Appendix A: Literature Review

Literature Review

Potential Health Risks from Brown Coal Ash from the 2014 Hazelwood Coal Mine Fire

Prepared for:
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Distribution

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List of Acronyms

Acronym	Definition
AAQ NEPM	National Environment Protection (Ambient Air Quality) Measure
ASC NEPM	National Environment Protection (Assessment of Site Contamination) Measure
CFGM	Coal-fire gas minerals
CO	Carbon monoxide
DHHS	Department of Health and Human Services
EPA	Environment Protection Authority
HIL	Health Investigation Levels
HSL	Health Screening Levels
MAH	Monocyclic aromatic hydrocarbons (examples include benzene and toluene)
NEPM	National Environment Protection Measure
PAH	Polycyclic aromatic hydrocarbons – products of incomplete combustion
PM	Particulate matter
$PM_{2.5}$	Particulate matter less than 2.5 µm in size
PM_{10}	Particulate matter less than 10 µm in size
USGS	United States Geological Survey
VOC	Volatile organic compound

1.0 Introduction

1.1 Background

Senversa was engaged by the Department of Health and Human Services (DHHS) to conduct a series of works to assess the potential for residual brown coal ash to be present in roof cavities of residences in the Morwell area and surrounds, as a result of the Hazelwood coal mine fire in 2014. These works will investigate the potential for residents to be exposed to ash residue, if present, and whether any exposures constitute a potential ongoing risk to health.

The works being undertaken are in response to Recommendation 9 of the Volume III of the Hazelwood Mine Fire Inquiry Report 2015/2016[1], which was tabled in the Victoria Parliament on 10 February 2016.

Recommendation 9 states that the State should "*ensure that ash contained in roof cavities in Morwell is analysed and acted on.*" This recommendation goes on to say that the *"State should:*

- *Commission an analysis of the ash contained in roof cavities of houses in Morwell and publish the results of that analysis to the community and Latrobe Valley Health Assembly, together with clear advice about the potential known, or unknown health effects.*
- *If the analysis of the ash residue in roof cavities reveals any content that is potentially hazardous to health or of unknown impact on health, conduct an audit of the extent of the exposure to ash and develop an action plan to remove the ash from all affected houses."*

1.2 Objectives

This literature review provides an overview of current scientific literature and guidance, as relevant to the proposed assessment of brown coal ash residue in roof cavities in Morwell. The objectives of the literature review were to:

- outline likely contaminants in brown coal ash, to inform the rationale for selecting specific contaminants for testing; and
- describe the evidence for potential health risks to the community from brown coal ash residue remaining in roof cavities, as a result of the 2014 Hazelwood coal mine fire.

With consideration to the above, the review focused on the following questions:

1. What evidence is there to identify the physical and chemical characteristics of brown coal ash?
2. What evidence is there of the health effects of brown coal ash?
3. What evidence is there of health risks from brown coal ash in roof cavities?
4. What evidence suggests a potential connection between brown coal mine fire ash in roof cavities and the presence of red mould on ceilings/cornices?

1.3 Methodology

To answer the above questions, a search was undertaken of available primary literature, government publications, and peer reviewed scientific publications. The following search terms were used: 'Victorian brown coal', 'brown coal ash', 'physical and chemical characteristics of brown coal ash', 'coal fly ash' and any of the following: 'major elements', 'chemical', 'roof cavity', 'roof cavities', 'attic', 'dust', 'red mould', 'health', 'health effects', 'health risk', 'health hazard', 'trace element', 'rare earth element'. Additional relevant citations listed in reviewed papers were also obtained where possible. Publications were excluded from the review if they were unavailable in full-text (for example, old publications unavailable via current online databases) or were unavailable in English.

It is noted that a large quantity of information and literature was identified in the searches, and it was not feasible to review all relevant publications in detail. The information summarised herein has therefore aimed to highlight readily available information which was considered most relevant to the objectives of the review, i.e. the identification of potential health risks which may be posed by brown coal ash residue in roof cavities, and selection of likely contaminants in brown coal ash.

2.0 Literature Review

2.1 Background Information

The Hazelwood Power Station, located three kilometres south of Morwell in the Latrobe Valley, generates thermal energy by burning pulverized coal. The coal is procured from the adjacent Hazelwood open cut brown coal mine, which caught fire on 9 February 2014 and continued to burn for 45 consecutive days. The fire was caused by embers spotting into the mine from nearby bushfires[2].

Coal fires occur in all coal-bearing regions of the world and number, conservatively, in the thousands[3]. Coal fires are characterized by the emission of noxious gases, particulate matter (PM), and condensation by-products[4]. There are currently active fires consuming coal seams in major coal-producing countries including China, the United States, India, Indonesia, Singapore, Malaysia and Thailand[5] with numerous seams burning for decades and some in China for several centuries[4]. The majority of coal fires are caused by either:

- mine related activities such as welding, electrical work or smoking;
- transmission of fire from lightening, bushfires or waste burn offs; or
- spontaneous combustion induced by coal fines, oil-soaked rags, lumber, hay or manure in culm banks or by exothermic oxidation reactions catalysed by oxygen circulating through coal seam joints[4].

Coal is a fossil fuel which forms from vegetation and other organic (carbon containing) matter that originally accumulated in swamps and peat bogs many millions of years ago. This material was subsequently buried, often to great depths, due to accumulation of overlying sediments and movements of the earth's crust. The burial process results in the organic deposits being subjected to high temperatures and pressures, which causes transformation into peat and then into coal. This process is called coalification.

The geochemical process of coalification is a continuous and irreversible process that produces progressively higher ranked coals[6] from lignite through to anthracite[7]. Coal is primarily composed of moisture, mineral matter, volatile matter, and fixed carbon although one of the first effects of coalification is removal of water. Volatile matter includes gases that are released by thermal decomposition of coal, such as hydrogen, carbon monoxide (CO), methane, and other hydrocarbons, tar vapours, ammonia, carbon dioxide, and water vapour other than residual moisture[7].

Victoria's brown coals, called lignite, are soft brown coals formed from naturally compressed peat. Victorian lignite is a low rank type of coal characterised by low ash, sulphur, heavy metals and nitrogen[8] but containing a high moisture content and a high volatile matter content[9]. These properties make brown coal easy to burn for power generation, but also make it susceptible to spontaneous combustion.

Coal ash, including fly ash, is a major by-product of the combustion of coal[10]. When coal is combusted, sediment layers within the coal are mobilised and trace elements contained within those sediments are released to the atmosphere[10]. Victorian coal produces low amounts of ash, and it has been suggested that this could be due to low amounts of sediment being deposited during coalification[10].

2.2 Physical and Chemical Characteristics of Brown Coal Ash

What evidence is there to identify the physical and chemical characteristics of brown coal ash?

2.2.1 Evidence in the Literature

The physical and chemical characteristics of brown coal ash will be dependent upon the composition of the precursor coal material. Some variability in the chemical composition of coal, and the coal ash that is subsequently produced following combustion, is to be expected based on local geological conditions. The discussion below provides a review of the available literature relating to coal and coal ash composition. This information includes data from Australian and international sources, with discussion of international data provided where the information was deemed relevant to the overarching understanding of coal and coal ash composition. Information specific to the Hazelwood mine coal and coal ash is summarised in **Section 2.2.2** below.

Ash is defined as the residue left after the burning of a substance and is a major by-product of the combustion of coal[11]. Victorian brown coal produces relatively low amounts of ash, and it has been proposed that this is a result of the environment of deposition within a raised swamp, where low amounts of sediment are deposited during the coalification process[10].

In industrial coal combustion processes used in coal fired power stations, two types of ash are produced: bottom ash and fly ash. Bottom ash is coarser residual material remaining within a combustion chamber after combustion has finished, while fly ash is a finer material that can become captured in the gas stream emitted from the combustion process[2]. Fly ash is typically captured through pollution control systems in coal fired power stations, however some can be released to atmosphere under normal operating conditions.

While a considerable amount of literature is available regarding the physical and chemical characteristics of fly ash, there is limited literature specifically relevant to properties of coal ash generated during mine fires. However, mine fire ash deposited remotely to the fire is expected to be similar to fly ash, as both comprise smaller particles able to be carried from the combustion source. The following information therefore primarily relates to coal and/or brown coal fly ash, however is supplemented by the limited information available regarding ash generated during mine fires.

2.2.1.1 Fly Ash

Coal fly ash is comprised of fine particles which contain a mixture of inorganic components primarily derived from the mineral components of the precursor coal (including clays, quartz, iron oxides and aluminosilicate glass formed by melting of mineral matter), and organic components from combustion of the coal[12].

The United States Geological Survey (USGS) describes the major chemical constituents of coal fly ash as including (in decreasing order of abundance) silicon, aluminium, and iron expressed as oxides (elements in combination with oxygen), and with contain lesser amounts of oxides of calcium, magnesium, potassium, sulphur, titanium, and phosphorus whose proportions tend to be more variable[12]. Coal ash also contains a number of trace elements, including chromium, nickel, zinc, arsenic, selenium, cadmium, antimony, mercury, lead and uranium[12.] Metals released from coal fires may be organically bound where the coal is charred rather than burned, but are more likely to be mineralised at higher temperatures[13]. At higher combustion temperatures (600˚C and higher), chromium (VI) species form, however the proportion of chromium present in this form is relatively small (6-8%)[13].

A literature review of the physico-chemical properties of fly ash was undertaken by Roy et al.[14]. The study provides results from a number of international studies which reviewed major components of fly ash.

Physically, the reviewed studies indicated that fly ash has a generally silt loam texture, with samples typically described as having a 'floury consistency' or a 'fine granular texture'. One cited study[15] described different morphological classes of particles, as follows:

- Solid spherical particles predominating the size range below 10 µm.
- Large irregular particles, some of which were agglomerates of small (<10 µm) spherical particles, predominating the >74 µm size fraction.
- Hollow spherical particles (cenospheres) and/or hollow spherical particles containing encapsulating particles as host particles predominating in the 20 to 74 µm size range.

The same study[15] also reported that dominant minerals present in fly ash were alpha-quartz, mullite, hematite and magnetite, but that amorphous glass material predominates. Small amounts of gypsum were also found in some, but not all ashes. Another study[16] reported that mullite and quartz minerals were more concentrated in the coarse fraction, while gypsum and goethite were more concentrated in fine fractions.

The chemical (elemental) composition of fly ash has been evaluated in a number of studies, with a comprehensive summary of a number of these studies also presented by Roy et al.[14].

It is noted that a large number of naturally occurring elements are present in both coal and associated fly ash, however many of these are also expected to be present in natural soils and rocks across local areas at similar concentrations to those found in the coal. Some studies have attempted to document constituents in soils and/or ecosystems around coal fired plants which are enriched relative to background conditions in the area. A number of these studies are summarised by Roy et al.[14] and indicated the following:

- Soils near a coal-fired power plant in Michigan were enriched with silver, cadmium, cobalt, chromium, copper, iron, mercury, nickel, titanium and zinc.
- Mercury levels in soils downwind of a coal fired power plant in Illinois were enriched relative to upwind locations.
- Selenium levels in lichen, grass and other vegetation were elevated downwind of two plants in Wyoming, and concentrations decreased with distance from the plant.
- A terrestrial ecosystem near three coal fired power plants contained elevated levels of lead, cadmium, copper, zinc, mercury, chromium and molybdenum (however it was noted that the source of these could not be confirmed and the major source of lead was probably automobile emissions).

Available data also indicates that concentrations of many elements in fly ash are enriched relative to source material and/or increase with decreasing particle size[14, 17]. These include arsenic, boron, barium, bromine, cadmium, chlorine, cobalt, copper, chromium, iron, gallium, mercury, iodine, indium, magnesium, manganese, molybdenum, nickel, lead, polonium, rubidium, sulfur, antimony, scandium, selenium, strontium, thallium, tungsten, vanadium and zinc, however those which were most enriched (greater than a factor of 2 relative to coal) were primarily arsenic, selenium, antimony and lead.

Organic constituents of fly ash included monomethyl and dimethyl sulphate, and polycyclic aromatic hydrocarbons (PAHs) including dibenzofuran and benzo(a)pyrene, however total hydrocarbon content has been reported to be low (about 9 mg/kg) [14]. Concentrations of PAHs, while detectable in fly ash, have been reported to be very low, for example total PAH concentrations less than 50 µg/kg in fly ash derived from high rank coal[18], however higher concentrations (up to 1 mg/kg) has been reported in other studies[19].

Some studies show some enrichment of radionuclides in fly ash[14], however a study conducted by the Australian Nuclear Science and Technology Organisation (ANSTO)[20] on 55 samples of Australian fly ash concluded that radionuclide concentrations in fly ashes (including ultra-fine fractions) are similar to or not significantly higher than ranges in background soil and typical building materials, and well below thresholds for classification as radioactive from a regulatory perspective. This is consistent with conclusions drawn by the United States Geological Survey (USGS)[21] radioactive elements in coal and fly ash are not of concern from a health perspective.

Dioxins and furans have also been detected in fly ash, however a number of studies[22] have demonstrated that concentrations are low (typically less than 25 pg/g (picograms per gram), which equates to 25 ppt (parts per trillion), with 2,3,7,8-Tetrachlorodibenzodioxin levels predominantly less than 2 pg/g). These concentrations were similar to background levels in typical soils, and are below relevant health based screening levels for assessment of exposure to dioxins in soils.

2.2.1.2 Ash from Mine Fires

While ash generated from the Hazelwood mine fire is expected to have generally similar characteristics to fly ash, some differences are also likely. The Hazelwood Mine Fire Enquiry Report[2] indicated that the following factors may have impacted on the mine fire ash composition:

- Sources of smoke and particulate matter from biomass burning (bushfires) were also present at the time of the Hazelwood mine fire.
- The coal combustion process was occurring in open air, rather than a controlled environment such as a combustion chamber.
- The temperature of combustion was variable spatially and temporally, and was different to that in a controlled combustion chamber.
- The use of water and firefighting foam to quench the fire may have added an additional source of chemical constituents (e.g. firefighting foam additives, such as glycol ether solvents).

Available literature studies indicate that ash generated from a mine fire is likely to have a higher proportion of organic compounds than brown coal ash produced during electricity production under controlled higher temperature conditions[23].

A study of the products of spontaneous combustion of coal seams in South Africa was undertaken in order to determine if potentially toxic chemical elements and compounds were mobilised into the environment[24]. Samples of the minerals forming on the surface of coal seams, and gases escaping from vents, were analysed. The coal-fire gas minerals (CFGM) identified included minerals of sulphur, ammonia, aluminium, silicon, potassium, magnesium, titanium, barium, iron and calcium. Other heavy elements found in the CFGMs were mercury, arsenic, lead, zinc, and copper. Arsenic and mercury were the major elements of potential environmental significance found accumulating around coal-fire vents. Benzene, toluene, xylenes, and low concentrations of a number of aliphatic hydrocarbons and halogenated compounds were also found in the gas form (as gases escaping from vents), however the study did not analyse for these compounds in the particulate/mineral phase.

2.2.2 Evidence from the Hazelwood Fire

With respect to the ash from the Hazelwood mine fire, it was found[2] that the ash produced by the Hazelwood mine fire had a lower $PM_{2.5}$ content than fly ash (6% in mine fire ash as compared to 27% in fly ash).

The EPA Victoria collected twelve ash samples during the fire at the Hazelwood mine when sufficient ash was being produced for collection. The samples were analysed for an extensive suite of potential constituents, including metals, polycyclic aromatic hydrocarbons (PAHs), monocyclic aromatic hydrocarbons (MAHs), halogenated volatile organic compounds (VOCs) and solvents[25]. The metals barium, boron, manganese and strontium were identified as key analytes found in significant percentages in the early mine fire ash samples and are common trace metals in brown coal[25]. Concentrations of metals (aluminium, arsenic, cadmium, chromium, cobalt, copper, iron, lead, mercury, nickel, selenium, tin, titanium, vanadium, zinc), and PAHs (acenaphthene, acenaphthylene, anthracene, chrysene, fluoranthene, fluorene, naphthalene, phenanthrene and pyrene) were present in the ash samples. MAHs (benzene, toluene, xylene, styrene and 1,2,4-methylbenzene) and the solvent acetone were also present in some ash samples at low concentrations[26]. It is noted that MAHs and acetone are highly volatile compounds and would be expected to volatilise rapidly from fine particles.

2.3 Health Effects of Brown Coal Ash

What evidence is there of the health effects of brown coal ash?

2.3.1 Evidence in the Literature

The health effects associated with inhalation exposure to ash produced from combustion of coal or other organic matter sources are well documented. However, any health effects associated with exposure to brown coal ash would generally occur as a result of inhalation exposures during a fire or combustion event, at which time airborne concentrations of coal ash constituents would be highest.

Melody and Johnston[23] reviewed literature on the health effects from mine fires and found few studies. They noted, however, that the chemical components of smoke from domestic coal use and from forest and open fires was similar to those measured in mine fires. This literature review has similarly not identified literature explicitly assessing health effects from mine fires, and as a consequence has broadened the review to include a number studies on the health effects of brown coal fly ash, coal combustion and peat fires.

Health effects from mine fire smoke are likely to include effects from inhalation exposure to gases, PM, VOCs and trace elements[23]. In many studies reviewed by Melody and Johnston[23], no attempt was made to distinguish between health effects caused by particulate matter (e.g. ash) and those caused by gases.

A rise of lung cancer, bronchitis, stroke, pulmonary heart disease, and chronic obstructive pulmonary disease in China linked to coal gas and particulate emissions has been reported[7]. A significant increase in hospital admissions due to asthmatic and other respiratory related problems has been reported during regional smoke haze episodes in Southeast Asia due to fine particles less than 2.5 µm in size ($PM_{2.5}$) [5]. At the time of the fire, the Australian Ambient Air Quality National Environment Protection Measure (AAQ NEPM) had an advisory reporting standard which recommended that the daily average $PM_{2.5}$ concentration should not exceed 25 µg per cubic metre, and the annual average should not exceed 8 µg per cubic metre[27]. At the beginning of 2016 an additional goal was introduced for $PM_{2.5}$ to further reduce concentrations to below a daily average concentration of 20 µg per cubic metre and an annual average concentration of 7 µg per cubic metre by 2025[28]. $PM_{2.5}$ is of particular health concern as fine particles can bypass the normal body defence mechanisms and can penetrate deep into alveoli region of the lungs[5]. It is noted that the AAQ NEPM standards apply for the purpose of monitoring the general quality of a local air shed. Although useful to inform normal pollution levels, they are not necessarily intended to be applied to significant local emergency events where short-term poor air quality may exceed this measure[29].

A study of trace metals associated with $PM_{2.5}$ generated during a peat fire in Indonesia assessed health risks to those working long term in close proximity to the fires (such as fire fighters and plantation workers); the study found an increased carcinogenic and non-carcinogenic health risk from the inhalation of these particles. The study also noted that other compounds such as PAHs and nitrated PAHs were not included in the study and that consideration of these is likely to increase the estimated health risk[5].

The potential health effects associated with longer term exposures to brown coal ash residue in roof cavities is discussed further in **Section 2.4** below.

2.3.2 Evidence from the Hazelwood Fire

During the Hazelwood coal mine fire, the Victorian EPA monitored a number of air quality parameters at several monitoring stations, to see what pollutants were present in smoke and/or gases released from the fire[30,2]. Indicators assessed were carbon monoxide, $PM_{2.5}$, PM_{10}, sulphur dioxide, nitrogen dioxide, volatile organic compounds including benzene, and ozone. Of these, the pollutants that exceeded relevant air quality standards at different times were airborne particles ($PM_{2.5}$ and PM_{10}) and carbon monoxide (however it is noted that the majority of carbon monoxide levels were below community exposure guideline values adopted by Emergency Management Victoria for emergency situations[31]). Benzene was also reported to exceed the relevant air quality criterion, but only on three occasions/locations, and only by a very small margin (measured concentrations of 9.2-14 ppb (parts per billion) were recorded, compared to a standard of 9 ppb). Sulfur dioxide, nitrogen dioxide and ozone did not exceed relevant air quality standards.

No indoor air monitoring was conducted during the fire, however residents reported that smoke and ash entered properties despite efforts to close windows and vents, particularly in older style houses with gaps in floorboards, windows and/or door frames[2].

Residents reported a number of health effects, including headaches, sore throats, general feelings of sickness, and sinus and respiratory syptoms[2]. The most commonly reported symptoms in a survey of 341 residents were flu-like, and the second most common were respiratory (shortness of breath, wheezing and asthma) [2]. However, most people reported that these symptoms abated when they removed themselves from the area impacted by smoke and ash.

The reported symptoms were consistent with those expected to occur due to exposure to particulate material in airborne smoke and ash, and possibly carbon monoxide. A rapid health risk assessment commissioned by the then Department of Health in February 2014, conducted by Monash University, found that the principal short term risks to the health of the Morwell community were from inhalation of fine particles ($PM_{2.5}$) and carbon monoxide. The report noted that there did not appear to be any significant risk from sulfur dioxide, and that the risk from other air toxic hazards was unknown.

The 2015/16 Hazelwood Mine Fire Inquiry Report concluded that it was likely that there was an increase in deaths in the Latrobe Valley between February and June 2014 when compared with the same period during 2009–2010 and that it was likely that the Hazelwood mine fire contributed to some of the increase in deaths in the Latrobe Valley in 2014[32]. However, the inquiry did not explore the causes of this probable increase and thus it is not possible to distinguish between mortality associated with ash, other products from the mine fire or other causes.

2.4 Health Risks from Brown Coal Ash in Roof Cavities

What evidence is there of health risks from brown coal ash in roof cavities?

2.4.1 Background Information

There appears to be little evidence or studies in the literature reviewed relating specifically to potential exposure or health effects associated with ash residue in roof cavities. As described above in **Section 2.3**, a number of health effects have been reported both overseas and in the Morwell community during fires, however these are concluded to be primarily associated with inhalation exposure to carbon monoxide and/or particulate matter which are present in the air during the fire event. Once deposited in a roof cavity, ash or other dust residue is not airborne, thus the magnitude and pathways of exposure (and associated health risk) will differ from during the fire. During normal occupation or use (i.e. when residents are within the main portion of the house and not in the roof space), the relevant migration and exposure pathways would comprise the following:

- Migration of ash from the roof space into living areas of the house through gaps or openings in the ceiling, including ceiling roses, air vents, conduits, holes, etc. The roof space dust or ash would then become a portion of the overall indoor dust load. It is noted that indoor dust is derived from a number of sources, including outdoor soil, road dust, human or pet hair and skin, carpet and clothing fibres, paint chips, fungal spores, etc. Studies indicate that approximately 30% of indoor dust is derived from outdoor soil[33] and less than 5% derived from hair and skin[34],[35].
- Exposure by residents to the particulate matter may include[36]:
  - Incidental ingestion of dust particles, e.g. small amounts of dust may adhere to the skin and then be ingested due to hand to mouth contact.
  - Dermal contact with dust particles, where contaminants in dust adhered to the skin may be absorbed through the skin.
  - Inhalation of airborne dust within the house.

The above exposure pathways are explicitly considered in the derivation of health-based guidelines and screening levels for contaminants in soil, including Health Investigation Levels (HILs) and Health Screening Levels (HSLs) specified within the National Environment Protection (Assessment of Site Contamination) Measure (ASC NEPM)[36]. Thus, where contaminant concentrations in ash or other dust within roof cavities are lower than HILs or HSLs (or other guidelines derived using a similar methodology), the ash/dust would not be expected to pose an unacceptable risk to human health.

A preliminary assessment of potential health risks from brown coal ash in roof cavities can therefore be made by comparing available data from the Hazelwood fire and/or other studies to relevant soil quality guidelines.

2.4.2 Evidence in the Literature

There has been limited research that specifically assesses the association between brown coal ash residue in roof cavities, and health risks. Studies which have measured coal ash properties and assessed the associated potential health risks have generally focused on exposure which occurs at locations closer to the mine or fire site. However, two studies with some relevance to the question were identified, as discussed below.

One study that considered six trace elements (arsenic, cadmium, copper, nickel, lead and zinc) in attic dust was conducted in Hungary and identified that long term (30 or more years) impacts from lignite mines, lignite fired power stations and traffic were able to be differentiated to some degree and spatially mapped[37]. The key elevated elements observed were arsenic, mercury, lead and copper. No health risk assessment was undertaken by the authors, however Senversa's review of the available data indicated that, with the exception of lead (Pb), the maximum reported trace element concentrations were below relevant health investigation levels (HILs) published in the ASC NEPM. The average and upper quartile Pb concentrations (139 mg/kg and 149 mg/kg) were well below the NEPM residential soil HIL (300 mg/kg), while the maximum concentration (881 mg/kg) exceeded the HIL. However, the Pb concentrations were concluded by the authors (and have been demonstrated in other studies) to most likely have originated from traffic emissions (due to historical use of leaded petrol), rather than coal mine emissions.

An investigation of contaminants in roof cavity dust was also conducted in Sydney[38], however there was no indication that the roof dust in the sampled homes may have been affected by ash derived from coal or other sources. The majority of the dust was composed of particles that were derived from local soil or plant material. Anthropogenic material was estimated to contribute up to 25% of the dust. Metal concentrations in the dust were "enriched" when compared to the natural soils from the Sydney area with the highest metal concentrations found in the smallest particles. Concentrations of metals were higher in houses proximal to industrial areas. The authors concluded that ceiling dusts posed a potential health risk if disturbed and allowed to enter living spaces within the residence, particularly due to elevated concentrations of lead in industrial areas, however as noted above the presence of lead in roof dust is likely attributable to vehicle emissions. It is noted that the metal concentrations found in the attic dust tested in Sydney homes were significantly higher than those found by EPA in the Hazelwood ash[25].

2.4.3 Evidence from the Hazelwood Fire

As mentioned above in **Section 2.2.1.2**, EPA collected and analysed ash samples for a range of contaminants during the Hazelwood fire[25]. The results indicated that a number of elements were present at higher concentrations in ash than in regional soil, primarily barium, boron, manganese, strontium, titanium and zinc. However, reported concentrations of all analytes (including metals, PAHs, MAHs and solvents) were below relevant HILs or equivalent health-based guidelines for soil. The results therefore do not suggest that ash from the Hazelwood fire, if present in roof spaces, would pose ongoing risks to human health.

2.5 Connection Between Brown Coal Ash and Red Mould

What evidence suggests a potential connection between brown coal mine fire ash in roof cavities and the presence of red mould on ceilings/cornices?

No evidence linking ash and red mould was identified in the literature search. Senversa notes that mould spores are ubiquitous in the environment. Moulds will grow when conditions are suitable (e.g. in damp environments)[39]. One possible theory is that the brown coal ash contains trace element(s) required by red moulds which is not normally present in the environment at the correct concentrations or not normally bioavailable, however, no literature studies or other information could be found to support this theory.

Further assessment of this factor will be undertaken through site based observations and field data collection, to be undertaken as part of this project.

3.0 Conclusions and Recommendations

Limited specific information regarding the chemical and physical nature of brown coal ash from mine fires, and associated health effects, is available in the literature. Some inferences can be made from studies reviewed and EPA's testing of ash samples during the fire. These are summarised as follows:

- Contaminants expected to be present in fly ash derived from coal and/or brown coal ash from the Hazelwood fire are the following:
  - A wide range of metals / trace elements, however many of these are likely to be present at concentrations similar to or lower than background soil. Based on literature reviewed and data collected by EPA during the Hazelwood fire, elements which may be enriched in ash may be arsenic, selenium, antimony, lead, barium, boron, manganese, strontium, titanium and zinc.
  - PAHs, however concentrations reported in both the literature and based on testing during the Hazelwood fire are below levels considered to be of potential concern for human health.
  - Other organic compounds, including MAHs and acetone, however reported concentrations in ash from the Hazelwood fire were very low (below screening levels for human health) and as these are highly volatile compounds they would be expected to rapidly volatise from ash and are not likely to still be present in ash residue in roof space.
  - Radionuclides, however concentrations reported are not higher than those in background soil and typical building materials, and below thresholds for classification as radioactive.
  - Dioxins and/or furans, however at low concentrations similar to background levels in typical soils.
- The available data do not indicate that contaminant concentrations in brown coal ash from the Hazelwood fire are likely to pose a risk to human health if present in roof cavities, however sampling and analysis for key parameters will assist with confirming this conclusion.
- No information was identified pertaining to a link between brown coal mine fire ash and red mould growth on ceilings/cornices.

Based on the above, the following recommendations are provided regarding the proposed sampling and analysis of ash within roof cavities in Morwell:

- While the available data do not indicate that these are likely to be present in ash at concentrations of potential concern, it is recommended that roof ash samples be analysed for PAHs and a broad metals suite (including at a minimum arsenic, selenium, antimony, lead, barium, boron, manganese, strontium, titanium and zinc). These results will be used to (a) confirm that the concentrations in ash are below levels of potential concern and (b) assess patterns in specific elements or PAH signatures and whether these can be linked to distance from the fire and/or quantities of ash present in roof cavities.
- Analysis for other potential components, including radionuclides, dioxins/furans, MAHs, is not considered necessary as both literature and site-specific data indicate that these are not present at concentrations higher than background levels in soil or other common materials.
- No specific sampling regime is recommended to assess a potential link between red mould and the presence of ash residue in roof cavities. However, the study will include the following activities to assess whether such linkage may be present:
  - Documentation (through visual observation and interviews with residents) of selected houses and locations where such mould has been observed.
  - Comparison of these locations to visual or chemical indicators (e.g. metal or PAH signatures) of the presence of ash within roof cavities.

4.0 References

1 Hazelwood Mine Fire Inquiry Report 2015/2016, Volume III – Health Improvement. No. 82, Session 2014-2016.

2 Hazelwood Mine Fire Inquiry, 2014. Hazelwood Mine Fire Inquiry Report. Available from: http://report.hazelwoodinquiry.vic.gov.au/.

3 Engle, M.A., 2011. Quantifying greenhouse gas emissions from coal fires using airborne and ground-based methods. Int. J. Coal Geo., 88(2-3), pp.147–151

4 Stracher, G.B. et al, 2004. Coal fires burning out of control around the world: thermodynamic recipe for environmental catastrophe. Int. J. Col Geo., 59(1-2), pp. 7-17

5 Betha, R. et al., 2013. Chemical Speciation of Trace Metals Emitted from Indonesian Peat Fires for Health Risk Assessment. Atmos. Res., 122 pp. 571-578

6 ASTM, 2005. Standard Classification of Coals by Rank, D388 - 05

7 Stracher, G.B. et al. (Ed), 2011. Coal and Peat Fires – A Global Perspective. Elsevier

8 http://www.energyandresources.vic.gov.au/earth-resources/victorias-earth-resources/coal (accessed 12 September 2016)

9 http://www.ga.gov.au/scientific-topics/minerals/mineral-resources/aimr (accessed 12 September 2016)

10 Swaine, D.J., 2013. Trace Elements in Coal, Butterworth-Heinemann

11 Swaine, D.J., 2013. Trace Elements in Coal, Butterworth-Heinemann

12 Deonarine, A. et al., 2015. USGS Fact Sheet 2015-3037: Trace elements in Coal Ash

13 Low, F., 2014. Emissions of Organically Bound Trace Elements During Brown Coal Air and Oxyfuel Combustion (PhD Thesis)

14 Roy W.R.et al., 1981. Coal Fly Ash: A Review of the Literature and Proposed Classification System with Emphasis on Environmental Impacts. Illinois State Geological Survey

15 Natusch, D.F.S, C.F. Bauer, C. F. Bauer, H. Matusiewicz, C. A. Evans, J. Baker, A. Loh, R. W. Linton, and P. K. Hopke, 1977. Characterization of trace elements in fly ash: Institute for Environmental Studies, University of llinois; IES Research Report no. 3, 34 p.

16 Page, A. L. , A. A. Elseewi, and I. R. Straughan, 1979. Physical and chemical properties of fly ash from coal-fired power plants with reference to environmental impacts. Residue Reviews, 71, p. 83-120.

17 Swaine, D.J., 1996. Trace elements in Coal Science, Liversidge Research Lecture No.30.

18 Ribeiro, J, T.F. Silva, J.G. Mendonca Filho, and D. Flores, 2014. Fly ash from coal combustion – an environmental source of organic compounds. Applied Geochemistry 44, pp. 103-110.

19 Fu, F., B. Tian, G. Lin, Y. Chen, 2010. Chemical characterisation and source identification of polycyclic aromatic hydrocarbons in aerosols originating from different sources. Journal of the Air and Waste Management Association, 60, pp. 1309-1314.

20 McOrist, G. and S. Brown, 2009. Association of Naturally Occurring Radionuclides in Australian Coal and Combustion Products (CCPs). Australian Nuclear Science and Technology Organisation: Minerals. Lucas Heights, NSW. 27 pp.

21 USGS, 1997. Radioactive Elements in Coal and Fly Ash: Abundance, Forms and Environmental Significance. United States Geological Survey. Fact Sheet FS-163-97.

22 Sear, L.K.A., 2001. The properties and use of coal fly ash, A valuable industrial by-product. Thomas Telford Publishing, London, 264 pp.

23 Melody, S.M. and Johnston, F.H, 2015. Coal Mine Fires and Health: What do we Know?. Int. J. Coal Geo., 152, pp. 1-14

24 Pone, J.D.N et al, 2007. The spontaneous combustion of coal and its by-products in the Witbank and Sasolburg coalfields of South Africa. Int. J. Col Geo., 72, pp. 124-140

25 EPA, 2015. Hazelwood Recovery Program Water, Soil and Ash Assessment - Morwell and Surrounds. Publication 1600.

26 http://www.epa.vic.gov.au/our-work/monitoring-the-environment/hazelwood-recovery-effort/testing-during-the-hazelwood-fire/ash-testing-data-during-the-fire

27 NEPC, 2010. National Environment Protection (Ambient Air Quality) Measure 2003 (as amended 2010). Canberra: National Environment Protection Council.

28 NEPC, 2016. National Environment Protection (Ambient Air Quality) Measure 2003 (as amended 2016). Canberra: National Environment Protection Council.

29 State Government, 2015. Community smoke, air quality and health standard Air quality assessment, forecasting and health protection messaging for particulate matter Version 1.0, December 2015

30 EPA, 2015. Summarising the air monitoring and conditions during the Hazelwood mine fire, 9 February to 31 March 2014. Publication number 1598, June 2015.

31 Emergency Management Victoria, 2015. *Standard for Managing Exposure to Significant Carbon Monoxide Emissions.* July 2015. Version 2.0.

32 Hazelwood Mine Fire Inquiry Report 2015/2016, Volume II – Investigations into 2009-2014 Deaths. No. 81, Session 2014-2015.

33 Calabrese, E.J. and Stanek, E.J., 1992. What proportion of household dust is derived from outdoor soil?. Journal of Soil Contamination, 1(3), pp. 253-263.

34 Mølhave, L, T. Schneider, S.K. Kjærgaard, L. Larsen, S. Norn, O. Jørgensen, 2000. House dust in seven Danish offices. Atmospheric Environment, 34(28), pp. 4767-4779.

35 enHealth, 2012. Environmental Health Risk Assessment: Guidelines for assessing human health risks from environmental hazards, Publication No. DO702: Environmental Health Standing Committee.

36 NEPC, 2013. National Environment Protection (Assessment of Site Contamination) Measure 1999 (as amended 2013. Canberra: National Environment Protection Council.

37 Völgyesi, P. et al., 2014. Attic Dust Reflects Long-term Airborne Contamination of an Industrial Area: A Case Study from Ajka, Hungary. App. Geochem. 46, pp. 19-29

38 Davis, J.J. and Gulson, B. L, 2005. Ceiling (attic) dust: A “museum” of contamination and potential hazard. Env. Res., 99(2), pp. 177-194.

39 http://www.cdc.gov/mold/dampness_facts.htm (accessed 12 September 2016)

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