Report on

Site Specific Cleanup Standards for HUL's Mercury Thermometer Manufacturing Factory at Kodaikanal, Tamil Nadu

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Table of Contents

List of Figures

List of Tables

7

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1.0 Background

The thermometer factory at Kodaikanal is understood to have operated from 1983 till 2001. Operations were stopped due to concerns regarding the disposal of mercury bearing glass scrap. Subsequently, several Environmental Assessment studies were carried out at the site. Following are some of the pertinent reports which were reviewed as part of this report:

- URS (2002), Environmental Site Assessment and Risk Assessment for Mercury. HLL Thermometer Factory Site, Kodaikanal, Tamil Nadu, India
- URS (2002), Remedial Action Plan, Site Remediation, HLL Thermometer Factory Site, Kodaikanal, Tamil Nadu, India
- URS (2002), Health and Safety Plan, Site Remediation, HLL Thermometer Factory Site, Kodaikanal, Tamil Nadu, India
- ERM (2005), Total Mercury Content in Sediment, Surface Water and Fish Samples drawn for HLL in area surrounding Kodaikanal
- ERM (2006), Former HLL Mercury Thermometer Factory, Kodaikanal, Tamil Nadu, India, Site Specific Target Levels
- NEERI (2007) Protocol for remediation of mercury contaminated site at HLL Thermometer factory, Kodaikanal
- NEERI & ERM (2008) Spoil remediation at HUL factory site, Kodaikanal, Tamill Nadu, India- Detailed Project Report (Final)

The purpose of this study is to generate risk-based site-specific target levels (SSTLs) that are protective to the human as well ecological receptor keeping in view future uses of the site.

2.0 Objectives of the Report

Objectives of the study are to review the risk assessment procedure and derive a Site Specific Clean up Standard using a de-novo approach. The site specific cleanup standards are to be determined based on the all possible exposure routes for the most sensitive receptor for the intended future use of the site.

5

3.0 Site Description

The HUL's factory site occupies an area of approximately 85,000 m^2 and is located at an elevation of 2180m above mean sea level. Access to the site is via St. Mary's Road, which forms a divide between two catchment areas; one located to the south and the other to the north of the road. The southern catchment area includes the HUL factory and the Pambar River, while the northern catchment area includes Kodai Lake which is located approx 1.0 km north of the site. Kodai Lake is located beyond a mount and is located in a different catchment area. The nearest surface water body to the site is the Pambar River (approximately 0.5 km aerial distance to the south). The Pambar river flows in a southwest direction to the Kumbakarrai Falls about 7 km to the southeast, and then drains eastward across the Tamil Nadu Plain. A narrow access path, called Levange path, is in the Forest Reserve located immediately south of the site boundary.

The general land use to the North and East of the site is predominantly low density private residential properties along St Mary's road.

The entire site is underlain by shallow bedrock, mainly granite gneiss and charnockite. The soil profile is very thin and comprises a few centimetres of predominantly sandy material in the upper part of the site grading down into densely vegetated peaty soils in the south of the site.

4.0 Human Health Risk Assessment

4.1 Routes of exposure

Mercury is a toxic, persistent pollutant that bio-accumulates and biomagnifies through food webs. In sediments, divalent mercury (mercuric ion) may be converted to methylmercury by bacterial action or by a non- enzymatic reaction with methylcobalamine under anaerobic conditions. Any methylmercury formed is then rapidly taken up and bioaccumulated by living organisms (WHO 1976). In terms of protection of human health, methylmercury is of more concern than the other forms of mercury. People are exposed to methylmercury mainly through their diet, especially through the consumption of freshwater and marine fish and consumption of other animals that consume fish (such as marine mammals). People may be exposed to elemental or inorganic mercury through inhalation of ambient air during occupational activities. Occupational exposures can occur where mercury or mercury compounds are produced, used in processes, or incorporated in products. Exposures to elemental mercury or inorganic mercury forms can also occur due to inhalation of dust particles, absorption through the skin, ingestion of soil, and consumption of vegetables grown locally in contaminated soil.

4.2 Possible Health effects

All humans are exposed to some low levels of mercury. The factors that determine the occurrence and severity of adverse health effects include:

- The chemical form of mercury;
- The dose;
- The age or developmental stage of the person exposed (Human foetus is considered to be the most susceptible);
- The duration of exposure; and
- The route of exposure (inhalation, ingestion, and dermal contact). Dietary patterns can increase exposure to a fish-eating population when fish are contaminated with mercury.

The primary targets for toxicity of mercury and mercury compounds are the nervous system, the kidneys, and the cardiovascular system. It is generally accepted that developing organ systems (such as the foetal nervous system) are the most sensitive to toxic effects of mercury. Foetal brain mercury levels appear to be significantly higher than in maternal blood and the developing central nervous system of the foetus is currently regarded as the main system of concern as it demonstrates the greatest sensitivity. Other systems that may be affected include the respiratory, gastrointestinal, hematologic, immune, and reproductive systems.

Effects on the nervous system (especially the developing nervous system) appear to be the most sensitive toxicological endpoint observed following

13

exposure to elemental mercury and methylmercury, while damage to the kidneys is the key end-point in exposure to inorganic mercury compounds.

4.3 Susceptible populations

Generally there are two susceptible subpopulations, namely, those who are more sensitive to the effects of mercury and those who are exposed to higher levels of mercury. The foetus, the newborn and children are especially susceptible to mercury exposure because of the sensitivity of the developing nervous system. In addition to *in utero* exposures, neonates can be further exposed by consuming contaminated breast milk. Thus, new mothers, pregnant women, and women who might become pregnant should be particularly aware of the potential danger of methylmercury. Individuals with diseases of the liver, kidney, nervous system, and lung are also at higher risk of suffering from the toxic effects of mercury.

4.4 Determination of safe level of mercury in soil

In order to estimate a "safe" concentration of mercury in soil, all routes of exposure must be considered as well as the environmental factors that influence the transport and fate of mercury and the anticipated effect of microbe-mediated processes in the soil. Some of these routes may be negligible and can be ignored. If all the normal exposures are subtracted from an allowable daily intake, then the remainder can be apportioned to the soil.

Many assumptions had to be made in the derivation of a soil guideline for mercury. Published estimates or assumptions were used whenever possible, but in cases for which there was no published information, estimates or assumptions were made subjectively to represent the worst case to be reasonably expected.

4.4.1 Principles of Human Exposure Assessment

Exposure assessment is the process of estimating or measuring the magnitude, frequency and duration of exposure to the receptors. Exposure is defined as contact between a chemical and the external surfaces of the human body. There are three main routes of entry for chemicals into the body.

- By ingestion through the mouth
- By inhalation through the nose and mouth
- By absorption through the skin

Intake is the amount of a substance ingested or inhaled by an individual. It is a function of chemical characteristics and the behaviour patterns of the target population. Intake is expressed in terms of a mass of chemical per kilogram body weight per day. The intake dose is the most commonly used metric for exposure in toxicity studies. Although, the internal (uptake) dose causes the majority of adverse effects on health, it is the intake dose which is the exposure metric that is often most used for risk assessment.

Uptake is the amount of a substance that enters the body following absorption by the gastrointestinal and/or pulmonary system or through the skin. The proportion of an ingested chemical that is absorbed from the gut into the body and reaches systemic circulation unchanged is referred to as the bio-available fraction.

$$ADE = \left(\frac{IR_{ing} \times EF_{ing} \times ED_{ing}}{BW \times AT}\right) + \left(\frac{IR_{inh} \times EF_{inh} \times ED_{inh}}{BW \times AT}\right) + \left(\frac{IR_{derm} \times EF_{derm} \times ED_{derm}}{BW \times AT}\right)$$

Where,

ADE = Average daily human exposure to a chemical from soil, mg kg^{-1} bw day^{-1}

IR = Chemical intake/ uptake rate, mg day^{-1}

EF = Exposure frequency, days $year^{-1}$

ED = Exposure duration, year

BW = Human body weight, kg

AT = Averaging time, days

The subscripts ing, inh and derm apply to the ingestion, inhalation and dermal contact routes respectively. IR_{ing} and IR_{inh} are normally estimated as intakes. IR_{derm} is normally estimated as an uptake.

Exposure frequency (EF) is related closely to the chemical intake/ uptake rate. It represents the number of days per year in which a daily exposure event is considered to occur. For example, the conceptual model for a residential property might assume that the exposure frequency for inhalation of household dust is 365 days per year. In the conceptual model, a frequency is assigned to each exposure pathway. In the present case, frequency is assigned directly for the respective generic land use scenario. Exposure frequency multiplied by the exposure duration gives the total exposure period for each pathway.

An important assumption is that the soil concentration is fixed over the duration of exposure. Although natural degradation process will gradually reduce the concentration of contaminants in surface and near surface soils, the rate at which this occurs is highly site-specific. Precautionary principle must therefore be to assume no degradation.

Average daily exposure is estimated from chemical intake/ uptake rates over a specified time period, the exposure duration (ED). The model considers chronic exposure scenarios (that is long-term low levels of exposure). ED is a critical parameter in exposure assessment and depends on the choice of time interval depends on the critical receptor. Many physical parameters (such as body weight) and those exposure parameters influenced by behaviour vary with age. For example, the soil ingestion rates for young children are likely to be significantly different from those of an adult.

The model estimates the average daily exposure over the period of exposure. Averaging time is assumed to be equal to the exposure duration. For example, a period of exposure covering the first six years of a child's life has an averaging time of 2190 days. The model estimates average daily exposure over the period of exposure. Averaging time (AT) is assumed to be equal to the exposure duration.

Actual daily exposure to soil contamination will vary considerably, especially where daily exposure is an amalgamation of individual events such as hand-to-mouth contacts, skin contact with soil and consumption of contaminated produce. It is generally recognized that young children, predominantly because of exposure pathways such as soil ingestion are likely to have higher average daily exposure to contaminants than seen in adults. Combining these higher exposure rates with their lower body weight means that a child's exposure to soil contaminants is likely to be considerably higher than for a corresponding adult over the same duration.

4.4.2 Defining the exposure scenario

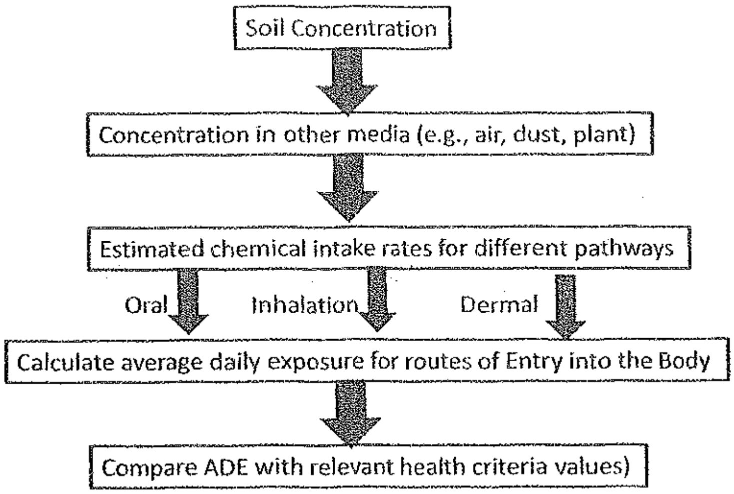
The model estimates chronic exposure to contaminants for people living and/ or working on the contaminated site. Central to defining the exposure scenario is the land use. This helps to identify the types of people that use the site, the types of activity they undertake, and the extent to which such activity patterns involve direct or indirect contact with soil. There are three factors to consider when identifying the critical receptor:

- Susceptibility of the presence of soil contamination,
- Likelihood that a receptor is present based on the category of land use,
- Likely degree of contact with soil or indirect contact with other contaminated media such as vegetables or airborne soil particles.

A young child is considered as the critical receptor because of the combination of higher childhood exposure for key pathways such as soil ingestion and lower bodyweight, which results is a higher estimated ADE. In addition the children are known to be more sensitive to the toxicity of chemicals.

Land use provides boundaries to formal and informal activities and helps to describe how people potentially behave. Factors considered include the frequency and duration of visits to the site and specific areas within the site, the likely activities that could bring about contact with soil contamination (for example growing fruits and vegetables). Combining the choice of critical receptor with the pattern of likely exposure will define the choice of exposure duration and averaging time.

Figure 1: Steps to estimating human exposure



Assumptions:

Soil concentration:

- Chemical composition is uniformly distributed from the soil surface to a depth consistent with the root zone of edible plants. Site investigations provide the details on the type of contaminant present and its distribution across the site (both horizontal and vertical).
- Chemical form is assumed to be the realistic worst case.
- Chemical concentration is fixed over the duration of exposure. Loss mechanisms including physical transport, dilution and degradation can be investigated and taken into account.

Media concentration:

- Estimated using reasonable worst case assumptions about the source of contamination and migration pathways. Soil investigations involved measurements of concentrations in various media including soil, plants and ambient and indoor air.

Estimated intakes:

- Likely exposure pathways based on reasonable worst case.
- Exposure characteristics based on reasonable worst-case behaviours including fruit and vegetable consumption, soil ingestion and dermal contact.

Health criteria values

All chemicals have the potential to cause harm to human health depending on the duration and level of intake. In the setting of soil guideline values (SGVs), health criteria value (HCV) is the collective term used to describe a level of exposure to a chemical derived from toxicity data for the purpose of safeguarding the human health.

Intake and/or uptake via different routes (via the nose, mouth, or through the skin) may lead to different local effects or may affect different organs. Adults and children using a contaminated site may be concomitantly exposed to the same via all three routes of exposure. The contaminant may produce systemic critical toxicity; therefore, each route of exposure may contribute to an aggregate systemic effect. Hence, total risk is the sum of risks from exposure by all routes.

Residential land use

This generic scenario assumes a typical residential property consisting of a two-storey house built on a ground-bearing slab with a private garden consisting of lawn, flowerbeds and a small fruit and vegetable patch. The occupants are assumed to be parents with young children, who make regular use of the garden area.

Exposure pathways

The young child may be exposed to the chemicals from soil in a number of ways through playing in the home garden, eating home grown produce, direct soil and dust ingestion and breathing indoor and outdoor air. An important judgement is to be made as whether the household is able to grow its own fruit and vegetables in the garden and what proportion of produce is grown in the garden. It is assumed that the property receives its water supply through public supply pipes and not through from a private well which is contaminated.

Total skin area and exposed skin area

$SA = 0.02350\ H^{0.42246}\ W^{0.51456}$

Where,

SA = Total body skin area, m^2

H = Body height, cm

W = Body weight, kg

However, it is reasonable to assume that not all the body will come into contact with soil and indoor dust across a range of typical activities such as playing and gardening. It is therefore necessary to judge the amount of exposed skin during indoor and outdoor activities, where direct surface contact is possible. Typical coverage of clothing can be used to establish the maximum exposed skin are for children and adults. The maximum exposed skin fraction is used to calculate the exposed skin fraction.

$$SE = \frac{SA\beta \max}{3}$$

Where,

SE = Exposed skin area, m^2

SA =Total body skin area, m^2

βmax = Maximum exposed skin fraction, $m^2\ m^{-2}$

Inhalation rate

In exposure assessment, the chemical intake is usually estimated as a function of the inhalation rate, which is the product of the number of breathing cycles and the respired air volume for each cycle. The inhalation rate depends partly on physical characteristics (for example, age, sex, body size and fitness level) and partly on the activity and work rate.

4.4.3 Allowable Daily Intake

The method adopted for estimating allowable daily intake has been taken from Bashor and Turri (1986).

WHO has established a provisional tolerable daily intake of 2 µg/kg bw/day for total mercury and a provisional tolerable weekly intake of 0.0016 microgram per kilogram body weight for methylmercury.

Following Tables list the average amounts of mercury absorbed from drinking water, and the inhalation of ambient air by different age groups of the population.

Table 1: Daily Exposure Estimates

a) Air

Population of Concern	Mercury in Air# (µg/m^3)	Inhalation Rate## (m^3/day)	Body Weight ## (kg)	Daily Exposure Estimate (µg/kg-day)	Daily Exposure Estimate (µg/day)
Children	0.01	18.7	20	0.00935	0.187
Women of Childbearing Age	0.01	20.0	60	0.00333	0.200
Adults in the General Population	0.01	20.0	70	0.00286	0.200

 # ERM has detected the average vapour concentration of mercury as 0.01µg/m^3 during April 2006.

##USEPA (1989)

b) Water

Population of Concern	Mercury in water@ (µg/L)	Ingestion Rate(L/day)@@	Body Weight (kg)	Daily Exposure Estimate (µg/kg/day)	Daily Exposure Estimate (µg/day)
Children	0.3	1	20	0.015000	0.300
Women of Childbearing Age	0.3	2	60	0.010000	0.600
Adults in the General Population	0.3	2	70	0.00857	0.600

@ *URS has detected the average mercury concentration as < 0.0003 mg/L.*

@@USEPA (2000)

Chronic Daily intake of mercury (CDI) =intake of mercury from (air + water)

CDI Children = 0.02435µg/kg/day

CDI Women of childbearing age =0.01333µg /kg/day

CDI Adults in the General Population= 0.01143 µg/kg/day

CDI of mercury is highest in children. Therefore, children are the considered as the most sensitive receptor.

Inhalation of Resuspended Particles from Soil

The amount of mercury that can be inhaled due to absorption of mercury onto dust particles is dependent on the level of activity or stress applied to the soil, the respiration rate of persons ex- posed, and the concentration of mercury in the soil. The mathematical model for this, such that a quantity in air can be established, is:

$P \times Cs \times R \times I = C_A$

Where:

P = Soil surface density (g/m^2)

C_S = Soil concentration (µg/g), i.e., site-specific target levels (SSTLs)

R = Resuspension factor (m^{-1})
I = Respiration rate (m^3/day)
C_A = Quantity of contaminated dust in air(μg)

This model assumes that the soil is homogenous and that the particles inhaled are all respirable. The resuspension factor (R) is one technique for estimating the ratio of the air concentration to the soil surface concentrations. Resuspension factors have been predicted for various combinations of particle types and applied stresses. The average volume of air inhaled by an adult is $10m^3$/day (EPA 1984). The surface density of soil is assumed to be 240 kg/m^2 or 2.4×10^5 g/m^2. The above equation is used to predict the concentration of particles resuspended in the air. By substitution this becomes:

$$2.4 \times 10^5 \times Cs \times R \times 18.7 = C_A$$

To find the amount of mercury absorbed due to inhalation of soil particles, the equation must be multiplied by the percentage of inorganic (99%) and organic mercury (1%) and by the percent absorptions (15% and 100%, respectively). The proportion of organic mercury is assumed to be 1% as a reasonable, worst case assumption.

Total Mercury Absorbed from Resuspended Soil

$$= (0.99 \times 0.15 + 0.01 \times 1.0) \times 0.04488\ Cs$$

Simplifying:

$$\text{Total Mercury Absorbed} = 0.00711348\ Cs$$

The inhalation of mercury absorbed onto dust particles is extremely low except for persons working or playing in very dusty, highly contaminated areas. Even in these cases the percent of respirable particles is probably low.

Ingestion of Contaminated Vegetables

If mercuric ion is converted to methylmercury in the soil and if the methylmercury is taken up by plants, then the methylmercury content in locally grown vegetables could be important sources of mercury ingestion. A worst case assumption is made in terms of assuming that 1% of the total mercury in soil is in the form of methyl mercury. The plant shall uptake 40.9% of the methyl mercury present in the soil, whereas the plants uptake 10% of the total mercury.

The daily intake is assumed to be 80 g/day of leafy, legume, root vegetables, and fruits for children. It is assumed that 10-15% of these vegetables will be locally grown.

The amount of mercury absorbed from the ingestion of contaminated vegetables, thus, can be calculated as follows:

Total mercury absorbed from vegetables = 80 g/day x 0.1x 0.15 x Cs =1.2 Cs

Skin Absorption

Researchers (Spear 1977a, 1977b) found that resuspension of pesticide-contaminated soil resulted in pesticide residues on crop foilage that are absorbed through the skin in sufficient quantities to lead to intoxication. Zweig *et at.* (1983) have quantified the linear relationship between foliar residue concentration and dermal exposure. A transfer coefficient, k_a, was defined as the ratio of dermal exposure rate (mg/hr) to dislodgeable foliar residue (DFR, mg/cm^2) with units of area over time. Log-log regression analysis on 43 separate observations showed that all observations fell on the same straight line and the ratios of dermal exposures and DFR (k_d) were within an order of magnitude. The mean value for k_d was calculated to be 7.84×10^3 cm^2/hr. Therefore, a first approximation of the dermal exposure rate is as follows:

Dermal exp. rate (mg/hr) = k_d (cm^2/hr) x DFR (mg/cm^2)

This equation could be used to estimate the dermal exposure rate to mercury from contact with dust-contaminated leaf surfaces in home gardens in Kodaikanal. The actual absorption would depend upon the form of the mercury. Skin absorption could also occur in children who play in mercury-contaminated soil. For exposure to leaf surfaces, the equations are as follows:

$(P \times Cs \times R)/L = DFR$

where:

P = Soil surface density (g/m^2)

Cs= Soil concentration (μg/g) and

R = Resuspension factor (l/m)

L = Leaf surface area per volume (cm^2/m^3)

$DFR \times k_d \times t \times Absorp_s = Absorp_f$

where:

$Absorp_s$ = Percent dermal absorption t = Time of exposure (hr/day)

$Absorp_f$ = Skin absorption of mercury from foliage (μg/ day)

For exposure directly to soil, the equation is:

$Absorp_s \times C_s$ = Dermal absorption from soil

Metallic mercury and some inorganic forms, especially mercuric chloride, may be absorbed through the skin in appreciable amounts. Several authors report that 5% of mercury in a 2% solution of mercuric chloride was absorbed through intact skin of guinea-pigs over a 5-hour period. There is no quantitative data available for skin absorption of short chain alkylmercuriais in man (WHO 1976). If skin absorption of all types of mercury is assumed to be 5%, then the amount of mercury absorbed from exposure to contaminated foilage is as follows:

$(P \times Cs \times R)/L \times t \times k_a \times 0.05 = Absorp_f$

If: $P = 2.40 \times 10^5\ g/m^2$

$R = 8 \times 10.9\ m^{-1}$

t=1 hour/day

$ka = 10^3\ cm^2/hr$

$L = 1550\ cm^2/m^3$

then:

$Absorp_f = 2.8 \times 10^{-5} \times C_s$ μg/day

This is negligible and will not be considered further.

The amount of mercury absorbed directly from soil is $0.05C_s$, if 5% absorption is assumed as a worst case.

Ingestion of Soil

The Centers for Disease Control has predicted that children will ingest about ten grams of soil per day (Ford and Gurba 1984). It is assumed, also, that children playing in soil may ingest one gram of soil per day (average play time as 1 hour).

The amount of mercury absorbed from the ingestion of soil can be calculated as follows:

Total Mercury Absorbed from Soil = 0.15 x 0.99 x Cs x 1g soil/day + 1.0 x 0.01 x Cs x1gsoil/day

Where:

Absorption of inorganic mercury = 0.15

Inorganic mercury in soil = 0.99

Percent absorption of organic mercury =1.00

Organic mercury in soil = 0.01

Cs = Concentration of total mercury in soil (μg/g)

Therefore, Total Mercury Absorbed from Soil = 0.16 x Cs μg/day

Table 2: A general equation for an allowable concentration of mercury in soil

(Allow) = (Wat) + (Air) + (Food) + (FoodCon) + MeHg x $AbsorP_m$ x Soil x Cs + InHg x Absorp x Soil x Cs + MeHg x AbsorPmi x R x P x Cs + InHg x Absorpu R x P x Cs+ $Absorp_s$ x Cs
Where:
(Allow) = Allowable limit for total mercury intake
(Wat) = Amount of mercury absorbed from drinking water, adjusted for % absorption
(Air) = Amount of mercury absorbed from ambient air, adjusted for % absorption
(Food) = Amount of mercury absorbed from other foods, adjusted for % absorption
(FoodCon) = Amount of mercury absorbcd from food grown on contaminated soil, adjusted for % absorption
MeHg = % organic mercury
$Absorp_m$ = %, absorption of organic mercury by the gastrointestinal tract
Soil = Amount of soil ingested per day
Cs = Concentration of mercury in soil
InHg = % inorganic mercury
$Absorp_i$ = % absorption of inorganic mercury by the gastrointestinal tract
$AbsorP_{mi}$ = % absorption of organic mercury by in- halation
R= Resuspension factor, m^{-1}
P= Soil surface density, weight/m2
$Absorp_a$ = % absorption of inorganic mercury by inhalation
$Absorp_s$ = % absorption of mercury through skin

Based on data available, an equation for calculating an acceptable soil concentration of mercury can be written as follows:

ADI = average background absorbed + Hg absorbed through skin + excess Hg in air absorbed + Hg absorbed from soil ingestion + Hg absorbed from contaminated vegetables

Substituting into the above equation gives:

$40\ \mu g/day = 0.487\ \mu g/day + 0.05\ C_s\ \mu g/day + 0.00711348\ \mu g/day + 0.16Cs\ \mu g/day + 1.2\ Cs$

Therefore, Cs, Site-specific target levels (SSTLs) = 28.01ug/g = ~ 28 μg/g

5.0 Ecological Risk Assessment

The approaches for human health risk assessment and ecological risk assessment are different. Human health risk is estimated for hypothetical individuals, they can be calculated for the points in space at which samples are collected. However, the endpoints for ecological risk assessments are largely defined at the population or community level. Therefore, it is not reasonable to estimate ecological risks at a specific point in space, except as a screening technique.

For assessment of contaminated soils, the human health assessment may assume that human lives for 30 years on a small site, but ecological risk assessment must acknowledge that vertebrate animal populations have large ranges, of which the contaminated area may constitute a small fraction.

Exposure assessments for wildlife and humans differ in several important ways. One key distinction is that many different wildlife species may be exposed, as compared with a single species of concern for a human health assessment. Exposure varies between different species and even between different populations of the same species; behavioral attributes and diet and habitat preferences influence this variation.

Wildlife can be exposed to environmental contaminants through inhalation, dermal contact with contaminated water or soil, or ingestion of contaminated food, water, or soil.

Species chosen for ecological risk assessment

Presence of several avian fauna including sparrow, spotted pigeon have been noted on the site. Animals generally seen at the site include monkey and bison. However, avian fauna is considered to be more critical than the terrestrial mammals (e.g., monkey and bison) due to their lower body weight, smaller home/ foraging range and their food habits which included the worms and insects from the soil. Test species for mercury contamination is considered to be quail (*Terrestrial Toxicity Reference Values (TRVs),* Manual: ERD-AG-003, 04/06/99). Toxicity reference values for most critical species of birds (quail), i.e., toxicity benchmark (NOAEL, mg/kg/d) is 0.45 mg/kg/d.

It is to be noted that quails are not present at the site, therefore it was decided to undertake an estimation of ecological risk for quails as well as sparrows (spotted pigeons), which will likely result in an even safer target level due to the relatively lower body weight of sparrows. Also sparrows are generally attracted to buildings for nesting and cover, hence are important species to be considered for the ecological risk assessment.

Ecological Risk Estimates for Quail

Quail are ground-dwelling birds with short, heavy bills adapted for foraging on the ground for seeds and insects. Most species inhabit brush, and open woodlands; some inhabit parklands.

Following are the calculations of determining site-specific target levels (SSTLs) for the ecological receptors.

- Concentration of Hg in soil = C_s
- Average body weight of the individual bird (BW) = 190 gm
- Food intake by bird (FI) = $0.648 \times BW^{0.651}$
- Home range/ foraging range = 9.98 ha (average for different seasons)
- Contaminated soil area = 0.859 ha
- Ratio between contaminated area and home range = 0.086072
- Hg directly ingested from soil (10%of FI) = $1.972621 \times C_s$

- Percentage of food taken as insects = 11.75% (average for different seasons)
- Accumulation factory of mercury for insects = 1.21
- Percentage of food taken as earth worms = 22.83% (average for different seasons)
- Accumulation factor of mercury for earth worms = 0.40
- Hg directly ingested from soil (10%of FI) = 1.972621 x C_s
- Hg ingested through insects as the part of food= 0.1175 x 0.086072 x 1.21 x 19.7221 x C_s = 0.241345 x C_s
- Hg ingested through earthworms as the part of food= 0.2283 x 0.086072 x 0.40 x 19.7221 x C_s = 0.155018 x C_s

- Toxicity Benchmarks, no observable adverse effects level (NOAEL) = 0.45 mg/kg/d (*Terrestrial Toxicity Reference Values (TRVs),* Manual: ERD-AG-003, 04/06/99)

- 0.45 x BW = (1.972621 + 0.155018 + 0.241345) Cs

Cs (for quails) = 36.09 mg/kg or µg/g.

Therefore, Cs, Site-specific target levels (SSTLs) = 36.09 mg/kg or µg/g.

Ecological Risk Estimates for Sparrows

B. Sparrows are very social birds and normally flock together. The flock's range covers 2.4 – 3.2 Km, and can cover a larger territory if required when searching for food. The sparrow's main diet is broad. The diet mainly consists of grain seeds, weeds and insects. It is a small stocky bird that weighs 26 to 32 grams. This bird has a wing span of 19-25 cm and is 14 – 16 cm long. They are attracted to buildings for nesting and cover.

Following are the calculations of determining site-specific target levels (SSTLs) for the ecological receptors.

- Concentration of Hg in soil = C_s
- Average body weight of the individual bird (BW) = 29 gm
- Food intake by bird (FI) = 0.648 x $BW^{0.651}$ = 5.8 gm
- Home range/ foraging range = 2.4 – 3.2 Kilometres (average)

- Contaminated soil area = 0.859 ha
- Ratio between contaminated area and home range = 0.0014
- Hg directly ingested from soil (10%of FI) = 0.58 x C_s
- Percentage of food taken as insects = 11.75%
- Accumulation factory of mercury for insects = 1.21
- Percentage of food taken as earth worms = 22.83% (average for different seasons)
- Accumulation factor of mercury for earth worms = 0.40
- Hg directly ingested from soil (10%of FI) = 0.58 x C_s
- Hg ingested through insects as the part of food= 0.1175 x 0.0014 x 1.21 x 5.8 x C_s = 0.001151 x C_s
- Hg ingested through earthworms as the part of food= 0.2283 x 0.0014 x 0.4 x 5.8 x C_s = 0.000739 x C_s

- Toxicity Benchmarks, no observable adverse effects level (NOAEL) = 0.45 mg/kg/d (*Terrestrial Toxicity Reference Values (TRVs)*, Manual: ERD-AG-003, 04/06/99)

- 0.45 x BW = (0.58+0.001151+0.000739) Cs

Cs (for sparrows) = 22.42 mg/kg or µg/g.

Therefore, Site-specific target levels (SSTLs) with reference to ecological risk assessment is 22.42 mg/kg (or µg/g).

6.0 Conclusions and Recommendations

It is to be noted that there are no safety factors added to these calculations because the criteria for mercury intake developed by World Health Organization already has sufficient safety factors incorporated.

It is recommended that the soil shall be remediated upto the lower of the values suggested based on human health risk assessment and ecological risk assessment. Therefore, site-specific target levels (SSTLs) shall be **22.42 µg/g**.

49

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