Asbestos contamination on brownfield development sites in the UK

Emma E. Hellowell^{a)}, Susan J. Hughes^{b)}

^{a)} Department of Civil and Environmental Engineering, University of Surrey, Guildford,
Surrey GU2 7XH, UK
Tel: 01483 300800
Email: e.hellowell@surrey.ac.uk

^{b)} Department of Civil and Environmental Engineering, University of Surrey, Guildford,
Surrey GU2 7XH, UK
Tel: 01483 300800
Email: sue.hughes@surrey.ac.uk

Corresponding Author: Emma E. Hellowell

Abstract

The development of brownfield sites in the UK requires site investigation for contamination as part of the regulatory planning process. This site investigation includes the collection of soil samples that are analysed for asbestos contamination. This research project analyses this untapped resource of brownfield asbestos data, using site investigation data submitted to a local Borough Council, in Surrey, UK. Over 100 site investigation reports were collected. This paper presents the trends in asbestos testing from 2001-2019 and data on the location, concentration, form and type of asbestos found in this Borough. The rate of asbestos detection has increased significantly, reflecting improvements in asbestos measuring techniques, to a rate of 22% for all samples tested between 2016 and 2019. The concentrations of asbestos found were very low, with 74% of samples having concentrations below the limit of detection of the laboratory and were predominantly of fibrous form. A significant proportion of samples contained more carcinogenic amphibole type. Most of the asbestos was found in the top 1m of Made Ground soil. Site history was found to be important with gas works having the highest asbestos detection rate, though a detection rate of 10% was found in soil samples on former residential sites. This information is important to inform and update risk assessment for site workers and site remediation in relation to asbestos. Hence based upon these results, a qualitative risk chart for asbestos is presented to provide guidance and in-sight into asbestos on brownfield sites for local authorities and developers.

Keywords Asbestos, contaminated land, site investigation, brownfield site, risk assessment.

Graphical abstract

Funding

This research was supported by the Natural Environment Research Council, UK (NERC) and the University of Surrey through a Daphne Jackson Fellowship.

1. Introduction

Asbestos is a hidden threat on many brownfield sites. It was used extensively as a building material and insulator prior to 2000 and is now commonly found in urban soil from the demolition of buildings, fly tipping or waste disposal. There is currently a lack of published information and knowledge on the levels, form and location of asbestos contamination in soils on development sites. This knowledge gap impacts the safety of site workers and the costs and methods for remediating these sites. As the regeneration of brownfield land for residential use is a key UK government policy, there is a need for greater information on asbestos levels and the risks associated with this contaminant in urban soil.

Previous studies on asbestos measurements in soil, primarily, relate to former asbestos mining areas e.g. in Italy (Turci et al. 2016), Greece (Anastasiadou and Gidarakos, 2007) and Libby, USA (USEPA 2015). A study in Columbia evaluated asbestos fibre release from contaminated soil using activity-based sampling and found the asbestos risk to be very low (Cely-García, 2020). In the UK, a recent DEFRA study (Department of Environment, Food and Rural Affairs, 2020) looked at the background levels of asbestos found nationally in UK public open space. In this DEFRA study, only 2 soil samples out of 272 detected asbestos and those were at concentrations of $< 0.0002\%$ by weight (with a detection limit of $< 0.0001\%$). Information on asbestos found on development sites is rare, due to confidentiality, however, a recent SoBRA study overcame this issue by collating laboratory data of asbestos measurements in soil, keeping the site location anonymous (Cole 2017, SoBRA 2020). This SoBRA (2020) survey evaluated asbestos in 37,000 soil samples in the UK and found that asbestos was detected in 20% of samples. There was, however, no further information on the soil samples in this study such as site location, history etc. The SoBRA survey highlighted the relatively high detection rate for asbestos on development sites and the need for further study.

The risks from asbestos are by inhalation and hence assessments for asbestos for excess lifetime cancer risk are based upon fibre concentration (Baker et al. 2018, Swartjes et al. 2003). At present this is not measured on brownfield sites, instead asbestos is measured and quantified in terms of its percentage weight in soil. A correlation between fibre concentration and measured soil concentration was initially evaluated by Addison et al. (1988) and has been expanded by RIVM Rijksinstituut voor Volksgezondheid en Milieu (Swartjes et al. 2003, Swartjes and Tromp, 2008). The results are inconclusive for low concentration measurements. More recent studies (USEPA 2008, 2015) determined lower guidance levels for fibre concentrations, which are likely to reduce allowable soil concentrations on development sites (Baker et al. 2018). The risks from asbestos in soil are, therefore, currently uncertain and further work is required to initially understand the form and concentrations of asbestos found on brownfield sites and then evaluate the relationship between this and fibre release.

A potential untapped source of asbestos data is the site investigation information routinely submitted to local government in the UK as part of the planning process. Intrusive site investigations on development sites generally include analysis of asbestos in soil samples. These site investigation reports are extensive and the information is scanned and stored in planning databases. The data is reviewed by local government officers, but not collated, nor analysed for environmental research. Rothwell and Cooke (2015) were the first researchers to investigate this information source in Gateshead, north east England to determine background levels of metal contaminants. The dataset has been further evaluated via a preliminary study into contamination within Surrey (Hellawell and Hughes, 2020). Both these studies found the planning dataset to be robust for contaminated land analysis, although issues were identified relating to the lack of systematic sampling and varied analytical techniques used, including pre-standardised methods stated in older reports.

This paper presents the results of the first evaluation and analysis of asbestos information from site investigation reports in this planning dataset. This is a comprehensive source of asbestos data,

covering 20 years of investigations, between 2001 and 2019, enabling historic and current evaluation of asbestos contamination on brownfield sites. This paper aims to improve knowledge and awareness of the occurrence of this carcinogenic contaminant on brownfield sites to inform risk assessment and develop guidance.

The objectives of this research are:

1. To evaluate the impact of the historical changes in asbestos detection techniques over time extracted from sampling date, frequency and detection rate information.
2. To perform a qualitative analysis on the occurrence, the distribution and form, and the potential sources of asbestos found on development sites in Surrey between 2000 and 2019.
3. To use the evidence from this analysis of historical site data to develop a risk assessment chart to provide guidance on asbestos risk on brownfield sites.

2. Method

The planning process in the UK requires a risk assessment and associated conceptual site model to be developed to evaluate the potential risk of a site and its redevelopment to the local environment, current and future land users (National Planning Policy Framework 2019, Environment Agency 2004, 2019). Desk studies are initially carried out to inform a preliminary risk assessment and if a risk is identified this is followed by an intrusive site investigation. The site's history, geology, hydrogeology etc. are evaluated and soil samples are taken and analysed for potentially toxic elements, including asbestos. The site data are collated in large, generally scanned hard copy reports and submitted to local government. After being interrogated by local government officers in relation to the planning application, the reports are stored on the planning database. This information has been collected from around 2000, when the main environmental legislation was introduced (and incorporated into planning regulations). The site investigation reports are available on most council planning websites. They can also be requested from local government under the Environmental Information Regulations (2004). Consequently, the data represents a vast, largely untapped source of contamination information, that is available country-wide.

For this research, one local government authority within the nationwide dataset, Elmbridge Borough Council was selected as the study area. This lies within the county of Surrey, 20km southwest of central London (figure 1). Elmbridge is a suburban area of approximately 9,600 hectares with a population of about 131,000. Previous industrial activities in the area include gravel extraction and infill, gasworks, aviation works, motor sports with numerous small engineering and industrial works. Due to its location adjacent to London, Elmbridge is a very affluent commuter-based area. Further expansion of urban areas is protected by green-belt and hence any available brownfield land is preferentially developed for residential use.

This area was selected as it represents a suburban area that was not tied to any particular industry and where, due to pressures for residential development, there has been considerable brownfield development. The Borough is predominantly underlain by clay deposits, with alluvium and gravel deposits in the north, near the River Thames. There is only one small water source protection zone and numerous protected ecosystems (Elmbridge Borough Council 2015).

Figure 1 The location of Elmbridge Borough in south east England and site sampling points.
(Boundary Source Data: Office for National Statistics licensed under the Open Government Licence v.3.0)

[2 column fitting image – supplied as Fig1.eps]

The brownfield sites in the study area were identified from the local government database of potentially contaminated sites (as required by Environmental Protection Act (1990) Part 2A legislation, DEFRA 2012). The site investigation reports on these sites were then accessed on the Elmbridge Borough Council planning database and website. To process the data, a database, based upon the model outlined in Ander et al. (2013) and Rothwell and Cooke (2015) was constructed. Relevant information from all brownfield development sites in Elmbridge was extracted from hard-copy site investigation and desk study reports submitted to the council and input to the database. This included information on the site, its history, geology, sample locations, laboratory used and method of analysis and chemical results. The data was assessed for quality and any anomalies noted within the database. Further information on site history was obtained from Ordnance Survey historical maps using EDINA (2020). In many cases, the location of the sampling point was only shown on a hardcopy site map. In this case, the sampling point co-ordinates were estimated using grid location software (UK Grid Reference Finder 2019) and historic map information.

The previous use of a site was categorised based upon the former Department of Environment Industry Profiles (1990), together with additional categories including residential and public open space. Some sites had more than one former use and for these sites all potentially contaminating uses were included.

120 sites were identified within Elmbridge Borough with intrusive geoenvironmental site investigation data. Information on these sites was obtained from 132 site investigation reports (some sites have numerous investigations). These reports contained information on 1714 soil samples from 1172 sampling locations. The location of the soil samples is shown in Figure 1. Not all soil samples taken on site are sent for chemical analysis for the full suite of potentially toxic elements. Therefore, of the 1714 soil samples taken, 789 (46%) were analysed for asbestos.

The soil samples were sent to a number of UKAS (United Kingdom Accreditation Service, 2018) accredited commercial laboratories in the UK for asbestos analysis. Information is provided in the site investigation reports on the test procedure used and whether this is accredited, e.g. MCERTs

(Environment Agency 2018a). Standard procedures for determining asbestos have only recently been established (Health and Safety Executive 2016) and a standardised test for asbestos quantification is currently under review in the UK (The Standing Committee of Analysts, 2017). The dataset therefore shows a variation in asbestos testing techniques over the 20-year period of this data collection. For 2000-2010 some laboratory reports state that 'visual' identification processes were used. Post 2012, all laboratories were using staining with polarised light microscopy (PLM) methods. (Transmission Electron Microscopy, TEM methods were not used within this dataset.) The HSG 248 (2016) method was applied to the most recent samples. It is recognised that the methods for detecting and quantifying the asbestos were not the most advanced, nor reliable: this data, however, represents the results obtained in commercial site analyses using the techniques available at the time of the measurement.

3. Results

The results are presented in three sections:

- Historical changes in asbestos detection over time
- Information on the asbestos and its location
- The relationship between asbestos and the former site use/development.

3.1 Historical changes in asbestos detection over time

The relatively low overall sampling rate for asbestos (46%) from the soil samples taken, led to this factor being investigated further. Figure 2 shows the percentage of Made Ground soil samples per year that were sent for asbestos analysis. This figure clearly shows the significant increase in the percentage of soil samples sent for asbestos analysis from 2001-2019. The results for 2016-2019, show that over 80% of soil samples were tested for asbestos.

Figure 2. Percentage of Made Ground soil samples sent for asbestos analysis per year
[1 column fitting image]

Figure 3a shows the actual number of asbestos tests carried out over the same time period on Made Ground samples. This shows the lack of asbestos testing prior to 2012. The detection rate for positive asbestos samples is presented in Figure 3b. These figures show that there were high detection rates

for a very low number of samples prior to 2005. This suggests that samples were only sent to laboratory when asbestos was suspected. The detection rate then falls significantly and starts to improve around 2012 increasing to 33% in 2019.

Figure 3a. Number of Made Ground samples tested for asbestos each year

Figure 3b. Detection rate each year: % of tests that had a positive result in Made Ground samples.

[1 column fitting image]

Asbestos was identified in 103 soil samples (of the 789 samples taken from 25 sites) sent to laboratories for asbestos analysis. This gives an overall detection rate of 13% for the dataset. In manually entering the data from the site investigation reports, the following was, however, noted:

1. soil samples were sometimes sent for asbestos analysis, when there was no likelihood of asbestos being present, e.g. natural ground samples at 8m depth.
2. data from investigations prior to 2012 sometimes used less robust laboratory methods for asbestos detection, e.g. visual analysis.

Asbestos does not occur naturally within this area of the UK and therefore it is likely to be within the Made Ground formation or at the top of any natural soil. 12% of samples sent for asbestos analysis were for samples deep within natural material. This shows a lack of understanding by those selecting the analysis of this contamination. Interrogating the site investigations where this occurred, indicated that this selection of inappropriate testing generally occurred when a geo-environmental and geotechnical site investigation were combined. A geotechnical investigation requires testing of deeper samples from within natural material for foundation analysis. It seems that these deeper geotechnical samples are sometimes (unnecessarily) sent for asbestos analysis incurring additional costs-

Table 1 summarises the detection rates prior and post 2012 for Made Ground samples indicating the influence of the improved asbestos testing methodology on the detection rate.

Table 1 – Detection rate pre and post 2012 on Made Ground samples reflecting the change in detection method.

	Pre 2012	Post 2012
Number of samples tested	149	495
Total no. positives	8	94
% positive	5.4	19.0

3.2 *Information on the asbestos and its location.*

Soil samples were initially screened to determine the presence of asbestos. If found, the form of the asbestos and the matrix material were described and for some samples the percentage weight of asbestos in the soil was quantified. The form of the asbestos is important as it affects the potential risk from the material. Figure 4 shows the relative frequency of the different types of asbestos found on all the sites within Elmbridge. Chrysotile (white) asbestos was most commonly found in 62 % of samples. The more carcinogenic amphibole asbestos, amosite (brown) and crocidolite (blue) were found in 24% and 14 % of samples respectively. (These values include soil samples where more than one form of asbestos was found). No other types of asbestos were identified in the samples.

Figure 4. Type of asbestos found in soil samples

[1 column fitting image]

The form of the asbestos matrix and concentration of asbestos found in the soil samples is shown in Figures 5a and 5b. 71.5 % of samples found were fibrous, compared to 17 % containing asbestos cement. Most of the samples (74%) were found to have concentrations of asbestos below the limit of detection of the laboratory. (This was generally 0.001%wt/wt).

Figure 5a. Form of the asbestos matrix
(ACM is asbestos containing material)

Figure 5b. Relative frequency of asbestos concentration found
[1 column fitting image]

The location of the asbestos was investigated in terms of strata and depth and is detailed in Figure 6. This shows asbestos was mainly found in samples within the first 1m of soil in Made Ground. Only one sample, that was classified from natural strata, contained asbestos and that sample was taken from the boundary of Made Ground and the natural strata. This confirms the premise outlined in section 3.1 that as asbestos is not naturally occurring in this region it is likely to be found at shallow depths (< 1m) in Made Ground. Asbestos was only found at depths of over 1.5m, in former infilled gravel pits/ landfill. The 0.6m depth line is drawn on the figure as this is considered the depth of double digging by gardeners and is often used in the UK as the basis for removal and replacement of material in remediation design.

Figure 6. Depth that positive samples were found.
[1 column fitting image]

3.3 Relationship between asbestos and the former site use/development

Information on the historic site use and the date the site was developed was obtained from desk study reports, submitted as part of the planning process. If information was not available historic ordnance survey maps for the site were interrogated. Figure 7 shows the results of asbestos detection related to the former site use. This clearly shows that the sites with the highest detection rates were engineering works, industrial activities and residential. The distinction between engineering works and industrial activity was relatively undefined in desk studies. Engineering works predominantly included larger sites, where perhaps metal processing was involved, whereas industrial activities were more commonly small groups of mixed workshops and warehouses.

Figure 7. Site main historical use and where asbestos was tested and detected.
[1 column fitting image]

The site history is further interrogated in Figure 8, which shows the percentage of soil samples where asbestos was found and type of asbestos for each site use. High detection rates for all types of asbestos were obtained for gasworks, docks and printing works, though these are based on a low number of sites. The figure also shows that there was a high percentage of samples containing amphibole asbestos (amosite and crocidolite) on the sites used for gasworks, print works and cement manufacturing.

Figure 8. Percentage of soil samples containing asbestos for different site uses
[1 column fitting image]

The effect of the age of a site on asbestos detection in the soil was then investigated and is shown in Figure 9. The date the site was developed was taken as the first time the site was significantly developed. Prior uses, where the site was part of the grounds of a large house were not considered, but when workshops or industrial outhouses were added, this was taken as the date of development. Clearly older developed sites are more likely to have had asbestos contaminating activities and there is no information to identify when asbestos may have been used on a site. The aim of this analysis was to see if there was any particular age of site that affected the detection of asbestos. This was not identified; however, Figure 9 shows that asbestos detection decreases significantly for sites developed post 1980. This reflects the legal prohibitions on asbestos import and use in the UK, which were introduced from 1969. The imports of crocidolite, amosite and chrysotile asbestos were banned from 1969, 1980 and 1999 respectively (CIRIA 2014).

Figure 9. Graph detailing asbestos detection in relation to the date the site was developed.
[1 column fitting image]

4. Discussion

The results have provided new information relating to asbestos contamination which has been synthesized in the form of a risk assessment chart (Figure 10). For new developments, the combination of the date of development and former site usage provide the primary indicators as to whether the site is likely to be high risk. This information can then be used in conjunction with any previous quantitative site investigation data to ascertain the type and form of asbestos expected and then combined with the proposed site use to evaluate the required level of asbestos screening and analysis. In this respect, the chart can be used to guide and inform site developers, consultants and local authorities. Although this chart has been developed based upon asbestos information obtained within sites in the UK, this format of chart can be applied to evaluate risk from asbestos on brownfield sites worldwide.

The chart highlights the potential risk from asbestos in soil for brownfield sites remediated and redeveloped prior to 2012. Before this date, there was a lack of awareness and hence, limited asbestos testing of soil samples and a lack of reliability of test procedures and results. Hence should sites developed pre-2012 be re-assessed for asbestos contamination? This is a potentially very sensitive subject. A desk-based assessment could evaluate higher risk sites for asbestos based upon current use, past site use, the remediation previously carried out and site geology. In the UK, these sites would already be included in the local government database on potentially contaminated sites under Part 2A legislation, probably classified as remediated and low risk. A review of the assigned risk may be required.

Figure 10. Risk assessment chart for asbestos based
[2 column fitting image]

Asbestos testing has increased significantly from 2001. 86% of soil samples from Elmbridge brownfield sites were analysed for asbestos in 2019, demonstrating that testing of this contaminant is now routine. Improvements and accreditation of laboratory PLM methods, introduced circa 2012 in the UK (AGS 2013), has resulted in more reliable asbestos measurements. The Health and Safety Executive HSG 248

(2016) method is now accepted in the UK for qualitative asbestos analysis, however, the proposed method for quantitative evaluation, referred to as the 'blue book' (The Standing Committee of Analysts, 2017) is still published as 'draft'. Quantification methods for asbestos are also currently being assessed by a proficiency study of asbestos measurement in UK laboratories by the Health and Safety Executive (2020). Detection techniques are, therefore, being refined and other methods including transmission electron microscopy (TEM) and activity-based sampling (ABS) are being evaluated (Wroble et al., 2017 and Department of Environment, Food and Rural Affairs, 2020). Further improvements in measurement are required to address the gap in knowledge between the current concentration-based field measurement and fibre-based risk assessment models (Baker et al. 2018).

The results from this study were compared with a recent study by the Society of Brownfield Risk Assessment, SoBRA (2020), that evaluated laboratory test results for asbestos in 170,000 soil samples, in the UK from unknown locations. The SoBRA study detection rate for four laboratories on samples taken between 2011-2015 was 1.4%, 6%, 11%, 13 %. This rate rose to 20% for 2017 data. The increasing detection rate may again indicate the improvement in techniques for detecting asbestos. This University of Surrey study showed a similar trend to the SoBRA results. The detection rate has increased for more recent samples and including all samples tested, the Surrey study had a detection rate of 22% for 2016-2019.

This study and the SoBRA results showed similar results for the quantitative analysis of samples, with most samples having less than 0.001%wt/wt of asbestos. The University of Surrey study samples had a considerably higher percentage of amphibole asbestos (amosite 28% and crocidolite 16%) than the SoBRA study, which found 14% amosite and 1.35% crocidolite in the 2017 laboratory data. The risks of cancer from these forms of asbestos are higher (Berman and Crump, 2008, Hodgson and Darnton, 2000). A further significant difference in these studies was in the form of the asbestos/matrix. The SoBRA study predominantly found the samples contained asbestos cement, whereas in this study, asbestos fibres were more commonly identified. Hence, this University of Surrey study using local Elmbridge data found soil samples contained higher levels of more carcinogenic amphibole and fibrous asbestos than the results from the national SoBRA study. This comparison implies there are local differences in asbestos data, potentially related to the past use of development sites.

The depth at which asbestos was found was also significant. Most positive detections were within the first 1m in the top soil or Made Ground. The main motivation for deeper site sampling would arise from knowledge of the former site use, in particular infilled landfill or gravel pits. Routine sampling for asbestos at depths greater than 1m is costly and may be unnecessary. The sample depth information is also relevant in considering the remediation of asbestos contaminated sites. In the UK, 0.6m is typically used as a depth for removal and infill, based upon the concept of double digging by gardeners. Figure 6 shows this would capture and remove most of the asbestos contamination found in the sites in Elmbridge. However, this also shows that this remediation option would potentially leave some asbestos contamination at depth on a site. The acceptability of this would need to be evaluated by a risk assessment.

Analysis of the past site use and asbestos showed differences in the detection rate and form of asbestos found. The former gasworks had the highest asbestos detection rate. This site was investigated 30 years after it had been remediated for residential use; demonstrating the potential risk of asbestos contamination on sites where asbestos contamination was not evaluated at the time of development. Other potentially higher risk former site activities were identified, e.g. printworks and dockyards, however the sample set for these was small and further data and assessment is required. The relationship between the age of a site and potential asbestos risk was less clearly defined, apart from the results showing significantly lower asbestos risk for sites developed post 1980. Unlike McIlwaine et

al.'s (2107) research for metal contamination, the data does not show a definitive period when asbestos contamination peaked.

The data and results of this research are relevant to all stakeholders involved in brownfield site regeneration. The research has shown there is a relatively high risk of low concentration asbestos, potentially of fibrous and amphibole form, within shallow Made Ground on brownfield sites. This information is relevant in evaluating risks from asbestos and remediation costs as the form and concentration of asbestos affects fibre release (Swartjes and Tromp 2003) and waste classification/waste disposal costs in the UK (Environment Agency 2018b). Further work is required in terms of evaluating the fibre release and hence exposure to asbestos by site workers and users from these soils (Baker et al. 2018). If this risk is identified, then the environmental, societal and economic impacts of asbestos contamination in brownfield soil would need to be further considered. This would be at a national and regional scale in terms of brownfield development policy and at a local scale in terms of incorporating the high potential for asbestos detection into a site sustainable land management plan (e.g. Bardos et al. 2016).

5. Conclusions

This paper investigated the occurrence of asbestos on brownfield sites, using planning site investigation data. This extensive dataset is available in all local authorities in the UK and this study shows the analysis of a small sub-set of the data for one local authority.

The dataset was in hardcopy format, buried within planning databases and covered the time period 2000 -2019. Prior to 2012, asbestos testing of soil samples was sparse and the measuring techniques were unreliable. Improvements and subsequently standardisation of the detection method led to higher asbestos detection rates and consequently asbestos testing is now almost routine on brownfield sites.

The concentration of asbestos found within soil samples was generally at very low concentrations (<0.001%wt/wt). The asbestos was predominantly chrysotile asbestos in fibrous form, though the more carcinogenic amphibole types were also frequently found. These results are similar to the SoBRA (2020) study, however differences in terms of the form and type of asbestos indicated local Elmbridge factors.

The key determinants for asbestos detection were identified as previous site history, date of survey, type, form, concentration and soil depth. Based on these findings, a qualitative risk chart for asbestos was developed. The chart can be updated as more site investigations are carried out and more of these local authority datasets are analysed, providing an evidence-based approach for assessing asbestos risk. Furthermore, whilst this risk chart has been developed from UK samples, asbestos contamination is a universal problem, hence this risk chart can readily be applied globally.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors are grateful to NERC and the University of Surrey for funding this research through the Daphne Jackson Fellowship. We would also like to thank Elmbridge Borough Council for access to data and help with data retrieval and advice.

References

- Addison, J., Davies, L.S.T., Robertson, A., and Willey, R.J. 1988. The Release of Dispersed Asbestos Fibres from Soils. IOM report TM/88/14, September 1988, Institute of Occupational Medicine Edinburgh, UK.
- AGS, Association of Geotechnical and Geoenvironmental Specialists 2013. Site Investigation Asbestos Risk Assessment for the Protection of Site Investigation and Geotechnical Laboratory Personnel, AGS Interim Guidance, February, Ver 2.4.
- Anastasiadou, K., Gidarakos, E., 2007. Toxicity evaluation for the broad area of the asbestos mine of northern Greece. *Journal of Hazardous Materials* 139, 9–18.
<https://doi.org/10.1016/j.jhazmat.2006.06.031>
- Ander, E.L., Johnson, C.C., Cave, M.R., Palumbo-Roe, B., Nathanail, C.P. & Lark, R.M., 2013. Methodology for the determination of normal background concentrations of contaminants in English soil. *The Science of the total environment*, 454-455, pp.604–618. Available at:
<http://www.ncbi.nlm.nih.gov/pubmed/23583985> [Accessed Nov 7, 2018].
- Bardos, R.P., Bone, B.D, Boyle, R. Evans, F. Harries, N.D., Howard, T., Smith, J.W.N. 2016. The rationale for simple approaches for sustainability assessment and management in contaminated land practice, *Science of th Total Environment*, 563-564,755-768.
- Baker, K., Sole, S., Hay, Simon, Mitcheson, B. Thomas, L. 2018. Discussion paper on guidelines for airborne concentrations of asbestos fibres in ambient air: implications for quantitative risk assessment, Society for Brownfield Risk Assessors, SoBRA
https://sobra.org.uk/?pmpo_getfile=1&file=2018/01/SoBRA_White_Paper_on_tolerable_asbestos_c_oncentrations_in_air_Dec17&ext=pdf
- Berman, D. W. and Crump, K. S., 2008. Update of potency factors for asbestos-related lung cancer and mesothelioma, *Crit. Rev. Toxicol.*, vol. 38, Suppl. 1, pp 1–47
- Cely-García, M.F., Lysaniuk, B., Pasetto, R., Ramos-Bonilla, J.P., 2020. The challenges of applying an Activity-Based Sampling methodology to estimate the cancer risk associated with asbestos contaminated landfilled zones. *Environmental Research* 181, 108893.
<https://doi.org/10.1016/j.envres.2019.108893>
- CIRIA 2014, Nathanail, C. P., Jones, A., Ogden, R., Robertson, A. Asbestos in soil and Made Ground: A guide to understanding and managing risk C733. Construction Industry Research and Information Association, CIRIA.
- Cole, S. 2017 Summary of work undertaken by SoBRA asbestos in soil sub-group in 2017, presentation to SoBRA Current Issues in Contaminated Land Risk Assessment Conference, London.
https://sobra.org.uk/?pmpo_getfile=1&file=2017/12/Dec_17_Barry_Mitcheson_3&ext=pdf
- Department for Environment, Food and Rural Affairs, (DEFRA) 2020. Determination of typical background concentrations of asbestos in near-surface soils of selected public open space areas of

England and Wales to define representative concentrations in areas not expected to be subject to significant contamination, Research Report SP1014, Eds. Collins, C., Craggs, M., Harries, N., Wood, D., Burdett, G

<http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=19295> [Accessed 21 Jan 2020]

Department for Environment Food and Rural Affairs (DEFRA) 2012. Environmental Protection Act 1990: Part 2A Contaminated Land Statutory Guidance. UK: Department for Environment, Food and Rural Affairs (Defra); April; 69 pp.

<http://www.defra.gov.uk/publications/2012/04/10/pb13735contaminated-land/>

Department of the Environment, Transport and the Regions (DETR) 2000. Planning Policy Guidance Note 3: Housing. London: DETR

Department of Environment 1990. Industry Profile, The National Archives, available at:

<https://webarchive.nationalarchives.gov.uk/20090605203216/http://www.environment-agency.gov.uk/research/planning/33708.aspx>

EDINA 2020 Edina Digimap Ordnance Survey Data, available at: <http://edina.ac.uk/digimap>

Environment Agency 2018a. Performance Standard for Laboratories Undertaking Chemical Testing of Soil, Version 5, November.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/769372/MCERTS_Performance_Standard_for_laboratories_undertaking_chemical_testing_of_soil.pdf

Environment Agency 2018b, Waste Classification - Guidance on the classification and assessment of waste Technical Guidance WM3 1st Edition v1.1

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/719394/Waste-classification-technical-guidance-WM3.pdf

Environmental Information Regulations 2004. Statutory Instrument 2004 No. 3391

Environmental Protection Act 1990. <https://doi.org/10.1016/j.envres.2019.108968>

Hellawell, E. E. and Hughes, S. J. 2020. The potential use of local government planning data for soil contamination analyses, Institution of Civil Engineers Journal of Municipal Engineering, DOI: 10.1680/jmuen.20.00011.

Hodgson, J. T. and Darnton, A. 2000. The quantitative risks of mesothelioma and lung cancer in relation to asbestos exposure. Annals of Occupational Hygiene, vol 44, 8, Oxford Journals, Oxford, UK, pp 565–601

Health and Safety Executive (HSE) 2016, HSG248 Asbestos: The Analyst's Guide for Sampling, Analysis and Clearance Procedures, (draft).

<https://webcommunities.hse.gov.uk/connect.ti/asbestos.licensing/viewdocument?docid=590885>

Health and Safety Executive 2020. Asbestos in Soils Scheme (AISS)

<https://www.hsl.gov.uk/proficiency-testing-schemes/aiss>

McIlwaine, R., Doherty, R. and Cox, S.F. and Cave, M. 2017. The relationship between historical development and potentially toxic element concentrations in urban soils. *Environmental Pollution* 220 (B). 1036-1049. <https://doi.org/10.1016/j.envpol.2016.11.040>

National Planning Policy Framework 2019, ISBN 978-1-5286-1033-9 , CP 48
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/810197/NPPF_Feb_2019_revised.pdf

Rothwell, K.A., Cooke, M.P., 2015. A comparison of methods used to calculate normal background concentrations of potentially toxic elements for urban soil. *Science of The Total Environment* 532, 625–634. <https://doi.org/10.1016/j.scitotenv.2015.06.083>

SoBRA Society of Brownfield Risk Assessment, 2020. The Distribution of Asbestos in Soil – what can the data mining of sample results held by UK laboratories tell us? Discussion Paper by the SoBRA asbestos sub-group, March 2020.
<https://sobra.org.uk/all-posts/sub-group-reports-and-papers-sg/asbestos/the-distribution-of-asbestos-in-soil-what-can-the-data-mining-of-sample-results-held-by-uk-laboratories-tell-us/>
[Accessed 25th March 2020]

Swartjes, F.A., and Tromp, P.C. 2008. A Tiered Approach for the Assessment of the Human Health Risks of Asbestos in Soils, *Soil & Sediment Contamination*, 17:137–149, Taylor & Francis Group, LLC ISSN: 1532-0383

Swartjes, F.A., Tromp, P.C., and Wezenbeek, J.M. 2003. Assessing risks of soil contamination with asbestos (*in Dutch*). RIVM report 711701034, 2003. RIVM, Bilthoven, The Netherlands

The Standing Committee of Analysts 2017. The Quantification of Asbestos in Soil
[http://www.standingcommitteeofanalysts.co.uk/library/The%20Quantification%20of%20Asbestos%20in%20Soil%20\(2017\)%20Draft.pdf](http://www.standingcommitteeofanalysts.co.uk/library/The%20Quantification%20of%20Asbestos%20in%20Soil%20(2017)%20Draft.pdf)

Turci, F., Favero-Longo, S.E., Gazzano, C., Tomatis, M., Gentile-Garofalo, L., Bergamini, M., 2016. Assessment of asbestos exposure during a simulated agricultural activity in the proximity of the former asbestos mine of Balangero, Italy. *Journal of Hazardous Materials* 308, 321–327.
<https://doi.org/10.1016/j.jhazmat.2016.01.056>

US EPA 2015. Site-Wide Human Health Risk Assessment, Libby Asbestos Superfund Site Libby, Montana, prepared by CDM Smith. United States Environmental Protection Agency
<https://semspub.epa.gov/work/08/1562963.pdf> Accessed 14/01/2020.

USEPA 2008. Framework for investigating asbestos-contaminated Superfund sites prepared by the Asbestos Committee of the Technical Review workgroup of the Office of Solid Waste and Emergency Response, United States Environmental Protection Agency, OsWER Directive #9200.0-68 September

UK Grid Reference Finder 2019. Accessed January 2019 at <https://gridreferencefinder.com/>

United Kingdom Accreditation Service, 2018. Accessed December 2018 at <https://www.ukas.com/>

Wroble, J., Frederick, T., Frame, A., Vallero, D., 2017. Comparison of soil sampling and analytical methods for asbestos at the Sumas Mountain Asbestos Site—Working towards a toolbox for better assessment. PLOS ONE 12, e0180210. <https://doi.org/10.1371/journal.pone.0180210>