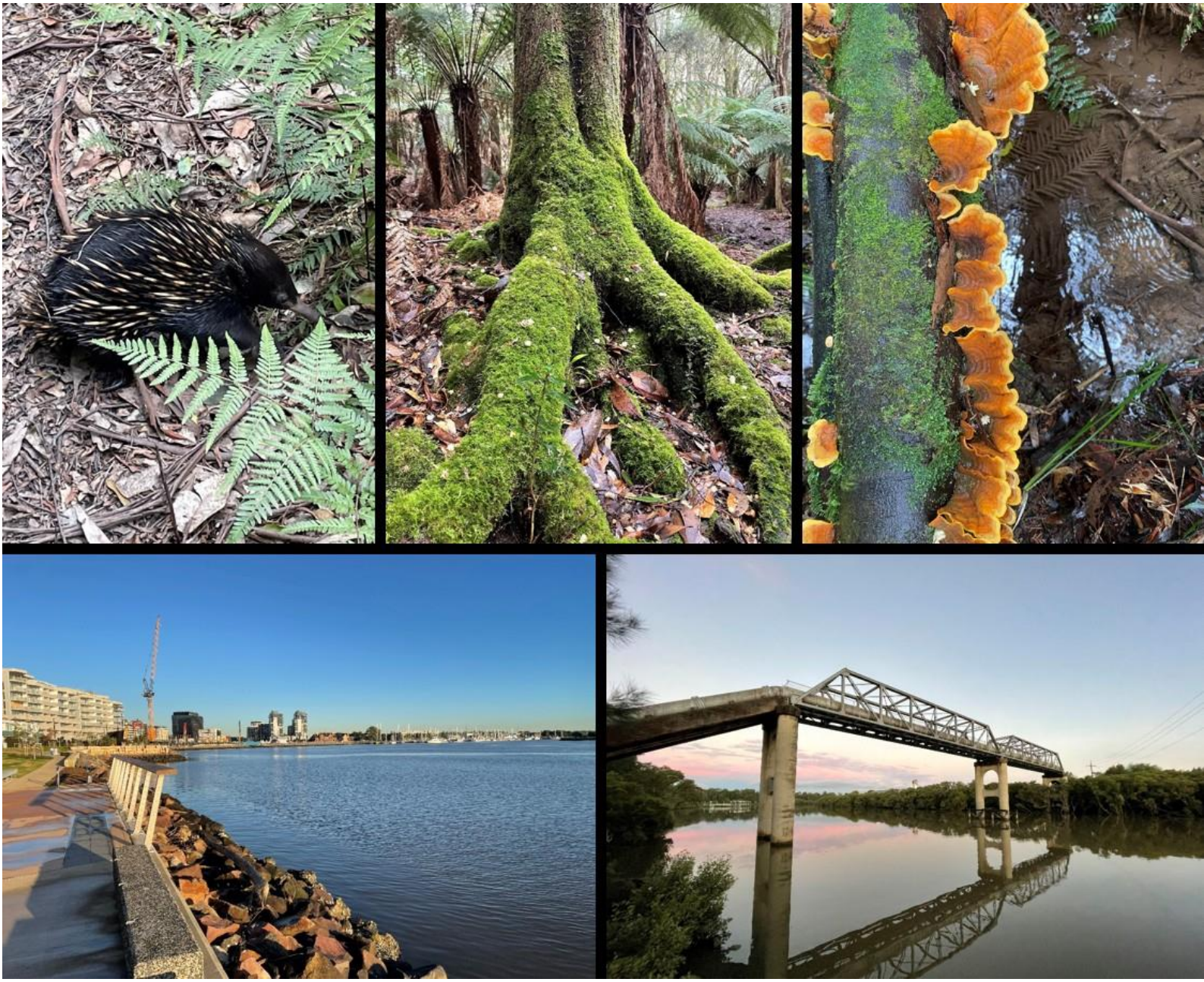

Literature review – sampling and analysis of asbestos

Prepared for: NSW Office of Chief Scientist and Engineer

21 October 2024

Document History and Status

Report Reference	OCSE/24/SAA001
Revision	C – Final
Date	21 October 2024
Previous Revisions	A – Draft (13 May 2024) B – Final (15 July 2024)

Limitations

Environmental Risk Sciences Pty Ltd has prepared this report for the use of NSW Office of Chief Scientist and Engineer in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in the **Section 1** of this report.

The methodology adopted and sources of information used are outlined in this report. Environmental Risk Sciences Pty Ltd has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information provided for use in this assessment was false.

This report was prepared in April/May 2024 and updated in June/July and October 2024 and is based on the information provided and reviewed at that time. Environmental Risk Sciences Pty Ltd disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

Table of Contents

Glossary of Terms

AC	see Asbestos Cement
ACM	See Asbestos-Containing Materials
Asbestos	The fibrous form of the mineral silicates belonging to the serpentine and amphibole groups of rock-forming minerals, including: actinolite, amosite (Brown Asbestos), anthophyllite, chrysotile (White Asbestos), crocidolite (Blue Asbestos), tremolite, or any mixture containing one or more of these.
Asbestos Cement (AC)	Preformed products comprising Portland cement, sand, binders, and reinforced with various combinations of both asbestos and non-asbestos fibres.
Asbestos-Containing Material	Any material or thing that, as part of its design, contains asbestos.
Bonded ACM	Products containing asbestos bound in a permanent matrix (e.g. VAT, asbestos cement, electrical backing boards). See also Friable ACM.
FC	Fibre Cement products (manufactured without the use of asbestos).
Fibro	Colloquialism for AC sheet products.
Friable ACM	means free asbestos, or an asbestos-containing material, which, when dry, is or may become crumbled, pulverised, or reduced to powder by hand pressure. See also Bonded ACM.
NOA	Naturally Occurring Asbestos: natural geological occurrence of asbestos minerals found in association with geological deposits, including rock, sediment, or soil. Does not include legacy contamination of the environment resulting from anthropogenic sources (i.e. commercial or industrial activities, or inappropriate disposal of ACM).
Respirable Asbestos Fibres	Asbestos fibres with the following geometric characteristics: Length: > 5 microns and Width: < 3 microns and Aspect Ratio: > 3:1 (i.e. relationship between length and width). The fibres of importance must comply with all 3 of these characteristics. Respirable asbestos fibres possess the optimum geometric and aerodynamic characteristics to be inhaled and penetrate into the gas exchange regions of the lungs (respiratory bronchioles and alveoli).
Trace analysis	Refers to the analysis technique used to identify respirable sized asbestos fibres in AS 4964.
Trace levels	Term ‘trace levels’ is used throughout AS 4964 to mean “at very low concentrations”. This term differs from the meaning of ‘trace analysis’ used in AS 4964 which describes the approach taken to analyse for trace levels.
VAT	Vinyl asbestos tile

Section 1. Background

1.1 Introduction

Environmental Risk Sciences Pty Ltd, Hibbs & Associates Pty Ltd and Envirolab Services Pty Ltd have been engaged by NSW Office of Chief Scientist and Engineer to prepare a literature review about the sampling and analysis methods for asbestos in recycled materials.

1.2 Objectives

The objectives of this literature review are as specified by NSW OCSE:

Scope of Literature Review

The Literature Review will inform Terms of Reference 3 (ToR 3), approaches to sampling and analysis for asbestos in recovered materials It will include:

1. *Overview on approaches to sampling for asbestos in recovered materials, including excavated fill, soils, recovered aggregate, recovered fines and road materials. The review includes:*
    a. *Appraisal of the sampling design and sampling objectives;*
    b. *Appraisal of the sampling methodology(s);*
    c. *Advantages and limitations of each sampling methodology; and*
    d. *How to ensure the sampling methodology is fit-for-purpose based on the circumstances on how the recovered materials are generated and used;*
2. *Available guidance on sampling for asbestos in recovered materials including real-world applicability and cost-effectiveness*
3. *Review of asbestos analytical methods to ensure best practice asbestos testing in recovered materials (e.g. AS 4964-2004, NEPM gravimetric and NEPM AF/FA testing, and other methods). The review includes:*
    a. *Appraisal and summary of each test method and the circumstances to which each test method is used; and*
    b. *Advantages and limitations of each test method, including limitations associated with limits of reporting ('LOR');*
4. *Review of asbestos sampling approaches and analytical methods, their LOR limitations and how these may impact upon the development of any potential thresholds for asbestos in recovered materials.*
5. *Any other information of relevant to ToR 3*

1.3 Methodology

The approach taken for this literature review has focused on detailed searching of websites relevant for sampling and analysis within resource recovery processes and/or sampling and analysis procedures for wastes.

The websites searched for this review include:

- Australian environmental regulators and related websites in NSW, VIC, QLD, SA and WA.
- US agencies (USEPA)

- Canadian agencies (Environment and Climate Change Canada, Health Canada)
- European agencies
    - European Environment Agency
    - European Commission
    - ECHA
    - RIVM (The Netherlands)
    - UK (UK Environment Agency, Health and Safety Executive (HSE))
- International agencies
    - World Health Organisation
    - International Labour Organisation
- Professional bodies such as:
    - Faculty of Asbestos Management of Australia & New Zealand
    - American Industrial Hygiene Association
    - British Occupational Hygiene Society
    - Australian Institute of Occupational Hygienists
    - New Zealand Occupational Hygiene Society
    - American Conference of Governmental Industrial Hygienists
    - Nederlandse Vereniging voor Arbeidshygiëne (Dutch Occupational Hygiene Society)

Search terms have included:

- Resource recovery
- Waste derived products
- End of waste code
- Asbestos
- Asbestos containing material
- Waste recycling/reuse
- Sampling and analysis of waste
- Sampling and analysis of asbestos containing waste

Section 2. Resource recovery materials

2.1 General

This section provides a short introduction to the types of resource recovery materials relevant in NSW.

Resource recovery materials are those where such materials have been used, become waste, may be processed in some way to allow reuse and then are reused.

While it is important to ensure that there are checks and balances in a system that allows reuse of waste does not result in human health or ecological risks, it is also important to consider whether such checks and balances are needed for new/virgin materials.

When first used as “new/virgin materials”, there is often limited requirements, if any, for testing or assessment of potential risks to human health or ecosystems. Often this is because people have used such materials for a long time and are comfortable that the risks are understood.

There are some materials (like pesticides used in agriculture) where there is an extensive system that controls how these chemicals can be used and checks for potential risks. However, for materials like concrete, most construction materials, aggregate, chairs, clothes, cars, plastics, synthetic turf and many others, it is assumed that they are safe and appropriate to use without significant controls.

New materials could contain asbestos fibres, given that they are naturally occurring. It is possible that trace levels of asbestos fibres might be found if new aggregate or freshly sawn timber or other bulk materials where they are taken directly from quarries, mines etc were tested for the presence of asbestos. These materials are not normally tested for the presence of asbestos so there are few data.

One example of such material which has been assessed for the presence of asbestos fibres is cracker dust in Western Australia. This material is quarry fines generated from the crushing of aggregate during quarrying. This material is used for road base, trench lining, landscaping, footpaths, car parks etc. An investigation was carried out to evaluate the potential for asbestos to be present in this material[1]. The findings indicated that cracker dust from many quarries did not contain detectable levels of asbestos fibres but a few did. A risk assessment indicated that levels were well within national guidelines and normal dust control measures at sites using this material would provide further protection.

2.2 Normal construction materials

Prior to discussing the types of materials covered by the resource recovery system in NSW, it is important to consider the materials normally used in construction and capital works and their potential for impacts on human health and the environment.

[1] https://www.dmp.wa.gov.au/Documents/Safety/MSH_IS_FAQs_CrackerDust.pdf

Materials like concrete, treated timber, asphalt, bricks, aggregate from quarries as well as specific building materials like plasterboard or surface finishes can release chemicals that move into places where people or the environment can be impacted.

For example:

- Concrete – changes in pH caused by rainfall washing across concrete surfaces can be significant depending on the extent of concrete, the age of the concrete and the nature of waterways that may be impacted. Such changes in pH have the potential to have significant effects on aquatic life. There will also be some metals present in cement so these could leach out, however, the levels are likely to be quite low.
- Asphalt – this material includes PAHs and other petroleum hydrocarbons. While being installed, asphalt is kept at warm temperatures so volatile components can be emitted to the atmosphere and have the potential to impact on human health depending on the situation. It is noted that odours are a common complaint during road construction.
- Bricks – these are made from natural materials that will contain metals and other naturally occurring chemicals. These may wash off during rain and reach local waterways where they may have effects.
- Treated timber – timber itself has chemicals within it that may leach out and where that timber has also been treated with pesticides or metals/metalloids to prevent degradation, it is more likely that the treatment chemicals will wash off into runoff. While the pesticides used for such treatment now are different, there is potential they will wash off and reach waterways and impact on aquatic organisms – depending on the situation. This was confirmed by the need to withdraw approval for CCA treated timber (copper, chromium, arsenic) for most purposes due to leaching of these metals/metalloids to levels that had potential to impact human health.
- Aggregate from quarries – naturally sourced aggregate is used in many places – railway ballast, garden mulch etc – the metals that will be in these rocks can wash out and have potential to impact on aquatic ecosystems or even human health (e.g. garden decorations in child care centres where children may play with the rocks).
- Construction materials like plasterboard, paint, glues, glass, roofing, surface finishes etc all contain chemicals that could wash off or leach.

The potential for impacts on human health and the environment from these materials has generally considered to be acceptable and, while there are general requirements for their use, there are not usually any specific requirements designed to address these aspects.

General stormwater results for urban areas, such as those listed in the Australian Guidelines for Water Recycling (Phase 2) Stormwater Harvesting and Reuse (NRMMC 2009), provide supporting information about the presence of a wide variety of chemicals in runoff from roads, buildings, gardens etc.

These materials are not routinely sampled and analysed for their potential environmental/human health impact, although many such materials are routinely tested to show they meet product specifications for sale.

2.3 Resource recovery materials

Resource recovery materials are those that have been used but the materials are not destroyed in that process. This means they can be collected up and have potential for reuse (perhaps multiple times). For some materials, the reuse opportunity does not require much processing/treatment but for others significant processing/treatment is required to generate material that is beneficial when reused.

The types of materials that can be reused include, for example:

- Ash
- Biomass (agricultural crop waste or other farming wastes – gin trash)
- Construction materials like cement fibre board, plasterboard
- Excavated natural materials (i.e. soil, rocks that are from areas where human activities have occurred but contamination is low)
- Excavated road material/reclaimed asphalt pavement
- Food waste
- Garden organics and certain timber wastes that may be composted or processed as mulch
- Recovered aggregate, railway ballast, fines, glass sand (i.e. crushed glass)
- Slag from industrial processes
- Grease trap waste (treated)
- Biosolids, effluent, manure

The goal of resource recovery is to reuse such materials instead of just disposing of them to landfill where such reuse can be undertaken in a way that is beneficial (i.e. there is a benefit – improving sustainability for example) and with minimal potential to impact on human health or the environment.

2.4 Other materials that are reused/recycled

Another aspect which is important to acknowledge is that are a range of other materials that are recycled/reused but, for which, there does not appear to be a requirement for detailed regulation.

One such material is recycled paper. Most office paper in Australia contains recycled paper but there is no requirement for detailed testing in regard to the potential for contamination from the initial use. It should be noted that, due to the use of inks and coatings, it is quite likely that contamination by a variety of chemicals is present in the recycled paper.

Another material type that is commonly recycled/reused is timber. Often timber that has been used in construction or furniture or even as railway sleepers is collected and made into new items. Such items could be new pieces of furniture or as part of retaining walls or other structures within gardens. Again, there is no requirement for testing for potential contamination in these materials nor are they subject to regulation.

Section 3. Asbestos

3.1 General

This section provides a short summary of the properties and hazards of asbestos.

Hazard identification examines the capacity of an agent to cause adverse health effects in humans and other organisms. It is a qualitative description based on the type and quality of data, complementary information (such as structure-activity analysis, genetic toxicity and pharmacokinetics) and the weight of evidence from these various sources (enHealth 2012). The presence of a hazard does not, by itself, automatically result in adverse health effects. It is the dose or level of exposure that is important in making decisions about the potential for health effects (i.e. the risks).

3.2 What is asbestos

Asbestos is the generic name given to the fibrous variety of six naturally occurring minerals.

Figure 3.1 shows a range of images of the various types of these minerals. **Figure 3.2** shows naturally occurring asbestos within a rock. **Figure 3.3** shows a map of locations across NSW that contain these minerals in significant amounts.

Figure 3.1: Images of different types of minerals that are asbestos[2]

[2] https://www.mesothelioma.com/asbestos-exposure/what-is-asbestos/

Figure 3.2: An example of how naturally occurring asbestos can be found within rocks in Australia (Photo taken by Phil Hibbs)

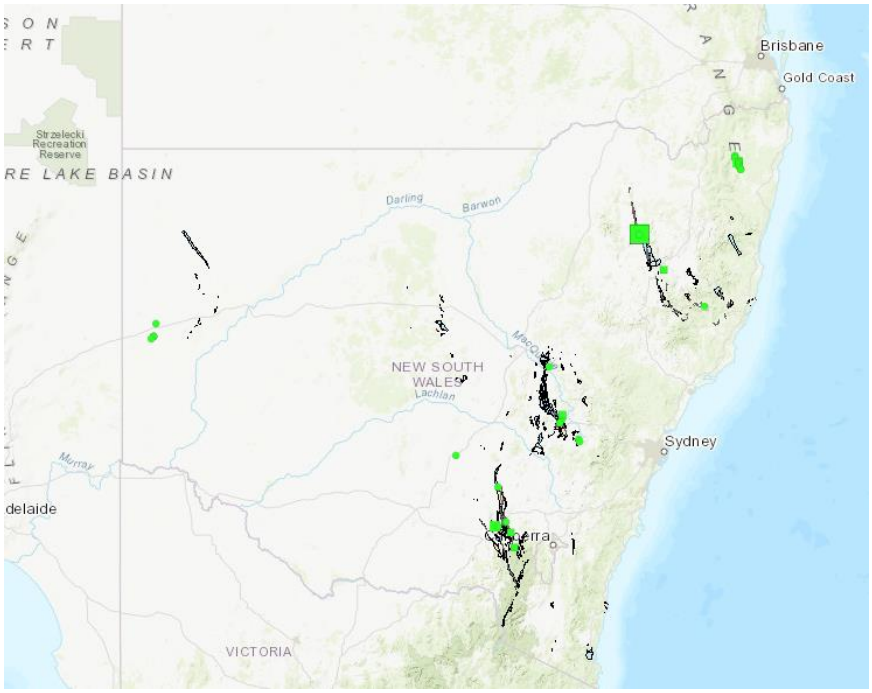

Figure 3.3: Locations of naturally occurring asbestos minerals in NSW [3]

[3] https://www.arcgis.com/apps/PublicInformation/index.html?appid=87434b6ec7dd4aba8cb664d8e646fb06

3.3 Sources of asbestos

Asbestos is the name given to a group of naturally occurring hydrated silicate minerals. Asbestos is a vague generic term of no specific geological significance, except that it describes the group of six (6) regulated minerals that are characterised by having crystallised in nature as long thin separable fibres.

This broad term encompasses a group of fibrous silicate minerals from the serpentine and amphibole mineral classes, and includes:

Serpentine:

- chrysotile

Amphibole:

- actinolite
- amosite
- anthophyllite
- crocidolite
- tremolite

Of the six asbestos minerals listed, only chrysotile, amosite and crocidolite were mined in any commercial significance, and of that chrysotile accounted for the majority (> 95%) of total world production.

Asbestos deposits (naturally occurring) have served as commercial sources in more than 40 countries, but the largest natural deposits are located in Canada, South Africa, China, and Russia. Amosite and crocidolite have been mined from South Africa. Chrysotile was mined at several locations in NSW and crocidolite was mined at Wittenoom in Western Australia.

3.4 Properties of asbestos

The asbestos minerals have a distinctive and unique combination of chemical and physical properties, which at one time gave them great commercial value and a varied and diverse range of applications in industry. These properties include:

- high tensile strength
- high resistance to heat and flame
- low thermal conductivity (i.e. good thermal insulation properties)
- high resistance to chemical and acid attack (except chrysotile)
- high electrical resistance
- good acoustic absorbance
- exceptional filtration properties
- high bonding strength
- fibrous nature (woven into fabrics ropes etc.)

3.5 Asbestos products and applications

The range of applications in which asbestos has been used is extensive and thousands of products have been manufactured that incorporate asbestos.

The typical applications for asbestos in the manufacturing, construction, and heavy engineering industries include the following:

- thermal and acoustic insulation
- fireproofing
- friction materials
- electrical insulation products
- binders or fillers in other products

The common uses of asbestos industrial, commercial, and domestic applications include:

- friction products (e.g. brake linings and clutch facings)
- fire retardants, thermal and acoustic insulation materials
- jointing materials, seals and gaskets
- building products as reinforcement, for acid and alkaline resistance (except chrysotile)
- filtering media (e.g. chemicals, pharmaceutical & food industries)
- binders or fillers in other products (asbestos cement materials, resins, caulking and sealants).

Because of the widespread commercial use of asbestos for over a century, as well as their natural occurrence, asbestos fibres are ubiquitous in the environment. Asbestos fibres are a common contaminant present in air, particularly in urban air.

3.6 Asbestos containing materials

3.6.1 General

As noted previously, the asbestos minerals have a unique combination of physical and chemical properties, which at one time gave them an almost indispensable place in industry. The range of applications and products in which asbestos was used was diverse and many thousands of products have been produced that incorporate asbestos. For many years, industry used asbestos to satisfy its fireproofing, thermal and acoustic insulation requirements, and as a binder or filler in a myriad of products.

Manufactured asbestos containing products (ACM) can be divided into two broad categories – products where the asbestos fibres are bonded within the matrix and products where there is friable asbestos.

3.6.2 Bonded ACM

Bonded ACM refers to those materials where the asbestos fibres are chemically/mechanically bonded into a permanent or semi-permanent matrix. Bonded materials are less likely to release fibres than friable materials.

The most common bonded ACMs used in the construction industry are the asbestos cement (AC) products. The AC products comprise Portland cement, sand, binders and various combinations of both asbestos and non-asbestos fibres. Asbestos was added to provide strength and improve the endurance of the material. All three major asbestos types were used and quantity of asbestos in the materials ranged from 5 – 15%. The use of asbestos in these materials was gradually phased out in the late 1970's.

The asbestos is bound / encapsulated within the cement matrix of the products. In general, the asbestos fibres cannot be released to become airborne in significant quantities unless the cement matrix is severely disrupted (e.g. cutting with power saws etc.). The situation for AC roof cladding is complicated by the weathering that occurs to the outer face of the sheets (i.e. the face exposed to the elements).

Fibre cement products are still manufactured but use cellulose fibre and no longer incorporate any asbestos.

A typical example of AC sheet cladding on a domestic property is shown in **Figure 3.4**.

Low density asbestos fibre board is another form of this type of material[4]. It contained fibres embedded in calcium silicate plaster and was typically used in acoustic ceiling tiles. This material contained a larger proportion of asbestos compared to asbestos cement sheet – up to 70% asbestos.

In good condition, bonded asbestos products such as asbestos cement sheet do not pose a risk because the asbestos fibres are bound together in solid cement and are not easily disturbed/blown into the air where people can breathe them in.

Figure 3.4: Bonded asbestos cement sheeting

[4] https://www.safeworkaustralia.gov.au/system/files/documents/1702/guide-identifying-handling-low-density-asbestos-fibre-board.pdf

3.6.3 Friable ACM

The legislative definition of friable asbestos is “material that is in a powder form or that can be crumbled, pulverised or reduced to a powder by hand pressure when dry, and contains asbestos”. Friable ACMs generally contain a high level of asbestos and the matrix is relatively easily disturbed with the ready release of airborne respirable asbestos fibres.

There are a number of categories of friable asbestos, in particular:

- loose fill type asbestos that was blown into ceiling spaces or used in the lagging around pipes as insulation
- heavily weathered pieces of bonded ACM that are easily crushable.

The loose fill type asbestos (see **Figure 3.5**) can readily produce airborne fibres (enHealth 2013)**.** Due to the friable nature of these materials, respirable fibres can migrate into areas of a building where people live or work (i.e. they don’t just stay inside the ceiling space).

Figure 3.5: Loose fill type asbestos – friable [5]

3.7 Levels of asbestos in the Australian environment

It is important to understand natural sources of asbestos when considering potential risks to human health. As with many situations where contamination may be present, the important aspect to understand is how different this situation is from the normal case.

Asbestos minerals are widely spread throughout the earth’s crust and are not restricted to the few mineable deposits (as shown in **Figure 3.3**). In particular, chrysotile is present in most serpentine rock formations which is a common type of geology.

Emissions of asbestos fibres from natural sources occur due to natural weathering – i.e. effects of wind and rain on rock containing the asbestos fibres that gradually wears away the surface exposing the fibres which may then be blown into the air. In addition, emissions of such fibres from

[5] https://www.abc.net.au/news/2014-08-01/mr-fluffy-sydney/5642608 and https://www.abc.net.au/news/2023-07-20/mr-fluffy-asbestos-found-in-victorian-homes-homeowners-urge-gov/102583794

these natural geologies can be enhanced by man's activities, such as quarrying or road building. Very little, however, is known about the overall load emitted from natural sources (WHO 2000).

Emissions of asbestos fibres from human activities occur during the following:

- mining and milling
- manufacture of asbestos containing products (now banned in Australia)
- construction activities (involving asbestos containing materials (i.e. demolition etc))
- transport and use of asbestos-containing products
- disposal of asbestos containing materials.

Asbestos fibres normally constitute only a relatively small fraction of the total number of fibres in ambient air. Other fibres (i.e. particles that are long and thin) can be present including:

- textile fibres – i.e. fine fibres from our clothes, linen and furniture that escape from fabrics during use or washing/drying – these can be naturally occurring (e.g. cotton/wool) or synthetic (e.g. microfibres, elastane, polyester etc)
- fibres from paper or wood – i.e. cellulose
- fibres from hair, fur, feathers, spider web
- mineral fibres other than asbestos – there are a range of other minerals that form fibre shaped particles and these can also be produced (i.e. synthetic mineral fibres)
- fibres from glass or rock wool – used in insulation materials
- fibres from fungi (including mould) or other microorganisms – hyphae from fungi etc

All of these materials are part of what constitutes particulate matter in air. Other materials also contribute to particulate matter – including fine particles from combustion as well as dust and sand particles, sea salt (close to the ocean) etc.

Figure 3.6 is from the USEPA[6] and shows different types of particles that are normally present in air. This includes fibres like human hair.

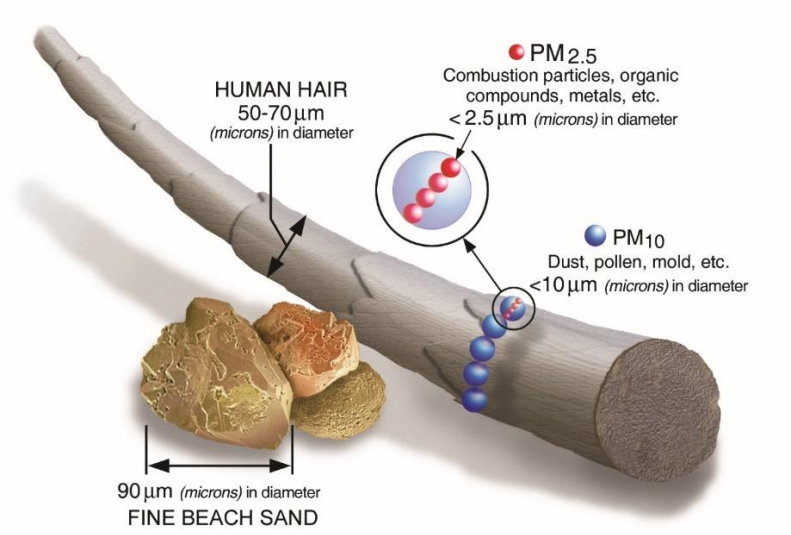

Figure 3.6: USEPA Particulate matter basics

[6] https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

The size and shape of the asbestos fibres is important because not all of the fibres can reach the lungs.

Respirable fibres are those equal to or longer than 5 µm with a diameter of up to 3 µm. The relationship between the length and width is also important so respirable fibres must also have an aspect ratio (i.e. ratio of length to width) equal to or greater than 3:1 (WHO 2000). This means that the fibres that are important are ones that are the right size to be able to reach into the lungs and they must also be long and thin.

Table 3.1 presents a summary of available data on background levels of asbestos in air in urban, rural and industrial areas. In addition, the table includes calculated lifetime burdens, i.e. the number of asbestos fibres inhaled over a lifetime in urban and rural areas compared with workplace exposures.

In addition, Safe Work Australia in its Health Monitoring: Guide for Asbestos (Safe Work Australia 2020) notes:

The typical environmental background level of asbestos in outdoor air is 0.0005 fibres/mL (i.e. 500 fibres/m^3) and 0.0002 fibres/mL (i.e. 200 fibres/m^3) in indoor air. If it is assumed that the daily inhalation volume for an average adult is 22 m^3 and that they spend 20 hours indoors and 4 hours outdoors, these concentrations mean that the average person inhales 5,500 fibres per day every day of their lives. This equates to more than 2 million fibres per year.

(i.e. this calculation is :18.3 m^3 of air indoors at 200 fibres/ m^3 = 3,667 fibres plus 3.67 m^3 of air outdoors at 500 fibres/ m^3 = 1,833 fibres giving a total of 5,500 fibres per day).

Despite this the general population does not contract asbestos-related disease in significant numbers. The background rate of mesothelioma (i.e. in those not exposed at their workplace etc) is less than one case per million people per year. By comparison, the annual death rate (all causes) for a male (45-64 years) in Australia in 2023 was 36 per 100,000 or 360 deaths per million people per year.

Table 3.1: Summary of background levels of asbestos reported in the environment

Exposure	Concentrations reported (f/cm^3 = f/mL)	Reference
Urban air (typically 10 times higher than rural)	0.000003 to 0.0198 for multiple countries 0.00004 to 0.05 (0.0011 mean) in US 0.0016 to 0.0037 (0.0016 mean) for 1990's US 0.0001 to 0.001 lowest background	(Krakowiak et al. 2009) (Abelmann et al. 2015) (ASCC 2008) (WHO 2000) (IARC 2012)
Rural air	0.0003 to 0.0218 for multiple countries 0.0000048 to 0.013 (0.00039 mean) in US 0.000014 to 0.000092 (0.000018 mean) in 2000's in US 0.00001 to <0.0001 lowest background	(Krakowiak et al. 2009) (Abelmann et al. 2015) (ASCC 2008) (WHO 2000) (IARC 2012)
Industrial air	<0.0006 to 91.4	(Krakowiak et al. 2009)
Heavy traffic road crossing or freeway	0.0009 to 0.0033	(WHO 2000)
Indoors	<0.001 buildings with no ACM <0.001 to 0.01 buildings with friable asbestos 0.00003 to 0.006 in homes, schools etc 0.00012 (mean) in US 0.0002 from SafeWork Australia	(WHO 2000) (WHO 2000) (IARC 2012) (ATSDR 2001) (Lee & Van Orden 2008) (Safe Work Australia 2020)

Exposure	Concentrations reported (f/cm^3 = f/mL)	Reference
Outdoor ambient levels or background	0.00003 to 0.0047 in the US 0.0005 from SafeWork Australia	(Glynn et al. 2018) (Safe Work Australia 2020)
Lifetime burdens	**Urban population** exposed to 0.00003 to 0.0002 f/cm^3, exposure for 70 years = ~1.5 x 10^7 to 10^8 accumulated fibres	(WHO 2000)
	Rural population exposed to 0.00001 f/cm^3, exposure for 70 years = 10^5 to 10^6 accumulated fibres	(WHO 2000)
	Asbestos workers exposed to 0.1 to 1 f/cm^3 Exposure for 50 years = 10^{10} to 10^{11} fibres Exposure for 0.7 year (incidental exposure) = 5x10^7 fibres	(WHO 2000)

These results are listed in terms of fibres per mL. Converting them to fibres/m^3 requires the values to be multiplied by 1,000,000. This corresponds to concentrations in terms of fibres/m^3 as follows:

- urban air – 3 to 50,000 fibres/m^3 or lowest background levels listed 100-1,000 fibres/m^3
- rural air – 5 to 20,000 fibres/m^3 or lowest background levels listed 10-100 fibres/m^3
- industrial air – 600 to 91 million fibres/m^3
- heavy traffic roads – 900 to 3,300 fibres/m^3
- indoors – 120 fibres/m^3 for mean for USA; 200 fibres/m^3 for Australia
- outdoor ambient/background levels – 30 to 4,700 fibres/m^3; 500 fibres/m^3 for Australia

A Dutch guidance document indicates that a background air concentration of 1,000 fibres/m^3 is appropriate for consideration in risk assessment (Oomen & Lijzen 2004). This is based on measurements within the Netherlands but this is in line with the values from a range of international sources as listed in **Table 3.1**.

enHealth produced guidance about asbestos in 2013 (enHealth 2013). The guidance included **Figure 3.7** which shows how background exposures compare to occupational exposures and confirms that Australian health authorities acknowledge the routine presence of asbestos in air at background levels.

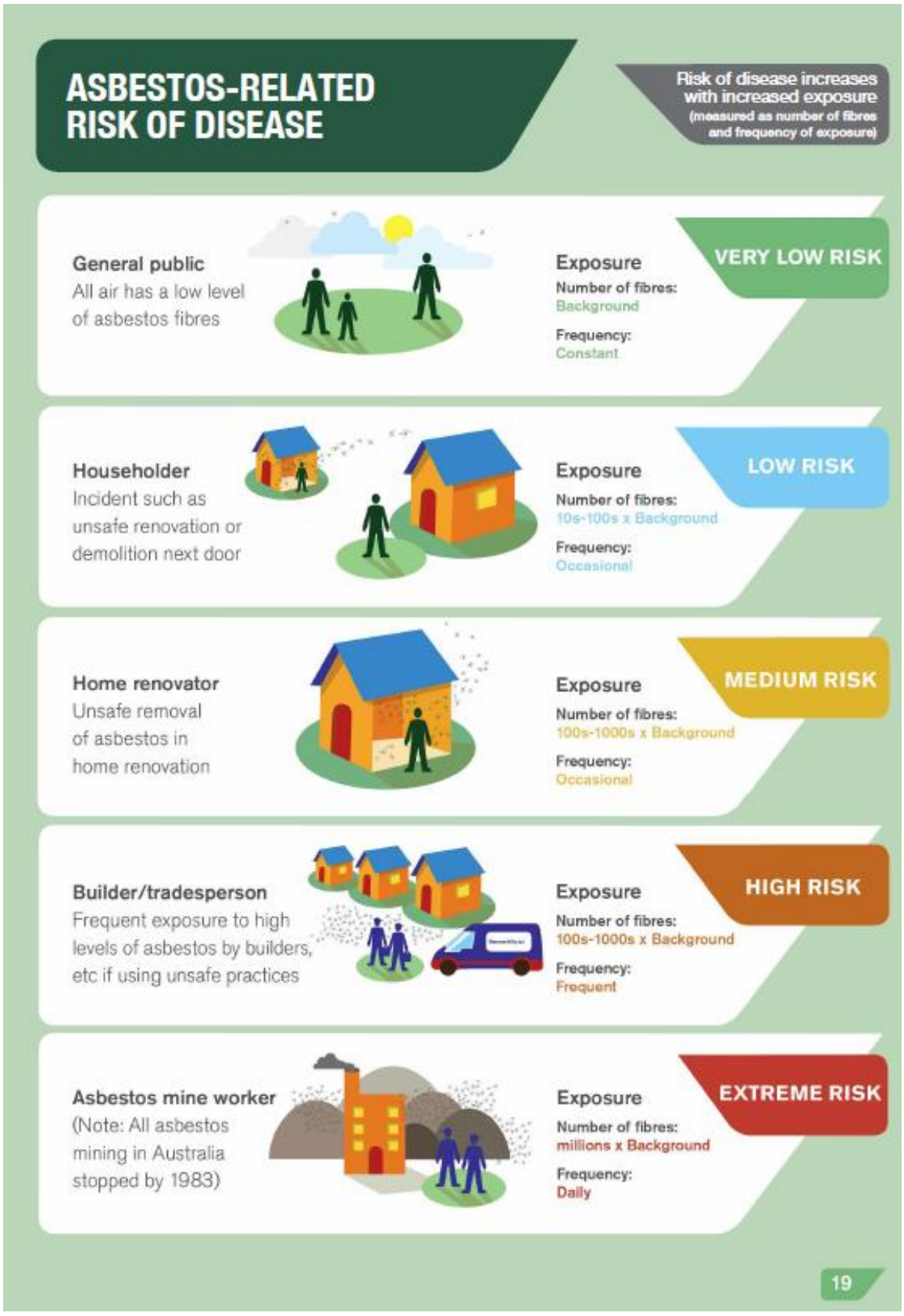

Figure 3.7: enHealth (2013) Risk of disease from exposure to asbestos comparison

3.8 Health effects associated with asbestos exposure

Health effects from exposure to asbestos result from inhalation of the fibres and are well documented. Inhalation is the only route of exposure of significance. There is no consistent scientific evidence that asbestos is hazardous to health when ingested.

Reviews of the potential health effects of asbestos are provided in the following documents:

- enHealth (2013) Asbestos: A guide for householders and the general public.[7]
- IARC (2012) Arsenic, metals, fibres, and dusts. A review of human carcinogens. Volume 100C [8]
- USEPA (2020) Risk Evaluation of Asbestos, Part 1: Chrysotile Asbestos [9]
- ATSDR (2001) Toxicological profile for asbestos [10]
- NTP (2021) Report on Carcinogens [11]

enHealth notes that the primary risk to health comes from the inhalation of asbestos fibres in the respirable size range (enHealth 2013). The fibres in the respirable size range possess the aerodynamic characteristics that allow them to be inhaled and penetrate into the gas exchange regions within the lungs.

There is a definite link between occupational exposure to asbestos and lung diseases such as asbestosis, bronchogenic carcinoma, and mesothelioma.

As asbestos fibres are widespread in the environment, this means everyone breathes in asbestos fibres during their lifetime. The small burden of fibres resulting from this background exposure appears to be tolerated, given the incidence of asbestos-related disease is extremely low in the general population.

As already discussed, Safe Work Australia notes that asbestos fibres are routinely present in indoor and outdoor air in Australia typically at 200 fibres/m^3 and 500 fibres/m^3 respectively (Safe Work Australia 2020).

For people exposed to high levels of fibres such as high occupational or para-occupational exposure, much higher levels of disease have been found. Most evidence of the adverse health effects of asbestos (IARC 2012) comes from epidemiological studies of groups of people with known occupational exposures to asbestos such as those employed in the asbestos mining, processing/production industries or in the building trade. However, it is also clear that environmental exposure such as living near an asbestos mine or para/non-occupational exposures (e.g. household contact with exposed workers or home renovations) can result in asbestos related diseases.

[7] https://www.health.vic.gov.au/publications/asbestos-a-guide-for-householders-and-the-general-public-february-2013
[8] https://publications.iarc.fr/120
[9] https://www.epa.gov/assessing-and-managing-chemicals-under-tsca/risk-evaluation-asbestos-0
[10] https://wwwn.cdc.gov/TSP/ToxProfiles/ToxProfiles.aspx?id=30&tid=4
[11] https://ntp.niehs.nih.gov/whatwestudy/assessments/cancer/roc

Extensive epidemiological research on asbestos shows clear associations between asbestos exposure and asbestosis, lung cancer, and mesothelioma. The epidemiological evidence for other types of cancer is less extensive but is still noted. IARC noted the following:

- Epidemiological evidence shows a high incidence of lung cancer among workers exposed to chrysotile, amosite, anthophyllite, and with mixed fibres containing crocidolite, and tremolite.
- Pleural and peritoneal mesotheliomas were reported to be associated with occupational exposures to crocidolite, amosite, and chrysotile.
- Gastrointestinal tract cancers were reported to have been demonstrated in groups occupationally exposed to amosite, chrysotile or mixed fibres containing chrysotile.
- An excess of cancer of the larynx in occupationally exposed individuals has also been noted (IARC 2012).

In summary, all types of commercially available asbestos are well known to cause fibrosis of the lung and pleura as well as cancer of the lung, mesothelium and possibly the gastrointestinal tract in humans (IARC 2012).

Asbestos-related health effects result primarily from chronic exposures to asbestos fibres in air, but relatively brief, high-level exposures can also cause these diseases. The increased risk of mesothelioma is dose-dependent (i.e. higher the dose, the more likely to see the disease) (enHealth 2005).

The four main asbestos-related conditions are pleural plaques, asbestosis, lung cancer and mesothelioma (HACA 2016):

- Pleural plaques are areas of white, smooth, raised scar tissue on the outer lining of the lung, internal chest wall and diaphragm. Pleural plaques are uncommon, and their occurrence is usually associated with exposure to asbestos. Most people with pleural plaques have no symptoms.
- Asbestosis is a chronic lung disease caused by inflammation or scarring in the lungs. It is associated with asbestos exposure and causes breathlessness, coughing, and permanent lung damage.
- Lung cancer is a tumour that develops in the lungs. People who are exposed to asbestos and smoke or have pre-existing lung disease have a higher chance of developing lung cancer.
- Mesothelioma is a cancer of the tissue that lines the body cavities, particularly the chest and abdominal cavities. It is almost exclusively caused by exposure to asbestos and usually takes a very long time to develop.

Asbestos-related diseases can take a long time to develop. Asbestosis can take 10 to 20 years to develop after initial exposure, whereas mesothelioma may take 30 to 45 years to develop (HACA 2016).

The focus of studies of health impacts from asbestos has been exposure via inhalation of fibres.

The Australian Drinking Water Guidelines (NHMRC 2011 updated 2022) provide the following information about the potential for impacts from asbestos fibres when ingested:

There has been little evidence that ingested asbestos causes cancer. A number of quite extensive epidemiological studies have been carried out on the effects of asbestos in the water supply. On the basis of these data, there is no demonstrated excess risk of cancer even with high numbers of asbestos fibres in drinking water. It is not clear whether asbestos fibres ingested in drinking water can pass through the walls of the gastrointestinal tract in sufficient numbers to cause adverse effects. Experiments with laboratory animals indicate that penetration, if it occurs at all, is extremely limited. Animal studies on the carcinogenic effects of ingested asbestos have been inconclusive.

As a result, it is not considered that exposure via ingestion is a relevant exposure pathway, especially for situations where concentrations are low.

Section 4. Sampling basics

4.1 Sampling objectives

Prior to designing a sampling program, the objectives of that program need to be decided – i.e. the reasons the sampling and analysis is being undertaken.

Most often the objective of a sampling program is to demonstrate that the material of interest complies with a relevant specification.

For example, quality control samples in a factory are taken to show that the "widget" being manufactured meets the required important characteristics (e.g. screws have correct gauge etc). When the manufacturing process is tightly controlled, the number of samples required to check quality can be small.

Identifying the relevant specification for the material of interest is the first step in determining sampling objectives.

The purpose of resource recovery is to take materials that have been used once (or more) and make them suitable to be used again. The idea is to improve sustainability by using these reused/recycled materials to replace virgin materials.

For resource recovery type materials, there may be limited information about the relevant specification:

- If such materials are to be used as fill or trench lining (for example), then the specification will primarily discuss the geotechnical characteristics of the materials that will make it suitable for the purpose. Such specifications are usually available from those constructing large infrastructure such as roads and rail projects. In NSW, such specifications are produced by Transport for NSW[12].
- If such materials are to be used as soil amendments, compost, mulch etc, then the Australian Standards for these types of materials are the relevant specifications. AS 4419-2018 provides requirements for soils for landscaping and garden use. AS 4454-2012 provides requirements for composts, soil conditioners and mulch (Australian Standard 2012, 2018).

Because resource recovery materials are made from various types of waste, additional aspects are added into a specification for these types of materials to ensure contamination, that may be present due to the original use of the material, is at a level that will not pose a risk to people or the environment. In NSW. This part of the specification is provided within the Resource Recovery Orders/Exemptions framework[13].

[12] https://standards.transport.nsw.gov.au/
[13] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework/current-orders-and-exemption

This means there may be a number of relevant specifications for a particular resource recovery material that need to be considered – the one defining the nature of the material for the purpose and the one ensuring contamination is appropriate.

Different types of sampling and analysis of the material may be specified in each of these specifications.

The different aspects that sampling and analysis may assist with include:

- Measuring geotechnical characteristics
- Measuring aspects listed in relevant standards/specifications related to the use of the material
- Measuring aspects listed in relevant resource recovery order/exemption related to potential for contamination.

For most of these types of characteristics, sampling is required that allows the long term average value for the characteristic of interest to be determined – i.e. the average nature of the material. In addition to understanding the average nature of the material, the resource recovery orders often contain a maximum value for some contaminants that should not be exceeded.

It is possible to design a sampling program that is sufficient to indicate the average nature of the material (and/or sufficient for estimating maximum values) to be reused/recycled. Such design is discussed in **Section 4.2**.

There are other aspects listed in some of the resource recovery orders/exemptions that indicate materials that are prohibited from being present in the materials being recycled/reused (e.g. asbestos containing materials). These requirements indicate more about how the process that is used to produce the resource recovery material is to be undertaken than the characteristics of the final product. It is assumed that these prohibitions are designed to indicate the types of materials that should be excluded up front by separating materials appropriately or that should be found and removed during the processing stage.

In these circumstances, it is more usual to put in place upstream management actions to ensure such materials cannot enter the waste stream rather than using sampling and analysis at the end of the process to show none is present. This concept is discussed in **Section 11** (i.e. critical control point type actions).

A sampling objective to demonstrate that there is zero amount of a material present in the final product is impossible.

All measurements have limits on what they can see; they all have a limit of reporting which depends on the type of analysis. In addition, the only way to demonstrate confidently that there is zero amount of a material present in the final product would be to analyse the entire amount of the material which, as discussed in **Section 4.2**, defeats the entire purpose of trying to recycle/reuse material.

It is only possible to design a sampling program that indicates that there is less than a certain amount of the material present – usually the amount is based on the limit of reporting (or a limit threshold).

4.2 Other aspects that impact on sampling objectives

Product specifications such as the Australian Standards for soil or soil amendments provide limits for parameters that indicate the material is suitable for the use including:

- pH
- electrical conductivity
- sodium
- phosphorus
- nitrogen
- organic carbon
- wettability
- particle size
- moisture content etc.

They also provide limits for a few potential contaminants including:

- heavy metals
- organochlorine pesticides
- physical contaminants like plastic or glass

These standards also indicate how these limits are to be applied. For AS 4454 – the Australian Standard for composts, mulches and soil conditioners – the limits for chemical contaminants are provided as upper limits meaning no sample is permitted to exceed the listed value.

The sampling objective for relevant materials is, therefore, to demonstrate compliance with these limits and these limits apply to any material to which the standard applies (new/virgin or recycled/reused). This means sampling/analysis is required for new/virgin materials to demonstrate such compliance. It is not known whether such sampling is undertaken for new/virgin materials or what the findings of such sampling are or where to find such results. A discussion of how this standard determines sampling rates is provided in **Section 6.2.2**.

Resource recovery orders/exemptions may include limits for additional contaminants which must also be complied with, but these only apply to recycled/reused materials. For resource recovery materials to be considered suitable for the purpose, they would need to comply with both sets of limits.

The resource recovery order/exemption for mulch does not include any additional limits that materials must comply with, so the Australian Standard requirements in AS 4454 are the ones that matter (NSW EPA 2016b). Sampling and analysis of mulch made from recycled/reused materials must be undertaken in line with the requirements of the Australian Standard (i.e. AS 4454). This level and type of sampling and analysis should also be undertaken for mulch made from new/virgin materials.

The resource recovery order/exemption for compost includes some additional limits (NSW EPA 2016a). Most of the limits listed in the order are for parameters already listed in the Australian Standard (AS 4454) and the limits are the same as those listed in the Australian Standard.

The differences between AS 4454 and the RRO/E for compost are:

- *Salmonella* spp. – the limit in the Australian Standard is “absent in 50 g dry weight basis” compared to “absent in 25 g dry weight” in the RRO/E
- *E. coli*. – an additional parameter that is not listed in AS 4454.

There is no information listed in the RRO/E regarding sampling rates for compost so it is assumed that the requirements of the Australian Standard must be followed. In both the Standard and the order, the limits are specified as maximum or upper limits meaning no individual sample can exceed the listed limit value.

4.3 Sampling design

To know exactly what the characteristics of some material are, strictly speaking, the whole amount of that material needs to be sampled and analysed. This is clearly not appropriate, relevant or possible for resource recovery materials as the destructive type analysis that is required means that it would all be used up by the analysis and not available for the particular use of interest which defeats the purpose.

The term *population* is used to refer to the whole amount of the material under investigation – the waste being processed for resource recovery, in this instance. The term *sample* is used to refer to the small amounts taken to assess the characteristics of interest of the material under investigation– i.e. portions of the population.

Statistical sampling techniques are, therefore, used to determine what will be a sufficient number of samples to adequately represent the characteristics of the population (i.e. estimate the characteristics of the material) under investigation. Measures such as the average value of a characteristic can be determined using such techniques. The precision of the estimate of the average will depend on the nature of the material and the strength of the design.

Different statistical approaches to designing sampling may be appropriate depending on the reason such sampling is being undertaken (i.e. sampling objectives).

For example, different approaches would be relevant if the purpose is to:

- demonstrate compliance with a regulatory value such as a licence limit (i.e. strong weight of evidence required)
- understand the average nature of the material to determine if fit for purpose (i.e. lesser weight of evidence required)
- demonstrate compliance with specification for the product (i.e. medium weight of evidence required)
- determine worst case or best case characteristics of the material (i.e. limited weight of evidence may be adequate – e.g. if a few samples indicate material is hazardous that may be sufficient)
- classify material for dangerous good classification etc (i.e. 1 sample may be sufficient if it indicates clearly the class in which the material will sit but many samples may be required to demonstrate that a material fits into a low hazard category).

Having some understanding of the variability of the characteristics of a material helps in the design of a sampling program. Also understanding the errors that occur in the measurement technique and/or in the sampling method helps in the design.

A classic example of the issues in sampling design is demonstrated by considering how to sample from a container containing white and black balls with the objective of the sampling being to assess the proportions of each type of ball. The idea is illustrated as follows:

To know exactly how many of each colour balls are present in the container, it would be necessary to take out each and every ball and record the colour. This can be done for this example as observing whether a ball is black or white is non-destructive. But as discussed above, this is not practical (or possible) for the situations of interest with resource recovery materials as the testing required is destructive.

On the other hand, if a single sample is taken from this container and the ball chosen is black, then you could say either:

- all the balls in the bag could be black as this is the characteristic of your single sample
- that you cannot determine the proportions of white and black balls in the bag but that there might be more black balls than white ones.

Statistical approaches can be used to determine how many of the balls you would need to take out of the container to get an estimate of the proportions.

If there are equal numbers of black and white balls in the container, then the number of samples required to get a good estimate of the proportions is likely to be smaller. If there are a small number of white balls compared to the number of black balls, then a higher number of samples will be needed to get a good estimate of the proportions.

The UK waste classification guidance provides a detailed appendix on the statistics of sampling as does the USEPA SW846 guidance (chapter 9) which includes how to use statistics to calculate the

number of samples required in a particular circumstance (UK Environment Agency 2021; USEPA 1986, 2002).

The reason (i.e. sampling objective) for sampling/analysis of resource recovery materials is to demonstrate compliance with the product specification. Such specifications include information in the NSW resource recovery orders/exemptions or Queensland end of waste codes (or similar) and specifications in the standards which indicate the characteristics of materials to be used for a purpose such as the Australian Standards or technical specifications for soil, mulch, fill etc.

Figure 4.1 illustrates how sampling results can be used to show compliance with a threshold/limit value or not with a level of confidence.

When multiple samples are taken from a stockpile, there will be multiple results and the mean/average and the confidence intervals can be determined if there are enough samples. Such results indicate that the material being assessed has a value for the characteristic of interest within the range indicated by the confidence intervals.

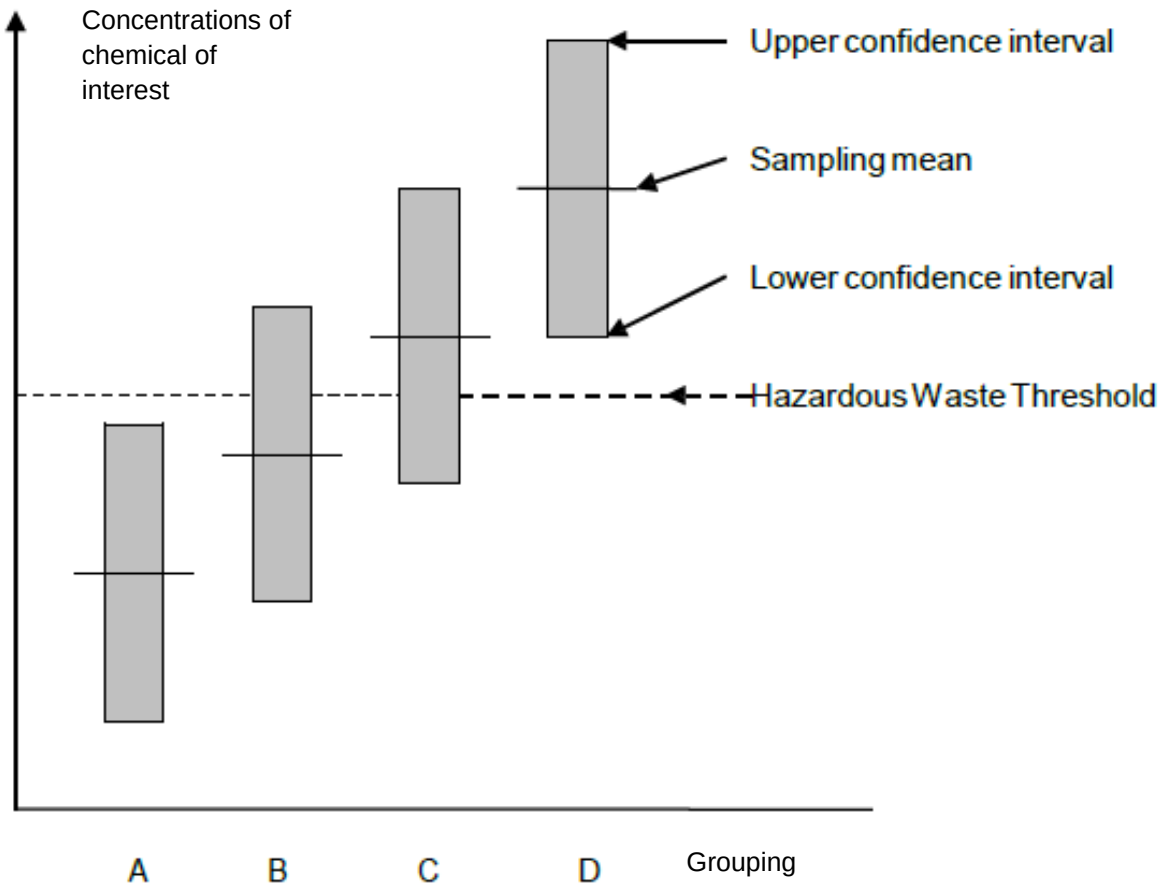

Figure 4.1: Statistical reliability of the sampling mean (UK Environment Agency 2021)

The threshold shown in **Figure 4.1** relates to whether a material of interest is hazardous waste, but the threshold can be the limit applied within a product specification for a resource recovery material – the concept is the same.

Group A and Group D (**Figure 4.1**) indicate situations where the material of interest is clearly in compliance or clearly not in compliance with the threshold to be applied:

- Group A has a mean/average value from the samples that have been collected and confidence intervals that are all below the threshold of interest, so this material is clearly in compliance.
- Group D has a mean/average value and confidence limits that are all above the threshold of interest so that material is clearly not in compliance.

In these situations, a minimum number of samples will be sufficient to determine compliance with limits in a product specification.

Group B and Group C (**Figure 4.1**) are situations where it is more difficult to determine compliance with the threshold of interest:

- Mean/average value for Group B is in compliance with the threshold of interest but the upper confidence limit is above the threshold so it cannot be stated with confidence that the material is in compliance.
- For Group C, the mean/average value is above the threshold, but the lower confidence limit is below the threshold, so it cannot be stated with confidence that the material is not in compliance.

In these situations, more samples should be taken. This will allow the confidence intervals to be recalculated and they may reduce in size which may then allow determination of compliance.

Figure 4.1 also demonstrates why it is difficult/impossible to demonstrate with confidence that a resource recovery material does not contain any of a particular contaminant that has prohibited from the material.

If the threshold is zero (however that is understood – less than the limit of reporting or actually zero), then it is not possible to show that a material complies.

- If zero is interpreted as less than the limit of reporting, then even if all samples have less than the limit of reporting for the relevant pollutant, the results still fall into Group B as you cannot show that the mean and both confidence limits are below the threshold (rather than equal too).
- If zero is interpreted as zero, it needs to be remembered that it is not actually possible to measure a concentration of zero – all methods for chemical and physical contaminants have a limit as to how low they can reliably measure.

The USEPA guidance (USEPA 2002) provides the following information regarding designing sampling programs.

- Concentrations of a contaminant will vary in the samples taken from a material of interest
- Understanding how those concentrations vary – i.e. their distribution – is what allows decisions to be made about compliance with a threshold/limit

- When there are a few samples of a material, a histogram of the results can be prepared as shown in **Figure 4.2** – i.e. bars showing the frequency at which a particular concentration was reported in the dataset.

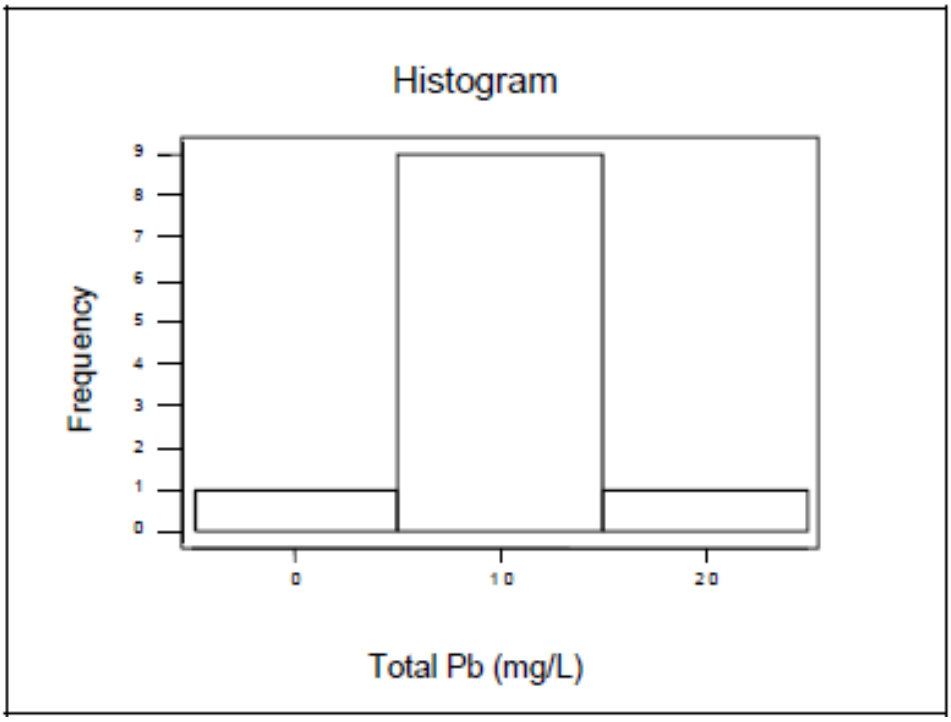

Figure 4.2: Histogram of results

- When more samples are available, the histogram can be smoothed out to give a curve – i.e. a distribution. Distributions can take many shapes. **Figure 4.3** shows 2 possibilities. The bars are smoothed out to give a flowing curve.

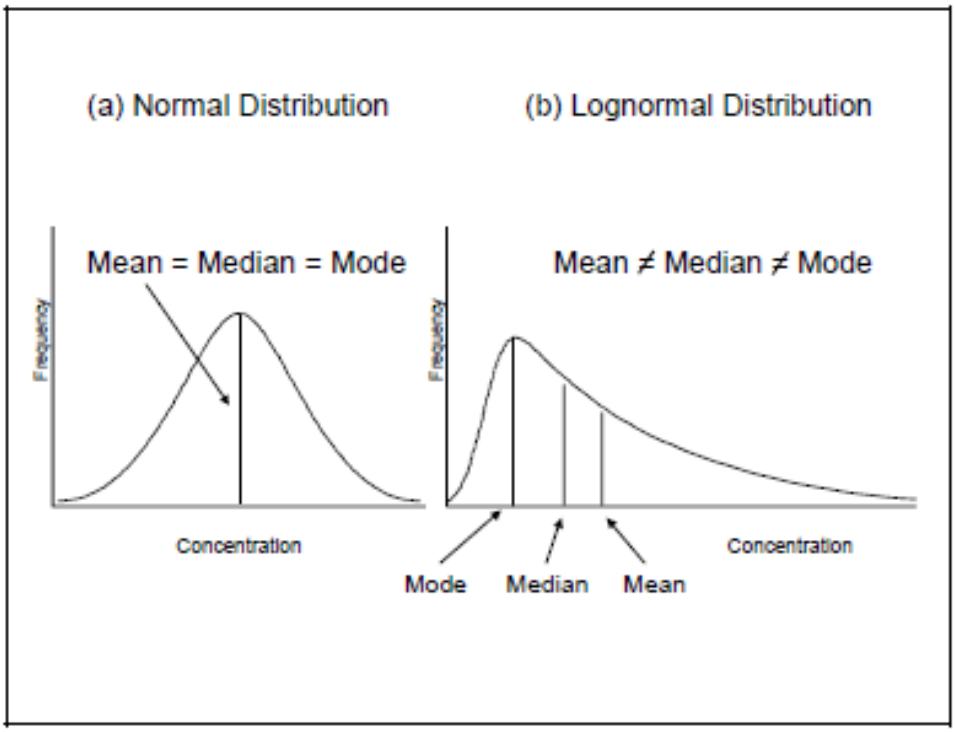

Figure 4.3: Examples of distributions

- Concentrations of chemicals in a material are often best described by a log normal distribution. This is because the limit of reporting (i.e. lowest level that can be reliably measured) gives a left limitation to the distribution. Other shapes are also possible.
- Often statistics assume a normal or near normal distribution for datasets. This assumption allows the statistical calculations to be simplified.
- If the results follow a distribution (or are expected too), then predictions can be made as to how many samples are needed to demonstrate that the results are below a limit with a specified level of confidence.
- Statistics like the mean/average or median (50^{th} percentile) give a measure of the central tendency of the dataset.
- Statistics like standard deviation give a measure of the variability of the results (USEPA 2002).

It is common practice to use the mean/average (or median) and some measure of variability to demonstrate compliance with a product specification (i.e. limit or threshold).

For contaminated land, the usual value is the 95% upper confidence limit of the mean or 95%UCL (USEPA 2002). This is shown in **Figure 4.4**.

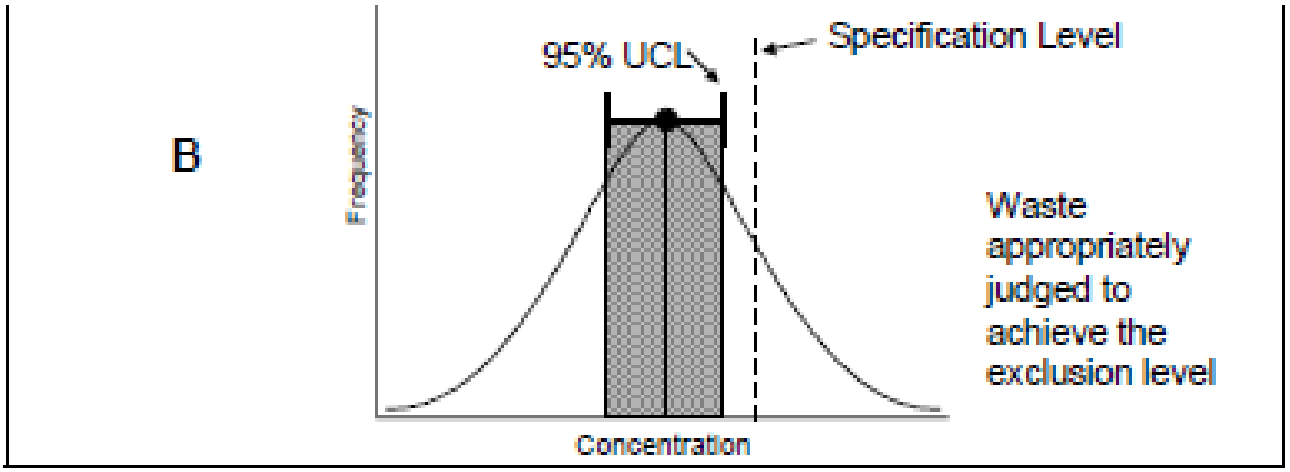

Figure 4.4: Illustration showing the 95% upper confidence limit of the mean (95%UCL)

Determining the true mean/average for a particular material type requires many samples to be taken – essentially would require the whole batch/lot of a material to be tested. Using a set of samples can allow an estimate of the central tendency and an estimate of the variability and these can be combined to allow the calculation of the 95%UCL. The USEPA have developed software to allow the calculation of the 95%UCL (i.e. ProUCL) (USEPA 2022).

Determining compliance with the product specification, then just requires demonstration that the 95%UCL is less than the relevant threshold.

The use of composite samples instead of discrete samples can help provide a more robust estimate of the mean or central tendency (USEPA 2002). Such an approach works well when analytical error is minor compared to sampling error. This is the case for most chemicals that could be of interest in resource recovery materials – where analytical methods are well established and well controlled. Sampling error relates to the variability in the material and this can be quite large in recovered materials so more subsamples combined together is a better way to estimate the mean/average for the material overall as shown in **Figure 4.5**.

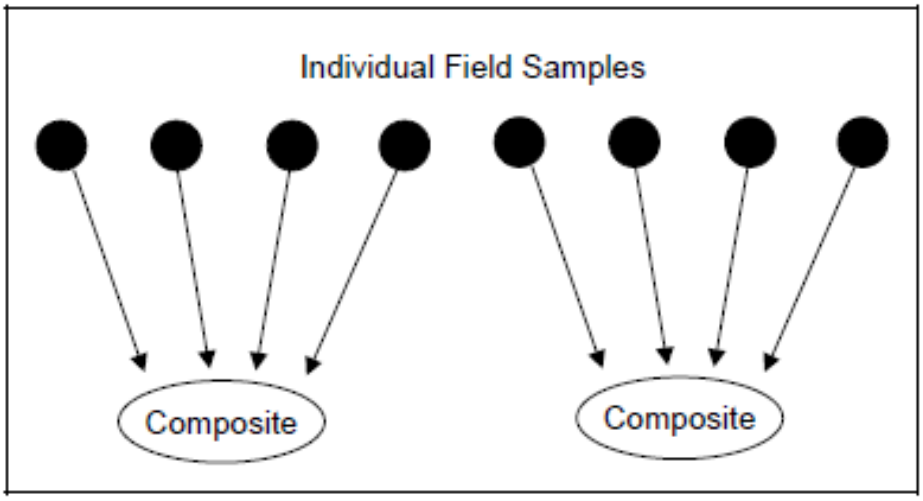

Figure 4.5: Comparison of composite and individual sample types

There are situations and contaminants where combining sub samples would not be appropriate and this is reflected in the product specifications such as the NSW resource recovery orders/exemptions. For example, where microbial quality is being assessed discrete samples will be more appropriate.

Composite sampling reduces the “between sample” variability as it mixes material together. This has the effect of flattening out the peaks and troughs that are measured in discrete samples and this can then reduce the total number of samples that need to be submitted to the laboratory.

Section 5.4 of the USEPA guidance provides details of how to calculate the appropriate number of samples to take for a given situation (USEPA 2002).

The UK guidance (UK Environment Agency 2021) provides the following methods for determining the appropriate number of samples required to allow the calculation of mean, standard deviation or 95%UCL for a particular material:

- Method A – mean and confidence limits – this method is the most obvious but does assume that the results for a particular waste fit a particular distribution such as a normal distribution (i.e. parametric statistics) which may not always be the case. This method requires some initial sampling to determine the standard deviation which is then used to calculate what the minimum number of samples would be to ensure the standard error and the mean/average combine to give a measurement less than the required limit.
- Method B – mean and confidence limits using non-parametric statistics – this approach uses the 50th percentile rather than the mean/average of the results and uses different statistics to calculate the confidence limits. It is appropriate when the nature of the material/likelihood of the contaminant present is not well understood. But the concepts are essentially the same as the first method.
- Method C – alternative non-parametric method similar to method B that is applicable when material has fairly consistent characteristics (i.e. could be described as homogeneous).
- Method D – method for application for on-site verification – refers to use of 99th percentile to demonstrate compliance with presence/absence requirements.

The details of these methods (including how to calculate the appropriate number of samples) are provided in Appendix D in this guidance (UK Environment Agency 2021).

The correct number of samples may be different for different specific situations which is why these guidance documents explain how to do these calculations rather than providing a table of sampling requirements (UK Environment Agency 2021; USEPA 2002).

It is noted that Australian Standards or NSW resource recovery orders/exemptions and other guidance materials often provide a minimum number of samples to be collected to demonstrate compliance with the product specification. This would be based on these concepts and some understanding of the nature of the resource recovery material from the initial application for an order/exemption.

Often sampling designs are not based solely on statistical assessments, as such assessments often result in a large number of samples being required. Sampling designs are more usually a combination of statistical considerations, policy determinations and practicalities (cost and time).

There needs to be a balance between the robustness of a finding and the practicalities of taking samples and analysing them in a timely manner.

Section 5. Sampling for asbestos containing materials

5.1 General

This section discusses the specifics about sampling that are included in Australian methods for analyse asbestos containing materials.

There appears to be much confusion between what is known as the “ASC NEPM method” / “WA method” and the “AS 4964 method” for the sampling and analysis of asbestos in soil (or other bulk materials).

The method adopted in the ASC NEPM is the method as described in the WA guidance – i.e. these methods are essentially the same. Any differences between the ASC NEPM method and the AS 4964 method are solely based on the amount of material sampled and sent to the laboratory for analysis.

All asbestos analysis is undertaken at the laboratories in accordance with AS 4964.

Laboratories report results as % by weight for ASC NEPM analysis but this reporting of concentrations isn’t part of AS 4964 and isn’t generally covered by NATA accreditation in relation to this method. Concentration results are often seen with an asterisk on laboratory certificates of analysis to confirm the calculated results are not covered by the NATA scope of accreditation.

The details of the analytical method used at the laboratory are discussed in **Section 8** of this report.

5.2 AS 4964 method

The reason that the ASC NEPM doesn’t just refer to the Australian Standard is because AS 4964 does not actually specify how much of a bulk material to sample from a stockpile (or other source).

This Australian Standard is entitled:

- Australian Standard (2004), Method for the qualitative identification of asbestos in bulk samples (Australian Standard 2004).

As indicated in the title, the method provides a process for identifying if asbestos fibres or asbestos containing materials are present or not in a bulk sample (i.e. qualitative not quantitative). It is not designed to allow concentration to be determined.

This method provides guidelines for sample sizes for building materials which may contain asbestos. These are usually described as homogeneous type materials as they are manufactured to a set specification. AS 4964 recommends a sample size of 5-100 g for building materials like asbestos cement sheet or fibre cement sheet. For floor tiles that may contain asbestos, a minimum of 100 cm^2 is recommended. Identification of the presence/absence of asbestos in these types of materials was the primary purpose of this method.

AS 4964 does also provide information on sampling non-homogeneous (i.e. heterogeneous) materials. For soils and ores, the method confirms the sample should be representative of the larger

bulk material as far as is practicable. "*Representative sampling of soil and ores is often very difficult to achieve because of the complexity and size of deposits*". The standard makes no recommendation for sample size or sampling rate for such materials – it just indicates that when sampling the person undertaking the sampling needs to justify that their sample size and sampling rate was sufficient for the purpose.

There is guidance within this method that indicates a soil sample of 30-60 g may be appropriate. However, this actually refers to the sample preparation phase where the material collected on a sieve is substantial and needs to be sub sampled to provide amounts that are more easily handled by an analyst to study under the microscope – all sub samples must still be assessed.

It is understood, however, that this amount of material (i.e. 30-60 g) has often been adopted as the normal recommended approach for sampling of bulk materials. This is a misunderstanding of the requirements of the method.

Guidance on applying AS 4964 to assessing mulch for the presence of asbestos has been recently published and is available at https://www.aioh.org.au/product/mulch-working-group/ .

5.3 ASC NEPM method

The ASC NEPM method for sampling for asbestos in soil is provided in the following documents:

- Schedule B1 of ASC NEPM (NEPC 1999 amended 2013)
- Guidelines for the Assessment, Remediation and Management of Asbestos Contaminated Sites in Western Australia (2021) (WA DOH 2021).

The method adopted in the ASC NEPM is the method as described in the WA guidance – i.e. these methods are essentially the same.

The method explains how to take samples and how much sample is required to assess soil that may contain asbestos containing materials. The ASC NEPM refers to AS 4964 to explain how the laboratory then does the analysis.

AS 4964 is the laboratory analysis method and the information in the ASC NEPM is a guideline for site investigation and sampling in relation to asbestos containing materials. The ASC NEPM also provides a calculation for estimating the quantity of asbestos in soil based on laboratory results.

The ASC NEPM guidance documents recommend that soil should be sampled using either targeted sampling or grid sampling:

- Targeted sampling requires knowledge of the historical activities at a site that might have resulted in contamination with asbestos containing materials and involves taking samples in the part of the site thought to be most likely to contain such materials.
- Grid sampling involves placing a grid across the site and taking a representative sample or samples in each grid square. WA DOH guidance refers to 4 m x 4 m grid while the ASC NEPM guidance refers to the use of up to a 10 m x 10 m grid.

Visual observations are also a useful part of site investigations when designing targeted or grid sampling.

Once the sampling design has been determined, surface sampling or sampling within the soil profile can be undertaken to look for bonded asbestos containing material as follows:

- Surface sampling involves observations of the surface in each grid area to look for pieces of bonded asbestos – i.e. emu-picking. If pieces of bonded asbestos are found at the surface or, if the conceptual site model indicates that bonded asbestos may be present, a 10 L sample of the soil (or resource recovery material) is to be collected for analysis.
- Sampling within the soil profile can be undertaken by digging a test pit. For test pits across a site, at least 1 x 10 L sample must be collected per 1 m depth in a test pit for each relevant part of the grid.

These 10 L samples are screened on-site – i.e. 10 L samples are not taken to the laboratory.

These large buckets of material are sieved in the field through a 7 mm sieve (or spread out on an appropriately coloured clean surface) to allow pieces of asbestos containing material to be found. All pieces collected on the sieve (or in the emu picking) are looked at to determine if they could be pieces of bonded asbestos. All pieces that could be bonded asbestos (or an appropriate subset if large numbers of pieces are found) are sent to the laboratory for analysis under a microscope to see if the bonded material does contain asbestos fibres or if it contains some other type of fibre.

If the conceptual site model for the site indicates that friable asbestos could occur at a site or if pieces of ACM are observed, then appropriate numbers of 500 mL samples of the bulk soil (or other bulk material when applied to resource recovery) are to be collected for detailed analysis at the laboratory. There is no need to collect 10 L field samples in this case. This is why understanding the conceptual site model is important prior to preparation of sampling and analysis plans and/or going to the site to actually collect the samples.

There has been some consideration of the use of 1 L samples instead of 500 mL samples for this bulk sampling part of a site investigation. Changing to this larger volume of material for samples to be sent to a laboratory is permitted within the updated WA DOH guidance (WA DOH 2021).

Section 4.10 of the ASC NEPM Schedule B1 provides information on laboratory analysis and the calculations for asbestos in soil concentration by gravimetric approach:

As outlined in enHealth (2005), the quantity of asbestos in soil may be estimated as follows:

$$\%\text{w/w asbestos in soil} = \%\text{ asbestos content x bonded ACM (kg) / soil volume (L) x soil density (kg/L)}$$

In the example included in enHealth (2005) it was assumed that:

> % asbestos content (within bonded ACM) = 15% and soil density (for sandy soils) = 1.65 kg/L

More representative results for asbestos concentration in soil can be calculated if the parameter values are analysed rather than assumed.

As per the ASC NEPM, "*As yet there is no validated method, readily available in Australia, of reliably estimating the concentration of free asbestos fibres in soil. Soil contamination by free asbestos fibres should, therefore, be simply determined according to the presence or absence of fibres, in accordance with AS 4964 – 2004: Method for the Qualitative identification of asbestos in bulk samples (Standards Australia 2004) by a laboratory accredited by NATA (or its mutual recognition agreement partners) for this method*".

Note: rather than reporting the presence / absence criteria, laboratories in Australia are currently reporting % by weight concentration. Further discussion of issues around reporting is provided in **Section 9**.

5.4 Other important aspects

There are some aspects of sampling and analysis for asbestos containing materials compared to analysis of a sample for a chemical contaminant that are important to understand. These relate to the difference between observing asbestos fibres and measuring amounts of a chemical present in a sample.

When measuring amounts of a chemical present in a sample using a particular detection method, the limit of reporting is primarily based on the characteristics of the detector. Detectors include devices such as mass spectrometers, photoionisation detector, electron capture detector, optical emission spectrometer, atomic emission spectrometer. Often the limit of reporting for these types of detectors relates to the electrical noise in a detector. Electrical noise can be controlled to an extent in the way the detector is manufactured and the shielding that is included. There is, however, a limit in what can be achieved. To be confident that a chemical is present in a sample, the response of the detector needs to be measurably different from the background electrical noise in the detector.

In addition to controlling electrical noise, another aspect that targets the limit of reporting is how much of the material is included in the extract that is analysed by the relevant detector.

When measuring asbestos containing materials, there is no specific detector other than the human eye. Any method for measuring asbestos fibres involves the use of a skilled analyst who looks at the sample in detail to find fibres and then determines if the fibres are asbestos fibres. There are many different types of fibres that can be present in a sample especially if it is a sample of soil or mulch or compost rather than a manufactured fibre cement board (for example). These fibres arise from moulds, vegetation, insects, microorganisms, a variety of minerals that form fibre shapes (i.e. not just asbestos minerals) and a variety of synthetic fibres like those from clothes (e.g. microfibre fabrics). Any analyst needs to have experience finding fibres in a sample and then needs to have experience determining if a fibre is actually an asbestos fibre.

This difference means this type of analysis is different/less robust/less repeatable than for chemicals where there is a specific type of detector that reacts similarly on every occasion it is used.

Different people have different skills/experience at:

- identifying fibres
- identifying whether a fibre is asbestos or something else

In addition, a person's abilities will differ from day to day depending on the workload, equipment, nature of the samples etc.

This means that demonstrating the likely absence of asbestos fibres in a sample is even more difficult than demonstrating a low level/likely absence of a chemical contaminant.

Section 6. Resource recovery sampling – Australia

6.1 General

This section discusses current Australian requirements for sampling of bulk materials and resource recovery materials, in general.

6.2 Sampling requirements for soils/bulk materials in NSW

NSW EPA provides guidance about sampling soils at a contaminated site (NSW EPA 2022). This guidance document also discusses sampling of stockpiles. This guidance document is particularly aimed at sampling of soil – whether in situ or in a stockpile – to allow comparison with national soil guidelines or to allow classification of the material as a waste for disposal.

For stockpiles, the guidance notes that the sampling strategy must consider that a stockpile is three dimensional so grid based sampling needs to consider all 3 dimensions.

This guidance provides minimum sample numbers for stockpiles based on guidance in the ASC NEPM and in WA guidance. **Table 6.1** shows these recommendations.

Table 6.1: Minimum number of samples for assessing stockpiles of up to 200 m^3

Stockpile volume (m^3)	Minimum number of samples recommended
<75	3
75-<100	4
100-<125	5
125-<150	6
150-<175	7
175-<200	8

For stockpiles larger than 200 m^3, the guidance recommends the following:

- Collect samples at a rate of 1 sample per 25 m^3

OR

- Samples can be collected at a reduced frequency, subject to a 95% UCL calculated for all applicable analytes, and this value is then compared with the relevant assessment criteria. This method is not appropriate for sampling stockpiles impacted, or potentially impacted, by asbestos.

Table 6.2 shows the numbers of samples required for different stockpile sizes based on both of these options.

Table 6.2: Guidance for assessing stockpiles bigger than 200 m^3

Stockpile volume (m^3)	Number of samples based on 1 per 25 m^3	Minimum number based on 95%UCL
200-300	12	10
400	16	10
500	20	10
600	24	10
700	28	10
800	32	10
900	36	10
1,000	40	10
1,500	60	10
2,000	80	10
2,500	100	10
3,000	120	12 (1 per 250 m^3)
4,000	160	16 (1 per 250 m^3)
4,500	180	18 (1 per 250 m^3)
5,000	200	20 (1 per 250 m^3)
>5,000	1 per 25 m^3	1 per 250 m^3

In relation to stockpiles that may be impacted by asbestos (as is relevant for this review), the guidance as set out in **Table 6.3** is provided.

Table 6.3: Guidance for assessing stockpiles that may contain asbestos

Purpose of sampling	Number of samples required	Other requirements
On-site reuse	Consider the sampling recommendations in **Table 6.2**	Stockpiles must be validated as fit for proposed land use at a site – i.e. must comply with relevant Health Investigation Levels as well as other matters under *Contaminated Land Management Act 1997* and relevant provisions of the POEO Act.
Off-site reuse	Refer to relevant resource recovery order/exemption to determine sampling requirements.	Only permissible if there is a relevant resource recovery order/exemption for the off-site location or if the material complies with the requirements for VENM. Otherwise, the material in such a stockpile (presumably soil) is a waste and must be disposed of lawfully.
Disposal to landfill	3 samples for stockpiles less than 75 m^3, plus 1 sample for every additional 75 m^3	Material must be classified as per Waste Classification guidance (NSW EPA 2014) and be taken to a landfill licenced to receive such material.
Transport to recycling facility	Consider the sampling recommendations in **Table 6.2**	Test each sampling location for: • non-friable asbestos using the ASC NEPM gravimetric procedure where the sample volume must be a minimum of 10 L per sample (i.e. the on-site section of the method) • asbestos fines/ fibrous asbestos ('AF/FA') where the sample collected must be a minimum of 500 mL (i.e. the volume of bulk sample that must be provided to the laboratory for testing. Comply with NSW EPA 2014, and if no asbestos is present, take to a recycling facility lawfully able to receive the waste for recycling. If a stockpile contains asbestos, it must not be recycled.

This guidance references EPA Victoria (2009) as the source of the sampling rate of 1 sample per 25 m^3 (EPA Victoria 2009). However, the specified EPA Victoria document does not include any information about the original source or basis for this sampling rate. It is possible the original source was Australian Standard AS 4482.1 but the current version does not include this information (Australian Standard 2005). The EPA Victoria (2009) guidance and the current updated draft of this guidance are discussed further in **Section 6.4.3**.

Other guidance available in NSW includes that from Transport for NSW – Environment Fact Sheet EFS-706 (waste sampling)[14]. This guidance applies to excavated natural materials (ENM) and recovered aggregates.

This fact sheet indicates that stockpile sampling must be undertaken in accordance with AS 1141 and that 10 composite samples must be taken for every 4,000 tonnes of material. Each composite sample is composed of 5 discreet sub samples of equal volume. The fact sheet includes information from ASTM D6009-19 in regard to how to take sub-samples from a stockpile appropriately – see **Section 7.2**. The sampling frequencies for stockpiles of less than 4,000 tonnes are listed in **Table 6.4**.

Table 6.4: Stockpile sampling frequencies – Transport for NSW fact sheet

Quantity (tonnes)	Number of samples required
<500	3 composites
500-1,000	4 composites
1,000-2,000	5 composites
3,000-4,000	7 composites
>4,000	10 composites

Table 6.5 provides sampling frequencies for in situ sampling as per Transport for NSW fact sheet (i.e. for materials that are not in a stockpile or even excavated from a particular location).

Table 6.5: Surface Sampling Points

Size of in situ area (m^2)	Number of sampling points	Minimum distance between 2 sampling points (m)
0-500	5	10
501-1,000	6	12.9
1,001-2,000	7	16.9
2,001-3,000	9	18.2
3,001-4,000	11	19.1
4,001-5,000	13	19.6
5,001-6,000	15	20
6,001-7,000	17	20.3
7,001-8,000	19	20.5
8,001-9,000	20	21.2
9,001-10,000	21	21.8
10,001-15,000	25	25
15,001-20,000	30	25.8
20,001-25,000	35	26.7
25,001-30,000	40	27.5

[14] https://www.transport.nsw.gov.au/operations/roads-and-waterways/environment-and-heritage/waste-and-resource-management

Size of in situ area (m^2)	Number of sampling points	Minimum distance between 2 sampling points (m)
30,001-35,000	45	27.9
35,001-40,000	50	28.3
40,001-45,000	52	29.3
45,001-50,000	55	30.2

6.3 Sampling requirements in relevant Australian Standards

6.3.1 General

Resource recovery materials must be shown to comply with the specifications relevant for the virgin material they are replacing.

For example, if they are to be used as soil then they must comply with the specification for soil or if to be used as fill then they must have the correct geotechnical characteristics etc.

A range of Australian Standards provide specifications for materials that may be relevant for resource recovery materials. These standards include a range of thresholds for various parameters along with sampling requirements to show a material complies with the thresholds. These standards provide the basic requirements. These standards may also be referred to in the additional requirements in Resource Recovery Orders/Exemptions (or equivalent in other jurisdictions).

The sampling requirements listed in these documents are discussed here for reference when reading the following sections discussing the regulation of resource recovery materials.

6.3.2 AS 4454

Australian Standard AS 4454 is the standard that sets the minimum requirements for composts, soil conditioners and mulches (Australian Standard 2012).

Sampling requirements specified in this standard include:

- Products shall be tested prior to distribution
- They shall be tested as soon as possible after receipt at a laboratory
- Due to variability in a stockpile or composting mass, samples must be composed of a series of subsamples that are then composited to produce the sample for the laboratory to analyse
- Subsamples are taken using a spade or trowel of appropriate size depending on particle size
- They must be taken from random positions in the stockpile – across the surface and within the depth of the pile
- Mix the stockpile/mass with a front end loader prior to sampling
- The size of the subsamples depends on the particle size of the compost/mulch:
    - Maximum particle size of 70 mm – 6 L subsamples should be collected
    - Maximum particle size of 50 mm – 4 L subsamples should be collected
    - Maximum particle size of 20 mm – 2.5 L subsamples should be collected
    - Maximum particle size of 10 mm – 1.25 L subsamples should be collected
    - Maximum particle size of 5 mm – 0.6 L subsamples should be collected
- The number of subsamples required for a particular volume of material is as follows:
    - <575 m^3 – 12 subsamples

  - 1,000 m^3 – 16 subsamples
  - 2,000 m^3 – 23 subsamples
  - 3,000 m^3 – 28 subsamples
  - >3,600 m^3 – 30 subsamples
- Once the subsamples have been collected, they need to be tipped onto a flat area of clean concrete/plastic/tarpaulin to allow mixing of all of the subsamples.
- Once mixed thoroughly, a sample of appropriate size for the laboratory to undertake all relevant analyses should be collected into the sample containers supplied by the laboratory.
- Appropriate sample size for the laboratory depends on the particle size and is as follows:
  - Maximum size of 70 mm – 25 L should be provided to the laboratory
  - Maximum size of 50 mm – 20 L should be provided to the laboratory
  - Maximum size of 20 mm – 15 L should be provided to the laboratory
  - Maximum size of 10 mm – 10 L should be provided to the laboratory.

This standard also includes product specification criteria for composts, soil conditioners and mulches. The product specification does not include any criteria in relation to asbestos containing materials.

There is no information about how many full samples are required to demonstrate that a certain volume of material is in compliance with the product specification criteria.

One way of interpreting the information in the standard is that a stockpile of 3,000 m^3 could be represented by a single full sample provided to the laboratory. This single sample would need to be made up by thorough mixing of 28 subsamples (each sub sample needs to be 0.6 L to 6 L depending on the particle size). This may not be the intention.

6.3.3 AS 4419

Australian Standard AS 4419 is the standard that sets the minimum requirements for soils for landscaping and garden use (Australian Standard 2018).

The appendix in this standard detailing the requirements for sampling is the same as that discussed above for AS 4454 so the same requirements for sampling are relevant.

This standard also includes product specification criteria for different types of soil but these criteria are focused on bulk density, nutrients, minerals and moisture related parameters. The product specification does not include any criteria in relation to asbestos containing materials.

6.3.4 AS 1141.3.1

Australian Standard 1141.3.1 is the standard that sets the minimum requirements for Sampling and Testing Aggregates (Australian Standard 2021).

The method defines aggregates as aggregate and rock products with a nominal size of 63 mm or less. The standard also notes that it can be applied to non-stabilised soil products or soil/rock blends provided particle size is less than 75 mm.

This standard explains in detail how to take samples from bulk materials like aggregates and includes figures showing equipment and how to use it. The standard does not explain how many

samples are required to assess material per volume or mass but does indicate how much mass should be collected per subsample which then gets composited into a combined sample for the laboratory to analyse and the mass that should be provided to the laboratory. The sampling rate based on volume or mass of bulk material is specified in other documents/guidance materials.

Sampling requirements include:

- Samples may be collected from a stockpile, a bin, a conveyor belt, a vehicle or roadbed/earthworks
- Sampling is designed to allow an understanding of the average properties of the material being investigated
- The size of the subsamples depends on the particle size of the aggregate:
    - Maximum particle size of 75 mm – 10 kg subsamples should be collected
    - Maximum particle size of 40 mm – 6 kg subsamples should be collected
    - Maximum particle size of 28 mm – 5 kg subsamples should be collected
    - Maximum particle size of 20 mm – 4 kg subsamples should be collected
    - Maximum particle size of 14 mm – 3 kg subsamples should be collected
    - Maximum particle size of 10 mm – 2 kg subsamples should be collected
    - Maximum particle size of 7 mm – 2 kg subsamples should be collected
    - Maximum particle size of 5 mm – 1 kg subsamples should be collected
    - Maximum particle size of <5 mm – 1 kg subsamples should be collected
- This is based on a bulk density of the aggregate material in the range 2,100 to 3,200 kg/m^3 and should be adjusted if a material has a substantially different bulk density
- Each sample should consist of at least 5 subsamples of approximately equal mass
- All subsamples should be mixed together thoroughly to generate the sample for laboratory analysis.
- The minimum mass of the sample for laboratory analysis is as follows:
    - Maximum particle size of 75 mm – 50 kg sample should be provided to the laboratory
    - Maximum particle size of 40 mm – 30 kg sample should be provided to the laboratory
    - Maximum particle size of 28 mm – 25 kg sample should be provided to the laboratory
    - Maximum particle size of 20 mm – 20 kg sample should be provided to the laboratory
    - Maximum particle size of 14 mm – 15 kg sample should be provided to the laboratory
    - Maximum particle size of 10 mm – 10 kg sample should be provided to the laboratory
    - Maximum particle size of 7 mm – 10 kg sample should be provided to the laboratory
    - Maximum particle size of 5 mm – 5 kg sample should be provided to the laboratory
    - Maximum particle size of <5 mm – 5 kg sample should be provided to the laboratory
- This standard has instructions for sampling from a stockpile, a bin, a conveyor belt, a vehicle or roadbed/earthworks including figures showing different types of sampling equipment.

This standard does not include product specification criteria for aggregates including no information on criteria in relation to asbestos containing materials.

6.4 Sampling requirements - resource recovery materials

6.4.1 NSW

There are a number of resource recovery orders and exemptions published by NSW EPA.

Sampling requirements to demonstrate that material complies with the order/exemption are listed within many of the orders. These sampling requirements are to demonstrate compliance of the material with maximum average concentration limits and absolute maximum concentration limits. They make use of composite samples (wherever appropriate) and specify a minimum number of samples to characterise a waste.

It is assumed determining what the minimum sample number in the order has been based on some consideration of average (or maximum) concentrations and the variability in concentrations for contaminants that may be documented in the initial application for such an order. However, no information has been provided in the resource recovery orders/exemptions.

Supporting documentation about how to make an application for a resource recovery order/exemption is provided in:

- NSW EPA (2017) Guidelines on resource recovery Orders and Exemptions. For the land application of waste materials as a fertiliser or soil amendment[15].
- NSW EPA (2017) Guidelines on resource recovery Orders and Exemptions. For the land application of waste materials as fill[16].

Both documents require that the material of interest is sampled prior to applying for an order/exemption to characterise the material. A minimum of 20 composite samples must be taken and analysed. Where a contaminant of interest is a volatile chemical or semi-volatile contaminant then discrete samples (i.e. individual not mixed samples) are required. Also, if sampling is being undertaken while the material is in situ (i.e. before it is excavated), then discrete samples are also required. It is not specified in these documents but is presumed that in this case a minimum of 20 discrete samples would be required.

No information is provided in these guidance documents about how the NSW EPA takes the information provided to determine the routine sampling requirements that are placed in the actual order/exemption. It is presumed that the information provided in the application is used as the basis for that determination – information such as minimum, maximum, average, standard deviation.

The sorts of potential contaminants that are covered by the various types of limits in the resource recovery orders are listed in **Table 6.6**. The list includes all those parameters listed in at least 1 order.

[15] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework/apply-for-an-order-and-exemption
[16] https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework/apply-for-an-order-and-exemption

Table 6.6: Parameters listed in 1 or more NSW EPA Resource Recovery Orders

metals/metalloids	% sulfur	*E. coli*
pH	*Salmonella* spp.	*Clostridium perfringens*
electrical conductivity	*Bacillus cereus*	ethylbenzene
combustible content	toluene	total petroleum hydrocarbons,
faecal coliforms	polycyclic aromatic hydrocarbons	gypsum (calcium sulfate)
benzene	total chlorine	organochlorine pesticides
xylenes	chlorinated hydrocarbons	leachable concentrations of various metals
fluoride	particle size characteristics	moisture content
total organic carbon	total nitrogen	sodium
PCBs	oil and grease	
presence of physical contaminants (like rubber, wood, paint, vegetable matter, plastic, glass, metal, plaster, clay lumps, asphalt, ceramics, slag, bitumen etc)		

The orders specify the following definitions/terminology:

- a composite sample must be a mix of 5 sub samples of equal size – guidance in the relevant Australian Standards note that the sub samples should be taken in an appropriate manner such as with a randomised or grid approach across the batch, truckload or stockpile or coning/quartering methodologies – i.e. can't just take 5 buckets from the same part of a stockpile.
- definition of a continuous process is a process that processes material on an ongoing basis. Clearly this is open to interpretation. It could indicate a process that is undertaken once a week or once a month every week or month into the future or it could indicate a process that happens all day every day.
- each composite sample must be taken from a batch, a truckload or a stockpile that has not been previously sampled but there is no indication in the orders of the size of a batch, a truckload or a stockpile that could be considered appropriate to be represented by a single composite sample.

The sampling requirements for each of the current approved orders/exemptions (apart from those for liquids and for biosolids, some food wastes and manure) are listed in **Table 6.7**.

Table 6.7: Summary of sampling requirements in NSW RRO/Es

Material of interest	Initial sampling	Routine sampling	Routine sampling – not continuous	Comments
Acetylene gas lime slurry	initial characterisation requires 20 composite samples and this level of sampling must be repeated every 2 years	routine sampling requires 5 composite samples and this level of sampling must be undertaken every 6 months	NA	NA
Ash from burning biomass	initial characterisation requires 20 composite samples and this level of sampling must be repeated every 2 years	routine sampling requires 5 composite samples from every 1,000 tonnes of ash processed or 5 composite samples each year (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 1,000 tonnes is required.	presumably it is considered that batch processes may be more variable than continuous processes
Basalt fines	initial characterisation requires 20 composite samples and this level of sampling must be	routine sampling requires 5 composite samples from every 10,000 tonnes of	where processing is not a continuous process, sampling of 10 composite	presumably it is considered that batch processes may be more variable than

Material of interest	Initial sampling	Routine sampling	Routine sampling – not continuous	Comments
	repeated every 2 years	basalt fines processed or 5 composite samples every 3 months (whichever is lesser)	samples per 4,000 tonnes is required	continuous processes.
Bulk agricultural crop waste	No sampling is required	NA	NA	NA
Fibre cement sheet (i.e. made with fibres other than asbestos – definition is for material comprising sand, cement and cellulose)	initial characterisation requires 20 composite samples and this level of sampling must be repeated every 2 years	routine sampling requires 5 composite samples from every 10,000 tonnes of cement fibre board waste processed or 5 composite samples every 3 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required – presumably it is considered that batch processes may be more variable than continuous processes.	NA
Coal ash	Where such material is used as a soil amendment • < 1,000 tonnes of coal ash is generated per year, collection of 3 composite samples per year is required • >1,000 tonnes of coal ash is generated per year, collection of 3 composite samples per year is required as well as an additional composite sample for every additional 1,000 tonnes (or part thereof)	Where such material is used as an engineering material (fill) and produced using a continuous process then: • initial characterisation requires 20 composite samples and this level of sampling must be repeated every 2 years • routine sampling requires 5 composite samples from every 10,000 tonnes of coal ash processed or 5 composite samples every 3 months (whichever is lesser)	Where such material is used as an engineering material (fill) and not produced using a continuous process, 10 composite samples per 4,000 tonnes is required.	NA
Coal washery rejects	initial characterisation requires 20 composite samples and this level of sampling must be repeated every 2 years (continuous process)	routine sampling requires 5 composite samples from every 10,000 tonnes of coal washery rejects processed or 5 composite samples every 6 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required	presumably it is considered that batch processes may be more variable than continuous processes.
Compost	No specific guidance is provided about the minimum levels of sampling required to demonstrate compliance with the order	NA	NA	Order just notes that a sampling plan must be prepared and the processor is required to ensure that the absolute maximum concentration limit (or other) is not exceeded

Material of interest	Initial sampling	Routine sampling	Routine sampling – not continuous	Comments
Excavated natural material	Sample in accordance with Table 1 in the document for all other relevant parameters – i.e. 3 samples for <500 tonnes, 4 samples for 500-1,000 tonnes, 5 samples for 1,000-2,000 tonnes, 7 samples for 2,000-3,000 tonnes, 10 samples for 3,000-4,000 tonnes	NA	NA	Sampling to determine if the material is acid sulfate soils as per acid sulfate soil manual Composite samples and discrete samples are required – composite samples are used for most parameters (metals, pH, conductivity and presence of physical contaminants) but discrete samples (i.e. individual sample from a stockpile analysed by the laboratory) are required for organic chemicals including benzene, toluene, ethylbenzene, xylenes, polycyclic aromatic hydrocarbons and total petroleum hydrocarbons.
Excavated public road material (material generated/used during construction and maintenance of public roads)	No sampling is required	NA	NA	It is noted that the material cannot contain coal tar, asbestos, or any hazardous waste, restricted solid waste, special waste or liquid waste. But there is no guidance on how this is to be demonstrated.
Food waste (solid)	No sampling is required	NA	NA	It is noted that the material cannot contain post consumer food waste, grease trap waste, animal waste, liquid waste and may not be corrosive or have any physical contaminants such as glass, metal, rigid plastics, flexible plastics or polystyrene. But there is no guidance on how this is to be demonstrated
Foundry sand	initial characterisation requires 20 composite samples and this level	routine sampling requires 5 composite samples from every	where processing is not a continuous process, sampling of	NA

Material of interest	Initial sampling	Routine sampling	Routine sampling – not continuous	Comments
	of sampling must be repeated every year	1,000 tonnes of foundry sand processed or 5 composite samples every month (whichever is lesser)	10 composite samples per 1,000 tonnes is required	
Gin trash	No sampling is required	NA	NA	Cotton Australia is required to check potential for residues in new types of cotton plants prior to processing and supplying gin trash for reuse. Presumably this is to address use of genetically modified plants or changes in pesticide regime used on cotton.
Mulch	No sampling is required	NA	NA	The material must not contain asbestos, engineered wood products, preservative treated or coated wood residues, or physical contaminants, including but not limited to glass, metal, rigid plastics, flexible plastics, or polystyrene. There is no guidance on how this is to be demonstrated.
Pasteurised garden organics	No specific guidance is provided about the minimum levels of sampling required to demonstrate compliance with the order	NA	NA	Order just notes that a sampling plan must be prepared and the processor is required to ensure that the absolute maximum concentration limit (or other) is not exceeded. Order also notes that the material must not contain asbestos, engineered wood products, preservative treated or coated wood residues but there is no guidance on how this is to be demonstrated.
Recovered plasterboard	initial characterisation requires 20 composite samples and this level of sampling must be	routine sampling requires 5 composite samples from every 10,000 tonnes of	where processing is not a continuous process, sampling of 10 composite	NA

Material of interest	Initial sampling	Routine sampling	Routine sampling – not continuous	Comments
	repeated every 2 years	plasterboard waste processed or 5 composite samples every 6 months (whichever is lesser)	samples per 4,000 tonnes is required	
Closed loop rapidly decomposed food waste	characterisation requires 10 composite samples from separate batches of processed waste within 12 months of commencement	Up to 2 composite samples per month must be collected after that	NA	The material must not contain animal waste, grease trap waste or physical contaminants, including but not limited to glass, metal, rigid plastics, flexible plastics, or polystyrene but there is no guidance on how this is to be demonstrated
Reclaimed asphalt pavement	No sampling is required but documented procedures are required to show how the potential to receive material that could contain asbestos or coal tar is minimised.	NA	NA	The material must not contain coal tar or asbestos but there is no guidance on how this is to be demonstrated other than via the documented procedures developed by the recycler.
Recovered aggregate (materials like concrete, brick, ceramics, natural rock and asphalt that can be processed into an engineered material)	initial characterisation requires 20 composite samples and this level of sampling must be repeated every year	routine sampling requires 5 composite samples from every 4,000 tonnes of recovered aggregate waste processed or 5 composite samples every 3 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required	NA
Recovered fines (continuous)	initial characterisation requires 1 composite sample per fortnight	routine sampling requires 1 composite sample per week	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required	NA
Recovered fines (batch)	initial characterisation requires 10 composite samples per 400 tonnes	it is not clear whether any routine sampling is required	NA	NA
Recovered glass sand	initial characterisation requires 20 composite samples – where inputs change this sampling must be repeated and it must be repeated every 2 years	routine sampling requires 5 composite samples per 4,000 tonnes or 5 composite samples every 3 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required	NA
Recovered railway ballast	initial characterisation requires 20 composite samples and it must be repeated every 2 years	routine sampling requires 5 composite samples per 4,000 tonnes or 5 composite samples every 3	where processing is not a continuous process, sampling of 10 composite	NA

Material of interest	Initial sampling	Routine sampling	Routine sampling – not continuous	Comments
		months (whichever is lesser)	samples per 4,000 tonnes is required	
Blast furnace slag	initial characterisation requires 20 composite samples and it must be repeated every 2 years	routine sampling requires 5 composite samples per 10,000 tonnes or 5 composite samples every 6 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required (one-off sampling of a batch, truckload or stockpile)	NA
Electric arc furnace slag	initial characterisation requires 20 composite samples and it must be repeated every year	routine sampling requires 5 composite samples per 2,000 tonnes or 5 composite samples every 3 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 2,000 tonnes is required (one-off sampling of a batch, truckload or stockpile)	NA
Processed electric arc furnace ladle slag	initial characterisation requires 20 composite samples and it must be repeated every year	routine sampling requires 5 composite samples per 2,000 tonnes or 5 composite samples every 3 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 2,000 tonnes is required (one-off sampling of a batch, truckload or stockpile)	NA
Processed electric arc welding slag	NA	where processing is via a continuous process, routine sampling of 5 composite samples per 20 tonnes is required	where processing is not a continuous process, sampling of 10 composite samples for every batch is required (one-off sampling of a batch, truckload or stockpile)	NA
Steel furnace slag	initial characterisation requires 20 composite samples and it must be repeated every 2 years	routine sampling requires 5 composite samples per 10,000 tonnes or 5 composite samples every 6 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required (one-off sampling of a batch, truckload or stockpile)	NA
Treated drilling mud	NA	where processing is via a continuous process, routine sampling of 10 composite samples per 100 tonnes is required	where processing is not a continuous process, sampling of 10 composite samples for every batch is required (one-off sampling of a batch, truckload or stockpile)	NA
Treated grease trap waste	NA	Routine sampling 1 individual sample (discrete) per day for 1 week to generate 1 composite sample.	NA	Where only small volumes are received, 1 composite sample per truckload should be collected.

Material of interest	Initial sampling	Routine sampling	Routine sampling – not continuous	Comments
		This is repeated each week (i.e. 4 composite samples per month). Plus an additional 5 individual samples per month combined into 1 composite sample. In total, 5 composite samples per month.		
Recovered tyres	initial characterisation requires 20 composite samples and it must be repeated every 2 years	routine sampling requires 5 composite samples per 4,000 tonnes or 5 composite samples every 6 months (whichever is lesser)	where processing is not a continuous process, sampling of 10 composite samples per 4,000 tonnes is required (one-off sampling of a batch, truckload or stockpile)	NA

These requirements generally indicate the following:

- 20 composite samples of a particular waste material appear to be sufficient to provide an initial characterisation of a type of waste to show it is likely to comply with the various limits specified in the order – it is presumed that the goal of this initial characterisation sampling is to show the material currently being received/processed is similar to the material as documented in the application for a resource recovery order provided to NSW EPA. This does not assist in demonstrating that prohibited materials are not present.
- To demonstrate actual compliance through time with the legal limits specified in the order, routine sampling is required – i.e. a certain number of samples per amount of resource material or per a specified period of time. In the listed RROs/Es this ranges from a few composite samples per 20 tonnes to a few composite samples per 10,000 tonnes or a few samples per month to a few samples per year depending on the type of resource recovery material.
- The large range in tonnage across all these orders is presumably because the different material types and processing operations result in a more variable or a less variable product. For those that are less variable/more consistent, the same number of samples can be representative for a large amount of the resource, while for more variable/less consistent resources, the same number of samples needs to be applied to a smaller amount to give the same level of confidence regarding compliance with limits in the orders.
- Composite samples are required for this type of sampling. Composite samples give a better indication of the average nature of the material rather than the spikes and troughs that could occur in discrete samples. This is appropriate when addressing this type of situation. There are some types of contaminants which require discrete/individual samples to be taken rather than composite ones.

Some but not all of the orders include a requirement that the resource/waste material is prohibited from containing certain types of materials (e.g. asbestos containing materials, coal tar or physical contaminants like glass or plastic). There is no guidance provided in the orders as to how to

demonstrate that a processor has complied with this requirement. There is also no information about the point in the process where this prohibition must be shown to be complied with. It is assumed that this is a requirement for the final product.

6.4.2 Queensland

In Queensland, end of waste codes have been developed. Such codes are provided to show when a waste material can be considered as a resource rather than a waste. They include limits and other requirements to show the material is fit for the purpose as well as the purposes for which the material can be used. The goal of the codes is to show the material has demonstrated benefits through sustainable reuse and poses negligible environmental risks. These codes are similar to the resource recovery orders/exemptions in NSW.

The sampling requirements within these end of waste codes are summarised in **Table 6.8**.

Table 6.8: Summary of sampling requirements – end of waste codes

Material of interest	Sampling requirements	Comment
ACQ treated timber shavings	Sampling as per Appendix A, Australian Standard 4454 is required (i.e. 12-30 subsamples of similar size depending on the size of a stockpile (i.e. per batch) which are then combined into a single sample for analysis – this composite sample is then sub sampled to provide a sample size suitable for delivery to the laboratory)	NA
Amorphous silica powder	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion
Blast furnace slag	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion
Carbide lime	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion
Chemically treated solid timber	No sampling is required	NA
Coal combustion products	Sampling every 6 months for 3 years (assuming mean and standard deviation are not significantly different) and then annually If the ash comes from a coal fired power station that might also combust biosolids or biomass, then sampling every 6 months will be required on an ongoing basis	No guidance is provided about how to take the samples or how many samples are required on each occasion (i.e. 1 sample per 6 months etc), however, the requirements specify that the material is to be manufactured to meet the requirements of AS 4454 or AS 4419 so sampling requirements specified in those documents would be relevant.
Coal seam gas drilling mud	For initial characterisation, sampling as per EPA Victoria's Industrial Waste Resource Guideline (i.e. IWRG 702) is required	If inputs are fairly consistent, then repeat this characterisation once per year If inputs may change, then additional sampling will be required – requirements from AS 4454 or 4419 would be relevant
Returned concrete	No sampling is required	NA
Concrete (solid washout)	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion

Material of interest	Sampling requirements	Comment
Ferronickel slag	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion
Fibre cement board	Sample to allow demonstration of compliance with product specifications at least quarterly Sampling of process dust is also required on a quarterly basis (for respirable crystalline silica only)	No guidance is provided about how to take the samples or how many samples are required per sampling occasion
Foundry sand	If inputs are fairly consistent, then sampling to demonstrate compliance with limits is required once per year. If inputs may change or are inconsistent, then sampling quarterly is required until there is at least 12 months worth of data demonstrating compliance with the limits.	Requirements specify that the material is to be manufactured to meet the requirements of AS 4454 or AS 4419 so sampling requirements specified in those documents would be relevant (i.e. in regard to how to take the samples and how many samples to take)
Garnet sand	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion
Glass fines	Routine sampling requires 5 composite samples per 4,000 tonnes or 5 composite samples every 3 months (whichever is lesser)	NA
Plasterboard	No sampling is required	NA
Recycled aggregates	No sampling is required	NA
Silica fume	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion
Sugar refinery clarifier sludge	Sample to allow analysis for nutrients at least once per year	Material should comply with requirements for fertilisers in Biosecurity Regulation 2016 but no requirement to sample to demonstrate.
Sugar mill by-products	Sample to allow demonstration of compliance with product specifications at least once per year. Sampling as per EPA Victoria's Industrial Waste Resource Guideline (i.e. IWRG 702) is required.	Additional monitoring may be required if the composition of the material has changed or is likely to
End of life tyres	No sampling is required	NA
Water treatment residuals	Sample to allow demonstration of compliance with product specifications at least once per year	No guidance is provided about how to take the samples or how many samples are required per sampling occasion. Requirements specify that the material is to be manufactured to meet the requirements of AS 4454 or AS 4419 so sampling requirements specified in those documents would be relevant (i.e. in regard to how to take the samples and how many samples to take).

6.4.3 Victoria

Victoria does not have a regulatory scheme like the resource recovery orders/exemptions in NSW or the end of waste codes in Queensland as yet.

EPA Victoria Publication No. 1756.2 (i.e. summary of waste framework) provides information about the possibility of declaration of use agreements or DoUs. This appears to be the regulatory system in place in Victoria to allow resource recovery of materials where appropriate.

A DoU is an agreement between a producer and a receiver as to how a specific industrial waste may be used. Such agreements are supposed to describe the waste, assess the risks that may be relevant and identify legitimate uses of such a waste based on that understanding of risks. These agreements are required to be renewed each year. EPA Victoria can apply additional conditions or cancel such agreements. The system provides for 2 types of DoU – those that EPA Victoria authorises and industry based DoUs for materials that pose a low risk which do not need EPA Victoria authorisation.

Further information about such agreements is provided at https://www.epa.vic.gov.au/for-business/waste/declaration-of-use . These agreements are initiated by industry.

The following information from this website is most relevant.

A DoU can be made for:

- immediate use of:
  - waste for resource recovery
  - waste other than soil for use as a substitute for an input or raw material in a commercial, industrial, trade or laboratory activity
- application of the following wastes to land:
  - commercial garden and landscaping organics that do not contain any physical or chemical contamination
  - untreated timber, including sawdust
  - natural organic fibrous waste.

As per the Environment Protection Act 2017, resource recovery in relation to waste, means:

- preparation for reuse of the waste
- recycling the waste
- reprocessing the waste
- recovering energy or other resources from the waste

There is a form to fill in that shows how to apply for a DoU. This form does not include any information about sampling and analysis requirements likely to be relevant in such situations. The form notes that the waste must be appropriately described and risks must be adequately assessed using the guidance in EPA Victoria Publication No. 1695.1. This guidance document does not contain information on the sorts of sampling and analysis of waste would be relevant for assessing risk or ensuing compliance with a product specification rather it explains how to assess risk using a risk matrix/qualitative approach.

DoUs are not permitted to be applied to wastes that are reportable priority wastes which may mean that many waste types that are considered for resource recovery in other states are not permitted for reuse in Victoria. EPA Victoria Publication 1967.2 provides a listing of all reportable priority wastes.

It is noted that there is another approach related to resource recovery in Victoria - the use of A16 permits. These provide a way of using reportable priority wastes for resource recovery uses where such uses could be considered to be safe and legitimate.

Information on this process is provided at https://www.epa.vic.gov.au/for-business/permissions/permits/how-to-apply-for-an-a16-permission-to-supply-or-use-reportable-priority-waste . Information to document the potential risks posed by such uses must be supplied to EPA Victoria and consider risks to human health and the environment using the guidance document EPA Victoria Publication No. 1695.1 which explains how to use a risk matrix qualitative approach to assessing potential risks. Again, industry must initiate the application for such a permit.

EPA Victoria guidance that may be relevant to understand what sampling requirements may be relevant for waste material proposed for reuse include the following:

- Industrial waste resource guidelines – sampling and analysis of waters, wastewaters, soils and wastes (2009) (IWRG701) (https://www.epa.vic.gov.au/about-epa/publications/iwrg701)
- Industrial waste resource guidelines – soil sampling (2009) (IWRG702) (https://www.epa.vic.gov.au/about-epa/publications/iwrg702)
- Soil sampling for waste soil – draft (IWRG702.2) (https://www.epa.vic.gov.au/about-epa/publications/iwrg702)
- Guide to classifying industrial waste (2021) (EPA Victoria Publication No. 1968.1)
- Waste classification assessment protocol (2021) (EPA Victoria Publication No. 1827.2)

Sampling requirements outlined in these documents include the following:

- IWRG701 provides general advice about how to design sampling programs but does not provide specific information about how many samples to collect to represent a particular waste material
- IWRG702 (2009) provides guidance about soil sampling requirements similar to the general soil sampling requirements of NSW EPA (see **Tables 6.1** and **6.2**). As outlined in the NSW guidance, sampling rates can be reduced if the 95%UCL for the material is compared to the limit/threshold rather than the average value.
- IWRG702.2 (currently draft) is an update of the 2009 guidance. For volumes of soil less than 5,000 m^3, it is recommended that at least 10 samples be collected (a minimum of 3 samples for <250 m^3) or the material should be sampled at a rate of 1 sample per 250 m^3. For volumes of soil greater than 5,000 m^3, a rate of 1 sample per 250 m^3 is also recommended but other statistical methods may be applied to determine bespoke sampling requirements as per the guideline. Further detail is provided in the following figure (**Figure 6.1**). This guidance recommends essentially the same numbers of samples as the previous version for different volumes of soil but provides additional options and statistical tools.
- The final 2 documents do not actually provide guidance on sampling rates for different waste types to be used in classification.

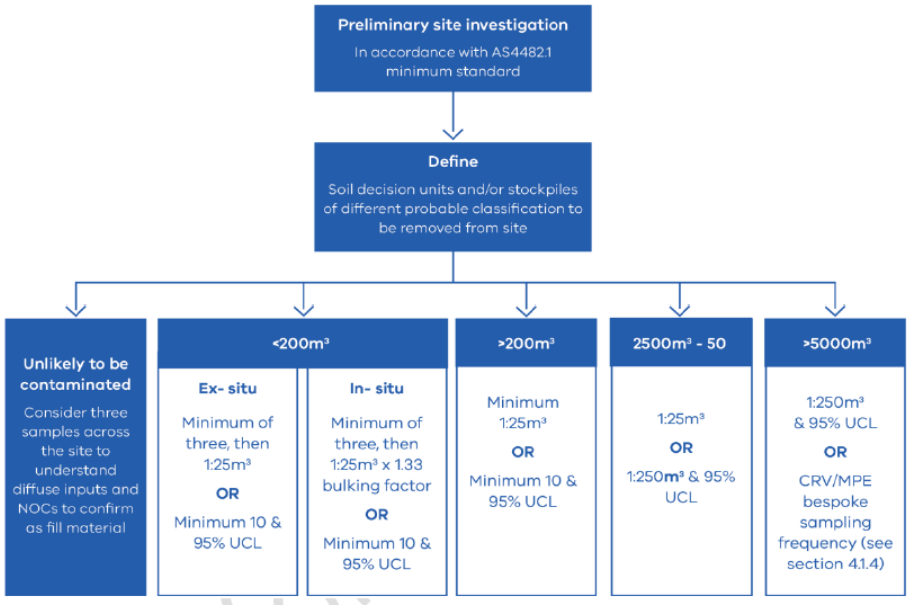

Figure 6.1: EPA Victoria guidance for sampling

6.4.4 South Australia

South Australia developed a system in 2010 to allow waste derived materials to cease to be wastes when material was able to comply with a published SA EPA standard or if a waste derived material is ready for reuse without needing further treatment to prevent any environmental harm[17].

South Australia has a number of guidance documents/standards related to reuse of waste derived products including:

- Standard for the production and use of waste derived fill (SA EPA 2013)
- Standard for the production and use of refuse derived fuel (SA EPA 2010a)
- Standard for the production and use of waste derived soil enhancer (SA EPA 2010b)
- Re-use and recycling of clean fill and building and demolition waste (SA EPA 2001).

For the waste derived fill standard (SA EPA 2013) when applied to waste soil, a minimum sampling rate of 1 sample per 250 m^3 is required with at least 5 samples to be collected to represent the fill source.

For other types of waste (i.e. other than waste soil) that might be able to comply with this product specification, the number of samples should be based on the specific characteristics of the waste of interest. SA EPA does not recommend the use of composite samples for this standard. Basic QA/QC considerations such as duplicate samples are also discussed. This sampling guidance also applies in an additional standard for waste derived fill specific to water treatment solids (SA EPA 2017).

[17] https://www.epa.sa.gov.au/environmental_info/waste_recycling

The waste derived fill standard has specific guidance about asbestos containing materials indicating that such materials are present in the material then such wastes should not be used for fill.

There is some additional information about how to properly assess material that could potentially contain asbestos containing materials to show that it meets the product specification. This includes:

- removing asbestos containing materials to the maximum extent possible
- undertake a thorough HHRA
- engage an auditor to review the HHRA and all supporting materials
- material should not be used at a destination with a sensitive land use
- adhere to all requirements of a site management plan and audit report.

There is no specific guidance on how to sample or how many samples are required to support the HHRA.

The waste derived soil enhancer standard also provides the same information in regard to sampling requirements to demonstrate compliance with the standard (SA EPA 2010b).

The refuse derived fuel standard provides similar information in regard to sampling requirements to demonstrate compliance with the standard but does not include a minimum number of samples (SA EPA 2010a).

All of these standards note that sampling frequency should initially be regular and thorough to gain confidence in regard to the waste inputs and the finished waste derived product but then such sampling may be reduced. There is no guidance as to what is meant by regular and thorough. These standards also note that sampling and reporting should be undertaken by an independent and suitably qualified/experienced environmental consultant or auditor.

6.4.5 Western Australia

The range of wastes being recovered for reuse is currently limited in Western Australia. According to the Waste Avoidance and Resource Recovery Strategy 2030[18], further work is being undertaken to allow for increasing recovery of the following key materials:

- Construction/demolition waste
- Organics (i.e. FOGO)
- Metals
- Paper and cardboard
- Plastics.

A discussion paper outlining the development of a resource recovery regulatory system was published in 2020[19]. Key aspects of such a system were considered to be:

- Changing the definition of waste in relevant legislation which provides a way for waste derived materials based on an appropriate system to no longer be referred to as waste

[18] https://www.wasteauthority.wa.gov.au/publications/view/strategy/waste-avoidance-and-resource-recovery-strategy-2030
[19] https://consult.dwer.wa.gov.au/waste-policy/waste-not-want-not/

- Create a system where the Department of Water and Environmental Regulation can approve determinations for waste derived materials
- These determinations are proposed to included product specification details and details of the conditions that will need to be imposed for the waste derived material use to be appropriate and controlled (i.e. similar to NSW or QLD systems).

The system is proposed to include general and case by case determinations. General determinations will be for materials that are common and generally well understood – e.g. construction and demolition waste, reclaimed asphalt from roads, fly ash/bottom ash.

Sampling and analysis requirements for such waste derived material determinations will be those proposed in the application for such a determination (i.e. by the applicant) or as determined by the regulator (i.e. DWER).

The *roads to reuse* program has been developed to allow construction and demolition waste (of appropriate quality) to be processed for use as recycled road base or recycled drainage rock. The specification requirements are outlined in *Roads to Reuse, Product Specification – recycled road base and recycled drainage rock* (WA Waste Authority 2021).

This specification requires:

- Detailed discussion prior to material being delivered to a processing site to ensure the producer of the waste understands the requirements for material being recycled including the requirements for no asbestos containing materials, no acid sulfate soils, no odorous material, no discoloured material.
- Inspection upon arrival at a processing site with non-permitted materials required to be removed prior to making use of the rest of the delivered load.
- Sampling of the delivery in line with AS 1141.3.1: Methods for sampling and testing aggregates.
- Sampling is preferred directly from conveyors or at the end of the processing – i.e. prior to putting the material into a stockpile.
- Sampling of a stockpile of material is not preferred and should only be used when conveyor/end of processing type sampling is not available (i.e. legacy stockpiles etc). This is because it is difficult to obtain representative samples of the material with confidence.
- The goal of sampling the material is both to understand the average nature of the material and variability in the characteristics of this material.
- When sampling from a conveyor belt as the material is processed, 1 discrete sample per 140 m^3 should be collected or 20 samples per 4,000 tonnes. The number of samples and the volume of material in each sample should be specified in the site sampling plan. Additional samples or additional volumes per sample should not be added into the program to ensure the material complies with the specification (i.e. to dilute the results).
- When sampling is from a stockpile, 20 samples are required per 4,000 tonnes (or 7 samples per 1,000 m^3 or for small stockpiles less than 100 m^3 a minimum of 3 samples) in line with the requirements of AS 1141.3.1 and Guidelines to sampling for the extractive industry from

Cement, Concrete and Aggregates Australia[20]. Additional samples should be taken if there is evidence of potential contamination.

- Once routine sampling has been undertaken for long enough to demonstrate that processing produces a consistent product, the frequency of sampling can be reduced – i.e. 5 samples per 4,000 tonnes. This must be approved prior to any change any sampling frequency.

This program only applied to a limited number of recyclers.

Current recycling at construction and demolition waste recycling facilities must be undertaken in accordance with the guideline – *Managing asbestos at construction and demolition waste recycling facilities* (the latest version was published in 2021)[21]. Such sites are required to have a relevant licence from DWER and to comply with this guidance. The sampling requirements within this guidance are listed below.

- Sampling is required for asbestos containing materials as well as fibrous asbestos (FA) and asbestos fine (AF) in material to be used for recycled road base or screened sand products. Minimum sampling rate is 40 locations per 4,000 tonnes within a stockpile or from a conveyor belt (or 14 samples per 1,000 m^3).
- Samples must be at least 10 L in volume and then put through a 7 mm sieve in the field.
- The material >7 mm is required to be examined for the presence of suspected asbestos containing material (and the weight should be noted to allow the concentration to be determined if any of the pieces are identified as containing asbestos).
- The material <7 mm needs to be at least 500 mL in volume and the entire volume submitted to the laboratory and tested in accordance with all steps in AS 4964.
- If asbestos is identified potentially above 0.001% by weight in any single sample, then the material should be deemed potentially contaminated and appropriate disposal should be arranged or further sampling can be undertaken to demonstrate its acceptability.
- In the case of a single exceedance at >0.001% but less than 0.01% by weight, a stockpile (assumed as 4,000 tonnes) may not be deemed contaminated if repeat samples from areas immediately adjacent to the location of the single sample do not exceed 0.001% by weight.
- If the asbestos containing material is limited to a localised area of a stockpile, then that part of the stockpile can be excavated and the rest of the stockpile can be considered suitable for resource recovery uses.
- If single fragments of bonded asbestos containing material are found in a stockpile, then this stockpile may not need to be deemed as contaminated depending on the nature of the material and the results for additional samples taken nearby to the location where the fragment was found.
- Once routine sampling for asbestos containing materials has been undertaken for long enough to demonstrate that processing produces a consistent product, the frequency of sampling can be reduced – i.e. 5 samples per 4,000 tonnes. This must be approved prior to any change any sampling frequency.
- For recycled drainage rock, sampling is only required if suspect materials are observed.

[20] https://www.ccaa.com.au/CCAA/CCAA/Docs/Technical/Guides/Guideline_to_Sampling_for_the_Extractive_Industry.aspx
[21] https://www.wa.gov.au/government/publications/guideline-managing-asbestos-construction-and-demolition-waste-recycling-facilities

The *Guideline to sampling for the extractive industry* by *Cement, Concrete & Aggregates Australia*[22] is mentioned in the WA guidance. This document provides similar information to that included in AS 1141.3.1 about how to take samples from stockpiles, conveyor belts etc.

[22] https://www.ccaa.com.au/CCAA/CCAA/Docs/Technical/Guides/Guideline_to_Sampling_for_the_Extractive_Industry.aspx

Section 7. International approaches to sampling

7.1 General

This section summarises international requirements for sampling of bulk materials and stockpiles for asbestos. The following organisations/websites have been considered to determine if they have guidance on sampling recovered materials (i.e. waste materials to be reused or recycled):

- US agencies (USEPA)
- Canadian agencies (Environment and Climate Change Canada, Health Canada)
- European agencies (European Environment Agency, European Commission, ECHA plus relevant individual country organisations/agencies such as RIVM and Umwelt Bundesamt)
- UK agencies such as the Health and Safety Executive (HSE)
- International agencies (World Health Organisation, International Labour Organisation)
- Professional bodies (unlikely to provide guidance on recovered materials but will be included):
    - Faculty of Asbestos Management of Australia & New Zealand
    - American Industrial Hygiene Association
    - British Occupational Hygiene Society
    - Australian Institute of Occupational Hygienists
    - New Zealand Occupational Hygiene Society
    - American Conference of Governmental Industrial Hygienists
    - Nederlandse Vereniging voor Arbeidshygiëne (Dutch Occupational Hygiene Society)

7.2 USA

7.2.1 General

The USEPA has a policy to encourage reuse and recycling of industrial waste when such wastes can be used as safe and effective substitutes for virgin raw materials. They also have information about sampling for asbestos.

7.2.2 Asbestos related guidance

The USEPA has a framework for investigating asbestos contamination at contaminated sites[23]. The California Air Resources Board also has guidance on sampling for asbestos[24].

The USEPA framework and the CARB method (CARB M435) both recommend the use of the Incremental Sampling Methodology[25].

This method has been developed by ITRC (Interstate Technology and Regulatory Council). ISM is a structured approach to taking composite samples. It has been shown to provide a reasonable estimate of the mean/average concentration of a contaminant in a volume of soil. Typically, 30 to

[23] https://www.epa.gov/superfund/asbestos-superfund-sites
[24] https://ww2.arb.ca.gov/resources/documents/test-method-435
[25] https://itrcweb.org/teams/training/incremental-sampling-methodology-ism-update

100 increments (i.e. 30-100 discrete sub samples) are collected then combined and sub sampled to produce the sample that is provided to the laboratory.

The guidance does discuss the difficulties in sampling/analysis of asbestos in soils or other similar materials due to the much lower levels of asbestos that would be present in such materials compared to actual manufactured building materials. The guidance notes:

> *The asbestos content of soil is usually low compared to bulk asbestos-containing materials, so the fraction of particles that are asbestos is small, and accurate quantification is very difficult.*

This would also be the case for most resource recovery materials.

The USEPA framework recommends monitoring for asbestos fibres in air as the basis for decision making at sites which may have asbestos contamination. The framework discusses sampling of soils and dust but then does not use that data for decision making. The only information on sampling rates is the recommendation to use the incremental sampling methodology which implies that the use of composite sampling is permitted for monitoring for asbestos in soil.

The framework discusses the use of activity based sampling for asbestos in air (i.e. air monitoring while the activity that may disturb the soils (or other materials) is being undertaken).

7.2.3 Sampling waste materials

The Resource Conservation and Recovery Act (i.e. RCRA) gives the USEPA authority to control hazardous and non-hazardous waste in the US[26]. All guidance about sampling and analysis of waste materials for RCRA is provided by the USEPA within the SW-846 guidance[27]. Most of the compendium refers to analytical methods. Chapter 9 of SW-846 provides basics on sampling waste materials prepared in 1986. In 2002, an update to this guidance was published. Material from these documents has been included in **Section 4.3**.

Documents about developing sampling plans include:

- Chapter 9, SW-846 Compendium[28]
- USEPA (2002) RCRA Waste Sampling Draft Technical Guidance [29]
- USEPA (2002) Guidance on Choosing a Sampling Design for Environmental Data Collection for Use in Developing a Quality Assurance Project Plan[30]
- USEPA (2000) Guidance for Data Quality Assessment[31].

Discussion of sampling design basics is provided in **Section 4**.

These documents discuss sampling design including the data quality objectives process. They do not specify sampling rates or sampling frequencies that might be useful to assess a particular waste

[26] https://www.epa.gov/laws-regulations/summary-resource-conservation-and-recovery-act
[27] https://www.epa.gov/hw-sw846/sw-846-compendium
[28] https://www.epa.gov/hw-sw846/sw-846-compendium
[29] https://www.epa.gov/hw-sw846/draft-technical-guidance-about-waste-sampling-under-resource-conservation-and-recovery-act
[30] https://www.epa.gov/quality/guidance-choosing-sampling-design-environmental-data-collection-use-developing-quality
[31] https://www.epa.gov/quality/guidance-data-quality-assessment

material. Depending on the type of sampling method, equations to allow the calculation of a relevant number of samples for a specific waste material are provided.

Sampling rates designed using detailed statistical methods often end up requiring significant numbers of samples. In the updated guidance for RCRA sampling, an assessment of the number of samples required to assess compliance of a material based on simple random sampling is provided.

- To have 95% confidence of a change in a characteristic of a material requires 27 to >1,000 samples depending on the size of the change (i.e. larger change in the characteristic smaller number of samples required) and the power of the analysis.
- To have 90% confidence of a change in a characteristic of a material requires 19 to >800 samples depending on the size of the change (i.e. larger change in the characteristic smaller number of samples required) and the power of the analysis.

Often sampling designs are not based solely on statistical assessments, given how many samples can be required depending on the assumptions made.

Sampling designs are more usually a combination of statistical considerations, policy determinations and practicalities (cost and time). There needs to be a balance between the robustness of a finding and the practicalities of taking samples and analysing them in a timely manner.

7.2.4 ASTM D6009-19 Standard guide for sampling waste piles

This Standard was developed by the ASTM Subcommittee D34.01.01 Planning for Sampling, under the jurisdiction of ASTM Committee D34 Waste Management. The Standard was originally approved in 1996, revised in 2006 and 2012, and most recently updated in 2019.

This standard provides guidance on the matters to consider when developing a sampling plan which include:

- Nature of the site
- Nature of the waste material – sources etc
- Physical characteristics of the stockpile/waste pile – shape, size, stability
- Chemical characteristics of the waste material – types of chemicals, variability
- Type of equipment available to do the sampling (and limits this places on the design).

The standard then outlines how to develop a sampling plan for the pile of material. Developing such a strategy requires consideration of the following factors:

- Collection of representative samples
- Heterogeneous stockpiles – consider variability in particle size and contaminant distribution
- Stratification of the stockpile and hotspots due to variations in the process that generated the waste.
- Determining the frequency or number of samples to be collected.

The document then outlines the various types of sampling strategies that could be adopted and shows how such sampling strategies can be applied to a stockpile as can be seen in **Figures 7.1** and **7.2**.

This document does not include a simplified approach to a sampling rate.

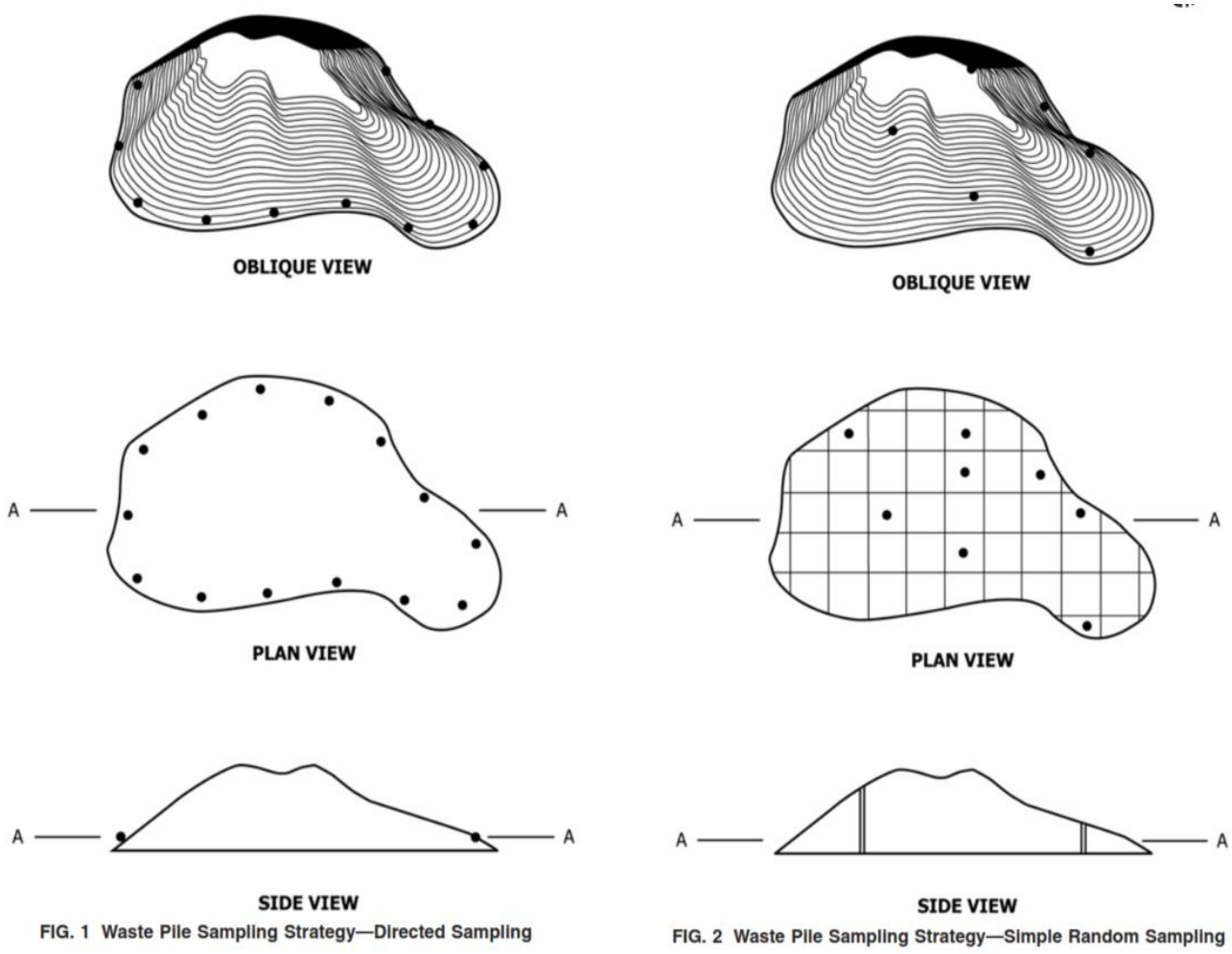

Figure 7.1: Illustration of sampling approached based on directed sampling or simple random sampling

Directed Sampling (refer **Figure 7.1**) is based on the judgment of the investigator and will not result necessarily in a sample that reflects the characteristics of the entire waste pile.

Simple Random Sampling (refer **Figure 7.1**) ensures that each element in the waste pile has an equal chance of being included in the sample.

Stratified Random Sampling (refer **Figure 7.2**) may be useful when distinct strata or homogeneous subgroups are identified within the waste pile

Systemic Grid Sampling (refer **Figure 7.2**) involves the collection of samples at fixed intervals based on a sampling grid and is used when the contamination is assumed to be distributed randomly. This method also is commonly used with waste piles when estimating trends or patterns of contamination or when the objective is to locate hot spots.

Other sampling methods and alternative approaches are also discussed in this ASTM method.

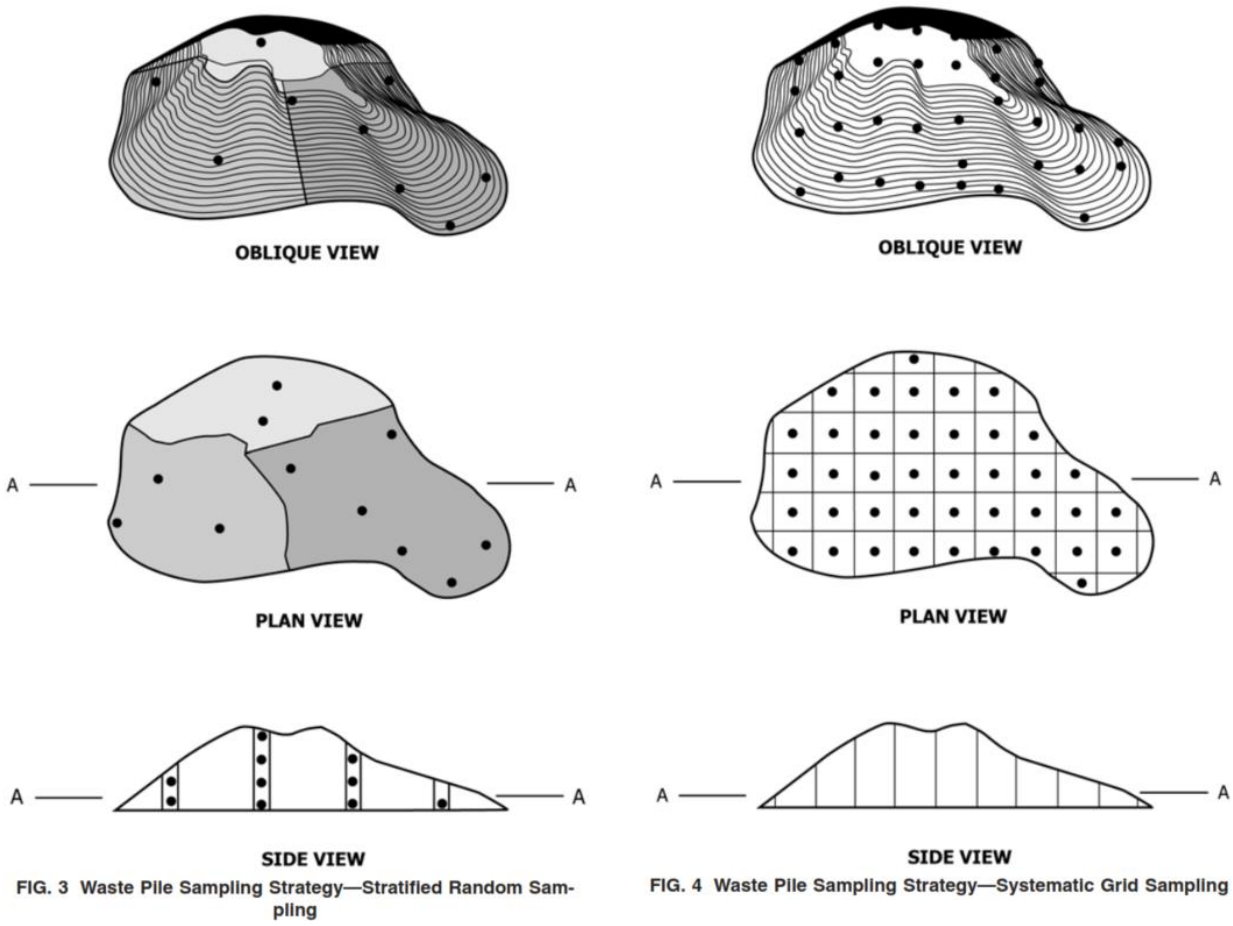

FIG. 3 Waste Pile Sampling Strategy—Stratified Random Sampling

FIG. 4 Waste Pile Sampling Strategy—Systematic Grid Sampling

Figure 7.2: Illustration of sampling approached based on stratified random sampling or systematic grid sampling

7.2.5 Florida

A white paper on sampling stockpiles for soil reuse at a site is available[32]. This paper was prepared for the Florida Department of Environmental Protection. The authors note the following:

- 2 approaches
  - Sampling design based on policy
  - Sampling design based on statistically validated approaches to estimate mean concentration in a specified volume of soil
- Review found 9 different approaches for stockpile sampling
  - Policy based approaches included:

[32] https://floridadep.gov/waste/district-business-support/documents/stockpile-sampling-soil-reuse-site

        - Discrete samples based on specified number in guidance (EPA Victoria, California Dept of Toxic Substances)
        - Composite samples (conventional ones – i.e. 5 sub samples of equal volume or similar) based on specified numbers in guidance (Minnesota Dept of Agriculture, British Columbia Ministry of Environment, Canadian Council of Ministers of the Environment (CCME))
    - Statistical based approaches included:
        - Composite samples (conventional ones – i.e. 5 sub samples of equal volume or similar) where number of samples is based on statistical analysis (ISO, RIVM)
        - Composite samples based on incremental sampling methodology (ISM) where number of samples is based on statistical analysis (ITRC, Hawaii Dept of Health)
- For discrete sampling approaches:
    - California Dept of Toxic Substances recommends 1 sample per 250 cubic yards.
    - EPA Victoria recommends 1 sample per 25 m^3.
    - CCME recommends use of discrete sampling for volatile chemicals and collection of 15 discrete samples uniformly distributed through a stockpile for such chemicals.
- For the composite sampling approaches:
    - first step is deciding what is the decision unit size (i.e. whole stockpile or part thereof etc)
    - second step is deciding how many subsamples/increments for each decision unit
    - finally, the number of replicates is determined – replicates are samples collected in the same way as the original sample but in different places in the stockpile.
- RIVM approach recommends the use of 50 subsamples/increments per composite and that 2 composite samples (based on 50 increments) was appropriate for a reliable estimate of the mean for the stockpile. This was based on a statistical simulation using datasets for genuine stockpiles and 30 different sampling models for a 2,000 tonne stockpile (Lamé et al. 2005).
- ITRC approach recommends use of 30-100 subsamples/increments per composite.
- British Columbia approach recommends stockpiles should not exceed 250 m^3, that stockpiles should be divided into 5 equal cells and that these should be sampled/analysed and checked for compliance with requirements separately for each cell. For each cell, sampling should be undertaken for each 10 m^3 within the cell but the number of subsamples/increments that are taken to combine into a composite is not specified.
- Minnesota approach recommends the use of 4-18 subsamples/increments per composite.

As a result of this review, the authors recommended the use of the ISM approach (i.e. as per ITRC guidance as discussed in **Section 7.2.2**) using a minimum of 30 subsamples/increments per composite sample and a minimum of 3 replicates for each sample based on the decision unit (i.e. whole stockpile or part thereof). The value for the material of interest that should be compared to the relevant requirement in a specification should be the 95%UCL for the 3 or more replicate samples taken in this way.

The authors also recommended that the decision unit size be based on the area where people or the environment could be exposed.

An example of this is adopting a decision unit of 200 cubic yards for material that will be reused at a residential site. This is the stockpile volume for which 30 subsamples/increments should be taken and mixed into 1 sample for analysis and that this should be done 3 times for the stockpile. The stockpile size is based on a quarter acre residential block with recycled soil being placed up to 6 inches deep across the site. 200 cubic yards is equivalent to around 150 m^3 which is around 225 tonnes (using bulk density of 1,500 kg/m^3).

This would also mean that, where material is to be reused over a larger area or in a different way (e.g. at an industrial site or where material is not present at the surface), a differently sized decision unit could be adopted.

7.3 Canada

Health Canada provides a range of guidance about asbestos including a Regulation "Prohibition of Asbestos and Products Containing Asbestos"[33].

An initial comment by Health Canada in their guidance on trace amounts of asbestos in consumer products[34] is as follows:

Asbestos is a naturally occurring substance. Low levels of asbestos fibres are omnipresent in the environment, including in both indoor and outdoor air. As a result of its natural presence, trace amounts of asbestos may be found as a contaminant in consumer products available in Canada.

The regulation prohibits the presence of asbestos fibres at greater than trace amounts in consumer products. Trace amounts are defined as less than 0.1%. This guidance indicates the following methods as suitable for use in analysing asbestos with a limit of reporting of <0.1%:

- USEPA – EPA600/R-93/116[35]
- NIOSH – Method 9002[36]
- ISO – Method 22262[37]

These method statements primarily relate to sampling and analysis of building materials that may contain asbestos (like roof tiles, vinyl tiles etc) and focus on the laboratory methods for the analysis of asbestos fibres. These laboratory methods are definitely appropriate for the laboratory parts of the process for samples of resource recovery materials. However, these method statements do not contain relevant information about the sampling of bulk materials like soil, aggregate or resource recovery materials.

The Canadian Council of Ministers of the Environment (CCME) provides guidance on waste management in Canada. Such guidance includes *Guide for Identifying, Evaluating and Selecting Policies for Influencing Construction, Renovation and Demolition Waste Management* [38]. This document discusses the limitations in recycling of construction, renovation and demolition waste

[33] https://canadagazette.gc.ca/rp-pr/p2/2018/2018-10-17/html/sor-dors196-eng.html
[34] https://www.canada.ca/en/environment-climate-change/services/management-toxic-substances/list-canadian-environmental-protection-act/asbestos/trace-asbestos-consumer-products-guidance.html
[35] https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=ORD&dirEntryID=33479
[36] https://www.cdc.gov/niosh/docs/2003-154/method-9999.html
[37] https://www.iso.org/standard/56773.html
[38] https://ccme.ca/en/resources/waste-management

materials. One of the limitations commonly discussed in the reuse/recycling of these materials is the potential for asbestos containing materials to be present in such wastes. No information is provided discussing sampling and analysis of these materials.

It does appear that, while the reuse of such materials is encouraged in Canada, there is not a system like the resource recovery orders/exemptions in NSW that specifies the sampling and analysis requirements for assessing the quality of materials for reuse.

7.4 European Union

The European Commission has developed a policy to address the health risks of asbestos [39]. This policy includes actions required to identify and register the presence of asbestos in buildings, ensure its safe removal/treatment and appropriate treatment of asbestos containing waste as well as protecting workers during all of these processes. The policy document does not discuss sampling and analysis of materials to determine the presence/absence of asbestos.

The JRC (Joint Research Centre) has produced a document on developing end of waste criteria/product specifications for materials to be reused[40]. While the report does not include specific guidance on sampling and analysis of waste materials as part of such a reuse process, it does indicate that a quality assurance process is required in such a code which would include sampling and analysis.

Finalised end of waste criteria documents for a few waste streams exist in Europe[41]. There are end of waste criteria for:

- Iron, steel and aluminium scrap
- Glass cullet
- Copper scrap

These documents do not specify detailed sampling and analysis requirements to demonstrate the waste is of appropriate quality for reuse and complies with product specifications. However, the copper scrap end of life criteria document includes a requirement to test representative samples of each grade of copper scrap for foreign materials (e.g. other metals, non-metallic materials etc) at least every 6 months. They also do not include information on sampling for the presence/absence of asbestos.

There are also a number of documents produced by JRC but which do not appear to have been finalised by the European Commission. These include resource recovery product specifications for:

- Plastics[42]
- Waste paper[43]

[39] https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:52022DC0488
[40] https://op.europa.eu/en/publication-detail/-/publication/be94cedf-5eea-4018-ac0c-bfca6c96c53e/language-en
[41] https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en
[42] https://op.europa.eu/en/publication-detail/-/publication/efc0dc69-2209-45d8-89c1-a96dd9ea34f1/language-en
[43] https://op.europa.eu/en/publication-detail/-/publication/cd8c682b-cd36-4bae-be31-72a29057da3b/language-en/format-PDF/source-318947044

- Biodegradable waste subjected to biological treatment[44]

Specific information on sampling requirements is not included in the plastics and waste paper documents. The biodegradable waste document points to a range of European Standards for guidance about developing a sampling plan for characterising wastes.

There are a range of European Standards detailing how to characterise waste that are likely to include information on sampling of waste:

- CEN/TS 17493:2023 Characterisation of waste: guidance on the determination of the content of elements and substances in waste (https://standards.iteh.ai/catalog/standards/cen/271eb6fa-9fbe-4dc4-b0fa-338d6e32f90d/cen-ts-17943-2023)
- CEN/TR 15310-1:2006 (various parts) Characterisation of waste – sampling of waste materials – Part 1: guidance on selection and application of criteria for sampling under various conditions; Part 2: Guidance on sampling techniques; Part 3: Guidance on procedures for sub-sampling in the field; Part 4: Guidance on procedures for sample packaging, storage, preservation, transport and delivery https://standards.iteh.ai/catalog/standards/cen/c48f28e0-3acf-433f-9682-bce9a47b2e5f/cen-tr-15310-1-2006
- CEN/TR 16130:2011 Characterisation of waste – on-site verification (https://standards.iteh.ai/catalog/standards/sist/e84c18db-f836-4685-9006-59bb7d261d28/sist-tp-cen-tr-16130-2011)
- EN 14899:2005 Characterisation of waste – sampling of waste materials – framework for the preparation and application of a sampling plan https://standards.iteh.ai/catalog/standards/cen/2a2f02a0-a0d4-4e3d-baca-78f9a227c32f/en-14899-2005
- EN 16457:2014 Characterisation of waste – framework for the preparation and application of a testing program – objectives, planning and report https://standards.iteh.ai/catalog/standards/sist/9cb68398-dfbf-4c6f-af39-6218b7a8646e/sist-en-16457-2014

These provide guidance about the statistics of developing sampling programs for waste materials depending on what is known about the waste rather than specific details of sample numbers and sampling frequency that could be applied to many waste materials.

7.5 UK

The UK provides a range of guidance on sampling of waste materials:

- Technical guidance WM3: waste classification – guidance on the classification and assessment of waste[45]

[44] https://op.europa.eu/en/publication-detail/-/publication/66031c1b-b894-4da3-b091-4e094e83f885/language-en/format-PDF/source-318947228
[45] https://www.gov.uk/government/publications/waste-classification-technical-guidance

- Materials facilities: waste sampling and reporting from October 2024[46]
- Developing a suitable sampling methodology[47]

The new guidance commencing in October 2024 can require sampling of inputs or outputs or both for a facility receiving waste for processing and reuse[48]. Input sampling is required if a facility accepts waste from one or more and processes it in some fashion. If waste is only received from one supplier and it is consolidated but not processed into specified outputs then no sampling is required. Output sampling is required if received material is processed into specified outputs. For input sampling, one sample is required for every 75 tonnes of incoming waste and these samples must be at least 55 kg and on average 60 kg. If waste is received from more than one supplier, the sampling requirements must be applied to each source/supplier separately. These sampling requirements apply to sites accepting glass, aluminium, steel, paper, card, plastic bottles/pots/tubs/trays, film/flexible plastic, other plastics and fibre based composite material (i.e. packaging material that is made of paperboard, paper fibres and laminated with plastic). Output sampling requirements include taking samples ranging from 10 kg to 50 kg and taking a sample every 15 to 60 tonnes depending on the type of specified output material.

The guidance on developing a suitable sampling methodology applies to materials facilities that accept wastes for processing etc[49]. This guidance provides information on how to take samples etc but refers to the guidance discussed above for sampling frequency and sample weights.

Regulation of resource recovery activities in the UK includes the following types of guidance:

- Activities involving the use of waste can be exempt from needing an environmental permit if the activity complies with the appropriate guidance for an exemption[50]. These exemptions cover the types of activity that can and can't occur at a site where waste is being used in some fashion, the types of waste that can be used in the activity and how the exemption would no longer apply. There doesn't seem to be any requirements for sampling and analysis included in the exemptions. Potential issues related to contamination are controlled by limiting the types and amounts of waste that can be used in the activity as well as limits on how and where the activity/processing can occur. If these limitations can be complied with then a particular site does not need an environmental permit.
- UK Environment Agency also has standard rules for some activities including a number of resource recovery type activities[51]. These documents note the type of materials that can be accepted for inclusion in the resource recovery material along with a range of guidance about where such activities can occur etc. As long as the rules are complied with and appropriate information is recorded to demonstrate such compliance, then the activity is

[46] https://www.gov.uk/guidance/materials-facilities-waste-sampling-and-reporting-from-october-2024#when-and-what-you-must-sample-and-measure
[47] https://www.gov.uk/government/publications/materials-facilities-developing-a-suitable-sampling-methodology/developing-a-suitable-sampling-methodology
[48] https://www.gov.uk/guidance/materials-facilities-waste-sampling-and-reporting-from-october-2024#when-and-what-you-must-sample-and-measure
[49] https://www.gov.uk/government/publications/materials-facilities-developing-a-suitable-sampling-methodology/developing-a-suitable-sampling-methodology
[50] https://www.gov.uk/government/collections/waste-exemptions-using-waste
[51] https://www.gov.uk/government/collections/standard-rules-environmental-permitting#storage-or-treatment-of-waste---recycling,-dredging,-clinical,-soil,-tyre-shred-or-wood-treatment

permitted with a simplified environmental permit. Requirements for sampling and analysis do not appear to be included.

- Regulatory position statements are also used by the UK Environment Agency to indicate requirements for sites managing wastes (or other activities) [52]. There are such statements for a range of activities regarding disposing waste, storing waste, treating waste or using waste. An example statement is the one for use of manufactured topsoil (RPS 190). This RPS refers to the British Standard BS 3882:2015 as the product specification for manufactured topsoil – this is the British Standard for topsoil, so it is appropriate to apply to manufactured topsoil from waste soil. The RPS also includes limitations on a range of matters including how much manufactured topsoil can be used at a single site or that such soil should not be used in agricultural situations or for home grown produce. Other regulatory position statements provide similar types of information. The requirements for sampling and analysis would presumably be provided in the British Standard or other standard used to define the quality of the treated waste output.

When sending waste to landfill, the sampling frequency requirements are specified in the guidance at https://www.gov.uk/guidance/dispose-of-waste-to-landfill . **Table 7.1** provides details of the sampling rates required for wastes being disposed to landfill. Resource recovery materials are most likely to be considered as heterogeneous wastes – that is wastes for which the characteristics vary to a greater extent through time. Homogeneous wastes are those that come from a manufacturing process or a single source which is consistent in its characteristics.

Table 7.1: Sampling frequency for wastes being disposed to landfill required by UK Environment Agency

Stockpile volume (tonnes)	Minimum number of samples required	
	Homogeneous waste	Heterogeneous waste
<100	2	5
100-500	3	8
500-1,000	5	14
1,000-10,000	11	22
Plus per additional 10,000	+5 (pro rata)	+10 (pro rata)

If waste has a bulk density of 1,500 kg/m^3, then 100 tonnes equates to approximately 66 m^3; 500 tonnes equates to approximately 300 m^3; 1,000 tonnes equate to approximately 700 m^3 and 10,000 tonnes equate to approximately 7,000 m^3.

When these sampling requirements are compared to the sampling requirements in NSW shown in **Table 6.1**, it can be seen that the UK requires similar/fewer samples per amount of material in a stockpile when that material is considered homogeneous but more samples per amount of material in a stockpile when the material is considered heterogeneous.

In regard to asbestos containing building materials such as fibre cement sheeting, the UK classifies these as hazardous waste and requires specific controls on how they can be disposed of, however,

[52] https://www.gov.uk/government/collections/basic-rules-environmental-permitting-regulatory-positions

there is little information/few controls on the potential for asbestos to be present in other waste materials that may be collected, processed and reused.

7.6 The Netherlands (RIVM)

The Netherlands has a focus on waste being a resource rather than waste[53]. They have developed resource loops where materials are considered for reuse where it is safe to do so as part of their implementation of a circular economy.

RIVM led an EU research program to develop an evidence based approach to assessing how to manage the presence of substances of concern in recycled materials[54]. The CleaR project was completed and reported in 2019. This project focused on chemicals that have restrictions in the EU REACH system for chemicals management where those chemicals may be present in materials to be reused.

The EU definition of recycling is *any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes*. It includes reprocessing of organic materials but does not include material that is used for energy recovery (i.e. as fuel in a waste to energy facility) or materials used as engineered fill – these are considered separately.

End of waste is terminology related to recycling. The EU considers a waste to no longer be a waste if the following apply:

- Material has undergone a recycling or recovery operation
- Treated material is to be used for a specific purpose(s)
- A market/demand exists for the treated material/specific purpose
- Treated material meets the technical requirements for the specific purpose(s) – i.e. meets the existing legislation/standards for the product that meets the specific purpose(s)
- The use of the treated material for the specific purpose does not lead to overall adverse environmental or human health impacts.

Considerations around end of waste allow a material to be taken from the Waste Framework Directive system in the EU and puts the material back under the EU REACH system for chemicals management when considering the presence of chemicals with restrictions under this regulation.

The CleaR report includes limited information on sampling such as:

- Determining whether to sample inputs to a recycling/recovery operation or outputs of a recycling/recovery operation for chemicals of interest depends on what question is being asked – e.g. what waste contains the chemical of interest (i.e. sample inputs) or does the final product comply with relevant standards in regard to the chemical of interest (i.e. sample outputs)).

[53] https://www.rivm.nl/en/circular-economy/waste-becomes-resource
[54] https://op.europa.eu/en/publication-detail/-/publication/26e22c04-5b62-11e9-9c52-01aa75ed71a1/language-en/format-PDF

- Risk assessment process to be applied to such chemicals then requires consideration of exposure scenarios which might be informed by the sampling/analysis information but may just be based on how output materials will be used.

The National Waste Management Plan is in place in the Netherlands[55]. The objectives of the plan are to restrict the creation of waste, restrict the environmental burden of production chains and optimise the use of waste in a circular economy. The plan provides individual sector plans which provide a minimum standard for use/reuse of waste or disposal if use/reuse is not possible. These sector plans are only available in Dutch, so it is not possible to easily determine what guidance they provide on sampling and analysis of waste materials for use in the circular economy.

There is a sector plan for asbestos and asbestos containing materials[56]. This plan applies to waste materials with more than 0.01% asbestos where asbestos containing materials may have been mixed into other wastes. The plan also applies (obviously) to asbestos fibres (100% asbestos), asbestos cement materials and other normal construction materials that contain asbestos. The minimum standard for this material includes that these types of material can be subject to any of the following:

- Disposed to a suitable landfill
- Treated with processes that destroy the fibres (thermal, chemical)
- Remove the fibres/materials to achieve less than 0.01% in the material overall – if this is possible the material changes to non asbestos containing and is no longer subject to the requirements of the plan

All other recovery options are not permitted.

This means processes that remove asbestos containing materials from waste are permitted as part of resource recovery activities to clean up waste materials to reach less than 0.01% asbestos by weight.

It is noted that other legislation does prohibit the processing for reuse of standard asbestos containing materials like reusing insulation at another location. However, this additional regulation does still allow processing of asbestos containing waste to remove asbestos containing materials to bring the concentration to under 0.01%. The sector plan does not appear to include instructions related to sampling and analysis. Given that the plan does not apply to waste materials containing less than 0.01% asbestos, it is presumed that no special requirements are required for materials that might contain trace levels of asbestos (i.e. less than 0.01% by weight).

Disposal to landfill is an option for this type of material (i.e. asbestos containing – i.e. >0.01% by weight) where it is not an option for many other types of resource recovery materials.

Another example of a sector plan is the one for soil[57]. This plan covers soil that may or may not be contaminated with a range of chemicals (PAHs, metals, oils etc), soil that may contain PCBs or

[55] https://lap3.nl/service/english/
[56] https://lap3.nl/sectorplannen/sectorplannen/asbest/
[57] https://lap3.nl/sectorplannen/sectorplannen/grond/

other POPs or soil that may contain asbestos (i.e. soil containing asbestos at a concentration higher than 0.01% be weight or where that concentration limit has not been exceeded but the asbestos was added to the soil deliberately). The minimum standard applied to the asbestos containing soil is that it may be processed to destroy or remove asbestos fibres such that the soil meets the 0.01% concentration limit and then the soil may be reused in accordance with previous parts of the plan (i.e. concentrations of other contaminants cannot exceed 120% of the industrial soil quality class limits). The sector plan does not appear to include instructions related to sampling and analysis but the requirements may be specified in NEN 5707+C2:2017[58] – the standard in the Netherlands for Soil – Inspection and sampling of asbestos in soil and batches of soil. The soil cannot be disposed of in a landfill unless it is not possible to clean it sufficiently in line with the minimum standard.

RIVM has also prepared guidance about ensuing recycling is sustainable[59]. This guidance document outlines a process for thinking about closing material loops which is illustrated in **Figure 7.1**. This document does not provide information on sampling and analysis as part of the process to consider sustainability.

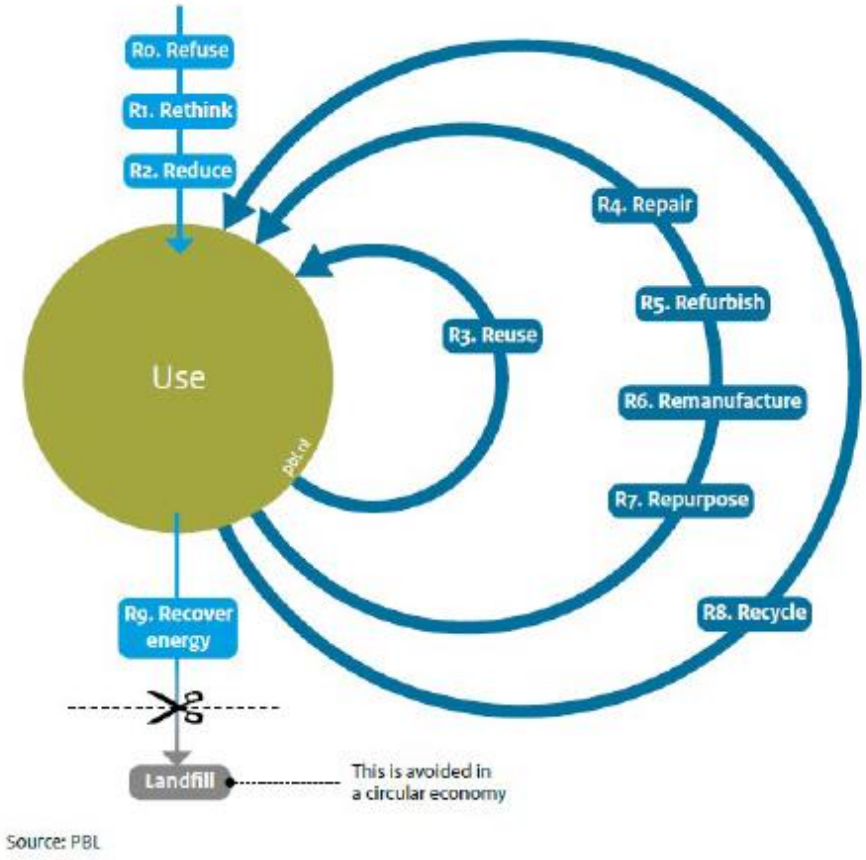

Figure 7.1: Classification of approaches to establishing the circular economy for a material type

[58] https://www.nen.nl/nen-5707-c2-2017-nl-243402
[59] https://www.rivm.nl/en/bibcite/reference/339331

7.7 International agencies

7.7.1 ISO 22262-1

The ISO standard 22262-1 “Part 1: Sampling and qualitative determination of asbestos in commercial bulk materials” includes information on sampling. The guidance on sampling provided in this standard has been summarised here. Discussion of the rest of the information included in this standard is provided in **Section 8** as it refers to the analytical procedures.

Section 6 of this standard describes considerations for sampling.

The guidance provided in this section is mainly designed to target the sampling of construction materials rather than bulk materials like soils or compost. The guidance notes that any samples collected should be representative of the material of interest and that the number of samples collected is dependent on the nature of the material of interest. No specific guidance is provided on how to take representative samples nor how to determine how many samples to take.

7.7.2 WHO

The World Health Organisation provides a wide range of guidance about the health effects of the various forms of asbestos fibres and how to clean up asbestos containing materials in emergencies [60]. Information about sampling waste materials for asbestos is not provided as this is not the role of WHO.

7.7.3 International Labour Organisation

The International Labour Organisation[61] also provides a wide range of materials about the risks posed by asbestos containing materials in a workplace, training materials for workers so they are informed about such risks and other policy documents. They do not present information about sampling waste materials for asbestos is not provided as this is not their role.

7.8 Professional bodies

A range of professional bodies exist to support occupational hygienists including in relation to asbestos.

Some of those bodies include:

- Faculty of Asbestos Management of Australia & New Zealand (FAMANZ)
- Asbestos and Hazardous Materials Consultants Association (AHCA)
- American Industrial Hygiene Association (AIHA)
- British Occupational Hygiene Society (BOHS)
- Australian Institute of Occupational Hygienists (AIOH)
- New Zealand Occupational Hygiene Society (NZOHS)
- American Conference of Governmental Industrial Hygienists (ACGIH)
- Nederlandse Vereniging voor Arbeidshygiëne (Dutch Occupational Hygiene Society)

[60] https://www.who.int/teams/environment-climate-change-and-health/chemical-safety-and-health/health-impacts/chemicals/asbestos
[61] https://www.ilo.org/

While these bodies provide guidance about asbestos, they do not provide specific information about sampling and analysis of asbestos in bulk heterogeneous materials like soil or wastes so they have not been discussed further.

Section 8. Analysis – asbestos fibre identification

8.1 General

Commercial laboratories have experience with analysing bulk sample building material by polarized light microscopy (PLM). However, the analysis of soil presents additional analytical challenges due to the matrix and to the relatively low levels of asbestos that are typically present. This is also likely to be the case for various waste materials that might be processed into resource recovery products/waste derived products.

This section provides an overview of the different analytical methods available for the analysis of asbestos in bulk materials and non-homogeneous materials such as soil and mulch.

Homogeneous samples exhibit a more or less uniform distribution of fibres through the entire sample e.g. asbestos cement, or in each discernibly discrete layer of the sample e.g. flooring material with multiple layers including adhesive. For material with layers, each layer must be analysed as a sub-sample.

Non-homogeneous samples contain small, discrete amounts of asbestos distributed unevenly in a large body of non-asbestos material e.g. dust and soil.

8.2 Australian Standard for asbestos identification

At the time of the preparation of this report, Standards Australia was in the process of approving AS 5370 (refer **Section 8.8)** and retiring AS 4964-2004. Consequently, some of the information relating to these two standards may change after publication of this report.

8.3 Training and assessment for asbestos analysis in Australia – identification in bulk materials and non-homogeneous samples

Appropriate training of those undertaking asbestos analysis in the laboratory is critical to ensuring the quality of results.

As discussed in **Section 5.4**, the detector for asbestos is the human eye, not a piece of electrical equipment that works the same every time it is used. As a result, different people have different skills/experience at:

- identifying fibres in general
- identifying whether a fibre is asbestos or something else

This impacts on each person's ability to do this analysis.

In addition, each person's abilities will differ from day to day depending on the workload, equipment, nature of the samples etc. This means respite periods may need to be included in managing the tasks undertaken by these analysts. There are also aspects such as colour blindness that must be considered.

However, there are no official courses available in Australia for training people to undertake analysis of asbestos in bulk materials (including soils and non-homogeneous materials) or in air.

The British Occupational Hygiene Society (BOHS) offers the following qualifications/training courses for asbestos analysis:

- BOHS P401 Identification of Asbestos in Bulk Samples
- BOHS P403 Air Sampling and Fibre Counting

While these training courses are offered in Australia through BOHS accredited training providers, they are not mandatory for laboratory technicians. The courses are run over five (5) days with both technical and practical components being examined.

There are numerous seminars / conference sessions on asbestos contamination in the built environment although very few seminars covering asbestos analysis theory and techniques. The Australian Institute of Occupational Hygienists (AIOH) has provided Continuing Education Sessions (CES) on asbestos analysis a few times as part of its annual conference. However, these are 1 day introductory courses and would not provide the same level of training and expertise as a nationally recognised training course for asbestos analysts.

The National Association of Testing Authorities (NATA) is the recognised national accreditation authority for analytical laboratories and testing service providers in Australia, including laboratories offering analysis of samples for asbestos content.

For asbestos analysts, there are two levels of competency defined by NATA:

- **Approved Analyst:** The analyst is required to have sound theoretical knowledge and practical training and can demonstrate competence in analytical testing. They must have participated in in-house and external proficiency testing schemes achieving satisfactory outcomes. Such staff may be put forward to become Approved Asbestos Analysts by the laboratory that employs them.
- **Authorised Signatory:** Signatories must have sound knowledge in theoretical principles, a high level of competency with routine and unfamiliar or complicated samples, equipment being used, and the guidance material being followed including NATA requirements in report authorisation and issuing (i.e. they must have more skills and experience than “approved analysts).

As there are no official training requirements in Australia, laboratories are required to create an in-house training program using sourced literature, personnel with previous experience, and a pool of materials to assist in training. This may lead to a consistent approach to training within a laboratory if their training systems are robust. However, such systems may differ between laboratories, as there is no consistency or guidance as to what is considered a good degree of competency. Some laboratories have a basic training package with a simple tick the box type of process where the operators do not have a fundamental understanding of the physics/optics behind the process. Other laboratories require their analysts (as distinct from an operator) to understand the physics.

During in-house training analysts are usually given real world samples, previously analysed by an experienced analyst, to practice on. Laboratories may keep samples that are considered rare or difficult, to challenge the analysts to improve their skills, although this is not a formal requirement for in-house training.

There are no formal requirements in Australia for the person providing training to analysts although their role is critical in providing knowledge. They have their own opinions, techniques, and experience which is then passed onto the next analyst, who may then in turn pass this on again which results in a dilution of knowledge. There is a suggestion of a shortage of experienced technical experts in the asbestos field which may result in some of this knowledge/experience eventually being lost.

There is a critical need to design a system to provide a high level of consistent training by a recognised independent training organisation for all analysts in Australia.

8.4 Laboratory accreditation (NATA)

The National Association of Testing Authorities, Australia (NATA) accredits laboratories to ISO 17025 which sets standards for Testing and calibration laboratories.

Laboratories can be accredited to perform a variety of test methods for identification of asbestos in bulk materials, including but not limited to AS 4964, ISO 22262-1, and AS 5370 (when it is ratified – see note in **Section 8.2**).

In addition to having the relevant standards on hand in the laboratory, the laboratory is required to prepare supplementary documentation to elaborate on analytical procedures within the specific laboratory that are not specifically covered by the standard (i.e. which room/equipment to use in the procedure, where relevant equipment is stored at the specific laboratory, which people in the laboratory are qualified to do the analysis etc).

It is noted that currently NATA accredits the laboratory, it does not assess the competence of individual analysts.

Before November 2011, NATA Technical Assessors conducted an in-depth interview with each individual analyst and this included a technical assessment of the analyst by requiring them to analyse samples in front of the assessor.

After November 2011, individual analysts were no longer assessed in depth by a NATA technical assessor.

As noted, currently individual analysts are assessed in-house. A senior previously qualified analyst determines the competence of new analysts. They assign Approved Asbestos Analysts and/or Approved Asbestos Signatory status and the laboratory must have a documented process explaining how this is undertaken for review by NATA. However, NATA have not established guidance for how to do this in-house assessment of analysts and so, depending on the laboratory's standards, this may differ from one laboratory to the next.

There is a critical need to provide guidance on the minimum requirements for such in-house assessments or to require all relevant laboratories to participate in proficiency testing programs (see **Section 8.5**) to provide evidence that their in-house assessment schemes are robust.

8.5 Proficiency testing programs

ISO 17025 contains requirements for laboratories to monitor their performance through both internal and external proficiency testing programs.

There is a requirement in ISO 17025 that laboratories monitor their performance by comparison with results of other laboratories – this means they must participate in proficiency testing programs.

In the case of asbestos analysis, this applies to the individual analysts and not the laboratory itself. Each analyst must demonstrate their competency. This is done through samples provided and assessed by an external organisation. In Australia, the main provider is Proficiency Testing Australia (PTA), but there are international proficiency testing programs (USA and UK) that are also accepted by NATA.

The PTA scheme is more straightforward to use as it does not require importation of samples containing asbestos into Australia, however, it does have drawbacks. After the analyst submits their results, they must return the provided samples before results are made available. This scheme requires that the samples are returned as their pool of certified samples is limited and laboratories have observed samples being reused after a period of years. The problem is that this does not give the analyst the opportunity to recheck their observations if they did not get the right answer. This is an important step as it can help an analyst learn and improve their skills so they can do better the next time they participate in such testing (i.e. not so they change their result on this occasion). It is also noted that the PTA scheme provides soil samples of 30-50 g. This removes the requirement for sample reduction which is an important step in the analytical method.

To participate in the international proficiency testing programs, laboratories need to be able to import the supplied samples into Australia. Laboratories can apply for an exemption to import asbestos containing material into Australia. The exemption then allows them to import samples so they can participate in international schemes such as the UK HSE's asbestos in material scheme (AIMS) and asbestos in soil scheme (AISS).

For both of the UK schemes, laboratories do not have to return the supplied samples after the results have been submitted. This makes these schemes more helpful than the PTA scheme as the supplied samples can be valuable training samples for in-house assessments and training.

The UK HSE's AISS scheme provides two samples for testing – one for qualitative analysis and the other for qualitative and quantitative analysis. Approximately 400-500 g in weight of material is provided in these samples which is more aligned to the size of sample required for ASC NEPM analysis of 500 mL. This process, therefore, more closely resembles the everyday requirements for analysts undertaking these analyses.

8.6 Analysis using Australian Standard AS 4964-2004

8.6.1 General

In Australia, analysis is undertaken following Australian Standard 4964-2004 *Method for the qualitative identification of asbestos in bulk samples* [62]. This method outlines what procedures need to be followed in the laboratory for the qualitative identification of amosite, crocidolite and chrysotile in a bulk sample (i.e. building material, soil sample or mulch sample etc). It is noted that this method is currently being reviewed ("pending revision").

The method involves preparing a sample for viewing under a stereo-microscope. As per Clause 423 of the Model Work Health and Safety Regulations, if a sample is collected for analysis, the analysis must be undertaken by a National Association of Testing Authorities, Australia (NATA) accredited laboratory. The analysis of soils and ore is separately identified on a NATA Accreditation schedule.

8.6.2 Sample preparation and analytical equipment

AS 4964 outlines the preparation tools and equipment required for asbestos analysis including:

- Reagents e.g. refractive index fluids
- Dissolution agents, refer **Section 8.6.7**
- Agate mortar and pestle
- Furnace
- Polarized light microscope (PLM) and dispersion staining
- Sample handling tools such as non-serrated tweezers and dissecting needles or similar
- Stereo-microscope
- Sieves

8.6.3 Sample examination process

Sample preparation is required for asbestos analysis and is dependent on the matrix being analysed. Materials are examined and classified as homogeneous or non-homogeneous to determine the laboratory procedure. **Figure 8.1** shows the flowchart for bulk samples within AS 4964.

[62] https://store.standards.org.au/product/as-4964-2004?utm_source=standards.org.au&utm_medium=referral&utm_campaign=standards-catalogue

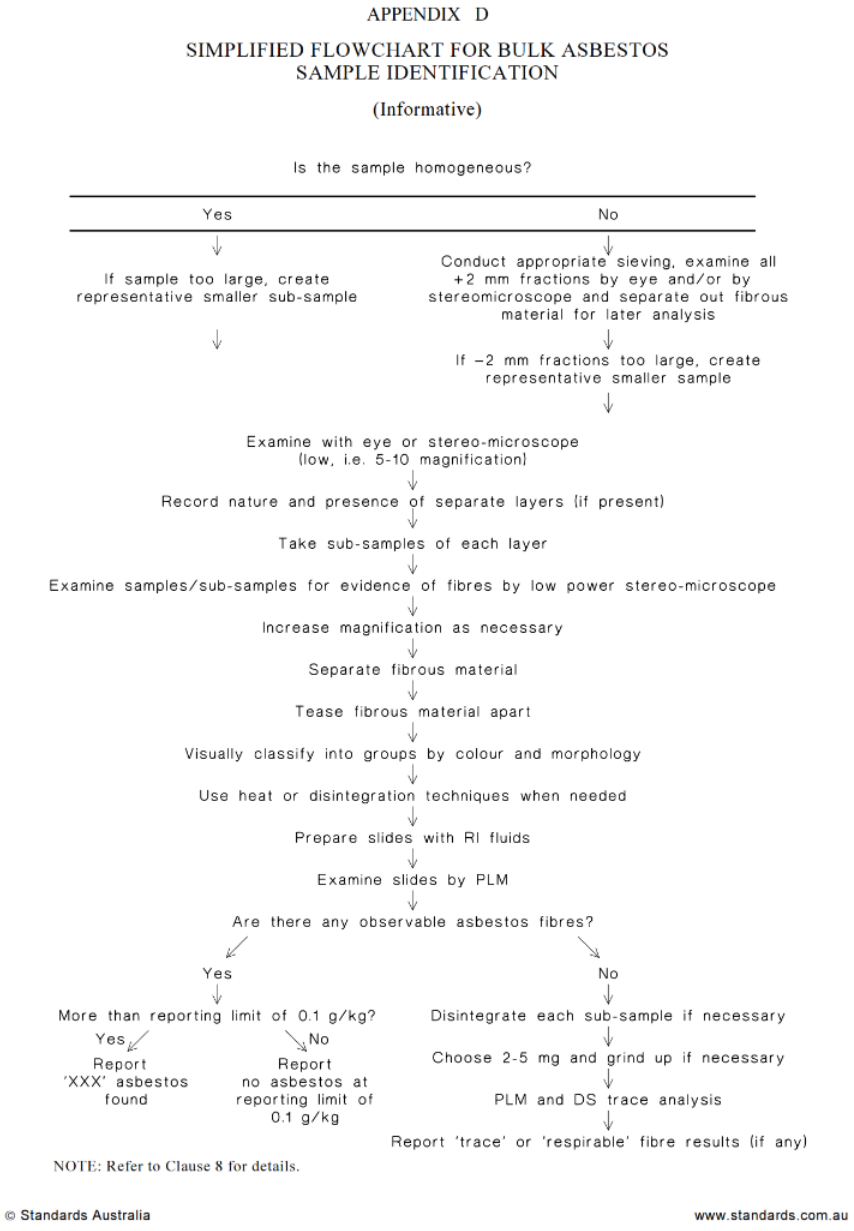

Figure 8.1: AS 4964 flowchart for bulk sample identification

8.6.4 Procedure for non-homogeneous analysis e.g. soil or mulch

The sample preparation procedure for soil (or mulch) is as follows:

- If the sample contains particles greater than 10 mm, then the whole sample (i.e. 500 mL sample as noted in **Section 5.2.2**) must be sieved through a 10 mm sieve at the laboratory.
- All the material collected on the sieve should be looked at under a magnifying glass and all fibrous matter should be collected for examination.
- For the material that went through the 10 mm sieve (i.e. ≤10 mm), further sieving through a 2 mm sieve should be undertaken.

- The material that is less than 10 mm but greater than 2 mm fraction of material must be examined under the microscope (low power).
- Any material that looks like fibres or suspected ACM is to be collected for further examination.
- If the ≤2 mm sieved material is greater than 60 g, the sample size is reduced to a sub-sample size of approx. 30 to 60 g for closer examination. The sample is then spread out to a thickness of no more than approximately 1 to 3 mm. The entire sub-sample is examined under the microscope with low and high power – and any material that looks like fibres or fibrous matter is taken for further examination.
- All the materials that look like fibres (fibre bundles/fibrous matter) need to be weighed and/or measured and using a suitable refractive index fluid, need to be subjected to polarised light microscopy with dispersion staining which allows confirmation of asbestos fibres or other fibres (i.e. placed on a microscope slide with an appropriate refractive index fluid and examined using the polarised light microscope and dispersion staining). The appropriate refractive index fluid is determined based on colour and morphology of the fibre.
- Sometimes these samples are heated to 400ºC before being subjected to the microscopy process to remove organic fibres like fine roots, mould spores and bodies, hyphae from fungi etc – this has no impact on the asbestos fibres as they do not degrade when heated to a maximum of 400 ±30°C.
- Finally, trace analysis is required on the sub-sample (≤2 mm sieved material) to identify if respirable sized asbestos fibres are present or fibres are present at very low concentrations.
- Trace analysis involves taking some small samples from the material, grinding the material if necessary, placing approximately 2-5 mg on a microscope slide using a suitable refractive index fluid and examining those samples in detail using polarised light microscopy/dispersion staining.

The method as outlined in AS 4964 is designed as a qualitative method.

However, as previously noted, most laboratories in Australia provide a % by weight concentration in line with the ASC NEPM method description. This is not an approved method for reporting under AS 4964 – i.e. not in line with accreditation under NATA for AS 4964 – however, it is accepted practice.

It is understood that some laboratories in Australia have NATA accreditation for in-house methods to report % by weight calculations although this is not the case for all laboratories undertaking this type of work in Australia. The process to allow such calculations would have to be clearly described in the in-house methods provided to NATA when the laboratory sought accreditation for that method.

There are recognised international methods for the separation of asbestos from the substrate and estimation of asbestos content in a sample (i.e. calculation of concentrations). Accreditation through NATA can be obtained for any international reference method which is adopted / adapted by laboratories and forms part of the quality management system for the laboratory. Uptake of such accreditation for various international methods for the analysis of asbestos containing materials by laboratories in Australia is not known.

8.6.5 Trace analysis

Asbestos fibres may be present in some samples at very low concentrations, or may be distributed throughout the sample, even though they are not visible before the disintegration process. The term ‘trace levels’ is used throughout AS 4964 to mean “at very low concentrations”. This term differs from the meaning of ‘trace analysis’ used in AS 4964 which refers to the analysis technique used to identify respirable sized asbestos fibres. Trace analysis is required for non-homogeneous samples and where no asbestos was identified in homogeneous samples.

For samples only containing trace levels, the following figure (**Figure 8.2**) provides guidance about how to report the results.

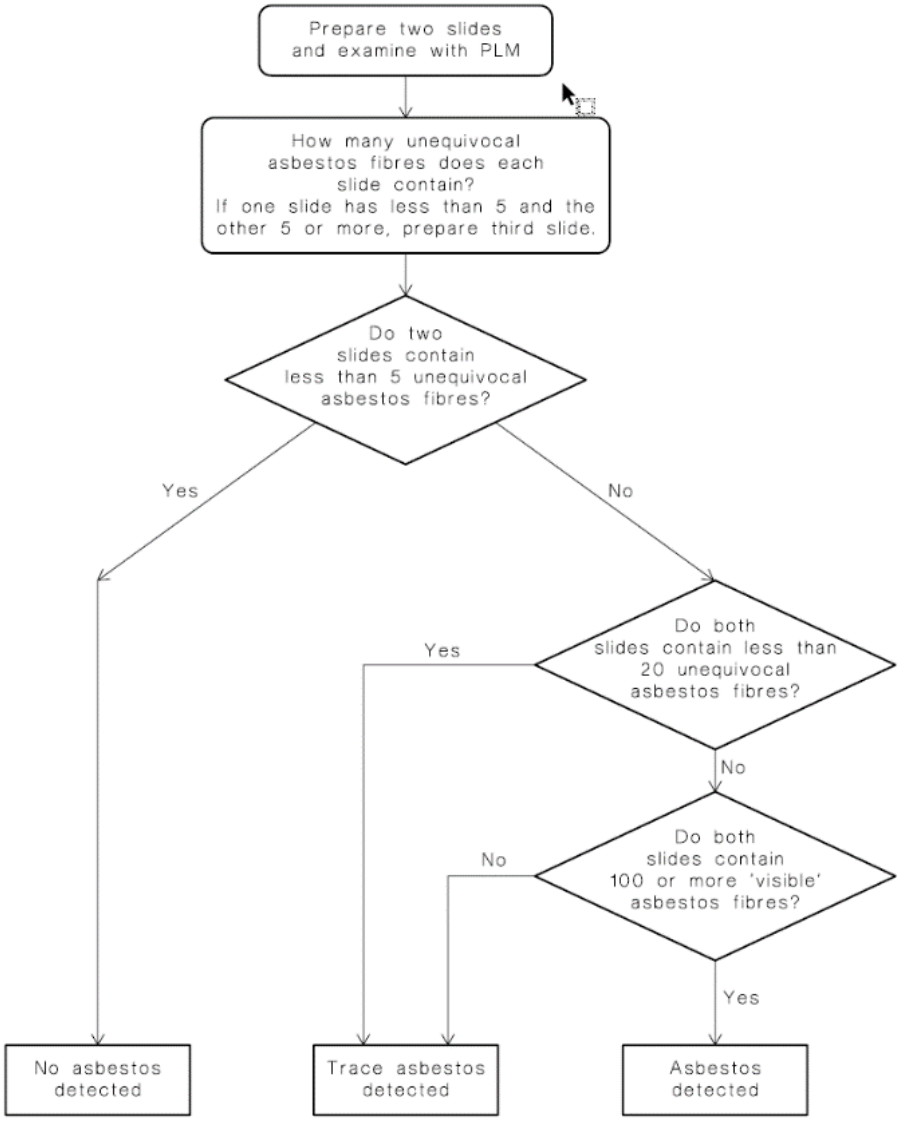

FIGURE 1 FLOW CHART FOR TRACE ASBESTOS PROCEDURE

Figure 8.2: AS 4964 flow chart for trace asbestos procedure

It is important to note that the Australian Standard (AS 4964 and proposed AS 5370) have a Reporting Limit of 0.01% w/w for respirable fibres. If the slides used for trace analysis contain less than 5 fibres that are determined to be asbestos, then the result is to be reported as ***"no asbestos was detected"*** in the sample.

8.6.6 Procedure for bulk sample analysis (homogeneous materials e.g. cement sheet)

The procedure for a bulk sample including where suspected ACM (e.g. cement sheet) is identified and removed as a sub-sample in soil or mulch is as follows:

- Examine the sample with a low power stereo-microscope to observe and record the presence and nature of any separate layers.
- Take sub-samples of each constituent layer of the sample, where required.
- Use a low power stereo-microscope to examine each sample and sub-sample in its entirety for evidence of fibres, increasing the magnification where necessary.
- Separate out fibres using dissecting needles or tweezers and visually classify the fibres into separate groups by means of colour and morphology.
- Place the fibres on a microscope slide with an appropriate refractive index fluid and examined using the polarised light microscope and dispersion staining.
- Trace analysis is required if there are no observable fibres. If examination has been able to fully characterise the sample and show that it does not contain asbestos, e.g. pure synthetic mineral fibre, trace analysis may not be necessary.

8.6.7 Sample treatment

Where required, interfering organic fibres or matter may be removed by treating the sample for several hours at a temperature not exceeding 400±30°C.

If no fibres are identified during the stereo-microscope assessment, it will be necessary to take a portion of each sub-sample and use an appropriate and effective disintegration procedure in order to free any fibres that may be present from the matrix. These disintegration methods may include:

- Crushing
- Grinding
- Scraping
- Ashing
- Use of an acid, alkali, detergent or solvent
- Stirring
- Ultrasonic treatment.

8.6.8 Analytical criteria

Unequivocal identification of asbestos fibres including chrysotile (White Asbestos), amosite (Brown Asbestos) and crocidolite (Blue Asbestos) is done using dispersion staining to determine the principal refractive indices of the fibres. This must be used in conjunction with other optical properties using polarised light microscopy. Optical properties used to confirm fibre type to support

dispersion staining include at least two and preferably three of the following in addition to the morphological features of the fibre:

- Pleochroism of the fibres
- Optical orientation in relation to the fibre axis
- Optical extinction in relation to the fibre axis

Birefringence strength and fibre colour can also be used in the identification process.

Conclusions on fibre type should be checked by comparing the observations against the diagnostic criteria.

8.6.9 Limit of reporting

Where pieces of asbestos containing materials that are larger than 2 mm (or even larger than 10 mm) are found in a bulk sample, it is possible to weigh those with sufficient accuracy and weigh the overall whole bulk sample to determine the % by weight and achieve a limit of reporting of 0.01% or even 0.001%. This estimation of concentrations is part of the ASC NEPM method description but is not included in the requirements for bulk samples within AS 4964. The trace analysis part of AS 4964 does allow the calculation of a concentration by weight as discussed below.

However, depending upon sample condition and fibre type, the limit of reporting for the trace analysis part of AS 4964 has been found to lie generally in the range of 1 in 1,000 to 1 in 10,000 parts by weight, equivalent to 1 to 0.1 g/kg (i.e. 0.1 to 0.01% by weight). It is not possible to get to 0.001% by weight for this part of the method. This detection limit (and the Reporting Limit) was determined empirically during method development.

For AS 4964, the term ‘trace asbestos detected’ implies a detection limit of 0.1 g/kg (0.01%), unless nature and type of sample indicates otherwise. Therefore, a product specification requirement (in the ASC NEPM for soil or in Resource Recovery orders or equivalent) of 0.001% is unrealistic as it cannot be measured by the currently available technology.

Furthermore, it is critical to remember that, at these low levels of asbestos (i.e. trace asbestos detected) in resource recovery type materials such as recovered fines, the risk due to respirable crystalline silica (RCS) in the material will be much greater than the risk due to exposure to low levels of airborne respirable asbestos fibres.

For resource recovery materials such as recovered fines, there should be controls in place while it is being used that provide controls to manage exposure to RCS. These controls will also be appropriate to adequately control potential exposure to extremely low levels of airborne respirable asbestos fibres.

8.6.10 Advantages of AS 4964

AS 4964 describes PLM as the primary technique for asbestos identification because of its simplicity, low cost and detection limit.

AS 4964 provides the following advantages:

- Meets current Australian WHS Regulation requirements for asbestos analysis of samples.
- It provides relatively simple sample preparation that enables a large proportion of commercial samples to be identified.
- Stereo-microscopy can distinguish between fibres and the non-fibrous parent material allowing for optical properties of fibres to be used in conjunction with dispersion staining for unequivocal indentation as an asbestos fibre.
- Any given type of asbestos possesses three refractive indices which all vary depending upon the location of the original ore body, the position inside the ore body, and the sample's history in terms of chemical agents, surface coatings and temperature. Although a considerable number of colour combinations are possible, provided a laboratory allows for the range of colours expected from the refractive index fluid, this is a reliable way to confirm fibre type.
- Portable – Field laboratories can easily be transported and set up for remote work and still be NATA Accredited.
- Quick analysis
- Results are repeatable between laboratories and technicians (*Note: For non-homogeneous samples such as soil and mulch, where low concentrations of asbestos are present in soil, results may not be repeatable due to the variability in the material being assessed rather than variability due to the laboratory or the technician. It's not advisable to collect duplicate asbestos in soil samples as the interpretation of results can be difficult or even misleading.*)
- International acceptance of results due to trustworthy results comes with analysis at a NATA Accredited laboratory.

8.6.11 Disadvantages of AS 4964

No attempt has been made in the Standard to quantify the amount of asbestos present apart from the descriptive terms 'asbestos detected', 'trace asbestos detected' or 'no asbestos detected'.

AS 4964 has the following known limitations:

- PLM is a qualitative technique only and doesn't provide the concentration of asbestos in samples.
  (There are recognised international methods for the separation of asbestos from the substrate and estimation of asbestos content in a sample. Accreditation through NATA can be obtained for these methods.
  We understand some laboratories have NATA approved in house methods for % weight by weight calculations although this is not representative of all asbestos laboratories. Methods used by individual laboratories are likely to differ between laboratories due to the lack of an Australian Standard with methods to reliably calculate and report on concentrations.)
- AS 4964 does not cover the identification of airborne and water-borne asbestos.
- AS 4964 notes that most samples of tremolite, actinolite and anthophyllite show a wide range of optical properties and cannot be unequivocally identified by PLM and dispersion staining. Due to the variability in their optical properties, when tremolite, actinolite or anthophyllite are detected by PLM, the results are reported as 'unknown mineral fibre' and their presence is confirmed by an independent analytical method.

- For valid asbestos identification, there must be sufficient sample of the unknown fibres for them to exceed the practical detection limit of the technique used.
- Sometimes, dispersion staining cannot be applied due to the effect of degraded samples, attached particles or coatings which means the fibres are not identifiable.
- Different sources of asbestos can lead to a variation in the optical properties shown by 'standard' reference materials.
- Heat degraded materials may cause analysis problems, e.g. heat-degraded crocidolite fibres can show optical orientation, colour and pleochroism different from those properties for 'standard' crocidolite.
- Even after disintegration, it may be difficult to detect the presence of asbestos in some asbestos-containing bulk materials using PLM and dispersion staining. This is due to the low grade or small length or diameter of the asbestos fibres present in the material, or to the fact that very fine fibres have been distributed intimately throughout the materials. Vinyl/asbestos floor tiles, some asbestos-containing sealants and mastics, asbestos-containing epoxy resins and some ore samples are examples of these types of material, which are difficult to analyse.
- Fibres finer than the resolving power of the microscope (ca. 0.3 µm) will not be detected.
- Independent confirming technique may be required such as infrared spectroscopy, X-ray diffraction, scanning electron microscopy or transmission electron microscopy, if PLM fails to give an unequivocal identification, or they require more complex sample preparation.
- Involves a lengthy training investment for technicians but this is relevant for all laboratory methods.
- There are other fibres that resemble either the serpentine or amphibole mineral groups as the morphological and/or optical properties are similar to asbestos. This can lead to misidentification particularly with an inexperienced analyst analysing non-homogeneous samples. AS 4964 is silent on this although it is a known disadvantage. Discussion regarding interfering fibres is included in HSG 248 (see **Section 8.7.8).**

8.7 Analysis using HSG 248

8.7.1 General

HSG 248 Asbestos: The Analysts Guide was first published in 2005 by the UK Health and Safety Executive. It was revised and the second edition was published in July 2021. It has been amended to align with the Control of Asbestos Regulations 2012 (CAR) in the UK. It contains guidance for analysts involved in asbestos work and is the authoritative source of asbestos analytical procedures within the UK.

HSG 248, when used in conjunction with ISO 22262-1 and AS 4964, provides the most comprehensive methodology for the identification of asbestos fibres in bulk building materials, soils, dusts, and ores.

Appendix 2 of HSG 248 (Determination of asbestos in bulk materials) explains the method used to examine the samples and to identify the type of asbestos present, together with guidance on record keeping and reporting.

HSG 248 also provides significantly more detail than AS 4964. It provides instructions on other matters including asbestos fibre air monitoring, clearance procedures for asbestos removal and information on personal safety such as the use of personal protective equipment (PPE), respiratory protective equipment (RPE) and decontamination processes. A commentary regarding these procedures is excluded from this report.

8.7.2 Competence and qualifications

Section 8.3 discusses the training and accreditation requirements for accredited analysts in Australia. HSG 248 provides significantly more information about these requirements as they apply to analysts in the UK. These much stronger requirements are discussed here to show the difference between Australia and the UK.

Specifically, section 3 of HSG 248 outlines the minimum competence and qualifications required by analysts undertaking asbestos assessment and related works in the UK.

The United Kingdom Accreditation Service (UKAS) assesses and accredits asbestos laboratories. Employers need to establish the functions, roles and duties of each individual analyst within their organisation together with the relevant qualifications, skills and expertise needed (i.e. the competencies required for each position) as part of UKAS Accreditation.

UKAS also provides accreditation for bulk sampling of ACM (i.e. collecting samples through asbestos identification surveys). Accreditation for sampling ACM by NATA is very uncommon in Australia whilst this type of accreditation in the UK is common.

To support the accreditation of individual positions, there are a wide range of training materials provided in the UK. This section references the British Occupational Hygiene Society (BOHS) materials including:

Asbestos Proficiency Modules

- P400 Asbestos Survey and Analysis (foundation course)
- P401 Identification of Asbestos in Bulk Samples (PLM)
- P402 Surveying and Sampling Strategies for Asbestos in Buildings
- P402RPT Report Writing for Asbestos Surveys
- P403 Air Sampling and Fibre Counting (PCM)
- P404 Clearance Testing and the Requirements for a Certificate for Reoccupation
- P405 Management of Asbestos in Buildings
- P408 Identification and Quantification of Asbestos in Soils
- P409 Strategies and Sampling of Soils for Asbestos (planned publication 2021)
- P410 Management of Asbestos Projects by the Analyst (planned publication 2021)
- D407 Managing Asbestos in Premises – The Dutyholder Requirements
- D412 Senior Management Responsibilities for Managing Asbestos
- D413 Asbestos Management Practicalities and Awareness
- CoCA Certificate of Competence in Asbestos

Refresher courses

- RP402 Surveying and Sampling Strategies for Asbestos in Buildings
- RP404 Clearance Testing and the Requirements for a Certificate for Reoccupation
- RP405 Management of Asbestos in Buildings

HSG 248 also references similar courses/qualifications provided by Royal Society for Public Health including those listed below:

- RSPH Level 3 Award in Asbestos Bulk Analysis
- RSPH Level 3 Award in Asbestos Surveying
- RSPH Level 3 Award in Asbestos Air Monitoring and Clearance Procedures
- RSPH Level 3 Award in Asbestos Management for Dutyholders
- RSPH Level 4 Certificate in Asbestos Laboratory and Project Management

Analysts can obtain qualifications and affiliations/memberships with professional associations that are designed to enhance their role, competence and authority. For example, the Faculty for Asbestos Assessment and Management (FAAM) has been established by the British Occupational Hygiene Society (BOHS). FAAM offers several grades of membership to promote professional recognition.

These types of courses and classifications of skill level do not exist in Australia.

8.7.3 Sample preparation and analytical equipment

HSG 248 outlines in detail the requirements for sample preparation and analytical equipment, including:

- Precautions for minimising the risk of release of asbestos fibres into the laboratory environment (Sample preparation must be conducted inside a fume cupboard, or in a suitable cabinet under HSG 248)
- Microscope, optical requirements, and camera systems (optional)
- Tools for sample preparation
- Reference Samples
- Reagents and other consumables
- Laboratory safety:
    - Equipment and design requirements
    - Maintenance and housekeeping

8.7.4 Sample examination process

Figure 8.3 shows the work flow for sample examination from HSG 248.

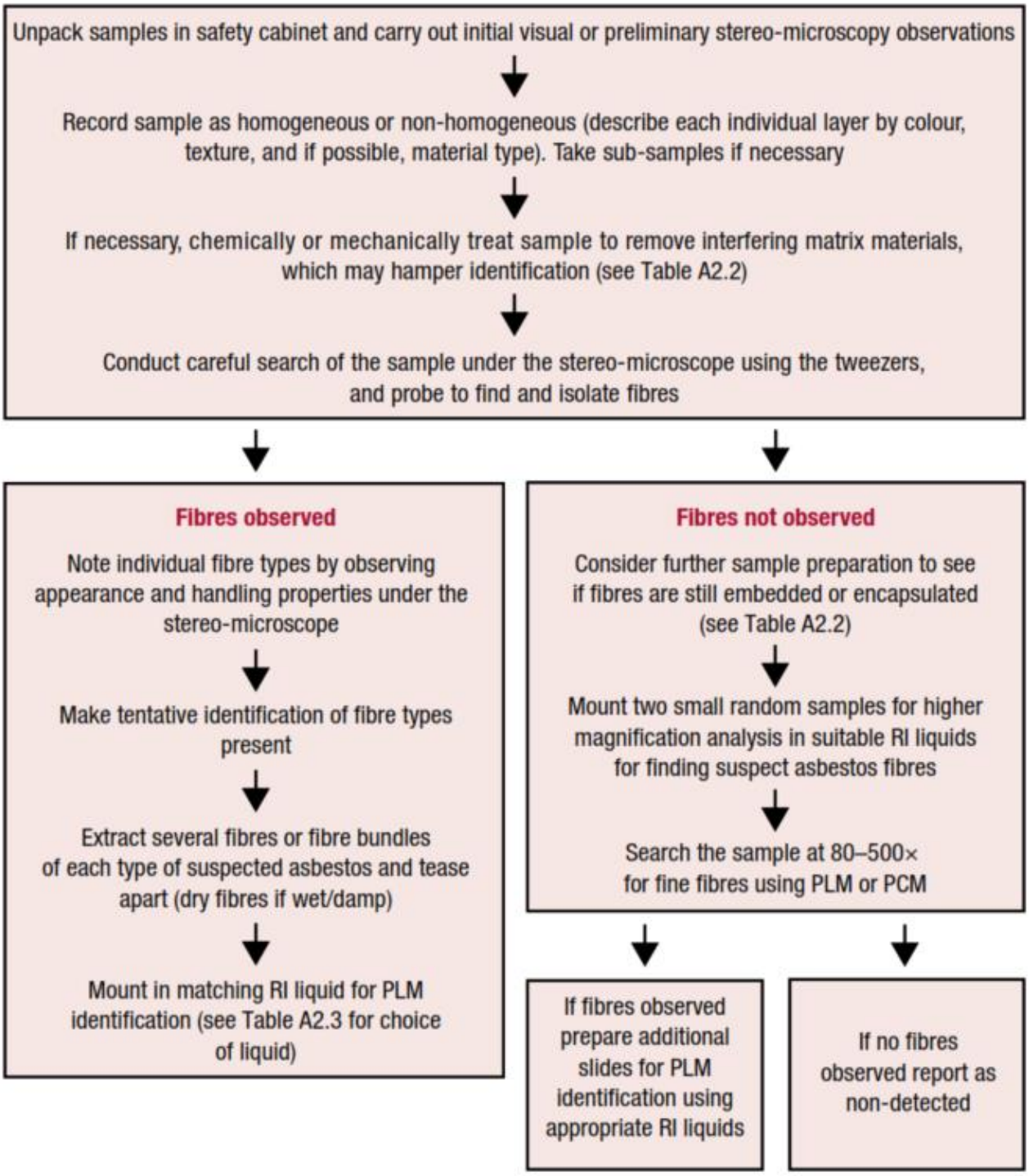

Figure 8.3: HSG 248 Sample examination work flow

8.7.5 Sample treatment

To identify asbestos fibres by PLM, it is necessary to isolate the fibres from the sample matrix material and it may be necessary to remove fine particles adhering to the fibres (both of which obscure optical effects and hinder identification).

Sections A2.18 to A2.25 of HSG 248 list the methods for sample treatment to isolate/release asbestos fibres from the sample matrix and include:

- Break-up of resistant (bonded) materials
- Acid treatment
- Solvent treatment
- Ashing
- Disaggregation (used in sample preparation for loose soils and aggregates – involves placing the sample in denatured alcohol or using pressure on the coverslip to separate fine attached particles in the RI liquid – goal is to separate the fibres from particles (where fibres may include asbestos and non-asbestos fibres))
- Sedimentation (used in sample preparation for vermiculite – separates particles by size using flotation – goal is to separate the fibres from particles (where fibres may include asbestos and non-asbestos fibres))
- Specialised product treatment (combination of the above methods).

8.7.6 Analytical procedures

The analytical procedure under HSG 248 is very similar to AS 4964 as follows:

- The sample is removed from its packaging and a preliminary visual examination of the whole of the bulk sample is made to assess the sample and material type.
- If samples are non-homogeneous and consist of layers of different material or are samples of debris made up of several different materials: each layer or material will need to be examined. An assessment of the required sample treatment (if any) will need to be made. (A representative sub-sample may be taken at this stage.)
- Sample treatment is undertaken (refer **Section 8.7.5**) to release or isolate fibres.
- A detailed and thorough search under the stereomicroscope is made to classify the fibre types present.
- Representative fibres of each suspected asbestos type seen are mounted in appropriate refractive index fluid on microscope slides.
- The different selected fibrous components are either identified using PLM, as one of the six regulated asbestos types, or determined to be non-asbestos.
- If no asbestos is identified by these procedures, additional searches for small asbestos fibres on random sub-samples of a few milligrams are undertaken using PLM (similar to the AS 4964 trace analysis technique) – i.e.
    - Mount two small random samples for higher magnification analysis in suitable RI liquids for finding suspect asbestos fibres
    - Search the sample at 80–500× for fine fibres using PLM or PCM.

8.7.7 Analytical procedures for non-homogeneous samples e.g. soil & mulch

HSG 248 provides a vague description for analysis of dust:

> "*For dust samples, an enhanced examination of the sample is needed with the analyst methodically searching through the sample using a stereomicroscope*"

noting that the analysis is the same as for bulk materials.

HSG 248 differs to AS 4964 in the preparation and analysis of soil samples. For larger non-homogeneous samples (e.g. soil samples), large plastic or foil trays are used to allow visual inspection of the entire sample in HSG 248. Soil samples with no visible fragments of ACMs or asbestos fibres require several sub-samples to be taken and mounted on microscope slides and searched using PLM for fine fibres using higher magnifications (> 100x), refer **Figure 8.4**.

HSG 248 does not give a detailed method for measuring the asbestos mass/concentration of asbestos fragments but uses sampling procedures that are compatible with other published sampling methods. Consequently, these samples can be further analysed after drying (or stored for further analysis) to allow the asbestos concentration by weight (%) to be determined if and when required. UKAS requires that soil analysis for asbestos is separately identified on the accreditation schedule of a laboratory – i.e. it is not assumed that analysts with skill and experience in identifying asbestos fibres in building materials like asbestos cement sheeting or vinyl tiles are also sufficiently skilled and experienced to undertake analysis of non-homogeneous materials like soil.

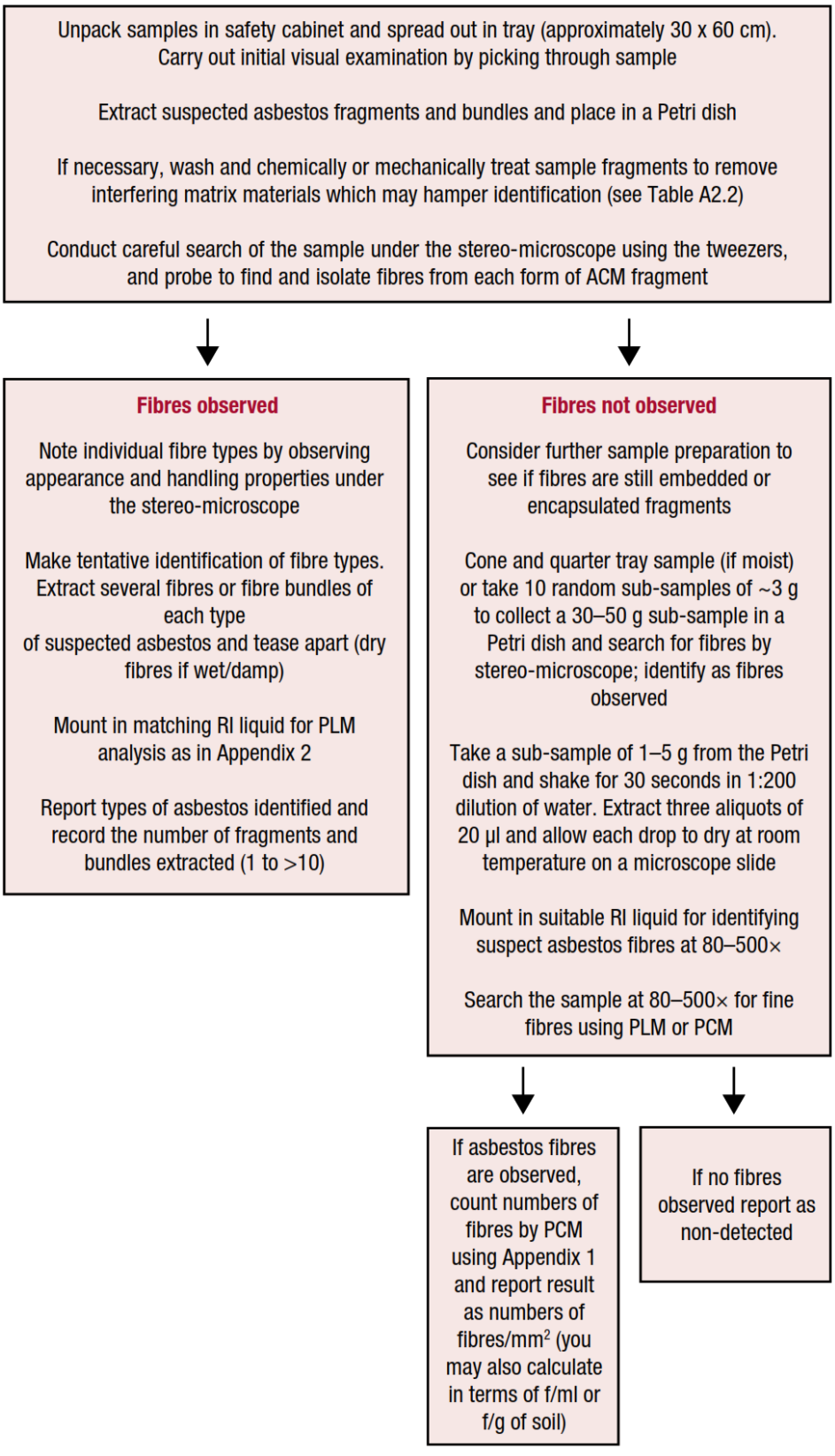

Figure 8.4: HSG 248 Examination/work flow for analysis of asbestos in soil samples

8.7.8 Interfering fibres

Sections A60 – A68 in HSG 248 list fibres with morphological and/or optical properties similar to those of asbestos and include:

- Shredded polyethylene
- Leather swarf fibres
- Macerated aramid fibres
- Spider web
- Talc fibres
- Fibrous brucite and wollastonite
- Diatomaceous earth – acicular fragments.

Most of these interfering fibres occur infrequently in samples. However, analysts need to be aware of their existence and their distinguishing characteristics in PLM.

8.7.9 Limit of reporting

With careful application of this method, a single fibre may be found in a few milligrams of dispersed material. In theory, for a fibre about 100 µm long by about 2 µm diameter, this implies an analytical sensitivity (based on one fibre found) in the order of 1 ppm by mass (i.e. 1 mg/kg or 0.001 g/kg which equates to 0.0001%). In practice, the detection limit will be higher (i.e. less sensitive) as there are a number of matrix-dependent factors that may make it more difficult to detect and identify the asbestos fibres.

8.7.10 Advantages of HSG 248

The advantages of HSG 248 are similar to AS 4964 (refer **Section 8.6.10**) although establishing a field laboratory would prove more challenging as a fume cupboard is required. Differing advantages include:

- Allows for analysis of all six regulated asbestos types.
- Contains a highly detailed description of the analytical technique.

8.7.11 Disadvantages of HSG 248

The disadvantages of HSG 248 are similar to AS 4964 (refer **Section 8.6.11**). Differing disadvantages include:

- Difficulties may occur in:
  - identifying fibres below about 1 µm width
  - distinguishing between tremolite and actinolite or between tremolite and anthophyllite
- In such cases, electron microscopy with energy dispersive X-ray analysis (EDXA) and/or electron diffraction techniques, X-ray diffraction or infra-red spectroscopy can be used to provide additional information.

8.8 Australian Standard DR AS 5370-202X

8.8.1 General

The Standards Australia CH-013 Committee Methods for Examination of Workplace Atmospheres has spent the last 4 years developing a standard to replace “AS 4964-2004 Method for the qualitative identification of asbestos in bulk samples”.

The new standard is to be known as “AS 5370 Sampling and qualitative identification of asbestos in bulk materials (ISO 22262-1:2012, MOD)”. It is based on “ISO Standard ISO 22262-1:2012 Air quality — Bulk materials — Part 1: Sampling and qualitative determination of asbestos in commercial bulk materials”.

As noted in **Section 8.2**, this updated standard was nearing completion at the time of preparing this report. Timing for the change from AS 4964 to the new final version of AS 5370 is not known.

8.8.2 Document structure

ISO 22262-1:2012 is a copyrighted standard. Consequently, the document text could not be directly modified to incorporate the requirements for Australian / New Zealand conditions.

Instead, the draft of the new standard consists of the text from ISO 22262-1:2012 plus Australia/New Zealand specific requirements in appendices and text boxes headed ‘National Variations’ (as shown below).

NATIONAL VARIATION

Seventh paragraph, *delete* the second sentence, which begins with “When the definition...”.

For practical purposes, since no known commercial materials exist in which commercial asbestos was intentionally added at mass fractions lower than 0,1 %, this part of ISO 22262 specifies that samples be classified as asbestos-containing (i.e. containing more than 0,1 % asbestos) if either chrysotile, amosite, crocidolite or anthophyllite, or any of these varieties in combination, is detected in the analysis. When the definition of an asbestos-containing material is either 0,5 % or 1 %, depending on the nature of the product, it is often necessary to proceed to other parts of this International Standard in order to quantify the asbestos for the purpose of defining the regulatory status of the material.

NATIONAL VARIATION

Eighth paragraph, *delete* the second sentence, which begins with "Accordingly, determination...".

The occurrence of tremolite, actinolite or richterite/winchite in a material is usually a consequence of natural contamination of the constituents, and the detection of these minerals does not necessarily indicate that the mass fraction is more than 0,1 % asbestos. Accordingly, determination of the regulatory status of these materials by any of the criteria can often be achieved only by quantitative analysis. Since these minerals were not specifically mined and utilized for their fibrous properties, they may also occur in materials as either non-asbestiform or asbestiform analogues, or as mixtures of both. Evaluation of these types of material may require a more detailed analysis.

In particular, the proposed Australian Standard DR AS 5370:2023 includes fundamental and significant components of the analytical processes in normative appendices rather than the text in the main body of the standard.

For example:

- Appendix ZA (normative) Asbestos identification techniques
- Appendix ZB (normative) Analysis of soils, dusts, aggregates, and minerals
- Appendix ZC (normative) Residual analysis of non-homogenous samples

Having the requirements for an Australian / New Zealand Standard presented as amendments to the ISO Standard in national variation text boxes and normative appendices has been the topic of some considerable debate on the Committee. While some members do not consider this to be an issue, others are of the opinion that it makes reading and using the document cumbersome and confusing. This issue is further exacerbated where there is a significant number of minor alterations to the Draft Standard.

The period for public comment has closed and the ballot for eligible committee members to vote on the acceptability or otherwise of the draft standard closed in May 2024. The result of this member ballot is not yet known.

8.8.3 Analytical methodology

Despite the issues highlighted in the previous section (**Section 8.8.2**), using the ISO 22262-1 international standard as the basis for the updated standard was good as it is a good technical standard which provides comprehensive summaries of the requirements for qualitative analysis of asbestos fibres by:

- Polarised Light Microscopy and Dispersion Staining (PLM)
- Scanning Electron Microscopy (SEM)
- Transmission Electron Microscopy (TEM).

Generally, it is viewed that SEM is useful for taking photos of the fibres *in situ* but TEM will be the method of choice in the future if it is decided to progress from PLM.

In addition to summarising the requirements for SEM and TEM, ISO 22262-1 specifies the technical requirements for analysis by PLM in far greater detail than AS 4964. However, it lacks specification of a method for trace analysis as is presented in AS 4964.

Polarised Light Microscopy (PLM) is by far the most popular and suitable method in Australia for the screening analysis of bulk building materials, soils, and ores for asbestos.

There are comparatively few commercial laboratories in Australia offering asbestos analysis by SEM or TEM. This is primarily based on instrumentation costs and lack of available trained operators. If the need for SEM/TEM develops in Australia due to new standard requirements or industry expectations, the capability of laboratories to offer this type of analysis will increase but the cost of this type of equipment is likely to remain a barrier for many laboratories, particularly the smaller ones. Furthermore, it will take a decade to build realistic commercial capacity in Australia to allow for appropriate upskilling of analysts as well as purchase/installation of such equipment.

8.8.4 Scope

The draft AS 5370 (and the original ISO 22262.1) specify methods for sampling bulk materials and the qualitative identification of asbestos in specific types of manufactured asbestos-containing products, soils, dusts, aggregates, minerals, and commercial minerals. It specifies procedures for separation of asbestos fibres from matrix materials such as asphalt, cement, and plastics products. It contains sample preparation procedures and describes in detail the methodology for identification of asbestos by polarised light microscopy and dispersion staining. Optionally, identification of asbestos can be carried out using scanning electron microscopy or transmission electron microscopy with energy dispersive X-ray analysis.

Information is also provided on common analytical problems, interferences and other types of fibre that may be encountered in the analysis for all methods**.**

8.8.5 Principle

Section 4 of DR AS 5370 (and ISO 22262-1) summarises the general principles for analysis by PLM with the option that fibres may be identified by SEM or TEM.

Types of samples – The method is applicable to sampling and analysis of commercial products, soils, dusts, aggregates and minerals from which individual fibres of asbestos can be manually separated from the matrix material, either by picking fibres from surfaces and newly fractured surfaces, or after chemical treatments, acid extraction or ashing, such that the fibres can be identified by one of the specified identification methods.

Range – The analytical range for suitably prepared samples in which the asbestos fibres are sufficiently large to be optically visible using a low-magnification stereomicroscope, is from less than 0.1 % to 100 %.

Limit of Detection/limit of reporting – The limit of detection of this method is defined as the level where detection and identification of one fibre or fibre bundle in the amount of sample can be found. It depends on:

- the nature of the matrix of the sample
- the size of the asbestos fibres and bundles
- the use of appropriate sample preparation and matrix reduction procedures
- the amount of time expended on examination of the sample
- the method of analysis used — PLM, SEM or TEM (although the rate limiting step is finding the fibres initially be stereo microscopy rather than their identification as asbestos fibres or other fibres).

It is noted that with suitable sample reduction and preparation, the limit of detection/limit of reporting can be reduced to <0.01% by weight.

Limitations of PLM – The ability to detect and identify asbestos by PLM is limited by the:

- Resolution of the optical microscope. Asbestos fibres with widths below approximately 0.2 µm are unlikely to be detected by PLM. However, for most asbestos types, a large

proportion of the mass comprises fibres that exceed this width and, therefore, can be reliably detected by PLM.
- Masking effects of other materials or obscured by the sample matrix. Accordingly, provided that the nature of the matrix material is such that it does not obscure any asbestos fibres present, a non-detected result by PLM indicates that the mass fraction of asbestos is below the limit of detection.

8.8.6 Sample preparation

Section 6 of the draft standard outlines the requirements for sample preparation, including:

- Ashing
- Removal of acid soluble materials
- Sedimentation and flotation
- Gravimetric reduction
- Dispersal of materials in liquid by ultrasonication.

8.8.7 Polarised light microscopy (PLM)

The identification of asbestos (and other mineral/materials) is made by examining the optical properties of individual fibres. It is beyond the scope of this review to comprehensively summarise the analytical process other than to note that it requires the observation of the following properties in the stated observation modes:

- morphology — observed in all illumination conditions
- colour and pleochroism — observed in plane polarised light
- birefringence — observed with crossed polars
- extinction characteristics — observed with crossed polars
- sign of elongation — observed with crossed polars and a 530 nm retardation plate inserted
- refractive indices — assessed under darkfield illumination using plane polarised light.

The above order of observations facilitates the assessment of the morphological and optical properties in a logical sequence.

Other information is included in:

- Annex B – the Michel-Lévy interference colour chart for estimating birefringence
- Annex C – the dispersion staining charts for the α and γ refractive indices of the various asbestos types in the appropriate RI liquids.
- Annex D – pictorial examples of the various asbestos types for observation of:
    - morphology
    - colour and pleochroism
    - sign of elongation
    - dispersion staining colours for the determination of the refractive indices of fibres.

8.8.8 Electron microscopy

Once fibres are found in a sample, they need to be identified as asbestos or not asbestos.

The identification of asbestos in some types of bulk materials can yield ambiguous results using PLM. Examination by electron microscopy (EM) (i.e. either SEM or TEM) can resolve the ambiguities and provide definitive identification of the fibres. In most cases, acquisition of an energy dispersive x-ray analysis (EDXA) spectrum can identify the asbestos varieties. EDXA is an analytical technique used for the elemental analysis or chemical characterisation of a sample.

It is beyond the scope of this review to comprehensively summarise the analytical processes for SEM and TEM. The standard summarises the requirements for the identification of asbestos by:

- Scanning Electron Microscopy (SEM)
- Transmission Electron Microscopy (TEM)

It also summarises the acquisition of EDXA spectra for each of the EM methods to determine the elemental composition of the fibres under examination. The elemental composition is used to determine the asbestos fibre type.

The added advantage of TEM is analysis by electron diffraction that provides data on the crystal structure of the fibre under examination and provides definitive evidence of the asbestos fibre type.

More information on these methods is included in the following sections of the draft AS 5370/ISO 22262.1:

- Annex E – SEM: including examples of EDXA spectra for each of the asbestos types.
- Annex F – TEM: including examples of EDXA spectra for each of the asbestos types and selected area electron diffraction (SAED) pattern for chrysotile.

8.8.9 Normative appendices

General

As noted, the draft AS 5370/ISO 22262.1 includes more detailed information in a number of appendices. These are discussed below.

Appendix ZA: asbestos identification techniques

Appendix ZA summarises the techniques for the identification of asbestos. The relevant attributes for each of the techniques are summarised in the diagram shown in **Figure 8.5**.

Figure 8.6 shows the work flows for the initial examination of samples of commercial materials.

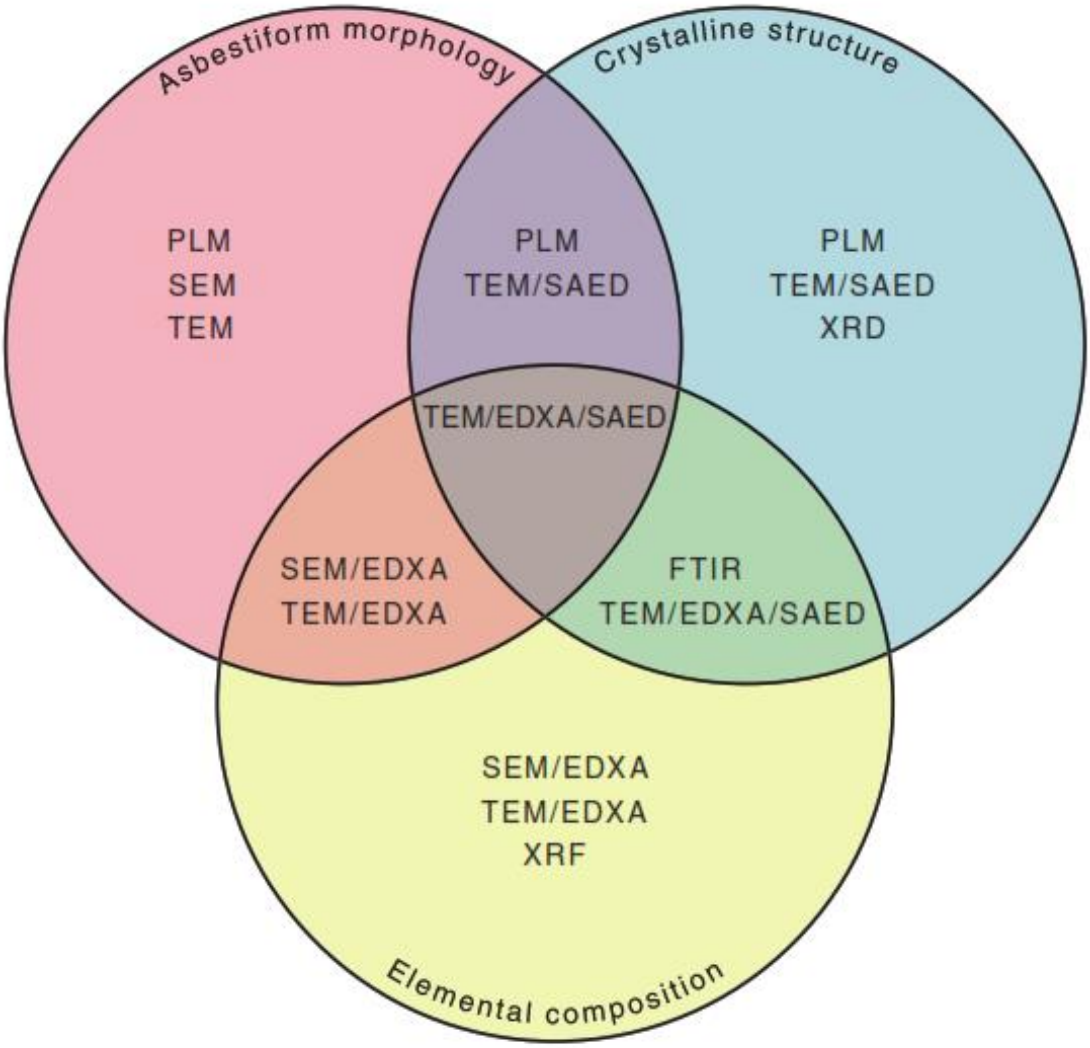

Figure 8.5: Fundamental properties and analytical techniques for asbestos (Appendix ZA in DR AS 5370)

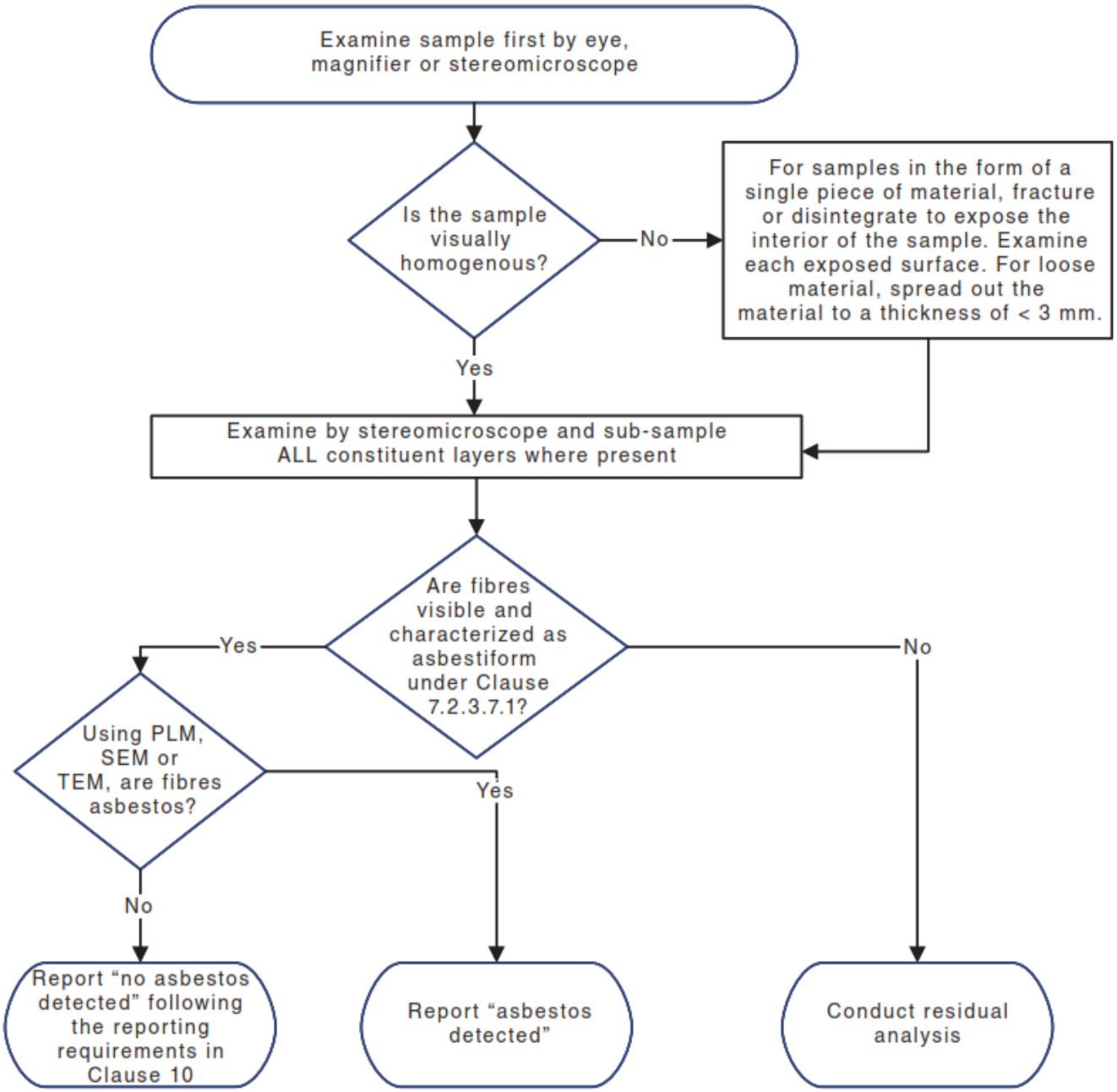

Figure 8.6: Initial examination process for commercial materials

Appendix ZB – analysis of soils, dusts, aggregates, and minerals

Appendix ZB summarises sample examination process for the analysis of soils, dusts, aggregates, and minerals. The work flow is shown in **Figure 8.7**. This involves screening the samples into the following fractions:

- >7 mm fraction
- ≤7 mm - >2 mm fraction
- ≤2 mm fraction.

Each of the fractions is examined for evidence of asbestos fibres by stereo microscope.

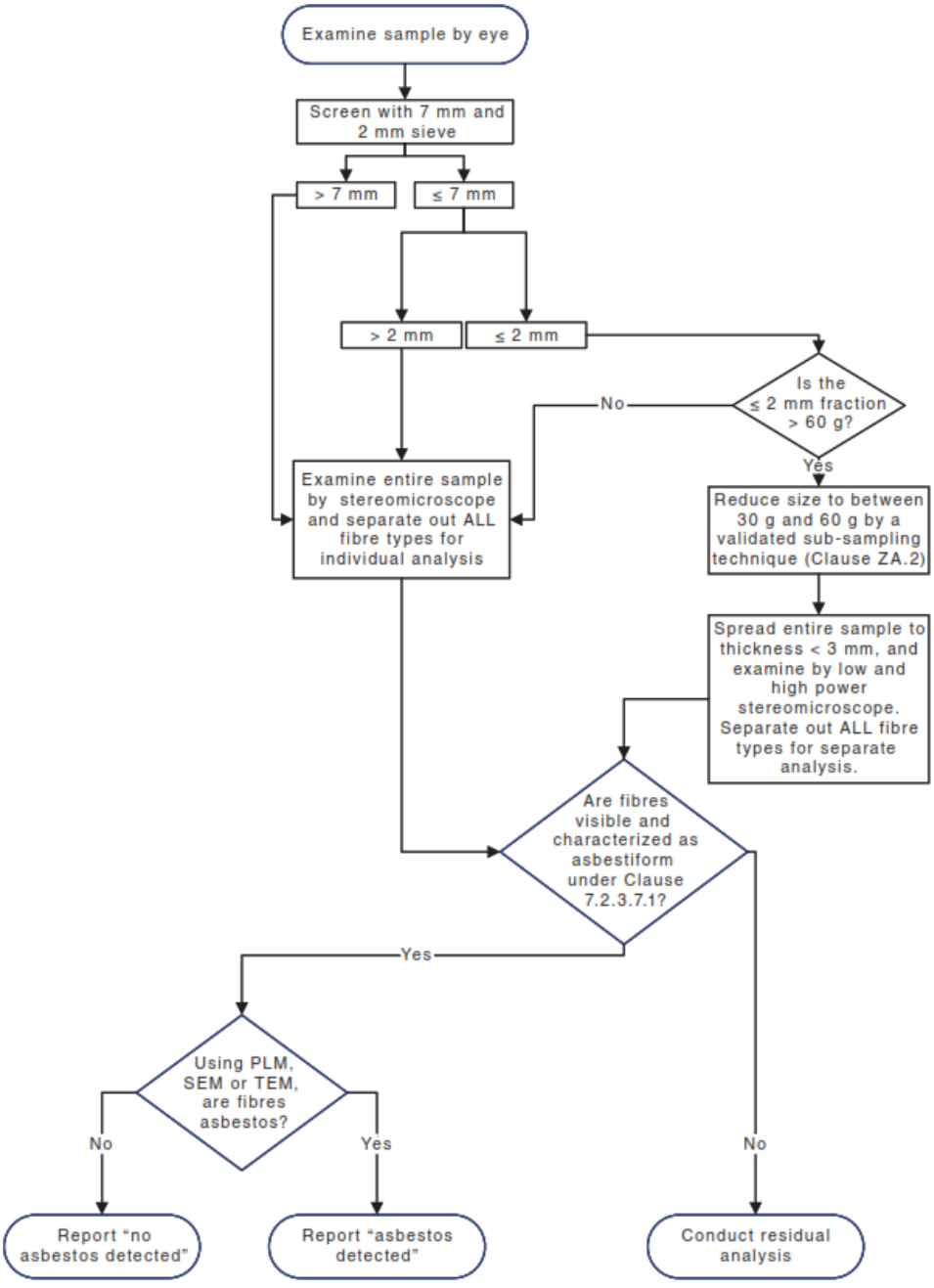

Figure 8.7: Initial examination process for soils, dusts, aggregates, and minerals

Appendix ZC – residual analysis of non-homogenous samples

Appendix ZC summarises the procedures and criteria for the residual analysis of non-homogenous samples. **Figure 8.8** outlines the work flow for this type of analysis.

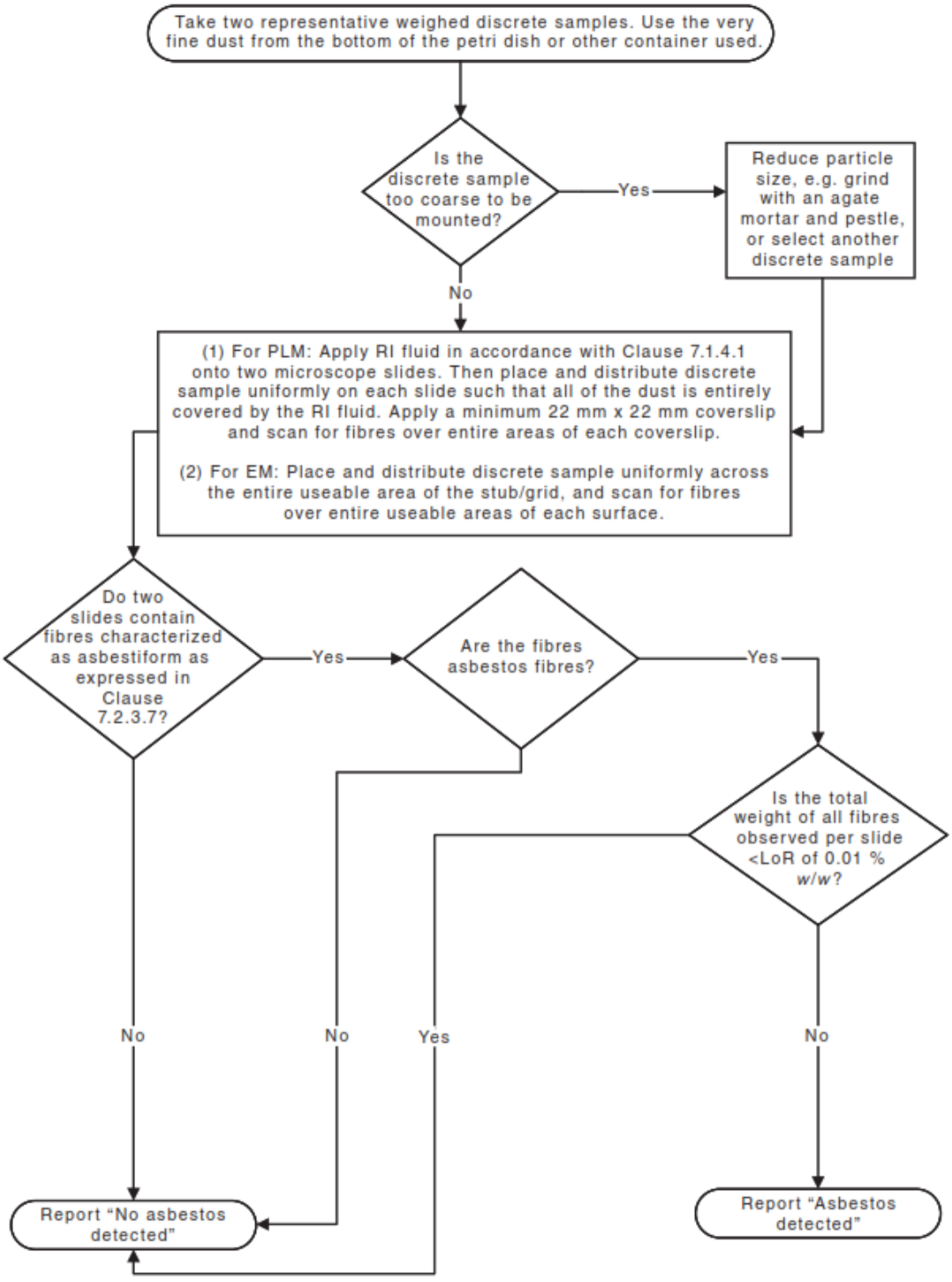

Figure 8.8: Residual analysis

8.9 ISO Standard ISO 22262-1:2012: Sampling and qualitative determination of asbestos in commercial bulk materials

ISO Standard ISO 22262-1:2012 “Air quality — Bulk materials — Part 1: Sampling and qualitative determination of asbestos in commercial bulk materials” was used as the basis for the development of DR AS 5370. Discussion of the ISO Standard has, therefore, already been included in **Section 8.8** and this discussion is not repeated here.

This ISO standard, when used in conjunction with HSG 248 and AS 4964, provides the most comprehensive methodology for the identification of asbestos fibres in bulk building materials, soils, dusts, and ores.

8.10 ASTM International

8.10.1 General

ASTM International was formerly known as the American Society for Testing and Materials. It is a non-profit organisation that develops and publishes a wide range of technical standards covering the procedures for testing and classification of materials. Over 12,500 voluntary consensus standards currently operate globally.

The ASTM International website lists 240+ documents relating to asbestos including Active Standards, Withdrawn Standards, Journal Articles, Research Reports, and Symposia Papers.

The document most relevant to the topic of this review are:

- ASTM D7521-22 – Standard Test Method for Determination of Asbestos in Soil.

The number immediately following the year indicates when the latest revision was published.

In addition, another useful ASTM document is:

- ASTM Advances in Environmental Measurement Methods for Asbestos STP1342-EB-DL.25664, Michael E. Beard and Harry L. Rook, editors, January 2000.

This publication contains papers presented at the symposium of the same name held 13-17 July 1997 in Boulder, Colorado. The symposium was sponsored by ASTM Committee D-22 on Sampling and Analysis of Atmospheres, and by the Environmental Information Association. The conference chairmen and co-editors of the publication were Michael E. Beard, Consultant and Harry L. Rook, NIST.

8.10.2 ASTM D7521-22 Standard test method for determination of asbestos in soil

General

This Standard was developed by the ASTM Subcommittee D22.07 Sampling, Analysis, Management of Asbestos, and Other Microscopic Particles. The Standard was originally approved in 2013, revised in 2016, and most recently updated in 2022.

This analysis method is used for the testing of soil samples for asbestos. The emphasis is on detection and analysis of sieved particles for asbestos in the soil. Debris identifiable as bulk building material that is readily separable from the soil is analysed and reported separately.

Scope

The scope for this method is summarised in Section 1 of the Standard Test Method D7521-22 and the relevant sections are copied below.

- Section 1.1 This test method covers a procedure to: (*1*) identify asbestos in soil, (*2*) provide an estimate of the concentration of asbestos in the sampled soil (dried), and (*3*) optionally to provide a concentration of asbestos reported as the number of asbestos structures per gram of sample.
- Section 1.2 In this test method, results are produced that may be used for evaluation of sites contaminated by construction, mine and manufacturing wastes, deposits of natural occurrences of asbestos (NOA), and other sources of interest to the investigator.
- Section 1.3 This test method describes the gravimetric, sieve, and other laboratory procedures for preparing the soil for analysis as well as the identification and quantification of any asbestos detected. Pieces of collected soil and material embedded therein that pass through a 19-mm sieve will become part of the sample that is analysed and for which results are reported.
- Section 1.3.1 Asbestos is identified and quantified by polarised light microscopy (PLM) techniques including analysis of morphology and optical properties. Optional transmission electron microscopy (TEM) identification and quantification of asbestos is based on morphology, selected area electron diffraction (SAED), and energy dispersive X-ray analysis (EDXA). Some information about fibre size may also be determined. The PLM and TEM methods use different definitions and size criteria for fibres and structures. Separate data sets may be produced.
- Section 1.4 This test method has an analytical sensitivity (i.e. limit of reporting) of 0.25 % by weight with optional procedures to allow for an analytical sensitivity of 0.1 % by weight.
- Section 1.5 This test method does not purport to address sampling strategies or variables associated with soil environments – such considerations are the responsibility of the investigator collecting and submitting the sample. Appendix X2 covers elements of soil sampling and good field practices.

Significance and use

The significance and use for this method are summarised in Section 5 of the Standard Test Method D7521-22, the relevant sections are copied below.

- Section 5.1 This analysis method is used for the testing of soil samples for asbestos. The emphasis is on detection and analysis of sieved particles for asbestos in the soil. Debris identifiable as bulk building material that is readily separable from the soil is to be analysed and reported separately.
- Section 5.2 The coarse fraction of the sample (>2 mm to <19 mm) may contain large pieces of asbestos-containing material that may release fibres and break down during the sieving process into smaller pieces that pass through the 2-mm sieve into the medium fraction. If

this alteration of the original sample is not desired by the investigator, these pieces should be removed from the sample before sieving and returned to the coarse fraction before analysis.

- Section 5.3 This test method does not describe procedures or techniques required to evaluate the safety or habitability of buildings or outdoor areas potentially contaminated with asbestos-containing materials or compliance with federal, state, or local regulations or statutes. It is the investigator's responsibility to make these determinations.
- Section 5.4 Whereas this test method produces results that may be used for evaluation of sites contaminated by construction, mine, and manufacturing wastes; deposits of natural occurrences of asbestos; and other sources of interest to the investigator, the application of the results to such evaluations and the conclusions drawn there from, including any assessment of risk or liability, is beyond the scope of this test method and is the responsibility of the investigator.

Method details

In a similar manner to AS 4964 and DR AS 5370, ASTM D7521-22 uses differential sieving of soil rather than grinding and homogenisation of soil. The soils are dried and screened with 19 mm, 2 mm and 106 µm mesh sizes. The method also provides for wet sieving of soil as an alternative method. The >19 mm fraction is not considered to be soil and is removed and analysed separately from the method (i.e. the results are not included with the other 3 fractions).

The remaining material is graded as follows:

- Coarse fraction: ≤ 19 mm to > 2mm
- Medium fraction: ≤ 2 mm to > 106 µm
- Fine fraction: ≤ 106 µm

The three particle size fractions are each analysed by stereomicroscopy and PLM to identify asbestos and visually estimate the concentration. If a single asbestos structure is observed in any of the fractions, a value of 0.25% is used for the nominal sensitivity/result. If asbestos is identified at <1% in the fine fraction, a point count is performed by preparing eight separate slide mounts and examine at 100× following EPA 600/R-93/116 until 400 points are counted (this is detailed in Section 8.13 of this ASTM method).

The total calculated asbestos content of the soil [the coarse (>2 mm), medium (≤2 mm and >106 µm), and fine (≤106 µm) fractions] in the soil sample using PLM analysis is determined using the formula shown in **Figure 8.9**.

If no asbestos is identified by PLM, then further analysis of the fine fraction may be conducted by TEM.

$$\text{Total Asbestos (\%)} = \frac{[\%_F \quad \text{PLM PC} * W_F] + [\%_M \quad \text{PLM} * W_M] + [\%_C \quad \text{PLM} * W_C]}{W_F + W_M + W_C} \qquad (3)$$

where:

$\%_F$ = Percentage of asbestos in the fine fraction determined by PLM point count;

$\%_M$ = Percentage of asbestos in the medium fraction determined by PLM VAE;

$\%_C$ = Percentage of asbestos in the coarse fraction determined by stereomicroscope and PLM, VAE;

W_F = Weight of fine fraction of sample;

W_M = Weight of medium fraction of sample; and

W_C = Weight of coarse fraction of sample.

Figure 8.9: Formula used in ASTM D7521-22 to calculate total asbestos concentration

8.10.3 ASTM Environmental Measurement for Asbestos STP1342

ASTM Advances in Environmental Measurement Methods for Asbestos STP1342-EB-DL.25664, Michael E. Beard and Harry L. Rook, editors, January 2000.

This publication contains papers presented at the symposium of the same name held 13-17 July 1997 in Boulder, Colorado. The symposium was sponsored by ASTM Committee D-22 on Sampling and Analysis of Atmospheres, and by the Environmental Information Association. The conference chairmen and co-editors of the publication were Michael E. Beard, Consultant and Harry L. Rook, NIST.

Many of the papers are not relevant to the purpose of this review but have been considered for the sake of thoroughness in a review of the techniques for the identification of asbestos.

8.11 NIOSH 9002 – Asbestos (bulk) by PLM

8.11.1 General

NIOSH 9002 Asbestos (bulk) by PLM was first published on 15 May 1989 and was last revised and reissued on 15 August 1994.

8.11.2 Scope

The method was developed for the qualitative identification of asbestos and the semi-quantitative determination of asbestos content of bulk samples. The method measures percent asbestos as perceived by the analyst in comparison to standard area projections, photos, and drawings, or trained experience. The method is not applicable to samples containing large numbers of fine fibres below the resolution of the light microscope.

8.11.3 General Requirements

NIOSH 9002 is a basic 'cookbook recipe' method. It does not contain the same level of detail as the other equivalent methods reviewed in the previous sections.

It lists the requirements for:

- Equipment and reagents
- Precautions for handling unknown and suspected asbestos samples
- Sample collection and preparation
- Calibration and quality control
- Qualitative assessment to determine the morphology and optical properties (colour, pleochroism, birefringence, extinction, sign of elongation and refractive indices by dispersion staining) of fibres under consideration.
- Quantitative assessment by estimating the area percent taking into account the loading and distribution of all sample material on the slide using a series of figures provided for comparison.
- It notes that point-counting techniques to determine percentages of the asbestos minerals are not generally recommended. It also notes that the point-counting technique is recommended by EPA/600/R-93/116 (June 1993) and permitted by the Asbestos Hazard Emergency Response Act (AHERA) even though not recommended in the NIOSH method.

8.11.4 Interferences

NIOSH 9002 lists the following potential interferences when analysing asbestos:

- Other fibres with optical properties similar to the asbestos minerals may give positive interferences.
- The optical properties of asbestos fibres may be obscured by coating on the fibres.
- Fibres finer than the resolving power of the microscope (ca. 0.3 µm) will not be detected.
- Heat and acid treatment may alter the index of refraction of asbestos fibres and change the colour.

8.12 California Air Resources Board Method 435 – Determination of asbestos content of serpentine aggregate

Method 435 for the determination of asbestos content of serpentine aggregate was originally published by the State of California Air Resources Board in June 1991 (CARB 435). CARB 435 is applicable to determining asbestos content of serpentine aggregate in storage piles, on conveyor belts, and on surfaces such as roads, shoulders, and parking lots [63].

It was reviewed and updated by the CalEPA (California EPA) in April 2017[64]. They released the Implementation Guidance Document for this method – Air Resources Board Test Method 435, Determination of Asbestos Content of Serpentine Aggregate, Field Sampling and Laboratory Practices.

The Implementation Guidance Document describes best practices for sample processing in the laboratory, for microscopic analysis, and quality control. It was prepared to assist laboratories, consultants, local air pollution control districts, and other stakeholders in the application and performance of the California Air Resources Board (ARB or Board) Test Method 435 – Determination of Asbestos Content of Serpentine Aggregate (now referred to as M435).

It is intended that the implementation document is used in conjunction with M435, which can be found in Appendix A of the method.

This document provides:

- Recommendations to help ensure that a representative field sample is obtained for a M435 analysis.
- Recommended laboratory sample preparation procedures that will increase the representativeness of the pulverised portion of the field sample that is used for analysis by polarised light microscopy (PLM).
- Guidance on asbestos analysis through the standardised use of PLM techniques for the optical characterisation and quantification of asbestos.
- Scientifically accepted quality control (QC) measures that can be applied within M435 to minimise field, laboratory, and analytical uncertainty.

8.13 USEPA Method for the Determination of Asbestos in Bulk Building Materials (EPA-600-R-93-116)

The “Determination of asbestos in bulk building materials” (EPA-600-R-93-116) method was published by the USEPA in July 1993.

The method is for the analysis of bulk building material (like fibrous cement sheeting) and includes stereoscopic examination and PLM as mandatory techniques. Other techniques such as electron microscopy (EM) can be used optionally to resolve qualitative or quantitative uncertainties.

[63] https://ww2.arb.ca.gov/resources/documents/test-method-435
[64] https://ww2.arb.ca.gov/sites/default/files/classic/toxics/asbestos/tm435/tm435.htm

The Simplified Flowchart for Analysis of Bulk Materials in **Figure 8.10** provides an overview of the available techniques.

Suspected asbestos-containing building materials visible in the soil can be picked out for stereoscopic microscopic examination as a first step prior to sample preparation.

Since this method was developed for suspected asbestos-containing building materials, it does not include preparation steps specific to the analysis of soil. Analysis of soil samples will benefit from milling of the sample after stereoscopic examination and from use of the optional electron microscopy step when samples are non-detect using the mandatory techniques (i.e. PLM)[65].

It is noted that this method defines asbestiform as having a mean aspect ratio of 20:1 to 100:1 for fibres longer than 5 µm, but also includes a reference to >10:1 aspect ratio.

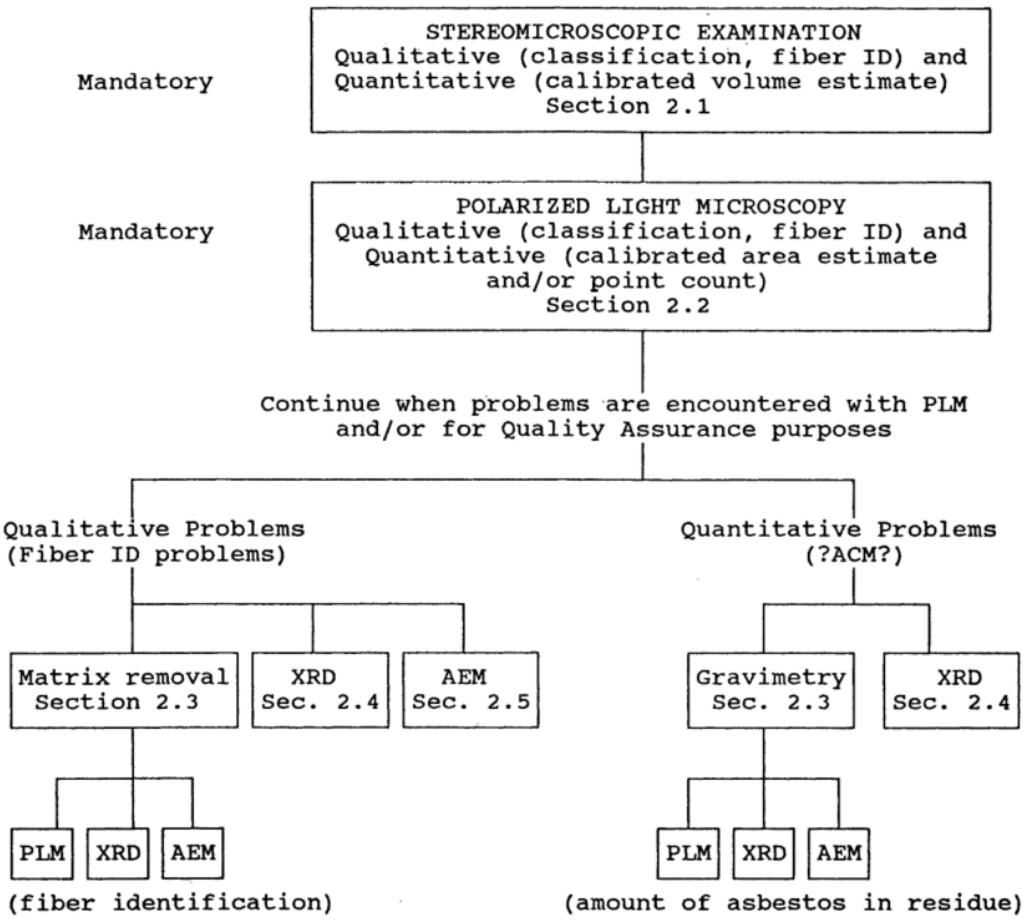

Figure 8.10: Simplified flowchart for the analysis of asbestos in bulk building materials

[65] Framework for Investigating Asbestos-Contaminated Comprehensive Environmental Response, Compensation and Liability Act Sites, Asbestos Committee of the Technical Review Workgroup of the Office of Land and Emergency Management, USEPA, OLEM Directive No. 9200.0-90, 2021.

The method summarises the requirements of methods for examination of samples by:

- Stereo microscopy
- Polarised light microscopy
- X-ray Powder Diffraction
- Electron microscopy

The method for point counting used in ASTM D7521-22 is described in Section 2.2 of this USEPA method.

8.14 Toxicological Profile for Asbestos

The US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry (ATSDR) prepares toxicological profiles for a range of environmental contaminants. The profile for asbestos was published in September 2001 (ATSDR 2001). The profile includes a comprehensive and extensive evaluation of the available toxicological and epidemiological information on asbestos.

Chapter 7 of the document summarises the requirements of analytical methods for biological samples (primarily lung tissue) and environmental air monitoring. It has been considered in this review for the sake of thoroughness but as it does not include analysis of soils, ores, and dusts, it has not been reviewed further.

8.15 Analysis of asbestos in air

Asbestos fibre air monitoring is carried out in accordance with:

- SafeWork Australia (2005) Guidance Note on the Membrane Filter Method for Estimating Airborne Asbestos Fibres 2nd Edition[66].

During asbestos removal / remedial works control (or static) air monitoring is carried out using a sampling pump in a fixed location to draw a measured quantity of air through a membrane filter. Standard monitoring periods are usually between two and eight hours depending on the task. At the end of the monitoring period the pump and filter are collected and the filter is removed in a laboratory. The filter is mounted onto a microscope slide and treated to transform it from an opaque membrane into a transparent, optically homogeneous specimen. The filter is analysed using a high-powered microscope.

The filters are analysed using Phase Contrast Microscopy and the fibres are sized and assessed with a calibrated eyepiece graticule. The fibres conforming to established size criteria on a given area of the filter are counted.

It should be noted, the membrane filter method (MFM) does not distinguish between different fibre types e.g. organic, synthetic or asbestos fibres. Any fibre which is within a defined geometric size criteria is counted as a fibre.

[66] https://www.safeworkaustralia.gov.au/doc/guidance-note-membrane-filter-method-estimating-airborne-asbestos-fibres-2nd-edition

The number of respirable fibres (fibres with the defined size criteria) in each field is noted. A standard number of fields are selected and the cumulative total of the number of fibres is recorded (fibres/fields).

Using the known flow rate for the pump and the sampling time, these data are converted to a concentration (fibres per millilitre of air) which is shown in the results column of the report.

When the total number of fibres is <10 fibres/100 fields and sufficient volume of air has been sampled, the detection limit for the airborne fibre concentration is <0.01 fibres/millilitre of air (fibres/ml) which is shown in the results column of the report. The parameters of sample duration and flow rate are adjustable to ensure the minimum volume of air is obtained to achieve the minimum detection limit of the method (i.e., 0.01 fibres/mL).

During laboratory analysis, the MFM requires a microscope field (of the filter) to be rejected and another counted if more than one-eighth of the area is covered by an agglomerate of fibres and/or particles (i.e., non-fibrous particulates). Additionally, at least half of the mounted filter area must be countable i.e., the filter must be rejected (voided) if it is overloaded with dust/particles.

8.16 Novel analytical equipment

There is research into new technologies for analysis of asbestos fibres. Such equipment may be able to provide a detector in the future other than the human eye.

One type is commercially available. Portable near infrared (NIR) spectrometers are currently on the market (known as a microPHAZIR) and they are being used as a screening tool by some local councils and landfills.

Materials that may contain asbestos are illuminated with a broad-spectrum (i.e. many wavelengths or frequencies) of near infrared light, which can be absorbed, transmitted, reflected, or scattered by the material of interest. Light is absorbed in varying amounts by the material at particular frequencies and the NIR instrument analyses the spectra and provides rapid analysis by comparing the result with a reference spectrum in the instrument library. Such equipment can be used for construction materials like fibre cement sheeting or tiles that may contain asbestos. They would not be appropriate for applying to bulk materials like compost, fill or mulch as the other materials in the bulk material would interfere.

Although these spectrometers are on the market, there are no scientific peer reviewed papers that we are aware of to validate the instrument. From the experience of consultants when comparing NIR results against laboratory analysis of physical samples analysed by PLM, there have been poor results for the NIR. The instrument is most reliable when the limitations of the instrument are understood, and the sampling matrix is cement sheet.

There is a risk of accepting materials that contain asbestos using this type of equipment due to a false NIR reading. This may result in asbestos contamination of recycled / recovered materials.

Anyone that uses the microPHAZIR to make a decision on unexpected finds i.e. reject a load, must understand the following limitations of the instrument:

- Doesn't meet WHS Regulation sample analysis requirements (currently samples must be analysed at a NATA accredited laboratory)
- Limited peer-reviewed scientific literature
- Movement of the microPHAZIR unit during use can give false results (measuring background/interfering wavelengths)
- Sample must be dry as moisture interferes with results
- Instrument window must be kept clean and secure
- Re-calibration is required if big temperature changes are experienced
- Doesn't penetrate into material e.g. not reliable through painted surfaces or dirt
- Doesn't perform well on dark samples
- 'Unidentified' result can be reported if asbestos concentration is less than 1 - 3% (which is an issue for resource recovery materials or other bulk materials as those should have much less (i.e. <0.01%)
- Manufacturers recommend testing each sample a minimum of three times at different locations on the sample and a raw/exposed edge is preferred.

When using this type of spectrometer, the user must be aware of these limitations and ensure that their reporting discusses the potential for impacts of these limitations on the results.

8.17 Other sources for measurement methods for asbestos

8.17.1 General

The following sub sections provide lists of other methods that may be useful analysis of asbestos. These are not yet (or not appropriate) for use as standard methods, so they are not useful for regulatory purposes but have been included for thoroughness.

The methods listed are those other than the ones discussed in detail in the previous sections – i.e. AS 4964, HSG 248, DR AS 5370, ISO22262-1, ASTM D7521-22 (and related), NIOSH 9002, CARB 435 and USEPA (EPA-600-R-93-116).

8.17.2 Bulk building materials

- Analysis of Asbestos in Bulk Materials – 1980 to 1997. R.L. Perkins.
- Comparison of Quantitative Techniques for Analysis of Bulk Asbestos Proficiency Testing Materials. J.R. Verkouteren, B.B. Steel, E.S. Windsor and R.L. Perkins.
- A Personal Perspective on Teaching Asbestos Analysis: Lessons from the Classroom and Laboratory. P.M. Cooke.
- Bulk Asbestos Laboratory Programs in the United States – Seventeen Years in Retrospect. B.W. Harvey, J.T. Ennis, L.C. Greene and A.A. Leinbach.
- The Habit of Asbestiform Amphiboles: Implications for the Analysis of Bulk Samples. A.G. Wylie.
- Asbestos Measurement in Soils and Bulk Materials: Sensitivity, Precision, and Interpretation – You Can Have It All. D.W. Berman.
- A Validated Method for Gravimetric Determination of Low Concentrations of Asbestos in Bulk Materials. E.J. Chatfield.
- "Internal Standard Addition" Method for Identifying Asbestos Containing Materials in Bulk Samples Containing Low Levels of Asbestos. P. Frasca, J.H. Newton and R.J. De Malo.

- ASTM's Bulk Method: Where Are We, Where Are We Headed, Where Should We Be Headed? I.M. Stewart.
- ISO22262.2:2014 Air quality — Bulk materials Part 2: Quantitative determination of asbestos by gravimetric and microscopical methods (for use in certain circumstances when ISO22262.1 is not sufficient).

8.17.3 Ambient, indoor and workplace air

- Strategy, Development and Laboratory Calibration of a Personal Passive Sampler for Monitoring the Asbestos Exposure of Maintenance Workers. G.J. Burdett and G. Revell.
- Direct-Reading Measurement of Fibre Length/Diameter Distributions - P.A. Baron, G.J. Deye, J.E. Fernback and W.G. Jones.
- International Organization for Standardization Methods for Determination of Asbestos in Air. E.J. Chatfield.
- Proposed ASTM Method for the Determination of Asbestos in Air by TEM and Information on Interfering Fibres. J.R. Millette, W.R. Boltin, P.J. Clark and K.A. Brackett.
- Shortcomings in Airborne Asbestos Analysis Filtered from New York State's Proficiency-Testing Data. J.S. Webber, A.G. Czuhanich and L.J. Carhart.
- Negative Exposure Assessments for Asbestos Floor Tile Work Practices. A.F. Oberta and K.E. Fischer.
- The Use of Scanning Confocal Microscopy to Measure the Penetration of Asbestos into Membrane Filters. G.J. Burdett, G. Archenhold, A.R. Clarke and D.M. Hunter.

8.17.4 Water

- Asbestos in Water Methods: USEPA 100.1 & 100.2 and AWWA Standard Method 2570. J.R. Millette, P. Few, and J.A. Krewer.
- A Rapid Procedure for Preparation of Transmission Electron Microscopy Specimens from Polycarbonate Filters. E.J. Chatfield.
- Measurements of Chrysotile Fibre Retention Efficiencies for Polycarbonate and Mixed Cellulose Ester Filters. E.J. Chatfield.
- Sludge, Crud and Fish Guts: Creative Approaches to the Analysis of Non-standard Water Samples for Asbestos. R.M. Bailey and M. Hu.
- Asbestos in Drinking Water Performance Evaluation Studies. G.B. Collins, P.W. Britton, P.J. Clark, K.A. Brackett and E.J. Chatfield.
- Proficiency Testing for All Fibre Sizes in Drinking Water: The Long and the Short of It. J.S. Webber, L.J. Carhart and A.G. Czuhanich.

8.17.5 Settled dust

- A Study of the Reproducibility of the Micro-Vac Technique as a Tool for the Assessment of Surface Contamination in Buildings with Asbestos Containing Materials. R.L. Hatfield, J.A. Krewer and W.E. Longo.
- Dust and Airborne Concentrations – Is There a Correlation? R.J. Lee, D.R. Van Orden and I.M. Stewart.
- Further Observations of Settled Asbestos Dust in Buildings. W.M. Ewing.

- Some Statistical Principles in Asbestos Measurement and Their Application to Dust Sampling and Analysis. D.P. Fowler and B.P. Price.
- An Overview of Settled Dust Analytical Methods and Their Relative Effectiveness. O.S. Crankshaw, R.L. Perkins and M.E. Beard.
- Applications of the ASTM Asbestos in Dust Method D5755. J.R. Millette and M.D. Mount.
- Correlated Measurements of Airborne Asbestos-Containing Particles and Surface Dust. E.J. Chatfield.
- Incorporating Dust Sampling into the Asbestos Management Program. S.M. Hays.

Section 9. Reporting

Laboratories are accredited against their own laboratory methods which are based on a known standard such as AS 4964. This means reporting can vary between laboratories.

Under AS 4964, the report must include a statement that the analytical method used was 'polarised light microscopy with dispersion staining'. The report must also include a description of the sample which should include the weight of the entire sample or sub-sample, or both.

Under AS 4964, reporting for homogenous samples simply requires reporting on what type of asbestos has been unequivocally identified e.g. a sample of cement sheet may be reported as containing chrysotile (White Asbestos) and only the weight of the cement sheet sample needs to be reported.

For non-homogenous samples in AS 4964, more detail is required. The test report is to "include a factual description (e.g. form, dimensions and/or weight) of the asbestos fibres present". A review of different lab reports by authors of this report indicates different laboratories do this differently:

- Some laboratories will only provide a weight of the sub-sample without providing information on the quantity e.g. Chrysotile fibre bundles identified in 0.0112g.
- Other laboratories report the weight of the sub-sample, some information about the nature of the sub-sample, the % by weight of asbestos in the sample and dimensions/form of the fibres. Not all of these are covered by NATA accreditation.

If only the weight of the sub-sample is reported without any additional information it makes undertaking a detailed risk assessment very difficult. 1 or 2 fibres/bundles in soil poses a different risk to >20 fibre bundles in a sample (noting results can't be looked at in isolation when reviewing results to conduct a risk assessment/provide advice).

We understand some laboratories have NATA Accreditation for in-house methods to report % weight by weight calculations which is not covered under AS 4964, although this is not representative of all asbestos laboratories. Its known that laboratories use different calculations for reporting % weight by weight. Some use 100 % asbestos content in the ASC NEPM calculation for cement sheet > 7 mm rather than using a 15% asbestos content for cement sheet > 7 mm.

In addition to such in-house methods, Section 4.10 of the ASC NEPM Schedule B1 provides details of the expected calculations to determine asbestos in soil concentration by gravimetric approach:

> As outlined in enHealth (2005), the quantity of asbestos in soil may be estimated as follows:
>
> %w/w asbestos in soil = % asbestos content x bonded ACM (kg) /soil volume (L) x soil density (kg/L)
>
> In the example included in enHealth (2005) it was assumed that:
>
> % asbestos content (within bonded ACM) = 15% and soil density (for sandy soils) = 1.65 kg/L

The ASC NEPM also notes:

"*As yet there is no validated method, readily available in Australia, of reliably estimating the concentration of free asbestos fibres in soil. Soil contamination by free asbestos fibres should, therefore, be simply determined according to the presence or absence of fibres, in accordance with AS 4964 – 2004: Method for the Qualitative identification of asbestos in bulk samples (Standards Australia 2004) by a laboratory accredited by NATA (or its mutual recognition agreement partners) for this method*".

Regulators in WA have worked with one of the large commercial laboratories to develop a reporting spreadsheet that reports the results of these analyses in the most appropriate way. An example of this reporting scheme is provided in **Figure 9.1**.

Test/Reference	LOR	Unit	
Asbestos in Soils (AS:4964-2004)			
Sample Description	-	Comment	Brown coarse grain soil
Total Dry Mass	0.1	g	1404
Total Analytical Fraction	0.1	g	1404
Asbestos Detected	-	Yes/No	Yes
Materials Identified	-	Comment	1. Grey fibre cement fragments with green paint layer (3x fragments > 7x7mm) 2. Weathered grey fibre cement fragments (9x fragments >2mm, 3x fragments < 2x2mm)
Fibres Identified and approximate Asbestos Content	-	Comment	1. Chrysotile and amosite asbestos detected; 15% 2. Chrysotile and amosite asbestos detected; 20% Synthetic mineral fibre detected Organic fibre detected
Asbestos Content (as asbestos)	0.01	% w/w	0.029
Trace Analysis	0.1	g/kg	No respirable fibres
Asbestos in Soils (ASC NEPM 2013) - non-NATA			
Asbestos Containing Materials (ACM) >7mm			
Total ACM (>7mm)	0.1	g	2.38
ACM % asbestos (weighted average)	-	%	15
ACM in Soil (as asbestos)	0.01	% w/w	0.025
Fibrous Asbestos (FA) >7mm			
Total FA	0.0005	g	< 0.0005
FA % asbestos (weighted average)	-	%	N/A
FA Asbestos in Soil	0.001	% w/w	< 0.001
Asbestos Fines (AF) <7mm			
Total AF	0.0005	g	0.232
AF % asbestos (weighted average)	-	%	20
AF Asbestos in Soil	0.001	% w/w	0.0033

Figure 9.1: WA proposed laboratory reporting scheme example

Section 10. Discussion

10.1 General

This section provides some discussion of issues arising from this literature review.

10.2 Background

Asbestos is a range of naturally occurring minerals. Trace amounts can be present in bulk materials – both new/virgin materials and waste materials being processed for resource recovery – so it is not possible to guarantee that small amounts of asbestos will not be present in any such material – whether new/virgin or recovered materials. Therefore, applying strict requirements (i.e. prohibition requiring zero) on resource recovery materials is problematic. In addition, not placing such requirements on other material types (i.e. new/virgin) does not mean they do not contain asbestos. International guidance indicates that many jurisdictions do not target trace levels of asbestos but rather only target controls on waste materials that contain more than trace levels.

10.3 Findings

10.3.1 New/virgin materials

There are many bulk materials such as concrete, asphalt, aggregate, bricks which are not subject to the same requirements as resource recovery materials.

Materials like concrete, asphalt, aggregate or bricks have been in use for many decades or even centuries. While they contain contaminants or have physical contaminants that may mean they pose a risk to people or ecosystems, they have been in use for long enough that those who regulate such systems assume the risks are well understood and well managed. This may not be the case. For example, recent identification of an additive in tyres that may impact on aquatic organisms where runoff from roads may enter waterways[67]. Other examples would be the high pH in runoff from newly poured concrete or the presence of PAHs in runoff or vapours from newly laid asphalt.

Such materials are not usually subject to detailed assessment for risks to people or the environment.

It is important to ensure any contamination/degradation of new/virgin materials when they are initially used and then reused in resource recovery products does not result in unacceptable risks to people or ecosystems. Having a system that ensures resource recovery materials are appropriately assessed is important but the extent of such a system should also consider the potential risks posed by new/virgin materials and the lack of assessment those materials receive.

[67] https://pubs.acs.org/doi/10.1021/acs.estlett.2c00050

10.3.2 Sampling – objectives

The objectives for sampling and analysis of resource recovery materials are usually that the testing needs to be able to demonstrate that the materials (in the form to be reused) comply with both:

- the relevant specification that applies to all materials that have that purpose (e.g. as soil or as compost or as fill) – whether they are new/virgin or derived from waste (e.g. Australian Standard or equivalent)
- additional requirements, if any, that apply to materials that are waste derived (e.g. resource recovery orders or equivalent).

The objective of sampling programs should be to demonstrate compliance with relevant aspects of the various specifications. As a result, setting practical and appropriate requirements in the specifications is the first step to getting appropriate sampling programs.

10.3.3 Sampling – design

Designing sampling schemes to demonstrate compliance with all of the aspects of the relevant specifications for heterogeneous waste is not straightforward.

Most international guidance provides principles and details of statistical tools to calculate how many samples are required to provide confidence of the average characteristics of a waste material rather than listing generic sampling rates which could be used for most wastes. Regulatory guidance then requires waste suppliers or receivers to develop an appropriate sampling program using the methods in the sampling guidance – i.e. use of some initial estimate of variability and the statistical tools to determine the number of samples.

Other guidance documents just indicate that representative samples are to be collected but provide only limited guidance about how to do this.

Documents like the resource recovery orders/exemptions include sampling requirements that have been determined by regulators – presumably based on some understanding of the variability of a waste type and statistical considerations as well as policy choices.

As noted in USEPA guidance, a sampling design based solely on statistical considerations can require a significant number of samples to provide confidence in the characteristics of the waste as determined by the sampling program.

Often sampling designs are not based solely on statistical assessments, given how many samples can be required. Sampling designs for regulatory systems are more usually a combination of statistical considerations, policy determinations and practicalities (cost and time). There needs to be a balance between the robustness of a finding and the practicalities of taking samples and analysing them in a timely manner.

The more recent reviews of stockpile sampling design indicate that the use of incremental sampling methodology is a preferred choice. This requires that a large number of samples should be taken from a stockpile. All of these individual samples are then combined to generate a single sample to send to the laboratory. Guidance for this type of sampling indicates somewhere between 30 and 100 individual samples should be taken from a stockpile and combined. Guidance from the Netherlands indicates that 50 samples should be adopted.

The critical aspects of this type of sampling are:

- Ensuring that the individual samples are combined appropriately to ensure the sample sent to the laboratory does represent the average nature of the material
- Deciding how big a stockpile should be represented by the combined sample
- There is still a need to do replicates for this type of sampling – even though the single sample sent to the laboratory is a combination of many individual samples this does not remove the need to do this process at least 2-3 times to properly understand the nature of the stockpile.

It is acknowledged that incremental type sampling does limit the number of samples that get sent to a laboratory for detailed analysis which minimises those costs, however, the level of effort to collect all the individual samples and combine them appropriately is large, so it is not clear whether this option is more or less cost effective.

The other aspect of this type of sampling design is whether or not it is actually appropriate to use composite sampling for analysis of asbestos, given the need to demonstrate that such fibres are not present in a bulk material rather than to understand the average nature of the material.

The USEPA guidance for assessing sites for asbestos contamination does recommend the incremental type sampling. However, other experts do not consider that composite sampling is appropriate to apply to materials where presence/absence is the objective (such as for asbestos). This is a matter of opinion and opinions differ amongst experts. In part, the view of experts depends on the actual objective of such sampling. Many international jurisdictions aim to show that a bulk material contains less than a certain amount of asbestos and this brings the goal of sampling into line with sampling for other contaminants which then would allow composite sampling to be used. This means that the nature of thresholds for asbestos in such materials will impact on the acceptability of particular sampling designs.

10.3.4 Training

Appropriate training of those undertaking asbestos analysis in the laboratory is critical to ensuring the quality of results.

As discussed in **Section 5.4**, the detector for asbestos is the human eye, not a piece of electrical equipment that works the same every time it is used. This impacts on each person's ability to do this analysis.

Different people have different skills/experience at:

- identifying fibres in general
- identifying whether a fibre is asbestos or something else

In addition, each person's abilities will differ from day to day depending on the workload, equipment, nature of the samples, the amount of sleep they got, etc. This means respite periods may need to be included in managing the tasks undertaken by these analysts. There are also aspects such as colour blindness (or at least differing interpretations of colour) that must be considered when training new analysts.

There are no official courses available in Australia for training people to undertake analysis of asbestos in bulk materials (including soils and non-homogeneous materials) or in air as discussed in **Sections 8.3-8.5**. There are courses available from international sources including those from BOHS but there is no requirement for analysts in Australia to take such courses.

NATA accreditation just requires that:

- each accredited laboratory has an in-house training scheme
- each analyst in that laboratory participates in that scheme
- each laboratory must keep records that each analyst has participated in that scheme.

This means that approved analysts and authorised signatories may receive different levels of training at different laboratories. There does not appear to be minimum guidance from NATA about how to develop an in-house training scheme or what such training should include. Given the difficulties in identifying fibres (asbestos or otherwise) in non-homogeneous materials due both to the likely small numbers of fibres and the nature of the bulk materials, this is an issue. It is highly likely that analysts are well trained in how to identify asbestos fibres in materials like asbestos cement sheeting or vinyl tiles but whether they receive training in how to find fibres and identify their nature in bulk non-homogeneous materials is not clear.

While accreditation under ISO 17025 (and in the NATA guidance materials) implies that laboratories must participate in proficiency testing programs, there is no strict requirement as to how often a laboratory should use these programs or how often each individual analyst must participate.

Useful improvements in training for asbestos analysts that could be considered include:

- use of international training programs (such as those offered by BOHS) as an essential component of in-house training schemes (international ones may need some tweaking to ensure they cover Australian requirements)
- alternatively, training programs based in Australia (external to a laboratory) could also be used but there should be minimum skill/experience requirements for the trainers to ensure they are appropriately skilled (useful to look at requirements BOHS lay out for their trainers)
- requirements as to the frequency laboratories should participate in external proficiency testing programs be included in NATA accreditation/guidance
- requirements as to the frequency individual analysts should participate in external proficiency testing programs be included in NATA accreditation/guidance
- external review of in-house training programs by suitably qualified professionals – could be useful to institute an expert committee whose task it is to review all such training programs before a laboratory is accredited by NATA.

10.3.5 Analysis

There are a range of robust methods for the analysis of asbestos fibres – they are all based on visual inspection of the fibres – i.e. the human eye is the detector. The primary method for analysis is polarising light microscopy which must be undertaken by appropriately qualified and experienced analysts. Other newer tools such as SEM and TEM can also be used but their availability in Australia is currently limited due to cost and lack of experienced operators.

While there are no methods on the horizon that are likely to be robust enough to replace visual inspection of materials as the detection method for asbestos fibres, there are tools like near infrared (NIR) spectrometers which may be useful in limited circumstances. They are, however, unlikely to be useful for assessing bulk materials/resource recovery materials. The newer methods such as the near infrared equipment may become more useful in time as the technology develops.

An important aspect arising from the consideration of the analytical methods for asbestos is the limit of reporting for the analysis as described in AS 4964.

Where pieces of asbestos containing materials that are larger than 2 mm (or even larger than 10 mm) are found in a bulk sample, it is possible to weigh those with sufficient accuracy and weigh the overall whole bulk sample to determine the % by weight and achieve a limit of reporting of 0.01% or even 0.001% (as per ASC NEPM method description).

However, depending upon sample condition and fibre type, the limit of reporting for the trace analysis part of AS 4964 has been found to lie generally in the range of 1 in 1,000 to 1 in 10,000 parts by weight, equivalent to 1 to 0.1 g/kg (i.e. 0.1 to 0.01% by weight). It is not possible to get to 0.001% be weight for this part of the method. This detection limit (and the Reporting Limit) was determined empirically during method development.

For AS 4964, the term ‘trace asbestos detected’ implies a detection limit of 0.1 g/kg (0.01%), unless nature and type of sample indicates otherwise. Therefore, a product specification requirement (in the ASC NEPM for soil or in Resource Recovery orders or equivalent) of 0.001% is unrealistic as it cannot be measured by the currently available technology.

Furthermore, it is critical to remember that at these low levels of asbestos in resource recovery type materials such as recovered fines, the risk due to respirable crystalline silica (RCS) in the material will be much greater than the risk due to exposure to low levels of airborne respirable asbestos fibres. Where materials such as recovered fines are being used, there should always be controls in place to manage exposure to RCS. These controls will also be appropriate to adequately control potential exposure to extremely low levels of airborne respirable asbestos fibres.

10.3.6 Reporting

In line with normal reporting practices, laboratories report results for analysis of materials for asbestos. However, there appears to be a number of issues with how this reporting is being undertaken including:

- How each laboratory is accredited by NATA – this impacts on whether they can report concentrations of asbestos in a material as an accredited result or not.
- Understanding the full set of information required by AS 4964 and including that information in the laboratory report.

10.4 HACCP

The following matters impact on managing the presence of asbestos in resource recovery materials:

- Asbestos is naturally occurring.
- Asbestos can be present in new/virgin materials but there are no requirements for this to be checked.
- Demonstrating that there are no asbestos fibres in a bulk material is not possible – there are always issues around the limit of reporting – no analytical method can determine there is zero present.
- Analytical detector for asbestos in a laboratory is the human eye (with assistance from microscopes) – this means the robustness of the analysis is less when compared to analysis with electrical equipment for other chemical contaminants which is assumed to operate/respond the same way at all times.
- It is not possible to remove asbestos fibres from waste once it reaches a resource recovery processing facility.

Given the findings of this review and other evaluations, there is a need for a different approach to managing the quality of resource recovery materials, especially in regard to asbestos.

One option is to consider the potential for applying HACCP. This is the Hazard Assessment, Critical Control Point system that has been applied for decades in food safety.

The principles and guidelines for this system are provided in:

- UN Food and Agriculture – Codex Alimentarius[68]
- US Food and Drug Administration[69].

In NSW, the Codex Alimentarius is referred to by the NSW Food Authority[70] and the process is required for food safety within the Australian Food Standards Code[71].

The HACCP process is a systematic approach to identify, evaluate and control food hazards prior to them occurring to minimise food safety issues. The idea is to notice when aspects relating to managing foods could be going wrong to ensure that they are corrected before food is damaged. An example is ensuring fridges, freezers or food warmers stay at the right temperature to prevent spoilage by installing thermometers with alarms to ensure managers are alerted when conditions change.

The principles of the HACCP process are:

- Principle 1: Conduct a hazard analysis.
- Principle 2: Determine the critical control points (CCPs).
- Principle 3: Establish critical limits.
- Principle 4: Establish monitoring procedures.
- Principle 5: Establish corrective actions.
- Principle 6: Establish verification procedures.

[68] https://www.fao.org/4/Y1579E/y1579e03.htm
[69] https://www.fda.gov/food/hazard-analysis-critical-control-point-haccp/haccp-principles-application-guidelines
[70] https://www.foodauthority.nsw.gov.au/industry/audits-and-compliance/food-safety-programs-haccp
[71] https://www.legislation.gov.au/F2008B00578/latest/text

- Principle 7: Establish record-keeping and documentation procedures.

Applying these principles involves the following process steps:

- Assemble a team that have appropriate expertise to consider the hazards for the specific food situation of interest.
- Describe the product.
- Identify the intended use including how people might be exposed.
- Construct a flow diagram showing the entire process (how it is received at the site of interest, how the raw ingredients are stored, how the ingredients are prepared, how they are mixed and cooked, how they are served or how they are stored until being served) from start to finish.
- Team does an on-site run through of the flow diagram to ensure it is correct.
- List all potential hazards relevant for each step.
- Conduct a hazard analysis.
- Consider measures to control identified hazards where required.
- Determine the critical control points which will ensure the overall process will be protected.
- Establish limits for each of the control points.
- Establish a monitoring plan for each of the control points.
- Establish corrective actions that can be applied if there is a non compliance with the limit for a control point.
- Establish verification procedures to show the corrective action(s) have been effective.
- Document the process and record keeping.

The same process could be applied to situations such as processing of wastes to produce a resource recovery product. Just as for food safety situations, determining hazards and the critical control points needs to be undertaken for the specific individual resource recovery materials and processes. It is not possible to suggest a single system for application to all of these materials.

The focus of international jurisdictions who require significant use of recovered materials is to ensure that appropriate separation happens in the waste generation part of the process and they commonly then do not require detailed testing of the resource recovery products for asbestos as they assume it has been dealt with up front.

The EU notes that this has been the key to the robustness of the industry that recycles building materials (EC 2018). They note that asbestos cannot be readily isolated from other components in the mineral fraction of demolition waste and that the only practical means of guaranteeing the absence of asbestos is to ensure thorough removal prior to demolition, and this, in turn, requires a comprehensive survey of the fabric of the structure to identify occurrences of this material.

However, there is a difficulty in adopting this type of system in NSW. The processes for generating the waste materials used in resource recovery (e.g. building demolition) are regulated by one government agency (SafeWork NSW) and the quality of resource recovery products is regulated by a different government agency (NSW EPA). To properly implement a HACCP process for managing resource recovery processes better coordination between the 2 agencies would be required – given the differing objectives of the legislation establishing these agencies, this may not be straightforward.

The information already in resource recovery orders/exemptions may inform the hazards relevant for a particular waste type. Also, documents such as the exemptions, standard rules and regulatory position statements from the UK Environment Agency can provide some example control points for consideration in NSW. One example of a control point would ensuring a sites processing resource recovery materials is located appropriately to minimise risks to people or the environment. This can be done by applying rules. The standard rules document in the UK for treatment of waste to produce soil, soil substitutes, and aggregate (SR2010No12) [72] provides such information.

Some of the rules about where a site that processes such materials include:

- No closer than 10 m to a watercourse
- No closer than 50 m from a spring, well or groundwater well used for human consumption
- No closer than 50 m from a spring, well or groundwater well used for other purposes (not potable purposes)
- No closer than 250 m from a habitat of Great Crested Newts or where the site is linked to breeding ponds by good habitat
- No closer than 50 m from protected species or ecosystems.

Other control points included in these documents are:

- A list of activities that can occur at the site
- A list of what wastes can be accepted for processing at the sites.

Other control points that would be important would be around the generation of the waste up front – things like rules for source separation at sites generating waste that may be used in resource recovery along with audit processes for ensuring those rules are complied with. These types of processes are already well established in jurisdictions like those in Europe so they may not actually be included in these guidance documents.

Another source of ideas for relevant controls would be the sector plans from the Netherlands. Guidance that may be useful in the hazard analysis step is the RIVM document about hazard analysis and sustainability[73]: *Towards sustainable recycling: A method for comparing the safety and sustainability of the processing of residual flows.*

[72] https://www.gov.uk/government/publications/sr2010-number-12
[73] https://www.rivm.nl/en/bibcite/reference/339331

Section 11. References

Abelmann, A, Glynn, ME, Pierce, JS, Scott, PK, Serrano, S & Paustenbach, DJ 2015, 'Historical ambient airborne asbestos concentrations in the United States – an analysis of published and unpublished literature (1960s–2000s)', *Inhalation toxicology*, vol. 27, no. 14, 2015/12/06, pp. 754-766.

ASCC 2008, *Literature review of asbestos fibre release from building materials following weathering and/or corrosion*, Australian Safety and Compensation Council,

ATSDR 2001, *Toxicological Profile for Asbestos (TP61)*, Agency for Toxic Substances and Disease Registry, US Department of Health and Human Services,

Australian Standard 2004, *Australian Standard - Method for the qualitative identification of asbestos in bulk samples AS4964-2004*, Standards Australia, https://store.standards.org.au/product/as-4964-2004?utm_source=standards.org.au&utm_medium=referral&utm_campaign=standards-catalogue

Australian Standard 2005, *Australian Standard Guide to the Investigation and Sampling of Sites with Potentially Contaminated Soil. AS4482*, Australian Standards, <http://infostore.saiglobal.com/store/Details.aspx?ProductID=315364>.

Australian Standard 2012, *Composts, Soil Conditioners and Mulches. AS 4454-2012*, Australian Standards, https://www.intertekinform.com/en-au/standards/as-4454-2012-121773_saig_as_as_267608/.

Australian Standard 2018, *Soils for Landscaping and Garden Use, Australian Standard 4419-2018*, Australian Standards, <https://store.standards.org.au/product/as-4419-2018>.

Australian Standard 2021, *Methods for sampling and testing aggregates, Method 3.1: Sampling — Aggregates AS 1141.3.1:2021* Standards Australia, <https://store.standards.org.au/product/as-1141-3-1-2021>.

EC 2018, *Development and implementation of initiatives fostering investment and innovation in construction and demolition waste recycling infrastructure*, European Commission,

enHealth 2005, *Management of Asbestos in the Non-Occupational Environment*, enHealth, Commonwealth of Australia, Canberra, https://www.azcor.net.au/template/a0eb54cf/pdf/1342168149011-4858.pdf

enHealth 2012, *Environmental Health Risk Assessment, Guidelines for assessing human health risks from environmental hazards*, Commonwealth of Australia, https://www.health.gov.au/resources/publications/enhealth-guidance-guidelines-for-assessing-human-health-risks-from-environmental-hazards?language=en

enHealth 2013, *Asbestos: A guide for householders and the general public*, Environmental Health Standing Committee (enhealth), Australian Health Protection Principal Committee, Commonwealth of Australia, https://www.health.vic.gov.au/publications/asbestos-a-guide-for-householders-and-the-general-public-february-2013.

EPA Victoria 2009, *INDUSTRIAL WASTE RESOURCE GUIDELINES - SOIL SAMPLING. Publication IWRG702*, EPA Victoria,

Glynn, ME, Keeton, KA, Gaffney, SH & Sahmel, J 2018, 'Ambient Asbestos Fiber Concentrations and Long-Term Trends in Pleural Mesothelioma Incidence between Urban and Rural Areas in the United States (1973–2012)', *Risk Analysis*, vol. 38, no. 3, pp. 454-471.

HACA 2016, *Naturally Occurring Asbestos FAQS - Health*, Heads of Asbestos Coordination Authorities, NSW Government, viewed 06/09/17, <http://www.safework.nsw.gov.au/health-and-safety/safety-topics-a-z/asbestos/naturally-occurring-asbestos/naturally-occurring-asbestos-publications/naturally-occurring-asbestos-faqs2>.

IARC 2012, *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 100C, Arsenic, Metals, Fibres and Dusts*, https://publications.iarc.fr/120.

Krakowiak, E, Górny, RL, Cembrzyńska, J, Sakol, G, Boissier-Draghi, M & Anczyk, E 2009, 'Environmental exposure to airborne asbestos fibres in a highly urbanized city', *Ann Agric Environ Med*, vol. 16, no. 1, pp. 121-128.

Lamé, F, Honders, T, Derksen, G & Gadella, M 2005, 'Validated sampling strategy for assessing contaminants in soil stockpiles', *Environmental Pollution*, vol. 134, no. 1, 2005/03/01/, pp. 5-11.

Lee, RJ & Van Orden, DR 2008, 'Airborne asbestos in buildings', *Regulatory Toxicology And Pharmacology*, vol. 50, no. 2, 2008/03/01/, pp. 218-225.

NEPC 1999 amended 2013, *Schedule B1, Guideline on Investigation Levels For Soil and Groundwater, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council, https://www.legislation.gov.au/F2008B00713/latest/text/12

NHMRC 2011 updated 2022, *Australian Drinking Water Guidelines 6, Version 3.8 Updated September 2022, National Water Quality Management Strategy*, National Health and Medical Research Council, National Resource Management Ministerial Council,

NRMMC 2009, *Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (Phase 2). Stormwater harvesting and reuse*, National Water Quality Management Strategy, National Resource Management Ministerial Council, Environment Protection and Heritage Council, National Health and Medical Research Council, <http://waterquality.gov.au/guidelines/recycled-water>.

NSW EPA 2014, *Waste Classification Guidelines. Part 1: Classifying Waste*, NSW Environment Protection Authority, <http://www.epa.nsw.gov.au/wasteregulation/classify-guidelines.htm>.

NSW EPA 2016a, *Resource Recovery Order under Part 9, Clause 93 of the Protection of the Environment Operations (Waste) Regulation 2014 - The compost order 2016*, NSW Environment Protection Authority,

NSW EPA 2016b, *Resource Recovery Order under Part 9, Clause 93 of the Protection of the Environment Operations (Waste) Regulation 2014 - The mulch order 2016*, NSW Environment Protection Authority, <https://www.epa.nsw.gov.au/your-environment/recycling-and-reuse/resource-recovery-framework/current-orders-and-exemption>.

NSW EPA 2022, *Sampling design part 1 - application, Contaminated Land Guidelines*, NSW Environment Protection Authority, <https://yoursay.epa.nsw.gov.au/sampling-design-guidelines>.

Oomen, AG & Lijzen, JPA 2004, *Relevancy of human exposure via house dust to the contaminants lead and asbestos RIVM report 711701037/2004*, RIVM,

SA EPA 2001, *Re-use and recycling of clean fill and building and demolition waste*, Prepared by Nolan-ITU for South Australia Environment Protection Authority (EPA),

SA EPA 2010a, *Standard for the production and use of Refuse Derived Fuel*, Environment Protection Authority, https://www.epa.sa.gov.au/files/4771351_standard_rdf.pdf

SA EPA 2010b, *Standard for the production and use of Waste Derived Soil Enhancer*, Environment Protection Authority, https://www.epa.sa.gov.au/files/4771360_standard_wdse.pdf

SA EPA 2013, *Standard for the production and use of Waste Derived Fill*, Environment Protection Authority, https://www.epa.sa.gov.au/files/4771359_standard_wdf.pdf

SA EPA 2017, *Waste derived fill (water treatment solids – SPACE) specification*, SA Environment Protection Authority, <https://www.epa.sa.gov.au/page/view_by_id/4256>.

Safe Work Australia 2020, *Health monitoring, Guide for asbestos*, Safe Work Australia, <https://www.safeworkaustralia.gov.au/doc/health-monitoring-asbestos>.

UK Environment Agency 2021, *Waste classification - guidance on the classification and assessment of waste (1st Edition; v1.2 GB). Technical Guidance WM3*, UK Environment Agency, Scottish EPA, Natural Resources Wales, <https://www.gov.uk/government/publications/waste-classification-technical-guidance>.

USEPA 1986, *SW846 Chapter 9 - Sampling Plans*, US Environmental Protection Agency, <https://www.epa.gov/hw-sw846/sw-846-compendium#chapters>.

USEPA 2002, *RCRA Waste Sampling Draft Technical Guidance Planning, Implementation, and Assessment*, US Environmental Protection Agency,

USEPA 2022, *ProUCL: Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations. Version 5.2*, United States Environmental Protection Agency, <https://www.epa.gov/land-research/proucl-software>.

WA DOH 2021, *Guidelines for the Assessment, Remediation and Management of Asbestos-Contaminated Sites in Western Australia*, WA Department of Health, <https://ww2.health.wa.gov.au/Articles/A_E/Asbestos-contaminated-sites>.

WA Waste Authority 2021, *Roads to Reuse - Product Specification – recycled road base and recycled drainage rock*, WA Waste Authority, <https://www.wasteauthority.wa.gov.au/programs/view/roads-to-reuse>.

WHO 2000, *Air Quality Guidelines for Europe, Second Edition*, https://www.who.int/publications/i/item/9789289013581