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FRAMEWORK FOR INVESTIGATING ASBESTOS-CONTAMINATED SUPERFUND SITES

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Executive Summary

This document presents a recommended framework for investigating and characterizing the potential for human exposure from asbestos contamination in outdoor soil and indoor dust at Superfund removal and remedial sites. This document is one piece of broader intra- and inter-Agency efforts to utilize recent developments regarding asbestos so that current scientific information can be used to better assess exposure and risk from asbestos (e.g., Agency efforts to update cancer and non-cancer assessments for asbestos). The recommended framework presented herein provides a process that supplements other EPA guidance concerning exposure and risk assessment (e.g., Risk Assessment Guidance for Superfund, EPA, 1989), and is specific to assessment of sites contaminated with asbestos. This recommended framework is needed because there are a number of unique scientific and technical issues associated with the investigation of human exposure and risk from asbestos, and it is important for risk assessors and risk managers to understand these issues when performing assessments of asbestos sites. This recommended framework discusses specific strategies that are based on the best available science and recommends common industrial hygiene methods for characterizing exposure and risk from asbestos.

Asbestos fibers in outdoor soil, indoor dust, or other source materials typically are not inherently hazardous, unless the asbestos is released from the source material into air where it can be inhaled. If inhaled, asbestos fibers can increase the risk of developing lung cancer, mesothelioma, pleural fibrosis, and asbestosis.

The relationship between the concentration of asbestos in a source material and the concentration of fibers in air that results when that source is disturbed is very complex and dependent on a wide range of variables. To date, no method has been found that reliably predicts the concentration of asbestos in air given the concentration of asbestos in the source. Additional research is ongoing to characterize this relationship.

This recommended framework emphasizes an empiric approach to site characterization because models to predict airborne asbestos concentrations from soil concentrations have not been validated. Specifically, a combination of soil, dust, and air samples are recommended to characterize exposure. Concentrations of asbestos in air at the location of a source disturbance are measured rather than predicted.

This recommended framework presents options to provide flexibility to site managers. At any point in the process, site managers can take action at a site without further site characterization (for example, if site characterization shows >1% asbestos in soil, framework users have the option to proceed directly to response).

Personal air monitors are generally preferred over stationary air monitors to measure an individual's exposure to fiber concentrations in air, since the personal monitors more accurately reflect the concentration of asbestos in the breathing zone of the exposed person. Activity-based sampling (ABS), a standard method used by industrial hygienists to evaluate workplace exposures, is a personal monitoring approach that can provide data for risk assessment and is

emphasized in this recommended framework. ABS can be useful for assessment of asbestos contamination of both outdoor soil and indoor dust.

To allow for improved risk assessments, the analytical procedure used to analyze samples from a site should capture information concerning the specific mineralogy of asbestos fibers that are present. Hence, the TRW Asbestos Committee is recommending that a modification of the International Organization for Standardization (ISO) Method 10312 generally should be used for measuring asbestos at Superfund and other asbestos sites.

Depending on its application, potential limitations of the approach may include the representativeness of samples over an area of concern and the ability to generalize findings from a point in time and space to future exposures, other locations, others engaged in dissimilar activities, and differing environmental conditions. Site-specific data quality objectives (DQOs) and sampling plans should consider such issues prior to sample collection. Furthermore, cost of ABS approaches and sample analysis, analytical sensitivity, and other site-specific factors should be considered in the planning process.

In order to assist with the complexities of the recommended exposure assessment for asbestos-contaminated sites, members of the TRW Asbestos Committee will provide technical assistance to site teams to develop optimal strategies for site investigation and characterization on a site-specific basis.

This recommended framework does not seek to provide direction or guidance on risk management decisions that may be required during a site assessment. Typically the key management decision at asbestos sites is how to interrupt or eliminate the complete inhalation exposure pathway. As always, risk management issues should be evaluated by the site manager, with input from the site-scientific teams, stakeholders, Regional management, and legal staff, as appropriate.

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RECOMMENDED FRAMEWORK FOR INVESTIGATING ASBESTOS-CONTAMINATED SUPERFUND SITES

1.0 Introduction

Historically, asbestos has been addressed in the Superfund program by reference to the term asbestos-containing material (ACM[1]) as it is used in the National Emission Standard for Asbestos, which is found in Subpart M of the National Emission Standards for Hazardous Air Pollutants (NESHAP), 40 CFR Part 61. Under the asbestos NESHAP, Category I and Category II nonfriable ACM are defined in part as certain products or materials containing >1% asbestos as analyzed by polarized light microscopy (PLM). (See 40 CFR 61.141.) OSWER Directive 9345.4-05 (Clarifying Cleanup Goals and Identification of New Assessment Tools for Evaluating Asbestos at Superfund Cleanups, EPA, 2004 [August]) indicated that the 1% definition may not be reliable for assessing potential human health hazards from asbestos-contaminated soils at Superfund sites, and that instead a risk-based, site-specific action level generally is appropriate when evaluating response actions for asbestos at Superfund sites. This OSWER Directive (9345.4-05) is provided in Appendix B.

Although the OSWER Directive (9345.4-05) is designed to help steer asbestos investigations to a risk-based paradigm, it does not provide guidance for investigating and evaluating asbestos at Superfund sites. The purpose of this document is to provide a recommended flexible and usable framework for investigating and evaluating asbestos contamination at removal and remedial sites. This document also provides remedial/removal managers, remedial project managers, on-scene coordinators, site assessors, and other decision makers with information that should assist in the evaluation of asbestos risks at Superfund sites, along with information to facilitate site decisions under conditions of incomplete characterization and to accommodate the varied nature of environmental asbestos contamination. This guidance is not intended to serve as a prescriptive guide for risk assessment or risk management activities at asbestos sites.

If asbestos present at a site is not to be addressed by the Superfund program, an effort should be made to identify other programs or regulations that may have the authority and capability of addressing exposures (e.g., the Asbestos Hazard Emergency Response Act [AHERA], asbestos NESHAP, or state/local authorities as discussed in the following section). Additional guidance is available elsewhere for developing a risk management-based response strategy that is protective of human health and the environment (EPA, 1988b) (www.epa.gov/superfund/resources/remedy/pdf/540g-89006-s.pdf).

This document provides technical and policy guidance to the EPA staff on making risk management decisions for contaminated sites. This document is one piece of broader intra- and inter-Agency efforts to utilize recent information on asbestos so that current scientific information can be used to better assess exposure and risk from asbestos (e.g., Agency efforts to update cancer and non-cancer assessments for asbestos). The recommended framework presented herein provides a process that supplements other EPA guidance concerning exposure and risk assessment (e.g., EPA, 1989), and is specific to assessment of sites contaminated with asbestos. It also provides information to the public and to the regulated community on how EPA

[1] Refer to Appendix A (Glossary and Acronym List) for more information.

intends to exercise its discretion in implementing its regulations at contaminated sites. It is important to understand, however, that this document does not substitute for statutes that EPA administers or their implementing regulations, nor is it a regulation itself. Thus, this document does not impose legally-binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the specific circumstances. Rather, the document suggests approaches that may be used at particular sites, as appropriate, given site-specific circumstances.

2.0 Applicability of Recommended Asbestos Framework

This asbestos framework provides guidance for assessing Superfund sites addressed under CERCLA response authority. In general, CERCLA authority may be appropriate to respond to the release or potential release of asbestos into the environment; however, CERCLA section 104(a)(3) does provide some potential qualified limitations on the authority to respond to certain releases of asbestos (including, for example, where the asbestos is a "naturally occurring substance in its unaltered form…" or where the asbestos is "part of the structure of" a residential building).

This recommended framework generally does not contain recommendations that would be appropriate for addressing asbestos in schools, for building demolition, or for addressing widespread asbestos occurrence from natural sources[2]. Authorities other than CERCLA may be more appropriate to address asbestos contamination in such circumstances.

Outside of CERCLA, EPA primarily addresses asbestos under two laws: (a) AHERA, and (b) asbestos NESHAP. EPA's regulations implementing AHERA require local education agencies to take appropriate action to inspect for and prevent the release of asbestos in schools. These regulations are found in 40 CFR Part 763, Subpart E—Asbestos-Containing Materials in Schools.

The asbestos NESHAP also may be applicable when seeking to curtail asbestos emissions from, among other things, asbestos mills, manufacturing and fabricating operations using commercial asbestos, spraying operations involving asbestos-containing materials, and demolition or renovation operations. Included among the asbestos NESHAP regulations are work practices designed to minimize the release of asbestos fibers during activities involving processing, handling, and disposal of asbestos, including when a building is being demolished or renovated. In the latter instances, owners and operators subject to the asbestos NESHAP are required to notify delegated state and local agencies and/or their EPA Regional Offices before demolition or renovation activity begins. The asbestos NESHAP also regulates asbestos waste handling and disposal for certain covered sources. The asbestos NESHAP requirements and standards are described in 40 CFR Part 61, Subpart M.

EPA generally maintains an oversight role while relying on state and local programs to enforce requirements under AHERA and the asbestos NESHAP; however, EPA's Regional asbestos management programs may separately enforce the AHERA and NESHAP requirements.

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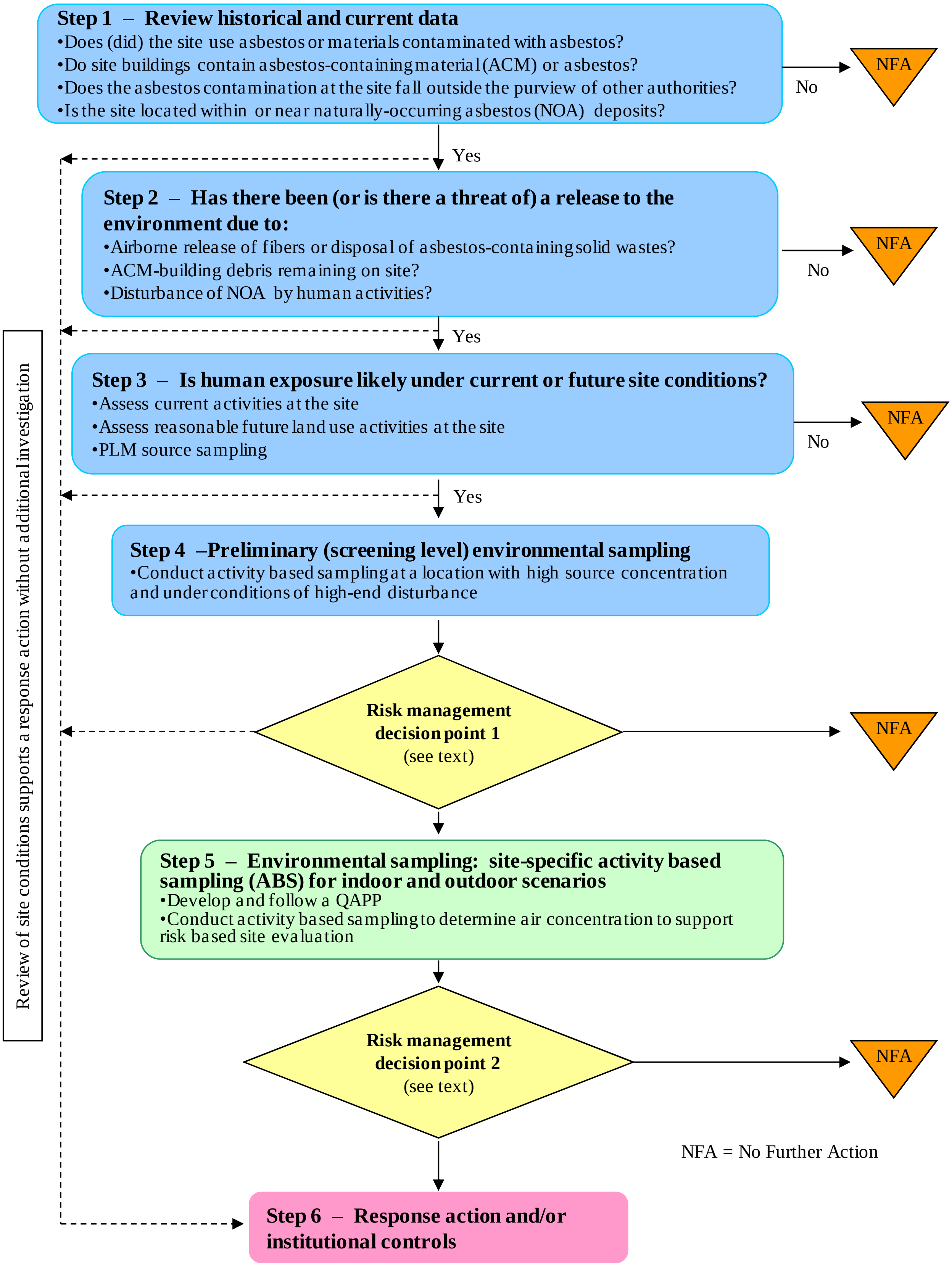
[2] See the Fact Sheet, "Naturally Occurring Asbestos: Approaches for Reducing Exposures" available online at: http:www.epa.gov/superfund/heatlh/contaminants/asbestos/noa.factsheet.pdf

In addition to these Federal authorities, State or local government entities may be in a position to provide for public health and welfare by implementation and application of local controls, such as zoning and construction restrictions and fugitive dust control ordinances.

3.0 Recommended Framework

Given the unique issues associated with evaluating exposures and potential health risks resulting from exposure to asbestos, a recommended asbestos site assessment framework (Figure 1) was developed to help promote a standardized, consistent, step-wise approach for investigating and evaluating asbestos under Superfund authority. Consistent with the National Contingency Plan (NCP) and other EPA guidance, the recommended framework may be applied to the assessment and evaluation of sites that are presently under investigation, and sites that had been formerly addressed using the 1% rule. The recommended asbestos site assessment framework can also be used when conducting five-year reviews (consult the five year review policy—Comprehensive Five-Year Review Guidance, EPA, 2001b). For sites in which some consideration of asbestos exposure has already occurred, the recommended site assessment framework may be entered from a step other than Step 1, depending upon the data that are available for the site. The bullets under the header in each Step of the recommended framework provide considerations or examples pertinent to that Step. The discussion in the following sections provides more details regarding proceeding through the flowchart.

Figure 1. Flow diagram of the recommended asbestos site assessment framework.



Step 1 – Review historical and current data

The first step in the recommended asbestos site assessment framework is to review all existing information available at a site in order to determine whether asbestos may require evaluation. The types of information that should be reviewed include data on past operations at the site as well as any collected past or current measurements or visual observations. In general, the information should be reviewed to determine if asbestos may be present from one or more of the following sources:

- Asbestos-containing materials or asbestos-contaminated sources. This includes the presence of manufactured products that intentionally included asbestos as an ingredient, but also includes products or processes that utilized materials in which asbestos is present as a contaminant (e.g., vermiculite from the Libby mine). It may also include sites where asbestos-contaminated or asbestos-containing materials were being transported to or transferred from other locations for processing.
- ACM in on-site buildings. Prior to the 1970s, asbestos was used in a wide variety of building materials. Thus, if the site contains buildings constructed prior to 1970, it is likely that some ACM may be present.
- Hazardous air emission addressed under the authority of NESHAP. EPA established emission standards for hazardous air pollutants (including asbestos). Among the NESHAP regulations are work practices to minimize the release of asbestos fibers during activities involving processing, handling and disposal of asbestos, including when a building is being demolished or renovated that contains ACM.
- Presence of "naturally occurring asbestos" (NOA). Asbestos occurs in natural mineral deposits at a number of locations around the country. Information on the presence of NOA deposits may be gained from numerous sources, including USGS, State geological offices, BLM, or DOI, local agencies charged with cataloging or regulating NOA, or by consulting a properly trained and experienced geologist.

If a thorough review of available site data provides a clear indication that asbestos is not present, then no further action to address asbestos is needed. If the available information indicates that asbestos is, or may reasonably be expected to be, present (and it is not being addressed by another authority, see Section 2), or if the data are insufficient to form a clear conclusion then proceed to Step 2.

Step 2 – Has there been (or is there a threat of) a release to the environment?

In recommended Step 2, all available information should be reviewed to determine if a release of asbestos to the environment has occurred or could occur due to human activities, or if a release may be likely in the future (see Appendix D, Land Use Considerations). This may include asbestos releases at on-site or off-site locations.

- With regard to commercial operations that involved use or transport of asbestos-containing or asbestos-contaminated materials, the releases of chief concern to EPA generally include release of asbestos-containing materials or airborne fibers to the outdoor or indoor environment, as well as, the disposal of various solid wastes at on-site or off-site locations. Under normal conditions, one or both of these types of release should be considered to be of potential concern unless strong evidence exists to indicate that neither type of release has occurred.

- With regard to other asbestos-contaminated areas such as residential properties, roadways, or public areas, the releases of chief concern to EPA generally include release of ACM or airborne fibers to the outdoor or indoor environment, as well as the disposal of various solid wastes at on-site or off-site locations. These types of release should be considered to be of potential concern unless strong evidence exists to indicate that neither type of release has occurred.

The use of ACM in buildings and the presence of NOA are two special situations that can affect EPA response actions.

- With regard to ACM in buildings, CERCLA contains a qualified limitation on response authority for releases or a threat of release "from products which are part of the structure of, and result in exposure within, residential buildings or business or community structures". If a building that contains asbestos is demolished, this demolition must be performed in accord with the requirements of NESHAP (40CFR part 61, Subpart M; Section 1.1), and this will normally preclude the release of asbestos to the environment. If a building has been demolished or is destroyed (e.g., by fire) and asbestos-containing debris is found to remain at the site, this should be considered a release of potential concern to Superfund. This is true even if the ACM is buried, since it may be uncovered if the site is developed in the future (see Appendix D, Land Use Considerations).

- With regard to NOA, Section 104(a)(3)(A) of CERCLA contains a qualified limitation on response authority for a release or a threat of release "of a naturally occurring substance in its unaltered form, or altered solely through naturally occurring processes, from a location where it is naturally found." This limitation does not affect EPA's authority to address a release or a threat of release of NOA that has been altered by anthropogenic activities. State and local authorities may be appropriate for NOA response and management, especially in locations where NOA is found to be widespread in native soils.

If it is determined that there has been a release and a response is appropriate, then one may either proceed directly to a response action (see Step 6), or proceed to Step 3 to further characterize potential exposure. If there has not been a release, but there is a threat of release, then further evaluation (Step 3) should be performed under either the removal or remedial program, depending on the magnitude and/or severity of the potential future release.

Step 3 – Is human exposure likely under current or future site conditions?

Recommended Step 3 is intended to help evaluate whether a complete human exposure pathway exists at or near the site under current or reasonably anticipated future site conditions. This should be achieved by developing a conceptual site model and performing an exposure pathway assessment (that may involve review or collection of PLM soil data[3]) consistent with the National Contingency Plan and existing Superfund guidance. For example, current and potential future accessibility of the site, as well as community awareness of exposure to potential hazards at the site, are also factors that may be considered. Typical exposure pathways for asbestos include inhalation of asbestos fibers released from disturbed soil or disturbed settled dust. As always, the evaluation of potential future risks should be based on an assessment of reasonably anticipated changes in land use (see Appendix D, Land Use Considerations).

If a complete human exposure pathway does not exist, typically no further evaluation of asbestos would be necessary. If it has been determined that a complete exposure pathway to contaminated outdoor soil or contaminated indoor dust exists under current conditions, or may reasonably be expected to occur in the future, it may be appropriate either to undertake a response action (see Step 6), or to proceed with further investigation of potential exposures at the site (Step 4).

Step 4 – Preliminary (screening level) environmental sampling

This recommended step is a preliminary screening step intended to help evaluate if human exposure levels are likely to be below a level of concern or LOC even under high-end exposure conditions. If exposures are judged to be below an asbestos air action level (see Section 5.8), then generally no further investigation would be needed under present site conditions. If exposures from this high-end evaluation are of potential concern (i.e., exceed the air action level), then a response action may be taken or more detailed investigation may be appropriate to more accurately and completely characterize the magnitude of the exposure.

Screening Procedure for Outdoor Soil Sources

As noted earlier, releases of asbestos to air from disturbances of soil sources may vary widely as a function of many factors. The purpose of this recommended step is to select a source area that is judged to have asbestos contamination that is at the high end of the range observed on-site (determined by site information or professional judgment), and to disturb the soil in a way that is likely to result in an air concentration that is at the high end of what could occur. This normally requires that the disturbance activity be vigorous, and that the disturbance occur under conditions

[3] When the asbestos content of soil is low (e.g., <1% PLM), the fraction of particles that are asbestos is small, and accurate quantification is generally very difficult. Thus, the results from these methods should generally be interpreted semi-quantitatively. Sampling at multiple sites has shown that even when soils are non-detect by PLM, concentrations of asbestos in the air via ABS may result in unacceptable health risks.

that favor release. To this end, an aggressive (high-end) soil disturbance, such as raking the soil, is recommended as a surrogate for high-end disturbance activities. For the raking scenario, a 10’ x 10’ foot area is raked to remove debris such as rocks, leaves, thatch and weeds using a leaf rake with a rake width of approximately 20 to 28 inches. Participants should strive to disturb the top half-inch of soil with an aggressive raking motion. This depth will vary based on the objective of the scenario. Each raking participant donning appropriate PPE will be fitted with a personal sampling pump contained in a backpack with the cassette secured to the shoulder straps near the operator’s lapels in the breathing zone. Personnel will rake a lawn or garden area to remove debris for a minimum of 2 hours (flow rate and sensitivity level dependent). Raking will occur in a measured area with vegetation, soil or rocks/gravel and will occur in an arched motion raking from the left of the participant to the right. The participants will rake the debris towards themselves facing one side of the square for 15 minutes then the participant will turn 90 degrees clockwise and begin a new side. Participants will continue to rake each side of the square and rotate 90 degrees. Once several small piles of debris have been made, the participant shall pick up the debris and place it in a trashcan. The sequence of raking, rotating and picking up debris shall be repeated for the duration of the sampling period. The participant should stay in the same plot for the entire sampling period. Additional information on ABS activities, including description, duration, and sampling considerations is available in the Standard Operating Procedures (SOP) via the ERT web site (www.ert.org/products/2084.PDF). The disturbance scenario should be performed when environmental conditions are favorable to produce maximum releasability and airborne exposure concentrations (e.g., the soil is dry and the wind is relatively calm for the location).

Screening Procedure for Indoor Sources

The benefits of ABS to assess asbestos exposure also may be useful for the indoor environment. If exposure to asbestos in indoor air is a concern, Agency and/or OSWER indoor policies may provide useful guidance (e.g., EPA, 2006b). The purpose of this recommended step is to select an indoor area that is judged to have asbestos contamination of dust that is at the high end of the range for the location and to disturb the settled dust in a way that is likely to suspend the dust and result in an air concentration of asbestos that is at the high end of what could occur during activity in the building. Selection of the location that is likely to have asbestos contamination of dust that is at the high end of the range may be determined by site information or professional judgment. The disturbance activity should be vigorous to maximize the likelihood of suspending any asbestos particles in the settled dust. The specific type and duration of disturbance activities used may be influenced by site-specific considerations (see www.ert.org/products/2084.PDF for additional details). If asbestos is detected in settled dust or wipe samples (see Appendix C), it may be appropriate to conduct a response action.

Considerations for ABS Sampling

When preparing a sampling plan and considering a strategy for ABS sampling at individual sites, site teams should consider the following questions to be addressed by the plan:

- What type(s) of ABS activities should be employed?
    - Consider:
        - current use and potential future use of the site;

        - evaluation if trespasser scenarios are appropriate for basing some ABS sampling types;
        - eliciting local official and community input.
- Should different areas of the site require separate ABS sampling types?
    - Consider:
        - differences in property use scenarios;
        - previous waste disposal practices in different areas of the site, e.g.,
            - Is ACM closer to the surface in some areas?
            - Are different asbestos types present (or previously disposed of at that site)?
            - Are there soil type or moisture differences?
            - Note proximity of different areas to the general public.
            - Note geographic acreage of the site.
- Given the above, how many ABS samples should be collected during any one ABS event?
- How many repetitions of ABS sampling should be collected over a specified time period?
    - Consider:
        - weather conditions [e.g., is there a need to sample at least once during driest conditions],
        - changes in soil moisture,
        - community concerns over the short or long term.

Because OSCs and RPMs may be unfamiliar with ABS sampling, assistance can be sought from EPA-ERT personnel and members of the TRW Asbestos Committee, if needed. See Section 6.0 for additional information on sampling and analytical considerations.

EPA workers and contractors with potential airborne exposure to asbestos should have appropriate training and use appropriate personal protective equipment (PPE), consistent with a properly developed health and safety plan (HASP) that follows EPA policies and OSHA (Occupational Health and Safety Administration) regulations. An appropriate Quality Assurance Project Plan (QAPP) and a Sampling and Analysis Plan (SAP) will be followed as required. Consultation with the Regional human subjects review board representative is generally recommended when ABS plans are developed (EPA, 2002a).

Risk Management Decision Point #1

After completing Step 4 of the recommended framework, risk managers and risk assessors should compare the air sampling results from Step 4 (the screening-level ABS exposure assessment) to the risk-based action level for asbestos in air (see Section 5.8) to determine the appropriate next step. Typically, there are two basic outcomes possible:

- Outcome 1: Asbestos is not detected
  Asbestos is not detected in the screening-level ABS air samples at concentrations that exceed the air action level. In this case, if there is reasonable confidence that the ABS samples represent the upper end of exposures that might occur at the site, and the analytical results have been obtained using the appropriate methods with an appropriate analytical sensitivity,

then no further evaluation of asbestos should be necessary. If confidence in the ABS results from Step 4 is not high (the area evaluated might not represent the high end of the concentration range at the site, the tests might have been done under conditions when release was not maximal, etc.), then it may be appropriate to proceed to Step 5.

- Outcome 2: Asbestos is detected
  Asbestos is detected in at least one or more ABS samples at concentrations at or above the air action level. In this case, it may be appropriate to conduct a response action (see Step 6) or collect additional data to further quantify the magnitude of exposure and risk, as well as the extent of contamination.

Step 5 – Environmental sampling: Site-specific activity based sampling (ABS) for indoor and outdoor scenarios

Recommended Step 5 is intended to provide sufficient information about exposures from indoor and outdoor sources that reliable risk assessment and risk management decisions can be based on the most informative and appropriate data. As discussed previously, the recommended approach for obtaining such data is normally ABS. The chief difference between ABS data obtained in Step 5 and the preliminary ABS data obtained in Step 4 is that, in Step 5, the samples should be representative in time and space, and should be representative of the range of different disturbance activities that may occur at the site over the duration of the exposure scenarios.

Collecting multiple ABS samples to capture the variability in airborne asbestos concentrations as a function of time, location, and disturbance activity can be important because estimates of exposure and risk from asbestos should be based on the average exposure concentrations that are experienced during each exposure scenario of concern, rather than on the values of individual samples (which may be either higher or lower than the average). The number and type of different ABS samples, air sampling approach, and analytical method needed to adequately characterize exposure for a specified scenario will vary from site to site and from scenario to scenario. As noted above, it is for this reason that the data collection effort performed under Step 5 should be based on a QAPP and a SAP developed in accord with standard EPA procedures. See Section 6.0 for additional information on sampling and analytical considerations. Because ABS sampling will be a new venture for many OSCs and RPMs, assistance can be sought from experienced EPA-ERT personnel and members of the TRW Asbestos Committee, if needed.

Recommended SOPs (standard operating procedures) for ABS for several outdoor soil and indoor dust disturbance scenarios are provided at www.ert.org/products/2084.PDF.

As noted in Step 3, EPA workers and contractors with potential airborne exposure to asbestos should have appropriate training and use appropriate PPE, consistent with a properly developed HASP that follows EPA policies and OSHA regulations. For some sites, it may be appropriate to consult with the Regional human subjects review board representative when sampling plans are developed.

Risk Management Decision Point #2

The analytical results obtained from the air samples following site-specific ABS may be used in the risk calculation for a baseline risk assessment considering both current and future risk. The baseline risk assessment and other criteria can then be used to make a risk management decision on appropriate response actions at the site (see Step 6). Three basic outcomes typically are possible:

1. Estimates of exposure and risk are below the site-specific risk management criteria and the level of uncertainty[4] in the exposure and risk estimates is acceptable to the risk manager. In this case, a no further action alternative normally is appropriate.

2. Estimates of exposure and risk are above the site-specific risk management criteria, and the level of uncertainty in the exposure and risk estimates is acceptable to the risk manager. In this case, proceed to Step 6.

3. In some circumstances, estimates of exposure and risk at individual sites have too much uncertainty to solely support reliable risk management decisions. For example, under the National Contingency Plan, response to a release of hazardous substances also includes response to the threat of a release and, in cases where a threat is posed but not an actual release, exposure or risk estimation can be more challenging. In these and similar situations, the risk manager should assess whether additional site assessment or investigation will likely be sufficient to reduce uncertainty to acceptable levels, or whether the collection of this data will provide minimal value and merely prolong a risk management decision. In all cases, however, justification of a response action (Step 6) must meet the criteria specified in the NCP.

Step 6 – Response Action and/or Institutional Controls

Response actions may be implemented either under removal or remedial authority, and may include a wide variety of different activities to reduce the potential for exposure (e.g., remove, cap, fence, etc.). Superfund removal and remedial actions undertaken pursuant to the CERCLA and NCP are based on a number of factors (see EPA, 2000b) and criteria (see EPA, 1988c).

If asbestos present at a site will not be addressed using CERCLA authority (www.epa.gov/superfund/policy/index.htm), an effort should be made to identify other programs or regulations that may have the authority and capability of addressing risks. Additional guidance is available for developing a risk management-based response strategy that is protective of human health and the environment (EPA, 1988b).

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[4] EPA is presently working to develop guidance for characterizing the statistical uncertainty in the long-term average concentration value based on a set of measured concentration values, and will issue guidance on this process in the future.

This recommended framework leaves discretion to the site manager and technical experts to evaluate whether a particular response action is appropriate for the site and to determine the proper method of implementation (EPA, 2006b). In some cases, a variety of institutional controls (ICs) may also be used to help limit current or future exposure and risk (for more information see www.epa.gov/superfund/action/ic/). Post-response site control actions and operation and maintenance activities should ensure the effectiveness and integrity of the remedy after the completion.

Finally, the response should include consideration of the current and reasonably anticipated future land use. For more information, please refer to the following:

"Land Use in the CERCLA Remedy Selection Process" (OSWER Directive 9355.7-04);
"Policy on Management of Post-Removal Site Control" (OSWER Directive 9360.2-02);
"Guidance on Implementation of the 'Contribute to Remedial Performance' Provision" (NTIS PB93-963413); and
"Superfund Removal Procedures: Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA" (OSWER Directive 9360.0-32).

4.0 Background

There are a number of special issues associated with the characterization and evaluation of asbestos exposures and risks which should be understood in order for risk managers to make informed site-specific management decisions. These issues are discussed in the sections below.

4.1 Mineralogy

Asbestos is a generic name applied to a variety of naturally-occurring, fibrous silicate minerals. Detailed descriptions can be found at the following two web sites:

- USEPA site: www.epa.gov/asbestos/pubs/asbe.pdf
- USGS site: minerals.usgs.gov/minerals/pubs/commodity/asbestos/

The commercial use of asbestos is based on a number of useful properties such as thermal insulation, chemical and thermal stability, high tensile strength, and flexibility. Asbestos is divided into two mineral groups—serpentine and amphibole. The division between the two types of asbestos is based upon the crystalline structure: serpentine asbestos has a sheet or layered structure, whereas amphiboles have a chain-like structure. The serpentine group contains a single asbestiform[5] variety (chrysotile), while the amphibole group contains a number of asbestiform varieties.

Asbestos is a CERCLA-listed hazardous substance (see 40 CFR 302.4-Designation of Hazardous Substances). Asbestos is also addressed by other EPA statutes and regulations (i.e., Toxic Substances Control Act [TSCA § 2642], Asbestos Hazard Emergency Response Act [AHERA] [1986], National Emissions Standards for Hazardous Air Pollutants [NESHAP § 61.141]) as well as other occupational regulations (e.g., 29 CFR Parts 1910, 1915, and 1926). Issues regarding

[5] Refer to Appendix A (Glossary and Acronym List) for more information.

the regulatory definition of asbestos may be important at certain sites (especially those involving the amphibole group) and legal counsel should be consulted where this may raise an issue. The term "asbestos" has often been applied to the fibrous habit of six minerals that have been commonly used in commercial products:

1. chrysotile (serpentine)
2. crocidolite (riebeckite)
3. amosite (cummingtonite-grunerite)
4. anthophyllite
5. tremolite
6. actinolite

It is important to recognize that these asbestiform minerals have been regulated chiefly because they have been preferentially mined for commercial applications, or have been seen as contaminants in commercially mined materials and recognized as asbestos. There are other forms of asbestos minerals, primarily of the amphibole group, that are not on this list which may be subject to CERCLA authority. Further, it is well established that exposures to certain groups of mineral fibers not regulated under TSCA, NESHAP, or OSHA can produce adverse health effects in humans (ATSDR, 2001 [www.atsdr.cdc.gov/toxprofiles/tp61.html]; Carbone et al., 2004; Sullivan, 2007). **This recommended framework is intended for Superfund sites, and for purposes of this framework the term asbestos is intended to cover all mineral forms of asbestos that may be subject to CERCLA authority and are associated with health effects in humans.** Additionally, this recommended framework may be useful for site assessment of other durable mineral fibers where health effects similar to asbestos are expected (e.g., erionite; Emri et al., 2002).

With regard to NOA, Section 104(a)(3)(A) of CERCLA provides a qualified limitation on response authority for a release or a threat of release "of a naturally occurring substance in its unaltered form, or altered solely through naturally occurring processes, from a location where it is naturally found". However, this limitation does not prohibit EPA from responding in otherwise appropriate circumstances to a release or a threat of release of NOA that has been altered by anthropogenic activities. State and local authorities may be appropriate for NOA response and management, especially in locations where NOA is found to be widespread in native soils.

4.2 Basic Strategy for Investigation

When the exposure pathway is asbestos released to the air from disturbance of contaminated soil or dust, the primary concern is inhalation exposure. When exposure to asbestos occurs via other media (such as drinking water) assessing other exposure pathways (such as ingestion of contaminated media) may be appropriate. Inhalation exposure to asbestos increases the risk of both carcinogenic effects (e.g., lung cancer, mesothelioma, laryngopharyngeal cancer, and possibly gastrointestinal tumors) and non-carcinogenic effects (e.g., asbestosis, pleural disease) (EPA, 1986 [cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=35551]; Hodgson, 2000; ATSDR, 2001; ATS, 2004; EPA, 1988a).

Asbestos fibers occur in air as the result of the disturbance of some source material (e.g., outdoor soil, indoor dust) by forces such as wind, weathering, or human activities. Thus, the key objectives during the investigation at any asbestos site generally are: (1) the identification of locations of asbestos contamination via source sampling, and (2) characterization of the levels of asbestos that may occur in air when the source is disturbed. The specific recommended approach emphasized here can then be used by risk assessors to estimate the level of human health risk attributable to the source, which in turn may be used by risk managers to determine whether use of a response action (source cleanup, ICs, etc.) may be appropriate in order to protect human health.

Currently available methods are not always sufficiently reliable to predict the airborne exposures of asbestos that may result from disturbance of asbestos-containing source materials such as contaminated soils or other bulk materials. Ongoing investigations by EPA and other researchers have revealed that airborne exposures associated with disturbance of contaminated soil depend on a number of factors including environmental conditions, soil composition, releasability or friability of the asbestos materials present, and the nature of the disturbance activities. Further, disturbance of contaminated soils and other bulk materials at concentrations below the level of detection of currently available methods (i.e., PLM) may still result in potentially hazardous airborne exposures (Addison, 1988; EPA, 2001a, 2006a; ATSDR, 2006). Therefore, this recommended framework emphasizes an empiric approach in which airborne concentrations of asbestos that occur when the source material (soil or dust) is disturbed are measured rather than predicted or modeled, commonly referred to as ABS. The use of ABS is a well-established approach widely utilized by industrial hygienists for exposure assessment in complex occupational environments (NIOSH 7400; www.cdc.gov/niosh/nmam/pdfs/7400.pdf). The use of personal air monitoring is also <u>required</u> by OSHA (www.osha.gov; OSHA 1910.1001(d)(1)(i); 29CFR1915(f)(1)(ii); 29CFR1926.1101(f)(1)(ii); 29CFR1926.1101) and recommended by MSHA (www.msha.gov/REGS/FEDREG/FINAL/2006finl/06-4494.pdf) regulations where these agencies have jurisdiction to assess compliance with their asbestos exposure limits. This recommended approach has also been generally accepted as an appropriate means of assessing the potential for airborne exposure to particulate contaminants in soil or dust. For more information on ABS see Williams et al. (2003); Ferro et al. (2004a,b); NRC (2004); Wallace and Williams (2005); Wallace et al. (2006a,b). Detailed methods for the performance of various ABS scenarios that may be appropriate to various environmental situations and conditions are provided at www.ert.org/products/2084.PDF.

One potential limitation to the ABS approach is the inability to generalize knowledge about the airborne levels of asbestos found in areas where ABS has been performed to areas of a site where information on source contamination exists, but ABS has not been performed. This is because the concentration of asbestos that occurs in air when a particular source is disturbed by some specified activity is likely to depend on several factors that might differ among areas, including the amount of asbestos that is present in the source at that location, the "releasability" of the asbestos from the matrix (e.g., soil, dust, ACM), and the environmental conditions (e.g., soil type and moisture content). Similar to what is done in developing a site conceptual model at any Superfund site, spatial representativeness of an ABS sampled area to a larger area requires consideration of several factors, e.g., site or facility historical operations, depth and details of asbestos waste disposal, soil characteristics, uniformity of soil cover, uniformity of fiber distribution depending on asbestos source, and other factors that would affect extrapolation from one area to another. The following subsections discuss these issues in greater detail.

4.2.1 Variations in Amount

In this recommended framework, ABS is used to determine whether fibers in soil or solid material can be released to the breathing zone of human receptors. ABS may need to be done at different areas of the same site if different levels of asbestos are present or site conditions vary by location. ABS results and associated risk should only be extrapolated to other portions of the site after careful consideration of the factors that would likely influence exposure and risk.

4.2.2 Variations in "Releasability"

ABS results can differ among locations, depending on the physical attributes of the asbestos or site-specific factors such as soil type and moisture content. Thus, even if the amount of asbestos is the same in two locations, the amount released to air by a specified disturbance may not be similar.

Furthermore, it is important to recognize that the releasability of asbestos at a location may change over time. For example, under present site conditions, asbestos in outdoor soil might exist primarily as large particles (i.e., large "chunks" of ACM or large lumps), which will tend to have low releasability of respirable asbestos fibers. Over time, however, these large non-respirable materials may become broken down by weathering and/or by mechanical forces (including the disturbance associated with a vigorous activity), thereby increasing the fraction of the material that exists as readily releasable fibers without altering the amount of asbestos that is present. Thus, in cases where data suggest that a substantial fraction of the asbestos present in soil exists in a poorly releasable form, it may be appropriate to interpret the results of ABS measurements to reflect current, but not necessarily future, site conditions (see Appendix D, Land Use Considerations). In cases where asbestos contamination is present in subsurface media, ABS may have limited utility to predict potential future risks if that contamination is exposed.

Releasability of asbestos from settled dust to the air cannot be modeled using a validated method; hence, activity-based sampling is recommended for assessing indoor exposures and ABS scenarios are provided at www.ert.org/products/2084.PDF.

At present, there is no established and validated technique for modeling or adjusting for differences in "releasability" of asbestos across different locations. EPA is actively pursuing the development and validation of several alternative methods for assessing releasability of asbestos from solid matrices such as soil, and when validated, these field or laboratory-based releasability devices may become valuable tools for use in conjunction with field-based ABS.

4.2.3 Methods for Collection of Air Samples

In the past, a wide variety of different techniques were used to measure the amount of asbestos in air. Since about 1970, nearly all samples have been collected by drawing air through a filter that traps airborne particles on the filter. In general, such samples may be divided into two broad categories: (a) those using a fixed ("stationary") air sampling device, and (b) those where the sampling device is worn by a person ("personal monitor"). Studies at several sites have shown that, in cases where asbestos-contaminated source material is being actively disturbed by an individual, the personal air samples consistently yield higher and more representative measurements of exposure than stationary air samples in the same vicinity (e.g., Doll and Peto, 1985; HEI, 1991; Lang et al., 2000; EPA, 2003; Sakai et al., 2006). Both have their advantages depending on the objective of the sampling (evaluation of personal exposure vs. characterization of ambient concentrations). Use of personal monitoring is consistent with National Academy of Science (NAS) recommendations concerning the assessment of personal exposures (NRC, 2004).

Therefore, this framework recommends the collection of personal air samples during active source disturbance activities. Collection of this type of sample can be essential in properly characterizing the levels of airborne asbestos exposure which may be expected to occur when a source material is disturbed. Recommended procedures for collection of ABS air samples are available (www.ert.org/products/2084.PDF). ABS may be employed to assess asbestos exposure in both outdoor and indoor environments. Stationary air monitors are useful in assessing exposures of a person when the person is not actively engaged in a source disturbance activity (e.g., indoor sitting on a couch watching television, inhalation of outdoor ambient air).

4.2.4 Methods for Analysis of Air Samples

As noted above, asbestos is not a single chemical entity, but includes fibers that may differ with respect to mineral type and particle sizes. There is general consensus among asbestos researchers that both mineral type (serpentine, amphibole) and fiber dimensions (length, width, and aerodynamic diameter) are likely to influence the toxicity of asbestos fibers (ATSDR, 2001). While the literature provides general indications of the influence of length on some toxic responses, there is no strong consensus on how the relative toxicity varies as a function of mineral type. For this reason, it is desirable that the analytical procedure used to analyze samples capture information concerning the specific mineralogy of asbestos fibers that are present at the site. (For some sites cost may limit the number of samples sent for full characterization, so it is recommended that a representative number of samples be fully characterized.) Such fiber characterization should allow for improved risk assessment at sites as new risk models become available. To this end, EPA is currently developing a standardized TEM method for measuring asbestos at Superfund sites. Until this method is available, a modification of the International Organization for Standardization (ISO) Method 10312-*Ambient air - Determination of asbestos fibres - Direct-transfer transmission electron microscopy* method is recommended for use at all remedial sites, as detailed in Appendix C, Analytical Methods for Determination of Asbestos in Air, Soil, and Dust. This method is also recommended for use at removal sites, but may not be appropriate for emergency responses at sites of natural or man-made emergencies or disasters due to resource limitations and time constraints.

4.2.5 Methods for Analysis of Dust Samples

ASTM (1995) has developed a standardized method for the collection of indoor dust samples using a micro-vacuum filter technique that may then be analyzed for asbestos by TEM using an indirect preparation. This method is generally capable of providing quantitative data on asbestos levels in dust (usually expressed as fibers per unit area, typically f/cm^2), with analytical sensitivity in the range of 100–1000 f/cm^2 being achievable in most cases.

4.2.6 Methods for Analysis of Soil Samples

Current analytical methods for asbestos in soil rely primarily on PLM. Two common techniques are NIOSH 9002 (NIOSH, 1994) and CARB 435 (CARB, 1991). The method required by the California Air Resources Board (CARB) reports data using point counting principles as ‘percent point count’, whereas the NIOSH method is based on an estimation of the asbestos fraction of the viewed area. The CARB method is undergoing revision (revision anticipated spring 2009) to align it with the risk management strategy objectives of the CARB. When the asbestos content of soil is low (e.g., <1% PLM), the fraction of particles that are asbestos is small, and accurate quantification is generally very difficult. Thus, the results from these methods should generally be interpreted semi-quantitatively. These methods, however, do allow for a comparison among samples, and are typically sufficient to allow grouping samples into similar levels for the purpose of extrapolation of ABS results across locations. In some instances, soil methods may fail to identify levels of asbestos that produce air asbestos concentrations that are potentially of concern. Sampling at multiple sites has shown that even when soils are non-detect by PLM, concentrations of asbestos in the air via ABS may result in unacceptable health risks. See Appendix C, Analytical Methods for Determination of Asbestos in Air, Soil, and Dust, for more information on sampling.

5.0 Cancer Risk Calculation

Calculation of excess lifetime cancer risks (ELCRs) can be used to determine whether airborne concentrations of asbestos are associated with unacceptable risks to human receptors at a given site. Although ingestion of asbestos can contribute to an increased cancer risk, EPA has not established a dose-response relationship for these endpoints. Likewise, EPA has not established a dose-response relationship for non-cancer effects at this time. Consequently, risk calculations from asbestos exposure are based solely on prediction of excess cancer risk for inhalation exposures.

The general equation for estimating risks from inhalation of asbestos is:

$$ELCR = EPC \bullet TWF \bullet IUR$$

where:

ELCR = Excess Lifetime Cancer Risk, the risk of developing cancer as a consequence of the site-related exposure

EPC = Exposure Point Concentration, the concentration of asbestos fibers in air (f/cc) for the specific activity being assessed

IUR = Inhalation Unit Risk $(f/cc)^{-1}$

TWF = Time Weighting Factor, this factor accounts for less-than-continuous exposure during a one-year exposure[6], and is given by:

$$TWF = \frac{Exposure\ time\ (hours\ exposed\ /\ day)}{24} \bullet \frac{Exposure\ frequency\ (days\ /\ year)}{365}$$

There are two points to emphasize in the application of this equation:

1. The exposure point concentration (EPC) must be expressed in the same units as the inhalation unit risk (IUR). The units of concentration employed in the current EPA approach for estimating cancer risks (EPA, 1986) are fibers per cubic centimeter (f/cc) as measured by phase contrast microscopy or PCM-equivalent (PCMe) concentrations measured using TEM[7].
2. The concentration-response function on which the asbestos IUR is based varies as a function of time since first exposure (EPA, 1986). Consequently, estimates of cancer risk depend not only on exposure frequency and duration, but also on age at first exposure. Therefore, it is essential to use an IUR value that matches the exposure period of interest (duration and age of first exposure).

The following procedure is recommended for calculating ELCR for asbestos and discussed in the following Sections 5.1 through 5.5.

5.1 Identification of Exposure Pathways of Potential Concern

The first step in developing a sampling plan or approach is to determine the exposure pathways of potential concern. The use of a conceptual site model is recommended for this effort. Sites evaluated by EPA to date have exhibited:

- asbestos in indoor dust,
- asbestos in soils around a home (e.g., in gardens, driveways, etc.),
- asbestos in fill/soil in recreational areas of a community, and
- recreational activities in areas where asbestos naturally occurs (native asbestos).

As with other site assessments, there may be multiple pathways and distinct receptor populations to consider. This is especially important as age and duration of exposure will impact the risk estimate. Therefore, the exposure pathway, receptor (age), and exposure duration must be linked.

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[6] See EPA (1994) and pending update to RAGS inhalation guidance (RAGS, Part F).

[7] See Appendix C, Analytical Methods for Determination of Asbestos in Air, Soil, and Dust, for more information about these analytical techniques.

One of the main objectives of this document is to establish the use of ABS as the preferred approach for assessing asbestos exposure at Superfund and other sites where personal activities in and around a site vary and a generalized sampling approach using fixed monitors would not adequately capture personal exposure. Once an exposure pathway of concern has been identified, sampling plans can be developed to characterize exposure for different activities.

Example pathways from recent EPA risk assessments at asbestos-contaminated sites have included simulating the following activities:

1. Gardening, weeding, and rototilling in asbestos-containing soil
2. Children playing in asbestos-containing soil
3. Organized sporting events (e.g., baseball, soccer) in parks with asbestos-containing soil
4. Walking, pushing a stroller, jogging, biking, and ATV use in asbestos-containing soil.

5.2 Determination of Pathway-Specific EPCs (Exposure point concentrations)

EPCs for each activity of potential concern can be determined from the results of sampling and analysis of airborne fiber concentrations at the site. As discussed in Section 3, ABS should be used for assessing risk from exposures associated with disturbance of asbestos-contaminated soils. Assessment of ambient air exposure concentrations during quiescent activities (those that do not involve active soil disturbance) should be assessed by air monitoring with stationary samplers. Ideally, selection of the sampling approach will be determined by the nature of the activity being assessed.

Once a set of measurements is collected to represent the exposure level for the scenario being evaluated, the EPC that would normally be used is the 95% upper confidence limit (UCL) of the mean of all of the relevant and representative measurements. While methods for computing the UCL are well-established for non-asbestos analytes using EPA's ProUCL software, computing the UCL of a set of asbestos measurements is more complicated because variability in the observed mean is contributed from two sources (authentic inter-sample variation and random Poisson counting variation), and methods for estimating the UCL for asbestos are not yet established. Thus, until methods are developed and approved by EPA, it is suggested that calculations be based on the simple mean of the data accompanied by a clear statement that this value is an uncertain estimate of the true mean and that actual risks might be either higher or lower. When computing the mean of a set of asbestos measurements, samples that are "non-detect" should be evaluated using a value of zero, not ½ the analytical sensitivity[8]. Taking site-specific characteristics into consideration, risk estimates based on other EPCs (e.g., maximum

[8] Use of ½ the sensitivity as a surrogate for asbestos non-detects may lead to a substantial overestimate of the true mean of a group of samples. Rather, the mean of a set of microscopy sample results is computed by treating non-detects as a zero. For example, consider the case where the true concentration is 0.001 s/cc, and the sensitivity is 0.010 s/cc. If this sample were analyzed 10 times, the expected result would be that 9 of the 10 analyses would yield a count of zero, and one of the samples would yield a count of 1, which would correspond to a concentration estimate of 0.010 s/cc (10-times the correct value). When averaged, the mean is 0.001 s/cc, which is the expected value. If ½ the sensitivity were assigned to the 9 NDs, the resulting average would be 0.055 s/cc, nearly six-times higher than the correct value. This alternative to the standard approach (assigning a surrogate value of ½ the analytical sensitivity; U.S. EPA, 1989) for computing the average of multiple sample results derived using microscopic counting methods has been reviewed and validated by EPA as part of the rulemaking process for microbial contamination in drinking water (U.S. EPA, 1999).

and minimum in addition to the central tendency) may be used to illustrate the range of risks and associated uncertainties (an example discussion of uncertainty is available in the Clear Creek Management Area Risk Assessment; available online at www.epa.gov/region09/toxic/noa/clearcreek/risk.html).

5.3 Calculation of TWFs (Time weighting factors)

Time weighting factors (TWFs) are used to determine the proportion of time (e.g., hours per day, days per year) over which specific exposure activities may occur. TWFs are combined with EPCs for each activity and an appropriate IUR value (see Section 4.4) to estimate excess lifetime cancer risks associated with activity-based exposures to asbestos.

In accordance with Risk Assessment Guidance for Superfund, Volume I (RAGS, Section 6.4.1, EPA, 1989), the exposure frequency and duration assumptions made in developing TWFs should represent reasonable maximum exposure (RME) scenarios.

It is generally recommended that an EPA risk assessor be part of the site assessment team for asbestos sites. The following sections are primarily geared toward risk assessors, although the concepts presented should be understood by site managers. Several example scenarios are included in Table 1 below. These scenarios are appropriate for a wide variety of sites and could be used at some sites without modification. Generally, however, exposures should be determined from activity-based sampling conducted during actual activities that occur or are likely to occur at the site in question.

TABLE 1. Time Weighting Factors (TWFs) for Example Exposure Scenarios.

Exposure scenario	Hours per day	Days per year	TWF†
Continuous	24	365	1
Baseline Residential	24	350	0.96‡
Gardening	10	50	0.057
Recreational	1	156	0.018
Child playing in soil	2	350	0.080

$$^{\dagger}TWF = \frac{hours}{24\ hours} \bullet \frac{days}{365\ days}$$

Years are not included in the TWF calculation, but are used to select the appropriate unit risk value from the lifetable.

‡ Note if the resident also exercises and gardens, then the TWF for the baseline residential scenario should be adjusted downward accordingly.

TABLE 2. Lifetime Inhalation Unit Risk (IUR) $(f/cc)^{-1}$ and Less-than-Lifetime Inhalation Unit Risk (IUR_{LTL}) $(f/cc)^{-1}$ Values for Various Continuous Exposure Scenarios

Age at first exposure (years)	Duration of exposure (years) 1	5	6	10	20	24	25	30	40	LT
0	0.010	0.046	0.055	0.084	0.14	0.147	0.15	0.17	0.19	0.23*
5	0.0085	0.039	0.046	0.070	0.11	0.13	0.13	0.14	0.16	
10	0.0068	0.031	0.038	0.058	0.094	0.098	0.10	0.11	0.13	
20	0.0046	0.021	0.027	0.038	0.063	0.065	0.066	0.075	0. 83	
30	0.0031	0.014	0.018	0.025	0.042	0.043	0.045	0.048	0.052	

* LT in this table means continuous lifetime exposure beginning at birth and lasting until death of the individual.
Continuous means that exposure occurs 24 hours/day, 365 days/year.
Some values are extrapolated from the risk estimates provided in the AAHAU (EPA, 1986), as detailed in Appendix E. All values are shown to 2 significant figures.
Complete Less-than-Lifetime Inhalation Unit Risk (IUR_{LTL}) values are available in Appendix E (Table E-4).

Each of these exposure scenarios also has a defined set of exposure durations and age at first exposure (Table 2), which is needed to select the appropriate less-than-lifetime IUR.

For comparison to activity-based exposures, a continuous exposure is included in the table to show that the TWF for 24 hours per day, every day of the year is 1 (unity). Exposure scenarios that are intermittent would result in TWFs that are <1. For example, gardening is a common soil-disturbing activity that may occur at a site. The gardening exposure scenario (shown in Table 1) results in a TWF value of 0.057. This gardening TWF is based on the 95th percentile value for hours per month that adults garden as provided in EPA's Exposure Factors Handbook (EPA, 1997), Table 15-62.

A recreational scenario also is included in Table 1 to account for activities such as walking, running, or biking, which may occur in areas of the site that may have asbestos contamination. The recreational scenario was developed based on best professional judgment. For an adult recreational receptor an individual was assumed to exercise for 1 hour per day, 3 days per week for the entire year. For this scenario, a 24-year exposure duration was assumed (age 20-44).

The child scenario assumes some type of regular outdoor activity that would disturb soil (i.e., playing on or in the dirt). The exposure time for this activity is assumed to be 2 hours per day, based on the 90^{th} percentile value in the Exposure Factors Handbook, Table 15-58. The exposure frequency for this activity was assumed to be 350 days per year, assuming that for 2 weeks each year, the child may be on vacation or otherwise away from home. In some locations, a lower exposure frequency may be warranted if conditions (e.g., snow cover, cold temperatures) prevent direct contact with soil.

5.4 Selection of Less-than-Lifetime IURs

In accord with Superfund guidance (OSWER Directive 9285.7-53 "Human Health Toxicity Values in Superfund Risk Assessments"), the Integrated Risk Information System (IRIS) is the generally preferred source of human health toxicity values (EPA, 1988a). The inhalation unit risk (IUR) value on IRIS for continuous exposure over a lifetime is 0.23 $(f/cc)^{-1}$. This value represents the combined risk of lung cancer and mesothelioma.

This recommended framework provides guidance on how to assess exposures at Superfund sites that may likely be shorter than a lifetime. For example, the default exposure duration for a resident at a Superfund site is 30 years (EPA, 1989. 1997). The Airborne Asbestos Health Assessment Update (EPA, 1986), which was used to derive the IRIS IUR, has been used to identify IUR values for a number of continuous, but less-than-lifetime, exposures. This approach is consistent with the current EPA Guidelines for Carcinogen Risk Assessment (EPA, 2005), which addresses risk from less-than-lifetime exposures where a lifetime average daily exposure or dose may underestimate risk. See Appendix E, Derivation of Cancer Unit Risk Values for Continuous and Less-Than-Lifetime Inhalation Exposure to Asbestos, for more details on these less-than-lifetime IUR values.

Selection of a less-than-lifetime IUR should consider: (1) age at first exposure and (2) the duration of the exposure for the receptor being evaluated. Table 2 presents the lifetime IUR and less-than-lifetime inhalation unit risk (IUR_{LTL}) for a set of exposure durations and population ages at the beginning of the exposure.

Note that the use of IUR_{LTL} values in Table 2 account for differences in risk associated with time of first exposure and exposure duration, but do not address the additional uncertainties that may be inherent in the less-than-lifetime exposure scenario (e.g., life stage or biological susceptibility).

For purposes of illustration, Table 3 presents IUR and IUR_{LTL} values for the exposure scenarios presented in Table 1.

TABLE 3. Inhalation Unit Risks (IURs) for Example Exposure Scenarios

Exposure Scenario	Age at first exposure (years)	Exposure duration (years)	IUR $(f/cc)^{-1}$
Continuous Lifetime	0	lifetime	0.23 (IRIS IUR)
Baseline Residential	0	30	0.17
Gardening	20	30	0.075
Running/Walking	20	24	0.068
Child playing in soil	1	5	0.045

5.5 Calculation of Excess Lifetime[9] Cancer Risks (ELCRs)

As noted in the general equation presented in Section 5.0, the basic equation for estimating ELCR resulting from exposure to asbestos is:

$$\text{Risk (ELCR)} = \text{EPC} \bullet \text{TWF} \bullet \text{IUR} \qquad \text{(As presented in Section 5.0)}$$

As noted above, when applying this equation to a less-than-lifetime exposure, TWF_i and IUR_{LTLi} values specific to the exposure scenario(s) must be used to calculate the appropriate $ELCR_i$ as follows:

$$ELCR_i = EPC_i \bullet TWF_i \bullet IUR_{LTLi}$$

Where:

- $ELCR_i$ = excess lifetime cancer risk for less-than-lifetime scenario i
- EPC_i = the scenario-specific exposure point concentration generated from activity-based sampling
- TWF_i = the scenario-specific time weighting factor
- IUR_{LTLi} = the Inhalation Unit Risk corresponding to the age at first exposure and exposure duration for the exposure scenario

Because CERCLA risk assessors may also need to characterize the cumulative risk to an individual resulting from exposure to several environments (e.g., different operable units across a site) or several scenarios (e.g., playing in the dirt, mowing the lawn, and indoor exposures), the cumulative excess lifetime asbestos cancer risk can be summarized as follows:

$$ELCR_c = \sum_i EPC_i \bullet TWF_i \bullet IUR_{LTLi}$$

[9] Note that in this context, "lifetime" refers to the risk of developing cancer sometime during one's lifetime from an exposure of duration specific to the activity being assessed; it does not refer to risk from a lifetime of exposure.

Where

$ELCR_c$ = the cumulative excess cancer risk attributed to exposure to multiple environments or multiple scenarios over the course of the exposure duration of the individual.

Examples: The following examples are intended to illustrate how TWF and IUR_{LTL} values are used in conjunction with ABS air monitoring data to estimate ELCRs for various exposure scenarios. These examples are provided to illustrate how the life table information can be used and how time-weighting can be incorporated into the risk calculation. These examples are not intended to be prescriptive or to cover all exposure scenarios.

<u>Example 1: Recreational Exposure - Adult</u>

In this scenario, an adult receptor is exposed to asbestos only while running or walking in a contaminated recreational area (e.g., a park) and is assumed to have no residential asbestos exposure. Under an RME scenario, the adult is assumed to run/walk 1 hour per day, 156 days per year over a 24-year period from ages 20 to 44 years old. The airborne asbestos concentration in the breathing zone measured during ABS was 0.04 f/cc, which is used as the EPC.

$$TWF = \frac{1\,hour}{24\ hours/day} \bullet \frac{156\,days}{365\ days/year} = 0.018$$

IUR_{LTL} = 0.068 $(f/cc)^{-1}$

(Table 3; 24-year exposure starting at age 20)

ELCR = EPC • TWF • IUR_{LTL}

= 0.04 f/cc • 0.018 • 0.068 $(f/cc)^{-1}$

ELCR = 4.9×10^{-5}

<u>Example 2: Recreational Exposure - Child</u>

In this scenario, a child receptor is exposed to asbestos only while playing in the dirt in this recreational area (e.g., a park) and is assumed to have no residential asbestos exposure. Under an RME scenario, the child is assumed to play 2 hours per day, 350 days per year over a 5-year period from ages 1 to 6 years old. The airborne asbestos concentration in the breathing zone measured during ABS was 0.02 f/cc, which is used as the EPC. The IUR_{LTL} for this scenario is determined by interpolation as shown in Appendix E, Table E-4.

$$TWF = \frac{2\ hours/day}{24\ hours/day} \bullet \frac{350\ days/year}{365\ days/year} = 0.080$$

IUR_{LTL} = 0.045 $(f/cc)^{-1}$
(Table 3; 5-year exposure starting at age 1)

ELCR = EPC • TWF • IUR_{LTL}
= 0.02 f/cc • 0.080• 0.045 $(f/cc)^{-1}$
ELCR = 7.2 x 10^{-5}

Example 3: Combined Residential Ambient Air Exposure and Gardening Exposure- Adult

In this scenario, an adult receptor is exposed due to disturbance of asbestos-contaminated soil while gardening and to asbestos in ambient air during quiescent activities. Under a residential RME scenario, the period of exposure is assumed to be 30 years, starting at age 20. The gardening scenario is assumed to be 10 hours per day, 50 days per year. Similarly, RME exposure to asbestos in ambient air is assumed to occur at all times that gardening is not occurring (14 hours per day for 50 days per year and 24 hours per day for 300 days per year). The asbestos concentration in the breathing zone while gardening during ABS was 0.02 f/cc, which is used as the EPC_G. The ambient air concentration measured in the community by stationary air monitors was 0.0007 f/cc, which is used as the EPC_{Amb}. The IUR_{LTL} for this scenario can be read directly from Table 2. ELCR is calculated as the sum of risk from exposure to asbestos from gardening and risk from ambient exposure to asbestos.

$$TWF_G = \frac{10}{24\ hours/day} \bullet \frac{50}{365\ days/year} = 0.057$$

$$TWF_{Amb} = \frac{14}{24\ hours/day} \bullet \frac{50}{365\ days/year} + \frac{24}{24\ hours/day} \bullet \frac{300}{365\ days/year} = 0.90$$

(14 hours/day while gardening plus 24 hours/day other days while at home.)

IUR_{LTL} = 0.075 $(f/cc)^{-1}$
(Table 3; 30-year exposure starting at age 20)

ELCR = $[(EPC_G \bullet TWF_G) + (EPC_{Amb} \bullet TWF_{Amb})] \bullet IUR_{LTL}$
= [(0.02 f/cc • 0.057) + (0.0007 f/cc • 0.90)] • 0.075 $(f/cc)^{-1}$]
ELCR = 8.5 x 10^{-5} + 4.7 x 10^{-5} = 1.3 x 10^{-4}

5.6 Uncertainties in the Current Cancer Risk Assessment Method

It is standard assessment practice in EPA to describe the underlying assumptions and the uncertainties. Detailed information can be found in the Risk Characterization Handbook (EPA, 2000a) and Risk Assessment Guidance for Superfund (EPA, 1989). EPA is also currently developing additional guidance on the assessment and communication of risks and uncertainties when evaluating sites involving naturally occurring asbestos.

The IUR_{LTL} (Table 2) and IRIS IUR (0.23 per f/cc) values are based on airborne fiber measurements using PCM, and no distinction is made between different mineral forms of asbestos. All fibers longer than 5 μm with an aspect ratio ≥3:1 and a width ≥0.25 μm and ≤3 μm are used to estimate exposure and risk (see Appendix C for more information). There are a number of variables that may potentially influence risk that are not accounted for by using exposure measurements based on this definition of a PCM fiber. For example, the IRIS Health Assessment (EPA, 1986) specifically recognizes the potential importance of different mineral forms of asbestos, but the data were not sufficient at that time to support the derivation of mineral specific potency factors. More recently there have been proposals that fiber dimension can be used to develop more refined potency estimates. Other variables such as fiber morphology and surface charge may also influence potency, but little information is currently available.

Because the less-than-lifetime unit risk and IRIS methods do not differentiate risks as a function of these or other variables, it is recommended that each asbestos risk assessment include an uncertainty discussion (an example discussion of uncertainty is available in the Clear Creek Management Area Risk Assessment; available online at www.epa.gov/region09/toxic/noa/clearcreek/risk.html). Where appropriate, this discussion could include alternative exposure metrics or risk calculations based on other published, peer-reviewed methods.

Additional areas of uncertainty in the use of the IRIS dose-response assessment, not specific to asbestos (i.e., they also pertain to other pollutants), may also be appropriate to discuss in the uncertainty characterization section of the risk assessment. These uncertainties may include differences between the study on which the dose-response assessment is based from the exposure circumstances being assessed, and recognition of assumptions inherent in methods employed to derive a continuous exposure toxicity value from exposure-response data involving discontinuous exposures (EPA, 1994). These uncertainties may also include differences with regard to the exposed population (e.g., workers vs. general population), the magnitude of exposure (e.g., generally higher study levels than those being assessed), and duration and frequency of exposure (e.g., 20-30 years of five to six 8- to 10-hour days a week vs. alternate exposure scenarios). See Appendix E, Derivation of Cancer Unit Risk Values for Continuous and Less-Than-Lifetime Inhalation Exposure to Asbestos, for more information. In addition, the TRW Asbestos Committee is available for consultation for those considering presentation of additional asbestos cancer risk estimates based on other published dose response assessments.

5.7 Non-Cancer Risks

At present, there is no IRIS inhalation reference concentration (RfC) available for the assessment of non-cancer risks from airborne asbestos exposure. Nevertheless, the occurrence of non-cancer disease is an important component of the suite of adverse effects experienced by humans with excess exposure to asbestos (ATSDR, 2003). Although no quantitative assessment is available, non-cancer health effects should be discussed in any risk assessment for asbestos exposure. The uncertainty section can present the limitations imposed by the current lack of a quantitative method for non-cancer effects of asbestos (an example discussion of uncertainty is available in the Clear Creek Management Area Risk Assessment; available online at www.epa.gov/region09/toxic/noa/clearcreek/risk.html). EPA scientists are presently working to develop an inhalation RfC for asbestos at the Libby site.

5.8 Identifying the Air Action Level

The OSWER directive (EPA, 2004), recommends the development of risk-based, site-specific air action levels to determine if response actions for asbestos in soil/debris should be undertaken. Because inhalation is the exposure pathway of concern for asbestos, an action (or screening) level for asbestos in air is an appropriate metric for site managers in making the determination of whether a response action, no action, or further, more detailed investigation at a given site is warranted (i.e., Risk Management Decision Point #1 in Step 4). The text in this section describes a range of air action values that may be useful for different site-specific circumstances. (In addition, the air action level may be useful in guiding the data collection effort for site investigations: air action levels support the identification of appropriate detection levels for establishing DQOs discussed in Section 7.0.)

It should be noted that the action level for asbestos in air is most appropriate for use with exposure point concentrations generated by ABS or ABS in combination with ambient air monitors. An air action level would not be appropriate when using the results from ambient air monitoring alone when disturbance activities are anticipated for the site. Disturbance of soil (or settled dust) has been shown to result in a significantly greater release of asbestos fibers to air than under ambient conditions (see Section 4). Activities can create personal dust clouds that result in higher asbestos exposures on personal monitors than on ambient air monitors.

A risk-based air action level for asbestos in air may be calculated by rearranging the standard risk equation to compute the concentration of asbestos in air that corresponds to a specified risk level for a specified exposure scenario of concern as follows:

$$\text{Action Level for Asbestos in Air (f/cc)} = \frac{\text{Target Risk}}{[IUR_{LTL} \cdot TWF]}$$

Using the standard Superfund residential exposure scenario (EPA, 1989), action levels for asbestos in air can be calculated using the time weighting factor for Baseline Residential Exposures (TWF = 350/365, see Table 1), the age 0-30 IUR_{LTL} (Table 2), along with the target risk levels of $1x10^{-4}$, $1x10^{-5}$, $1x10^{-6}$ (the Superfund risk range of E-4, E-5, and E-6, respectively):

Example E-4 Air Action Level for Baseline Residential Asbestos Exposures (f/cc)

$$= 1x10^{-4} \div [0.17\ (f/cc)^{-1} \cdot 0.96]$$
$$= 0.0006\ f/cc$$
$$\sim 0.001\ f/cc$$

Example E-5 Air Action Level for Baseline Residential Asbestos Exposures (f/cc)

$= 1x10^{-5} \div [0.17 \text{ (f/cc)}^{-1} \bullet 0.96]$
$= 0.00006$ f/cc
~ 0.0001 f/cc

Example E-6 Air Action Level for Baseline Residential Asbestos Exposures (f/cc)

$= 1x10^{-6} \div [0.17 \text{ (f/cc)}^{-1} \bullet 0.96]$
$= 0.000006$ f/cc
~ 0.00001 f/cc

The selection of an appropriate target risk level ($1x10^{-4}$, $1x10^{-5}$, or $1x10^{-6}$) is a risk management decision. The three alternatives are shown to illustrate the range of air action levels that may be selected if the residential scenario is appropriate for the site. The air action level for a site may be influenced by the scenario selected and by sampling and/or analytical constraints.

It is recommended that the action level for asbestos in air be carefully considered to ensure that it is appropriate for the site. Technical and statistical issues should be carefully considered in determining whether the average air concentration from ABS can be compared to these risk-based action levels for asbestos in air (e.g., it would not be appropriate to compare air concentrations generated by a short-term ABS scenario, such as raking or lawn mowing, with an air action level which assumes a continuous residential exposure scenario).

For asbestos, because there is no economically and technically feasible analytical method available to measure asbestos in soil at levels <0.25%, this framework recommends a procedure that is economically and technically feasible (i.e., the use of ABS and TEM) to derive an action level for asbestos in air. For example, because of background asbestos levels or resource limitations, E-5 and E-6 risk levels may not be practical target risk levels for some sites. For those site assessments involving short term, intermittent exposures, it is common practice to use the E-4 baseline residential action level for asbestos in air (0.001 PCME f/cc) because of analytical costs, sampling volume limitations, and other analytical issues (i.e., analyst fatigue). When assessing only indoor residential exposures, a lower air action level (0.0001 PCME f/cc, corresponding to E-5 risk level) may be achieved, because high volume stationary monitors may be used (see Section 6).

Using this procedure allows development of a health-based screening level that is representative of actual inhalation exposures (the critical exposure route) by means of site-specific, measured (not modeled) air concentrations. Generic air action levels using a default, 30-year residential scenario are shown above. Derivation of site-specific action levels for other exposure scenarios would follow the same procedure.

6.0 Sampling and Analytical Considerations

As noted above, air action levels are among the factors to be considered in specifying DQOs for a site. That is, the approximate concentration of a contaminant that would be of potential health concern to exposed humans can guide decisions about sample collection and analysis (e.g., to determine the optimal sensitivity of the sample collection method desired for the risk evaluation).

For this purpose, the air action level is considered an LOC. The LOC is typically used in Step 5 of the recommended framework to establish analytical sensitivities required for site-specific ABS.

In brief, the LOC typically is determined by rearranging the risk equation to compute the concentration of asbestos in air that corresponds to a specified risk level for a specified exposure scenario of concern (often a *de minimis* risk level):

$$\text{LOC (f/cc)} = \frac{\text{Target Risk at LOC}}{[\text{IUR} \bullet \text{TWF}]}$$

The IUR and TWF parameters are described in the preceding Section 5, *Cancer Risk Calculation*.

Calculation of a hypothetical site-specific LOC can be illustrated using Example 1 where exposure is for 1-hour day, 156-day year for 24 years beginning at age 20:

$$TWF = \frac{1\,hour}{24\ hours/day} \bullet \frac{156\,days}{365\ days/year}$$

TWF = 0.018

IUR = 0.065 $(\text{f/cc})^{-1}$ (from Table 3)

Assuming a target risk of $1\text{x}10^{-6}$:

$$\begin{aligned}\text{LOC (f/cc)} &= 1\text{x}10^{-6} \div [0.065\ (\text{f/cc})^{-1} \bullet 0.018] \\ &= 0.0009\ \text{f/cc}\end{aligned}$$

The choice of the target level of risk to use in this equation is a risk management decision and should be consistent with CERCLA and the NCP. In general, it is expected that the value will fall within the risk range of E-4 to E-6. As discussed above, however, the choice of target risk level may be influenced by sampling and analytical constraints, as discussed below, at www.ert.org/products/2084.PDF, and in Appendix C, Analytical Methods for Determination of Asbestos in Air, Soil, and Dust. Thus the target risk level may be selected to accommodate site-specific resource constraints. It is important to note that for a site with multiple ABS scenarios, more than one LOC may be appropriate.

The LOC determined above can be used to establish the analytical sensitivity requirements, which must be determined prior to sample collection. It is defined as the concentration corresponding to the detection of one structure in the analysis. For a direct preparation, the analytical sensitivity for a sample is determined by the volume of air drawn through the filter, the active area of the filter, the number of grid openings (GOs) analyzed by a microscopist, and the area of each GO analyzed as follows:

$$S = EFA \div [GOs \bullet A_{GO} \bullet V \bullet 1000]$$

where:

S	=	Analytical sensitivity (1 structure/cc)
EFA	=	Effective filter area (mm^2)
GOs	=	Number of grid openings evaluated
A_{GO}	=	Area of each grid opening (mm^2)
V	=	Volume (L)
1000	=	Unit conversion factor (cc/L)

Sample volume and the number of grid openings analyzed can typically be controlled during sample collection and analysis. However, there may be several practical constraints on each of these parameters. For example, the volume of air collected is given as the product of pump flow rate (L/minute) and collection time (minutes). Most personal sampling pumps have a maximum flow rate in the range of 5–10 L/minute, and the maximum sampling time for a personal air sample associated with ABS is usually about 2–4 hours. This volume also may be constrained by the level of dust in the air, since sample collection should not exceed the point where the filter surface contains more than 5–25% particulate. Thus, the volume for personal air samples is generally no larger than 2000–4000 L. In theory, the number of grid openings can be any number, but the time and cost of analysis is directly related to the number of grid openings analyzed (see Appendix C, Analytical Methods for Determination of Asbestos in Air, Soil, and Dust).

7.0 Data Adequacy: Applying the DQO Process

In general, estimates of risk from exposure to asbestos in air should be based on estimates of the appropriate exposure concentration during the time frame of the exposure scenario rather than on the values of individual samples (see EPA, 1989). Because concentrations in air can be highly variable as a function of both time and space, it is usually desirable to collect repeated samples at multiple locations within an exposure area (or repeated samples from the same location) in order to achieve a reliable basis for estimation of the average exposure level for each exposure scenario of concern (additional guidance concerning ABS is available from ERT: www.ert.org/products/2084.PDF).

Because there is no default rule for identifying the minimum number of samples that are required to adequately characterize exposure and risk at a site (EPA, 1992), it is critical to prepare detailed QAPPs or SAPs to guide asbestos data collection activities. These plans should be prepared in accordance with existing Agency guidance including appropriate data quality objectives. For assistance in developing these documents, refer to the following:

- Guidance for Quality Assurance Project Plans, EPA/240/R-02/009 [www.epa.gov/quality/qs-docs/g5-final.pdf] and
- EPA Requirements for Quality Assurance Project Plans, EPA/240/B-01/003 [www.epa.gov/quality/qs-docs/r5-final.pdf] or

- Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4, EPA/240/B-06/001 [www.epa.gov/quality/qs-docs/g4-final.pdf]

QAPPs and SAPs may be modified as necessary in consultation with Regional risk assessors and risk managers to meet project-specific DQOs. Proper application of the DQO process will help maximize the probability that data collected will be adequate to support reliable risk assessments and management decisions, or to alert the risk manager when collection of adequate data may be cost prohibitive relative to the cost of a response action.

8.0 Risk Management Issues

As is true of all site investigations, risk managers balance a number of different considerations in deciding how to proceed at a site. One consideration can be the relative cost of performing a site investigation compared with the cost of site cleanup. This is often true for asbestos because of the relatively high cost of sample collection and sample analysis. Two possible scenarios that may occur include:

- High-Level Sources are Present
  In some cases, available information may be sufficient to conclude that sources present are very likely to be of concern, even though detailed exposure and risk estimates are not yet available. For example, if data indicate high levels of asbestos are present in soil (e.g., >1% PLM) or indoor dust (e.g., >10,000 s/cm^2)[10], a risk manager may determine that a response action should be undertaken, and that further efforts to characterize the source or potential airborne exposures before action is taken are not needed.

- Further Investigation is Not Cost Effective
  In cases where available data are not sufficient to clearly determine if a source is or is not of significant health concern, the risk manager may consider whether the cost of further investigation to characterize the magnitude of the exposure and risk is likely to approach or exceed the cost of performing a response action. If at any point in the use of the recommended framework the cost of investigation is anticipated to be greater than the cost of an appropriate response action, it may be reasonable to proceed directly to a decision concerning a response action without further site characterization (assuming that the site poses an unacceptable risk to human health as defined by the NCP). However, if it is determined that site investigation may be helpful in narrowing the scope (and hence reducing the cost) of a response action, then further investigation to define the location and extent of sources requiring response action normally should be pursued.

8.1 Consideration of "Background"

In some cases, it may also be important to consider "background" levels of asbestos for site assessment and risk management, since "background" concentrations may, in some cases, contribute significantly to the total concentration of asbestos measured in site media (soil, air, dust).

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[10] Microvacuum testing results should be compared with results obtained from the same as well as similar structures or sites to be able to conclude there are significantly elevated concentrations of asbestos in the test building.

The definition of "background" may differ from case to case, but is often taken to refer to the concentration of asbestos in outdoor or indoor air under conditions when there is no known local disturbance that results in a significant release. The level of "background" asbestos in outdoor air has been investigated in numerous studies (see ATSDR, 2001 for a summary; EPA, 2002b). In general, except for areas of NOA, levels tend to be highest in urban environments, and lower in rural or "pristine" environments. For indoor air, ATSDR (2001) reports that “measured indoor air values range widely, depending on the amount, type, and condition (friability) of ACM used in the building”. In its review, ATSDR notes that the available data suffer from lack of common measurement reporting units. When characterization of "background" levels of asbestos in outdoor or indoor air are needed to support risk management decisions, the data should be collected using the same sampling methods and analytical procedures as are used for on-site data, except that this type of sample is generally collected using stationary air monitors with high flow rates and a long sampling period in order to achieve high sample volumes (and hence low analytical sensitivity). In addition, as is true for all efforts to characterize background, it is important to collect multiple samples that are representative over time and space, and which are sufficient in number to provide a proper basis for statistical comparison of site data with background data.

9.0 Limitations

Although this guidance provides information concerning assessing asbestos exposure at Superfund sites, some asbestos sources may not be addressed under the authority of CERCLA. Site assessors should consult their management and legal counsel when evaluating whether to use the authority of CERCLA at a particular site. Ultimately, the site assessors should strive to address any unacceptable current or potential future asbestos exposure risks (see Appendix D, Land Use Considerations).

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Appendix A – Glossary and Acronym List For Purposes of this Guidance

AAHAU	**Airborne Asbestos Health Assessment Update (1986)**
ABS	**Activity-based sampling** An empiric approach in which airborne concentrations of asbestos are measured during an event where the source material (soil or dust) is disturbed rather than predicted or modeled from source material concentration.
ACBM	**Asbestos-containing building materials**
ACM	**Asbestos containing material**
Actinolite	A mineral in the amphibole group. It is generally not used commercially, but is a common impurity in chrysotile asbestos.
AHERA	Asbestos Hazard Emergency Response Act of 1986 In 1986, the Asbestos Hazard Emergency Response Act (AHERA) was signed into law as Title II of the Toxic Substance Control Act. Additionally, the Asbestos School Hazard Abatement Reauthorization Act (ASHARA), passed in 1990, requires accreditation of personnel working on asbestos activities in schools, and public and commercial buildings. See applicability discussion (Section 2).
Amosite	A type of asbestos in the amphibole group; it is also known as brown asbestos.
Amphibole	A group of double chain silicate minerals.
Analytical sensitivity	The sample-specific lowest concentration of asbestos the laboratory can detect for a given method.
Anthophyllite	A type of asbestos in the amphibole group; it is also known as azbolen asbestos.
Asbestiform	Fibrous minerals possessing the properties of commercial grade asbestos (e.g., flexibility, high tensile strength, or long, thin fibers occurring in bundles).
Asbestos	The generic name used for a group of naturally occurring mineral silicate fibers of the serpentine and amphibole series, displaying similar physical characteristics although differing in composition.
Asbestosis	A non-cancerous disease associated with inhalation of asbestos fibers and characterized by scarring of the air-exchange regions of the lungs.
Aspect ratio	Length to width ratio of a particle or fiber.
ASTM	**American Society for Testing and Materials**
ATSDR	**Agency for Toxic Substances and Disease Registry** A principal federal public health agency involved with hazardous waste issues, responsible for preventing or reducing the harmful effects of exposure to hazardous substances on human health and quality of life. ATSDR is part of Center for Disease Control and Prevention which is part of the U.S. Department of Health and Human Services.
Bulk sample	A sample of suspected media (e.g., soil or dust) is obtained from a site to be analyzed microscopically for asbestos content. Bulk sample analysis can be part of a process to assess the hazard from asbestos at a site.
CARB 435	**California Air Resources Board analytical method 435** A specialized polarized light microscopy (PLM) method used for testing asbestos content in the serpentine aggregate storage piles, on conveyer belts, and on covered surfaces such as roads, play-yards, shoulders and parking lots. The method includes reporting the asbestos content by performing a 400 point count technique which has a detection limit of 0.25%. Many agencies and laboratories also use this method for measuring asbestos in soil. The method is undergoing revision (completion anticipated in 2009).
Carcinogen	Any substance that causes cancer.
CERCLA	**Comprehensive Environmental Response, Compensation, and Liability Act**

Chrysotile	A fibrous member of the serpentine group of minerals. It is the most common form of asbestos used commercially, also referred to as white asbestos.
Cleavage Fragment	Fragments that may be formed by crushing, mining, or breaking massive materials.
Contaminant	A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.
Continuous Exposure	Exposure that occurs 24 hours/day, 365 days/year.
Crocidolite	A type of asbestos in the amphibole group; it is also known as blue asbestos.
Detection limit	The minimum concentration of an analyte in a sample, that with a high level of confidence is not zero.
Direct preparation	In direct preparation, the filter is examined by microscopy. In contrast with indirect preparation, where a filter with too much material undergoes a separation step (commonly dispersion in water) to allow for analysis.
Dose	The amount of a substance to which a person is exposed (air, soil, dust, or water) over some time period.
DQO	**Data Quality Objectives**
ED	**Electron diffraction** A specialized technique used to study matter by firing electrons at a sample and observing the resulting interference pattern. See Appendix C.
EDX	**Energy Dispersive X-Ray Analysis**
ELCRs	**Excess lifetime cancer risks**
EPA	**United States Environmental Protection Agency**
EPC	**Exposure point concentration**
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [acute exposure], of intermediate duration, or long-term [chronic exposure].
f/cc	Fibers per cubic centimeter. Units of measurement for asbestos in air.
Fibrous habit	Having the morphologic properties similar to organic fibers.
GOs	**Grid openings** An area that overlays a mounted sample to aid in its microscopic examination.
HASP	**Health and safety plan**
Hazardous substance	Any material that poses a threat to public health and/or the environment. Typical hazardous substances are materials that are toxic, corrosive, ignitable, explosive, or chemically reactive.
ICs	**Institutional controls** Institutional controls are actions, such as legal controls, that help minimize the potential for human exposure to contamination by ensuring appropriate land or resource use.
Indirect preparation	A method whereby a filter with too much material undergoes a separation step to allow for analysis.
Ingestion	The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see route of exposure].
Inhalation	The act of breathing. A hazardous substance can enter the body this way [see route of exposure].
IRIS	**Integrated Risk Information System** A compilation of electronic reports on specific substances found in the environment and their potential to cause human health effects.
ISO 10312	**International Organization for Standardization Method 10312** See Appendix C for details.

IUR	**Inhalation unit risk** The excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration 1 µg/m³ in air.
MCE	**Mixed cellulose ester** A type of filter used for air sampling.
Media	Soil, water, air, plants, animals, or any other part of the environment that can contain contaminants.
Mesothelioma	A malignant tumor of the covering of the lung or the lining of the pleural and abdominal cavity often associated with exposure to asbestos.
Microvacuum samples	A microvacuum sample, commonly called microvacuum, as per ASTM D5755, is similar to a wipe sample with the exception that a predefined area is "vacuumed" using a low-volume (1–5 L/minute) personal air pump equipped with a sample cassette that contains a cellulose filter instead of wiping with a wet wipe.
NCP	**National Contingency Plan**
NESHAP	**National Emission Standards for Hazardous Air Pollutants** Section 112 of the Clean Air Act requires EPA to develop emission standards for hazardous air pollutants. In response, EPA published a list of hazardous air pollutants and promulgated the National Emission Standards for Hazardous Air Pollutants (NESHAP) regulations.
NIOSH	**National Institute for Occupational Safety and Health** The National Institute for Occupational Safety and Health (NIOSH) is the federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness. NIOSH is part of the Centers for Disease Control and Prevention in the Department of Health and Human Services.
NIOSH 7400	A light microscopy analytical method, also known as NIOSH Phase Contrast Microscopy [PCM] Method 7400.
NIOSH 9002	A polarized light microscopy (PLM) analytical method useful for the qualitative identification of asbestos and the semi-quantitative determination of asbestos content of bulk samples. The method measures percent asbestos as perceived by the analyst in comparison to standard area projections, photos, and drawings, or trained experience. The method is not applicable to samples containing large amounts of fine fibers below the resolution of the light microscope.
NOA	**Naturally occurring asbestos**
OSHA	**Occupational Safety and Health Administration** The Occupational Safety and Health Administration, since its inception in 1971, aims to ensure employee safety and health in the United States by working with employers and employees to create better working environments.
PC	**Polycarbonate** A type of filter used for asbestos air sampling.
PCM	**Phase contrast microscopy** A light-enhancing microscope technology that employs an optical mechanism to translate small variations in phase into corresponding changes in amplitude, resulting in high-contrast images. Historically, this method was used to measure airborne fibers in occupational environments; however, it cannot differentiate asbestos fibers from other fibers.
PCMe	**PCM-equivalent** This refers to chrysotile and amphibole structures identified through transmission electron microscopy (TEM) analysis that are equivalent to those that would be identified in the same sample through phase contrast microscopy analysis, with the main difference being that TEM additionally permits the specific identification of asbestos fibers. PCMe structures are asbestiform structures greater than 5 microns in length having at least a 3 to 1 length to width (aspect) ratio.

Personal air monitor	Also known as a low-flow or low-volume sample pump, this is an air sample pump that is portable so that it can be worn by a member of the sampling team during activity based sample collection. The air flow for a personal sample pump is typically 1 to 10 liters per minute.
Pleural fibrosis	The development of fibrous tissue in the pleura.
PLM	**Polarized light microscopy** A microscope technology that uses the polarity (or orientation) of light waves to provide better images than a standard optical microscope.
PPE	**Personal protective equipment**
Prismatic	A term commonly used in descriptions of minerals for crystals having the shape of a prism.
QAPP	**Quality Assurance Project Plan** The EPA has developed the QAPP as a tool for project managers and planners to document the type and quality of data needed for environmental decisions and to describe the methods for collecting and assessing those data. The development, review, approval, and implementation of the QAPP are components of EPA's mandatory Quality System.
RfC	**Reference concentration** An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious non-cancer health effects during a lifetime. The inhalation reference concentration is for continuous inhalation exposures.
RME	**Reasonable maximum exposure**
Route of exposure	The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].
s/cc	Structures per cubic centimeter. Units of measurement for asbestos in air.
SAED	**Selected area electron diffraction** A crystallographic laboratory technique, a specialized electron microscopy technique, which can be performed inside a transmission electron microscope (TEM).
SAP	**Sampling and Analysis Plan** A plan intended assist organization in documenting the procedural and analytical requirements for a one-time or time-limited project involving the collection of water, soil, sediment, or biological samples taken to characterize areas of potential environmental contamination. It combines, in a short form, the basic elements of a Quality Assurance Project Plan (QAPP) and a Field Sampling Plan (FSP).
Serpentine	A name given to several members of a polymorphic group of magnesium silicate minerals—those having essentially the same chemistry but different structures or forms. Chrysotile asbestos is a member of the serpentine group.
SOP	**Standard operating procedure**
Stationary air monitor	An air sample monitor that is placed in a single location and is not moved during one or more sampling events.
TEM	**Transmission electron microscopy** A microscope technology and an analytical method to identify and count the number of asbestos fibers present in a sample. It uses the properties of electrons to provide more detailed images than polarized light microscopy (PLM). Capable of achieving a magnification of 20,000x.
Tremolite	A mineral in the amphibole group, that occurs as a series in which magnesium and iron can freely substitute for each other. Tremolite is the mineral when magnesium is predominant; otherwise, the mineral is actinolite. It is generally not used commercially in the United States.

TSCA	**Toxic Substances Control Act** The Toxic Substances Control Act (TSCA) of 1976 was enacted by Congress to give EPA the ability to track the 75,000 industrial chemicals currently produced or imported into the United States.
TWF	**Time Weighting Factor** This factor accounts for less-than-continuous exposure during a year.
UCL	**Upper confidence limit**
UR	**Unit Risk**
Vermiculite	A chemically inert, lightweight, fire resistant, and odorless magnesium silicate material that is generally used for its thermal and sound insulation in construction and for its absorbent properties in horticultural applications. A major source of vermiculite is the mine in Libby, Montana, which has been demonstrated to contain various amounts of amphibole minerals.
Wipe sample	A wipe sample consists of using a wipe and a wetting agent that is wiped over a specified area using a template. The wipe picks up settled dust in the template area and provides an estimate of the number of fibers per area.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

AUG 10 2004

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

OSWER 9345.4-05

MEMORANDUM

SUBJECT: Clarifying Cleanup Goals and Identification of New Assessment Tools for Evaluating Asbestos at Superfund Cleanups

FROM: Michael B. Cook, Director
Office of Superfund Remediation and Technology Innovation

TO: Superfund National Policy Managers, Regions 1-10

Purpose

The purpose of this memo is twofold. The first purpose is to clarify that Regions should develop risk-based, site-specific action levels to determine if response actions should be taken when materials containing less than 1 percent asbestos (including chrysotile and amphibole asbestos) are found on a site. Regions should not assume that materials containing less than 1 percent asbestos do not pose an unreasonable risk to human health. The second purpose is to outline some activities underway to assist in the evaluation of asbestos risks at Superfund sites.

It is important to note that this memorandum is not a regulation itself, nor does it change or substitute for any regulations. Thus, it does not impose legally binding requirements on EPA, States, or the regulated community. This memorandum does not confer legal rights or impose legal obligations upon any member of the public. Interested parties are free to raise questions and objections about the substance of this memorandum and the appropriateness of the application of this memorandum in a particular situation. EPA and other decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from those described in this memorandum. The use of the word "should" in this document means that something is suggested or recommended, but not required.

Background

The 1 percent threshold for asbestos-containing materials was first used in the 1973 National Emissions Standards for Hazardous Air Pollutants (NESHAP), where the intent of the threshold was:

... to ban the use of materials which contain significant quantities of asbestos, but to allow the use of materials which would: (1) contain trace amounts of asbestos which occur in numerous natural substances, and (2) include very small quantities of asbestos (less than 1 percent) added to enhance the material's effectiveness. (38 FR 8821)

All subsequent EPA regulations and the Asbestos Hazardous Emergency Response Act Statute included this 1 percent threshold. In the 1990 NESHAP revisions, EPA retained the threshold, stating that it was related to the phase contrast microscopy (PCM) analytical method detection limits. The Occupational Safety and Health Administration (OSHA) Standards also defined an asbestos-containing material as a material containing more than 1 percent of asbestos[1] (29 CFR Part 1910.1001 and 29 CFR Part 910.134). The wide use of the 1 percent threshold in regulations may have caused site managers to assume that levels below the threshold did not pose an unreasonable risk to human health. However, it is important to note that the 1 percent threshold concept was related to the limit of detection for the analytical methods available at the time and also to EPA's prioritization of resources on materials containing higher percentages of asbestos.

<u>Issue</u>

Currently, many site managers continue to employ the use of the 1 percent threshold to determine if response actions for asbestos should be undertaken. However, based upon scientific discussions and findings reported by EPA and ATSDR from the Libby, Montana Superfund site, as well as EPA's "Peer Consultation Workshop on a Proposed Asbestos Cancer Risk Assessment[2]," there may be confusion regarding the appropriate use of the 1 percent threshold at Superfund sites. This concern was discussed at EPA's "Asbestos Site Evaluation, Communication, and Cleanup Workshop[3]," and it was concluded that the 1 percent threshold for asbestos in soil/debris as an action level may not be protective of human health in all instances of site cleanups. The 1 percent threshold is not risk-based and an accurate exposure value could only be determined through site sampling techniques that generate fibers from soil and bulk samples. Therefore, we recommend the development of risk-based, site-specific action levels to determine if response actions for asbestos in soil/debris should be undertaken.

Recent data from the Libby site and other sites provide evidence that soil/debris containing significantly less than 1 percent asbestos can release unacceptable air concentrations of all types of asbestos fibers (i.e., serpentine/chrysotile and amphibole/tremolite). The most critical determining factors in the level of airborne concentrations are the degree of disturbance, which is associated with the level of activity occurring on the site, and the presence of complete exposure pathways. For example, activities such as excavation or plowing generate large amounts of dust that can result in the generation of airborne fibers that can be inhaled even from a complex soil matrix. To address this evolving issue, OSRTI will be hosting a review of methods for determining conversion of soil to air concentrations in 2004.

Future Action

OSRTI has formed three technical working groups to assist in developing guidance and policy relating to risk assessment, field sampling, and analytical methods. These working groups have already contributed to a new toolbox that is located on the EPA Intranet. The location of the tool box is http://intranet.epa.gov/osrtinet/hottopic.htm.

The toolbox will be continually updated as products are developed and will eventually contain information on risk assessments, generic site sampling, and analytical approaches for asbestos cleanup projects. In the interim, numerous site reports that discuss specific concerns and issues from current asbestos site actions are contained in the toolbox. Additionally, to facilitate the development of sampling plans, there are examples of approved site sampling plans with data quality objectives, and a list of asbestos analytical laboratories which have passed an EPA audit.

Our goal is to have the majority of the guidance and policy documents prepared by the end of this year. If you have any questions, please consult with Richard Troast of my staff, who is the lead scientist within OSRTI for asbestos. He can be reached at (703) 603-8805 or by e-mail at: troast.richard@epa.gov.

cc:

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Endnotes:

1. Pursuant to industry comments, the 1994 amendments to the OSHA Standards incorporated a definition of asbestos-containing material that included the 1 percent threshold to be consistent with EPA, and noted that the National Institute for

Occupational Safety and Health (NIOSH) had raised questions whether even one percent may be below the accuracy level for certain microscopic methods. However, OSHA's Hazard Communication Standard requires a Material Safety Data Sheet (MSDS) to be prepared by the manufacturer or importer of a chemical substance, mixture, or product containing more than 0.1 percent of any carcinogen, including asbestos. Additionally, OSHA has recently issued several letters stating that some of the requirements in the OSHA Asbestos Construction Standard (29 CFR 1926.1101) do cover materials containing less than one percent asbestos.

2. USEPA's *Peer Consultation Workshop on a Proposed Asbestos Cancer Risk Assessment* was held in San Francisco, California on February 25-27, 2003. The purpose of the workshop was to discuss the scientific merit of the proposed methodology developed for EPA by Dr. Wayne Berman and Dr. Kenny Crump. The proposed methodology distinguishes carcinogenic potency by asbestos fiber size and asbestos fiber type and advocates use of a new exposure index to characterize carcinogenic risk. Proceedings from this conference can be located at: http://www.epa.gov/superfund/programs/risk/asbestos/index.htm.

3. USEPA's *Asbestos Site Evaluation, Communication and Cleanup Workshop* was held in Keystone, Colorado on September 23-26, 2003. The purpose of the workshop was to provide an opportunity to share lessons learned from working on large sites contaminated with asbestos. The meeting was also used to identify key outstanding technical and policy issues, and to begin to develop a consistent approach to measuring "success", especially short-term impacts and long-term risk reduction. Proceedings from this conference can be located at: http://www.epa.gov/superfund/programs/risk/asbestos/workshop/index.htm.

Appendix C – Analytical Methods for Determination of Asbestos in Air, Soil, and Dust Samples

Introduction:

Characterization of potential human exposure to asbestos generally involves analytical testing using contemporary methodologies that afford: (1) accurate identification of fibrous material present in sample media, (2) accurate and precise quantitative results, (3) reproducibility among multiple testing laboratories, (4) flexibility, (5) consensus acceptance of the method among asbestos professionals, and (6) cost effectiveness. Keeping these six parameters in mind, EPA has reviewed the extensive number of published and in-house asbestos analytical methods and selected what are believed to be the most appropriate methods to use for investigating Superfund sites that may be contaminated with asbestos. EPA and others are continuing research efforts to improve upon the current analytical methods, and to develop new methods to better understand the more complex asbestos-related issues that are facing the scientific community. Each of EPA's recommended analytical methods for air, soil, and dust media are summarized below. Analysis of asbestos in aqueous media is not address in this appendix because ingestion of asbestos via drinking water has not historically been considered an important exposure route when compared to inhalation. The release of asbestos from soil and dust to the air is thought to be the primary route of exposure, and warrants inclusion of a methodology for soil and dust analyses. The methods detailed below are for Superfund investigations; their applicability to regulatory assessment (e.g., worker protection under OSHA regulations) or for natural or man-made disasters should be evaluated on a case by case basis.

Air Media:

ISO 10312:

EPA/OSWER recommends the International Organization for Standardization (ISO) method 10312:1995(E) "Ambient air – Determination of asbestos fibers – Direct-transfer transmission electron microscopy method" for sampling at Superfund sites. While this method was published for ambient air monitoring, it is applicable to general air monitoring activities (e.g., activity-based sampling (ABS), indoor air monitoring, etc.). The method includes detailed procedures to prepare and analyze air samples using Transmission Electron Microscopy (TEM). Few details are specified in the method as to how to collect samples (other than describing the types of air collection filters that are applicable to the method). ISO 10312 is similar to the method referenced in 40 CFR Part 763, referred to as the AHERA Method. However, the AHERA method differs from the ISO method in the manner in which fibers and fiber bundles are counted and measured. The ISO method also allows recording of all fibers to inform future analysis should new toxicity models be developed. For these reasons, EPA/OSWER feels the ISO method to be a better format for performing assessment on Superfund sites.

Method Specifics:

Applicability: The ISO method is used for the determination of the concentration of asbestos structures in air samples, and includes measurement of the lengths, widths, and aspect ratio (ratio of length to width) of the asbestos structures. The method allows determination of the type of asbestos fibers present in a sample, but cannot discriminate between individual structures of asbestos and non-asbestos forms of amphibole minerals.

For this method (ISO 10312), a sample of air is collected. This is accomplished by using a pump to draw a specified volume of air across a filter to collect suspended asbestos fibers that are in the air. A key component to collecting an air sample to determine exposure is capturing airborne (suspended) asbestos from soil or settled dust. Soil can be suspended (airborne) by the activity being performed or by using an aggressive method (e.g., raking) for disturbing the soil while collecting the air sample. Settled dust can be suspended by the activity being performed or by using a modified-aggressive (e.g., fan) or aggressive method (e.g., leaf blower and fans) for disturbing the dust while collecting the air sample. When the testing is complete the sample cassette, which typically contains a mixed cellulose ester filter, is sent to the laboratory for analysis. Results are reported as the number of asbestos structures per cubic centimeter of air sampled.

Air samples can be collected using either polycarbonate (PC) or mixed cellulose ester filters (MCE), and the ISO method provides preparation techniques for both filter types. The collection efficiency of MCE filters has been questioned, even though MCE filters are used predominantly in industry. EPA is conducting studies to evaluate PC and MCE filters. The use of MCE filters for Superfund assessment will not be discouraged unless subsequent data are released indicating that MCE filters should not be used in asbestos sampling. The ISO method specifically calls for the use of MCE filters with a maximum pore size of 0.45 µm. However, many EPA sites require sampling in relatively dusty environments (e.g., ABS), and require large sample volumes to achieve sensitivity requirements. The 0.45 µm filters, due to their minute pore size, cause a high back pressure in the sampling train at flow rates above approximately 3 liters per minute that battery-operated personal sampling pumps are incapable of overcoming. Further, the 0.45 µm filters clog easily in dusty environments, and therefore cannot be used for direct analysis. Hence, EPA is recommending the use of 0.8 µm MCE filters for most Superfund applications (0.8 µm filters are specified for NIOSH Phase Contrast Microscopy [PCM] Method 7400 and may be used for the NIOSH TEM method, 7402). This recommendation is made after consultation with NIOSH and other asbestos experts as to their applicability.

Technique: There are three primary steps in a sample analysis by the ISO 10312 method: sample preparation, TEM calibration, and TEM analysis. These procedures will be briefly described.

1. Sample preparation: For MCE filters, a small area of the sample filter is placed onto a glass slide and “collapsed” with an acetic acid – dimethylformamide solution. Collapsing the filter concentrates fibers trapped in the filter on the upper surface of the filter. The slide and filter are then placed into a plasma etcher where a portion of the filter is etched away, further exposing fibers. The plasma etcher must be calibrated by the laboratory to ensure the proper amount of filter is removed. Too much etching will cause loss of fibers, and too little will result in fibers being “hidden” by filter media from view of the electron microscope. Note that the laboratory must keep accurate records of their plasma calibration processes. Following etching, the etched sample is placed in a vacuum controlled carbon coating device, where a thin layer of carbon is deposited onto the filter.

This process helps hold fibers in-place and allows for proper TEM examination. Finally, very small portions of the coated filter are cut away and individually placed onto a specially designed gold TEM grid. This grid is composed of small openings (referred to as grid openings) that are of uniform and measurable size. Each grid is composed of about 100 grid openings, the dimensions of which are to be measured and recorded by the laboratory during calibration. Each grid opening has an area of approximately 0.01 mm^2. The exact size, as measured by the laboratory, is used in the calculation of concentration of fibers on the sample filter.

2. Calibration: Three processes are used for asbestos identification by TEM; (1) electron microscopic visualization of the sample for determining dimensional measurements, (2) electron diffraction (ED) or selected area electron diffraction (SAED), where unique diffraction patterns of suspect fibers can be generated, and (3) energy dispersive X-Ray (EDX) analysis, where chemical makeup of the suspect fiber can be determined. Prior to sample analysis, the microscope and micro-analytical techniques (ED, SAED, EDX) must be calibrated or verified per the procedures detailed in the ISO method. These calibration procedures will not be discussed here (as they are in development), but it is important to understand that these calibration requirements are necessary to ensure the laboratory is reporting results accurately. The laboratory must keep accurate records of all calibration results for each TEM instrument. These records should be audited by any potential customer of the laboratory before samples are sent to the laboratory.

3. TEM Analysis: After calibration and sample preparation, sample grids can be analyzed by TEM. A grid preparation is placed into the sample chamber of the instrument and a vacuum is pulled. After instrument equilibration, the TEM analyst sets the instrument to the proper magnification (approximately 20,000 times magnification), centers the focus of the scope onto a grid opening, and begins a systematic back-and-forth visual observation of the grid opening looking for suspect asbestos fibers and fiber structures. Structures include bundles, clusters, and matrices, and are all to be recorded as described in the ISO method. This is probably the most significant difference between the ISO and AHERA methods. The AHERA method counts only the primary structures while ISO counts the components of the structures individually. Therefore, where primary structures are present in the sample, ISO provides a more comprehensive count for quantitative risk assessment purposes. Structures visually detected in a grid opening will be measured for length and width characteristics, and then will be analyzed for diffraction patterns and chemistry make-up using energy dispersive X-Ray analysis. Specifics on fiber measurement and identification are given below.

Fiber Measurement and Identification:

Under the ISO method, two specific counting schemes are detailed. The first scheme is more general and allows for the counting of fibers that are 0.5 µm in length or greater, and have aspect ratios of 5:1 or greater. In routine practice, TEM is able to resolve fibers down to approximately 0.1 µm in width, as compared to the resolution for routine PCM (0.25 µm). Therefore, short thin fibers that would not be detected using PCM will be detected using TEM under the general counting scheme. EPA recommends modification of the aspect ratio to 3:1 for this counting scheme. The other counting scheme allows for the counting of PCM equivalent fibers, or PCMe. Under this scheme, the analyst is to count fibers that are longer than 5 µm in length with aspect ratios of 3:1 or greater. PCMe fibers and structures under the ISO method also have a defined width range of between 0.2 µm and 3.0 µm. (Note that **EPA recommends a width range between 0.25 µm and 3.00 µm**, as recommended by World Health Organization [WHO, 1986].) The purpose of counting fibers as PCMe fibers is that the method is attempting to mimic the size fraction of fibers that would be detected if the sample were being run under PCM.

For risk calculations, the inhalation unit risk for asbestos was derived for PCM measurements, and IRIS includes a statement that it should not be applied directly to any other analytical techniques. However, the IRIS summary also acknowledges that use of PCM alone in environments which may contain other fibers may not be adequate (EPA 1988). Therefore, methods for counting PCM-equivalent (PCMe) structures have been designed so that fiber counts made with the two techniques (PCM and TEM) would be approximately equal. EPA recognizes there is some uncertainty associated with using PCMe fiber counts to calculate risk with the inhalation unit risk, but the amount of uncertainty is thought to be relatively small compared to other sources. Alternatively, the use of PCM in environments where other mineral or organic fibers are present is likely to contribute a much larger source of uncertainty. Thus, TEM is preferred to PCM for characterization of environmental exposures.

The TRW Asbestos Committee acknowledges the importance of characterizing the fiber size distribution and mineralogy of air samples at sites. Fiber size distribution and mineralogy data can only be obtained using TEM. These may be important in characterizing the sources of asbestos at a site and capturing information for the future (e.g., for assessing non-cancer health effects). Nevertheless, the TRW recognizes that PCM may be used for limited screening (e.g., where there is great uncertainty about the location of the contamination). If PCM analysis is chosen for the site, the TRW should be consulted, a subset of the samples should be analyzed by TEM to characterize fiber size distribution, and all filters should be archived for possible later re-analysis. In addition, only TEM is able to differentiate asbestos from other fibers. For the PCM-based screening approach, many samples are taken from a large area of a site (PCM is a cost effective approach appropriate for screening) and a subset of samples are then confirmed by a more definitive technique (TEM). This is consistent with the current standard practice for site characterization. It is anticipated that the PCM-based screening approach will be the exception rather than the rule for most asbestos sites, particularly for pre-NPL work (SI, Removal, State collaborations) because TEM is the preferred analytical method for characterization of environmental exposures.

As a TEM analyst visually detects a structure that morphologically resembles an asbestos mineral, further identification is required for confirmation. The ISO method details the process of performing electron diffraction analysis on a structure. This is a technique by which the crystal structure of a fiber is examined. As chrysotile and many amphiboles have unique diffraction patterns, identification information can be gleaned from this analysis. The ISO method also details the use of energy dispersive X-ray analysis, which gives the chemical make-up of the fiber being analyzed. By applying visual observation, electron diffraction and X-ray analysis on a percentage of the fibers detected in each grid opening, a reasonable identification of each fiber can be obtained. It should be noted that it is extremely important that the laboratory keep accurate documentation relative to electron diffraction and X-ray analyses. With today's techniques in digital photography, a laboratory should have the ability to photograph electron diffraction patterns and a photograph or digital representation of the fiber's X-ray pattern. A laboratory should be able to make these available upon request.

Quantitative analysis:

Results of an analysis can be reported in two ways. One is to report the number of asbestos structures found per square mm of an effective filter media. The formula for this is

$[A / (B \times C)] \times 385\ mm^2$

where:

A is the number of structures detected
B is the measured size of one grid opening (mm^2)
C is the total number of grid openings analyzed
385 mm^2 is the effective area of a 25 mm sample filter

The more common way to report results is to report concentration of asbestos as structures per cubic centimeter of air sampled. For this calculation, one would take the result of the formula above and divide by 1,000,000.

Example: if 1 asbestos structure was detected in a 1000 liter air sample, and 10 grid openings, each of which is 0.01 mm^2, were analyzed, the concentration of asbestos in the air sample would be:

$$\frac{\frac{1}{0.01 \times 10} \times 385}{1{,}000{,}000} = 0.0039\, s/cc$$

An important thing to remember about TEM analysis is that results are statistical. Because of the extreme magnification of TEM, analysis of the entire 385 mm^2 area of a filter would be extremely resource intensive and costly. Therefore, a representative area of a filter is analyzed, and the final results are extrapolated to the entire filter. This interpolation is only valid if there is uniform distribution of fibers onto the sample filter. There is historical evidence that under proper air sampling procedures, asbestos fibers will be distributed relatively uniformly onto a sample filter, even though there is to be expected some variability in the number of asbestos fibers, or fiber clusters, found in separate grid openings. Because of this, the TRW Asbestos Committee recommends that for any asbestos analysis, the laboratory must analyze a minimum of 10 grid openings. The laboratory must inspect multiple grid openings to detect anomalies in particulate and fiber distribution (e.g., an analyst should generally not find 20 fibers in one grid opening and 0 fibers in an adjacent grid opening). Additionally, the ISO method requires a low magnification examination of the grid preparations to establish the acceptability of specimen grids. If anomalies in fiber distribution are detected, the laboratory should qualify the results for the sample as estimated. The ISO method can be implemented to report the results and include detailed tables and instructions on how to calculate confidence levels for each sample analyzed. This level of detail may be important when considerations of required sensitivity levels relative to site-specific air action levels need to be made.

NIOSH/OSHA PCM:

PCM is a low magnification (up to 400 times magnification) optical microscopic technique used primarily for OSHA worker protection asbestos regulations. The regulatory guidance and details of the OSHA method are given in 29CFR part 1915.1001, Appendix A. NIOSH publishes a similar method (NIOSH 7400/7402) that may be used for OSHA compliance, as well as an analytical technique in general research on asbestos-related human health issues. These two methods are limited to analysis of air samples collected on 0.45 µm to 1.2 µm MCE filters. Typically, 0.8 or 0.45 micron filters are employed. The PCM method is limited in capability as the technique can only distinguish fibrous material from non-fibrous material. The technique cannot distinguish asbestos fibers from organic fibers (e.g., hair), and is limited in its ability to distinguish asbestos fibers from vitreous fibers (i.e., glass), as the optical characteristics (refractive index, etc.) cannot be determined by PCM. In addition, various forms of amphibole asbestos cannot be distinguished from one another, nor can chrysotile be easily distinguished from asbestiform amphibole in a complex mixed asbestos matrix. The method is also limited in the fact that only fibers that have diameters >0.25 µm can be detected. Specific method protocols mandate that only fibers that are ≥5 µm in length and that have aspect ratios of ≥3:1 are counted (NIOSH counting rules "B" do allow for using an aspect ratio of 5:1, even though 3:1 is preferred by NIOSH). Counting rules for both the NIOSH and OSHA methods usually count bundles as only one fiber, thus underestimating fiber concentrations relative to the ISO 10312 method.

Soil Media:

Currently no fully validated methods exist for accurate and precise quantitative measurement of asbestos in soil media below concentrations of about 0.25%. EPA has performed studies on soil media using a site-specific methodology incorporating both PLM[11] and electron microscopy techniques. The results indicate the PLM method to be quantitative at 0.5% and higher, and the electron microscopy technique to be unreliable. The inability to produce or obtain samples of known asbestos concentrations below 0.5%, of sufficient homogeneity to perform validated analysis renders both PLM and TEM soil analysis techniques ineffective below approximately 0.25%.

The California Air Resources Board (CARB) developed the CARB 435 method in 1991 for the analysis of asbestos fibers in aggregates, including serpentine rock aggregates. The method is undergoing revision, which includes a multi-lab validation study to examine variability among laboratories. EPA is recommending the use of the CARB 435 method as a qualitative screening method for determination of presence or absence of asbestos in soil during initial phases of a site assessment.

[11] PLM allows for rapid identification of fibrous materials; however, the resolution of the microscope limits identification of fibers finer than about 1 µm in diameter. Also, PLM suffers from significant bias for low concentration samples, especially below 1%.

The CARB method protocol incorporates crushing and grinding of rock aggregate, and then sieving (200 mesh) to generate a relatively homogeneous material of sufficient particle size to include asbestos fibers. For performing analysis on soil media, the crushing step may be omitted. Samples should not be crushed or pulverized below 250 µm. CARB has identified the Braun-type mill as the appropriate equipment for preparation. The soil sample is ground to achieve particle size consistency, sieved and dried, then analyzed for asbestos using a polarizing light microscope equipped with a specialized ocular for performing point count analyses. In EPA studies, it was found that visual estimation of asbestos concentration was more accurate than point counting; therefore, a client may have a laboratory modify the CARB method to include visual estimation or conduct the point count and require a field of view report of asbestos structures. For identification purposes, the analyst will perform various observations of potential asbestos fibers with PLM. The analyst will note morphological characteristics of fibers such as length, width, and aspect ratio (current CARB method requires counting fibers with a 3:1 and greater aspect ratio, even though minimum lengths and widths are not specified), as well as optical characteristics, such as color, birefringence, extinction angle characteristics, and refractive index. Chrysotile and the amphibole asbestos fibers have unique morphological and optical characteristics that will lend to their identification. Specific characteristics identifiable to each asbestos species are listed in the CARB 435 method.

Settled Dust Media:

For indoor measurement of asbestos collected in dust samples, ASTM Method D5755-95, Standard Test Method for Micro-vacuum Sampling and Indirect Analysis of Dust by Transmission Electron Microscopy for Asbestos Structure Number Concentrations, is recommended by EPA. The method, commonly referred to as the microvacuum method is used for general testing of non-airborne dust samples. It is used to assist in the evaluation of dust that may be found on surfaces in buildings such as ceilings, floor tiles, shelving, duct work, carpet, etc. The method provides an index of the concentration of asbestos structures in the dust per unit area sampled.

This method describes a technique in which a dust sample is collected by vacuuming a known surface area with a standard 25 or 37 mm air sampling cassette using a plastic tube attached to the inlet orifice of the cassette which acts as a nozzle. The ASTM method specifies use of an air velocity of 100 cm/s, which is calculated based on an internal sampling tube diameter of 6.35 mm at a flow rate of 2 L/minute. The amount of suction used is very minimal (i.e., 2 L/minute) and does not compare to what a normal household vacuum would create. Additionally, the area is "vacuumed" using tubing with an opening that is 6.35 mm (much smaller than a normal vacuum cleaner). ***In essence, a microvacuum sample is really an air sample that is collected over a specific area, rather than for a specific volume of air.*** Results are reported as the number of asbestos fibers per unit area.

The sample is transferred from inside the cassette to an aqueous solution of known volume. Aliquots of the suspension are then filtered through a 25 mm MCE or PC filter. The filters are then dried and a portion of each filter is prepared for TEM analysis using a procedure similar to that detailed in the ISO 10312 method. The calibration and operation of the TEM, and structure identification procedures for the ASTM method are also similar to the ISO method. However, the counting protocols for the ASTM method are identical to those required for the AHERA protocol. Technically, one could request the laboratory to "bin" the ASTM structures according to defined structure size requirements, such as PCMe structures, even though the ASTM method does not mention the flexibility to do so.

The ASTM method is referred to as an "indirect method" of analysis. This is because asbestos structures and other particles are "washed off" the vacuum filter via an aqueous transfer. Only an aliquot of the resulting aqueous wash is then transferred to the MCE or PC filter for final preparation for TEM analysis. A typical analysis using the ASTM method calls for the transfer of material from the vacuum filter with 100 mL of water. A 10 mL aliquot is taken from this for final analysis. This results in a 10–fold dilution of sample. The "on filter" concentration of asbestos for the ASTM method is calculated in the same manner as the ISO 10312 method, with the exception that the 10 times dilution factor must be incorporated into the ASTM result. Using this convention, the ASTM method would then be considered to give a result 10 times less sensitive than the ISO method. For example, if one asbestos structure were detected in 10 grid openings, each of which is 0.01 mm^2 in area, the ISO method would result in an on-filter concentration of 3850 s/mm^2, whereas the ASTM method would result in an on-filter concentration of 38500 s/mm^2. Sensitivity could be potentially increased in the ASTM method by analyzing larger aliquots of aqueous sample. However, this would also raise the amount of non-asbestos interference material in the sample and could result in a TEM grid that is overloaded and could not be analyzed. The ASTM method references the sensitivity of the method at about 1000 s/cm^2 of surface area vacuumed. The 38500 s/mm^2 on-filter concentration calculated above is equivalent to a final surface area concentration of 385 s/cm^2 of surface area vacuumed (with respect to the standard 100 cm^2 surface area). ASTM (2006) provides a statistical method to be used when counts are low (e.g., fewer than 5 structures) and recommends a method for determining asbestos detection limit. In brief, the ASTM method considers counting one asbestos structure equivalent to counting four structures. ***Note that with all indirect sample preparation techniques, the asbestos observed for quantitation may <u>not</u> represent the physical form of the asbestos as sampled. More specifically, the procedure described neither creates nor destroys asbestos, but it may alter the physical form of the mineral fibers and break up clusters and matrices.***

Conclusion:

Contemporary analytical testing methodologies should be employed in order to adequately characterize potential human exposure to asbestos at Superfund sites. The methodologies described above generally provide the following necessary information for Superfund site investigation: (1) accurate identification of fibrous material present in a sample media, (2) accurate and precise quantitative results, (3) reproducibility among multiple testing laboratories, (4) flexibility, (5) consensus acceptance of the method among asbestos professionals, and (6) cost effectiveness.

EPA and other agencies are continuing research efforts to improve current sampling and analytical methodologies, and to develop new methods to further the understanding of the more complex asbestos-related issues that are facing the scientific community. The methods presented herein generally are intended for Superfund investigations, and not necessarily for other regulatory venues such as worker protection under OSHA regulations.

Appendix D – Land Use Considerations

One of the critical elements in development of ABS typically is determining site-specific exposure scenarios based on land use. The evaluation of probable land use scenarios normally is an iterative process. Probable land use can be selected based on the land use of the site with reference to current and currently planned future land use and the effectiveness of institutional or legal controls placed on the future use of the land (Risk Assessment Guidance for Superfund; EPA 1989). For information regarding land use determinations, refer to OSWER Directive 9355.7-04 "Land Use in the CERCLA Remedy Selection Process" and similar directives.

Land use assumptions can be based on a factual understanding of site-specific conditions and reasonably anticipated use. The land use evaluated for the assessment can be based on a residential exposure scenario unless residential land use is not plausible for the site.

The basic or primary land use exposure scenarios for evaluation may include:

- Residential
- Commercial/Industrial
- Agricultural
- Recreational
- Excavation/Remediation (Short term exposure scenario)

The basic land use may be further divided and categorized as dictated by available information.

- Future land use assumptions should be consistent with the reasonably anticipated future land use.
- A range of land uses, and therefore exposure assumptions, may be considered, depending on the amount and certainty of information supporting a land use evaluation.
- Discussions with planning boards, appropriate officials, and the public, as appropriate, should be conducted as early as possible in the scoping phase of the project.
- Federal, State, and local facilities/property may have different land use considerations than private property because the future land use assumptions (e.g., agricultural, industrial, recreational, etc.) at sites which may be transferred to the public may be different than at sites where a governmental agency will be maintaining control of the facility.
- Numerous sources of information, including planning boards, master plans, flood zones, etc., can be utilized in making educated decisions regarding potential land use for a site. Land use assumptions may take into consideration the interests of all affected parties, including the local residents and State/Local governments.
- Land use issues are to be carefully documented and all assumptions clearly defined.

For asbestos sites, the future land use considerations listed above apply; however, additional consideration must be given to how the asbestos material could change in the future. Natural weathering and changes resulting from human activities may change the nature (fiber size distribution) and extent (spatial distribution) of asbestos contamination across the site. For example, subsurface asbestos may migrate to the surface over time.

Appendix E – Derivation of Cancer Unit Risk Values for Continuous and Less-Than-Lifetime Inhalation Exposure to Asbestos

1.0 OVERVIEW

As discussed in EPA (1986), excess cancer risk from inhalation exposure to asbestos is quantified in a two-step procedure:

Step 1: Derive Cancer Potency Factors

Potency factors are derived by fitting established risk models to data from available epidemiological studies in workers exposed to asbestos in workplace air. The potency factor for lung cancer is referred to as KL, and has units of $(f/cc\text{-}year)^{-1}$. The potency factor for mesothelioma is referred to as KM, and has units of $(f/cc\text{-}years^{3})^{-1}$.

Step 2: Implement Life Table Calculations

Potency factors are not equivalent to cancer unit risks. In order to compute the lifetime excess risk of lung cancer or mesothelioma to an exposed individual, it is necessary to implement a life-table approach. In brief, the exposure pattern for the exposed population is specified by indicating the concentration of asbestos in air, the age at which exposure begins and the age at which exposure ends. Based on this, the potency factors are used to compute the probability of dying from lung cancer or mesothelioma in each year of life. These probabilities of asbestos induced death are combined with the probability of death from all other causes to yield an estimate of the lifetime total probability of dying as a consequence of asbestos-induced cancer.

2.0 RISK ESTIMATES PROVIDED BY EPA (1986)

Based on epidemiological data available at the time, and expressing the concentration of asbestos in terms of PCM fibers per cc, EPA (1986) derived the following potency factors for lung cancer and mesothelioma:

Lung cancer: KL = 1E-02 $(\text{PCM } f/cc\text{-}years)^{-1}$
Mesothelioma: KM = 1E-08 $(\text{PCM } f/cc\text{-}years^{3})^{-1}$

Because these potency factors are based on occupational exposures (8 hours per day, 5 days per week), they must be adjusted for application to non-occupational settings. For evaluation of continuous exposure (24 hours per day, 7 days per week), EPA (1986) performed this adjustment as follows:

$$Adjustment\ Factor = \frac{24\ hours/day}{8\ hours/day} \bullet \frac{7\ days/week}{5\ days/week} = 4.2$$

Thus, the potency factors used by EPA (1986) for computing risks from continuous exposure were:

KL = 4.2E-02 (PCM f/cc-years)$^{-1}$
KM = 4.2E-08 (PCM f/cc-years^3)$^{-1}$

EPA (1986) utilized these potency factors to implement life table risk calculations for a number of alternative exposure scenarios. These scenarios all assume exposure occurs 24 hours per day, 7 days per week, but each scenario may begin and end at different ages. The results are provided in Table 6-3 of EPA (1986), which is reproduced here as Table E-1 of this Appendix. As seen, risks (expressed as asbestos-induced cancer deaths per 100,000 people) are provided for exposure to 0.01 PCM f/cc for a range of differing ages at onset (age at first exposure) and exposure durations, stratified by cancer type (lung cancer and mesothelioma) and by gender.

In this table, the exposure duration column labeled "LT" (lifetime) should be understood to mean the risk associated with exposure from the age at onset until death, either from asbestos-induced disease, or from any other cause of death.

3.0 RE-ADJUSTMENT OF EXTRAPOLATION FROM WORKERS TO CONTINUOUS EXPOSURE

In 1988, IRIS revised the method for extrapolation from workers to continuous exposure so that the factor was based on the ratio of the amount of air inhaled per day rather than the ratio of the exposure time per day. The risks associated with occupational exposure were adjusted to continuous exposure based on the assumption of 20 m^3 per day for total ventilation and 10 m^3 per 8-hour workday in the occupational setting:

$$Revised\ Adjustment\ Factor = \frac{20\ m^3/day}{10\ m^3/day} \cdot \frac{7\ days/week}{5\ days/week} = 2.8$$

Table E-2 presents the risk values for people with continuous exposure (24 hours per day, 7 days per year) after re-adjustment of the risk values presented in EPA (1986) by a factor of 2.8/4.2. For convenience, results are also averaged across gender and summed across cancer type. All values are shown to two significant figures.

4.0 DERIVATION OF UNIT RISK VALUES

4.1 Continuous Exposure

The risk values for people with continuous exposure (24 hours/day, 7 days/week) given in Table E-2 may be converted to unit risks by dividing by a factor of 100,000 (so that risks are expressed as cases per person), and dividing by the assumed exposure concentration of 0.01 PCM f/cc (so that risk is expressed as cases per person per f/cc). The results for the combined risk of mesothelioma and cancer in males and females combined are shown in Table E-3. As above, results are expressed to two significant figures.

Continuous Lifetime Unit Risk

Note that the unit risk for lung cancer and mesothelioma (combined) in an individual with continuous exposure from birth (age of onset = 0) for a lifetime is 0.23 (PCM f/cc)$^{-1}$. This is the unit risk value that is presented in IRIS. This value is applicable only to an individual with exposure from birth to death, and should not be used to evaluate risks to people whose exposures do not span a full lifetime.

Less-Than-Lifetime Unit Risks

Table E-3 gives the unit risk values for residents for a number of less-than-lifetime exposure scenarios. These should be used whenever the continuous exposure scenario of interest (age of onset and exposure duration) is represented in Table E-3. However, there may be a number of other exposure scenarios of interest to Superfund risk assessors that are not presented in this table. For example, no unit risk value is given for a resident who is exposed starting at birth and lasting 30 years (the usual assumption for an RME resident).

Ideally, unit risk values for residential exposure scenarios not already included in Table E-3 would be derived using the life table approach. However, EPA (1986) did not include the detailed mortality and smoking data needed to exactly reproduce the unit risk values reported. Therefore, as an alternative to regenerating the original life table analysis, the residential unit risk values in Table E-3 were plotted (see Figure E-1) and were fit to an equation of the following form:

$$UR_{a,d} = k1 \cdot [1-\exp(-k2 \cdot d)]$$

where:

$UR_{a,d}$	=	Unit risk for a continuous exposure beginning at age of onset "a" and extending for a duration of "d" years
k1 and k2	=	empiric fitting parameters derived from the data

This equation was selected to model the data because it arises from a value of zero when duration is zero, and plateaus as exposure duration approaches lifetime.

Both k1 and k2 depend on age at onset. These relationships are well characterized equations of the following form:

$$k1 = b1 + b2 \cdot \exp(-a / b3)$$
$$k2 = b4 + b5 \cdot \exp(-a / b6)$$

where b1 to b6 are empiric fitting parameters. The resulting best-fit parameters derived by minimization of the sum of the squared errors are summarized below:

Parameter	Value
b1	-0.0176401
b2	0.2492567
b3	24.7806941
b4	0.0415839
b5	0.0039973
b6	-18.2212632

These equations fit the data well, with an R^2 value of 0.9998 and an F-value of 21306.9. The root mean squared error (the average difference between the observed and predicted unit risk value) is 0.0008. Fitting the data using a commercial surface fitting software package did not yield any solutions that were superior.

These equations may be used to estimate unit risks for any continuous exposure duration of interest for any age of onset between zero and 50. For example, the unit risk for a resident exposed from age zero to age 30 is computed as follows:

$$k1 = -0.0176401 + 0.2492567 \cdot \exp(-0 / 24.7806941) = 0.232$$
$$k2 = 0.0415839 + 0.0039973 \cdot \exp(-0 / -18.2212632) = 0.0456$$
$$UR_{0,30} = 0.232 \cdot (1-\exp(-0.0456 \cdot 30)) = 0.17$$

Note that multiple significant figures are carried during the calculation, but that the final result is expressed to only two significant figures.

Also note that this value is substantially higher than would be derived using a simple time-based adjustment of the lifetime residential unit risk value reported in IRIS (0.23 • 30/70 = 0.099). This emphasizes the need to avoid simple linear interpolation in the derivation of less-than-lifetime unit risk factors for asbestos.

Table E-4 uses this mathematical approach to compute continuous (24 hours/day, 365 days/year) unit risks for a number of additional exposure scenarios of potential interest to Superfund risk assessors. In some cases there are minor differences in the value derived from the fitted equations and the values shown in Table E-3. This is due to minor discrepancies in the fitted mathematical surface (shown in Figure E-1) and the data used to define the surface. However, these differences are very small compared to the overall uncertainty in the unit risks values and should not be considered as cause for concern.

4.2 Less-Than-Continuous Exposure

As noted above, the unit risk values given in Table E-3 and E-4 are all based on the assumption that exposure is continuous (24 hours/day, 365 days/year) during the exposure period of interest. If exposure is less than continuous, this is accounted for by using the TWF approach described in Section 5.3. If exposure is continuous, the value of the TWF is, by definition, 1.0.

Example 1: Evaluation of Risks to Workers

When exposure of workers is to be evaluated, the TWF that should be used is simply the inverse of the adjustment factor of 2.8 that was used by IRIS (1988) to extrapolate from workers to continuous exposure:

$$TWF_{(worker)} = 1 / 2.8 = 0.357$$

If the worker worked for 25 years beginning at age 20, the appropriate unit risk factor (taken from Table E-4) would be:

$$UR_{20,45} = 0.069$$

Based on these two factors, the excess lifetime cancer risk would be computed as:

$$ELCR = C \bullet 0.357 \bullet 0.069$$

Example 2: Recreational Jogger

In this example, the goal is to compute the risks to an individual who is exposed by running on a jogging trail that is located in an area where the air is contaminated by asbestos from some local source. Assume that the time spent jogging through the contaminated area is 2 hours per run, and that jogging through the contaminated area occurs 80 days per year. Based on these assumed example values, the TWF for this scenario would be:

$$TWF = \frac{2\ hour/day}{24\ hour/day} \cdot \frac{80\ days/year}{365\ days/year} = 0.0183$$

Assume the person jogs starting at age 30 and continues for 30 years. The continuous unit risk for this scenario is 0.048 (see Table E-4).

The ELCR is then computed as:

$$ELCR = C \bullet 0.0183 \bullet 0.048$$

TABLE E-1
EXCESS CANCER RISKS FOR CONTINUOUS EXPOSURES
(Excess cancer deaths/100,000 people per 0.01 PCM f/cc)
Stratified by Disease and Gender (USEPA 1986 Table 6-3)

Mesothelioma in Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	14.6	67.1	120.8	196.0	275.2
10	9.4	42.6	75.5	118.7	152.5
20	5.6	25.1	43.5	65.7	78.8
30	3.1	13.3	22.4	31.9	35.7
50	0.6	2.1	3.2	3.9	3.9

Lung Cancer in Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	1.0	4.6	9.2	18.5	52.5
10	1.0	4.6	9.2	18.6	43.4
20	1.0	4.6	9.2	18.2	34.3
30	1.0	4.6	9.0	16.7	25.1
50	0.7	3.1	5.5	8.1	8.8

Mesothelioma in Males

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	11.2	51.0	91.1	145.7	192.8
10	7.0	31.2	58.2	84.7	106.8
20	4.1	17.5	30.1	44.5	51.7
30	2.1	8.8	14.6	20.4	22.3
50	0.3	1.1	1.8	2.0	2.1

Lung Cancer in Males

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	2.9	14.8	29.7	59.2	170.5
10	2.9	14.9	29.8	59.5	142.0
20	3.1	15.0	30.0	59.4	113.0
30	3.1	14.9	29.8	56.6	84.8
50	2.5	11.5	20.3	29.1	30.2

LT = Lifetime (from age of onset until death from any cause)

TABLE E-2
EXCESS CANCER RISKS FOR CONTINUOUS EXPOSURES
(Excess cancer deaths/100,000 people per 0.01 PCM f/cc)
Adjusted by Factor of 2.8 / 4.2

Mesothelioma in Males and Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	8.6	39.4	70.6	113.9	156.0
10	5.5	24.6	44.6	67.8	86.4
20	3.2	14.2	24.5	36.7	43.5
30	1.7	7.4	12.3	17.4	19.3
50	0.3	1.1	1.7	2.0	2.0

Lung Cancer in Males and Females

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	1.3	6.5	13.0	25.9	74.3
10	1.3	6.5	13.0	26.0	61.8
20	1.4	6.5	13.1	25.9	49.1
30	1.4	6.5	12.9	24.4	36.6
50	1.1	4.9	8.6	12.4	13.0

Total (Mesotheloma + Lung Cancer) -- Population Average

	Duration of Exposure				
Age at Onset	1	5	10	20	LT
0	9.9	45.8	83.6	139.8	230.3
10	6.8	31.1	57.6	93.8	148.2
20	4.6	20.7	37.6	62.6	92.6
30	3.1	13.9	25.3	41.9	56.0
50	1.4	5.9	10.3	14.4	15.0

TABLE E-3
UNIT RISK VALUES FOR CONTINUOUS EXPOSURES
$(PCM\ f/cc)^{-1}$

Mesothelioma in Males and Females

Age at Onset	Duration of Exposure				
	1	5	10	20	LT
0	8.6E-03	3.9E-02	7.1E-02	1.1E-01	1.6E-01
10	5.5E-03	2.5E-02	4.5E-02	6.8E-02	8.6E-02
20	3.2E-03	1.4E-02	2.5E-02	3.7E-02	4.4E-02
30	1.7E-03	7.4E-03	1.2E-02	1.7E-02	1.9E-02
50	3.0E-04	1.1E-03	1.7E-03	2.0E-03	2.0E-03

Lung Cancer in Males and Females

Age at Onset	Duration of Exposure				
	1	5	10	20	LT
0	1.3E-03	6.5E-03	1.3E-02	2.6E-02	7.4E-02
10	1.3E-03	6.5E-03	1.3E-02	2.6E-02	6.2E-02
20	1.4E-03	6.5E-03	1.3E-02	2.6E-02	4.9E-02
30	1.4E-03	6.5E-03	1.3E-02	2.4E-02	3.7E-02
50	1.1E-03	4.9E-03	8.6E-03	1.2E-02	1.3E-02

Total (Mesotheloma + Lung Cancer) in Males and Females

Age at Onset	Duration of Exposure				
	1	5	10	20	LT
0	9.9E-03	4.6E-02	8.4E-02	1.4E-01	2.3E-01
10	6.8E-03	3.1E-02	5.8E-02	9.4E-02	1.5E-01
20	4.6E-03	2.1E-02	3.8E-02	6.3E-02	9.3E-02
30	3.1E-03	1.4E-02	2.5E-02	4.2E-02	5.6E-02
50	1.4E-03	5.9E-03	1.0E-02	1.4E-02	1.5E-02

TABLE E-4

Extrapolated Unit Risk Values for Continuous and Less-Than-Lifetime[1] Exposures (PCM f/cc)

Age at Onset	Exposure Duration (years)																		
	1	2	3	4	5	6	8	10	12	14	16	20	24	25	30	40	50	60	LT
0	1.0E-02	2.0E-02	3.0E-02	3.9E-02	4.7E-02	5.5E-02	7.1E-02	8.5E-02	9.8E-02	1.1E-01	1.2E-01	1.4E-01	1.5E-01	1.6E-01	1.7E-01	1.9E-01	2.1E-01	2.2E-01	2.3E-01
1	9.9E-03	1.9E-02	2.8E-02	3.7E-02	4.5E-02	5.3E-02	6.8E-02	8.1E-02	9.4E-02	1.0E-01	1.2E-01	1.3E-01	1.5E-01	1.5E-01	1.7E-01	1.9E-01	2.0E-01	2.1E-01	2.2E-01
2	9.6E-03	1.9E-02	2.7E-02	3.6E-02	4.4E-02	5.1E-02	6.5E-02	7.8E-02	9.0E-02	1.0E-01	1.1E-01	1.3E-01	1.4E-01	1.5E-01	1.6E-01	1.8E-01	1.9E-01	2.0E-01	2.1E-01
3	9.2E-03	1.8E-02	2.6E-02	3.4E-02	4.2E-02	4.9E-02	6.3E-02	7.5E-02	8.7E-02	9.7E-02	1.1E-01	1.2E-01	1.4E-01	1.4E-01	1.5E-01	1.7E-01	1.8E-01	1.9E-01	2.0E-01
4	8.8E-03	1.7E-02	2.5E-02	3.3E-02	4.0E-02	4.7E-02	6.0E-02	7.2E-02	8.3E-02	9.3E-02	1.0E-01	1.2E-01	1.3E-01	1.3E-01	1.5E-01	1.6E-01	1.8E-01	1.8E-01	1.9E-01
5	8.5E-03	1.7E-02	2.4E-02	3.2E-02	3.9E-02	4.6E-02	5.8E-02	7.0E-02	8.0E-02	8.9E-02	9.8E-02	1.1E-01	1.3E-01	1.3E-01	1.4E-01	1.6E-01	1.7E-01	1.7E-01	1.9E-01
6	8.2E-03	1.6E-02	2.3E-02	3.1E-02	3.7E-02	4.4E-02	5.6E-02	6.7E-02	7.7E-02	8.6E-02	9.4E-02	1.1E-01	1.2E-01	1.2E-01	1.3E-01	1.5E-01	1.6E-01	1.7E-01	1.8E-01
7	7.9E-03	1.5E-02	2.3E-02	2.9E-02	3.6E-02	4.2E-02	5.4E-02	6.4E-02	7.4E-02	8.3E-02	9.1E-02	1.0E-01	1.2E-01	1.2E-01	1.3E-01	1.4E-01	1.5E-01	1.6E-01	1.7E-01
8	7.6E-03	1.5E-02	2.2E-02	2.8E-02	3.5E-02	4.1E-02	5.2E-02	6.2E-02	7.1E-02	7.9E-02	8.7E-02	1.0E-01	1.1E-01	1.1E-01	1.2E-01	1.4E-01	1.5E-01	1.5E-01	1.6E-01
9	7.3E-03	1.4E-02	2.1E-02	2.7E-02	3.3E-02	3.9E-02	5.0E-02	5.9E-02	6.8E-02	7.6E-02	8.4E-02	9.6E-02	1.1E-01	1.1E-01	1.2E-01	1.3E-01	1.4E-01	1.5E-01	1.6E-01
10	7.0E-03	1.4E-02	2.0E-02	2.6E-02	3.2E-02	3.8E-02	4.8E-02	5.7E-02	6.6E-02	7.3E-02	8.0E-02	9.2E-02	1.0E-01	1.0E-01	1.1E-01	1.3E-01	1.4E-01	1.4E-01	1.5E-01
11	6.8E-03	1.3E-02	1.9E-02	2.5E-02	3.1E-02	3.6E-02	4.6E-02	5.5E-02	6.3E-02	7.1E-02	7.7E-02	8.9E-02	9.8E-02	1.0E-01	1.1E-01	1.2E-01	1.3E-01	1.3E-01	1.4E-01
12	6.5E-03	1.3E-02	1.9E-02	2.4E-02	3.0E-02	3.5E-02	4.4E-02	5.3E-02	6.1E-02	6.8E-02	7.4E-02	8.5E-02	9.4E-02	9.6E-02	1.0E-01	1.2E-01	1.2E-01	1.3E-01	1.4E-01
13	6.3E-03	1.2E-02	1.8E-02	2.3E-02	2.9E-02	3.4E-02	4.3E-02	5.1E-02	5.8E-02	6.5E-02	7.1E-02	8.2E-02	9.1E-02	9.2E-02	1.0E-01	1.1E-01	1.2E-01	1.2E-01	1.3E-01
14	6.1E-03	1.2E-02	1.7E-02	2.3E-02	2.8E-02	3.2E-02	4.1E-02	4.9E-02	5.6E-02	6.3E-02	6.8E-02	7.9E-02	8.7E-02	8.9E-02	9.7E-02	1.1E-01	1.1E-01	1.2E-01	1.2E-01
15	5.9E-03	1.1E-02	1.7E-02	2.2E-02	2.7E-02	3.1E-02	3.9E-02	4.7E-02	5.4E-02	6.0E-02	6.6E-02	7.5E-02	8.3E-02	8.5E-02	9.3E-02	1.0E-01	1.1E-01	1.1E-01	1.2E-01
16	5.6E-03	1.1E-02	1.6E-02	2.1E-02	2.6E-02	3.0E-02	3.8E-02	4.5E-02	5.2E-02	5.8E-02	6.3E-02	7.2E-02	8.0E-02	8.2E-02	8.9E-02	9.8E-02	1.0E-01	1.1E-01	1.1E-01
17	5.4E-03	1.1E-02	1.6E-02	2.0E-02	2.5E-02	2.9E-02	3.7E-02	4.4E-02	5.0E-02	5.6E-02	6.1E-02	7.0E-02	7.7E-02	7.8E-02	8.5E-02	9.4E-02	1.0E-01	1.0E-01	1.1E-01
18	5.2E-03	1.0E-02	1.5E-02	1.9E-02	2.4E-02	2.8E-02	3.5E-02	4.2E-02	4.8E-02	5.3E-02	5.8E-02	6.7E-02	7.4E-02	7.5E-02	8.1E-02	9.0E-02	9.5E-02	9.8E-02	1.0E-01
19	5.1E-03	9.9E-03	1.4E-02	1.9E-02	2.3E-02	2.7E-02	3.4E-02	4.0E-02	4.6E-02	5.1E-02	5.6E-02	6.4E-02	7.1E-02	7.2E-02	7.8E-02	8.6E-02	9.1E-02	9.4E-02	9.8E-02
20	4.9E-03	9.5E-03	1.4E-02	1.8E-02	2.2E-02	2.6E-02	3.3E-02	3.9E-02	4.4E-02	4.9E-02	5.4E-02	6.2E-02	6.8E-02	6.9E-02	7.5E-02	8.3E-02	8.7E-02	9.0E-02	9.3E-02
21	4.7E-03	9.2E-03	1.3E-02	1.7E-02	2.1E-02	2.5E-02	3.1E-02	3.7E-02	4.3E-02	4.7E-02	5.2E-02	5.9E-02	6.5E-02	6.6E-02	7.2E-02	7.9E-02	8.3E-02	8.6E-02	8.9E-02
22	4.5E-03	8.8E-03	1.3E-02	1.7E-02	2.0E-02	2.4E-02	3.0E-02	3.6E-02	4.1E-02	4.6E-02	5.0E-02	5.7E-02	6.2E-02	6.3E-02	6.9E-02	7.6E-02	8.0E-02	8.2E-02	8.5E-02
23	4.4E-03	8.5E-03	1.2E-02	1.6E-02	2.0E-02	2.3E-02	2.9E-02	3.5E-02	3.9E-02	4.4E-02	4.8E-02	5.4E-02	6.0E-02	6.1E-02	6.6E-02	7.2E-02	7.6E-02	7.8E-02	8.1E-02
24	4.2E-03	8.2E-03	1.2E-02	1.6E-02	1.9E-02	2.2E-02	2.8E-02	3.3E-02	3.8E-02	4.2E-02	4.6E-02	5.2E-02	5.7E-02	5.8E-02	6.3E-02	6.9E-02	7.2E-02	7.4E-02	7.7E-02
25	4.1E-03	7.9E-03	1.2E-02	1.5E-02	1.8E-02	2.1E-02	2.7E-02	3.2E-02	3.6E-02	4.0E-02	4.4E-02	5.0E-02	5.5E-02	5.6E-02	6.0E-02	6.6E-02	6.9E-02	7.1E-02	7.3E-02
26	3.9E-03	7.7E-03	1.1E-02	1.4E-02	1.8E-02	2.1E-02	2.6E-02	3.1E-02	3.5E-02	3.9E-02	4.2E-02	4.8E-02	5.2E-02	5.3E-02	5.8E-02	6.3E-02	6.6E-02	6.8E-02	7.0E-02
27	3.8E-03	7.4E-03	1.1E-02	1.4E-02	1.7E-02	2.0E-02	2.5E-02	3.0E-02	3.4E-02	3.7E-02	4.1E-02	4.6E-02	5.0E-02	5.1E-02	5.5E-02	6.0E-02	6.3E-02	6.4E-02	6.6E-02
28	3.7E-03	7.1E-03	1.0E-02	1.3E-02	1.6E-02	1.9E-02	2.4E-02	2.8E-02	3.2E-02	3.6E-02	3.9E-02	4.4E-02	4.8E-02	4.9E-02	5.3E-02	5.7E-02	6.0E-02	6.1E-02	6.3E-02
29	3.5E-03	6.9E-03	1.0E-02	1.3E-02	1.6E-02	1.8E-02	2.3E-02	2.7E-02	3.1E-02	3.4E-02	3.7E-02	4.2E-02	4.6E-02	4.7E-02	5.0E-02	5.5E-02	5.7E-02	5.8E-02	6.0E-02
30	3.4E-03	6.6E-03	9.7E-03	1.2E-02	1.5E-02	1.8E-02	2.2E-02	2.6E-02	3.0E-02	3.3E-02	3.6E-02	4.0E-02	4.4E-02	4.5E-02	4.8E-02	5.2E-02	5.4E-02	5.5E-02	5.7E-02
31	3.3E-03	6.4E-03	9.3E-03	1.2E-02	1.5E-02	1.7E-02	2.1E-02	2.5E-02	2.9E-02	3.2E-02	3.4E-02	3.9E-02	4.2E-02	4.3E-02	4.6E-02	4.9E-02	5.1E-02	5.3E-02	5.4E-02
32	3.2E-03	6.2E-03	9.0E-03	1.2E-02	1.4E-02	1.6E-02	2.1E-02	2.4E-02	2.7E-02	3.0E-02	3.3E-02	3.7E-02	4.0E-02	4.1E-02	4.4E-02	4.7E-02	4.9E-02	5.0E-02	5.1E-02
33	3.1E-03	6.0E-03	8.7E-03	1.1E-02	1.4E-02	1.6E-02	2.0E-02	2.3E-02	2.6E-02	2.9E-02	3.1E-02	3.5E-02	3.8E-02	3.9E-02	4.2E-02	4.5E-02	4.6E-02	4.7E-02	4.8E-02
34	3.0E-03	5.7E-03	8.3E-03	1.1E-02	1.3E-02	1.5E-02	1.9E-02	2.2E-02	2.5E-02	2.8E-02	3.0E-02	3.4E-02	3.7E-02	3.7E-02	4.0E-02	4.2E-02	4.4E-02	4.5E-02	4.6E-02
35	2.9E-03	5.5E-03	8.0E-03	1.0E-02	1.3E-02	1.5E-02	1.8E-02	2.1E-02	2.4E-02	2.7E-02	2.9E-02	3.2E-02	3.5E-02	3.5E-02	3.8E-02	4.0E-02	4.2E-02	4.2E-02	4.3E-02
36	2.8E-03	5.3E-03	7.7E-03	1.0E-02	1.2E-02	1.4E-02	1.8E-02	2.1E-02	2.3E-02	2.5E-02	2.7E-02	3.1E-02	3.3E-02	3.4E-02	3.6E-02	3.8E-02	3.9E-02	4.0E-02	4.1E-02
37	2.7E-03	5.1E-03	7.5E-03	9.6E-03	1.2E-02	1.3E-02	1.7E-02	2.0E-02	2.2E-02	2.4E-02	2.6E-02	2.9E-02	3.2E-02	3.2E-02	3.4E-02	3.6E-02	3.7E-02	3.8E-02	3.8E-02
38	2.6E-03	5.0E-03	7.2E-03	9.2E-03	1.1E-02	1.3E-02	1.6E-02	1.9E-02	2.1E-02	2.3E-02	2.5E-02	2.8E-02	3.0E-02	3.0E-02	3.2E-02	3.4E-02	3.5E-02	3.6E-02	3.6E-02
39	2.5E-03	4.8E-03	6.9E-03	8.9E-03	1.1E-02	1.2E-02	1.5E-02	1.8E-02	2.0E-02	2.2E-02	2.4E-02	2.7E-02	2.8E-02	2.9E-02	3.0E-02	3.2E-02	3.3E-02	3.4E-02	3.4E-02
40	2.4E-03	4.6E-03	6.6E-03	8.5E-03	1.0E-02	1.2E-02	1.5E-02	1.7E-02	1.9E-02	2.1E-02	2.3E-02	2.5E-02	2.7E-02	2.7E-02	2.9E-02	3.1E-02	3.1E-02	3.2E-02	3.2E-02
45	1.9E-03	3.7E-03	5.4E-03	6.9E-03	8.2E-03	9.5E-03	1.2E-02	1.3E-02	1.5E-02	1.6E-02	1.7E-02	1.9E-02	2.0E-02	2.0E-02	2.1E-02	2.2E-02	2.3E-02	2.3E-02	2.3E-02
50	1.5E-03	2.9E-03	4.1E-03	5.3E-03	6.3E-03	7.2E-03	8.7E-03	1.0E-02	1.1E-02	1.2E-02	1.3E-02	1.4E-02	1.4E-02	1.4E-02	1.5E-02	1.5E-02	1.5E-02	1.5E-02	1.6E-02

FIGURE E-1
UNIT RISKS FOR CONTINUOUS EXPOSURES AS A FUNCTION OF AGE AT ONSET AND EXPOSURE DURATION