A Tiered Approach for the Assessment of the Human Health Risks of Asbestos in Soils

FRANK A. SWARTJES1 AND PETER C. TROMP2

1National Institute for Public Health and the Environment, Bilthoven, The Netherlands
2TNO Environment and Geosciences, Apeldoorn, The Netherlands

A tiered approach for the assessment of human health risks of soil contamination with asbestos has been developed. When in a specific tier the human health risk can not be rejected, the assessment in the following tier has to be performed. Because the risks of asbestos are caused by inhalation of asbestos fibers, the emission of fibers from soil to air is the determining factor. In Tier 0 of the tiered approach a generic soil quality standard is used. This Intervention Value is 100 mg/kg_{soil,\,dw} asbestos equivalents (0.01% by weight), i.e. the sum of the concentration of chrysotile asbestos and ten times the concentration of amphibole asbestos, for bound (non friable) as well as for friable asbestos. Tiers 1 to 3 are site-specific. Tier 1 concerns a simple qualitative testing procedure, in which the potential or probability for emission of asbestos fibers from soil to air is assessed. In Tier 2 the respirable fraction in the soil and house dust, which relates to the potential site-specific exposure to humans, is determined and tested. Finally, when the risk can not be excluded, the concentration of asbestos fibers in outdoor and/or indoor air has to be measured and tested according to a standardized procedure, in Tier 3.

Keywords Asbestos, soil contamination, Intervention Value, risk assessment, chrysotile, amphibole

1. Introduction

Asbestos is often found in the soil or on the soil surface. Therefore, it is essential to have a testing framework that permits assessment of risks related to the presence of asbestos in or on the soil. According to the Dutch Soil Protection Act, risks of soil contamination must be assessed on the basis of a generic soil quality standard (Intervention Value) and, if these values are exceeded, on the basis of a site-specific risk assessment (Swartjes, 1999). The risks of asbestos to the ecosystem are negligible. Risks of dispersal only occur through wind blow, not via leaching into the groundwater. The main concern of asbestos in soil is the risk to human health.

2. Procedure

To be able to assess the human health risks of asbestos in soil in a scientifically based and efficient way a tiered approach has been developed. This tiered approach is described in...
this paper. It contains the scientific foundation for the Intervention Value, used in Tier 0, and a procedure for site-specific assessment of soils contaminated with asbestos, as Tiers 1 to 3 of the tiered approach. Successively, in each tier the degree of conservatism decreases, while site-specificism increases. As a consequence, complexity and hence effort needed also increase in each tier. When in a specific tier the human health risks can not be rejected, the assessment in the following tier has to be performed. The underlying principle is: “simple when possible and complex when necessary.”

3. Human Health Risks

3.1. Human Health Criteria for Asbestos in Air

The risks after oral intake, i.e. cancer to the gastrointestinal tract, are assumed negligible. The major effects on human health after inhalation of asbestos fibers are (ATSDR, 1995):

- mesothelioma (cancer of the pulmonary membrane and peritoneum);
- asbestosis (brown lung disease);
- increased risks for bronchial carcinoma (lung cancer).

The latency period between first exposure to asbestos and the manifestation of a disease can be substantial, i.e. up to several decades. Acute (short-term) exposure to asbestos is considered irrelevant. The effects on human health depend on the type of asbestos (chrysotile or amphibole asbestos), dimensions (diameter and length) of the asbestos fibers, period of exposure, the durability and fissility of the asbestos fibers, the concentrations to which humans are exposed and individual human characteristics.

The Dutch Health Council considered the carcinogenic potency of fibers with a length smaller than 5 $\mu$m 10 times less than the carcinogenic potency of fibers with a length larger than 5 $\mu$m (Dutch Health Council, 1988). Besides, the carcinogenic potency of amphibole fibers were assumed 10 times higher than the carcinogenic potency of chrysotile fibers. This resulted in the following differentiated asbestos equivalent factors (related to a chrysotile fiber with a length $>5 \mu$m):

- 1 chrysotile fiber, length $>5 \mu$m: equivalence factor 1;
- 1 chrysotile fiber, length $<5 \mu$m: equivalence factor 0.1;
- 1 amphibole fiber, length $>5 \mu$m: equivalence factor 10;
- 1 amphibole fiber, length $<5 \mu$m: equivalence factor 1.

Besides, the Dutch Ministry of Housing, Spatial Planning and the Environment formulated human health quality objectives (Ministry of VROM, 1991). On the basis of the above-mentioned equivalence factors the following human health quality criteria in air were defined as yearly average values:

- Negligible Risk level: 1,000 fiber equivalents/m$^3_{air}$;
- Maximum Permissible Risk level: 100,000 fiber equivalents/m$^3_{air}$.

3.2. Human Exposure to Asbestos in Soil

3.2.1. Emission. Because the risks of asbestos are caused by inhalation of asbestos fibers, the emission of fibers from soil to air is the determining factor. The emission is strongly influenced by the characteristics of the asbestos-containing materials, like (the degree of) friability, the type of asbestos (chrysotile or amphibole) and the amount of respirable
fibers (fibers smaller than 200 µm) (Lee, 1985) in soil. In addition, emission of asbestos fibers depends on a large number of site-specific factors, which can be subdivided in soil characteristics, weather influences, indoor and outdoor activities on the site, and position and extent of the contamination (see Figure 1). The major soil characteristic is the humidity of the soil (Tromp, 2002; Addison et al., 1988).

Two types of exposure are relevant (see also Figure 1), i.e. inhalation of asbestos fibers in outdoor air (direct exposure) and inhalation of asbestos fibers in indoor air, after “tracking in” of asbestos fibers, possibly attached to soil particles (indirect exposure). The intensity of inhalation depends on residence time, human activity (breathing rate) and the height above soil level where inhalation takes place.

3.2.2. The CSOIL Exposure Model. With the CSOIL model (Van den Berg, 1995; Otte et al., 2001) the exposure of soil-born contaminants to humans that live, work, or recreate on a contaminated site can be calculated. The model is used for the derivation of the human health part of the remediation standards in The Netherlands, i.e. the Intervention Values and, in combination with measurements in the contact media, for the calculation of the site-specific exposure as the basis for the determination of the remediation urgency (Swartjes, 1999). However, there are at least two problems with the calculation of the human exposure to asbestos in soils using CSOIL:

- In CSOIL the calculation of the distribution of contaminants over the soil compartments is based on the fugacity theory (Mackay et al., 1985). Subsequently, transport of volatile contaminants from the pore water phase and the soil gas phase into (indoor and outdoor) air is calculated from convection-diffusion equations. Both elements, the fugacity theory and convective-diffusive transport, are not applicable to asbestos fibers.
- To assess the exposure to asbestos, the influence of the activity on the site and the humidity of the soil on the emission of asbestos into the air should be included at a minimum. However, these factors are not incorporated in the CSOIL exposure model.
Moreover, no reliable quantitative relationships are known between both factors and the respirable fiber concentration in the air.

4. Experimental Data

An inventory has been made of the measured asbestos concentrations in air from own experiments (Tromp, 2002) and data from the literature. The result of this inventory was a database of more than 1000 measured data. These data resulted from worst case simulation experiments (simulated activities using a wind blower with dry soil and loose asbestos fibers) and field experiments from daily practice activities (driving on contaminated roads and digging, dumping and sifting of humid soil with a mixture of friable and bound asbestos). During these activities air sampling was performed using both personal air samples (in the breathing zone of the workers) and stationary air samples near the activities. Most of the analyses were performed with scanning electron microscopy in combination with energy dispersive X-ray analysis (SEM/EDX) in conformity with ISO 14966 (ISO, 2002). The worst case simulation experiments were performed with known amounts of asbestos in soil. For most of the field experiments the average concentration of asbestos on the site was determined with a visual inspection and a soil sampling program according to the Dutch standard protocol NEN 5707 (NEN, 2003). The soil samples were dried and subsequently divided into sieve fractions. The separate sieve fractions were weighed and spread out into thin layers and inspected by stereomicroscopy for the presence of suspected asbestos containing particles and fiber structures. Using polarized light microscopy, these selected particles were analyzed for asbestos. On the basis of the weight of the sieve fractions and the asbestos containing materials and the estimated asbestos percentage in these materials, the total concentration of asbestos was calculated in mg/kg_{soil,dw}.

The results are presented in Figure 2, which shows the airborne asbestos concentration during the simulation experiments and field measurements with friable and bound asbestos (chrysotile and amphibole asbestos), as a function of asbestos concentration in soil. The fiber concentrations in this graph concern average values of several comparable measurements. Also the 95% confidence intervals of the average airborne asbestos concentrations of the comparable measurements are given.

Figure 2 shows that the average asbestos concentration increases with asbestos concentration in soil. However, the 95% confidence intervals are rather large. In the field experiments with friable asbestos, for example, the highest measured airborne concentration at a soil concentration of 100 mg/kg_{soil,dw} is higher than the lowest measured airborne concentration at a soil concentration of 10,000 mg/kg_{soil,dw}. In general, the worse case simulation experiments give higher airborne asbestos concentrations, while the field measurements with bound asbestos give, according to expectation, relatively low airborne asbestos concentrations. Besides, the following conclusions can be drawn from Figure 2:

- Fiber concentrations in the air exceeding the Maximum Permissible Risk level (100,000 fiber equivalents/m$^3_{air}$) are only found for highly contaminated soils, i.e. at soil concentration in excess of 10,000 mg/kg_{soil,dw}$^1$ (1%), and materials with

$^1$Actually, 100,000 fiber/m$^3_{air}$ is not exceeded at soil concentrations in excess of 100,000 mg/kg_{soil,dw} of asbestos fibers. However, a concentration of 100,000 fiber equivalents/m$^3_{air}$ (the Maximum Permissible Risk level) could theoretically be exceeded at a soil concentration of 10,000 mg/kg_{soil,dw} of asbestos, when all asbestos fibers concern amphibole fibers with a length $>$ 5 $\mu$m).
Figure 2. Average airborne asbestos concentrations from several comparable measurements (symbols) in fibers/m$^3$, and 95% confidence intervals (hyphens), from worst case simulation experiments (squares) and from field measurements with friable (diamonds) and bound (triangles) asbestos, as a function of asbestos concentration in soil. Straight lines represents the 95% confidence intervals of all data.

Friable asbestos. In such situations, even the slightest activity in combination with dry air (no worst case conditions) is sufficient to exceed the Negligible Risk level in the air (1000 fibre equivalents/m$^3$).

- For less contaminated soils with bound asbestos (less than 10,000 mg/kg$_{soil,dw}$ (1%)) no airborne asbestos fibers were found. For less contaminated soils with friable asbestos materials (less than 100 mg/kg$_{soil,dw}$ (0.01%)) the MPR risk level in the air is never exceeded and the NR level in the air is hardly exceeded. The same conclusion holds in case of activities such as digging, dumping and sifting.

In Figure 3 the average airborne asbestos fiber equivalent concentration with increasing distance to the emission source is given, calculated with the emission model PLUIIM-PLUS (TNO, 1989), for an asbestos concentration in soil of 100,000 mg/kg$_{soil,dw}$ and a corresponding airborne concentration near the source of approximately 10,000–100,000 fibers equivalents/m$^3$ (see Figure 2). The horizontal line in Figure 3 at an average airborne fiber concentration of 1000 equivalents/m$^3$ represents the Negligible Risk level. Although the emission model was validated for gasses, aerosols and particles smaller than 10 μm (PM$_{10}$), it is assumed to be suited for the calculation of airborne asbestos fibers, because analyses showed that the aerodynamic diameter of airborne fibers is always smaller than 10 μm. This assumption was validated using measurements in air in the vicinity of asbestos industrial activities in the Netherlands (Tempelman et al., 1981). Nevertheless, the PLUIIM-PLUS emission model is only used to have an indication of the influence of the distance to the source on the airborne asbestos concentration and not for the derivation of soil quality criteria.
From Figure 3 the following conclusions can be drawn:

- The airborne fiber concentration decreases sharply with distance and is generally lower than the Negligible Risk level at a distance of more than circa 100 meters from the source.
- Exceeding of the Maximum Permissible Risk level in air can virtually only be measured close to the asbestos source and with intensive activity, such as digging, dumping and traffic at the site.

Furthermore, experimental data on the relation between soil humidity and the relative asbestos emissions have been evaluated (Tromp, 2002; Addison et al., 1988; see Figure 4). Data of three experiments have been included in this graph, i.e. dust cloud simulation experiments with a sandy and an average soil (25% clay and 75% sand) and a laboratory experiment with a sandy soil.

From Figure 4 it can be concluded that the humidity of the soil and the type of soil have a substantial influence on the emission of asbestos fibers. In an outdoor situation in the Netherlands, a typical level of humidity of the soil is approximately 10%. Compared to dry soil, the airborne fiber concentration for a soil with humidity of 10% is more than 1 order of magnitude lower.

5. Generic Soil Standard (Tier 0)

According to the Dutch Soil Protection Act an Intervention Value, being a generic soil quality standard independent of land-use and human behavior on the site, is used to trigger
possible remediation (Swartjes, 1999). If the resulting average concentration exceeds the Intervention Value the site is labeled as “seriously contaminated.” This implies that the site in principle has to be remediated and the urgency of remediation has to be determined on the basis of a site-specific risk assessment.

5.1. Determination of Asbestos in Soil

When the presence of asbestos is suspected, a site survey has to be performed in which the asbestos concentration will be determined. The determination of asbestos in soil has to be performed in conformity with the Dutch standard protocol NEN 5707 (Tromp and Tempelman, 1994; NEN, 2003). All aspects of the soil survey have been included in these Dutch standards, i.e. investigation strategy, visual inspection, soil sampling and laboratory analyses. The survey includes the three following stages:

1. A preliminary survey. The objective of the survey is the formulation of a hypothesis about the nature and the spatial distribution of the contamination of asbestos in soil on the basis of historical information.
2. An exploratory survey. The objective of this survey is the verification of the hypothesis from the preliminary survey, with little effort of investigation. The survey consists of a visual inspection of the soil surface and random sampling combined with a visual inspection of the sampled soil.
3. An in-depth survey. The objective of this survey is the determination of the average concentration of asbestos in soil per spatial unit of 1000 m². The extent of the asbestos contamination is determined by means of an extended visual inspection of the soil surface and systematic sampling of the deeper soil layers, followed by laboratory analysis of the sampled soil.
5.2. History

In 1993, a so-called ad hoc Intervention Value\(^2\) for asbestos of 100 mg/kg\(_{\text{soil, dw}}\) up to 2000 mg/kg\(_{\text{soil, dw}}\)\(^3\) (0.01% – 0.2%) was derived in the Netherlands, depending on the type of asbestos. The shape and length of the asbestos fibers were not taken into account. It was concluded that the calculation with the CSOIL exposure model, which was the basis of this ad hoc Intervention Value, must be considered of limited significance. This ad hoc Intervention Value was never formalized. Alternatively, the zero-level was generally accepted in practice. In the Occupational Safety and Health Decree of 1999 (letter to the Dutch Parliament), the residual concentration standard for bound asbestos was increased from 0 to 10 mg/kg\(_{\text{soil, dw}}\). For friable asbestos the zero-level was maintained. This decision was based on the data available from the results of available experiments at that time, including a safety factor. Subsequently, the residual concentration standard was also declared applicable to the utilization and re-use of soil materials in de Ministerial Circular on Target and Intervention Values Soil Remediation (Ministry of VROM, 2000).

5.3. Intervention Value

In 2003 and 2004, an extended analysis of the experimental asbestos data, as described in chapter 4, was performed. From these data it can be concluded that with respect to the “standard” Dutch situation a suitable Intervention Value for friable asbestos is 100 mg/kg\(_{\text{soil, dw}}\) for the sum of the concentration of chrysotile asbestos (also serpentine asbestos or white asbestos) and 10 times the concentration of amphibole asbestos (other asbestos types). At this concentration, it is unlikely that the Negligible Risk level in air is exceeded, even under worst case conditions. The value of 100 mg/kg\(_{\text{soil, dw}}\) (asbestos equivalents) was incorporated in the interim policy on asbestos in soils, sediments, dredge materials and demolition waste (granules) (Ministry of VROM, 2002). A “standard” situation implies circumstances under which there are no systematic activities, like digging, dumping or sifting of soil material, and the (top) soil (layer) is relatively wet for most of the year.

In the case of bound asbestos, the concentration in the air will hardly ever exceed the Negligible Risk level. However, because it is difficult to determine when bound asbestos turns into friable asbestos due to aging (weathering and erosion), it was proposed to include this nuance in the site-specific risk assessment only. As a consequence, the above-mentioned value of 100 mg/kg\(_{\text{soil, dw}}\) (asbestos equivalents) is valid for bound as well as for friable asbestos. The value also applies to the residual concentration for the recycling of soil material, dredging and demolition waste (granules) and as criterion for remediation of roads and private property. The Intervention Value of 100 mg/kg\(_{\text{soil, dw}}\) (asbestos equivalents) was incorporated in the new Dutch soil policy on soil contamination (Ministry of VROM, 2006).

6. Site-Specific Risk Assessment (Tiers 1 to 3)

In this chapter a protocol is described for the assessment of site-specific human health risks in case of soil contamination with asbestos, with the purpose to determine the urgency of

\(^2\)An ad hoc Intervention Value is derived by the National Institute of Public Health and the Environment (RIVM) for a specific case for a contaminant for which no Intervention Value has been incorporated in the Ministerial Circular on Target Values and Intervention Values for soil remediation (Ministry of VROM, 2000). Such an ad hoc Intervention Value is only valid for this specific case and, hence, has a lower status; requirements to the scientific foundation and review procedure for ad-hoc Intervention Values are less strict.

\(^3\)In analogy with concentrations of other contaminants, the concentration of asbestos in soil is expressed as weight of asbestos per kilogram dry soil: mg/kg\(_{\text{soil, dw}}\).
Assessment of the Human Health Risks of Asbestos in Soils

remediation. Analogous to the Remediation Urgency Methodology for other contaminants, an unacceptable site-specific human health risk is assumed, unless there is evidence to the contrary (“risk, unless...”) (Swartjes, 1999). The protocol comprises three tiers (Ministry of VROM, 2004; Swartjes et al., 2003):

- Tier 1: simple qualitative testing: assessing the potential or probability of human exposure to asbestos;
- Tier 2: determinating and testing the respirable asbestos fraction in soil;
- Tier 3: measuring the concentration of asbestos fibers in outdoor and/or indoor air.

When in a specific tier the human health risks can not be rejected, the assessment in the following tier has to be performed. In case it can not be refuted in Tier 3, there is an unacceptable site-specific human health risk. The underlying principle of the tiered approach is: “simple when possible and complex when necessary.”

Since reliable qualitative relations between important site-specific parameters like wind velocity (distribution with depth) and activity on the site with soil to air fiber migration are lacking, no calculation procedures (like human exposure models) have been used in any of the three tiers.

The tiered approach has been incorporated in the new Dutch soil policy on soil contamination with the purpose to determine the urgency of remediation, on the basis of site-specific human health risks (Ministry of VROM, 2006).

6.1. Simple Qualitative Testing (Tier 1)

For simple qualitative testing in Tier 1 it is examined if exposure to asbestos fibers is possible or likely for the specific site. No additional experimental research has to be performed. The Tier 1 assessment can be performed on the basis of the measured asbestos concentration in soils, the condition of asbestos (bound or friable) and the layout of the location (type of soil surface, presence of buildings or vegetation, intended land development). When one or more of the following criteria are met, exposure to asbestos is impossible or unlikely and human health risks can be excluded:

- Asbestos is only present under buildings, paved areas or a water body (in sediment), on condition that no excavation or dredging activities are expected.
- Asbestos is present at a soil depth of more than 0.5 meter, on condition that no excavation activities are expected.
- The site is permanently, year round, completely covered with vegetation.
- For bound (non friable) asbestos only: the average soil concentration does not exceed \(1,000 \text{ mg/kg}_{\text{soil, dw}}\) (asbestos equivalents), on condition that the bound materials are not seriously weathered or eroded. The decision on the degree of erosion is subjective. However, in this simple testing procedure in Tier 1 a material is considered non-friable if it cannot be broken manually. For friable asbestos no additional simple testing is performed, because the same soil concentration as the Intervention Value \((100 \text{ mg/kg}_{\text{soil, dw}}\) asbestos equivalents) is used as criterion.

6.2. Determination of the Respirable Fraction in Soil (Tier 2)

Because the inhalation of asbestos fibers is the only relevant exposure route concerning human health, the potential of asbestos fibres in soil for inhalation is investigated in Tier 2, regardless whether or not the fibers actually are emitted into the air. To this purpose, a
distinction is made in respirable fibers and all other remaining forms of asbestos in soil. The upper dimension for respirability of fibers corresponds with a fiber diameter of 3 \( \mu \text{m} \) and a fiber length of 200 \( \mu \text{m} \) (ATSDR, 1995). Fibers smaller than these dimension are contributed to the respirable fraction. Since emission in needed for exposure trough inhalation, the respirable fraction relates to the potential site-specific exposure to humans, independent of actual site use or site-specific factors.

The determination of the respirable concentration of asbestos fibers in the upper soil layer takes place in conformity with the Dutch standard protocol NEN 5707 (Tromp and Tempelman, 1994). This standard describes a sedimentation procedure in water, in which the respirable fraction is separated from the coarse particles. Subsequently, the separated fraction is filtrated through a gold coated Nuclepore filter. This filter is analyzed with scanning electron microscopy in combination with energy dispersive X-ray analysis (SEM/EDX) in conformity with ISO 14966 (ISO, 2002).

When “tracking in” of asbestos fibers (attached to soil particles) to the indoor environment cannot be excluded, the amount of asbestos in house dust must additionally be determined. Since it is assumed that bound asbestos degrades by indoor human activity, both asbestos fibers and asbestos conglomerates are measured. The sampling of house dust takes place with adhesive tape on horizontal surfaces with visible dust. The analysis of deposited asbestos fibers in house dust takes place with SEM/EDX in conformity with the Dutch standard protocol NEN 2991 (NEN, 2005). For testing the amount of respirable fibers in soil or dust, a limit value of \( 4.3 \times 10^{10} \) fiber equivalents in soil is used. This value corresponds to a limit value of respirable fibers of 10 mg/kg soil, dw (asbestos equivalents) (Swartjes et al., 2003). For testing the amount of asbestos fibers and asbestos conglomerates in indoor dust, a limit value of 100 fibers/cm\(^2\) is used (NEN, 2005).

6.3. Measurement of the Concentration of Asbestos Fibers (Tier 3)

Tier 3 focuses on the actual presence of asbestos fibers in air. To this purpose the asbestos concentration in air has to be measured additionally.

6.3.1. Outdoor Air. For measuring the asbestos fiber concentration in outdoor air, two options are given:

- measurement of the concentration of asbestos fibers in the outdoor air at the site, under “standardized realistic worst case circumstances” (Tier 3\textsubscript{outdoors\textsubscript{a}});
- measurement of the concentration of asbestos fibers in a laboratory simulation, under worst case circumstances (availability test; Tier 3\textsubscript{outdoors\textsubscript{b}}).

Measurements in the outdoor air are performed at a height of 1.5 meters above the soil surface, during simulation of “daily practice activities” in the soil (digging, dumping and sifting). A worst case location at the site is selected according to the highest asbestos concentration in soil. During measurements the weather has to be dry, just like the three previous days, with a moderate wind speed as a minimum (wind velocity maximal 4 Beaufort).

Measurements in a laboratory simulation are performed in a 1–2 m\(^3\) test chamber. First, a worst case sample of the most contaminated location is taken to the laboratory. After drying the sample, the soil is spread out in the test chamber. During measurement, activity is simulated with a fan in such a way that the airspeed on the soil surface amounts to 3–5 meters/second.
Like in Tier 2, analyses of the asbestos fiber concentration are performed with SEM/EDX in conformity with ISO 14966 (ISO, 2002). For testing, a limit value of 1,000 fiber equivalents/m$^3_{\text{air}}$ is used, i.e. at the Negligible Risk level.

To facilitate the choice between these options, the advantages and disadvantages of both methods are listed in Swartjes et al. (2003). The major advantage of measurements on location is that this represents real life conditions. The biggest disadvantage is that the possibility for performance depends on weather conditions. Another disadvantage is the lack of a standardized protocol for the simulation of “daily practice activities.” For measurements during worst case laboratory simulations, it is the question if the results are representative for outdoor conditions. On the other hand, the testing procedure is simple, standardized (test results are comparable) and the performance is not hampered by weather conditions.

6.3.2. Indoor Air. The site-specific measurement of the concentration of asbestos fibers in indoor air (Tier $3_{\text{indoors}}$) should be performed in houses or other buildings adjacent (no more then 100 meters) to the contaminated site, only when the contamination includes friable asbestos. In that case, the concentration of asbestos fibers in indoor air should be measured under “standardized conditions,” in conformity with the Dutch standard protocol NEN 2991 (NEN, 2005) and ISO 14966 (ISO, 2002). Air samplers are located in room units in which an asbestos contamination of house dust is determined. Furthermore, preference is given to room units with high exposure potential (due to the location, accessibility, user activities, etc.). The duration of measurements is 6–8 hours and during measurements simulation of “daily practice activities” are performed. Again, for testing a limit value of 1,000 fiber equivalents/m$^3_{\text{air}}$ is used (Negligible Risk level).

7. Conclusions and Recommendations

7.1. Conclusions

A tiered approach for the assessment of human health risks of soil contamination with asbestos has been developed. In Tier 0 a generic soil quality standard (Intervention Value) is derived from measured data. This value is 100 mg/kg$_{\text{soil, dw}}$ asbestos equivalents (0.01% by weight), i.e. the sum of the concentration of chrysotile asbestos and ten times the concentration of amphibole asbestos, for bound (non friable) as well as for friable asbestos. Tiers 1 to 3 are site-specific. Tier 1 concerns a simple qualitative testing procedure, in which the potential or probability for emission of asbestos fibers from soil to air is assessed. In Tier 2 the respirable fraction in the soil and house dust, which relates to the potential site-specific exposure to humans, is determined and tested. Finally, when the risk can not be excluded, the concentration of asbestos fibers in outdoor and/or indoor air has to be measured and tested according to a standardized procedure, in Tier 3.

7.2. Recommendations

The following recommendations for further research in the future are given:

- An extended (international) database should be created containing soil and air concentrations, information on the type of asbestos and on the measurement conditions. To improve assessment of the emission of asbestos fibers, specific
supplemental measurements should be performed, particularly in the range of 100 en 10,000 mg/kgsoil,dw (0.01%–1%).

- In order to incorporate the influence of site-specific factors on human-health risks, further research or the relationship between soil and weather characteristics, activity on the site and the emission of asbestos fibers to the air should be investigated. Also the impact of changes in land-use on these factors, and hence on the emission of asbestos fibers to the air, must be investigated. The ultimate goal should be a qualitative description of the influence of these factors. Since it is doubtful whether the derivation of a quantitative description is possible, a feasibility study for the derivation of qualitative and quantitative relationships could be done first.

Furthermore, research should focus on the following topics:

- The influence of “tracking in” of asbestos fibers from soil to the indoor environment (attached to shoes and, to a lesser extent, to clothing) on indoor exposure and the influence of the material and soil characteristics such as soil humidity on this process.
- The transition of bound asbestos to friable asbestos (relevant processes/activities, time span).
- Evaluation of the quality and practical implementation of the measurement procedures for assessment of outdoor concentrations of asbestos fibers (at the site and through laboratory simulation) and of indoor concentrations of asbestos fibers, which are part of Tier 3 of the assessment of site-specific human health risks.

References


