Wendy Liu, Kristiann Allen, Marc Tadaki and Jennifer Salmond

Policy Challenges Of Managing Naturally Occurring Respirable Mineral Dust in Aotearoa New Zealand

Abstract

Researchers and environmental planners have raised concerns about human exposure to naturally occurring respirable mineral dust (RMD), including erionite and naturally occurring asbestos. However, it is unclear how existing policy frameworks address and manage the risks of exposure to RMD, and little has been offered regarding how satisfactory policy frameworks could be developed. We draw on international research, policy documents and key informant interviews to examine how these risks are presently addressed globally and in the context of the Aotearoa New Zealand policy landscape, identifying key domestic challenges confronting effective risk governance. We recommend a collaborative effort from various disciplines to understand these new risks. We further recommend the development of an independent mechanism to evaluate risks from long-term or latent hazards such as these.

Keywords policy landscape complexity, respirable mineral dust, policy salience, erionite, naturally occurring asbestos, risk management, foresight

Wendy Liu is a lecturer in the School of Architecture and Planning and an academic associate at Koi Tū: the Centre for Informed Futures at the University of Auckland. **Kristiann Allen** is Co-Director of the Complex Conversations Lab in the Faculty of Arts at Waipapa Taumata Rau University of Auckland and Executive Secretary, International Network for Governmental Science Advice (INGSA). **Marc Tadaki** is a senior lecturer in the Department of Environmental Management at Lincoln University. **Jennifer Salmond** is a professor of geography in the School of Environment at the University of Auckland.

The task of managing the risks posed by respirable mineral dust (RMD) illustrate the wider Anthropocene dilemma of how to live with newly identified 'natural' hazards about which we, as yet, have limited knowledge (Brocal, Sebastián and González, 2017; Liu et al., 2024). RMD comprises non-biological particles of natural rocks and soil of inhalable size (less than 10 microns) and includes erionite and other crystalline zeolites and asbestiform minerals (including naturally occurring asbestos (NOA)) (Musante et al., 2002). Mineral fragments in rock and soil can become airborne as a result of natural weathering and erosion processes or disturbed by anthropogenic processes such as construction or mining (Guthrie and Mossman, 2018; Liu et al., 2024). Although the inhalation of any type of respirable particulate can be harmful (Valavanidis, Fiotakis and Vlachogianni, 2008), some rock minerals, such as the group of six minerals collectively known commercially as asbestos (Metintas et al., 2002; Frank and Joshi, 2014), and others, such as erionite (Carbone et al., 2011; Van Gosen et al., 2013; Brook et al., 2020), are known to be especially harmful or carcinogenic (Berry et al., 2022). If inhaled, these minerals can gradually accumulate in lungs, causing diseases such as pleural thickening and pleural plaques (World Health Organization, 2018; Li et al., 2024), asbestosis (Burilkov and Michailova, 1970; Wolff et al., 2015) and lung cancers (Doll, 1955; Baris et al., 1987; Attfield and Costello, 2004; Carbone at al., 2011; Wolff et al., 2015). There is, therefore, a plausible possibility of long-term health outcomes if we do not take action now to minimise occupational and population exposure to RMD (Morman and Plumlee, 2013).

Recently, concern has been raised about human exposure to RMD in urban environments, where increasing urban development may disturb minerals in rocks and soil, unintentionally exposing dense local populations to carcinogens (Patel et al., 2022; Scarfi et al., 2025). However, the need for mitigative action is complicated by difficulties in quantifying exposure and, hence, the risk posed to the population from RMD, especially in complex urban airsheds (Möller, Schuetzle and Autrup, 1994). When airborne particulate matter originates from rock or soil material, the naturally occurring air pollution is often made up of complex mineral and organic components; these mixtures have erratic source terms that are in turn governed by an array of natural and anthropogenic processes (Guthrie and Mossman, 2018). This makes it difficult to calculate exposure or predict the concentration and composition of the resulting particulate matter (Davidson, Phalen and Solomon, 2005). Further, air samples of particulate matter comprise an array of different particles from a range of different source terms (Kelly and Fussell, 2012). Identifying RMD within this complex mixture is challenging, and further complicated by the need to provide particle-specific information about chemistry and morphology to ascertain the particle type.

> In Aotearoa New Zealand, due to its unique volcanic geology, erionite and other zeolites ... have been found in sedimentary deposits in quarries, in surface rock exposures, and in open cliff faces in or near urban areas, in several areas throughout both the North and South Islands ...

A further complicating factor is the lag between exposure to RMD and human health outcomes (Carbone et al., 2011; Frost, 2013). It can take 20–40 years from exposure for cancer to develop or symptoms to become diagnosable (Frank and Joshi, 2014; Carbone et al., 2011; Patel et al., 2022). As a consequence, evidence of the health impacts and level of population exposure to these minerals globally is scarce. Planners and policy actors have yet to agree on the magnitude of risk and how to mitigate it, despite the logical potential for harm (Liu et al., 2024). Thus, even minerals that are known carcinogens, such as erionite (Dogan, Dogan and Hoskins, 2008; Harper, 2008), or minerals that are very similar in morphology and chemistry to known carcinogens (such as NOA) are often not regulated or controlled by occupational or environmental exposure standards (Gualtieri, 2020; Liu et al., 2024).

In Aotearoa New Zealand, due to its unique volcanic geology, erionite and other zeolites (including clinoptilolite, mordenite and offretite) (Reid et al., 2021) have been found in sedimentary deposits in quarries, in surface rock exposures, and in open cliff faces in or near urban areas, in several areas throughout both the North and South Islands (Patel et al., 2024; Scarfi et al., 2025). Human exposure to erionite is of particular concern in the Auckland region, where it has recently been discovered in the geology. With the region accounting for one third of New Zealand's population, Auckland's growth in infrastructure and urban densification projects, and the development of land which has previously been considered marginal, present an increased risk to exposed populations (Brook et al., 2020). Given their potential for both occupational and environmental exposure to RMD, it is important to examine the risks and develop and implement appropriate mitigation plans.

To support coherent and anticipatory management of RMD, this article first provides a review of the relevant policy and research literature. Using Google Scholar and Scopus, we identified and reviewed 226 research articles and reports and 61 government documents (including guidance) and technical reports associated with NOA and erionite, from 1978 to 2024. This time frame is consistent with the emergence of the erionite-related malignant mesothelioma epidemic first described in Turkey in 1978 (Carbone et al., 2011), which drew worldwide attention (Emri, 2017). We also interviewed nine key actors who were representatives of relevant policy and industrial sectors in Aotearoa New Zealand, and seven national and international experts from Australia and the United States. Interviewees came from major government agencies, industrial actors and relevant research institutes spanning workplace health and safety, environment and waste, land use, economic development, recreation, insurance, transport, infrastructure, and construction, mining and tunnelling. The interviews explored: 1) perceptions of risks posed by erionite and NOA; 2) potential solutions and capacity to mitigate these risks; 3) the motivations to act (or not) on reducing risks; and 4) standards of evidence required to justify anticipatory action (see Appendix for a list of semi-structured research questions for each interview topic).

After first summarising basic knowledge of erionite and NOA management globally, we draw on these interviews to examine challenges regulating naturally occurring RMD in Aotearoa New Zealand, before considering how mitigation principles and approaches could be considered in the New Zealand context to support proactive management.

The case of naturally occurring asbestos and erionite

International cases of erionite and NOA management

Within the policy instrument literature, there is a consensus around a high-level typology of five instrument types for managing environmental risks such as those posed by RMD, albeit with some variation in grouping and emphasis across the literature (Howlett, 2011; Bali et al., 2021). The basic typology often includes: economic (fiscal incentives or disincentives); regulatory; research and educational; cooperation; and informational instruments, depending on how the role of government intervention is perceived and thus structured (Kuhndt et al., 2006, p.4). Goulder and Parry (2008) used the terms 'incentive-based' and 'direct regulatory' instruments to describe the kinds of 'carrot or stick' approaches that are on the more interventionist side of this typology, compared with research and educational or informational tools to address policy problems. Some scholars suggest that the full typology can be reduced to two simple categories, namely 'encouraging' (supportive) or 'enforcing' (restrictive), or sometimes both (e.g., Gustafsson and Anderberg, 2021).

International cases of NOA management regulations

Since RMD is not regulated anywhere, it is helpful to consider how asbestos, a carcinogenic natural mineral, has been managed internationally. Many countries worldwide have general regulations on asbestos (e.g., see Muhammad, 2010; Le et al., 2011). However, these regulations are targeted primarily at minimising risk for mining or industrial production operations, and the exposures associated with the use, disturbance or removal of human-made products containing asbestos such as concrete, insulation and other building materials (Gualtieri et al., 2022). As a consequence, these regulations have limited application to NOA. For example, some regulations are limited specifically to the six asbestiform minerals known collectively as 'asbestos' (Ross et al., 2008; Strohmeier et al., 2010), but NOA is frequently found in rocks and soil as a complex blend of asbestiform minerals with similar or near identical morphology and chemistry (Lee et al., 2008). This narrow geological definition, combined with compliance monitoring and testing techniques designed for high concentrations, makes regulations difficult to apply in cases involving the inadvertent disturbance of NOA. Such locations may not meet regulatory definitions of asbestos (or asbestos concentrations) for assessing risks associated with exposures to NOA (Noonan, 2017). Consequently, the disturbance of rocks and soil containing NOA has been frequently overlooked as a source of exposure, and there has been limited discussion of specific cause–effect linkages between exposure and health outcomes in these settings (Hendrickx, 2009, Harper, 2008).

> … the disturbance of rocks and soil containing [naturally occurring asbestos] has been frequently overlooked as a source of exposure, and there has been limited discussion of specific cause-effect linkages between exposure and health outcomes in these settings …

There are limited examples of policies and regulations which have been specifically developed to mitigate the risk of RMD for construction (Lee et al., 2008) and non-asbestos quarrying/mining activities in areas where NOA minerals are common. In California, airborne toxic control measures were adopted to reduce some public exposure to NOA in rocks or soil from unpaved surfaces and quarrying/mining and construction operations (California Air Resources Board, 2002). These control measures specify that in the presence of NOA, specific procedures for sampling, evaluation and monitoring should be applied to reduce exposure risk for workers and the general public. California also provides local-level guidance available for homeowners and schools (Department of Toxic Substances Control, 2006) located in areas with a high prevalence of NOA in the rock and soil, and there are requirements for record-keeping and air monitoring. Since 2016, the California Department of Transportation has required the identification and management of NOA during the planning, design, construction, maintenance and operation of its transportation facilities (California Department of Transportation, 2016). However, even for those with NOA-specific guidance or regulations, enforcement has been challenging, and monitoring remains insufficient, partly due to a lack of funding or resources (e.g., Li et al., 2014), or the difficulties in distinguishing the potential for exposure resulting from the mere presence of NOA in soils or rocks, especially when no mining activities are involved (Harper, 2008).

Risk mitigation approaches for managing asbestos are equally ill-suited to the management of the risk posed by RMD. For example, workplace asbestos management plans include regulating the mining and processing of asbestos, reducing demand for asbestos-containing products, searching for substitutes, and setting up and equipping medical facilities for asbestos-affected communities (Li et al., 2014), but fail to address issues relevant for managing the risks posed by NOA, such as quantifying ambient fibre counts from different disturbance processes (Harper, 2008). Calls for new or revised regulations on the remediation of contaminated sites, review of safety standards for asbestos handling, and clean-up of asbestos-contaminated areas and waste management (Basel Convention Regional Centre for Asia and the Pacific, 2011; Li, Doing and Liu, 2014; Bolan et al., 2023) also have little relevance beyond those providing and promoting awareness-raising programmes (Espina et al., 2013). Some workplace NOA management plans invoke proactive foresight of policy measures to address the latency of health effects, along with more robust hazard identification or enhanced exposure monitoring requirements such as detailed record-keeping of exposure. For example, in Australia, Workplace Health and Safety Queensland articulated specific considerations required when preparing an asbestos management plan for NOA and ongoing management for NOA in 2021, including an air monitoring programme to assess exposure levels and the effectiveness of risk control measures (Workplace Health and Safety Queensland, 2021). However, there are no statutory requirements for an asbestos register for NOA (Queensland Government, 2021), and only the identified or assumed occurrence of NOA at a workplace must be included in the asbestos management plan for the workplace.

> In the US state of North Dakota, medical studies showed that occupational exposure to road gravel containing erionite could lead to changes to lung tissue ...

International cases of erionite management

Our second case example through which to examine the management (or non-management) of RMD risks focuses on erionite. Erionite is a carcinogenic zeolite found in volcanic regions on every continent (Berry et al., 2022). To date, erionite has been identified as a health risk in at least three countries: Turkey (Dogan, Dogan and Hoskins, 2008), the United States (Van Gosen et al., 2013) and Australia (Department of Mines and Petroleum, 2015). Erionite is perhaps the more useful example to illustrate the policy complexity of addressing a naturally occurring but often anthropogenically triggered respiratory hazard. That is because it has rarely been mined commercially for industrial purposes (Stevens et al., 2024), and thus the major concern remains hazard exposure from unintentional disturbance of erionite-containing rock and soil. Therefore, hazard response and management regimes have included deploying different instruments which span several policy sectors and implementation levels, depending on the nature of human interaction with the hazard. We categorised responses to erionite risks in different jurisdictions in both public and occupational exposure scenarios, demonstrating the contextual and inconsistent nature of the policy response to date (Table 1).

In the case of Turkey, an epidemic of malignant mesothelioma in three villages in a region of central Anatolia during the 1970s was attributed to exposure to erionite (Carbone et al., 2011). According to Metintas et al., malignant mesothelioma was the cause of mortality in 52 of the 103 deaths, 'representing 50.5% of all deaths' (Metintas et al., 2010, p.88). In this case, erionite was thought to be present in the rock-based building materials, soils and roads around the villages. The Ministry of Health of Turkey identified the villages at the highest risk and relocated those villagers to new housing sites. In addition, it initiated a programme to prevent unnecessary use of soil and limit natural erosion (Carbone et al., 2011).

In the US state of North Dakota, medical studies showed that occupational exposure to road gravel containing erionite could lead to changes to lung tissue (Ryan et al., 2011), and thus the use of gravels containing erionite is restricted to limit the potential for occupational exposure, primarily of gravel pit and road maintenance workers, who are considered to be at the highest risk of exposure (Environmental Protection Agency and North Dakota Department of Health, 2010). Additional measures include prohibiting mining in areas where the presence of erionite is known or suspected, and areas nearby should be tested before being mined. The state goes on to recommend that residents with family histories of mesothelioma should reduce or avoid exposure to materials containing or likely to contain erionite (North Dakota Department of Health, 2009). More recently, in 2023, the North Dakota Draft Resource Management Plan (federal government) requires testing surface deposits for erionite minerals if any activity is proposed in certain geological formations or geologically down-gradient from them. If erionite is identified, the proposed project may not be approved or may be subject to required design features (US Department of the Interior Bureau of Land Management, 2023).

In the state of Western Australia, erionite was mentioned in the 'Guidance note on the public health risk management of asbestiform minerals associated with mining' by the Western Australia Department of Heath as a mineral that 'may have fibre characteristics that make them potentially hazardous as asbestiform minerals' (Western Australia Department of Health, 2013). Analyses of erionite hazards are found under the 'Management of fibrous minerals in Western Australian mining operations' guideline of the Department of Mines and Petroleum (Rogers, 2018). A fibrous minerals management plan must be formulated if fibrous minerals exist on a mine site to manage exposure to an acceptable level by implementing required control measures and procedures (Department of Mines and Petroleum, 2015).

RMD management in New Zealand

Naturally occurring RMD like erionite falls outside the existing policy landscape in New Zealand. Many of the minerals of concern within the category of RMD are not commercially mined or processed here, and thus there is no exposure data from industrial settings to provide evidence and link exposure to outcomes. Current policies focus on potential hazards of commercial products and processes from these minerals, thereby missing those that are naturally occurring, yet triggered through human activity. This may be partly attributed to the lack of common usage or commercial application of the specific minerals, which means they have largely escaped toxicity assessment, for which the epidemiological analysis for targeted regulation is complex (Parliamentary Commissioner for the Environment, 2022). Furthermore, the national asbestos exposure register, which contains details of people exposed to asbestos and those diagnosed with asbestos-related diseases in New Zealand, is no longer being maintained. This means that the evidence required to assess the latency of effects and to link cause and effect is no longer being stored (WorkSafe New Zealand, 2024a).

More recently, research suggests that erionite has the potential to present a risk to occupational and public health (Giordani et al., 2017; Brook et al., 2020). Yet there is limited medical evidence of the

Table 1: Examples of erionite interventions, their intended aims, and 'supportive' or 'restrictive' classification (based on the literature or government official reports)

Interventions and settings	Aim of intervention	Type of intervention
National level: Turkey		
Residents' relocation	Separation from hazard	Restrictive
Set up malignant mesothelioma centres	Early detection	Supportive
Monitor early signs	Precaution	Supportive
Early detection of erionite-rich areas	Precaution	Restrictive
National level: United States of America		
National Toxicology Program designated erionite as a known human carcinogen	Awareness and information	Supportive
The US EPA recognised there is sufficient evidence in humans of the carcinogenicity of erionite and investigated the possible health effects of exposures	Awareness and information	Supportive
Precautions described in existing guidance for working in areas with NOA: for example, workplace practices are required to minimise asbestos emissions and minimise the use of asbestos-containing materials on unpaved road surfaces in California (California Air Resources Board, 2002)	Precaution	Restrictive
Risk reduction recommendations by the CDC for workers engaging in activities that may cause disturbance	Reduce exposure	Restrictive
State level: Western Australia		
Recognition of erionite as a mineral that 'may have fibre characteristics that make them potentially hazardous as asbestiform minerals'	Awareness and information	Supportive
Management of fibrous minerals in mining operations	Mitigate exposure	Restrictive
State level: North Dakota		
Restrict the use of gravels containing erionite	Separation from hazard	Restrictive
Repave all roads that contain erionite	Mitigate exposure	Restrictive
Prohibit mining in areas where erionite is known or suspected	Restriction	Restrictive
Require that areas nearby be tested before mined	Precaution	Restrictive
Provide a testing and exclusion radius map	Information	Supportive
Provide information about erionite	Awareness and information	Supportive
Local level: Dunn County		
North Dakota Geographical Survey discuss sampling results with county commissioners	Awareness and information	Supportive
Provide local communities with information about erionite	Awareness and information	Supportive
Work with the EPA to investigate possible health effects of exposures	Information/ evidence	Supportive
Precautionary measures to reduce occupational exposures	Precaution	Restrictive

Sources: Carbone et al., 2007; Environmental Protection Agency and North Dakota Department of Health, 2010; Department of Mines and Petroleum, 2015; North Dakota Department of Health, 2009 effects of erionite on humans, despite laboratory results from cells and rats (Wagner et al., 1985; Coffin et al., 1992), and, alongside isolated geographical international cases (Carbone et al., 2011), the evidence base of its health consequences is limited. However, state-of-the-art toxicity tests recently undertaken indicate that erionite found in New Zealand is carcinogenic, and some forms of erionite are found to be more toxic than asbestos in causing malignant transformations (Scarfi et al., 2025).

The use of 'activity standards', such as those used to control emissions from solid fuel burners, have been shown to be effective in air quality management in New Zealand. In the case of erionite, a range of activities could potentially cause exposure to rock and soil materials containing NOA and erionite. These could be managed to proactively reduce the risks of exposure in relevant areas (Hendrickx, 2009). Such activities include excavation (e.g., mining, quarrying, construction, tunnelling, urban development and earthworks, agriculture, forestry), recreation (activities that can disturb the material, such as mountain and dirt biking, off-road four-wheel driving, landscape works, etc.) (Van Gosen et al., 2013), transportation (movement of quarried or excavated material), weathering processes (Hendrickx, 2009), and disposal, use or sale of spoil (Sharp et al., 2022). However, to date, there is little or no information about the impact of such activities on ambient concentrations or the resulting risk of exposure to airborne RMD. Although carcinogenic RMD such as NOA and erionite are not currently mined or quarried in New Zealand, industrial activities that commercialise other rock or mineral products which are potentially contaminated with erionite or NOA-containing minerals (e.g., zeolites for use in cat litter, lining stock runs or gardening) (Harper, 2008; Bilgin, 2017) may also result in exposure pathways for both occupational and environmental exposures.

Standard occupational exposure limits or environmental exposure limits and policy levers are difficult to apply to RMD. While RMD in this category forms part of the particulate matter observed in the air, which is regulated under environmental standards in most jurisdictions as PM10 or PM2.5, these standards are not designed to protect populations against highly toxic or carcinogenic particulate matter and may not provide adequate protection in areas where they occur naturally. For example, despite the International Agency for Research on Cancer and the World Health Organization listing erionite as carcinogenic to humans (group 1), there are currently no agreed guidelines or regulations for exposure limits in New Zealand or internationally.

It appears to be a risk management blind spot that could be leaving the population, particularly the most highly exposed populations, vulnerable to the risk of significant, latent and adverse health effects.

Epidemiological evidence to link exposure to disease prevalence has been limited by the challenges of measuring highly variable concentrations of ambient fibres, often at low concentrations which are at, or near, measurement detection limits (Van Gosen et al., 2013). Efforts are further hampered by difficulties distinguishing individual erionite fibres from other, less toxic, mineral fibres, and the low-density and often highly mobile populations in areas where natural outcrops of erionite are found (such as North Dakota: Carbone et al., 2011). Thus, the development of exposure limits for erionite has been slow, despite the continual emergence of new evidence of the presence of fibres in the air (Talbot et al., 2024; Fan et al., 2024).

Although there exists international evidence about erionite and its management, this evidence is not immediately transposable to other places like New Zealand. For example, erionite evidence and mitigations in Turkey, the US and Western Australia are more well-established than in other countries. However, these areas have significantly drier climates and very different vegetation, so it is difficult to draw relevant analogies from these cases and apply them to the New Zealand context. There is also a lack of information on whether it is a significant risk in New Zealand, due to the inability to quantify exposure and link this to medical outcomes. The evidence overseas may not be perceived by policy actors or stakeholders as adequate for establishing similar cause-and-effect links in the New Zealand context, partly due to differences in population size and mobility and to the prevalence of different exposure quantities and pathways.

This combination of factors means that potentially there is currently an insufficient risk management regime for the case where RMD such as erionite or NOA is disturbed and made respirable unintentionally through human activities and natural processes not directly related to commercial production or use of that mineral. It appears to be a risk management blind spot that could be leaving the population, particularly the most highly exposed populations, vulnerable to the risk of significant, latent and adverse health effects.

Challenges for regulating RMD in Aotearoa New Zealand

Jurisdictional mobility of the issue and the lack of a 'home' policy sector

The oversight responsibility for workplace and population risk mitigation is typically conceived as the role of governments and, therefore, embedded within national, federal or local government structures (Vaz, Koria and Prendeville, 2022). According to our interview participants, a potential RMD hazard response and management

Table 2: Policy sectors, government departments (with potential policy responsibility) and their administration of legislation or regulations

Sector	Government agencies or departments	Relevant legislation, regulation and/or policy
Occupational health and safety (including mining, quarrying and tunnelling operations)	WorkSafe New Zealand	Health and Safety at Work Act 2015 Health and Safety at Work (Hazardous Substances) Regulations 2017 Health and Safety at Work (Asbestos) Regulations 2016 Health and Safety at Work (Mining Operations and Quarrying Operations) Regulations 2016 'Managing asbestos in your building or workplace – for PCBUs' (2024)
Public health and health system	Ministry of Health	Hazard exposure register Cancer Registry Act 1993
Hazardous substances	Environmental Protection Authority (reports to the minister for the environment, the associate minister for the environment, and the minister for climate change)	Environmental Protection Authority Act 2011 Hazardous Substances and New Organisms Act 1996
Ecosystem, resource management, environmental protection, emerging pollutants, land use, contaminants in soil and rock	Ministry for the Environment	Resource Management Act 1991 Hazardous Substances and New Organisms Act 1996 National environmental standard for assessing and managing contaminants in soil to protect human health regulations 2011 Hazardous Activities and Industries List (HAIL)
Economic development, business, employment, health and safety, insurance	Ministry of Business, Innovation and Employment (MBIE) New Zealand Petroleum and Minerals (part of MBIE)	Health and Safety at Work Act 2015 Crown Minerals Act Accident Compensation Act 2001
Primary sector	Ministry for Primary Industries	Hazardous Substances and New Organisms Act 1996 (relevant to MPI in respect of new organisms under section 97A)
Transportation (road construction, tunnelling, waste and hazardous substance transportation)	Ministry of Transport	Land Transport Act 1998 Land Transport Rule Dangerous Goods 2005 Rule 45001/2005
Insurance	ACC	Accident Compensation Act 2001
Regional and local authorities for implementation, monitoring and evaluation	Regional and local councils	Implementation, monitoring and enforcement of national directions and regional and local activities, including but not limited to: recreation, construction, trucking and tunnelling, forestry, transportation, infrastructure, contaminated land, land use, construction, transport, earthworks

regime could include the deployment of different instruments spanning at least nine distinct policy sectors (Table 2) in addressing the potential issues of exposure, mainly depending on the nature of human interaction with the hazard.

Interviews with government officials across sectors with potential policy responsibility revealed a desire to see 'more evidence of the health risk associated with it [exposure]'. They argued that 'if it were possible to draw a clear link between some cases of mesothelioma or other respiratory disease and erionite', then regulation would be more desirable. This lack of available local evidence, combined with the latency of health risks posed by erionite, contributes to low issue salience, which in turn inhibits urgent policy or regulatory attention. Moreover, commercial interests (mining, quarrying, forestry) and physical infrastructure pressures (roading, construction, tunnelling) have high salience on national and regional policy agendas. This is further compounded by a lack of inter-sectoral and inter-jurisdictional policy coordination across the hazard exposure life cycle. For example, one industry representative interviewed said there were cases of RMD-containing soil being removed from the construction site in the workplace setting but then left to dry outside the work site. For such a scenario, it remains unclear who would be the lead regulator.

Indeed, although international efforts to provide guidance for both NOA and erionite could inform a New Zealand response on risk management, key informant interviews undertaken for this study emphasised the barriers caused by lack of clarity as to which government agency is, can or should be responsible for managing the risks posed by RMD. Geographical differences were also cited as reasons for not following the example of other jurisdictions. For instance, several policy actors identified the guidance provided for erionite management in Western Australia as a prompt for policy consideration in New Zealand. However, variations in the local wind, climate and vegetation, and predominant patterns of land use in international cases, combined with the unique composition of political bodies and stakeholders, may constrain the effectiveness of learning from international measures to mitigate risk here in New Zealand.

Due to the difficulties in monitoring and measuring ambient concentrations, the absence of quantitative evidence documenting the causal pathways of this hazard and the lack of local epidemiological evidence, quantitative risk assessment has been notoriously difficult to establish. New Zealand's occupational health and safety regulator, WorkSafe, requires a 'person conducting a business or undertaking' to manage worker health risks caused by exposure to different types of airborne dust, and specifically clarified the inclusion of asbestos and respirable crystalline silica dust (WorkSafe New Zealand, 2024b). Erionite has been added to the list of agents included in the New Zealand Carcinogens Survey 2021 (WorkSafe New Zealand, 2021). However, the potential risk management framework or approach for erionite has not been clearly articulated or explained as of January 2025.

Indeed, legislation applied to environmental risks more broadly may also not be adequate for specific risks associated with highly toxic or carcinogenic materials. For example, the Ministry for the Environment introduced an annual and daily standard for environmental $PM_{2.5}$ concentrations based on levels recommended by the World Health Organization (Ministry for the Environment, 2020). There are also occupational health limits for exposure to $PM_{2.5}$ designed to mitigate the risks for workers. However, unlike the asbestos regulations (Health and Safety at Work (Asbestos) Regulations 2016), neither of these reflects the specific health risks associated with RMD. Further, neither the Ministry for the Environment's daily standards nor occupational health limits have provisions to protect against specific risks for people inhaling RMD when undertaking activities which may expose them inadvertently: for example, dusty activities such as emptying zeolite-based kitty litter (which may be contaminated with erionite) into the tray, or those working in stores putting bulk products into bags or bins, or working with zeolite-based fertiliser or garden material. Similarly, current standards might not provide sufficient protection for people living close to worksites which inadvertently disturb rock materials, including quarries, roadworks and construction.

As the New Zealand record shows, institutional structures cannot protect an institution indefinitely, but it is worth considering what might make some structures more effective and resilient than others.

Complexity of cross-sectoral interactions and inter-linkages in Aotearoa New Zealand

Depending on the rock- or soil-disrupting activity and/or the stage of that activity, nine policy sectors were identified as having the potential to mitigate the risk posed by RMD in various ways (Table 2). That is, while RMD risk management mainly concerns the occupational health and safety and environment sectors, regulations in other policy sectors, such as transportation, land use, primary industries, insurance and waste management, could also play a role in an anticipatory strategy to reduce the risk.

The complexity of hazard disturbance activities, exposure pathways and intervention points administered by multiple policy sectors make managing the risks of RMD even more challenging. This situation makes it easy for risks from naturally occurring RMD with latent effects to go unnoticed, especially where there are competing financial incentives or a lack of willingness or capability to be anticipatory. Sectors may not fully analyse the potential interactions or spillover effects of their respective mandates and instruments with those of other policy sectors or those at different administrative levels. Our research reinforced the potential benefits offered by an anticipatory strategy that takes a life-cycle approach to managing naturally occurring RMD like erionite, especially when considered together with strengthened inter-sectoral coordination. As commented by an interviewee, 'If you think about the life cycle, there's a motivation for a new asset of some kind, or programme'.

Issue salience challenges

Key informant interviews also depicted a distinct 'lack of foresight capacity in managing hazards with latent effects', and the absence of a specific decision framework for latent risks such as those posed by RMD in New Zealand. Maintaining a life-long exposure register with long-term administrative support and resources that are accessible by health practitioners and authorities could help. However, as of December 2023 WorkSafe no longer even operates the asbestos exposure register, let alone adding a mineral for which the evidence base is only emerging. Similarly, although there was a New Zealand mesothelioma register, it is no longer available.

By contrast, in Ontario, Canada, the Ontario Asbestos Workers Registry was created in 1986 to notify the workers and their physicians of the need for a medical examination if their asbestos exposure reaches a certain threshold (2000 hours) (Pefoyo et al., 2014). While the association between exposure to fibrous erionite and human mesothelioma is not as well established as it is with asbestos, a robust record of historical exposures linked to geographic and health data would help to better understand the risks in the local context.

It is crucial to consider how governance frameworks and associated policy instruments could address different exposure scenarios across the life cycle of RMD and their latent impacts over decades. However, the lack of meaningful action (and, indeed, a reversal of previous actions) on this gap is exacerbated by political short-termism and market-driven activities (Nel and Stevenson, 2014), as well as the promotion of urban development and infrastructure building. For effective actions at key points of intervention, a strategic framework would need to encompass even those policy sectors that deal indirectly with erionite or NOA, as it is disturbed in different ways over time (e.g., digging/quarrying, transportation, disposal, sale of fill, etc.).

Discussion and conclusion: lessons learnt from the examples of mitigating RMD risks

The case examples of erionite and naturally occurring asbestos demonstrate that managing this particular type of hazard is challenging in Aotearoa New Zealand. Our analysis of the complex policy landscape of responsibility for naturally occurring RMD highlighted three key factors that impede proactive mitigative action: jurisdictional ambiguity and lack of a 'home' policy sector; complex cross-sectoral interactions and interlinkages over the course of the hazard life-cycle; and issue salience challenges. At the same time, we have shown the importance of taking a life-cycle approach that can coordinate across policy sectors, levels and jurisdictions, and the need for anticipatory foresight that transcends typical policymaking horizons.

Finally, the case of RMD points to the need for better long-term and independent risk identification and analysis at the national level. Evidence-informed horizon scanning and ongoing monitoring are essential activities, yet both are currently lacking in Aotearoa New Zealand. The establishment of an independent risk identification and analysis mechanism (in whatever form this might take) could address long-term, complex and latent risks that transcend single sectors, jurisdictions and time horizons. Such a mechanism, along with an integrated approach to policies that have an impact on land use (Parliamentary Commissioner for the Environment, 2024), can develop a forward-looking and coordinated approach to complex policy issues that transcend single sectors, jurisdictions and time horizons. It would also be relevant to supporting ongoing reforms of regulatory frameworks for resource management, among others, in Aotearoa New Zealand.

Appendix: Semi-structured interview topics and interview questions

1) Perceptions of risk and its salience
   a) Tell us about the risks you deal with in your role and how these are addressed; tell us about the risks you think the construction sectors are facing.
   b. Can you rank these risks in terms of how important it is that they are addressed?
   c. Can you tell us how you ranked them?
   d. Can you tell us how you came to view these issues as risks?
   e. Thinking about the different functional groups you work with, do you think others would view the issues you named in the same way? Who? Why or why not?
   f. Have you heard about erionite in the soil of some areas around Auckland? Would something like that make it onto your list of risks, and why?
   g. Do you think others would place it there also? Why or why not?

2) Potential solutions and capacity to mitigate the risks
   a. Of the risks you named, do any NOT have satisfactory methods or strategies to manage them? If that's the case, why do you think that is?
   b. Based on what is known about erionite, do you think it would be easy or difficult to address the risk it might pose? Why? Probe …

3) Motivations to act or not
   a. Thinking about the top risks you named, which groups or individuals do you think would be most concerned about whether and how that risk is managed? Why?
   b. Of the groups or individuals you named, who do you think has the most influence in how that risk is managed? Why?
   c. If erionite were to make it onto your list of risks, who would be most influential in managing the risk and why?

4) Standards of evidence: what is effective, and what else is needed?
   a. Thinking about the top risks you mentioned, what evidence (and/or advice) do you provide/are provided and what is most effective in promoting mitigative action? What else might be needed? What are the standards of evidence?
   b. Thinking about risks of which the consequences/impacts don't show up for quite a long time after exposure, what evidence (and/or advice) do you think would make it easier to take mitigative action? And why?
   c. For a potential risk that is just starting to be understood, like erionite, what kind of evidence would you look for, and what evidence would you need to see to motivate a significant management response?

References

Attfield, M.D. and J. Costello (2004) 'Quantitative exposure-response for silica dust and lung cancer in Vermont granite workers', *American Journal of Industrial Medicine*, 45 (2), pp.129–38

Bali, A.S., M. Howlett, J.M. Lewis and M. Ramesh (2021) 'Procedural policy tools in theory and practice', *Policy and Society*, 40 (3), pp.295–311, https://doi.org/10.1080/14494035.2021.1965379

Baris, I., M. Artvinli, R. Saracci, L. Simonato, F. Pooley, J. Skidmore and C. Wagner (1987) 'Epidemiological and environmental evidence of the health effects of exposure to erionite fibres: a four-year study in the Cappadocian region of Turkey', *International Journal of Cancer*, 39 (1), pp.10–17

Basel Convention Regional Centre for Asia and the Pacific (2011) 'Report of "Pilot project and technical training on environmentally sound management of asbestos waste"', UNEP-FAO-RC-ESM-Asbestos-PPTT-BCRCChina-Report-20111010.En.pdf

Berry, T.A., E. Belluso, R. Vigliaturo, R. Gieré, E.A. Emmett, J.R. Testa, G. Steinhorn and S.L. Wallis (2022) 'Asbestos and other hazardous fibrous minerals: potential exposure pathways and associated health risks', *International Journal of Environmental Research and Public Health*, 19 (7), 4031

Bilgin, O. (2017) 'Technologic tests of turkey-gordes zeolite minerals', *Journal of Minerals and Materials Characterization and Engineering*, 5 (5), pp.252–65

Bolan, S., L. Kempton, T. McCarthy, H. Wijesekara, U. Piyathilake, T. Jasemizad … and N. Bolan (2023) 'Sustainable management of hazardous asbestos-containing materials: containment, stabilization and inertization', *Science of the Total Environment*, 881, 163456

Brocal, F., M.A. Sebastián and C. González (2017) 'Theoretical framework for the new and emerging occupational risk modeling and its monitoring through technology lifecycle of industrial processes', *Safety Science*, 99, pp.178–86

Brook, M.S., P.M. Black, K.N. Dirks, J. Salmond, T.A. Berry and G. Steinhorn (2020) 'Erionite in Auckland bedrock and malignant mesothelioma: an emerging public and occupational health hazard?', *New Zealand Medical Journal*, 133 (518), pp.73–8

Burilkov, T. and L. Michailova (1970) 'Asbestos content of the soil and endemic pleural asbestosis', *Environmental Research*, 3 (5–6), pp.443–51

California Air Resources Board (2002) 'Naturally occurring asbestos', https://ww2.arb.ca.gov/our-work/programs/naturally-occurring-asbestos/about

California Department of Transportation (2016) 'Management of naturally occurring asbestos (NOA)', https://dot.ca.gov/-/media/dot-media/programs/environmental-analysis/documents/env/dd71-r1-signed-a11y.pdf

California Environmental Protection Agency and California Air Resources Board (2002) 'Final regulation order: Asbestos Airborne Toxic Control Measure for Construction, Grading, Quarrying, and Surfacing Mining Operations', section 93105, http://www.arb.ca.gov/toxics/atcm/asb2atcm.htm

Carbone, M., Y.I. Baris, P. Bertino, B. Brass, S. Comertpay, A.U. Dogan … and A. Miller (2011) 'Erionite exposure in North Dakota and Turkish villages with mesothelioma', *Proceedings of the National Academy of Sciences*, 108 (33), pp.13618–23

Carbone, M., S. Emri, A.U. Dogan, I. Steele, M. Tuncer, H.I. Pass and Y.I. Baris (2007) 'A mesothelioma epidemic in Cappadocia: scientific developments and unexpected social outcomes', *Nature Reviews Cancer*, 7(2), pp.147–54

Carlin, D.J., T.C. Larson, J.C. Pfau, S.H. Gavett, A. Shukla, A. Miller and R. Hines (2015) 'Current research and opportunities to address environmental asbestos exposures', *Environmental Health Perspectives*, 123 (8), pp.A194–7

Coffin, D.L., P.M. Cook and J.P. Creason (1992) 'Relative mesothelioma induction in rats by mineral fibers: comparison with residual pulmonary mineral fiber number and epidemiology', *Inhalation Toxicology*, 4 (3), pp.273–300

Davidson, C.I., R.F. Phalen and P.A. Solomon (2005) 'Airborne particulate matter and human health: a review', *Aerosol Science and Technology*, 39 (8), pp.737–49

Department of Agriculture and Food (2023) 'Climate trends in Western Australia', Government of Western Australia, https://www.agric.wa.gov.au/climate-change/climate-trends-western-australia

Department of Health (2013) 'Guidance note on public health risk management of asbestiform minerals associated with mining', Government of Western Australia, https://www.health.wa.gov.au/-/media/Files/Corporate/general-documents/Asbestos/PDF/GNote-Public-Health-Risk-Mgt-Asbestos-associated-with-Mining-Activities.pdf

Department of Mines and Petroleum (2015) *Management of Fibrous Minerals in Western Australian Mining Operations: second edition*, Department of Mines and Petroleum, Western Australia, https://www.dmp.wa.gov.au/Documents/Safety/MSH_G_ManagementOfFibrousMineralsInWaMiningOperations.pdf

Department of Toxic Substances Control (2006) 'Recommended housekeeping activities to reduce exposure to naturally-occurring asbestos in schools', Department of Toxic Substances Control, State of California, https://dtsc.ca.gov/wp-content/uploads/sites/31/2018/09/Fact-Sheet-Housekeeping-for-Naturally-Occurring-Asbestos.pdf

Dogan, A.U., M. Dogan and J.A. Hoskins (2008) 'Erionite series minerals: mineralogical and carcinogenic properties, *Environmental Geochemistry and Health*, 30, pp.367–81

Doll, R. (1955) 'Mortality from lung cancer in asbestos workers', *British Journal of Industrial Medicine*, 12 (2), pp.81–6

Emri, S.A. (2017) 'The Cappadocia mesothelioma epidemic: its influence in Turkey and abroad', *Annals of Translational Medicine*, 5 (11), pp.239–50

Environmental Protection Agency and North Dakota Department of Health (2010) *Radiographic Changes Associated with Exposure to Erionite in Road Gravel in North Dakota*, https://deq.nd.gov/erionite/MedicalStudy/ErioniteMedicalStudyFinalReport-10-04-2010.pdf

Espina, C., M. Porta, J. Schüz, I.H. Aguado, R.V. Percival, C. Dora, T. Rodriguez Guzman, T. Meredith, P.J. Landrigan and M. Neira (2013) 'Environmental and occupational interventions for primary prevention of cancer: a cross-sectorial policy framework', *Environmental Health Perspectives*, 121 (4), pp.420–6

Fan, W., A. Gualtieri, K. Dirks, P. Young and J. Salmond (2024) 'Investigating deposition of fibrous zeolite particles on leaf surfaces: a novel approach for detecting airborne hazards', *Journal of Hazardous Materials*, 480, 135982

Frank, A.L. and T.K. Joshi (2014) 'The global spread of asbestos', *Annals of Global Health*, 80 (4), pp.257–62

Frost, G. (2013) 'The latency period of mesothelioma among a cohort of British asbestos workers (1978–2005)', *British Journal of Cancer*, 109 (7), pp.1965–73

Giordani, M., M. Mattioli, P. Ballirano, A. Pacella, M. Cenni, M. Boscardin and L. Valentini (2017) 'Geological occurrence, mineralogical characterisation, and risk assessment of potentially carcinogenic erionite in Italy', *Journal of Toxicology and Environmental Health*, Part B, 20 (2), pp.81–103

Goulder, L.H. and I.W. Parry (2008) 'Instrument choice in environmental policy', *Review of Environmental Economics and Policy*, 2 (2), pp.152–74

Gualtieri, A.F. (2020) 'Naturally occurring asbestos: a global health concern? State of the art and open issues', *Environmental and Engineering Geoscience*, 26 (1), pp.3–8

Gualtieri, A.F., M. Lassinantti Gualtieri, V. Scognamiglio and D. Di Giuseppe (2022) 'Human health hazards associated with asbestos in building materials', in J.M. Malik and S. Marathe (eds), *Ecological and Health Effects of Building Materials*, Springer Cham

Gustafsson, M. and S. Anderberg (2021) 'Dimensions and characteristics of biogas policies: modelling the European policy landscape', *Renewable and Sustainable Energy Reviews*, 135, 110200

Guthrie, D. and T. Mossman (eds) (2018) *Health Effects of Mineral Dusts*, Walter de Gruyter

Harper, M. (2008) '10th anniversary critical review: naturally occurring asbestos', *Journal of Environmental Monitoring*, 10 (12), pp.1394–408

Hendrickx, M. (2009) 'Naturally occurring asbestos in eastern Australia: a review of geological occurrence, disturbance and mesothelioma risk', *Environmental Geology*, 57, pp.909–26

Howlett, M. (2011) 'Public managers as the missing variable in policy studies: an empirical investigation using Canadian data', *Review of Policy Research*, 28 (3), pp.247–63

Kelly, F.J. and J.C. Fussell (2012) 'Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter', *Atmospheric Environment*, 60, pp.504–26

Kuhndt, M., T. Machiba, M. Herrndorf, T. Muchorowski, A. Villar, C. Liedtke et al. (2006) *Policy Instruments for Resource Efficiency: towards sustainable production and consumption*, Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, https://www.cscp.org/wp-content/uploads/2017/12/GTZ-CSCP-PolicyInstrumentsResourceEfficiency.pdf

Le, G.V., K.E.N. Takahashi, E.K. Park, V. Delgermaa, C. Oak, A.M. Qureshi and S.M. Aljunid (2011) 'Asbestos use and asbestos-related diseases in Asia: past, present and future', *Respirology*, 16 (5), pp.767–75

Lee, R.J., B.R. Strohmeier, K.L. Bunker and D.R. Van Orden (2008) 'Naturally occurring asbestos: a recurring public policy challenge', *Journal of Hazardous Materials*, 153 (1–2), pp.1–21

Li, J., Q. Dong, K. Yu and L. Liu (2014) 'Asbestos and asbestos waste management in the Asian-Pacific region: trends, challenges and solutions', *Journal of Cleaner Production*, 81, pp.218–26

Li, X., X. Su, L. Wei, J. Zhang, D. Shi and Z. Wang (2024) 'Assessing trends and burden of occupational exposure to asbestos in the United States: a comprehensive analysis from 1990 to 2019', *BMC Public Health*, 24 (1), 1404

Liu, W., J. Salmond, K. Allen and M. Tadaki (2024) 'Managing emerging environmental risks when we do not know enough about them: the case of respirable mineral dust', *Environmental Science and Policy*, 155, 103715

Metintas, M., G. Hillerdal, S. Metintas and P. Dumortier (2010) 'Endemic malignant mesothelioma: exposure to erionite is more important than genetic factors', *Archives of Environmental and Occupational Health*, 65 (2), pp.86–93

Metintas, S., M. Metintas, I. Ucgun and U. Oner (2002) 'Malignant mesothelioma due to environmental exposure to asbestos: follow-up of a Turkish cohort living in a rural area', *Chest*, 122 (6), pp.2224–9

Ministry for the Environment (2020) *Proposed Amendments to the National Environmental Standards for Air Quality: particulate matter and mercury emissions: consultation document*, Wellington: Ministry for the Environment, Proposed amendments to the national environmental standards for air quality consultation document

Möller, L., D. Schuetzle and H. Autrup (1994) 'Future research needs associated with the assessment of potential human health risks from exposure to toxic ambient air pollutants', *Environmental Health Perspectives*, 102 (Suppl 4), pp.193–210

Morman, S.A. and G.S. Plumlee (2013) 'The role of airborne mineral dusts in human disease', *Aeolian Research*, 9, pp.203–12

Muhammad, B. (2010) 'Asbestos status in Pakistan', Capacity-building and Awareness-raising Workshop on Environmental Sound Management (ESM) of Asbestos Waste in Asia and the Pacific, Beijing

Musante, C.J., J.D. Schroeter, J.A. Rosati, T.M. Crowder, J.A. Hickey and T.B. Martonen (2002) 'Factors affecting the deposition of inhaled porous drug particles', *Journal of Pharmaceutical Sciences*, 91 (7), pp.1590–600

Nel, E. and T. Stevenson (2014) 'The catalysts of small town economic development in a free market economy: a case study of New Zealand', *Local Economy*, 29 (4–5), pp.486–502

Noonan, W. (2017) 'Environmental asbestos exposure and risk of mesothelioma', *Annals of Translational Medicine*, 5 (11)

North Dakota Department of Health (2009) 'Erionite fact sheet', https://deq.nd.gov/erionite/General/Erionite_Fact_Sheet.pdf

Office of the Prime Minister's Chief Science Advisor and Royal Society of New Zealand (2014) *Asbestos Exposure in New Zealand: review of the scientific evidence of non-occupational risks*, Auckland; Wellington: Office of the Prime Minister's Chief Science Advisor and Royal Society of New Zealand

Parliamentary Commissioner for the Environment (2022) *Knowing What's Out There: regulating the environmental fate of chemicals*, Wellington: Parliamentary Commissioner for the Environment, https://pce.parliament.nz/media/g0pk2axl/regulating-the-environmental-fate-of-chemicals.pdf

Parliamentary Commissioner for the Environment (2024) *Going with the Grain: changing land uses to fit a changing landscape*, Wellington: Parliamentary Commissioner for the Environment, https://pce.

parliament.nz/media/qfxluadl/going-with-the-grain-changing-land-uses-to-fit-a-changing-landscape.pdf

Patel, J.P., M.S. Brook, M. Kah and A. Hamilton (2022) 'Global geological occurrence and character of the carcinogenic zeolite mineral, erionite: a review', *Frontiers in Chemistry*, 10, 1066565

Patel, J.P., M.S. Brook, M. Kah, A. Hamilton, M.C. Gamberini, C. Zoboli, E. Mugniaoli, D. Malferrari, R. Fantini, R. Arletti and A.F. Gualtieri (2024) 'Characterization and potential toxicity of asbestiform erionite from Gawler Downs, New Zealand', *American Mineralogist*, 109 (9), pp.1499–512

Pefoyo, A.J.K., L. Genesove, K. Moore, A. Del Bianco and D. Kramer (2014) 'Exploring the usefulness of occupational exposure registries for surveillance: the case of the Ontario Asbestos Workers Registry (1986–2012)', *Journal of Occupational and Environmental Medicine*, 56 (10), pp.1100–10

Queensland Government (2021) 'Queensland Government Asbestos Management Policy for its Assets: implementation standard 1: minimum requirements for asbestos, https://www.forgov.qld.gov.au/__data/assets/pdf_file/0017/183203/implementation-standard-minimum-requirements-asbestos-management.pdf

Reid, G., S. Klebe, N. van Zandwijk and A.M. George (2021) 'Asbestos and zeolites: from A to Z via a common ion', *Chemical Research in Toxicology*, 34 (4), pp.936–51, doi:10.1021/acs.chemrestox.0c00286

Rogers, A.J. (2018) 'Exposures estimates of the Wittenoom mining workforce and town residents: implications associated with risk estimation for persons exposed to asbestiform riebeckite', *Toxicology and Applied Pharmacology*, 361, pp.168–70

Ross, M., A.M. Langer, G.L. Nord, R.P. Nolan, R.J. Lee, D. Van Orden and J. Addison (2008) 'The mineral nature of asbestos', *Regulatory Toxicology and Pharmacology*, 52 (1), pp.S26–S30

Ryan, P.H., M. Dihle, S. Griffin, C. Partridge, T.J. Hilbert, R. Taylor, R., S. Adjei and J.E. Lockey (2011) 'Erionite in road gravel associated with interstitial and pleural changes: an occupational hazard in western United States', *Journal of Occupational and Environmental Medicine*, 53 (8), pp.892–8

Scarfì, S., V. Almonti, S. Mirata, M. Passalacqua, S. Vernazza, J.P. Patel, M. Brook, A. Hamilton, M. Kah and A.F. Gualtieri (2025) 'In vitro cyto-and geno-toxicity of asbestiform erionite from New Zealand', *Environmental Research*, 120415

Sharp, E.L., G.J. Brierley, J. Salmond and N. Lewis (2022) 'Geoethical futures: a call for more-than-human physical geography', *Environment and Planning* F, 1 (1), pp.66–81

Stevens, M.E., D.J. Paustenbach, N.J., Lockhart, D.E. Busboom, B.M. Deckard and D.W. Brew (2024) 'The presence of erionite in North American geologies and the estimated mesothelioma potency by region', *Inhalation Toxicology*, 36 (3), pp.158–73

Strohmeier, B.R., J.C. Huntington, K.L. Bunker, M.S. Sanchez, K. Allison and R.J. Lee (2010) 'What is asbestos and why is it important? Challenges of defining and characterizing asbestos', *International Geology Review*, 52 (7–8), pp.801–72

Talbot, N., H. Patel, S.B. Costello, P. Davy, J. Salmond, M. Brook and K. Dirks (2024) 'A mobile monitoring method for the screening of vehicle-movement-induced airborne erionite from roads in high-development residential areas', *Atmospheric Pollution Research*, 15 (2), 102007

US Department of the Interior Bureau of Land Management (2023) *North Dakota Draft Resource Management Plan and Environmental Impact Statement*, volume 1, https://eplanning.blm.gov/public_projects/1505069/200366341/20072587/250078769/North%20Dakota%20Resource%20Management%20Plan%20Revision%20Volume%201.pdf

Valavanidis, A., K. Fiotakis and T. Vlachogianni (2008) 'Airborne particulate matter and human health: toxicological assessment and importance of size and composition of particles for oxidative damage and carcinogenic mechanisms', *Journal of Environmental Science and Health*, Part C, 26 (4), pp.339–62

Van Gosen, B.S., T.A. Blitz, G.S. Plumlee, G.P. Meeker and M.P. Pierson (2013) 'Geologic occurrences of erionite in the United States: an emerging national public health concern for respiratory disease', *Environmental Geochemistry and Health*, 35, pp.419–30

Vaz, F., M. Koria and S. Prendeville (2022) 'Design for policy from below: grassroots framing and political negotiation', *Policy Design and Practice*, 5 (4), pp.410–26

Wagner, J.C., J.W. Skidmore, R.J. Hill and D.M. Griffiths (1985) 'Erionite exposure and mesotheliomas in rats', *British Journal of Cancer*, 51 (5), pp.727–30

Western Australia Department of Heath (2013) 'Guidance note on public health risk management of asbestiform minerals associated with mining', https://www.health.wa.gov.au/~/media/Files/Corporate/general-documents/Asbestos/PDF/GNote-Public-Health-Risk-Mgt-Asbestos-associated-with-Mining-Activities.pdf

Wolff, H., T. Vehmas, P. Oksa, J. Rantanen and H. Vainio (2015) 'Asbestos, asbestosis, and cancer, the Helsinki criteria for diagnosis and attribution 2014: recommendations', *Scandinavian Journal of Work, Environment and Health*, pp.5–15

Workplace Health and Safety Queensland (2021) *Statewide Strategic Plan for the Safe Management of Asbestos in Queensland* 2022–2025

WorkSafe New Zealand (2021) *New Zealand Carcinogens Survey 2021*, https://www.worksafe.govt.nz/research/new-zealand-carcinogens-survey-2021/

WorkSafe New Zealand (2024a) 'Asbestos in the home', http://worksafe.govt.nz/topic-and-industry/asbestos/asbestos-in-the-home/

WorkSafe New Zealand (2024b) 'Controlling dust with on-tool water suppression', https://www.worksafe.govt.nz/topic-and-industry/dust/controlling-dust-with-on-tool-water-suppression/

World Health Organization (2018) 'Elimination of asbestos-related diseases', https://www.who.int/news-room/fact-sheets/detail/asbestos-elimination-of-asbestos-related-diseases