ENSR

Columbia Gas Transmission Corporation

Charleston, West Virginia

Cleanup Action Levels for Mercury in Soils at Mercury Measuring Stations at Natural Gas Sites

ENSR Consulting and Engineering

August 1997

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EXECUTIVE SUMMARY

Columbia Gas Transmission Corporation (Columbia) has entered into an Administrative Order on Consent (AOC) with the United States Environmental Protection Agency (U.S. EPA) that requires characterization and response actions, where necessary, for the numerous major facilities and other sites associated with Columbia's natural gas system. As part of this agreement, Columbia has committed to an aggressive characterization and remediation program to address all of the mercury measuring stations (MMS) in its system within a three year period. The mercury measuring station work plan recently approved by EPA (on May 28, 1997) lists the mercury cleanup action level as 20 mg/kg.

This document presents a risk assessment and fate and transport analysis that demonstrates that this cleanup action level is protective of potential exposures that may occur as a result of mercury releases at MMS. The potential exposure pathways evaluated are:

- direct contact, for potential incidental ingestion of soil based on residential and industrial exposure scenarios;
- soil-to-groundwater, for potential use of underlying groundwater as a source of drinking water; and
- soil-to-air, for potential inhalation exposures by a pipeline worker.

U.S. EPA guidance and assumptions and U.S. EPA developed and approved environmental transport models were used in this analysis. Although the assessment was conducted to apply to MMS sites, the analysis was still very conservative in that it employed many health-protective assumptions. The cleanup action level of 20 mg/kg is considered to be conservative based on the following:

- Potential contact with soils at MMS are limited to pipeline workers. The 20 mg/kg cleanup action level is much lower than the U.S. EPA Region III industrial soil Risk-Based Concentration, or RBC, for mercury of 61 mg/kg, and is even lower than the residential soil RBC of 23 mg/kg. These RBCs are based on a direct contact (incidental soil ingestion) scenario.

- The analysis of the soil-to-groundwater and the soil-to-air pathways assumed a 5 m by 5 m by 1 m source area at an MMS (16 ft by 16 ft by 3.3 ft) having a uniform 20 mg/kg concentration of elemental mercury. Mercury spills at MMS are not uncommon, but are typically small scale, resulting from broken or spilled manometers, which generally hold less than 7 ounces of elemental mercury. The results of Columbia's pilot study of 242 MMS indicate that: at 60% of the sites, mercury was detected less than 5 feet (1.5 m) from the meter location; at 97% of the sites, mercury was detected less than 10 feet (3 m) from the meter location; and at 90% of the sites mercury was detected at less than 2 feet (0.6 m) in depth. Therefore, mercury in soil at typical Columbia MMS is located in a much smaller area than was assumed for the modeling analysis.

- Because of a lack of elemental mercury values in the scientific literature for parameters that describe interactions between mercury and soil and water, values for the very soluble compound mercury chloride were used. Thus the modeling has greatly overestimated the mobility of elemental mercury in both soil and groundwater.

- Using these conservative parameter values, modeling of mercury from a surface source of 20 mg/kg to a water table less than one meter below the source area would not result in mercury concentrations in groundwater above the federal drinking water standard (MCL) of 2 µg/L.

- Even if a mercury source were to be present in groundwater equal to the solubility of elemental mercury, 70 µg/L (an extremely unlikely scenario), groundwater concentrations would decrease to below the MCL within approximately 3.3 m (or 11 ft) downgradient of the source area.

- In addition to this modeling evaluation, previous field research performed by the Gas Research Institute evaluating soil and groundwater in the area of mercury releases associated with manometers at natural gas facilities shows no evidence of adverse environmental effects from the mercury in the immediate area of the release, even when no remedial actions have been performed.

Therefore, it is concluded that a concentration of 20 mg/kg of mercury in soil at MMS is a conservative, i.e., health protective, cleanup action level for use in the Columbia MMS program.

CLEANUP ACTION LEVELS FOR MERCURY IN SOILS AT MERCURY MEASURING STATIONS AT NATURAL GAS SITES

1.0 INTRODUCTION

Columbia Gas Transmission Corporation (Columbia) has entered into an Administrative Order on Consent (AOC) with the United States Environmental Protection Agency (U.S. EPA) that requires characterization and response actions, where necessary, for the numerous major facilities and other sites associated with Columbia's natural gas system. One group of sites addressed by the AOC is mercury measuring stations (MMS) where mercury filled manometers are or were used to measure the flow of natural gas. Manometers were used throughout the natural gas industry to monitor pressure and flow of natural gas at wellheads, metering sites along pipelines, and in other natural gas operations. The mercury used in manometers is elemental mercury (Hg^0). Mercury spills from these manometers are not uncommon. Mercury spills at these sites are typically small scale, resulting from broken or spilled manometers, which generally hold less than 7 ounces of elemental mercury.

In 1996, Columbia conducted a pilot study of MMS. A risk-based action level for mercury of 23 mg/kg, based on a residential exposure (U.S. EPA, 1997a), was used during the pilot program to determine the number of sites potentially requiring remediation. Of the 242 MMS evaluated under the pilot study, approximately 62% exhibited mercury concentrations in soils in excess of the action level. In response to these results, Columbia has committed to an aggressive characterization and remediation program to address all of the MMS in its system within a three year period. The mercury measuring station work plan recently approved by EPA (on May 28, 1997) lists the mercury cleanup action level as 20 mg/kg.

Columbia's MMS are located in 10 states in the mid-Atlantic region of the U.S. A review of standards and guidance levels for these states, where available, indicate that some state standards are below the 20 mg/kg cleanup action level being used in the Columbia program. Some state levels are as low as 3 ppm (Delaware) based on a soil-to-groundwater pathway. Standards are based on conservative assumptions that are not appropriate for the Columbia MMS program.

The purpose of the analysis presented here is to provide a sound technical basis for the conclusion that the 20 mg/kg cleanup action level for mercury being used to evaluate Columbia's MMS is appropriate and protective of health and the environment. In particular, this analysis includes a fate and transport evaluation of the soil-to-groundwater pathway. Columbia is committed to using a health risk-based approach in evaluating its MMS sites under the AOC. The cleanup action levels used in the program are risk-based. This analysis uses the basic steps of the risk assessment process, which are explained below.

1.1 Overview of the Risk Assessment Process

The four step paradigm of human health risk assessment as employed by the U.S. EPA (U.S. EPA, 1989) and state regulatory programs is as follows:

- Hazard Identification
- Toxicity Assessment
- Exposure Assessment
- Risk Characterization

In the hazard identification step of a risk assessment, the substances to be quantitatively evaluated are identified. In the toxicity assessment, the relationship between the magnitude of exposure (dose) and the occurrence of a specific heath effect (response) is evaluated. The exposure assessment addresses exposure pathways, and magnitude and frequency of potential exposure to substances in the environment that are used to calculate potential exposure doses. In the risk characterization, the results of the toxicity assessment are combined with the results of the exposure assessment to derive quantitative estimates of potential risk.

As stated earlier, the purpose of this assessment is to confirm that the 20 mg/kg cleanup action level is appropriate for use in all states in the AOC program. This type of analysis is not a conventional risk assessment that uses site data to calculate specific site-related risks. Therefore, the discussion of the risk assessment steps in the following sections focuses only on information that is relevant to this type of evaluation, and does not provide the level of detail required to perform a site-specific risk assessment.

The hazard identification step has been addressed by identifying elemental mercury (and related forms that sometimes occur upon release into the environment) as the chemical of interest. The toxicity assessment for mercury is discussed in Section 2. Sections 3 and 4 address the exposure assessment and risk characterization, respectively, for mercury at Columbia MMS. Section 4 also describes the derivation of cleanup action levels for mercury. Because the assumptions made about the movement of mercury in the environment are fundamental to some of the established or proposed federal and state standards or action levels for mercury, Section 5 presents a discussion of the fate and transport of mercury present at Columbia MMS and presents the results of several analytical models used to evaluate mercury fate and transport at

MMS. Section 6 presents an evaluation of potential inhalation exposures at MMS. Section 7 presents the summary and conclusions, and Section 8 provides references.

2.0 TOXICITY ASSESSMENT

The purpose of the toxicity assessment is to identify the potential adverse health effects a compound may cause, and to define the dose-response relationship. Potential adverse health effects are typically characterized by the U.S. EPA as either potentially carcinogenic or noncarcinogenic. The fundamentals of toxicity assessment are described below, followed by a review of the toxicity assessment as defined by U.S. EPA for various forms of mercury.

2.1 Fundamentals of Toxicity Assessment

This section summarizes the fundamental toxicological assumptions underlying the dose-response relationships established by U.S. EPA for potential noncarcinogenic effects and potential carcinogenic effects.

2.1.1 Noncarcinogenic Effects

Substances with known or potential noncarcinogenic effects are assumed to have a dose below which no adverse effect occurs or, conversely, above which an adverse effect may be seen. This dose is called the threshold dose. The U.S. EPA develops numerical values, reference doses (RfD) and reference concentrations (RfC), for use in human health risk assessment by applying uncertainty factors ranging from 10 to 10,000 to the threshold doses identified in animal or, in rare cases, human studies. Therefore, for substances with noncarcinogenic effects, an RfD or RfC provides reasonable certainty that the exposure dose it specifies is below the threshold and that no noncarcinogenic health effects are expected to occur at that exposure level even if daily exposure were to occur for a lifetime.

RfD values relate to oral and dermal exposure and are expressed in units of milligrams of substance per kilogram of body weight per day (mg/kg-day). Exposure to a substance at the RfD level every day for a lifetime is not expected to result in the occurrence of any adverse health effects. RfC values relate to inhalation exposure and are expressed in terms of milligrams of substance per cubic meter of air (mg/m^3). Exposure to a substance at the RfC level 24 hours per day, every day for a lifetime is not expected to result in the occurrence of any adverse health effects.

2.1.2 Carcinogenic Effects

The underlying assumption of regulatory risk characterization for substances with known or assumed potential carcinogenic effects is that no threshold dose exists. In other words, it is assumed that a finite level of risk is associated with any dose above zero, theoretically even a single molecule. The U.S. EPA has developed computerized models that extrapolate animal data to predict carcinogenic responses in humans in environmental situations. These models are used to develop a numerical estimate of the carcinogenic potency of a substance. This numerical estimate is referred to as a cancer slope factor (CSF).

2.2 Toxicity Assessment for Mercury

U.S. EPA has developed quantitative estimates of toxicity for both inorganic and organic forms of mercury. The inorganic forms addressed by U.S. EPA are elemental mercury and mercury chloride, and the organic form is methylmercury. Mercury chloride and methylmercury are both classified by U.S. EPA as possible human carcinogens (Group C), defined by U.S. EPA as based on limited or inadequate data in humans and limited data in laboratory animals (U.S. EPA, 1997b); U.S. EPA has questioned the significance of the animal study results. However, elemental mercury is not considered by U.S. EPA to be classifiable as to potential carcinogenicity (Group D) (U.S. EPA, 1997b). Neither animal studies nor human epidemiological studies have demonstrated elemental mercury to be carcinogenic.

U.S. EPA has developed an inhalation RfC for elemental mercury (0.0003 mg/m^3), an oral RfD for mercury chloride (0.0003 mg/kg-day), and an oral RfD for methylmercury (0.0001 mg/kg-day) (U.S. EPA, 1997b).

U.S. EPA has published a draft report entitled "Mercury Study Report to Congress" in which it has conducted an evaluation of anthropogenic mercury emissions in the U.S. (U.S. EPA, 1996c). EPA has reviewed the available data for methylmercury and has endorsed the current RfD for methylmercury of 0.0001 mg/kg-day. It should be noted that two epidemiological studies are currently underway to assess the effects of dietary consumption of fish containing methylmercury; however, the results of these studies are not yet available and it is uncertain as to how these data may affect the calculation of the RfD for methylmercury. It is not expected that the toxicity values for inorganic mercury will be affected by these studies.

The focus of this analysis is on spills of elemental mercury at MMS. As discussed in Section 5 below, the conversion of elemental mercury to mercury(II) forms, such as mercury chloride, will likely be insignificant, and the conversion of mercury(II) to organic forms of mercury is also small in nonaquatic soil environments, and can only occur in the presence of certain bacteria.

Therefore, for this analysis, it will be assumed that the mercury at MMS is inorganic mercury and that the great majority of the mercury at these sites will be in the form of elemental mercury. However, due to the incomplete toxicological database for elemental mercury, this analysis will use the RfD for mercury chloride to assess potential oral exposures, and the RfC for elemental mercury to assess potential inhalation exposures.

3.0 EXPOSURE ASSESSMENT

The purpose of the exposure assessment is to evaluate the magnitude and frequency of potential exposure to substances at a site. Potential routes of exposure to substances associated with a release at a site are identified below. Potential human receptors are also identified below based on typical characteristics of the MMS sites and surrounding areas. The extent of a receptor's potential exposure to the substances via the exposure pathways identified is quantitatively estimated.

3.1 Potential Exposure Pathways

The Columbia MMS characterization/remediation program is addressing historical spills of elemental mercury onto surface soils in the immediate vicinity of MMS. Workers could be exposed to mercury in surface soils via incidental ingestion or dermal contact. Elemental mercury is a liquid at most ambient temperatures, and can volatilize into the atmosphere; therefore, workers could also be exposed via inhalation of mercury vapors. In addition, mercury could theoretically leach from surface soils through the soil column into underlying groundwater, although this is unlikely. If that groundwater is used as a drinking water supply, a local resident could be exposed to mercury via ingestion of water.

3.2 Potential Receptors

The MMS associated with Columbia's pipeline system are typically housed in secure structures. Access is limited to Columbia workers, who visit the MMS on a regular but infrequent basis (approximately once per month). MMS are present along the entire pipeline system; many of the MMS locations are in remote areas. Although some MMS may be present near residential areas, nearby residents are not expected to be exposed to any mercury-containing soils, as these MMS are typically housed within locked enclosures. Therefore, the most appropriate receptor for evaluating exposure to mercury releases onto soils at MMS is the pipeline worker. The appropriate receptor for evaluating exposure to mercury that may have migrated into off-site groundwater used as drinking water is an off-site resident.

3.3 Potential Exposure Scenarios

An exposure scenario is used to quantitatively define the exposure parameters used to calculate a receptor's potential exposure to substances at a site via the exposure pathway of concern. Exposure is a function not only of the concentration of a substance in an environmental medium (referred to as the exposure point concentration), but also of the receptor's exposure frequency (e.g., the number of days per year exposed to the environmental medium), exposure time (e.g., the number of hours per day exposed to the environmental medium), and exposure rate (e.g., the number of milligrams of soil incidentally ingested per day). The exposure dose is normalized by the receptor's body weight.

U.S. EPA's standard default exposure factors for a worker assume the following: a 70 kg adult works 8 hours per day, 250 days per year, incidentally ingests 50 mg soil per workday, consumes 1 L drinking water per workday, and breathes 20 m^3 air per workday (U.S. EPA, 1991a). However, this exposure scenario does not realistically depict a pipeline worker whose duties include MMS inspections. In the Columbia system, a worker is responsible for inspecting approximately 50 MMS per month, generally in a three to four day period. The inspections can last from 5 to 30 minutes each, but generally occur in a 10-15 minute period. Conservatively assuming that a worker spends 0.5 hours per MMS at 50 MMS once each month for 12 months of the year, the worker would spend approximately 300 hours or 38 days out of 250 workdays per year at MMS.

For the hypothetical off-site resident that could use groundwater beneath the site as a source of potable water, this receptor is assumed to consume 2 liters of drinking water daily and weigh 70 kg. These are standard residential exposure assumptions used by U.S. EPA (U.S. EPA, 1991a).

Since the purpose of this analysis is to confirm that Columbia's cleanup action level of 20 mg/kg of mercury at MMS is protective of public health, this analysis will assume that all MMS have concentrations of mercury in soil of 20 mg/kg (i.e., it assumes that all MMS will have 20 mg/kg mercury in soil after remediation). Again, it should be noted that Columbia's pilot study on MMS indicated that only two thirds of MMS exhibited mercury concentrations in excess of the 20 mg/kg cleanup action level.

4.0 RISK CHARACTERIZATION

In the risk characterization step, the results of the toxicity assessment and the exposure assessment are combined to generate quantitative estimates of potential carcinogenic risk and noncarcinogenic risk. By rearranging the equation used to calculate risk and assuming a specified level of "acceptable" risk, one can solve for a target exposure point concentration in a particular environmental medium of interest. These target exposure point concentrations are sometimes referred to as risk-based concentrations (RBC), which are concentrations in environmental media that are not expected to pose a significant risk to human health based on acceptable target risk levels.

For noncarcinogens, the target risk level is expressed as a hazard quotient (HQ) of 1.0. When using an RfD to assess exposure, the hazard quotient is the ratio of a calculated exposure dose to the reference dose (exposure dose / RfD). When using an RfC to assess exposure, the hazard quotient is the ratio of an air concentration to the reference concentration (air concentration / RfC). An HQ of less than or equal to 1.0 indicates that no adverse health effects are expected to occur as a result of the exposure.

4.1 U.S. EPA Region III Risk-Based Concentrations for Mercury

U.S. EPA Region III has developed risk-based concentration (RBC) tables (U.S. EPA, 1997a) that present chemical concentrations in residential soils, industrial soils, air, fish and tap water that correspond to a hazard quotient of 1.0 for noncarcinogens, calculated based on the use of conservative exposure assumptions.

The U.S. EPA Region III RBC for a residential exposure scenario for inorganic mercury in soil is 23 mg/kg. This value was calculated to be protective of a young child's daily exposure to soils via ingestion. (The specific equations and parameters used to calculate the RBCs are presented in U.S. EPA's RBC document - only those parameters that have a bearing on this analysis are discussed here.) The RBC for inorganic mercury in soil for an industrial exposure scenario is 61 mg/kg. The industrial scenario assumes daily exposure to soils via ingestion, 250 days per year.

As stated previously, Columbia, in conjunction with U.S. EPA Region III, has identified 20 mg/kg as the cleanup action level for use in the MMS characterization/remediation program. It is important to note that this level is a very conservative (i.e. health-protective) concentration for use in this program because it is lower than the level U.S. EPA considers appropriate for a residential exposure scenario, and as discussed above, it is likely that only workers have access to areas at MMS that may have mercury-containing soils.

U.S. EPA Region III also provides an RBC for tap water, i.e., for a residential drinking water scenario. The tap water RBC for inorganic mercury is 11 µg/L (U.S. EPA, 1997a). The federal drinking water standard or maximum contaminant level (MCL) for mercury is 2 µg/L (U.S. EPA, 1996d). Therefore, because the MCL is lower than the RBC, the MCL is a very conservative, i.e. health protective, value for mercury in drinking water.

The RBC for ambient air is, of course, equal to the RfC for elemental mercury of 0.0003 mg/m^3.

4.2 Other Screening Levels for Mercury

The Region III RBC address direct contact exposures only, e.g., incidental ingestion of soil, or ingestion of groundwater. Dermal contact with mercury in soil is not included in the derivation of the Region III RBC. However, this potential exposure pathway is not expected to contribute significantly to total risk from exposure to mercury in soil, as only a small percentage (e.g., 1%) of mercury in soil is estimated to be bioavailable for dermal uptake (U.S. EPA, 1995).

Federal U.S. EPA has considered intermedia transfer of substances in the environment, for example the volatilization of substances from soil to air, or the leaching of substances from soil to groundwater. U.S. EPA has issued guidance for calculating soil concentrations that considers ingestion and the soil-to-air and the soil-to-groundwater pathway exposures (U.S. EPA, 1996a, b). These values are identified as soil screening levels (SSLs). The generic SSL for mercury for the ingestion pathway is 23 mg/kg, and the soil-to-air pathway is 10 mg/kg, both based on a residential exposure scenario. The generic SSL for the soil-to-groundwater pathway for mercury is 2 mg/kg based on a residential drinking water scenario and assuming a dilution and attenuation factor (DAF) of 20. The DAF accounts for the physical, chemical, and biological processes that reduce compound concentrations as the compound moves from the source to a receptor point (U.S. EPA, 1996a).

4.3 Purpose for the Development of MMS-Specific Cleanup Action Levels

Because the SSLs are screening values and the methodology for their calculation was developed for easy implementation, the values are necessarily very conservative. The SSL document (U.S. EPA, 1996a), therefore, stresses that the generic SSLs are presented for informational purposes only, and that site-specific SSLs, calculated using site-specific data, are more appropriate than the generic SSLs. Therefore, Section 5 discusses alternative evaluations of the soil-to-groundwater pathway for inorganic mercury, and Section 6 discusses evaluation of the soil-to-air pathway using site-specific data.

5.0 FATE AND TRANSPORT ANALYSIS OF ELEMENTAL MERCURY AT MMS: SOIL-TO-GROUNDWATER PATHWAY

Theoretically, potential exposure to mercury for a hypothetical off-site resident could result from consumption of drinking water potentially impacted by mercury leaching from soil to groundwater. This section evaluates the soil-to-groundwater pathway for an off-site resident scenario at Columbia's MMS. Analyses of the fate and transport of compounds in the subsurface environment can involve two main pathways and several different processes:

- Movement of compounds through the unsaturated zone (above the water table).
    - Sorption - the tendency of a compound to adhere to the mineral particles it is in contact with rather than to dissolve into an aqueous solution.
    - Advection - transportation of solutes by the motion of flowing groundwater, in the unsaturated zone. This generally involves infiltration from precipitation and flow down, towards the water table.
    - Dispersion - the tendency of a solute to spread out from the expected path due to advective transport.
    - Molecular diffusion - the process by which a compound dissolved in water moves from an area of higher concentration to one of lower concentration.
    - Volatilization of compounds into the atmosphere.
    - Biodegradation.
- Movement of compounds through the saturated zone (below the water table).
    - Adsorption - the attraction and adhesion of a layer of ions from an aqueous solution to the solid mineral surfaces with which it is in contact.
    - Advection - transportation of solutes by the motion of flowing groundwater.
    - Dispersion - the tendency of a solute to spread out from the expected path due to advective transport.
    - Molecular diffusion - the process by which a compound dissolved in water moves from an area of higher concentration to one of lower concentration.
    - Biodegradation.

For Columbia MMS, the fate and transport of mercury would involve both of these pathways. Since inadvertent releases of elemental mercury occur at the ground surface, the unsaturated zone pathway is very important. Mercury is a volatile compound, so a model which is able to generally, as the target groundwater concentration, and using both a dilution factor and a soil-to-water partitioning equation. These equations take into account concentrations adsorbed to soil organic carbon and dilution of leachate concentrations directly below the source area.

The U.S. EPA SSL document uses a very simple relationship to predict the effect of a soil concentration on groundwater quality, or vice-versa, to calculate a soil concentration that is protective of a specified groundwater concentration. The target groundwater concentration, generally an MCL, is multiplied by the K_d and a dilution and attenuation factor (DAF). The default value provided for the DAF in the soil screening guidance is 20. As presented in Section 4, the default SSL for mercury in soil for the soil-to-groundwater pathway is 2 mg/kg [0.002 mg/L (MCL) x 52 L/kg (K_d) x 20 (DAF)].

The default DAF value was selected from a distribution of values by EPA (Table 7 in U.S. EPA, 1996a) to be very conservative. A DAF of 20 assumes a source area of 0.5 acre in size. By contrast, MMS sites are less than one percent of an acre (0.006 to 0.002 acre). If the DAF is adjusted directly to account for an MMS source area size of 5 m by 5 m (Equation 37 in U.S. EPA, 1996a), a DAF value of 170 is obtained. As stated previously, Columbia MMS are generally smaller than this, from 1 m to 3 m square. Data from Columbia's MMS pilot study indicate that mercury is limited to within 10 feet (approximately 3 m) of the meter location at 97% of the MMS, and is limited to within 5 feet (1.5 m) of the meter location at 60% of the sites. The DAF for a 3 m by 3 m source area would be 285. Table 5 of the Soil Screening Guidance (U.S. EPA, 1996a) provides DAF values orders of magnitude larger for sites less than 0.5 acres in size based on an EPA model (EPACMPT model). Use of the simple site-specific adjustment providing a DAF of 170 to 285 would result in soil-to-groundwater SSLs of approximately 18 mg/kg to 30 mg/kg for mercury.

This approach is still a very conservative screening level method as the time for a compound to leach into groundwater is not taken into account, nor are the processes of decay, attenuation or dispersion. In addition, the K_d of 52 L/kg used by EPA (1996a) to calculate the mercury SSL falls at the extreme lower end (more stringent) of the range of possible K_ds for mercury(II). Use of higher K_ds would result in correspondingly higher SSLs.

If the concentrations of the compounds of interest at a site are less than the calculated SSL, it can be concluded that there is no significant health risk due to the conservative nature of the SSL development. However, if such is not the case, a fate and transport analysis is a more appropriate method for determining an action level. Although the screening level method above indicates that a cleanup action level of 20 mg/kg is appropriate for the soil-to-groundwater pathway, fate and transport analysis is considered to be a more realistic approach and is provided below.

5.4 Fate and Transport Analysis

Notwithstanding the fact that the GRI research indicated that there is no significant adverse impact to the immediate environment, including groundwater, at natural gas MMS, we conducted a fate and transport analysis to confirm negligible mercury movement in the subsurface and subsequent leaching to groundwater at typical Columbia MMS.

A conservative, general conceptual model was developed to analyze the migration of mercury at MMS. The source in these scenarios was assigned an area of 5 m by 5 m (16 by 16 ft), the approximate area of a medium-sized natural gas metering structure. The MMS pilot study results presented in Section 5.3 indicate that this is a very conservative assumption for the evaluation of Columbia MMS. The source area was assumed to have a uniform concentration of mercury equal to the MMS cleanup action level of 20 mg/kg. Since the research performed by the GRI showed that mercury is generally not observed below 1 m, the source area was assigned a thickness of 1 m. Again, this is a conservative assumption when compared to the MMS pilot study results that indicate that mercury in soil at 90% of the 242 MMS evaluated was confined to 0 to 2 feet in depth (0.6 m). In this analysis, the water table was assumed to be 3 m below the surface (i.e. 2 m below the bottom of the source area).

The fate and transport modeling of mercury was performed to:

- evaluate the fate of mercury between source and water table,
- evaluate mercury concentration at the water table to predict groundwater concentration, and
- predict movement and concentration of mercury in the groundwater.

Two scenarios were considered in the fate and transport modeling to address the above objectives:

- Scenario 1 - the migration of elemental mercury through the unsaturated zone to the water table.
- Scenario 2 - the transport of elemental mercury in the groundwater assuming elemental mercury migrated to the water table at concentrations above the solubility of elemental mercury.

5.4.1 Scenario 1

The National Center for Environmental Assessment in the U.S. EPA's Office of Research and Development has developed a computer modeling program, EMSOFT, a one-dimensional analytical fate and transport model for evaluating the behavior of chemicals in the unsaturated zone. The model is based on the work of Jury et al. (1983), who derived an equation for calculating total soil organic chemical concentrations as a function of depth and time. Unlike many other metals, mercury is a liquid at ambient conditions, and it is volatile. As such, elemental mercury behaves in the unsaturated zone much like an organic compound. The U.S. EPA Soil Screening Guidance recommends the use of EMSOFT as a model that accounts for volatilization, water convection (leaching), and the impact of a soil-air boundary on the flux of substances (U.S. EPA, 1996a).

EMSOFT was, therefore, used to predict leaching of mercury from the unsaturated zone to the aquifer. This model assumes that a constant concentration of a chemical is initially present in a soil layer of thickness (L) located at the surface. Other assumptions include constant vertical porewater flux and uniformity in soil properties. The model accounts for chemical degradation, advection, diffusion in the liquid and gas phases, and partitioning among air, water, and soil. It, therefore, incorporates all of the major fate and transport processes that affect mercury in the unsaturated zone.

The mercury in soil was modeled as a 1 m deep layer with a uniform concentration of 20 mg/kg of mercury overlying 2 m of clean soil. Soil and chemical parameters were selected from the literature including the U.S. EPA Soil Screening Guidance (1996a, b) where possible, publications from the Gas Research Institute and the Handbook of Chemistry and Physics (Lide, 1990) as shown in the Table 5-2.

It should be noted from Table 5-2 that the K_d value for mercury(II) is used in this analysis. This value was selected as a default value due to the lack of K_d values for elemental mercury in the literature. As noted earlier, the solubility of elemental mercury is much less than that of most mercury(II) compounds. Therefore, the model results are likely to greatly overestimate concentrations of elemental mercury in soil beneath the source area, resulting in a conservative, i.e., health-protective, evaluation.

Figure 5-1 shows the average mercury concentration profile through the two model layers over times of 0, 10, 15, 25, 50, and 75 years developed by the EMSOFT model. The peak concentration of mercury moves down through the soil column over time. However, due to volatilization, the concentration decreases greatly over time.

Figure 5-2 presents mercury concentration changes over time at selected depths based on the results of the EMSOFT model (presented in Figure 5-1). The source area is assumed to extend to 1 meter below the surface; thus, the red diamond line represents changes in mercury concentration at the base of the source area over time. The lower horizontal dashed line represents the generic SSL of 2 mg/kg; this is the value presented in the Soil Screening Guidance document (U.S. EPA, 1996a) and is calculated using the default DAF of 20, which assumes a 0.5 acre source area size. The upper horizontal dashed lines represent the generic SSLs of 18 mg/kg and 30 mg/kg; the values calculated assume DAFs of 170 for a source area of 0.006 acre (5 m by 5 m) in size and of 285 for a source area of 0.002 acre (3 m by 3 m) in size, as described in Section 5.3. These figures demonstrate that in a short time, virtually all predicted concentrations of elemental mercury in soil at an MMS source area of starting concentration of 20 mg/kg fall below the generic SSL of 18 mg/kg (calculated for a 5 m by 5 m acre source area) and are well below the generic SSL of 30 mg/kg (calculated for a 3 m by 3 m source area). In addition, mercury concentrations at greater than 1.75 m (5.6 ft) in depth (i.e., 75 cm below the source area) do not exceed the very conservative SSL of 2 mg/kg. It can be concluded from these results that even for very shallow water tables, elemental mercury from MMS at concentrations of 20 mg/kg or less are unlikely to adversely impact underlying groundwater quality.

5.4.2 Scenario 2

The unsaturated zone modeling in Scenario 1 demonstrated that a mercury source of 20 mg/kg in soil would not migrate to the water table at levels that could leach into groundwater at unacceptable levels and, therefore, that a groundwater exposure scenario is not likely. However, as a means of further evaluating the potential behavior of mercury at MMS, a saturated zone transport model was performed for the case that assumes that elemental mercury does reach the water table. The Horizontal Plane Source (HPS) Model (Galya, 1987; Galya and Clark, 1990) was used to evaluate the potential for mercury contamination to migrate to a potential receptor.

The groundwater source concentration of mercury was set to 70 µg/L, the midpoint of the range of elemental mercury solubility values found in the literature (Henke et al., 1993). This is a very conservative value, because even if mercury in the soil were to migrate far enough and at levels high enough to impact the groundwater, it is very unlikely the water would ever reach equilibrium and become fully saturated with mercury. The remaining model parameters are shown and described in Table 5-3.

Figure 5-3 shows the predicted groundwater concentration of mercury as a function of the distance from the source. The model results indicate that mercury concentration is predicted to fall below the MCL of 2 µg/L after migrating a distance of approximately 3.3 m (or 11 ft) from the edge of the source area. Therefore, even given the unlikely scenario assumed in this analysis, groundwater levels would fall below the MCL 11 feet from the source area. It is, therefore, unlikely that mercury concentrations above the MCL would ever reach a receptor.

5.4.3 Uncertainty Analysis

Many assumptions have been made in this analysis, and these assumptions have been identified in the text. Some of the assumptions have a firm scientific basis, while others do not. Some level of uncertainty is introduced into the risk characterization process every time an assumption is made. In regulatory risk assessment, the methodology dictates that assumptions err on the side of overestimating potential exposure and risk and this can then lead to overestimates of potential risk.

Use of a cleanup action level of 20 mg/kg for mercury in soil in the MMS program is very conservative. This value is lower than the value of 23 mg/kg for a direct contact residential scenario (U.S. EPA, 1997a). As stated previously, access to MMS is generally restricted to pipeline workers, and an industrial action level for mercury in soil for direct contact exposure is 61 mg/kg (U.S. EPA, 1997a).

The interest in whether this cleanup action level is protective of underlying groundwater quality lead to this analysis. The fate and transport analysis addressed a hypothetical MMS site and used the assumption that the soil containing mercury at a uniform concentration of 20 mg/kg at an MMS would not exceed an area of 5 m by 5 m and a depth of 1 m. These assumptions are supported by the GRI research and are generally consistent with Columbia's characterization results from its pilot study of 242 MMS. Columbia results indicate that mercury is limited to:

- within 10 feet (3 m) laterally of the meter location at 97% of the MMS;
- within 5 feet (1.5 m) laterally of the meter location at 60% of the MMS; and
- within 2 feet (0.6 m) in depth at 90% of the MMS.

It was further assumed that the depth to groundwater at this hypothetical site is 3 m. This will be a conservative assumption for most MMS, but depth to groundwater could be less than 3 m in some areas. The unsaturated zone model results presented in Figures 5-1 and 5-2 indicate that if the water table were 0.75 m (or 2.5 ft) below the source area, soil concentrations at the water table surface would not be expected to be in excess of 2 mg/kg mercury, the very conservative generic SSL value.

The unsaturated zone model used to make these calculations also used very conservative input parameters for the physical and chemical properties of elemental mercury. For example, the K_d value for mercury(II) of 52 was used in the absence of a value for elemental mercury from U.S. EPA documents. GRI estimates that the K_d value for elemental mercury could range from 10^4 to 10^6, values much higher than the one used in this analysis. Therefore, the unsaturated zone model is likely overestimating the transport of elemental mercury to underlying groundwater. GRI's own site-specific research indicated that groundwater at the MMS research sites had concentrations of mercury much lower than the MCL due to regional background.

Mercury can behave as a dense nonaqueous phase liquid (DNAPL) since it is a liquid at most ambient temperatures. The unsaturated zone model cannot take into account physical transport of elemental mercury through pores and crevices in the subsurface. However, the small quantities of elemental mercury that may be spilled at MMS and mercury's affinity for organic material in soil would not result in the classic DNAPL behavior exhibited by some of the chlorinated solvents. Depending on the nature of the subsurface soils, droplets of elemental mercury could theoretically eventually move down to the water table. However, the second scenario addressed this possible outcome by assuming that saturating concentrations of elemental mercury were present in the groundwater, and modeling the transport and attenuation as the groundwater moves laterally. Again, using conservative values for physical parameters for mercury, the model predicted that concentrations of mercury would decrease to the MCL value of 2 µg/L within 3.3 m of the source area.

TABLE 5-1
Properties of Elemental Mercury

Property	Value
Atomic number	80
Atomic radius	1.5 A
Atomic volume	14.81 cm^3/g-atm
Atomic weight	200.59 atomic mass units
Boiling point	357 C
Boiling point/rise in temperature	0.0746 C/torr
Conductivity (heat)	0.022 cal/sec/cm^3 * C
Contact angle	132 degrees
Density	13.546 g/cm^3 @ 20C
Diffusivity (in air)	0.112 cm^2/sec
Heat Capacity	0.0332 cal/g @ 20 C
Henry's law constant	0.0144 atm m^3/mol
Interfacial tension (Hg/H2O)	375 dyn/cm @ 20 C
Melting point	-38.87 C
Reflectivity	71.2% @ 5500 A light
Resistivity (heat)	95.8 x 10-6 ohm/cm @ 20 C
Saturation vapor pressure	0.18 N/m^2 (pascal) @ 20 C
Specific gravity	13.546 @ 20 C
Surface tension (in air)	436 dyn/cm @ 20 C
Vaporization rate (still air)	0.007 mg/cm^2*hr for 10.5 cm^2 droplet @ 20 C
Viscosity	1.554 cp @ 20 C
Electronegativity	1.92 (Pauling scale)
Solubility (water)	60 - 80 µg/L @ 20 C
Valence state	0 (mercury compounds: 1+ or 2+)

Source: Henke, et al. (1993).

TABLE 5-2
Model Parameters for Scenario 1
Unsaturated Zone Modeling

Parameter	Value	Source
K_d* (ml/g)	52	U.S. EPA, 1996a
Kh (dimensionless)**	0.47	Henke et al., 1993; U.S. EPA, 1996a
Air diffusion coefficient** (cm^2/day)	970	Henke et al., 1993
Aquifer diffusion coefficient** (cm^2/day)	0.76	Lide, 1994
Soil porosity	0.43	U.S. EPA, 1996a
Soil water content	0.3	U.S. EPA, 1996a
Soil bulk density (g/cm^3)	1.5	U.S. EPA, 1996a
Infiltration rate (cm/day)	0.092	Value used for Pennsylvania in Sorenson et al., 1996

* This value is reported for mercury (II). This is the lowest (most conservative) value found for a mercury compound. As available information suggests the elemental mercury is less mobile than most mercury (II) compounds (Henke et al, 1993), this is considered to be a conservative value.

** Value for elemental mercury.

TABLE 5-3
Modeling Parameters for Scenario 2
Saturated Zone Modeling

Parameter	Value	Source
K_d* (ppm)	52	U.S. EPA, 1996a
Decay rate (1/years)	0	Estimated
Infiltration (m/year)	0.34	Value used for Pennsylvania in Sorenson et al., 1996
Hydraulic conductivity (m/yr)	3154	Value used for a sand in Freeze & Cherry, 1979
Gradient (dimensionless)	0.01	Estimated
Longitudinal dispersivity (m)	0.1	Estimated
Transverse dispersivity (m)	0.01	Estimated
Vertical dispersivity (m)	0.001	Estimated
Aquifer thickness (m)	3	Estimated
Bulk density (Kg/L)	1.5	U.S. EPA, 1996a
Porosity	43%	U.S. EPA, 1996a

* This value is reported for mercury (II). This is the lowest (most conservative) value found for a mercury compound. As available information suggests the elemental mercury is less mobile than most mercury (II) compounds (Henke et al, 1993), this is considered to be a conservative value.

FIGURE 5-1
Unsaturated Zone Model Results
Average Soil Concentration Profiles vs. Depth for Selected Times

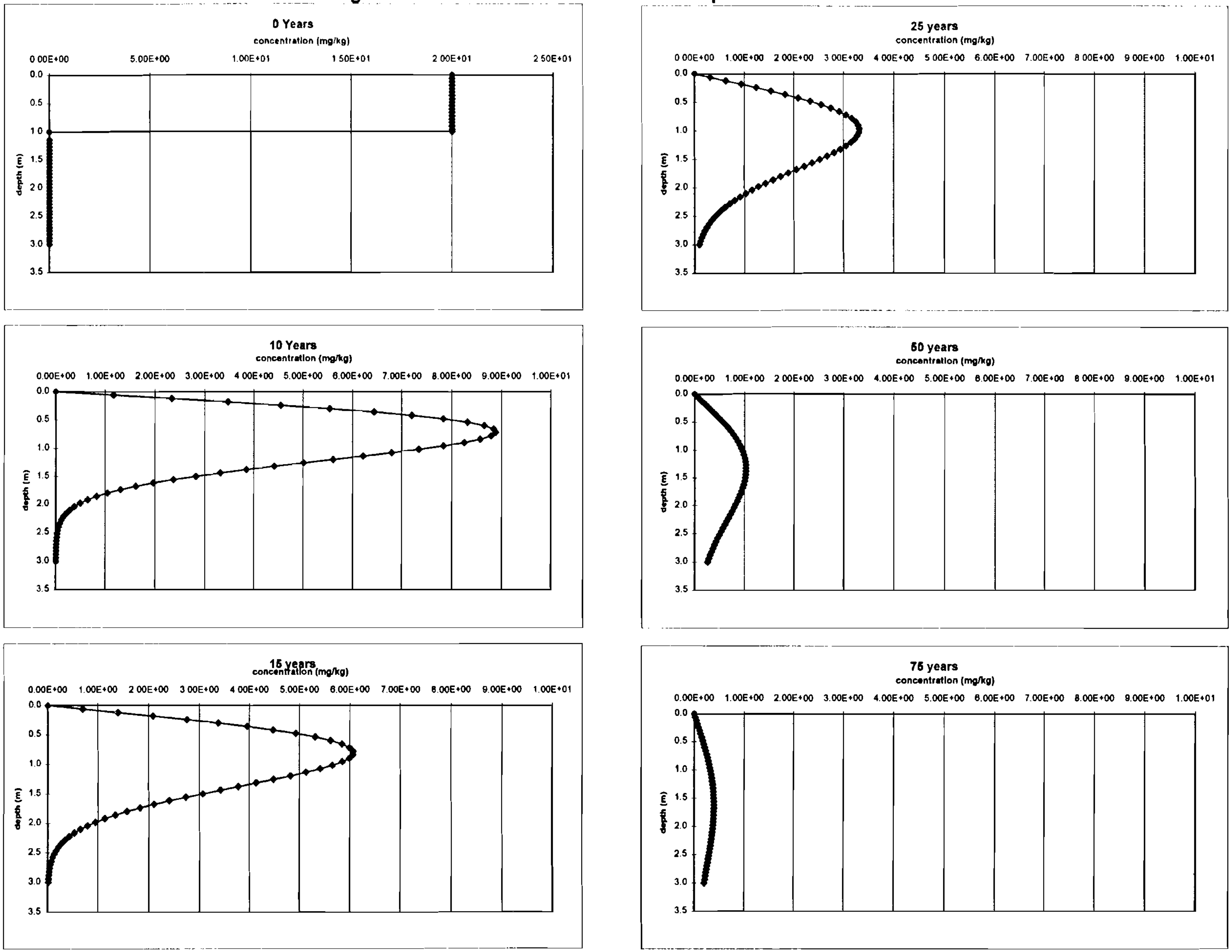


Figure 5-2

Concentration Changes Over Time at Depths of 1.0, 1.5, 1.75 and 2.0 m
(assuming elemental mercury present in the soil at 0-1 m at 20 mg/kg)

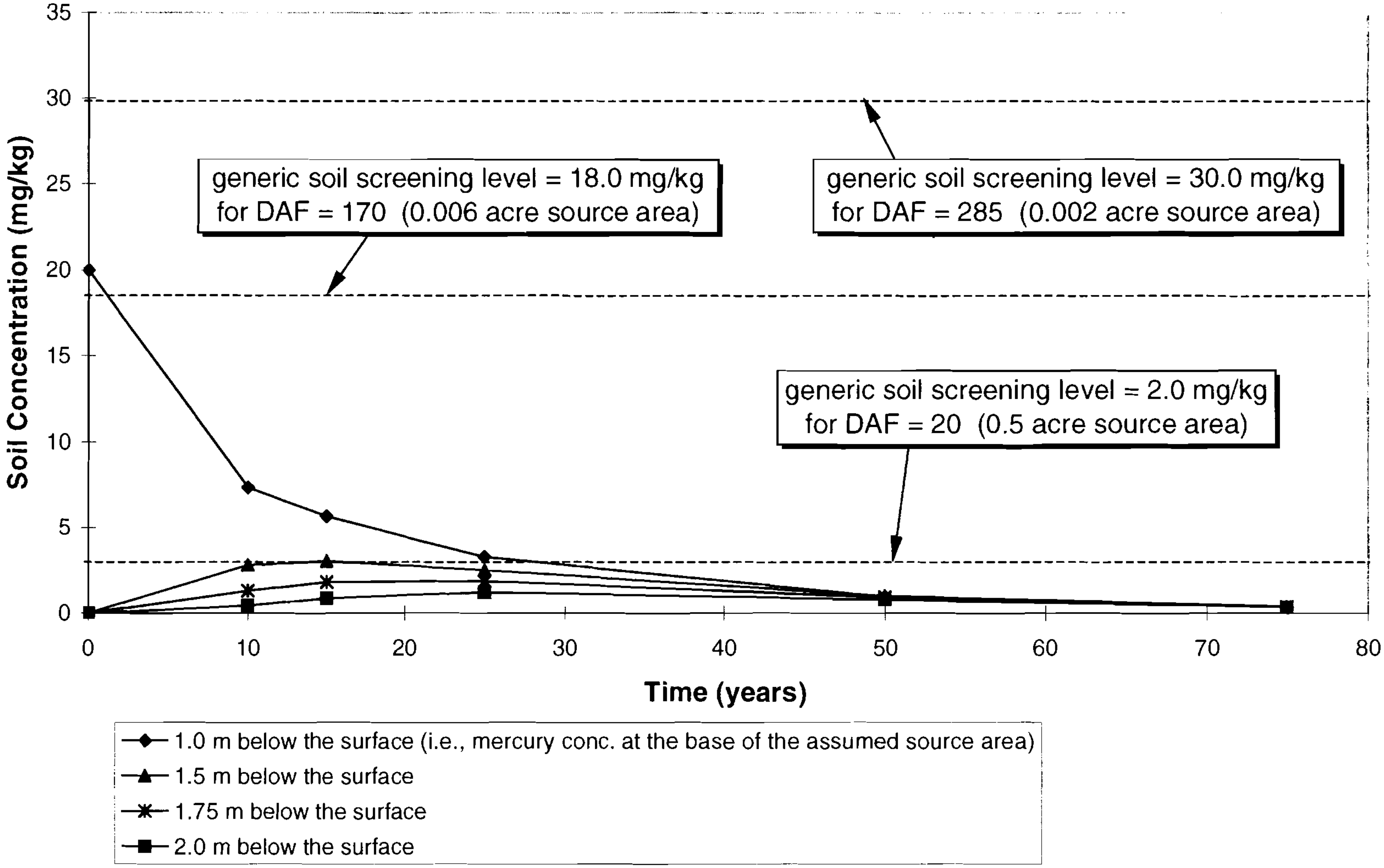
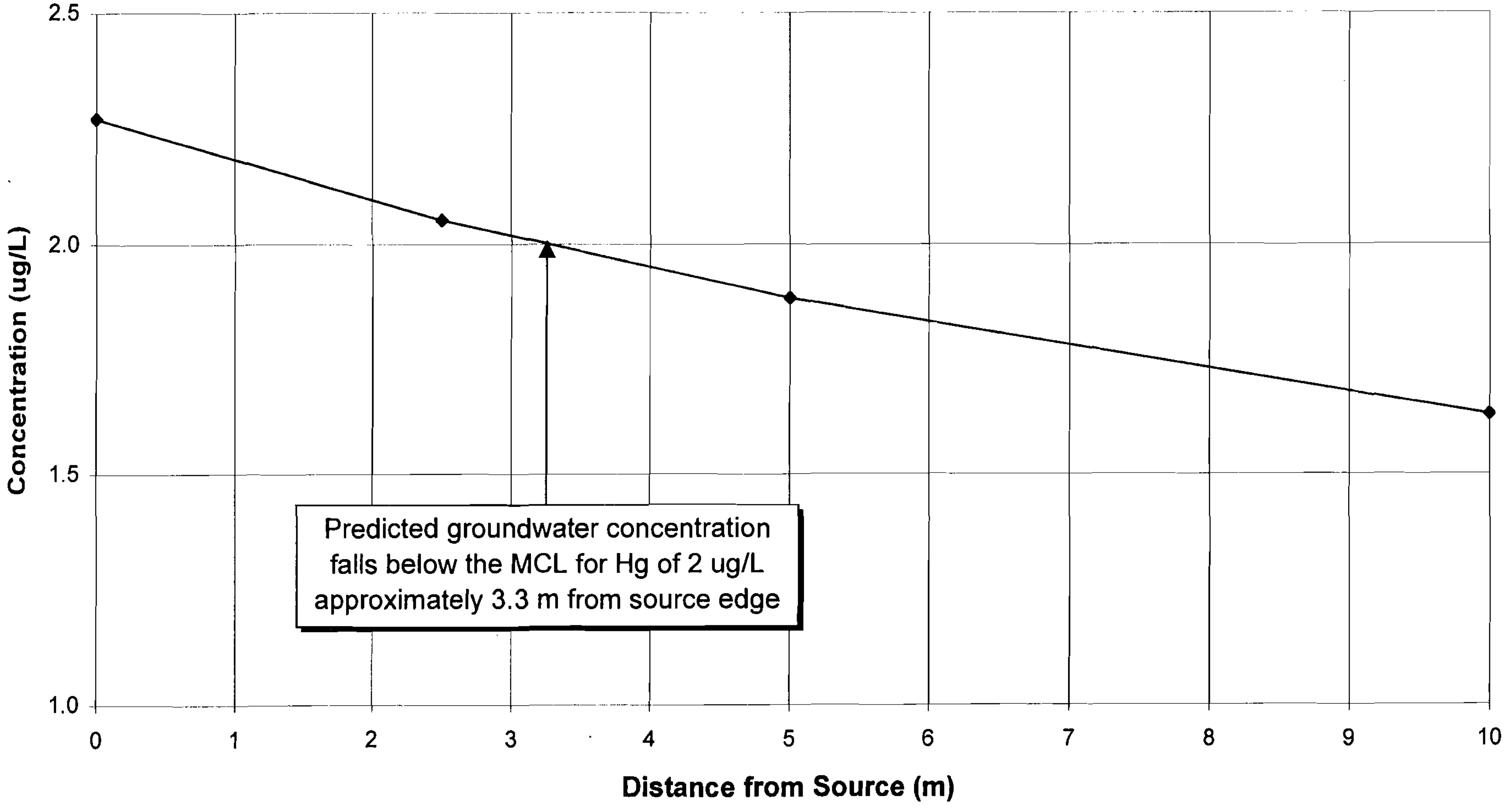


FIGURE 5-3

Saturated Zone Transport Model Results

Source Concentration of 70 ug/L (Elemental Hg Solubility)



Predicted groundwater concentration falls below the MCL for Hg of 2 ug/L approximately 3.3 m from source edge

6.0 EVALUATION OF INHALATION EXPOSURES AT MMS: SOIL-TO-AIR PATHWAY

Potential exposure to mercury in soils at MMS for a worker scenario includes direct contact via incidental ingestion of soil, and inhalation of mercury volatilized from the soils. This section evaluates the soil-to-air (inhalation) pathway for an MMS worker scenario.

6.1 Target Hazard Quotient Considerations

The target hazard quotient for the worker scenario in this analysis is 1.0, which is the target hazard quotient for noncarcinogenic effects used in the Soil Screening Guidance (U.S. EPA, 1996a) and in the CERCLA program (U.S. EPA, 1989). The total hazard quotient for a receptor, such as a worker, is the total of the hazard quotients from each potential exposure pathway. Therefore, both potential ingestion and inhalation exposures must be considered when calculating the total hazard quotient for the worker receptor, or conversely when allocating a target hazard quotient of 1.0 among the separate exposure pathways.

The RBC (ingestion) for mercury in soil for an industrial exposure scenario is 61 mg/kg (U.S. EPA, 1997a). This value is calculated using a target hazard quotient of 1.0 and assuming that a worker is exposed to mercury containing soils via inadvertent ingestion 250 working days per year. The cleanup action level for Columbia's MMS sites is 20 mg/kg, much lower than the industrial RBC. In addition, as described in Section 3.0, Columbia workers are expected to be present at MMS for the equivalent of approximately 40 working days per year. Assuming an exposure point concentration equal to the 20 mg/kg cleanup action level and a realistic but conservative exposure frequency of 40 days per year, the hazard quotient associated with the worker's incidental soil ingestion exposure is 0.05. Therefore, the target hazard quotient for the evaluation of the soil-to-air pathway is 1 minus 0.05, or 0.95. This adjustment is made to ensure that the total hazard quotient does not exceed 1.0 for this scenario.

6.2 U.S. EPA Soil Screening Level Procedure for the Soil-to-Air Pathway

The U.S. EPA Soil Screening Guidance (U.S. EPA 1996a,b) describes procedures to calculate soil screening levels (SSLs). As described in Section 5, SSLs are risk-based and allow for incorporation of site-specific data. Sites where concentrations fall below SSLs require no further action or study.

This evaluation of the soil-to-air pathway for mercury at MMS follows the SSL procedure. The SSL procedure is an updated version of the procedure presented in the document Risk Assessment Guidance for Superfund (RAGS), Part B (U.S. EPA, 1991b), and EPA states that the SSL procedures should serve as a replacement to the RAGS Part B procedure.

The SSL procedure for the inhalation of volatiles and fugitive dusts is presented in Section 2.4 of the SSL document (U.S. EPA, 1996a). However, this MMS evaluation is focused only on the volatile inhalation component for two reasons: elemental mercury is a volatile compound, and construction of the MMS are such that the areas are planked or gravel covered and most are housed, thus the potential for particulate suspension is low, and the contribution of particulate inhalation to total risk is likely to be negligible.

This SSL procedure is one used to calculate volatilization from soil to outdoor air. Models do exist that address migration of vapors into buildings, however, EPA chose to use the outdoor air model for generic SSL calculation due to the need for site-specific considerations when using indoor air models. The indoor air models assume an enclosed structure configuration such as for a house that has a concrete basement or foundation, and the calculated air concentration is a function of the frequency and width of cracks in the concrete flooring and air exchange capacity of the building. Default values for these parameters are available for conventional structures, but none address the configuration of typical MMS, which are generally fairly open structures with a high degree of air exchange. Moreover, Columbia worker safety programs address precautions workers must take when working in mercury containing areas.

The SSL document (U.S. EPA, 1996a) procedures have been used to calculate a volatile Screening Level using Equation (5) in the guidance:

$$\textit{Volatile Screening Level (mg/kg)} = \frac{THQ \times AT \times 365\ d/yr}{EF \times ED \left(\frac{1}{RfC} \times \frac{1}{VF}\right)}$$

The parameters in this equation are defined in Table 6-1. Based on the assumed exposure from ingestion (see Section 6.1), the target hazard quotient used is 0.95 for an exposure frequency of 40 days per year. VF in this equation is the Volatilization Factor and is calculated using Equation (6) in the guidance (U.S. EPA, 1996a):

$$VF\ (m^3/kg) = Q/C \times \frac{(3.14 \times D_A \times T)^{1/2}}{(2 \times P_b \times D_A)} \times 10^{-4}\ (m^2/cm^2)$$

where:

$$D_A = \frac{\left[(\Theta_a^{10/3}\ D_i H' + \Theta_w^{10/3} D_w)/n^2\right]}{P_b K_d + \Theta_w + \Theta_a H'}$$

The parameters in these equations are also defined in Table 6-1, and references are provided. The majority of the parameters were provided by U.S. EPA guidance (U.S. EPA, 1996a, 1991a, 1997a), and several of these are discussed below.

The Q/C term is defined as the inverse of the mean concentration at the center of a square source and is expressed in units of g/m^2-s per kg/m^3. This term is used to account for dispersion in air. Table 3 of the SSL document (U.S. EPA, 1996a) provides Q/C values by source area, city and climate zone. The Q/C used in this evaluation is the value for Huntington, West Virginia, for a 0.5 acre source (the smallest source area provided in the U.S. EPA tables). This location was considered to be the most appropriate from the 29 cities provided in the table (based on the ten state region covered by Columbia's natural gas pipeline system).

As stated in Section 5, the K_d value for mercury(II) at pH 6.8 is from Table 46 of the SSL document (U.S. EPA, 1996a). K_d values specifically for elemental mercury were not available in the literature. The values for the dimensionless Henry's Law Constant (H') and diffusivity in air (Di) are from Tables 36 and 37, respectively, for elemental mercury (U.S. EPA, 1996a).

6.3 SSL Calculation

Solving the above equations for a worker exposure frequency and a target hazard quotient of 0.95 results in an volatile SSL of approximately 62 mg/kg. This is well above the Columbia cleanup action level of 20 mg/kg. Thus it can be concluded that a cleanup action level for mercury of 20 mg/kg is protective of both potential ingestion and inhalation exposures to elemental mercury for an MMS worker scenario.

Although the volatilization factor model in RAGS Part B (U.S. EPA, 1991b) is outdated, equation (7) of that document can still be used to evaluate combined inhalation and ingestion exposures for an industrial scenario:

$$C\,(mg/kg) = \frac{THQ \times BW \times AT \times 365\,days/yr}{ED \times EF \times [((1/RfD_o) \times 10^{-6}\,kg/mg \times IR_{soil}) + ((1/RfD_i) \times IR_{air} \times (1/VF))]}$$

where

Parameters	Definition (units)	Value
C	mercury concentration in soil (mg/kg)	20 (AOC cleanup action level)
THQ	target hazard quotient (unitless)	1
RfD_o	oral reference dose for mercury (mg/kg-day)	0.0003
RfD_i	inhalation reference dose for mercury (mg/kg-day)	0.0000857
BW	adult body weight (kg)	70 kg
AT	averaging time (yr)	25 yr (always equal to ED)
EF	exposure frequency (days/yr)	to be solved for
ED	exposure duration (yr)	25 yr
IR_{soil}	soil ingestion rate (mg/day)	50 mg/day
IR_{air}	workday inhalation rate (m^3/day)	20 m^3/day
VF	soil-to-air volatilization factor (m^3/kg)	23720.56

All of the parameters are either chemical-specific or provided by U.S. EPA (1991b) except the cleanup action level of 20 mg/kg and the VF calculated as described previously. Solving the equation for exposure frequency (EF), a worker could frequent MMS having mercury concentrations in soil equal to the cleanup action level of 20 mg/kg for 130 days per year (8 hours per day) and not exceed a target quotient index of 1.0. Conversely, assuming an exposure frequency of 40 days per year and a cleanup action level of 20 mg/kg and solving for the hazard quotient, the hazard quotient is 0.3, which is well below the regulatory target of 1.0.

Therefore, it is concluded that the cleanup action level of 20 mg/kg is protective of MMS worker exposure for the combined soil-to-air and incidental soil ingestion pathways.

6.4 Uncertainty Analysis

Calculation of the volatilization factor (VF) using equation (6) of U.S. EPA, 1996a, does not take into account mass balance; it assumes an infinite source. To address this issue, EPA (1996a) provides a mass-limit model for inhalation of volatiles in equation (55):

$$VF = (Q/C) \times [(T \times 3.15E7\ s/yr)/(P_b \times d_s \times 10^6\ cm^3/m^3)]$$

The parameters are the same as those in Table 6-1, with d_s, the average source depth, equal to 1 meter here, and T is the exposure interval expressed in years. [Note: the units for the conversion factor 10^6 cm^3/m^3 are incorrectly presented in EPA's equation (55) as g/Mg; this has been corrected here.] Solving the equation results in a VF equal to 28,292 m^3/kg. The VF calculated using the infinite source model in EPA equation (6) is 23,721. EPA states:

> "If the VF calculated using an infinite source volatilization model for a given contaminant is less than the VF calculated using equation (55), then the assumption of an infinite source may be too conservative for that specific contaminant at that source. Consequently, VF as calculated in equation (55), could be considered a minimum value for VF."

Therefore, the calculations presented in the previous section are conservative, i.e., health protective, values, and are likely to overestimate rather than underestimate potential risks. Also, if the mass-limit VF calculated using EPA equation (55) is used to calculate a volatile SSL based on a target hazard quotient of 0.95, an SSL of approximately 74 mg/kg results. This is much higher than the 20 mg/kg cleanup action level used by Columbia. Finally, the fact that the cleanup action level of 20 mg/kg is associated with a hazard quotient of 0.3 that is much below 1.0 indicates that the cleanup action level is a conservative value.

TABLE 6-1

Parameters Used for the Calculation of a Volatile Screening Level for Mercury

Parameter	Definition	Value	Units	Source
VF	volatilization factor	**23720.56**	m^3/kg	calculated
D_A	apparent diffusivity	**1.42E-05**	cm^2/s	calculated
Q/C	inverse of mean conc. at center of square source	53.89	g/m^2-s per kg/m^3	(a)
T	exposure interval	7.90E+08	s (25 years)	(b)
P_b	dry soil bulk density	1.5	g/cm^3	(c)
θ_a	air-filled porosity	0.28	L_{air}/L_{soil}	n-θw (c)
n	total soil porosity	0.43	L_{pore}/L_{soil}	1-(Pb/Ps) (c)
θ_w	water filled soil porosity	0.15	L_{water}/L_{soil}	(c)
Ps	soil part. density	2.65	g/cm^3	(c)
Di	diffusivity in air	3.07E-02	cm^2/s	(d)
H'	Henry's law dimensionless	0.467	unitless	(e)
D_w	diffusivity in water	6.30E-06	cm^2/s	(d)
K_d	soil-water partition coe.	52	cm^3/g	(f)
K_{oc}	soil organic carbon-water part. coe.	8666.667	cm^3/g	K_d/F_{oc}
F_{oc}	organic carbon content of soil	0.006	g/g	(c)
THQ	target hazard quotient	0.95	unitless	(g)
AT	averaging time	25	years	(b)
EF	exposure frequency	40	days/year	(g)
ED	exposure duration	25	years	(b)
RfC	reference concentration for mercury	3.00E-04	mg/m^3	(h)

(a) Table 3 of SSL document (U.S. EPA, 1996a), value for Huntington, WV.
(b) U.S. EPA, 1991a.
(c) U.S. EPA, 1996a, eqn. (6).
(d) Table 37 of SSL document (U.S. EPA, 1996a), value for elemental mercury.
(e) Table 36 of SSL document (U.S. EPA, 1996a), value for elemental mercury.
(f) Table 46 of SSL document (U.S. EPA, 1996a), value for mercury (+2) at pH = 6.8.
(g) See text.
(h) U.S. EPA, 1997b.

7.0 CONCLUSIONS

A cleanup action level of 20 mg/kg is recommended for natural gas mercury station sites on the east coast and is appropriate to the Columbia MMS program. This level is considered to be conservative based on the following:

- Potential contact with soils at MMS are limited to pipeline workers. The 20 mg/kg cleanup action level is much lower than the U.S. EPA Region III industrial soil Risk-Based Concentration, or RBC, for mercury of 61 mg/kg, and is even lower than the residential soil RBC of 23 mg/kg. These RBCs are based on a direct contact (incidental soil ingestion) scenario.

- The analysis of the soil-to-groundwater and the soil-to-air pathways assumed a 5 m by 5 m by 1 m source area at an MMS (16 ft by 16 ft by 3.3 ft) having a uniform 20 mg/kg concentration of elemental mercury. Mercury spills at MMS are not uncommon, but are typically small scale, resulting from broken or spilled manometers, which generally hold less than 7 ounces of elemental mercury. The results of Columbia's pilot study of 242 MMS indicate that: at 60% of the sites, mercury was detected less than 5 feet (1.5 m) from the meter location; at 97% of the sites, mercury was detected less than 10 feet (3 m) from the meter location; and at 90% of the sites mercury was detected at less than 2 feet (0.6 m) in depth. Therefore, mercury in soil at typical Columbia MMS is located in a much smaller area than was assumed for the modeling analysis.

- Because of a lack of elemental mercury values in the scientific literature for parameters that describe interactions between mercury and soil and water, values for the very soluble compound mercury chloride were used. Thus the modeling has greatly overestimated the mobility of elemental mercury in both soil and groundwater.

- Using these conservative parameter values, modeling of mercury from a surface source of 20 mg/kg to a water table less than one meter below the source area would not result in mercury concentrations in groundwater above the federal drinking water standard (MCL) of 2 µg/L.

- Even if a mercury source were to be present in groundwater equal to the solubility of elemental mercury, 70 µg/L (an extremely unlikely scenario), groundwater concentrations would decrease to below the MCL within approximately 3.3 m (or 11 ft) downgradient of the source area.

- In addition to this modeling evaluation, previous field research performed by the Gas Research Institute evaluating soil and groundwater in the area of mercury releases associated with manometers at natural gas facilities shows no evidence of adverse environmental effects from the mercury in the immediate area of the release, even when no remedial actions have been performed.

Even though this standard is considered conservative, certain environmental considerations should be taken into account at some sites. The cleanup action level should be evaluated more closely if there are organic solvents present in soil in the area as these can increase the solubility of mercury, or if there is an oxidizing environment (Electrode Potential (Eh) is above 0 and electrons are donated from elemental mercury to oxidizing compounds in the soil). However, because the modeling used parameters for the soil-to-groundwater pathway for mercury(II), which is much more mobile than elemental mercury, the model has already greatly overestimated the movement of elemental mercury in soil. Therefore, these considerations should not significantly affect the use of the 20 mg/kg cleanup action level for mercury at MMS. This level should be considered health-protective for short-term as well as long-term exposures.

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