidic environment, contributes bacterial components believed to favor an attack on the material itself. In a first stage, this treatment frees the asbestos fibers from the matrix in which they are encapsulated. After this, the asbestos is altered and rendered inert by means of a high-temperature, high-pressure hydrothermal process. At the end of this process, both a solid and a liquid phase is obtained. The solid phase consists essentially of silicates and oxalates together with an organic component resulting from the thermal transformation of the bacterial component; and the liquid phase is rich in various metal ions (in particular magnesium, nickel, manganese, potassium and calcium), which can be recovered through electrolytic processes.

In general, this process for treating an asbestos containing material comprises the following (**Figure 12**):

- Treating the material with milk whey so as to obtain an acidic liquid phase and a solid phase containing the asbestos;
- Subjecting the solid phase containing the asbestos to a hydrothermal process at a temperature of from 120°C to 250°C and at a pressure of from 5 bar to 20 bar.

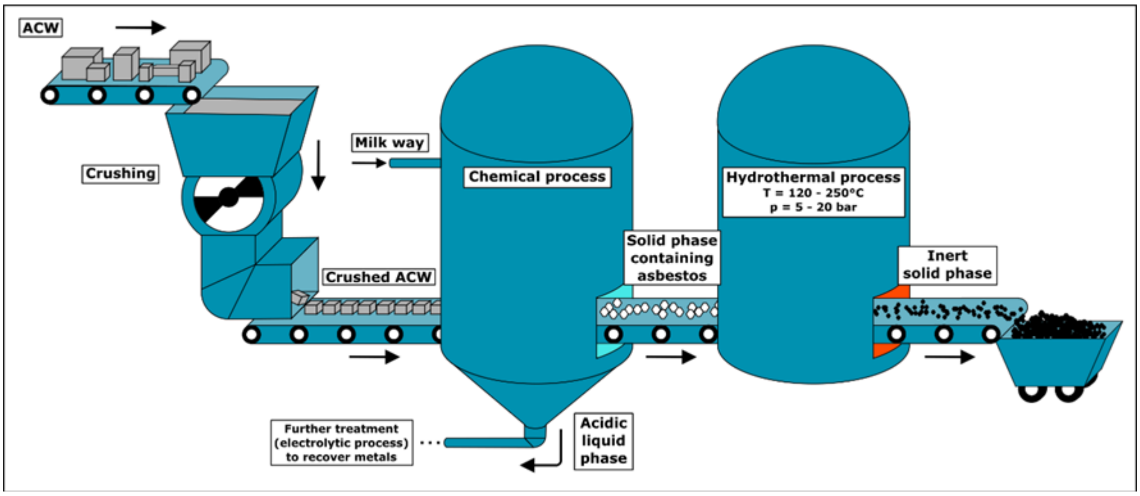

Figure 11: Example of a process scheme for the combination of an acid and thermal process

As stated above, the TreSeNeRie-procedure in the Netherlands, which uses a NaOH-solution to dissolve the ACW at temperatures of 200°C and at an elevated pressure, is an example of a process that uses a combination of acid and thermal procedures.

4.4 SUMMARY: AVAILABLE ASBESTOS CONTAMINATED WASTE TREATMENTS

Unfortunately, the methods for transforming asbestos containing materials (ACM) known to date often have non-negligible disadvantages. In particular, acid treatments lead to the accumulation of a large amount of waste products, which also need to be disposed of. Furthermore, it should be kept in mind that in order to treat millions of tons of ACW, it would be necessary to use enormous amounts of reagents, which would entail non-negligible environmental risks and very high costs. With regard to thermal treatments, the largest disadvantage, besides the enormous amount of energy required to bring the furnaces to very high, constant temperatures, is given by the fact that suitable equipment is highly costly and thus scarcely available across the territory. As such, multiple installations would not be recommendable and thus a strategic location is necessary to limit the transportation distances in order to reduce environmental risks and logistical costs that are linked with the transportation of asbestos.

In **Table 10**, a list is given of all the treatments that have been described in this chapter. For each treatment a short summary is given as to how the technique works and the possible destinations for the end-products as well as both the advantages and disadvantages of each treatment.

Technique	Principle	Destination	Advantages	Disadvantages
PHYSICAL				
Encapsulation + double bagging	– Encapsulating unbound asbestos fibers in concrete matrix – Double wrapping in big bags, taped and labelled	– Landfilled – On landfill for structuring – Further treatment	– Simple – Relatively inexpensive	– No permanent solution because it doesn't eliminate problem – Increases volume of materials landfilled – Expensive method in long run
THERMAL				
Vitrification	– Melting (1100°C-1600°C) with plasma torch or standard furnace for destruction of fiber structure	– Landfilled – Low-grade construction applications e.g. road, building – Tiles	– Renders asbestos completely inert; destruction of the asbestos fiber – Successfully converted from lab scale to fixed large-scale industrial plant (INERTAM) – Chosen by EPA as best demonstrated available technology	– High heat losses due to large difference between melted material and environment – Usage plasma torch: relatively low efficiency of heating – Due to high temperatures: low output, expensive, technical challenges – High degree of control necessary which is economically difficult to maintain – Expensive equipment and scarce availability leading to larger logistical cost and higher environmental risk

Technique	Principle	Destination	Advantages	Disadvantages
Ceramitization	– Mixing ACM with clay – Melting (800-950°C) for complete elimination of asbestos fibers and conversion of mixture into ceramic materials	– Landfill, – Low-grade construction applications e.g. road, buildings – Tiles – If compacted, disorientation allows for usage as electrical insulation or refractory material	– Mixture with additives allows for lower temperature range – Lower temperature range lowers energy consumption – Economically more competitive	– Still high energy due to high temperatures leading to high cost – Expensive equipment and scarce availability leading to larger logistical cost and higher environmental risk
Vitro-Ceramitization	– Mixing with e.g. blast furnace slags or industrial sludge – Heating (1300-1400°C) forming mixture of high metal content	– Coating and protective surface in building, mechanical and chemical industries	– End-product has high mechanical strength	– High energy due to high temperature, leading to high cost – Expensive equipment and scarce availability leading to larger logistical cost and higher environmental risk
Pyrolysis Furnace	– Pelletizing of ACW – Melting of pelletized ACW in furnace (1300-1600°C), with or without additives, using MSW as fuel	– Building	– Harmless end-product – Lowering need of landfill space	– High energy due to high temperature, leading to high cost – Expensive equipment and scarce availability leading to larger logistical cost and higher environmental risk
Denaturation	– Heating to >1000°C to alter fiber structure	– After crushing: usage as secondary material in e.g. cement, road foundation	– Asbestos-free material before crushing, which leads to less risk – Relatively inexpensive due to lower energy consumption	– High energy due to high temperature leading to high cost – Expensive equipment and scarce availability leading to larger logistical cost and higher environmental risk

Technique	Principle	Destination	Advantages	Disadvantages
CHEMICAL				
Chemical Treatment with acids or bases	– Dissolution in acid or bases	– Secondary material that are recyclable and usable in ceramic industry – Landfill – In cement – As pavestones	– Transportable installation – Complete destruction of fiber structure – Lowers amount of volume that needs to be landfilled	– Very high liquid/solid ratio – Often very corrosive and aggressive additives – Accumulation of waste products that need to be disposed in case of large scale processing
COMBINATION				
Thermochemical Treatment	– Shredding and mixing ACM with fluxing agent – Heating (1200-1250°C) for (rapid) demineralization	– Low-grade construction applications	– Presence of fluxing agent results in more rapid process (20min) than denaturation, at much lower temperatures than vitrification – Lower energy input and so lower cost than vitrification – Cost favorable to landfill	– Still needs further research needed – High energy due to high temperature leading to high cost – Expensive equipment and scarce availability leading to larger logistical cost and higher environmental risk
Combination acid-thermal	– Dissolution of the ACM in acid – Heating (120-250°C)	– Dissolution of the ACM in acid – Heating (120-250°C)	– Dissolution of the ACM in acid – Heating (120-250°C)	– Dissolution of the ACM in acid – Heating (120-250°C)

Technique	Principle	Destination	Advantages	Disadvantages
Mechanochemical Treatment	– Structural destruction by mechanical energy	– Asbestos-free and inert additives for cement – Catalyst	– Limited gas and dust pollution – Can be done in relatively small plants that are transportable and easy in use – Does not need thermal equipment – Fast and economic process	– During grinding, microfibers can be lost in atmosphere so filters necessary

Table 10: Summary of the different treatments for asbestos containing waste

5 DECISION-SUPPORT PHASE & CONCLUSION

5.1 INTRODUCTION

Several medical studies have shown a direct link between asbestos exposure and specific diseases such as asbestosis, mesothelioma and lung cancer. For this reason, the production and usage of asbestos applications has known a sharp decline and more strict regulations were introduced concerning not only the production, usage, storage and export of asbestos and asbestos containing materials (ACM) but also the safe removal and disposal of these materials. In Flanders, OVAM started a feasibility study in 2013 in order to develop a phasing-out plan. By 2018 this study is expected to be completed. The ultimate goal is to achieve an asbestos-safe Flanders by 2040.

At this moment, there is still a total of 3.7 million tons of asbestos and ACM present in and around buildings and on landfills in Flanders. In order to achieve an asbestos-safe Flanders, these materials will all have to be removed and disposed of in a way that is as safe and sustainable as possible.

The current policy concerning asbestos treatment in Flanders is as follows:

- Friable asbestos:
    - Encapsulation in cement
    - Double bagged and tagged
    - Landfilled
- Non-friable asbestos:
    - Double bagged
    - Landfilled

Although this technique is relatively easy, it results in a considerable increase in volume and the resulting blocks still have to be landfilled. As such, the problem is not eliminated but merely postponed to future generations. This is not in line with the objectives of the asbestos policy in Flanders, in particular realizing a circular economy. With the current method of immobilization, the asbestos is treated and ‘permanently landfilled’. In other words, the need for disposal space, linked with the current method for treating ACW, is conflicting with the idea of sustainable land use.

As such, EU-measures need to be taken to serve as incentives and support to research and technologies with regard to the development of environmentally-friendly alternatives and processes for, for example, the inertisation of Asbestos Containing Waste (ACW). These processes should aim at the rendering harmless of active asbestos fibers and at the converting of these waste streams into a material that does no longer represent a risk for the public health.

Future policy concerning asbestos treatment in Flanders should focus on the development of alternative treatment methods for asbestos offering a solution to the deficiencies of the current policy. The current regulations in Flanders are still focused on landfilling whether or not preceded by immobilization by cementation. Sufficient research should be initiated to obtain the best suitable treatment method for asbestos in Flanders and furthermore, the new policy concerning asbestos should support this technological research and should aim at the possibility to implement the obtained technique.

Substantial research has already been done, and is still ongoing, in particular for the development of treatment methods for ACMs. These may stabilize or even modify the hazardous fiber structure of asbestos, allowing possible reuse. The first types of asbestos treatment methods comprise the so-called stabilization methods. One previously mentioned example of a stabilization method is the encapsulation of friable ACW in cement. The second types, in which the fiber structure is modified and transformed into an inert substance, consists of the crystallochemical processes. These are based on either thermal, chemical or mechanical principles. A combination of these principles is also possible, *e.g*. thermochemical and mechanochemical.

In this study extensive research has been done into these alternative methods. The table in **Annex 2** gives an overview of the current technique in Flanders, *i.e.* the encapsulation of friable asbestos followed by double bagging and tagging of the non-friable asbestos on the one hand and on the other hand, of the main alternative crystallochemical techniques that have been described in this study: vitrification, denaturation, ceramitization, pyrolysis furnace, chemical treatment, thermochemical treatment and mechanochemical treatment. Several methods that were developed failed to pass laboratory or pilot stages. *E.g.* methods based on chemical principles. By these treatment methods the fiber structure is destroyed through addition of either acids or bases. Although the end-product is chemically stable and non-toxic, the environmental (very corrosive and/or aggressive acids/bases) and economic disadvantages (very expensive method due to high liquid-solid ratio) often result in the abandonment of these types of methods. Other methods, such as the mechanochemical treatment method and furnace pyrolysis, are currently considered for other waste streams but have only been described in theory for asbestos containing waste. This research is currently not yet advanced enough for large-scale application.

In this chapter it will be analyzed what techniques are feasible to further research and develop in the region of Flanders.

5.2 DECISION-SUPPORT PHASE: QUANTIFICATION & MULTI-CRITERIA ANALYSIS

5.2.1 Theory

The goal of this study is in the first place to identify several possible treatment methods for the elimination of asbestos. This was done in the above “Chapter 4: Treatment of Asbestos Containing Waste” and summarized in the table in **Annex 2**. The second goal is to identify the method(s) best suitable to apply in Flanders for the treatment of asbestos, which as has been discussed, is still present in large amounts. In order to do this, all methods discussed in this report have been quantified in the same manner. For each criteria a quotation is given (--, -, 0, +, ++). By this quantification, it is possible to have an overview for each criteria which method(s) has(ve) the most potential of being used as a treatment method in Flanders (**Annex 3**).

Based on the quantification given in **Annex 3**, a multi-criteria analysis (MCA) has been carried out. This type of analysis is done because in comparative studies where different alternatives are weighed against each other, a completely linear equation often is not enough. In a realistic scenario, certain criteria are more important than others. As such, the idea behind a MCA is that different criteria that are used for the comparison of alternatives, in this case the various alternative techniques for the treatment of asbestos, can be assigned a weight. In addition, it can be indicated in the analysis whether values for certain criteria need to be maximized (in case of benefits) or should be restricted (in case of cost or adverse effects). Setting values or thresholds indicate if a value is evaluated as very positive or very negative.

In most cases, there is no alternative that optimizes all criteria at the same time. MCA identifies the alternative that yields the most optimal results taking all criteria into account and gives an idea of the accuracy of this estimate. MCA therefore can be of great value to support a comparative in which different alternatives are compared by using a series of criteria.

The MCA in this study is carried out by means of a specific software package (D-sight; **Figure 12**). This package was designed by the CODE-SMG laboratory at ULB (Université Libre de Bruxelles). The software applied a PROMETHEE-GAIA approach.

Figure 12: Used software package: D-sight

The PROMETHEE methodology aims to obtain a ranking of the alternatives and assumes a pairwise comparison. Within these pairwise analysis one can choose for several functions in order to evaluate the differences between the alternatives (**Figure 13**). In addition, it is possible to define limit values to indicate when a difference is considered to be significant. Since the quantification-values range from -2 to 2, a linear-function approaches the shape the closest in this study.

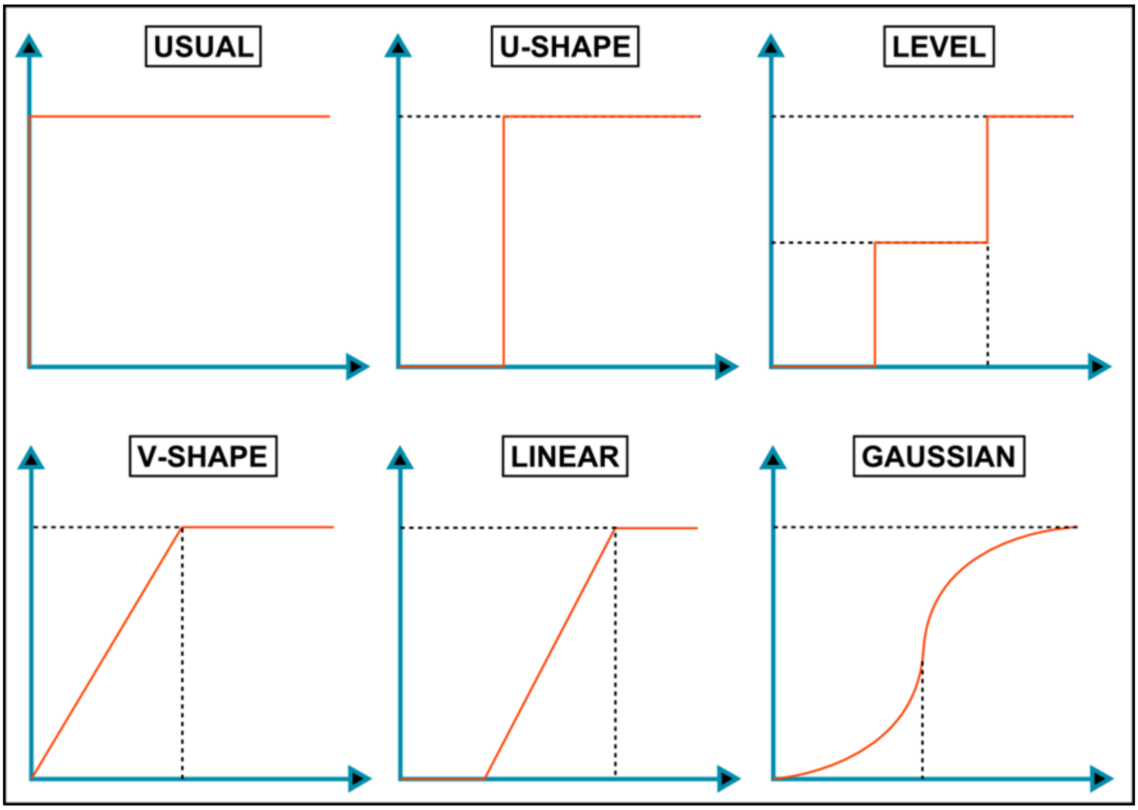

Figure 13: Function types for comparison of alternatives using PROMETHEE methodology

The use of these functions makes it possible to determine a score for each alternative. This score ranges between 0 and 100. Based on these scores a mean comparison is made with respect to the other alternatives (see example below). Assigning weights to criteria further makes it possible to allow certain criteria to weigh in the calculation of the total score.

The result of the analysis is presented in a bar chart illustrating the total scores for each alternative. This bar chart shows which of the alternatives, based on the assumptions used (see above), has the best overall score.

The result of an analysis can be further projected into a GAIA plane, a two-dimensional output from a principal components analysis (PCA). The graph represents the similarity/difference between alternatives on the basis of the criteria. It is therefore used for the interpretation of the results. Note, however, that the GAIA plain just shows the correlation between the criteria (C1-C6; **Figure 14**) and alternatives (A1-A8; **Figure 14**), not the calculated scores. A conceptual representation is shown below (**Figure 14**).

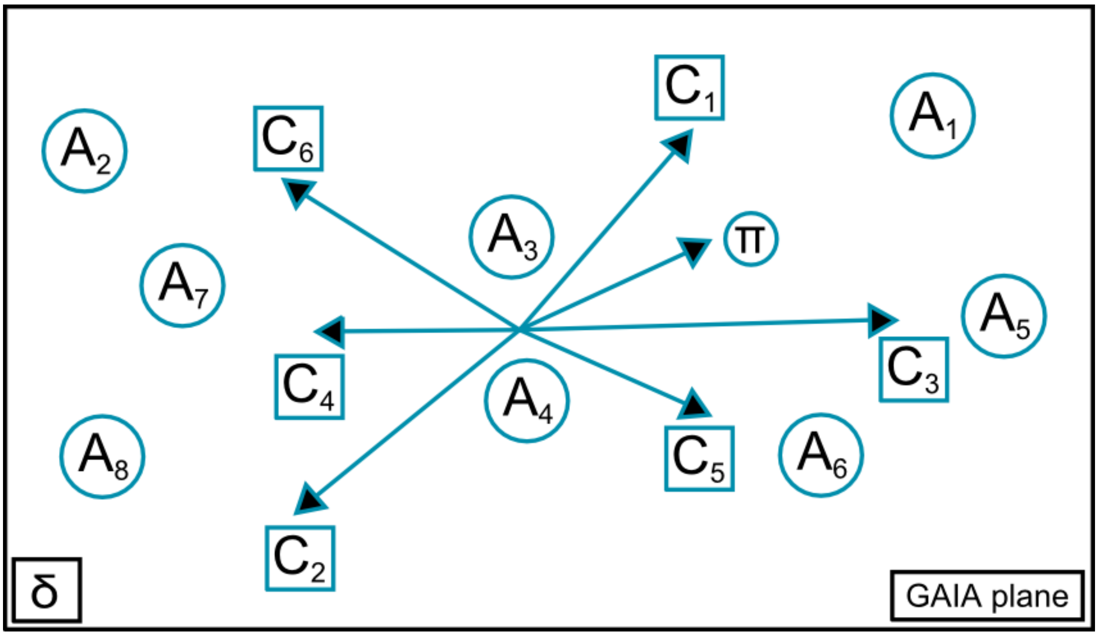

Figure 14: GAIA plane

For interpretation the following properties apply:

- The longer the axis (arrow), the more difference there is in this criterion between the alternatives;
- The longer axis (arrow), the more difference there is in this criterion between the alternatives;
- Criteria which have the same preference are displayed as arrows which are oriented in the same direction;
- Criteria which have a different preference are displayed as arrows which are oriented in the opposite direction;
- Criteria that are not connected to each other’s preference, are shown as orthogonal axes;
- Similar alternatives are displayed as points that are near each other in the GAIA plain;
- Alternatives that score well for a given criterion, are shown as the points which lie in the direction of the relevant criterion axis.

5.2.2 Results

The attributing of the weights is a very important step in the MCA. However, it is also a very subjective step since different stakeholders will have different priorities, and as a result give a different weight to different criteria. To (partially) eliminate this subjectivity, two scenarios are worked out with the method described above, in order to obtain a more complete comparison between the different alternatives. And in addition, a general overview is given (Stability intervals; **Figure 19**), based on the second scenario, on how much the weight of a certain criterion has to vary to alter the outcome.

Weights are given to a total of 7 criteria, corresponding to the different groups that are defined in the Conclusion Table in **Annex 2**:

- Acceptance criteria
- End-product

- Process
- Energetic
- Emissions
- Financial
- State of the art

Weights are only given to criteria that could be quantified, as such, the criteria that are defined as ‘descriptive’ in ANNEX 3 are not taken into account.

In **Table 11**, the weights are listed for each of the criteria in the three different scenarios. In scenario 1, all criteria are given the same weight, in scenario 2, the most important factor is considered to be the end-product but next to this similarity, the scenario is focused on the state of the art of each technique and the different aspects of the process.

Criteria	Scenario 1	Scenario 2
Acceptance criteria	14.3%	10%
End-product	14.3%	30%
Process	14.3%	10%
Energetic	14.3%	20%
Emissions	14.3%	5%
Financial	14.3%	5%
State of the art	14.3%	20%
TOTAL	**100%**	**100%**

Table 11: Attributed weights to the different criteria in scenario 1 and 2

Below, the results of the MCA is presented in three different ways:
- As histograms, which show the result of the analyses and where the highest score represents the preferential alternative;
- As GAIA plains, which represents the similarities/differences between the alternatives based on the criteria;
- As a spider diagram, which represents the input and as such gives a visual on how the different alternatives relate to each other instead of just representing the results of the analyses (i.e. histograms).

5.2.2.1 Scenario 1

In the first scenario, all criteria have been given the same weight. From the histogram given in **Figure 15**, it can be concluded that the thermochemical techniques is the preferable technique in this scenario, closely followed by denaturation and chemical treatment. This high score for thermochemical treatment is partially the result of the fact that this is a proven method for the treatment of asbestos (e.g. ARI-technology). As a result, the information of the financial and the process criteria is very complete in comparison with some of the other techniques. This can be seen in the GAIA-plane of scenario 1 (**Figure 16**). However, this results in a distorted picture of the results, especially when looked at the criteria energy and emissions of the method compared to the other techniques.

General conclusions that can be made from the GAIA-plane for scenario 1 is that in the first place, when all criteria are given the same weight, all criteria have relatively short axes which means that there is little variation of the criteria between the different alternatives. Furthermore, the axes of the energetic factor is oriented in the opposite direction of those of the financial factor, meaning that the energy-efficient techniques are more expensive.

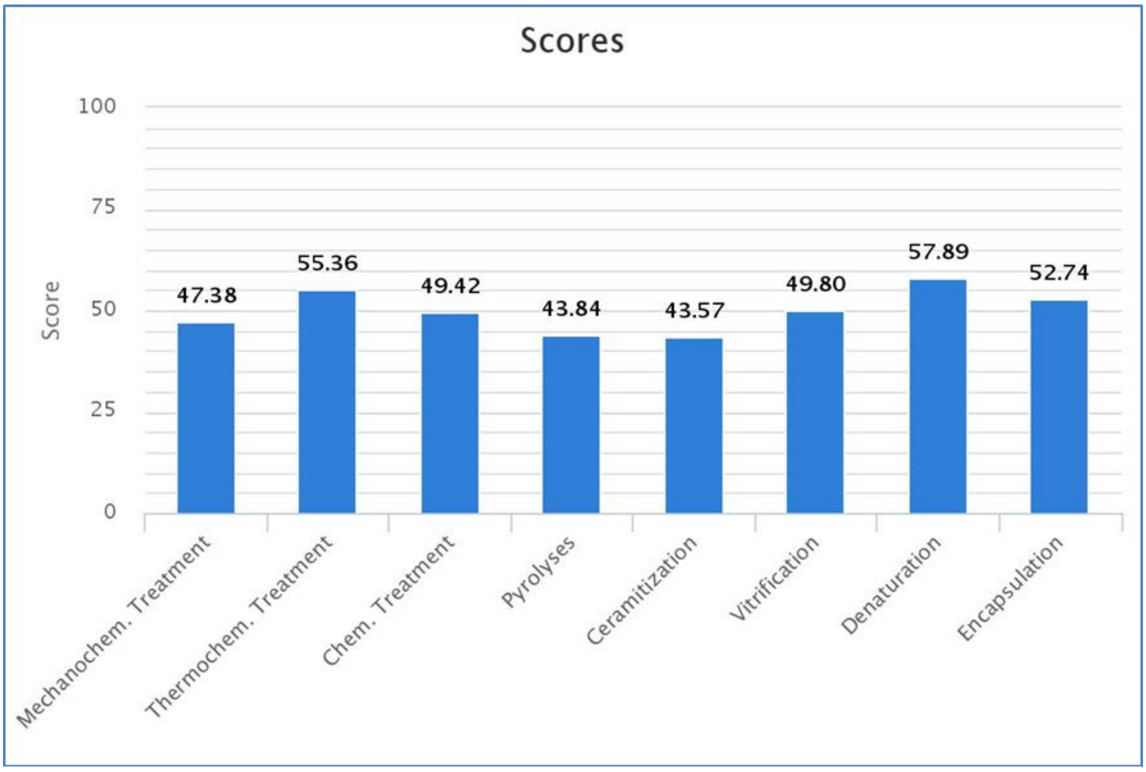

Figure 15: Histogram comparing all the alternatives to each other, in scenario 1

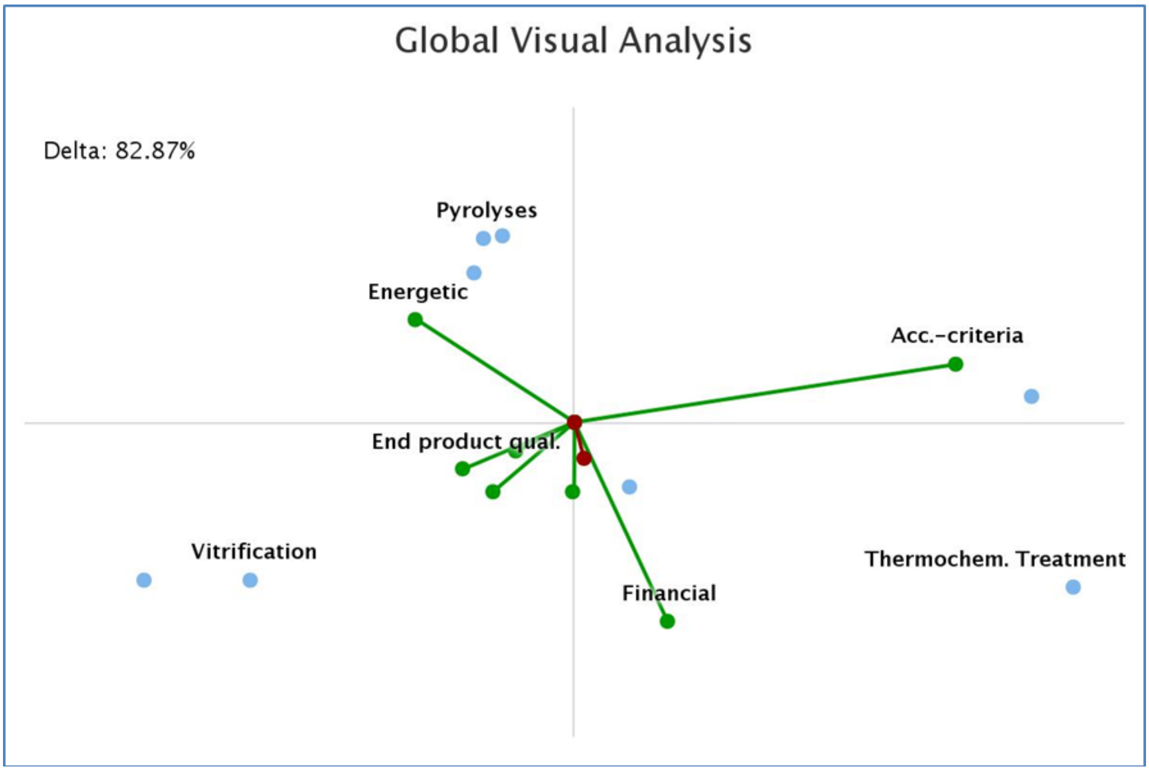

Figure 16: GAIA-plane: 2D-output from a principal components analysis in scenario 1

Many research has already been done on chemical and thermochemical methods. Most of these studies/projects/pilots… were abandoned mostly due to the same large disadvantages which are:

- The need of very hazardous acids or bases; and
- The need of very high liquid/solid ratio.

As a result of these disadvantages and the multiple failed studies/projects/pilots/…, both the chemical and thermochemical methods are not included in scenario 2. Furthermore, the mechanochemical treatment is also left out the further analyses, since only theoretical info has been found on this technique.

5.2.2.2 Scenario 2

The weights given to the different criteria are listed in **Table 11**. The results of the analysis is presented in the histogram in **Figure 17** and the GAIA-plane shown in **Figure 18**.

Based on the histogram, denaturation receives the highest score in this scenario (59,49%). This is followed by vitrification, with a score (54,00%) that comes the closest to that of denaturation but is clearly much lower. The GAIA-plane clarifies that denaturation and vitrification both score well on the financial- and emission-related criteria. On the other hand, denaturation has a better score for the end-product and process criteria, while vitrification scores better on the criteria ‘state-of-the-art’. Furthermore, it can be observed that in this scenario, the decision-axis (red axis) indicate a very robust result in the direction of denaturation.

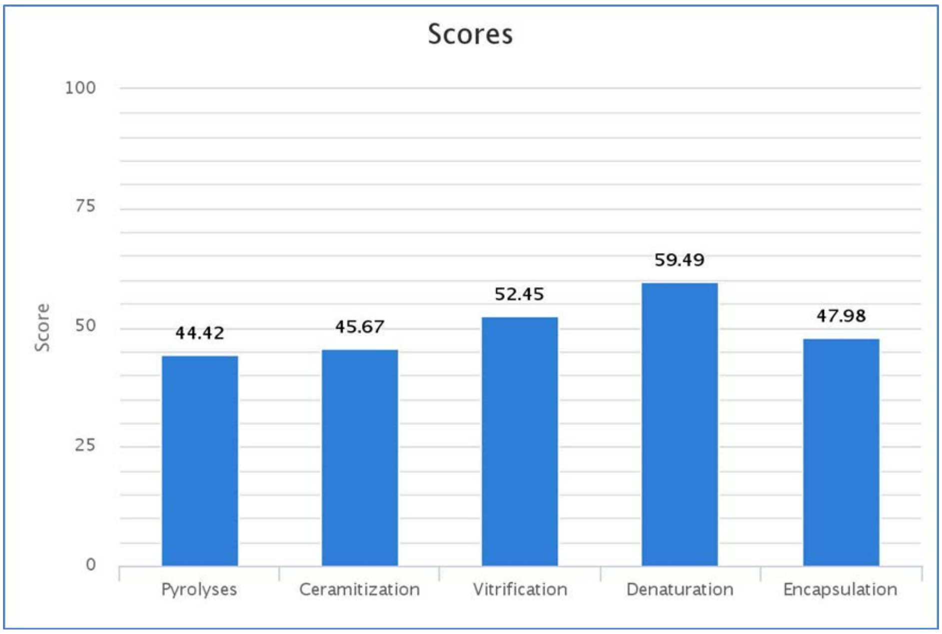

Figure 17: Histogram comparing a selection of the alternatives to each other, in scenario 2

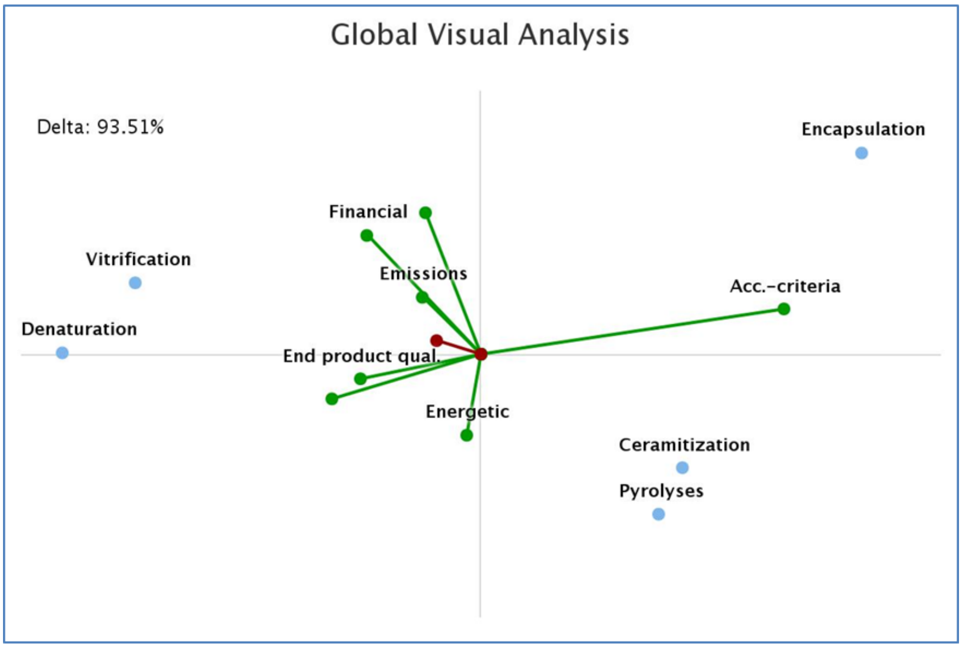

Figure 18: GAIA-plane: 2D-output from a principal components analysis in scenario 2

5.2.2.3 Stability intervals

Instead of doing this analysis again for different sets of weights, the stability intervals have been calculated using the software of D-sight. The results of this analysis is given in **Figure 19**. The black dots indicate the current weight of the criterion and the blue bars indicate the stability of the criterion, with 100% being the maximum stability.

The stability intervals indicate the range in which the weight of a criterion can be changed without affecting the ranking, or in other words, it shows how robust the results are. Specifically for this study and with the weights used in scenario 2, the following conclusions can be drawn:

- Any change in the following criteria: End-product, Process, Energetic, Emissions and Financial; results in the same outcome as described in Scenario 2;
- The weight of the criterion Acceptance criteria has to increase to over 20,46% before any changes in the results will happen; and
- The weight of the criterion State of the art has to increase to over 43,76% before any changes in the results will happen.

It can be concluded that the results of the MCA using scenario 2, are very robust since a change in weight of most of the criteria does not affect the outcome of the analysis.

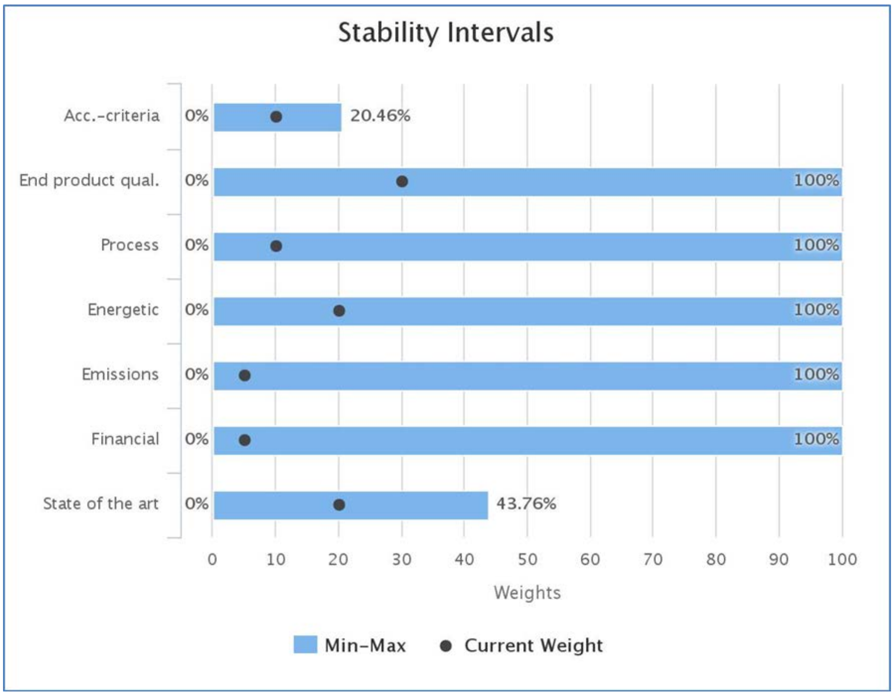

Figure 19: Stability intervals

5.3 CONCLUSION

Based on the Multi-Criteria Analysis one technique clearly outruns the other alternatives, namely denaturation. The second-best alternative is vitrification, albeit with a rather large difference in score (respectively 59,49% and 52,45%; **Figure 17**). When the scores of the different criteria of these two techniques are compared to each other and to the currently used technique of encapsulation and double-bagging, the advantages and disadvantages can clearly be identified. This comparison is given with the histogram in **Figure 20** and the spider-diagram in **Figure 21**.

From these figures, it can be concluded that denaturation scores best on all criteria except 'State of the art' and 'Acceptance criteria'.

- Acceptance criteria: Denaturation and vitrification have the same score since they both are quantified as -1 (**Annex 3**) and Encapsulation has a higher score since it can treat both friable and non-friable asbestos. Current policy is aimed at encapsulating the friable asbestos in cement and double-bagging the (then) non-friable asbestos.
- State of the art: in this criteria vitrification and encapsulation have the same score and denaturation score a little lower. The difference here lies in the fact that both vitrification and encapsulation are both successful techniques that are proven on full scale, while the denaturation technique as it is described in this study is proven but on pilot scale.

Based on the total score, vitrification is the second-best technique. When compared to encapsulation and double-bagging, the following conclusions can be drawn:

- The qualities of the end-product and the conditions of the process of vitrification are much better than those of encapsulation and double-bagging;
- In the criteria of energy and emissions, vitrification scores slightly lower than encapsulation, due to the fact that vitrification needs very high energy-levels as a result of the high processing temperatures (1.600°C) and needs a lot of cooling water resulting in high levels of water emission.
- On the financial criteria and the state of the art, vitrification and encapsulation score the same.
- The reason of the low score on the factor 'acceptance criteria' for vitrification in comparison to encapsulation, has already been discussed above.

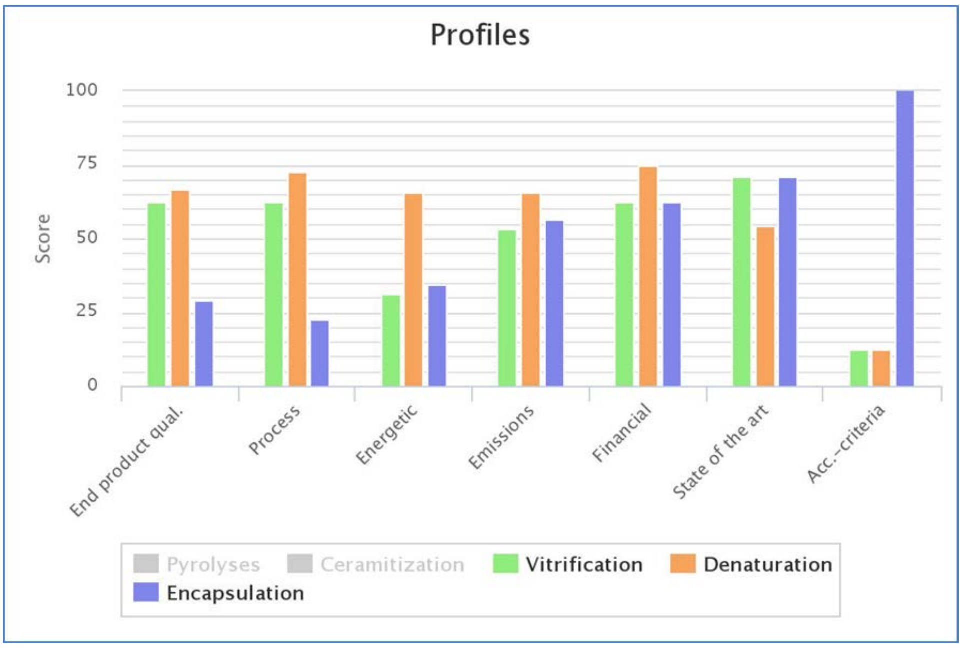

Figure 20: Histogram comparing of denaturation, vitrification and encapsulation

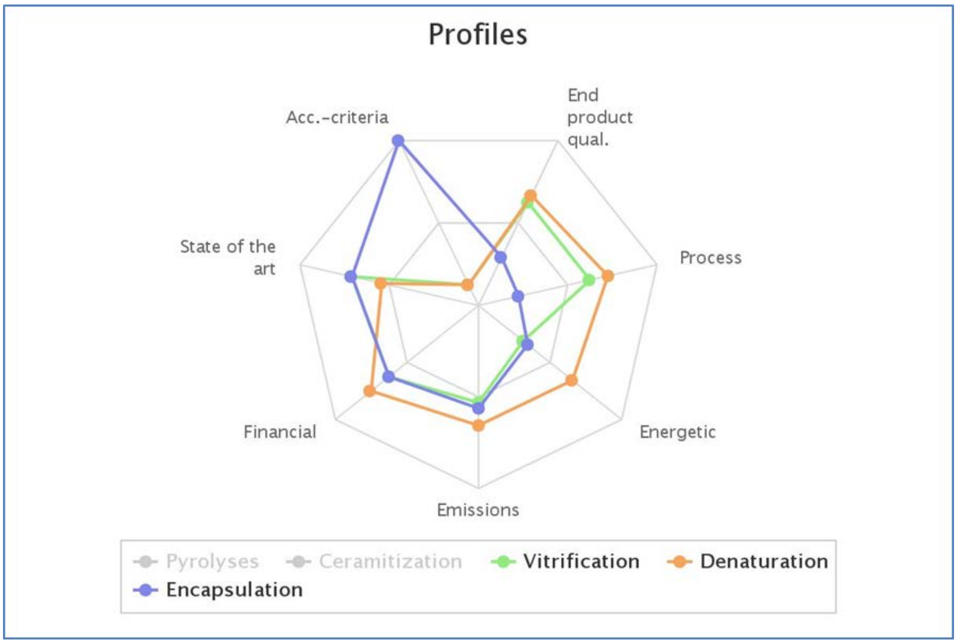

Figure 21: GAIA-plane comparing of denaturation, vitrification and encapsulation

Based on this study it can be concluded that denaturation and vitrification are the two preferable alternatives for the current processing policy of encapsulation and double-bagging.

For these two techniques, a very complete picture can be made, showing several advantages with respect to the current policy of immobilization by cementation. Because of the complete destruction of the fibrous structure at elevated temperatures, these techniques provide a permanent solution for the current asbestos problems. In addition, the end-products, respectively ‘plasmarok’ and ‘beststof’, do not need to be landfilled but, instead, can be used as secondary resources in various applications. These advantages provide solutions for the deficiencies linked to the current stabilization processes.

Further research focused on both vitrification and denaturation is recommended, to determine the Best Available Technique for the situation in Flanders. Possible topics for this study could include, among others, technical, financial, socio-economic, environmental impact, *etc.* research. This further research could result in the setting up of a pilot installation. The combination of this research and the pilot installation, preferably leads to clear results with regard to the necessary standards that need to be set in order to allow the safe re-use of the resulting end-product.

		Encapsulation + double bagging	Denaturation	Vitrification (with plasma gun)
Technique				
-		– Encapsulating unbound asbestos fibers – Double wrapping in big bags, taping and labelling	– Heating to >1000°C to alter fiber structure	– Melting with plasma torch or standard furnace (1100-1600°C) for destruction of the fiber structure
Acceptance criteria				
-		– ACW and friable asbestos (NO non-friable asbestos) – In closed and clean containers (max. dimensions: 2.4x2.4x6m) – Double bagged in plastic bags or big bags, labeled with an asbestos sticker	– Only non-friable asbestos – In big bags of specific dimensions (not too big) – All asbestos-types	– ACW – Double bagged in plastic bags or big bags OR in metal containers OR on pallets; and labeled with asbestos sticker – Each packaging form has its own strict criteria – ACW needs to be clear of aerosols, explosives, heavy metals, paper and carton packaging material
End-product				
-	End-product	1m³ Blocks of immobilized ACW in a cement matrix, double bagged in big bags	– = “Beststof” – Fiber structure of asbestos is altered to non-hazardous structure – Denatured ACW is grinded to a fine powder (≈Ø0.2)	Inert, free-of-asbestos vitrified material
-	Applicability	– Landfilled – On landfill: blocks used for structuring, e.g. roads, zoning – Further treatment	– Secondary material in several industries, e.g. cement, road foundation	– Substitute for quartz and basalt in building materials
-	Standardized	– When landfilled, strict acceptance conditions (Indaver): • Max. size of fibers or flakes = 10mm	– Shadow of the fiber, very brittle material: • Question: Is it still asbestos? • Possible answer: certificating entire	No data

		Encapsulation + double bagging	Denaturation	Vitrification (with plasma gun)
		• Max. size other materials = 30mm • Homogeneous distribution of fibers in inorganic matrix • Density = min. 1ton/m³ • Compressive strength = min. 1.5N/mm² • Standard dimensions = 80x120cm to 100x120cm with max. height of 120cm • Weight = min. 0.5ton – max. 2ton • Double plastic bagged, labelled conform ARAB and ADR legislation	process instead of end-product to ensure destruction of asbestos – Tested by several laboratories, such as INTRON (SGS), ENCI (Heidelberg), TNO… – Standardized process with 1100°C to ensure that all the asbestos types are destroyed	
-	Stability	No permanent solution: asbestos cement can erode/break/…, resulting in to the release of the asbestos fibers	Chemically stable, especially after crushing of denatured ACW	Glassy, chemically stable matrix
		Process		
-	Supply product	– Arrival of big bags ACW and friable asbestos in closed containers – Bags are opened and distributed manually on belt conveyor	– Arrival of big bags ACW, transferred in their entirety onto a wagon by means of a crane – Wagon enters a tunnel furnace , where it will remain for ~75h and it moves at a speed of 1.5 wagon/hour	– Arrival of big bags, containers of pallets of ACW – Dumped on conveyor belt
-	Batch/continuous	Discontinuous process	Continuous, closed process in tunnel furnace	Semi-continuous

		Encapsulation + double bagging	Denaturation	Vitrification (with plasma gun)
-	Buffer	The sorted and in size reduced ACW has to be stored in storage bunker	Vacuum storage space available	From the moment the ACW is on conveyor belt: continuous process
-	Separation	– Manual sorting out of metal and plastic – Magnetic belt removes remaining metal	Not required	Not required
-	Size reduction/Crushing	Maximum size of 1 cm³ achieved by at least 3 different crushers	Crushing of ACW after denaturation (≈Ø0.2) to “beststof”	After control, via conveyor belt to a shredder installation where it is shredded and mixed to ensure optimal loading of furnace
-	Laborious/Automated	Relatively simple but laborious method	Inside tunnel furnace: fully automated	Mostly automated
-	Control	/	– Control of composition (1 big bag per receiving load) in vacuum cabin – Sampling and testing after denaturation from the center of each wagon to ensure complete destruction of the fiber structure	Visual and manual entrance control
-	Installation	Fixed installation (Rematt): process always done under same conditions with little unknown factors BUT ACW needs to be transported twice	– Fixed installation (Twee “R” Recycling Group) – Length tunnel furnace = 180m – Plot plant = ca. 75 (width) x 240 (length) meter – Site = 2.2 hectare	Fixed installation (Inertam)
			Energetic	
-	Primary energy	477.3MJ/ton (2007)	Usage of gas = 7 million m³	2.400 kWh/ton ACW or ca. 8,64 GJ/ton

		Encapsulation + double bagging	Denaturation	Vitrification (with plasma gun)
-	Excipients/Additives	– Hydraulic binder = cement – Hardening accelerator	Natural gas	Bicarbonate for gas washing
-	Water consumption	– 2400m³/year – Water from showers, cleaning of installations and rain is used to make the concrete	/	Cooling water from plasma torch
-	Others	– Creation of vacuum – Purification of ventilation air	– Creation of vacuum – Filtration of burned gasses	/
Emissions				
-	Water	No waste water: water from showers, cleaning of installations and rain is used to make the concrete	/	Production of waste water: Cooling water from plasma torch
-	Air	– No air pollution: • Process in isolated spaces, in constant vacuum • Ventilation air is purified by HEPA filters, according to Vlarem's emission limit values	– No air pollution: • Process in isolated spaces, in constant vacuum • Gasses resulting from burning of big bags are being burned again and then passed through a filtration system	Limited emission of air due to extremely high combustion temperatures
-	Solid	Increase in mass and volume: +150%	Mass and volume reduction	– Mass and volume reduction – Production of residue resulting from gas washing: landfilled on Category 1 landfills
Safety aspects				
-		– Usage of closed system from asbestos-cement industry, completed with the zone system for asbestos removal	– Control of composition before denaturation in vacuum cabin – Possible storage in vacuum storage space	– Flue gasses, resulting from the reactor: • Burned in afterburner chamber

		Encapsulation + double bagging	Denaturation	Vitrification (with plasma gun)
		– Measures to prevent distribution of friable asbestos: • Vacuum • Air lock • Filtration of suctioned air • Protection with plastic – Limitation of emissions due to HEPA-absolute filters – Mandatory use of personal protective equipment	– Closed system: big bags go in their entirety in furnace and only leave once denatured – First contact with ACW is when denatured – Control if denaturation was successful by sampling the ACW – Filtration system for resulting gasses	• Washed by bicarbonate washer • Filtered by fabric filter – Most important risk: escaping of asbestos fibers during treatment of ACW: No manual manipulation from the moment the bagged ACW is accepted up until the material is vitrified
Financial				
-	Costs process	– Base tariff: €1100/ton, includes: • Reception of the ACW • Weighing of the container with third parties • Processing of ACW conform the necessary standards • Transport to landfill • Landfill levies – Deviations from base tariff: • Quantity discount • Supplement if ACW is not conform the acceptance conditions	€175/ton	– Tariff varies depending of composition, delivered quantities, conformity with acceptance criteria: • Range = €1.000-2.500/ton • Average = €1.500/ton = 35% more expensive than immobilization by cementation • Supplement if ACW is not conform the acceptance conditions (packaging, presence of contaminants)
-	Costs business model	No data	Total investment cost ≈ €23 million, i.e. site, installation, employment (20 jobs)…	No data
State of the art				
-	Proven/Failed	Proven, mature and relatively simple technique	Proven technique on lab scale in the Netherlands, other	– Proven technique for other waste streams: Japan, France

		Encapsulation + double bagging	Denaturation	Vitrification (with plasma gun)
			countries small full-scale installation	– Proven technique for asbestos: INERTAM (France)
-	State of the art	Licensed for the acceptance and processing of 15.000 tons of ACW and 400 tons of friable asbestos, until October 2021.	– Several pilot installations in various settings: • In Germany • In England (periodical furnace) • In Belgium (Beersel) – Tested end-product (e.g. by INTRON, ENCI, TNO…) – Expected annual capacity (Twee “R” Recycling Group) = 100.000 tons	– Started in February 1995 – Licensed annual capacity = 8.000 tons of ACW – Actual annual capacity = 7.000 tons of ACW – Capacity per hour = 1 ton
-	Patented	Not patented	Technique patented in at least 23 countries	Patented (e.g. US 4678493 A)
-	Optimalization	Reduction of water consumption during the process	/	Extra production lines to increase capacity
-	Innovative	No	In the Netherlands	No: already full-scale installations operational for both ACW and other waste streams
-	Alternative	No alternatives known in Flanders	Denaturation by microwave heating	– Vitrification in conventional ovens – Vitrification with an electrical furnace (Geomelt vitrification process)

Table 12: Conclusion table: Encapsulation + double bagging, denaturation and vitrification (with plasma gun)

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ANNEX I

Annex	Date	Regulation	Specific
I.a	01/06/1995	VLAREM II = Order of the Flemish Government concerning General and Sectorial provisions related to the environment	• Section 1.1: General provisions • Section 2.6: Policy tasks concerning management of asbestos • Section 4.7: Control of Asbestos • Section 5.2: Devices for the treatment of waste • Section 6.7: Control of asbestos (non-classified establishments)
I.b	14/12/2007	VLAREBO = Order of the Flemish Government establishing the Flemish regulation on soil remediation and soil protection	• Addendum 1, Section 2: Waste streams
I.c	17/02/2012	VLAREMA = Decision of the Flemish Government establishing the Flemish regulation on the sustainable management of material cycles and waste	• Subsection 2.3.2: Criteria for raw materials, intended for the use as building material – Article 2.3.2.1 • Section 4.1: Classification of waste • Section 4.3: Separate collection of waste

ANNEX I.A: VLAREM

- ## SECTION 1.1

Deel 1. ALGEMENE BEPALINGEN

- Hoofdstuk 1.1. RECHTSGROND EN DEFINITIES
  - Definities
    - Artikel 1.1.2.

De begrippen en definities vermeld in artikel 1 van het besluit van de Vlaamse Regering van 6 februari 1991 houdende het algemeen reglement voor de milieuvergunning, hierna Titel I van het VLAREM genoemd, zijn ook van toepassing op dit besluit.

Voor de toepassing van dit besluit gelden bijkomend de hierna opgenomen definities. Deze zijn thematisch gerangschikt in functie van de betrokken tekstonderdelen, maar zijn - behoudens afwijkende bepaling - eveneens van toepassing op dezelfde termen en begrippen in andere tekstonderdelen.

DEFINITIES ASBESTBEHEERSING (Hoofdstukken 2.6., 4.7. en 6.4.)

Asbest

- "asbest": de vezelachtige silicaten actinoliet, amosiet (bruin asbest), anthofylliet, chrysotiel (wit asbest), crocidoliet (blauw asbest) en tremoliet;
- ruw asbest
- "ruw asbest": het produkt verkregen bij een eerste verbrijzeling van asbesthoudend gesteente;

Hechtgebonden asbest:

- «Hechtgebonden asbest» : asbestcement, asbesthoudende vloertegels en vloerbekledingen, asbesthoudende bitumen en roofingproducten en asbesthoudende pakkingen en dichtingen waarvan het bindmiddel bestaat uit cement, bitumen, kunststof of lijm;

Ingevoegd bij art. 33, 4°, b), B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

Niet hechtgebonden asbest

- «Niet hechtgebonden asbest» : alle andere asbesthoudende materialen;

Ingevoegd bij art. 33, 4°, b), B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

Gebruik van asbest

- «gebruik van asbest»: werkzaamheden waarbij per jaar een hoeveelheid van meer dan 100 kg ruwe asbest wordt behandeld en die betrekking hebben op:

a) de produktie van ruw asbest uit asbest-houdend gesteente met uitzondering van alle procédé's die rechtstreeks verbonden zijn met het winnen van het gesteente; en/of

b) de vervaardiging en industriële afwerking van produkten die ruwe asbest bevatten, zoals asbestfrictiemateriaal, asbestfilters, asbestweefsels, asbestpapier en -karton, koppelings-, dichtings-, verpakkings- en verstevigingsmateriaal van asbest, vloerbedekkingen van asbest en asbesthoudende vulmiddelen;

Gewijzigd bij art. 1, 5°, B.Vl.Reg. 19 januari 1999, B.S. 31 maart 1999, eerste editie.

Werken met asbesthoudende produkten

- "werken met asbesthoudende produkten": andere werkzaamheden dan gebruik van asbest, ten gevolge waarvan asbest in het milieu terecht kan komen;

- SECTION 2.6

Deel 2. MILIEUKWALITEITSNORMEN EN BELEIDSTAKEN TER ZAKE

o Hoofdstuk 2.6. BELEIDSTAKEN TERZAKE ASBESTBEHEERSING

▪ Artikel 2.6.0.1.

De bepalingen van dit hoofdstuk worden vastgesteld in uitvoering van de wet van 26 maart 1971 op de bescherming van de oppervlaktewateren tegen verontreiniging en van de wet van 28 december 1964 op de bestrijding van de luchtverontreiniging.

▪ Artikel 2.6.0.2.

De EU-Commissie wordt overeenkomstig de Richtlijn 87/217/EEG door de Openbare Vlaamse Afvalstoffenmaatschappij via de geëigende kanalen:

- driejaarlijks ingelicht over de tenuitvoerlegging van deze Richtlijn.
- in kennis gesteld van de voor de bepaling van de asbestconcentraties gebruikte monsternemings- en analyseprocedures en -methoden alsmede van informatie die van belang is om de doelmatigheid hiervan te beoordelen.

Gewijzigd bij art. 153 B.Vl.Reg. 7 maart 2008, B.S. 21 mei 2008.

- SECTION 4.7

Deel 4. ALGEMENE MILIEUVOORWAARDEN VOOR INGEDEELDE INRICHTINGEN

o Hoofdstuk 4.7. BEHEERSING VAN ASBEST

▪ Artikel 4.7.0.1.

§ 1.

Onverminderd de bepalingen terzake water-, bodem-, grondwater- en luchtverontreiniging en afvalstoffenbeheersing moeten overeenkomstig de Richtlijn 87/217/EEG bij het gebruik van asbest en werken met asbesthoudende produkten de nodige maatregelen getroffen om ervoor te zorgen dat emissies van asbest in het milieu en afvalstoffen van asbest voor zover dat met redelijke middelen mogelijk is aan de bron worden verminderd en voorkomen. Bij gebruik van asbest impliceren deze maatregelen dat gebruik wordt gemaakt van de beste beschikbare technieken, met inbegrip van recycling of behandeling waar zulks dienstig is.

Tevens dienen de nodige maatregelen getroffen om ervoor te zorgen dat:

1° tijdens het vervoer, het laden en het lossen van afvalstoffen die asbestvezels of asbeststof bevatten, deze vezels en stof niet vrijkomen in de lucht en geen vloeistoffen worden verloren die asbestvezels kunnen bevatten;
2° afvalstoffen die asbestvezels of -stof bevatten, indien gestort op plaatsen waar zulks met vergunning mogelijk is, zodanig worden behandeld, zijn verpakt of afgedekt, met inachtneming van de plaatselijke omstandigheden, dat er geen asbestdeeltjes in het milieu terechtkomen;
3° activiteiten die verbonden zijn aan het werken met asbest bevattende produkten geen noemenswaardige milieuverontreiniging door asbestvezels of -stof veroorzaken;
4° bij de sloop van asbestbevattende gebouwen, constructies en installaties en het verwijderen van asbest of asbesthoudende materialen daaruit, waarbij asbestvezels of asbeststof kunnen vrijkomen, geen asbest in het milieu terechtkomt.

Toegevoegd bij art. 54 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

§ 2.

De volgende asbesthoudende toepassingen kunnen zelf worden verwijderd voor zover deze via eenvoudige handelingen (bvb. vlot losschroeven) kunnen worden weggenomen :

1° hechtgebonden asbest die niet beschadigd is of waarbij er geen vrije vezels zichtbaar zijn en waarbij verwijdering geen aanleiding geeft tot een wijziging van de toestand;
2° hechtgebonden asbest die beschadigd is of waarbij er vrije vezels zichtbaar zijn en die verwerkt is in een buitentoepassing waarbij geen derden aanwezig zijn, voor zover de verwijdering geen aanleiding geeft tot een wijziging van de toestand;
3° asbesthoudende koorden, dichtingen of pakkingen, remvoeringen en analoge materialen.

Andere toepassingen mogen alleen verwijderd worden door gespecialiseerde bedrijven.

Toegevoegd bij art. 54 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

§ 3.

Bij de sloop en verwijdering van asbesthoudend materiaal als vermeld in § 2, 1°, 2° en 3°, moet vezelverspreiding en blootstelling van personen aan asbestvezels verhinderd worden door de volgende maatregelen te nemen :

1° bevochtigen of fixeren van het materiaal;
2° de elementen één voor één verwijderen, bij voorkeur manueel, gebruik makend van handwerktuigen of in laatste instantie traagdraaiend gereedschap;
3° de materialen niet gooien;

4° de materialen niet breken;
5° de materialen opslaan in gesloten verpakkingen. Bij de werkzaamheden mogen geen minderjarigen aanwezig zijn.

Voor persoonlijke bescherming tegen blootstelling wordt gebruik gemaakt van een stofmasker type P3 of gelijkwaardig stofmasker.

Toegevoegd bij art. 54 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

§ 4.

De asbesthoudende toepassingen worden afzonderlijk opgeslagen en niet gemengd met het andere sloopafval;

Toegevoegd bij art. 54 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

§ 5.

Het gebruik van mechanische werktuigen met grote snelheid (schuurschijven, slijpmachines, boormachines, e.d.), hogewaterdrukreinigers en luchtcompressoren, voor het bewerken, snijden of schoonmaken van objecten of ondergronden in asbesthoudend materiaal, objecten of ondergronden bekleed met asbesthoudend materiaal of voor het verwijderen van asbest is verboden.

Toegevoegd bij art. 54 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

- Artikel 4.7.0.2.

Voor bestaande installaties dient bij de toepassing van de eis met betrekking tot het gebruik van de beste beschikbare technieken zoals gesteld in artikel 4.7.0.1. § 1, rekening gehouden met:

1° de technische kenmerken van de inrichting;
2° de gebruiksgraad en de residuele levensduur van de inrichting;
3° de aard en het volume van de verontreinigende emissies van de inrichting;
4° de wenselijkheid geen overmatige hoge kosten te veroorzaken voor de betrokken inrichting, met name rekening houdende met de economische situatie van de tot de betrokken categorie behorende ondernemingen.

- Artikel 4.7.0.3.

Voor de emissies in de lucht en de afvalwaterlozingen gelden inzonderheid respectievelijk de bepalingen:

1° van artikel 5.3.2.4 en de bijlage 5.3.2, sub 2°, b), voor wat de voorwaarden voor de lozing van afvalwater betreft;
2° van artikel 4.2.5.3.1 en de bijlagen 4.2.5.2 en 4.4.5.A voor wat de meetverplichtingen en meetmethoden voor de lozing van afvalwater betreft;

3° van artikel 4.4.3.1 en de bijlage 4.4.2 voor wat de grenswaarden voor de emissies in de lucht betreft;

4° van artikel 4.4.4.1 en de bijlagen 4.4.3 en 4.4.4 en 4.4.5.B voor wat de meetverplichtingen en de meetmethode voor de emissies in de lucht betreft.

Ingevoegd bij art. 8 B.Vl.Reg. 24 maart 1998, B.S. 30 april 1998, tweede editie.

- ## SECTION 5.2

Deel 5. SECTORALE MILIEUVOORWAARDEN VOOR INGEDEELDE INRICHTINGEN

- Hoofdstuk 5.2. INRICHTINGEN VOOR DE VERWERKING VAN AFVALSTOFFEN
    - Afdeling 5.2.4. Stortplaatsen van afvalstoffen in of op de bodem
        - Artikel 5.2.4.0.3. Overgangsbepalingen

1. **Overgangsbepalingen d.d. 1 juni 1995 (samen te lezen met de tekst van het besluit van de Vlaamse regering van 1 juni 1995 B.S.: 31 juli 1995).**

   In afwijking van het bepaalde in artikel 3.2.1.2. gelden voor bestaande stortplaatsen de volgende overgangsbepalingen:

   1. *de verbodsbepalingen van art. 5.2.4.1.2. en de aanvaardingscriteria van art. 5.2.4.1.3.§ 3. en van art. 5.2.4.1.4.§ 2. voor afvalstoffen op stortplaatsen gelden voor alle bestaande stortplaatsen vanaf 1 januari 1997;*

   2. *de bepalingen inzake de periode van nazorg en de nazorgactiviteiten op stortplaatsen (art. 5.2.4.4.6.) gelden vanaf 1 januari 1996 voor de stortplaatsen die niet definitief zijn afgewerkt op 31 december 1995;*

   3. *het jaarlijks rapport waarin verslag wordt uitgebracht van de stortexploitatie of de nazorgactiviteit (art. 5.2.4.4.8.) wordt voor alle bestaande stortplaatsen een eerste maal ingediend 18 maanden na de datum van in werking treden van dit besluit.*

2. **Overgangsbepalingen in het kader van de implementatie van de Europese richtlijn 1999/31/EG van 26 april 1999 betreffende het storten van afvalstoffen.**

   Voor de stortplaatsen, vergund vóór 16 juli 2001 gelden de volgende overgangsbepalingen:

   1. *De voorwaarden inzake inrichting en infrastructuur zijn van kracht voor die stortplaatsen of die gedeelten van de stortplaatsen die worden ingericht na 16 juli 2001;*

      De voorwaarden inzake de uitbating van de stortplaats en de aanvaarding van *afvalstoffen op de stortplaats met inbegrip van de algemene bepalingen van afdeling 5.2.1 worden voor alle bestaande stortplaatsen van kracht de eerste van de vierde maand volgend op datum van publicatie van dit besluit in het Belgisch Staatsblad;*

De voorwaarden inzake afwerking en nazorg worden van kracht voor die gedeelten van de stortplaats die:

- *worden ingericht na 16 juli 2001, of*
- *worden in gebruik genomen na publicatie van dit besluit in het Belgisch Staatsblad, of*
- *niet definitief zijn afgewerkt op 31 december 2005;*

2. *De exploitant stelt een aanpassingsplan op.*
   Dit aanpassingsplan dient volgende gegevens te bevatten:

   een toetsing van de bestaande exploitatievoorwaarden aan de bepalingen van afdeling 5.2.1 (met uitzondering van artikel 5.2.1.4) en afdeling 5.2.4.

   de nodige corrigerende maatregelen om de bestaande exploitatie in overeenstemming te brengen met de nieuwe bepalingen van afdeling 5.2.1 (met uitzondering van artikel 5.2.1.4) en van afdeling 5.2.4.

   een plan met de aanduiding van het gedeelte van de stortplaats dat zal worden afgewerkt volgens de oude voorwaarden en van het gedeelte dat volgens de nieuwe voorwaarden zal worden afgewerkt.

   een voorstel tot financiële zekerheid overeenkomstig de bepalingen van deze afdeling.

   Uiterlijk 16 juli 2002 wordt dit aanpassingsplan in 4 exemplaren ingediend bij de Bestendige Deputatie van de provincie tot wiens ambtsgebied de percelen van de stortplaats behoren.

   De vergunningverlenende overheid maakt één exemplaar van het aanpassingsplan over aan de Openbare Vlaamse Afvalstoffenmaatschappij en de afdeling , bevoegd voor milieuvergunningen met de vraag om advies en aan de afdeling , bevoegd voor milieuhandhaving met de vraag om een verslag. De adviezen en het verslag worden binnen de 2 maanden uitgebracht.

   Het verslag van de afdeling , bevoegd voor milieuhandhaving omvat een beoordeling van de huidige exploitatie, alsmede een toetsing van de huidige exploitatie aan de nieuwe bepalingen. Het advies van de Openbare Vlaamse Afvalstoffenmaatschappij en de afdeling , bevoegd voor milieuvergunningen omvat een beoordeling van het *volledige aanpassingsplan alsmede een voorstel tot aanpassing van de lopende vergunning.*

De Bestendige Deputatie legt het aanpassingsplan voor advies voor aan de provinciale milieuvergunningscommissie.

De vergunningverlenende overheid beslist over het aanpassingsplan binnen een termijn van vier maanden. Tegen de beslissing van de Bestendige Deputatie kan door de exploitant, de Openbare Vlaamse Afvalstoffenmaatschappij of de afdeling , bevoegd voor milieuvergunningen binnen een termijn van dertig dagen ingaand de dag na de betekening van de beslissing beroep worden ingesteld bij de Vlaamse minister voor Leefmilieu. De Vlaams minister doet uitspraak over het beroep binnen een termijn van vijf maanden na opnieuw advies van voormelde instanties en van de gewestelijke milieuvergunningscommissie te hebben ingewonnen. Een afschrift van de beslissing(en) over het aanpassingsplan worden betekend aan de exploitant, de Openbare Vlaamse Afvalstoffenmaatschappij, de afdeling , bevoegd voor milieuhandhaving, de afdeling , bevoegd voor milieuvergunningen, alsmede aan de gemeente.

Op basis van het aanpassingsplan beslist de vergunningverlenende overheid of de exploitatie al dan niet mag worden voortgezet. Op basis van het goedgekeurde aanpassingsplan voor de stortplaats geeft de vergunningverlenende overheid toestemming voor de noodzakelijke werkzaamheden en bepaalt zij een overgangsperiode voor de uitvoering van het plan. Deze overgangsperiode kan uiterlijk tot 16 juli 2009 lopen. Het door de vergunningverlenende overheid goedgekeurde aanpassingsplan geldt als aanpassing van de lopende vergunning met behoud van de looptijd van de vergunning.

De stortplaatsen waarvoor geen vergunning tot voortzetting van de exploitatie wordt verleend moeten zo spoedig mogelijk en uiterlijk tegen 31 december 2005 worden gesloten overeenkomstig de bepalingen van de eerdere vergunning inzake sluiting en nazorgprocedure.

Indien de exploitant niet tijdig een aanpassingplan indient, moet de stortplaats zo spoedig mogelijk en uiterlijk tegen 31 december 2005 worden gesloten. De stortplaats moet in dat geval worden afgewerkt overeenkomstig de in de vergunning opgelegde voorwaarden.

3. *Overgangsbepalingen met betrekking tot subafdeling 5.2.4.1 in het kader van de implementatie van de Europese beschikking 2003/33/EG van 19 december 2002 tot vaststelling van criteria en procedures voor het aanvaarden van afvalstoffen op stortplaatsen overeenkomstig artikel 16 en bijlage II van Richtlijn 1999/31/EG betreffende het storten van afvalstoffen.*

   a) *Overeenkomstig artikel 7 van de Europese beschikking 2003/33/EG heeft de subafdeling 5.2.4.1 en de bijlage 5.2.4.1 uitwerking met ingang van 16 juli 2004, met uitzondering van de criteria van punt B die van kracht worden op 16 juli 2005.*

   b) *Voor de op 16 juli 2005 bestaande en vergunde stortplaatsen waarvoor een toelating tot verdere uitbating is verleend met toepassing van de overgangsbepalingen van punt 2 van onderhavig artikel, gelden de volgende overgangsbepalingen:*

      1) *de stortplaatsen die onder de vroegere subrubriek 2.3.6, a) als categorie 3-stortplaats zijn vergund, blijven voor de termijn van de lopende vergunning als dusdanig vergund onder de nieuwe subrubriek 2.3.6, a); de bepalingen van subafdeling 5.2.4.1 voor stortplaatsen categorie 3 zijn hierop van toepassing;*

      2) *de bestaande en vergunde stortplaatsen voor asbestcementafval die als categorie 3-stortplaats zijn vergund, blijven voor de termijn van de lopende vergunning vergund, opgesplitst in enerzijds onder de nieuwe subrubriek 2.3.6.c).3) als monostortplaats voor asbesthoudend bouwmateriaal waarin asbest in gebonden vorm aanwezig is en anderzijds onder de nieuwe subrubriek 2.3.6.a).1) als stortplaats voor inerte afvalstoffen;*

      3) *de stortplaatsen die onder de vroegere subrubriek 2.3.6, b) als categorie 2-stortplaats zijn vergund, blijven voor de termijn van de lopende vergunning als dusdanig vergund onder de nieuwe subrubriek 2.3.6, b); de bepalingen van subafdeling 5.2.4.1 voor stortplaatsen categorie 2 zijn hierop van toepassing;*

      4) *de stortplaatsen die onder de vroegere subrubriek 2.3.6, c) als categorie 1-stortplaats zijn vergund, blijven voor de termijn van de lopende vergunning vergund als opgesplitst in enerzijds een categorie 1-stortplaats en anderzijds een categorie 2-stortplaats onder de nieuwe subrubriek 2.3.6, b); de bepalingen van subafdeling 5.2.4.1 voor stortplaatsen categorie 1 respectievelijk stortplaatsen categorie 2 zijn hierop van toepassing;*

      5) *voor alle bestaande vergunde stortplaatsen geldt dat enkel die afvalstoffen of groepen van afvalstoffen mogen worden aanvaard waarvoor in de milieuvergunning expliciet vergunning is verleend;*

6) *de exploitant van een stortplaats als bedoeld in punt 3) of 4) is er toe gehouden uiterlijk voor 1 december 2006 bij wijze van mededeling kleine verandering aan de vergunning verlenende overheid kenbaar te maken onder welke subcategorieën van categorie 2 en/of van categorie 1 de bestaande stortplaats valt.*

- Subafdeling 5.2.4.1. De aanvaarding van afvalstoffen op de stortplaats
  - Artikel 5.2.4.1.9. Criteria voor gevaarlijke afvalstoffen die aanvaardbaar zijn op stortplaatsen voor niet gevaarlijke afvalstoffen

§ 5.

Bouwmateriaal dat asbest bevat en ander geschikt asbestafval mogen zonder tests op stortplaatsen voor niet gevaarlijke afvalstoffen worden gestort wanneer ze in overeenstemming zijn met de bepalingen van artikel 6, c),i ii) van de EG-richtlijn 1999/31/EG die luiden als volgt:

1° het betreft stabiele, niet-reactieve gevaarlijke afvalstoffen met een uitlooggedrag dat gelijkwaardig is aan dat van de aanvaardingscriteria op stortplaatsen voor niet gevaarlijk afval;
2° ze moeten voldoen aan de relevante aanvaardingscriteria;
3° deze gevaarlijke afvalstoffen worden niet gestort in cellen die zijn bestemd voor biologisch afbreekbare niet gevaarlijke afvalstoffen.

Voor stortplaatsen die asbest bevattend bouwmateriaal en ander geschikt asbestafval ontvangen, moet aan de volgende eisen zijn voldaan:

1° het afval bevat geen andere gevaarlijke stoffen dan gebonden asbest, met inbegrip van door een bindmiddel gebonden of in kunststof verpakte asbestvezels;
2° de stortplaats aanvaardt uitsluitend asbest bevattend bouwmateriaal en ander geschikt asbestafval; dat afval mag ook in een afzonderlijke cel van een stortplaats voor niet gevaarlijke afvalstoffen worden gestort, als die cel voldoende geïsoleerd is;
3° om verspreiding van vezels te voorkomen, wordt het stortgebied dagelijks en voorafgaand aan elke verdichtingsbewerking met daartoe geëigend materiaal afgedekt en wordt het, als het afval niet is verpakt, regelmatig besprenkeld;
4° uiteindelijk wordt de stortplaats/cel geheel afgedekt om verspreiding van vezels te voorkomen;
5° op de stortplaats/cel worden geen werkzaamheden uitgevoerd die het vrijkomen van vezels tot gevolg kunnen hebben (bv — het boren van gaten);
6° na sluiting van de stortplaats/cel wordt een plattegrond van de locatie bewaard, waarop is aangegeven dat er asbestafval is gestort;

7° er worden passende maatregelen genomen om de mogelijkheden tot gebruik van de locatie na sluiting van de stortplaats te beperken teneinde te voorkomen dat mensen in contact met het afval komen.

Vervangen bij art. 36 B.Vl.Reg. 12 mei 2006, B.S. 30 juni 2006, derde editie.

§ 6.

Afvalstoffen bestaande uit asbesthoudende bouwmaterialen waarbij asbestvezels in gebonden vorm aanwezig zijn, kunnen worden gestort op stortplaatsen of delen van stortplaatsen die beantwoorden aan de bepalingen voor categorie 1-stortplaatsen, behalve voor wat betreft de voorwaarden inzake inrichting en afwerking met inbegrip van de financiële zekerheid, meer bepaald zoals bedoeld in artikel 5.2.4.3.3, artikel 5.2.4.5.2 en artikel 5.2.4.7.1, waarvoor in de milieuvergunning, mits naleving van de hierna vermelde voorwaarden inzake inrichting en afwerking die gelden voor categorie 1-stortplaatsen, kunnen worden afgezwakt. Aan de voorwaarden die gelden voor de inrichting en afwerking van categorie 3-stortplaatsen moet in ieder geval worden voldaan.

Voorwaarden waaronder voor de inrichting en afwerking van stortplaatsen die asbest bevattend bouwmateriaal ontvangen, de voorwaarden die gelden voor categorie 1-stortplaatsen in de milieuvergunning kunnen worden afgezwakt:

1° het afval bevat geen andere gevaarlijke stoffen dan gebonden asbest, meer bepaald asbestcement in de vorm van dakleien, golfplaten, buizen,…, of andere asbesthoudende bouwmaterialen waarin asbest in gebonden vorm aanwezig is; het in gebonden vorm aanwezig zijn wordt nagegaan aan de hand van de meetmethode voor de vezelvrijstelling van asbesthoudend afvalmaterialen en moet worden geattesteerd door een daartoe erkend milieudeskundige;

2° de afvalstoffen dienen te voldoen aan de criteria voor het storten van afvalstoffen op categorie 3-stortplaatsen zoals bedoeld in artikel 5.2.4.1.7, § 4; in het geval van afvalstoffen bestaande uit asbestcement zijn de afvalstoffen aanvaardbaar zonder tests zoals bedoeld in artikel 5.2.4.1.7, § 3; andere asbesthoudende materialen moeten worden onderworpen aan de procedure bepaalt in punt A van deze subafdeling om te bepalen of ze voldoen aan de criteria voor afvalstoffen die aanvaardbaar zijn op categorie 3-stortplaatsen zoals bepaald onder artikel 5.2.4.1.7, § 4; als uitzondering op het verbod om plastiek en andere kunststoffen gebruikt in de bouwsector te storten op een stortplaats voor inert afval, mag het afval zowel in geval van afvalstoffen bestaande uit asbestcement, als in geval van andere asbesthoudende bouwmaterialen, worden aanvaard in een verpakking bestaande uit kunststof; de verpakking moet een vlotte controle van de inhoud ervan toelaten;

3° de stortplaats aanvaardt uitsluitend asbest bevattend bouwmateriaal; dit afval mag ook in een afzonderlijke cel van een stortplaats worden gestort, als deze cel voldoende geïsoleerd is;

4° om verspreiding van vezels te voorkomen, wordt het stortgebied dagelijks en voorafgaand aan elke verdichtingsbewerking met daartoe geëigend materiaal afgedekt en wordt het, als het afval niet is verpakt, regelmatig besprenkeld; voor de dagelijkse afdek wordt bij voorkeur gebruik gemaakt van daartoe geschikte inerte afvalstoffen; indien dergelijke afvalstoffen niet beschikbaar zijn, worden bodemmaterialen aangewend; het gebruik van afvalstoffen als afdek wordt in het werkplan bepaald;
5° uiteindelijk wordt de stortplaats/cel geheel afgedekt om verspreiding van vezels te voorkomen;
6° op de stortplaats/cel worden geen werkzaamheden uitgevoerd die het vrijkomen van vezels tot gevolg kunnen hebben; (bvb het boren van gaten);
7° na sluiting van de stortplaats/cel wordt een plattegrond van de locatie bewaard waarop is aangegeven waar er asbestafval is gestort;
8° er worden passende maatregelen genomen om de mogelijkheden tot gebruik van de locatie na sluiting van de stortplaats te beperken ten einde te voorkomen dat mensen in contact met het afval komen.

• SECTION 6.7

Deel 6. MILIEUVOORWAARDEN VOOR NIET-INGEDEELDE INRICHTINGEN

• Hoofdstuk 6.4. BEHEERSING VAN ASBEST

▪ Artikel 6.4.0.1.

§ 1.

Overeenkomstig de EG-richtlijn 87/217/EEG van 19 maart 1987 dienen bij het gebruik van asbest en werken met asbesthoudende producten de nodige maatregelen getroffen om ervoor te zorgen dat emissies van asbest in het milieu en afvalstoffen van asbest voor zover dat met redelijke middelen mogelijk is aan de bron worden verminderd en voorkomen. Bij gebruik van asbest impliceren deze maatregelen dat gebruik wordt gemaakt van de beste beschikbare technologieën, met inbegrip van recycling of behandeling waar zulks dienstig is.

Tevens dienen de nodige maatregelen getroffen om ervoor te zorgen dat:

1° tijdens het vervoer, het laden en het lossen van afvalstoffen die asbestvezels of asbeststof bevatten, deze vezels en stof niet vrijkomen in de lucht en geen vloeistoffen worden verloren die asbestvezels kunnen bevatten;
2° afvalstoffen die asbestvezels of -stof bevatten, zodanig worden behandeld, verpakt zijn of afgedekt, met inachtneming van de plaatselijke omstandigheden, dat er geen asbestdeeltjes in het milieu terechtkomen;

3° activiteiten die verbonden zijn aan het werken met asbest bevattende produkten geen noemenswaardige milieuverontreiniging door asbestvezels of -stof veroorzaken;

4° bij de sloop van asbestbevattende gebouwen, constructies en installaties en het verwijderen van asbest of asbesthoudende materialen daaruit, waarbij asbestvezels of asbeststof kunnen vrijkomen geen asbest in het milieu terechtkomt. Tevens zijn hierop van toepassing de emissiegrenswaarden zoals vermeld in bijlage 4.4.2.bis, 16°.

§ 2.

De volgende asbesthoudende toepassingen kunnen zelf worden verwijderd voor zover deze via eenvoudige handelingen (bvb. vlot losschroeven) kunnen worden weggenomen :

1° hechtgebonden asbest die niet beschadigd is of waarbij er geen vrije vezels zichtbaar zijn en waarbij verwijdering geen aanleiding geeft tot een wijziging van de toestand;

2° hechtgebonden asbest die beschadigd is of waarbij er vrije vezels zichtbaar zijn en die verwerkt is in een buitentoepassing waarbij geen derden aanwezig zijn, voor zover de verwijdering geen aanleiding geeft tot een wijziging van de toestand;

3° asbesthoudende koorden, dichtingen of pakkingen, remvoeringen en analoge materialen.

Andere toepassingen mogen alleen verwijderd worden door gespecialiseerde bedrijven.

Ingevoegd bij art. 205 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

§ 3.

Bij de sloop en verwijdering van asbesthoudend materiaal als vermeld in § 2, 1°, 2° en 3°, moet vezelverspreiding en blootstelling van personen aan asbestvezels verhinderd worden door de volgende maatregelen te nemen :

1° bevochtigen of fixeren van het materiaal;

2° de elementen één voor één verwijderen, bij voorkeur manueel, gebruik makend van handwerktuigen of in laatste instantie traagdraaiend gereedschap;

3° de materialen niet gooien;

4° de materialen niet breken;

5° de materialen opslaan in gesloten verpakking.

Bij de werkzaamheden mogen geen minderjarigen aanwezig zijn.

Voor persoonlijke bescherming tegen blootstelling wordt gebruik gemaakt van een stofmasker type P3 of gelijkwaardig stofmasker.

Ingevoegd bij art. 205 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

§ 4.

De asbesthoudende toepassingen worden afzonderlijk opgeslagen en niet gemengd met het andere sloopafval;

Ingevoegd bij art. 205 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

§ 5.

Het gebruik van mechanische werktuigen met grote snelheid (schuurschijven, slijpmachines, boormachines, e.d.), hogewaterdrukreinigers en luchtcompressoren, voor het bewerken, snijden of schoonmaken van objecten of ondergronden in asbesthoudend materiaal, objecten of ondergronden bekleed met asbesthoudend materiaal of voor het verwijderen van asbest is verboden.

Toegevoegd bij art. 205 B.Vl.Reg. 19 september 2008, B.S. 27 januari 2009.

ANNEX I.B: VLAREMA

- ### ARTICLE 2.3.2.1

HOOFDSTUK 2. Afbakening van de afvalfase

- **Afdeling 2.3. Specifieke criteria**
  - **Onderafdeling 2.3.2. Criteria voor grondstoffen, bestemd voor gebruik als bouwstof**
    - **Artikel 2.3.2.1.**

§ 1.

Rekening houdend met de geldende voorwaarden voor werken of bouwstoffen moeten de volgende criteria voor de samenstelling minimaal zijn vervuld om de materialen, vermeld in bijlage 2.2, afdeling 2, te beschouwen als grondstoffen die bestemd zijn voor gebruik als bouwstof :

1° De maximale totaalconcentraties aan organische verbindingen, vermeld in bijlage 2.3.2.A, worden niet overschreden;

2° De maximale totaalconcentraties aan metalen, vermeld in bijlage 2.3.2.A, zijn richtwaarden. Voor de metalen waarbij de totaalconcentraties lager zijn dan de waarden voor vrij gebruik van uitgegraven bodem, vermeld in bijlage V van het VLAREBO, moet de uitloogbaarheid niet bepaald worden;

3° De maximale uitloogbaarheidswaarden van metalen voor gebruik in of als niet-vormgegeven bouwstof, vermeld in bijlage 2.3.2.B, worden niet overschreden. De maximale uitloogbaarheid geldt voor een standaardgebruik waarbij de toepassingshoogte van de niet-vormgegeven bouwstof, gemeten loodrecht op het aardoppervlak, 0,7 m bedraagt, het soortelijk gewicht 1550 kg/m3 is, en de effectieve infiltratie in het werk 300 mm/j bedraagt. Bij afwijkende uitloogbaarheid, afwijkend soortelijk gewicht en een afwijkende beoogde toepassingshoogte moet de berekende immissiegrenswaarde voor de bodem voldoen aan bijlage 2.3.2.C;

4° De uitloogbaarheid van metalen, voor gebruik in of als vormgegeven-bouwstoffen, moet resulteren in berekende immissiegrenswaarden die voldoen aan de waarden, vermeld in bijlage 2.3.2.C;

5° Het berekende totaalgehalte aan asbestvezels bedraagt maximaal 100 mg/kg droge stof.

- SECTION 4.1

HOOFDSTUK 4. Algemene bepalingen over het beheer van materiaalkringlopen en afvalstoffen

- Afdeling 4.1. Indeling van afvalstoffen
  - Artikel 4.1.2. Overeenkomstig artikel 22 van het Materialendecreet worden de volgende afvalstoffen als bijzondere afvalstoffen aangewezen :

1° drukwerkafval;
2° afgedankte voertuigen;
3° afvalbanden;
4° afgedankte elektrische en elektronische apparatuur;
5° afgedankte batterijen en accu’s;
6° andere afgewerkte olie dan de olie, vermeld in 16°, g);
7° oude en vervallen geneesmiddelen;
8° gebruikte dierlijke en plantaardige vetten en oliën;
9° gebruikte wegwerpluiers;
10° fvallandbouwfolies;
11° zwerfvuil;
12° afval van de zee- en binnenvaart;
13° gebruikte injectienaalden;
14° afgedankte fotovoltaïsche zonnepanelen;
15° baggerspecie en ruimingsspecie;
16° de volgende afvalstoffen die ontstaan bij het onderhouden, herstellen of slopen van motorvoertuigen, motorvaartuigen, motorvliegtuigen en hun toebehoren :
  a) stof dat vrije asbestvezels bevat;

b) remschoenen, remschijven, remplaten, remblokken en koppelingsplaten die asbest bevatten;
c) afgedankte batterijen en accu's;
d) vervuilde of onbruikbare solventen;
e) destillatieresidu's van solventrecuperatie, resten van verf, lak en vernis, slib van spuitcabines;
f) synthetische remvloeistof;
g) afgewerkte olie;
h) vervuilde of onbruikbare brandstoffen;
i) koelvloeistoffen;
j) koelmiddelen die ozonafbrekende stoffen of gefluoreerde broeikasgassen bevatten;
k) vervuilde filters van spuitcabines, spuitbussen, verpakkingen die gevaarlijke stoffen, met uitzondering van olie, hebben bevat of die door die stoffen werden verontreinigd en niet meer gebruikt worden;
l) oliehoudende stoffen, zoals oliefilters, brandstoffilters, gebruikt absorptiemateriaal, afvalstoffen uit de olie-waterafscheider, oliehoudende schokdempers, verpakkingen die olie hebben bevat of die door olie werden verontreinigd en niet meer gebruikt worden;
m) katalysatoren;
n) patronen van airbags, die chemicaliën bevatten;

17° klein gevaarlijk afval;
18° papier- en kartonafval;
19° asbesthoudend afval;
20° pvc-afval;
21° afgedankte apparatuur en recipiënten die ozonafbrekende stoffen of gefluoreerde broeikasgassen bevatten;
22° gebruikte pcb's;
23° medisch afval;
24° bouw- en sloopafval;
25° dierlijke bijproducten die voldoen aan de definitie van afvalstof;
26° afvalstoffen van de titaandioxide-industrie;
27° landbouwafvalstoffen;
28° mijnbouwafvalstoffen;
29° slib dat afkomstig is van de drinkwaterproductie, de reiniging van riolen, septische putten en vetvangers, en van waterzuiveringsinstallaties.

- ## SECTION 4.3

- Afdeling 4.3. Afzonderlijke inzameling van afvalstoffen
  - Artikel 4.3.1.:

Ten minste de volgende huishoudelijke afvalstoffen moeten gescheiden worden aangeboden en verder afzonderlijk worden gehouden bij de ophaling of inzameling :

1° klein gevaarlijk afval van huishoudelijke oorsprong;
2° glazen flessen en bokalen;
3° papier- en kartonafval;
4° grofvuil;
5° groenafval;
6° textielafval;
7° afgedankte elektrische en elektronische apparatuur;
8° afvalbanden;
9° puin;
10° asbestcementhoudende afvalstoffen;
11° pmd-afval.

Ten minste de volgende huishoudelijke afvalstoffen moeten gescheiden worden aangeboden en verder afzonderlijk worden gehouden bij de ophaling of inzameling, of, indien aantoonbaar niet mogelijk, naderhand uitgesorteerd worden :

1° houtafval;
2° metaalafval.

  - Artikel 4.3.2.:

Tenminste de volgende bedrijfsafvalstoffen moeten gescheiden worden aangeboden door de afvalstoffenproducent en afzonderlijk worden gehouden bij de ophaling of inzameling :

1° klein gevaarlijk afval van vergelijkbare bedrijfsmatige oorsprong;
2° glasafval;
3° papier- en kartonafval;
4° gebruikte dierlijke en plantaardige oliën en vetten;
5° groenafval;
6° textielafval;
7° afgedankte elektrische en elektronische apparatuur;
8° afvalbanden;
9° puin;
10° afgewerkte olie;

11° gevaarlijke afvalstoffen;
12° asbestcementhoudende afvalstoffen; afgedankte apparatuur en recipiënten die ozonafbrekende stoffen of gefluoreerde
13° broeikasgassen bevatten;
14° afvallandbouwfolies;
15° afgedankte batterijen en accu's.
16° pmd-afval.
17° houtafval;
18° metaalafval.

De afvalstoffenproducent die bedrijfsrestafval heeft, is verplicht om met de inzamelaar, afvalstoffenhandelaar of -makelaar van het bedrijfsrestafval een contract te sluiten waarin de afvalfracties, vermeld in het eerste lid, en hun vooropgestelde inzamelwijze duidelijk vermeld worden.

In afwijking van het eerste lid mag de afvalstoffenproducent verschillende afvalfracties die in aanmerking komen voor hoogwaardige materiaalrecyclage, alsook houtafval, samenvoegen in hetzelfde recipiënt, onder de volgende cumulatieve voorwaarden:

1° het zijn droge, niet-gevaarlijke afvalfracties waarbij de samenvoeging van de fracties het uitsorteren en de hoogwaardige verwerking van de afzonderlijke afvalfracties niet verhindert;
2° het recipiënt wordt overgebracht naar een vergunde sorteerinrichting waar de fracties volledig worden uitgesorteerd;
3° de afvalstoffenproducent daarover een contract heeft gesloten met een inzamelaar, afvalstoffenhandelaar of -makelaar, waarin de samengevoegde fracties worden gespecificeerd.

In afwijking van het tweede lid geldt dat het sluiten van een contract voor het bedrijfsrestafval niet verplicht is als voldaan is aan de volgende cumulatieve voorwaarden:

1° het bedrijfsrestafval van de afvalstoffenproducent is vergelijkbaar naar aard, samenstelling en hoeveelheid met huishoudelijke afvalstoffen;
2° het bedrijfsrestafval van de afvalstoffenproducent wordt ingezameld in één ronde met huishoudelijk afval;
3° voor de inzameling van het bedrijfsrestafval wordt de volledige en reële kost doorgerekend aan de afvalstoffenproducent.

- ## ADDENDUM 2.1

- **Bijlagen**
  - **Bijlage 2.1. Lijst van afvalstoffen**
    - **Inleiding**

1. De verschillende soorten afvalstoffen in de lijst worden volledig gedefinieerd door de code van zes cijfers voor de afvalstoffen en de code van twee en vier cijfers boven de hoofdstukken. Dat houdt in dat een afvalstof als volgt in de lijst kan worden opgezocht:

A. Zoek de herkomst van de afvalstof op in de hoofdstukken 01 tot en met 12 of 17 tot en met 0 en bepaal de bijbehorende code van zes cijfers voor de afvalstof (met uitzondering van de codes in de hoofdstukken die op 99 eindigen). Er valt op te merken dat de activiteiten in een specifieke installatie onder verschillende hoofdstukken kunnen vallen. Zo zijn de afvalstoffen van een autofabriek afhankelijk van de processtap te vinden in hoofdstuk 12 (afval van de machinale bewerking en oppervlaktebehandeling van metalen), hoofdstuk 11 (anorganisch metaalhoudend afval van de behandeling en coating van metalen) en hoofdstuk 08 (afval van het gebruik van coatings). NB: gescheiden ingezameld verpakkingsafval (met inbegrip van mengsels van verschillende verpakkingsmaterialen) wordt ingedeeld onder 15 01, niet 20 01.
B. Als er in de hoofdstukken 01 tot en met 12 of 17 tot en met 20 geen geschikte afvalcode kan worden gevonden, moet er in de hoofdstukken 13, 14 en 15 worden gezocht om de code van de afvalstof te bepalen.
C. Als geen van deze afvalcodes van toepassing is, moet u de afvalcode aan de hand van hoofdstuk 16 bepalen.
D. Als de afvalstof ook niet in hoofdstuk 16 onder te brengen is, moet u de code "99" (niet elders genoemd afval) gebruiken in het deel van de lijst dat overeenkomt met de bij de eerste stap bepaalde activiteit.

2. In de zin van de afvalstoffenlijst wordt onder "gevaarlijke stof" verstaan: elke stof die overeenkomstig richtlijn 67/548/EEG, zoals gewijzigd, als gevaarlijk is of zal worden ingedeeld; onder "zwaar metaal" wordt verstaan: elke verbinding van antimoon, arseen, cadmium, chroom(VI), koper, lood, kwik, nikkel, seleen, telluur, thallium en tin, alsook die metalen in metallische vorm, voor zover ze als gevaarlijke stof zijn ingedeeld.

3. Als een afvalstof door een algemene of specifieke verwijzing naar gevaarlijke stoffen als gevaarlijk wordt aangeduid, is de afvalstof alleen gevaarlijk als deze stoffen in zulke hoge concentraties (dit wil zeggen gewichtspercenten) aanwezig zijn, dat de afvalstof een of meer van de eigenschappen, vermeld in artikel 4.1.3, §2, bezit. Wat de punten H3 tot en met H8, H10 en H11 betreft, zijn de grenswaarden, vermeld in artikel 4.1.3, §2, tweede lid, van toepassing. Voor de kenmerken H1, H2, H9 en H12 tot en met H15 bevat artikel 4.1.3, §2, momenteel geen specificaties.

4. Overeenkomstig de preambule van richtlijn 1999/45/EG, waarin wordt gesteld dat voor legeringen een nadere evaluatie noodzakelijk is omdat het misschien niet mogelijk is de precieze eigenschappen daarvan vast te stellen door gebruik te maken van de beschikbare conventionele methoden, is artikel 4.1.3, §2, tweede lid, niet van toepassing op zuivere (niet met gevaarlijke stoffen verontreinigde) metaallegeringen. Dat blijft het geval in afwachting van de uitvoering van de verdere werkzaamheden waartoe de Commissie en de lidstaten zich met het oog op een specifieke indelingsmethode voor

legeringen hebben verbonden. De indeling van de afvalstoffen die in de onderhavige lijst uitdrukkelijk worden genoemd, blijft ongewijzigd.

5. De nummering van de lijst vertoont lacunes die dienen om verwarring met oudere versies van de lijst te vermijden. Alleen die nummers die exact dezelfde betekenis dragen in de huidige en in oudere versies, hebben een nummering die ook in de oudere versies gebruikt werd. Alle nieuw opgenomen afvalstoffen, of afvalstoffen die ten opzichte van de oudere versie een gewijzigde omschrijving hebben gekregen, verwierven een nummering die niet in de oudere versies voorkomt. Nummeringen uit oudere versies waaraan een omschrijving was verbonden die in de huidige versie niet meer exact terugkomt, werden geweerd.

- Hoofdstukken van de Lijst van Afvalstoffen
    - Afval van exploratie, mijnbouw, exploitatie van steengroeven en de fysische en chemische bewerking van mineralen
    - Afval van landbouw, tuinbouw, aquacultuur, bosbouw, jacht en visserij en de voedingsbereiding en -verwerking
    - Afval van de houtverwerking en de productie van panelen en meubelen, alsmede pulp, papier en karton
    - Afval van de leer-, bont- en textielindustrie
    - Afval van olieraffinage, aardgaszuivering en de pyrolytische behandeling van kool
    - Afval van anorganische chemische processen
    - Afval van organische chemische processen
    - Afval van bereiding, formulering, levering en gebruik (BFLG) van coatings (verf, lak en email), lijm, kit en drukinkt
    - Afval van de fotografische industrie
    - Afval van thermische processen
    - Afval van de chemische oppervlaktebehandeling en coating van metalen en andere materialen; non-ferro-hydrometallurgie
    - Afval van de machinale bewerking en de fysische en mechanische oppervlaktebehandeling van metalen en kunststoffen
    - Olieafval en afval van vloeibare brandstoffen (exclusief spijsolie, 05 en 12)
    - Afval van organische oplosmiddelen, koelmiddelen en drijfgassen (exclusief 07 en 08)

- Verpakkingsafval; absorbentia, poetsdoeken, filtermateriaal en beschermende kleding (niet elders genoemd)
- Niet elders in de lijst genoemd afval
- Bouw- en sloopafval (inclusief afgegraven grond van verontreinigde locaties)
- Afval van de gezondheidszorg bij mens of dier en/of verwant onderzoek (exclusief keuken- en restaurantafval dat niet rechtstreeks van de gezondheidszorg afkomstig is)
- Afval van installaties voor afvalbeheer, off-site waterzuiveringsinstallaties en de bereiding van voor menselijke consumptie bestemd water en water voor industrieel gebruik
- Stedelijk afval (huishoudelijk afval en soortgelijk bedrijfsafval, industrieel afval en afval van instellingen), inclusief gescheiden ingezamelde fracties

▪ **Lijst van afvalstoffen (enkel codes met betrekking tot asbest)**

06 07 01*	asbesthoudend afval van elektrolyse
06 13 04*	afval van asbestverwerking
10 13 09*	afval van de fabricage van asbestcement dat asbest bevat
10 13 10	niet onder 10 13 09 vallend afval van de fabricage van asbestcement
15 01 11*	metalen verpakking die een gevaarlijke vaste poreuze matrix (bijvoorbeeld asbest) bevat, inclusief lege drukhouders
16 01 11*	remblokken die asbest bevatten
16 02 12*	afgedankte apparatuur die vrije asbestvezels bevat
17 06	isolatiemateriaal en asbesthoudend bouwmateriaal
17 06 01*	asbesthoudend isolatiemateriaal
17 06 05*	asbesthoudende bouwmaterialen

ANNEX 1.C: VLAREBO

• ADDENDUM I

- **Bijlage I.** Lijst van risico-inrichtingen waarvan de exploitatie is aangevat voor 1 juni 2015

Overeenkomstig artikel 21, eerste lid, 1°, van het besluit van de Vlaamse Regering van 14 december 2007 houdende vaststelling van het Vlaams reglement betreffende de bodemsanering en de bodembescherming wordt de lijst van risico-inrichtingen waarvan de exploitatie voor 1 juni 2015 is aangevat, in de onderstaande tabel vastgesteld.

Verklaring van de symbolen aangegeven in de kolom 'categorie'

O= Inrichting waarvoor conform het Bodemdecreet en dit besluit een oriënterend bodemonderzoek verplicht is bij overdracht, sluiting en faillissement.

A= Inrichting waarvoor conform het Bodemdecreet en dit besluit een oriënterend bodemonderzoek verplicht is bij overdracht, sluiting en faillissement, en om de twintig jaar.

B= Inrichting waarvoor conform het Bodemdecreet en dit besluit een oriënterend onderzoek verplicht is bij overdracht, sluiting en faillissement, en om de tien jaar.

Rubriek 2. Afvalstoffen

Rubriek (1)	Omschrijving en Subrubrieken (2) (3) (4)	Categorie
2.	Afvalstoffen inrichtingen voor de verwerking van afvalstoffen overeenkomstig het decreet van 2 juli 1981 betreffende de voorkoming en het beheer van afvalstoffen en zijn uitvoeringsbesluiten.	

2.1. Opslag en overslag van afvalstoffen

Rubriek (1)	Omschrijving en Subrubrieken (2) (3) (4)	Categorie
2.1.	Opslag en overslag van afvalstoffen	
2.1.1.	Opslag van afvalstoffen niet aan een verwerking van de afvalstoffen verbonden	A
2.1.2.	Opslag en overslag van afvalstoffen die niet aan verwerking verbonden zijn, met een opslagcapaciteit van:	
	b) meer dan 1 ton voor afvalstoffen die ook asbestafval als bedoeld sub c) kunnen omvatten	A
	c) meer dan 1 ton voor asbestafval bestaande uit asbestcement of andere asbesthoudende bouwmaterialen waarin asbest in gebonden vorm aanwezig is	A
2.1.3.	Tussentijdse opslagplaats voor uitgegraven bodem die niet voldoet aan een toepassing als vermeld in het Bodemdecreet en het Vlarebo.	
	1° met een capaciteit van maximaal 10.000 m3	O
	2° met een capaciteit van meer dan 10.000 m3	A

2.2. Opslag en nuttige toepassing van afvalstoffen

Rubriek (1)	Omschrijving en Subrubrieken (2) (3) (4)			Categorie
2.2.	Opslag en nuttige toepassing van afvalstoffen			
2.2.1.	Opslag en sortering van:			
	a)	interte afvalstoffen		A
	b)	selectief ingezamelde huishoudelijke afvalstoffen en met huishoudelijke afvalstoffen vergelijkbare bedrijfsafvalstoffen, met inbegrip van gevaarlijk afval (containerpark). Het is een inrichting van een exploitant die belast is met de inzameling van huishoudelijke afvalstoffen		A
	c)	niet gevaarlijke afvalstoffen bestaande uit papier en karton, hout, textiel, kunststoffen, metaal, glas, rubber, bouw en sloopafval, met een opslagcapaciteit van		
		1°	maximaal 100 ton	A
		2°	meer dan 100 ton	B
	d)	andere niet gevaarlijke afvalstoffen, met een opslagcapaciteit van :		
		1°	maximaal 100 ton	A
		2°	meer dan 100 ton	A
	e)	gevaarlijke afvalstoffen, uitgezonderd de in subrubriek 2.2.1, b) ingedeelde inrichtingen, met een opslagcapaciteit van:		
		2°	meer dan 1 ton voor afvalstoffen andere dan asbestafval bestaande uit asbestcement of andere asbesthoudende bouwmaterialen waarin asbest in gebonden vorm aanwezig is	B
		3°	meer dan 1 ton voor asbestafval bestaande uit asbestcement of andere asbesthoudende bouwmaterialen waarin asbest in gebonden vorm aanwezig is	B
2.2.2.	Opslag en mechanische behandeling van:			
	a)	inerte afvalstoffen, met een opslagcapaciteit van:		
		1°	maximaal 1.000 m³	A
		2°	meer dan 1.000 m³	A
	b)	niet gevaarlijke afvalstoffen uit 2.2.1.c., met een opslagcapaciteit van:		
		1°	maximaal 100 ton	A
		2°	meer dan 100 ton	B
	c)	niet gevaarlijk schroot, met een opslagcapaciteit van:		
		1°	maximaal 10 ton	O
		2°	meer dan 10 ton tot en met 100 ton	A
		3°	meer dan 100 ton	B

	d)	Voertuigwrakken of afgedankte voertuigen, met een opslagcapaciteit van:		
		1°	maximaal 25 ton of 25 voertuigwrakken of afgedankte voertuigen die noch vloeistoffen, noch andere gevaarlijke onderdelen bevatten (deze afgedankte voertuigen zijn enkel afkomstig van erkende centra voor depollutie, demontage en vernietiging van afgedankte voertuigen), en/of maximaal 5 ton of 5 voertuigwrakken of afgedankte voertuigen die wel nog vloeistoffen en/of andere gevaarlijke onderdelen bevatten,	O
		2°	meer dan 25 ton of 25 voertuigwrakken of afgedankte voertuigen tot maximaal 100 ton of 100 voertuigwrakken of afgedankte voertuigen die noch vloeistoffen, noch andere gevaarlijke onderdelen bevatten (deze afgedankte voertuigen zijn enkel afkomstig van erkende centra voor depollutie, demontage en vernietiging van afgedankte voertuigen), en/of meer dan 5 ton of 5 voertuigwrakken of afgedankte voertuigen tot maximaal 100 ton of 100 voertuigwrakken of afgedankte voertuigen die wel nog vloeistoffen en/of andere gevaarlijke onderdelen bevatten,	A
		3°	meer dan 100 ton of 100 voertuigwrakken of afgedankte voertuigen die al dan niet vloeistoffen of andere gevaarlijke onderdelen bevatten (afgedankte voertuigen die noch vloeistoffen, noch andere gevaarlijke onderdelen bevatten zijn enkel afkomstig van erkende centra voor depollutie, demontage en vernietiging van afgedankte voertuigen)	B
	e)	scheepssloperijen en sloperijen andere dan bedoeld onder c) en d)		B
	f)	andere niet-gevaarlijke afvalstoffen met een opslagcapaciteit van:		
		1°	maximaal 100 ton	A
		2°	meer dan 100 ton	A
	g)	andere niet-gevaarlijke afvalstoffen met een opslagcapaciteit van:		
		2°	meer dan 1 ton	B
2.2.3.	Opslag en biologische behandeling van: nuttige toepassing op de plaats van productie, inclusief thuiscompostering, alsook boerderijcompostering wanneer er gewerkt wordt met uitsluitend bedrijfseigen uitgangsmateriaal en de compost uitsluitend bestemd is voor de eigen percelen, wordt niet als een opslag of behandeling van afvalstoffen beschouwd;			

	g)		biologische behandeling van gevaarlijke afvalstoffen	A
2.2.4.			Dierlijke bijproducten niet bestemd voor menselijke consumptie die worden beschouwd als afvalstoffen zoals bedoeld in het decreet van 23 december 2011 betreffende het duurzaam beheer van materiaalkringlopen en afvalstoffen.	
	a)		Opslagbedrijf	A
	b)		Intermediair categorie 3-bedrijf	A
	c)		Intermediair categorie 1- of categorie 2-bedrijf	A
	d)		Verwerkingsbedrijf van categorie 3-materiaal	A
	e)		Verwerkingsbedrijf van categorie 2-materiaal	A
	f)		Verwerkingsbedrijf van categorie 1-materiaal	A
2.2.5.			Opslag en fysisch-chemische behandeling al of niet in combinatie met een mechanische behandeling, van:	
	a)		niet gevaarlijke slibs, met een opslagcapaciteit van:	
		1°	tot en met 1 ton	O
		2°	meer dan 1 ton	B
	b)		gevaarlijke slibs, met een opslagcapaciteit van:	
		1°	tot en met 1 ton	A
		2°	meer dan 1 ton	B
	c)		afgewerkte olie, met een opslagcapaciteit van:	
		1°	tot en met 1 ton	A
		2°	meer dan 1 ton	B
	d)		organische oplosmiddelen, met een opslagcapaciteit van:	
		1°	tot en met 1 ton	A
		2°	meer dan 1 ton	B
	e)		andere niet gevaarlijke afvalstoffen, met een opslagcapaciteit van:	
		2°	meer dan 1 ton	B
	f)		andere gevaarlijke afvalstoffen, met een opslagcapaciteit van:	
		2°	meer dan 1 ton	B
2.2.6.			Opslag en reiniging van recipiënten (verpakkingen en containers) door inwendig wassen van:	
	a)		recipiënten die stoffen hebben bevat die als afvalstoffen bij de inerte afvalstoffen zijn gerangschikt	A
	b)		recipiënten die biologische stoffen hebben bevat die als afvalstoffen bij de niet-gevaarlijke biologische afvalstoffen zijn gerangschikt	A
	c)		recipiënten die stoffen hebben bevat die als afvalstoffen bij de andere niet-gevaarlijke afvalstoffen zijn gerangschikt	B

	d)	recipiënten die stoffen hebben bevat die als afvalstoffen bij de gevaarlijke afvalstoffen zijn gerangschikt	B
2.2.8.	Opslag en behandeling van baggerspecie afkomstig van het ruimen, verdiepen en/of verbreden van bevaarbare en onbevaarbare waterlopen behorende tot het openbaar hydrografisch net en/of van de aanleg van nieuwe waterinfrastructuur:		
	a)	opslag in afwachting van behandeling	A
	b)	mechanische, fysisch-chemisch en/of biologische behandeling	A

2.3. Opslag en verwijdering van afvalstoffen

Rubriek (1)	Omschrijving en Subrubrieken (2) (3) (4)		Categorie
2.3.	Opslag en verwijdering van afvalstoffen		
2.3.1.	Opslag en mechanische behandeling, andere dan deze bedoeld in rubriek 2.3.7., van:		
	a)	niet-gevaarlijke afvalstoffen	A
	b)	gevaarlijke afvalstoffen	B
2.3.2.	Opslag en fysisch-chemische behandeling, al of niet in combinatie met mechanische behandeling, andere dan deze bedoeld in rubriek 2.3.7., van:		
	a)	niet-gevaarlijke slibs	A
	b)	gevaarlijke slibs	A
	c)	afgewerkte olie	A
	d)	organische oplosmiddelen	B
	e)	andere niet-gevaarlijke afvalstoffen	A
	g)	andere gevaarlijke afvalstoffen	B
2.3.3.	Opslag en biologische behandeling, andere dan deze bedoeld in rubriek 2.3.7., van :		
	c)	andere gevaarlijke afvalstoffen	B
2.3.4.	Opslag en verbranding of meeverbranding, al dan niet als experiment, met of zonder energiewinning en met of zonder terugwinning van stoffen van :		
2.3.4.1	Opslag en verbranding van:		
	b)	verontreinigd behandeld houtafval	A
	c)	afgewerkte olie	A
	e)	niet-gevaarlijke huishoudelijke afvalstoffen	A
	f)	niet-gevaarlijke bedrijfsafvalstoffen die vergelijkbaar zijn met huishoudelijke afvalstoffen	A

	h)		risicohoudend medisch afval en vloeibaar en pasteus niet-risicohoudend medisch afval	A
	j)		andere niet-gevaarlijke afvalstoffen	A
	k)		andere gevaarlijke afvalstoffen	A
	l)		dierlijk afval met uitzondering van krengen in dierencrematoria	A
	m)		waterzuiveringsslib	A
2.3.4.2	Opslag en medeverbranding van:			
	b)		verontreinigd behandeld houtafval	A
	c)		afgewerkte olie	A
	d)		andere niet-gevaarlijke afvalstoffen	A
	e)		andere gevaarlijke afvalstoffen	A
	f)		dierlijk afval met uitzondering van krengen in dierencrematoria	A
	g)		waterzuiveringsslib	A
2.3.5.	Opslag en reiniging van metalen recipiënten door uitbranden			B
2.3.6.	Stortplaatsen, andere dan die vermeld in rubriek 2.3.7, van:Het rechtstreeks terugstorten op de plaats van ontginning, van materialen of stoffen in hun natuurlijke staat, voorzover ze afkomstig zijn van geologische afzettingen die tot het tertiare of het kwartaire tijdperk behoren (zand-, klei-, leem, mergel en grindafzettingen) is geen stortactiviteit0			
	a)		Categorie 3: stortplaats voor inerte afvalstoffen	
		1)	stortplaats voor inerte afvalstoffen	A
		2)	monostortplaats voor inerte afvalstoffen	A
	b)		Categorie 2: stortplaats voor niet gevaarlijke afvalstoffen	
		1)	stortplaats voor gemengde niet-gevaarlijke huishoudelijke vaste afvalstoffen met hoog gehalte aan organisch/bioafbreekbaar en anorganisch afval	B
		2)	stortplaats voor voornamelijk organisch niet-gevaarlijke afvalstoffen	B
		3)	stortplaats voor anorganische niet-gevaarlijke afvalstoffen met laag organisch/bioafbreekbaar gehalte	B
		4)	monostortplaats voor niet-gevaarlijke afvalstoffen, andere dan inerte afvalstoffen	B
		5)	stortplaats voor niet-gevaarlijke afvalstoffen van iedere andere oorsprong die voldoen aan de criteria voor de aanvaarding van afvalstoffen op stortplaatsen voor niet gevaarlijk afval (criteria: zie afdeling 5.2.4 van titel II van het VLAREM)	B
		6)	stortplaats voor stabiele, niet-reactieve gevaarlijke afvalstoffen (bij voorbeeld verharde of verglaasde afvalstoffen) met een uitlooggedrag dat	B

			gelijkwaardig is aan dat van de onder 5° vermelde niet gevaarlijke afvalstoffen, en die voldoen aan de relevante aanvaardingscriteria (criteria: zie afdeling 5.2.4 van titel II van het VLAREM); die gevaarlijke afvalstoffen worden niet gestort in cellen die voor biologisch afbreekbare niet gevaarlijke afvalstoffen bestemd zijn	
	c)		Categorie 1: stortplaats voor gevaarlijke afvalstoffen	
		1)	stortplaats voor gevaarlijke afvalstoffen die voldoen aan de criteria voor de aanvaarding van afvalstoffen op stortplaatsen voor gevaarlijke afvalstoffen (criteria: zie afdeling 5.2.4 van titel II van het VLAREM)	B
		2)	monostortplaats voor gevaarlijke afvalstoffen	B
		3)	monostortplaatsen voor gevaarlijke afvalstoffen die bestaan uit asbestcement of andere asbesthoudende bouwmaterialen waarin asbest in gebonden vorm aanwezig is	B
		4)	Ondergrondse opslagplaats voor gevaarlijke afvalstoffen	B
2.3.7.			Opslag, behandeling en verwijdering van baggerspecie met uitzondering van het ter plaatse uitspreiden van niet-verontreinigde ruimingsspecie	
	a)		monostortplaatsen voor baggerspecie en/of ruimingsspecie afkomstig van het ruimen, verdiepen en/of verbreden van bevaarbare en onbevaarbare waterlopen behorende tot het openbaar hydrografisch net en/of van de aanleg van nieuwe waterinfrastructuur	A
	c)		opslag van sub a) bedoelde baggerspecie en/of ruimingsspecie in afwachting van behandeling	A
	d)		mechanische, fysisch-chemische en/of biologische behandeling van sub a) bedoelde baggerspecie en/of ruimingsspecie	A
2.3.9.			Installaties voor de verwijdering van niet-gevaarlijke afvalstoffen, met een capaciteit van meer dan 50 ton per dag, met uitzondering van de installaties, vermeld in 2.4.3, a), i en ii.	A
2.3.11.			Het verzamelen of storten van winningsafval op een terrein, ongeacht of dat afval zich in vaste vorm, in een oplossing, in een suspensie, of in vloeibare toestand bevindt, gedurende de volgende termijnen:	
	a)		geen termijn voor afvalvoorzieningen van categorie A en voorzieningen voor in het afvalbeheersplan als gevaarlijk gekarakteriseerd afval;	A
	b)		een termijn van meer dan zes maanden voor voorzieningen voor gevaarlijk afval dat onverwacht wordt gegenereerd;	A

ANNEX 2: CONCLUSION TABLE

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
Technique									
		Encapsulating unbound asbestos fibers	Heating to >1000°C to alter fiber structure	Melting with plasma torch or standard furnace (1100-1600°C) for destruction of the fiber structure	1. Mixing ACM with clay or blast furnace slags/industrial sludge (vitro) 2. Melting (800-950°C or 1.300-1.400°C) for conversion of mixture into ceramic materials of mixture with high metal content	1. Pelletizing of ACW 2. Melting of pelletized ACW in furnace (1.300-1.600°C), with or without additives, using MSW as fuel	1. Dissolution in acids or bases	1. Shredding and mixing of ACM with fluxing agent 2. Heating (1.200-1.250°C) for rapid demineralization	1. Structural destruction by mechanical energy
Acceptance criteria									
		• ACW and friable asbestos (NO non-friable asbestos) • In closed and clean containers (max. dimensions: 2.4x2.4x6m) • Double bagged in plastic bags or big bags, labeled with an asbestos sticker	• Only non-friable asbestos • In big bags of specific dimensions (not too big) • All asbestos-types	• ACW • Double bagged in plastic bags or big bags OR in metal containers OR on pallets; and labeled with asbestos sticker • Each packaging form has its own strict criteria • ACW needs	ACW	ACW	ACW	• Friable asbestos • Asbestos cement and other non-friable asbestos • ACW may be polluted with radionuclides, PCBs and metals	ACW

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
				to be clear of aerosols, explosives, heavy metals, paper and carton packaging material					
End-product									
	End-product	1m³ Blocks of immobilized ACW in a cement matrix, double bagged in big bags	• = "Beststof" • Fiber structure of asbestos is altered to non-hazardous structure • Denatured ACW is grinded to a fine powder (≈Ø0.2)	Inert, free-of-asbestos vitrified material	• Silicate mineral with practical use • Ceramitization: o Ceramic materials • Vitro-ceramitization: o Products with high mechanical strength	• Destruction of hazardous fiber structure: • Harmless end-product	• Non-toxic • Secondary material • Complete and permanent destruction of fiber structure • E.g. Sodium silicate as catalyst, detergents, absorbent material, cements, water treatment…	Demineralized inorganic materials into non-asbestos minerals (wollastonite, olivine, glass, diopside…) and possible ash fraction	Amorphous material

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
	Applicability	• Landfilled • On landfill: blocks used for structuring, e.g. roads, zoning • Further treatment	Secondary material in several industries, e.g. cement, road foundation	Substitute for quartz and basalt in building materials	• Ceramitization: o Tiles o Low-grade construction applications, e.g. road, buildings o Tiles o If compacted: electrical insulation or refractory material • Vitro-ceramitization: o Suitable as coating and protective surfaces in building, mechanical and chemical industries	• Landfilled • Building industry	• Landfilled • Ceramic industry • In cement • As pavestones	• Secondary material for low-grade construction applications • Landfilled	• Inert additives in cement • Catalyst

		Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
	Standardized	• When landfilled, strict acceptance conditions (Indaver): o Max. size of fibers or flakes = 10mm o Max. size other materials = 30mm o Homogeneous distribution of fibers in inorganic matrix o Density = min. 1ton/m^3 o Compressive strength = min. 1,5N/mm^2 o Standard dimensions = 80x120cm to 100x120cm with max. height of 120cm o Weight = min. 0,5ton – max. 2ton o Double plastic bagged, labelled conform	• ! View when denaturation complete is more or less the same (shadow fiber) BUT very brittle material: o Question: Is it still asbestos? o Possible answer: certificating entire process instead of end-product to ensure destruction of asbestos • Tested by several laboratories, such as INTRON (SGS), ENCI (Heidelberg), TNO… • Standardized process with 1100°C to ensure that	No data	No data	No data	No data	No data	No data

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
		ARAB and ADR legislation	all the asbestos minerals are destroyed						
	Stability	No permanent solution: asbestos cement can erode/break/…, resulting in to the release of the asbestos fibers	Chemically stable, especially after crushing of denatured ACW	Glassy, chemically stable matrix	Chemically stable	Chemically stable (especially after crushing)	Complete destruction of fiber structure	Inert, chemically stable	Stable?
Process									

		Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
	Supply product	• Arrival of big bags ACW and friable asbestos in closed containers • Bags are opened and distributed manually on belt conveyor	• Arrival of big bags ACW, transferred in their entirety onto a wagon by means of a crane • Wagon enters a tunnel furnace, where it will remain for ~75h and it moves at a speed of 1,5 wagon/hour	• Arrival of big bags, containers of pallets of ACW • Dumped on conveyor belt	Flexible	Flexible	• ACW enters in closed double plastic bags in airtight bunkers • Vacuum environment	• ACW in big bags enters the entrance hall through a sluice • Bags not opened to prevent manipulation: put on conveyor belt in their entirety by trucks	Flexible
	Batch/continuous	Discontinuous process	Continuous, closed process in tunnel furnace	Semi-continuous	/	Semi-continuous	/	In theory: continuous process but not yet proven!	/
	Buffer	The sorted and in size reduced ACW has to be stored in storage bunker	Vacuum storage space available	From the moment the ACW is on conveyor belt: continuous process	Limited	Limited	Limited	• Closed supply, rotary hearth, secondary thermic oxidation unit, quench cooler and HEPA filtration	Limited
	Separation	• Manual sorting out of metal and plastic • Magnetic belt removes remaining metal	Not required	Not required	Not required	Not required	Not required	Not required	Not required?

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
	Size-reduction/Crushing	Maximum size of 1 cm³ achieved by at least 3 different crushers	Crushing of ACW after denaturation (≈Ø0.2) to “beststof”	After control, via conveyor belt to a shredder installation where it is shredded and mixed to ensure optimal loading of furnace	Possible compaction: resulting in different applications of end-product		ACW is grounded with a mortar, after which it goes to the reactor	• In crusher: o ACW wetted with water o ACW crushed and mixing with additives, such as borax	Fragmentation = concept of the technique
	Laborious/automated	Relatively simple but laborious method	Inside tunnel furnace: fully automated	Mostly automated?	No data	No data	No data	Automated	No data
		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
	Control	/	• Control of composition (1 big bag per receiving load) in vacuum cabin • Sampling and testing after denaturation from the center of each wagon to ensure complete destruction of the fiber structure	Visual and manual entrance control	No data	No data	No data	Process control unit present	No data

		Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
	Installation	Fixed installation (Rematt): process always done under same conditions with little unknown factors BUT ACW needs to be transported twice	• Fixed installation (Twee "R" Recycling Group) • Length tunnel furnace = 180m • Plot plant = ca. 75 (width) x 240 (length) meter • Site = 2,2 hectare	Fixed installation (Inertam)	No data	No data	Transportable	Fixed installation (ARI-Technologies)	• Relatively small plan • Transportable • No thermal equipment • Easy in use
Energetic									
	Primary energy	477.3MJ/ton (2007)	Usage of gas = 7 million m^3	2.400 kWh/ton ACW or ca. 8,64 GJ/ton	No data	No data	No data	• Electricity consumption = 60kWh/ton or 212MJ/ton • For the heating of the rotary heart, propane is used: o Natural gas consumption at a rate of 1ton/h = 5,47GJ/ton	No data
	Additives	• Hydraulic binder = cement • Hardening accelerator	Natural gas	Bicarbonate for gas washing	No data	No data	Acidic or base solution, e.g. NaOH, HF	Alkaline sodium borate solution (= 2% of the total processing cost)	No data

		Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
	Water consumption	• 2.400m³/year • Water from showers, cleaning of installations and rain is used to make the concrete	/	• Cooling water from plasma torch	No data	No data	• One of the two (NaOH) most important additives	• Water used, amongst other things, for: o Wetting of ACW in crusher o Cooling of installation	No data
	Others	• Creation of vacuum • Purification of ventilation air	• Creation of vacuum • Filtration of burned gasses	/	/	/	/	• Creation of vacuum • Purification of ventilation air	/
Emissions									
	Water	No waste water: water from showers, cleaning of installations and rain is used to make the concrete	/	Production of waste water: Cooling water from plasma torch	No data	No data	/	• ACW is wetted in crusher with water • Most of the processing and cooling water evaporates into the air through a chimney • Ca. 11 l/min or 0,66 m³/h of waste water, containing salts of flue gas cleaning are discharged in sewer system	No data

		Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
	Air	• No air pollution: o Process in isolated spaces, in constant vacuum o Ventilation air is purified by HEPA filters, according to Vlarem emission limit values	• No air pollution: o Process in isolated spaces, in constant vacuum o Gasses resulting from burning of big bags are being burned again and then passed through a filtration system	Limited emission of air due to extremely high combustion temperatures	No data	No data	Measures have been taken to make pollution impossible, e.g. absolute filter	Different HEPA filters are installed to prevent air pollution	No data
	Solid	Increase in mass and volume: +150%	Mass and volume reduction	• Mass and volume reduction • Production of residue resulting from gas washing: landfilled on Category 1 landfills	No data	No data	• Process results in: o Volume reduction	• Process results in: • Mass-reduction of 33% • Average volume-reduction of 73%	No data
	Others	/	/	/	/	/	• Remaining acidic solution can be neutralized by adding calcium hydroxide	• Adequate protection for the soil is provided	/
Safety aspects									

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
		• Usage of closed system from asbestos-cement industry, completed with the zone system for asbestos removal • Measures to prevent distribution of friable asbestos: o Vacuum o Air lock o Filtration of suctioned air o Protection with plastic • Limitation of emissions due to HEPA-absolute filters • Mandatory use of personal protective equipment	• Control of composition before denaturation in vacuum cabin • Possible storage in vacuum storage space • Closed system: big bags go in their entirety in furnace and only leave once denaturated • First contact with ACW is when denatured • Control if denaturation was successful by sampling the ACW • Filtration system for resulting gasses	• Flue gasses, resulting from the reactor: o Burned in afterburner chamber o Washed by bicarbonate washer o Filtered by fabric filter • Most important risk: escaping of asbestos fibers during treatment of ACW: No manual manipulation from the moment the bagged ACW is accepted up until the material is vitrified	No data	No data	• Meets all the regulatory requirements • Vacuum environment • Extracted air passes through an absolute filter	• Bags are not opened when arriving but are put in their entirety on the conveyor belt to prevent manipulation of the ACW • Employees have to wear protective clothing type C with e.g. positive pressure respirators • A vacuum entrance hall • Air extraction through HEPA absolute filters • On crusher: ventilation system with another HEPA filter	No data
Financial									

		Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
	Costs process	• Base tariff: €1.100/ton, includes: o Reception of the ACW o Weighing of the container with third parties o Processing of ACW conform the necessary standards o Transport to landfill o Landfill levies • Deviations from base tariff: o Quantity discount o Supplement if ACW is not conform the acceptance conditions	€ 175/ton	• Tariff varies depending of composition, delivered quantities, conformity with acceptance criteria: o Range = €1.000-2.500/ton o Average = €1.500/ton = 35% more expensive than immobilization by cementation o Supplement if ACW is not conform the acceptance conditions (packaging, presence of contaminants)	No data	No data	• Too expensive: Dutch government stated that the processing cost of the method cannot be more than the current price of dumping = €50 - € 100	• €270-370/ton, not including: o Transportation costs ≈ €120-130/ton o Processing costs of possible residue o Government taxes • Estimated total cost = €390-500/ton	No data
		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
	Costs business model	No data	Total investment cost ≈ €23 million, i.e. site, installation, employment (20 jobs), etc.	No data	No data	No data	No data	• Capital expenditure of installation of 27tons/day ≈ €3,87 million • Capital expenditure of installation of 45tons/day = €5,16 million • Depreciation of 10 years + other parameters (e.g. working 300 days/year, labor, fuel, maintenance and operating costs, profit margin of 15%), results in the above processing cost • Cost ratio: o Labor = 35-45% o Investment = 25% o Fuel = 20-25% o Others = 10-15% (operating, maintenance…)	No data
State of the art									

		Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
	Proven/failed	Proven, mature and relatively simple technique	Proven technique on lab scale in the Netherlands, other countries small full-scale installation	• Proven technique for other waste streams: Japan, France • Proven technique for asbestos: INERTAM (France)	Proven technique on lab scale	• Proven technique for decomposition of other waste materials. • Not proven for ACW	Failed technique; too expensive and not sustainable (unsafe end-product)	• Proven technique according to ARI-technologies • Still in pilot phase: o Installation in US (Tacoma, Washington) o Continuity not yet proven	• Not proven. o Theoretical technique.
	State of the art	Licensed for the acceptance and processing of 15.000 tons of ACW and 400 tons of friable asbestos, until October 2021.	• Several pilot installations in various settings: o In Germany o In England (periodical furnace) o In Belgium (Beersel) • Tested end-product (e.g. by INTRON, ENCI, TNO…) • Expected annual capacity (Twee “R” Recycling Group) = 100.000 tons	• Started in February 1995 • Licensed annual capacity = 8.000 tons of ACW • Actual annual capacity = 7.000 tons of ACW • Capacity per hour = 1 ton	New method for decomposition of ACW	• Known method for decomposition of organic materials at elevated temperatures • New method for decomposition of ACW	• Never further than pilot phase: o Too expensive o E.g. by TreSeNeRie, Sita, Solvay…	• Certified by EPA as alternative to landfilling ACW • Added to European BREF document on Waste treatments (4.3.3.2)	• In use in several countries BUT focus on elimination of organic molecules • Treatment of inorganic wastes, e.g. ACW, is new: o Only tested in theory, on laboratory scale

		Encapsulation + Double bagging	**Denaturation**	**Vitrification (with plasma gun)**	**Ceramitization**	**Pyrolyses furnace**	**Chemical treatment**	**Thermochemical treatment**	**Mechanochemical treatment**
	Patented	Not patented	Technique patented in at least 23 countries	Patented (e.g. US 4678493 A)	Patented (EP2428254 B1)	Patented (e.g. WO 2012165770 A1)	Not patented	Patented (ARI-technology)+I34	• Patented in several countries for other waste materials. • Not patented for ACW
	Optimization	Reduction of water consumption during the process	/	Extra production lines to increase capacity	Upgrade to pilot phase to prove technique	Upgrade to pilot phase to prove technique	Solution current disadvantages	• Reduction of costs by addition of energy-rich, suitable waste streams • Upscaling the installation since smaller installation are less efficient than larger ones • Certain adjustments to the installation, e.g. to the hopper	Upgrade to pilot phase to prove technique
	Innovative	Not patented	In the Netherlands	No: already full-scale installations operational for both ACW and other waste streams	Yes	Yes	Yes, if solution current disadvantages	Yes, technique not proven on full scale	Yes
	Alternative	No alternatives known in Flanders	Denaturation by microwave heating	• Vitrification in conventional ovens • Vitrification with an electrical furnace (Geomelt vitrification process)	No data	No	No alternatives, either acidic or base solution	No alternative on installation of ARI-technologies	No

ANNEX 3: QUANTIFICATION OF TREATMENT METHODS

	Encapsulation + Double bagging	Denaturation	Vitrification (with plasma gun)	Ceramitization	Pyrolyses furnace	Chemical treatment	Thermochemical treatment	Mechanochemical treatment
Technique								
	0	0	0	0	0	0	0	0
Acceptance criteria								
	1	-1	-1	0	0	0	1	0
End-product								
End-product	-1	1	1	1	1	1	1	1
Applicability	-1	1	2	1	1	1	1	1
Standardized	1	1	0	0	0	0	0	0
Process								
Supply product	0	0	0	0	0	0	0	0
Batch/continuous	-1	2	0	0	0	0	1	0
Buffer	0	0	0	0	0	0	0	0
Separation	-1	1	1	1	1	1	1	1
Size-reduction/Crushing	-1	-1	-1	-1	0	-1	-1	-1
Laborious/automated	-1	1	1	0	0	0	1	0
Control	0	0	0	0	0	0	0	0
Installation	1	1	1	0	0	2	1	2
Energetic								
Primary energy	1	0	-1	0	0	0	-1	0
Additives	-1	1	-1	0	0	-1	-1	0
Water consumption	-1	1	-1	0	0	-1	-1	0
Others	-1	-1	1	0	0	0	-1	0
Emissions								
Water	1	0	-1	0	0	0	-1	0
Air	1	1	1	0	0	-1	-1	0
Solid	-1	1	1	0	0	1	1	0
Others	0	0	0	0	0	0	0	0
Safety aspects								
	0	0	0	0	0	0	0	0
Financial								
Costs process	2	1	2	-2	-2	-1	2	-2
Costs business model	0	1	0	0	0	1	1	0

State of the art								
Proven/failed	2	0	2	0	-1	-2	1	-1
Patented	1	-1	-1	-1	-1	1	-1	1
Optimization	0	0	0	0	0	0	0	0
Alternative	-1	1	1	-1	-1	-1	-1	-1

Legend	
Very negative	-2
Negative	-1
Neutral/No data	0
Positive	1
Very positive	2

	-2	-1	0	1	2
Technique					
	(Descriptive parameter: no quantification)				
Acceptance criteria					
		Non-friable OR friable	No data	Both friable and non-friable	
End-product					
End-product		Not stable	No data	Stable	
Applicability		Not re-usable	No data	Re-usable	Re-usable and proven
Standardized		Not standardized	No data	Standardized process	
Process					
Supply product	(Descriptive parameter: no quantification)				
Batch/continuous	Discontinuous and open process	Discontinuous process	Semi-continuous process	Continuous process	Continuous and closed process
Buffer	(Descriptive parameter: no quantification)				
Separation		Required	Neutral/No data	Not required	
Size-reduction/Crushing	Before and after	Only once	No data	Not required	
Laborious/automated		Laborious	No data	Automated	
Control	(Descriptive parameter: no quantification)				
Installation			No data	Fixed	Transportable
Energetic					
Primary energy		>1 GJ/ton	No data	< 100 MJ/ton	
Additives		Additives needed	No data	No additives needed	
Water consumption		Water consumption	No data	No water consumption	
Others		Extra (e.g. vacuum)	No data	No extra	
Emissions					
Water		Yes	No data	No	
Air		Yes	No data	No	
Solid		Mass and/or volume increase	No data	Mass and/or volume reduction	
Others	(Descriptive parameter: no quantification)				
Safety aspects					
	(Descriptive parameter: no quantification)				
Financial					
Costs process	Example not present	Example present and failed	Neutral	Example present	Example present and succeeded
Costs business model		Example not present	No data	Example present	

State of the art					
Proven/failed	Failed	Not proven	Proven on lab scale	Proven on pilot scale	Proven on full scale
Patented		Patented	No data	Not patented	
Optimization	(Descriptive parameter.: no quantification)				
Alternative		No	No data	Yes	