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ENV-6.00

MEMORANDUM

JAN 7 1994

To: Chief, Activity Management Branch, D-5930

From: James S. Pierce
Chief, Materials Engineering Branch

Subject: Krejci Dump Site Surface Soil Sampling Requirements

The attachment to this memorandum provides the surface soil sampling requirements for the Krejci Dump site with supporting calculations. This memorandum is the primary document discussing the rationale for the selection of sampling density and methodology. It is referenced in the Work Plan su. cted to the National Park Service and the State of Ohio.

Attachment

cc: D-3730, D-3734 (chron)
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D-3734 (Gemperline)
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D-5930 (McCaig)
(w/2 copies attachment)

WBR:MGemperline:hh:09/16/93:64319
Revised:MGemperline:01/06/94
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Bureau of Reclamation (BOR) 1994. Internal Memorandum. “ Krejci Dump Site Surface Soil Sampling Requirements”.
From, Chief, Materials Engineering Branch, D-3730. To, Chief, Activity Management Branch, D-5930, ENV-6.0, January 7, 1994.

Determination of Krejci Dump Site Surface Soil Sampling Requirements

This appendix is divided into three parts. The first part discusses the minimum number of samples required for surface soil hot spot detection. The second quantifies uncertainty in the measurement of the mean decision unit concentration. The third outlines the decision making process and logic.

Part 1. Minimum Number of Samples Required for Surface Soil Hot Spot Detection

Introduction

The following discussion focuses on determining the minimum number of samples required to detect a surface hot spot which would pose a threat to human health in the vicinity of the Krejci dump site. The analysis is restricted to surface soils which may be present ingestion or dermal contact hazards.

A greater than 5 percent chance of not finding a hot spot, or the cumulative sum of hot spots, having a size and mean concentration such that the Hazard Index of an Exposure Unit is greater than 1 or the cancer risk is greater than 1E-4 is considered unacceptable. The size of a hot spot that needs to be detected depends on the hot spots mean concentration. The higher the mean concentration the smaller the hot spot which would be considered unacceptable. The smaller the hot spot, the more difficult it is to detect and consequently more samples are required to find it.

The analysis requires developing the characteristics of a smallest hot spot that could reasonably exist at the site which would result in an unacceptable cancer risk or a calculated hazard index to be above 1. A distribution of contaminants in this hot spot is hypothesized based in part on previously measured site contaminant concentrations. Common statistical methods are applied to determine the number of samples required to assure that at least one sample in N random sampling events will be obtained from within the hypothetical smallest significant hot spot at a detectable concentration.

Many site and exposure conditions are simplified for mathematical convenience. These simplifications are discussed so the reader may develop an understanding of the uncertainties involved in the calculation.

Two sets of calculations are presented. The first set which is summarized in tables 1 and 2 calculates the minimum number of samples required for the east and west sites independently. The second set calculates the minimum number of samples required for independent red and orange decision units located within the East and West Site. The first set is presented to describe the calculation derivation without the added complexity of multiple decision units. The results of the second set of calculations provides the most appropriate calculated required number of samples for individual Krejci Dump Site decision units. The terms exposure unit and decision unit will be defined in more detail at appropriate locations in the subsequent discussion.

Exposure Units

The Krejci site consists of two exposure units, the east site and the west site. They are physically separated by highway 271 as shown on figure 1. This distinction implies that the population which has potential to be exposed to East site contaminants will not be exposed to contaminants which may exist on the West site. Conversely, the population which has potential to be exposed to West site contaminants will not be exposed to East site contaminants.

Hot Spot Model

The mean concentration of a hot spot may be approximated from data obtained in previous investigations and a simple hot spot contaminant distribution model. The hot spot model diagramed in figure 2 is adopted for this purpose.

The model hot spot is circular in plan view. Its highest concentration,Cmax, is in the center. Concentration decreases linearly with distance from the center. The mean value can be shown to be 1/3 the maximum concentration. It is necessary to estimate the maximum concentration to use the model. A reasonable maximum concentration is estimated as follows.

Previous action at the site attempted to remove observable contaminants and obviously contaminated soil. These materials were drummed and latter characterized. Maximum contaminant concentrations in these drums represent the maximum site soil contaminant concentration at the time of the removal action. The

maximum measured concentrations of contaminants of concern, COC's, are indicated as C_{past} in table 1. Uncontained site contaminant concentrations have decrease with time by biological degradation, volatilization, leaching, diffusion, and mechanical dispersion. Consequently lower maximum concentrations should exist on the site today. For example, it has been calculated that, during a six year period, volatilization of PCB's can reduce the soil concentration by approximately 50 percent(EPA, 1991).

Except for PCB's the value of the past maximum measured concentration, C_{past}, are used to represent C_{max}. The average hot spot concentration, C_{ave} is estimated as 1/3 C_{max}. These values are indicated in table 1. The maximum concentration of PCB's in soils at the site was reduced by 50 percent to reflect volatilization which is expected to have occurred since the 1987 removal action. The corresponding average concentration (C_{ave}) in a hot spot at the site is estimated as 1/3 of the reduced maximum value as indicated in table 1.

Normalized Concentration

The concept of normalized concentration is introduced to simplify calculations when multiple contaminants are involved. The concept is to convert real contaminant concentration to the equivalent concentration of a user selected standard contaminant so that it reflects an equivalent toxicity or carcinogenic risk. Consequently, calculations are made with a user selected standard

contaminant and its corresponding toxicity or carcinogenicity instead of multiple contaminants with varying toxicity. Beryllium is selected as the standard for non-carcinogenic calculations and PCB is selected as the standard for calculations involving carcinogens.

The normalization is based on the commonly used methods of calculating the hazard index and cancer risk (EPA 1989). It is commonly accepted that a calculated hazard index less than 1 indicates an acceptable level or human health risk for an exposure unit. The following equation exemplifies how the Hazard Index is calculated for multiple contaminants:

$$HI = \frac{M_1}{Rfd_1} + \frac{M_2}{Rfd_2} + \cdots + \frac{M_i}{Rfd_i} \qquad (1)$$

where : Rfd_i = reference dose for contaminant i

M_i = daily mass of absorbed contaminant i

The following expression is obtained by dividing both sides of the equality by Rfd_1 and rearranging.

$$HI = \frac{1}{Rfd_1} * \left(M_1 + M_2 * \frac{Rfd_1}{Rfd_2} + \cdots + M_i * \frac{Rfd_1}{Rfd_i}\right) \qquad (2)$$

The term in parentheses represents the absorbed mass of contaminant normalized with respect to contaminant 1.

For simplicity, assume that the absorbed mass of a contaminant is

$$HI = \frac{K}{Rfd_1} * \left(C_1 + C_2 * \frac{Rfd_1}{Rfd_2} + \cdots + C_i * \frac{Rfd_1}{Rfd_i}\right) \qquad (3)$$

given by:

where K is a constant associated with exposure and contaminant absorption and is the same for all contaminants. C_i is the average concentration of contaminant i in the exposure unit. Substituting equation 3 into equation 2 yields:

$$M_i = K * C_i \qquad (4)$$

The expression in parentheses is the sum of the normalized concentration of all contaminants with respect to contaminant 1. Note that K can easily be made a function of the absorption characteristics of each contaminants resulting in a K_i value associated with each term in parentheses. However, the uncertainties in estimating the percent absorption associated with dermal contact and ingestion make its inclusion a moot point.

The calculation of normalized concentrations for carcinogens is the same as for non-carcinogens except that the Rfd value is replaced with the following calculated value Rfd^*_i:

$$Rfd_i^* = \frac{Risk}{SlopeFactor_i} \qquad (5)$$

where risk = dimensionless term representing acceptable carcinogenic risk

slope factor = slope of line representing risk vs ratio of daily adsorbed mass of contaminant to body mass.

The normalization factors representing the ratio of Rfd_{Be}/Rfd_i and Rfd^*_{PCB}/Rfd^*_i for non-carcinogen and carcinogen COC's

are presented in table 1. A hazard index equal to 1, calculated by equation 4 using Rfd_i* values of equation 5, would indicate a risk equal to the risk value used in equation 5.

Normalized C_{max} and C_{ave} concentrations for each COC are presented in table 1. The cumulative values of C_{max} and C_{ave} are presented in table 2 for the beryllium and PCBs standards.

Human exposure and risk model

As stated earlier, the size of the hot spot that needs to be detected depends on the mean hot spot concentration. It also depends on the adsorbed dose of contaminants which would result in a hazard index equal to 1 or a human health risk equal to 1E-4. The adsorbed dose depends on the rate and duration of soil ingestion and dermal contact.

The term maximum allowable adsorbed daily dose, MADD, is introduced to describe the mass of normalized contaminant which may be ingested daily without unacceptable risk. MADD is calculated using the Reference Dose (Rfd) or the slope factor. The Rfd is multiplied by the mass of a person to obtain MADD for non-carcinogens. Likewise the reciprocal of the slope factor is multiplied by risk and the mass of a person to obtain MADD for carcinogens.

Sixteen kilograms is used to represent the mass of a potential receptor of contaminants at the site. The calculated maximum adsorbed daily doses (MADD) for selected standard contaminants, Beryllium and PCB's, are shown in table 2.

It is the goal of this analysis to determine the minimum number of samples required to detect the smallest hot spot having a mean concentration large enough to result in a person acquiring the maximum allowable daily dose, MADD.

A person spending one percent of a 70 year life on the site will spend approximately 250 days on the site. A person spending 250 days in an exposure unit during their lifetime is considered a reasonable value for a conservative estimate of long term exposure. A reasonable yet conservative short term exposure scenario is a person spending 100 percent of his time at the site.

Carcinogens are the primary concern when considering the long term scenario; non-carcinogens are the primary concern when considering the short term scenario.

A typical value used for soil ingestion (SI) is 200 mg of soil per day. A reasonable value of dermal exposure (DE) to soil is 10000 mg per day. Let the expression SIA represent the fraction of the ingested contaminant which is adsorbed into the body. Likewise, let DEA represent the fraction of the contaminant encountered by dermal exposure which is adsorbed into the body. The values of SIA and DEA used in this analysis are presented in table 2. The equivalent daily soil exposure (EDSE) is introduced to simplify subsequent calculations. It is defined as the equivalent daily mass of soil exposure for which 100 percent of the contaminant is adsorbed.

The equivalent daily lifetime soil exposure (EDLSE) is the

$$EDSE=SI*SIA+DE*DEA \quad (6)$$

average daily equivalent soil exposure a person might be subject to over a lifetime. It is calculated as:

$$EDLSE=EDSE*\frac{250days}{lifetime}*\frac{1lifetime}{70years}*\frac{1year}{365days} \quad (7)$$

The equivalent daily soil exposure (EDSE) represents a hypothetical soil exposure related to the short term scenario associated with non-carcinogens. The equivalent daily lifetime soil exposure (EDLSE) is significant to the long term scenario associated with carcinogens. The calculated EDSE and EDLSE are shown in table 2 for the beryllium and PCB standard contaminants.

The maximum acceptable uniformly distributed concentration of carcinogenic contaminants within the exposure unit, (C_{index}), is obtained by dividing the maximum allowable daily dose (MADD) by the equivalent daily lifetime soil exposure (EDLSE).

$$C_{index}=\frac{MADD}{EDLSE} \quad (8)$$

Similarly C_{index} associated with non-carcinogenic contaminants is obtained by dividing MADD by EDSE.

Calculated values of C_{index} are shown in table 2 for the beryllium and PCB standards. If the normalized average concentration of contaminants in the exposure unit is less than C_{index}, then the hazard index is expected to be less than 1 and the

carcinogenic risk less than 1E-4.

Hot Spot Size

The smallest hot spot that would cause the average exposure unit concentration to be greater than or equal to (C_{index}) is sought. The contribution to the average exposure unit concentration from a single hot spot is:

$$C = C_{ave} * \frac{A_{hotspot}}{A_{exp}} \quad (9)$$

where: $A_{hot\ spot}$ = area of the hot spot

A_{exp} = area of the exposure unit

C_{ave} = average hot spot concentration = 1/3 C_{max}

C = Average exposure unit concentration

The hot spot area that would cause the average exposure unit concentration to be equal to C_{index} is obtained by setting C = C_{index} in equation 9 and rearranging:

$$A_{hotspot} = A_{exp} * \frac{C_{index}}{C_{ave}} \quad (10)$$

This is the area of the model hot spot which has the maximum concentration at the center as shown on figure 1. Note that as C_{ave} increases $A_{hot\ spot}$ decreases. By selecting C_{ave} = 1/3 C_{max} we obtain the area for the smallest hypothetical hot spot which would, by itself, result in an average exposure unit soil concentration high enough for the hazard index to be greater than 1 or the risk greater than 1E-4.

$A_{hot\ spot}$ for the beryllium and PCBs standards are shown in table 2. Note that if C_{ave} is equal or less than C_{index} then $A_{hot\ spot}$ is equal or greater than the area of the exposure unit and the analysis is no longer valid.

Minimum number of samples required to assure detection of unacceptable hot spot

The number of surface soil samples is sought which assure that at least one sample will be obtained from within the hot spot at a detectable level, C_d, or higher.

Figure 2 shows concentration contours within a model hot spot with C_{max} equal to one. Assume that one of these contours represents the detection limit concentration of the analytical method used to determine soil contaminant concentration. The circle representing this contour defines the area A1 within the hot spot which is detectable. It is calculated by the following expression and presented in table 2.

$$A1 = A_{hotspot} * \left(1 - \frac{C_D}{C_{max}}\right)^2 \qquad (11)$$

The ratio of this area, A1 to the total exposure unit area A_{exp}, is the probability ,P, that a single sampling event at the site will be selected within the detectable region of the model

$$p = \frac{A1}{A_{exp}} \qquad (12)$$

hot spot.

$$\log(0.05) = N * \log(1 - \frac{A1}{A_{exp}}) \quad (19)$$

The probability, q, of failing to sample area A1 with each trial is:

$$q = 1 - p \quad (13)$$

The probability of i successes in N trials, p(i,N), is given by:

$$p(i,N) = \frac{N!}{i! * (N-i)!} * p^i * q^{N-i} \quad (14)$$

Substituting equations 12 and 13 into equation 14 yields:

$$p(i,N) = \frac{N!}{i! * (N-i)!} * (\frac{A1}{A_{exp}})^i * (1 - \frac{A1}{A_{exp}})^{N-i} \quad (15)$$

The probability of having no successes in N trials, p(0,N), is given by:

$$p(0,N) = (1 - \frac{A1}{A_{exp}})^N \quad (16)$$

It is desired to limit the probability of having no samples from within the detectable region of the hot spot to five percent, i.e. p(0,N)= .05. Equating this to the right hand side of equation 16 and rearranging yields:

$$0.05 = (1 - \frac{A1}{A_{exp}})^N \quad (17)$$

$$\log(0.05) = \log(1 - \frac{A1}{A_{exp}})^N \quad (18)$$

$$N = \frac{\log(0.05)}{\log\left(1 - \frac{A1}{A_{exp}}\right)} \qquad (20)$$

As noted earlier, the value of A1 depends on the chemical analytical method detection limit or a higher preselected concentration at which we wish to detect the hot spot. Table 2 shows values of C_d and A1 for beryllium and PCB's. Note that these detection limits also represent the normalized detection limits of analytical methods used to locate individual contaminants. Consequently the maximum detection limit for individual contaminants is determined by dividing the standard contaminant detection concentration by the individual contaminant normalization factor. These calculated values are presented in table 3.

The number of randomly selected samples, N, required to assure that at least one sample will be from within the detectable area of a hot spot having unacceptable risk is calculated using equation 20. The calculated values of N for the east and west site exposure units are presented in table 2.

Although the analysis assumes a single circular hot spot as the worst case, the analysis is also applicable to sites having numerous smaller hot spots that are smaller in size, however demonstrate the same concentration distribution and size as the model hot spot when summed together.

Staged sample plan design

A two stage sampling approach is required for carcinogens (PCB's in this case) because the true maximum normalized carcinogen concentration in the exposure unit is less than the selected screening method detection limit concentration and yet the corresponding hot spot large enough to cause the average normalized concentration to be greater than C_{index}. Detailed analysis of the calculations presented reveals that equation 20 does not yield the minimum required number of samples when the detection limit is greater than $C_{index}/3$. This limitation occurs because the value of A1 decreases as C_{max} approaches C_{index} when the detection limit is greater than $C_{index}/3$. Equation 20 is still applicable when the detection limit of the desired analytical method is greater than $C_{index}/3$, however a staged approach must be used.

In a two stage sampling plan, the purpose of the first stage is to use find small, high concentration hot spots by high density sampling using low cost field screening methods. A second stage involves locating large low concentration hot spots with low density sampling using fewer high cost laboratory methods having lower detection limits.

The staged sampling plan design is accomplished by calculating the solution to equation 20 independently for the field screening detection limit concentration and the more accurate laboratory analytical method detection limit. However, when performing the calculation for the lower detection limit,

the maximum site concentration C_{max} is set equal to 3 times the field screening detection limit. The values of C_{max}, C_{ave}, $A_{hot\ spot}$, A1, and N corresponding to the second stage are presented in table 2. Observe that the number of field screening samples is significantly greater than the number of laboratory samples.

General Equation

Elements of the above analysis can be combined into an equation which gives the general solution for N.

$$N=\frac{\log(.05)}{\log\left(1-3*\frac{C_{ind}}{C_{max}}*\left(1-\frac{C_D}{C_{max}}\right)^2\right)} \qquad (21)$$

where C_{index} is given by:

$$C_{ind}=\frac{Rfd_{Standard}*16}{(SI*SIA+DE*DEA)*\frac{\%t}{100}} \qquad (22)$$

Here the value %t is the percent of the time a person spends in the exposure unit during the period of concern. In the presented analysis %t was 1 percent of a 70 year period for carcinogens and 100% of a any short term exposure period for non-carcinogens. $Rfd_{standard}$ is the reference dose representing the standard contaminant, beryllium, or the risk divided by the slope factor representing the standard carcinogenic contaminant, PCBs. Note that the numerator in equation 22 is the value MADD presented in table 2.

Keep in mind that all concentrations referred to in equations 21 and 22 are normalized with respect to the standard contaminant. Also, C_{max} is the sum of the normalized maximum concentrations of individual contaminants expected in an exposure unit.

Equations 21 and 22 will subsequently be modified to reflect other concerns and used to calculate N without the use of cumbersome spread sheets presented in tables 1 and 2.

Decision Units

Intuitively, lagoons, landfills, and the west site entrance area have a greater probability of contamination than the remainder of the east and west sites. It is prudent to assure that these areas are investigated independently so that their contribution to the exposure unit human health risk be evaluated. Some of these areas seem to warrant a greater sampling density than others. The term decision unit is introduced to identify areas for which independent decisions will be made regarding the required number of samples. The site map on figure 3 shows the decision units in orange and red. These include an east site orange unit and a west site orange unit; two east site lagoons indicated by R3 and R4; and east site and west site landfills indicated by R1 and R5. It is desired that the red decision units have a higher sampling density than the orange decision units. This is because site history indicates that the probability of contamination is greater in these areas and, if remediation is

required, the additional information will assist in alternative analysis selection.

Minimum sampling requirements for decision units

Observe in equations 21 and 22 that the minimum number of samples required does not depend on the size of the exposure unit. For example, the same number of samples for carcinogens would be required to investigate a 1 acre or 1000 acre exposure unit in which a person spends 1 percent of his life.

It is appropriate at this point in the discussion to consider sampling density,SD,which is the required number of samples per unit area. This is calculated by dividing both sides of equation 21 by the exposure unit area A_{exp} .

$$Density = \frac{\log(.05)}{A_{exp} * \log\left(1 - 3 * \frac{C_{ind}}{C_{max}} * \left(1 - \frac{C_D}{C_{max}}\right)^2\right)} \qquad (23)$$

It is not readily apparent, but can be demonstrated, that if the exposure unit area and percent of time spent in the exposure unit are reduced proportionately, the sampling density remains unchanged. Consequently, if the decision unit area A_{des} is substituted for A_{exp} in equation 23 and in equation 22 the percent of time a person spends in a decision unit is reduced by the ratio A_{des}/A_{exp}, then the same sampling density arrived at for the whole exposure unit will also be calculated for the decision unit. This result does not satisfy the desire to investigate

individual decision units with different sampling densities.

The solution to this problem is to assign each decision unit a fractional value, FV, representing the portion of the maximum allowable daily dose, MADD, which is permitted to be absorbed from the surface soils within the decision unit. The values of FV must sum to 1 in each exposure unit. Equation 22 is subsequently rewritten as

$$C_{ind} = \frac{MADD * FV}{(SI * SIA + DE * DEA) * \frac{\%t}{100}} \qquad (24)$$

The selected values of FV for each decision unit is indicated in table 4. These values were selected so that the calculated sampling density in the red zones are approximately double the sampling density in the orange zones.

The calculation of the sampling density,SD, is summarized in table 4 for non-carcinogens and carcinogens. The %t in each decision unit is equal to $1\% * A_{des}/A_{exp}$ for carcinogens and $100\% * A_{des}/A_{exp}$ for noncarcinogens. C_{max}, C_d, A_{exp},SI,SIA,DE,DEA and MADD are the same as the values used to generate table 2. The calculation of C_{index} and SD follow from equations 24 and 23 substituting A_{des} for A_{exp}. The corresponding sample spacing is calculated in feet and meters. Sample density and grid spacing is calculated for both stages of the carcinogen sampling effort and the single stage of the non-carcinogen sampling effort.

It is convenient to use the same sample spacing within all orange decision units and within all red decision units. Stage 1 carcinogen sampling of orange decision units qt 50 foot centers and red decision units at 25 foot centers appears appropriate. These numbers appear to over sample red zones and under sample the west site orange zone. However, considering the uncertainties in the analysis, the spacing is reasonably close to the presented solutions. Stage 2 sampling for carcinogens on 200 foot grid spacing in orange decision units and 150 foot grid spacing in red decision units appears reasonable. Note that only the R1 red decision unit has more than one sample required at the stage 2 detection level. Consequently one sample from a random location in R2, R3, R4, and R5 decision units is adequate. Sampling non-carcinogens with 250 foot grid spacing in the orange decision units and 150 foot grid spacing in the R1 decision unit is adequate. Again, one sample from a random location within R2, R3, R4, and R5 is appropriate.

Part 2. Quantifying maximum expected uncertainty in the measurement of mean decision unit concentration for hot spot contamination which poses a threat to human health

Introduction

Contaminant concentration is not expected to be normally distributed in a decision unit characterized by hot spots. The true distribution of contaminants depends on the hot spot size

and the distribution of contaminants within the hot spot.

The sampling plan must assure that a significant hot spot is adequately sampled if a meaningful estimate of the decision unit mean contaminant concentration is to be made. The number of sampling locations required to determine the mean concentration of the decision unit depends on the allowable uncertainty in the resulting value. The uncertainty in estimating the mean concentration is quantified by making simplifying assumptions regarding the nature of the hot spot.

The significant hot spot of a decision unit, as before, is characterized as shown in figure 2 and has an area calculated by equation 10 substituting A_{des} for A_{exp}. C_{index}, the average decision unit concentration which would pose a threat to human health, calculated by equation 24, is presented in table 4.

The process of selecting the number of specimens to collect in each decision unit is iterative. It involves selecting a specimen collection density, evaluating the uncertainty in the mean decision unit concentration, adjusting the collection density if the uncertainty is unacceptable and repeating the analysis. Only the decision unit specimen collection densities which were finally selected by this process are used in the subsequent discussion on related to quantifying uncertainty.

Composite sampling plan summary

The orange decision units are divided into decision sub-units as indicated on figure 4. These sub-units reflect different

drainage on the plateau surface and consequently it is desired to know the mean concentration of surface contaminants in each. Red decision units will be considered to consist of only one decision sub-unit.

Four composite samples will be created to independently represent the mean concentration in each red decision unit and orange decision sub-unit. Since there are 12 decision units and sub-units there will be 48 independent composites. Tables 5 and 6 define the variables used in the analysis of theses samples.

From the previous discussion on selecting the number of samples for hot spot detection, it is apparent that a larger sampling density is required for detection of carcinogens than non-carcinogens at this site. Consequently, the subsequent discussion will focus on the uncertainty associated with determining the mean normalized carcinogen concentration, PCBs in this case. The uncertainty in calculating the mean normalized non-carcinogen concentration is expected to be less.

Computer modeling

It is desired to understand 1) the uncertainty associated with using a single composite normalized concentration, Cn, to estimate sub-unit normalized mean concentration; 2) the uncertainty with using a mean of the decision sub-unit composite normalized concentrations,Co, to represent the true sub-unit mean; and 3) the uncertainty with using the mean of the composite normalized concentrations in a decision unit, Cm, to represent

the true decision unit mean. These uncertainties are investigated for a hot spot large enough to cause a decision unit or a decision sub unit to have a concentration equal to C_{index}.

Computer simulated specimen collection and compositing was performed for each decision unit and sub-unit characterized as having a single significant hot spot, i.e. a hot spot that would cause the average decision unit or sub-unit concentration to be equal to C_{index}. Note that a smaller hot spot would cause an orange sub-unit concentration to equal Cindex than would be necessary for the orange decision unit as a whole.

One thousand composites were collected from each decision sub-unit. Histograms representing the frequency of the simulated measured composite concentrations,Cn, are presented on figures A-1 through A-10 for each decision sub-unit. The computer modeled mean, C_{index}, is shown on the figure.

One thousand sets of four composites were collected in each decision sub-unit. The mean value of each set was calculated,Co for Co. Histograms representing the frequency of simulated mean composite normalized concentration for each subunit are presented on figures A-11 through A-20.

One thousand times a set of four composites were collected for each sub-unit in the east site orange decision and the concentrations averaged, Cm. This was also done for the west site orange decision unit. Histograms representing the frequency of simulated mean normalized concentration for the decision units are presented on figures A-21 and A-22. Co equals Cm since red

decision units have only 1 decision sub-unit.

If the simplifying assumptions used to develop these figures are correct, the uncertainty is not expected to be greater than is indicated for any condition which poses a threat to human health. For example, if the hot spot is larger, a better estimate of the mean is expected. If the hot spot is smaller it is not expected to pose a threat to human health.

Part 3. Decision Making

It is desired to decide, during the sample collection effort, if detected hot spots require independent investigation, if decision sub-units shown in green and yellow on figure 5 require investigation, if measurements indicate a potential error in the assumptions used to determine the minimum sampling requirements, and when to stop sampling. Flow charts showing the decision process are presented on figures 6 and 7 for red and orange decision units respectively. Tables 5 and 6 define subscripts, variables and values used in these figures.

Boxes 1,2,3 and 4 represents decision steps related to comparing background concentration of naturally occurring contaminants with site concentrations. PCB will not be considered in this step since in is not naturally occurring. Any PCB's found on the site will be considered significant contamination in accordance with the Ohio EPA "How Clean is Clean Policy".

Composite and individual point sampling of the areas shown in blue on the background map on figure 13 will be conducted at

the same sampling density and following the same procedures used for the east site orange decision unit with the following exception. Eight sub-composites will be collected at one eight the composite specimen collection density.

The first decision relies on a comparison of the background composite concentrations with decision unit and sub-unit composite concentrations. The test to determine if significant contamination exist in a decision unit or sub-unit, following Ohio EPA "How Clean is Clean Policy" is then conducted.

Decision 1.

The mean and standard deviation of the background composites will be calculated. The data is expected to demonstrate a log-normal distribution. The desired confidence in the estimated mean background concentration is 10 percent of the maximum detection limit indicated in table 3. This confidence value is attainable by proposed analytical methods and reflects the site specific risk to human health posed by individual contaminants. Additional composites will be collected until the desired confidence in the estimated mean background concentration is attained. Contamination will be considered significant if it is discovered in site composites at, or above, the mean background concentration plus a the product of the tolerance factor and the background standard deviation ,Cb. The site composite concentrations are designated by Cl. The tolerance factor is obtained from a table in the "How Clean is Clean Policy". If Cl

are less than Cb then the decision process moves to decision 2 of the decision tree on figures 11 and 12; otherwise it proceeds to decision 4.

Decision 2.

Samples collected at independent points on the site will be compared with independent point samples from the background area. Again the mean and standard deviation of the background contaminant concentration will be determined using the individual point samples. The desired confidence in the background mean is again selected as 10 percent of the maximum detection limit indicated in table 3. Contamination will be considered significant if it is discovered in site composites at, or above, the mean background concentration plus the product of the tolerance factor and the background standard deviation (Cbh). If the site individual point sample concentrations (Ch) are less than the corresponding background mean concentration plus the product of the standard deviation and the tolerance factor (Cbh) then the sampling program for the decision unit is complete i.e. no significant contamination was found; otherwise it proceeds to decision 3.

Decisions number 3 and greater are required if significant contamination was discovered in a decision unit.

Decision 3

Decision 3 compares the measured mean normalized decision unit concentration Cm with Cind. The mean normalized decision unit concentration is equal to the composite concentration for red decision units; it is equal to the mean of all sub-unit composites for the orange decision units. If Cm is less than Cind then the decision process proceeds to decision 4 ; this implies that the average normalized concentration of the decision unit is not expected to pose a threat to human health. Cind is given on table 4. If Cm is greater than Cind then the decision process proceeds to decision 5; the average concentration is great enough to possibly pose a threat to human health. Yellow decision sub-units adjacent to contaminated red decision units are investigated if the decision process is directed to decision 5 as indicated on figure 11. Yellow decision units are investigated with the same sampling density and procedures used to investigate adjacent orange decision units.

Decisions 4 and 5.

Decisions 4 and 5 make the same comparison but have different outcomes. Decisions 4 and 5 direct the process depending on the potential existence of hot spot contamination. If the normalized concentration of an individual point sample is greater than the values of Cd in table 4 then there is consequential hot spot contamination i.e. hot spots may exist which pose a threat to human health and more extensive investigation may be required. If the normalized concentration of

individual point samples are less than Cd then consequential hot spots are not expected to exist. The process proceeds to decisions 6 or 7 if originating from decision 4; the process proceeds to decisions 8 and 9 if originating from decision 5 and the decision unit is red; the process proceeds to decisions 10 and 11 if originating from decision 5 and the decision unit is orange.

Decisions 6 and 7.

Decision steps 6 and 7 make the same comparison but have different outcomes. Orange decision sub-unit composite concentrations and red decision unit composite concentrations ,Cn, are not expected to exceed the upper limit values Cu shown in table 5 if the mean decision unit concentration is less than Cind. This is the case for decisions 6 and 7. If they do, then the assumptions used in the conceptual hot spot model may be inappropriate and should be reevaluated. This is indicated by a question mark on figures 11 and 12. Otherwise, if Cn is less than Cu, and no consequential hot spots are detected, then the sampling effort in the respective decision unit or sub-unit is complete as indicated by the stop consequence of decision 6 and 7. If consequential hot spots are discovered and Cn is not greater than Cu then the hot spots will be investigated in more detail as indicated by outcome of decision 7.

Hot spots are investigated by quadrupling the sampling density in the vicinity surrounding the location of contaminant

detected at levels above Cd. This is accomplished by sampling the midpoints between the location where contaminant is detected above Cd and the four adjacent sampling locations. The sample density will not be increased to more than four times the original sample density unless presently undefined data needs are identified.

Decisions 10 and 11

Decisions 10 and 11 are only pertinent to Orange decision units. They make the same comparisons but have different outcomes. An orange decision sub-unit mean concentration Co greater than Ct may be measured if the true subunit mean concentration is greater than or equal to Cind. It is desired to investigate adjacent yellow sub-units if this occurs as indicated on figures 6 and 7. If Co is less than Ct it is not likely that the true mean concentration of the decision subunit is greater than Cind and adjacent yellow zones need not be investigated. Decisions 10 proceeds to decisions 8 and 9. Decision 11 proceeds to decision 12.

Decisions 8 and 9

Decisions 8 and 9 are the same as decision 6.

Decision 12

If the mean decision unit composite concentration is greater than Cind and consequential hot spots are detected then it may be

necessary to investigate hot spots in more detail. If a large portion, 30 percent or more, of the independent samples in the decision sub-unit or red decision unit indicate consequential hot spot contamination, then additional sampling is not required to characterize the site. If less than 5 percent of the independent point samples indicate the presence of consequential hot spot contamination then the hot spots will be investigated as described in the decision 7 discussion. If between 5 and 30 percent of the independent point samples indicate the presence of consequential hot spot contamination then the process proceeds to decision 13.

Decision 13

If it appears that the independent point samples which indicate the presence of consequential hot spot contamination are all associated with the same hot spot, indicated by a strong spacial correlation, then there in no need for further investigation. If not, hot spots will be investigated.

Yellow and Green Decision Units

Yellow and greed decision units and subunits are shown on figure . The investigation of yellow sub-units will be only for the contaminant type found in the adjacent orange or red zone. The sampling density will be the same used in the orange decision units. The decision to investigate green decision subunits, adjacent to yellow decision subunits will be made using the same values and decision process which resulted in the yellow sub-unit

investigation.

Table 1. General Information Needed for Calculating Minimum Sample Number Requirement

Exposure Unit	Area (Acres)										
East site	30.30										
West site	16.70										
COC	Cpast (mg/kg)	Cmax (mg/kg)	Cave (mg/kg)	Rfd	Slope Factor	Non-Carcinogen Normalization Factor Standard=Be	Carcinogen Normalization Factor Standard=PCB	Cmax Be Normalized Contaminant Concentration (mg/kg)	Cmax PCB Normalized Contaminant Concentration (mg/kg)	Cave Be Normalized Contaminant Concentration (mg/kg)	Cave PCB Normalized Contaminant Concentration (mg/kg)
Mercury	0.1	0.1	0.0333								
Cobalt	48	40	13.33								
Lead	770	770	256.7								
PCB	8000	4000	1333		8.1		1		4000		1333
Beryllium	0.1	0.1	0.0333	4E-04		1		0.1		0.0333	
Chromium VI	56	56	18.67	0.005		0.08		4.48		1.4933	
Chromium III				1		0.0004					
Cadmium	9.8	9.8	3.267	0.005		0.08		0.784		0.2613	
Nickel	41	41	13.67	0.02		0.02		0.82		0.2733	
Cyanide	0.4	0.4	0.1333	0.02		0.02		0.008		0.0027	
Cresols	3500	3500	1167	0.05		0.008		28		9.3333	
Antimony	2.1	2.1	0.7	4E-04		1		2.1		0.7000	
Barium	3.5	3.5	1.167	0.007		0.0571		0.2		0.0667	
Manganese	42	42	14	1		0.0004		0.0168		0.0056	

Bureau of Reclamation (BOR) 1994. Internal Memorandum. " Krejci Dump Site Surface Soil Sampling Requirements". From, Chief, Materials Engineering Branch, D-3730. To, Chief, Activity Management Branch, D-5930, ENV-6.0, January 7, 1994.

Table 2. Calculations for Minimum Sample Number Requirement

					Cumulative	Cumulative						
	Standard				Normalized	Normalized				West Site	East Site	
	Contaminant	SIA	DEA	MADD	Cmax	Cave	EDSE	EDLSE	CIndex	A hot spot	A hot spot	
				(mg/day)	(mg/Kg)	(mg/Kg)	(mg/day)	(mg/day)	(mg/kg)	(Acres)	(Acres)	
Non-carcinogen	Beryllium	1	0.1	0.006	36.5088	12.1696	1200		5.3333333	7.3187834	13.27899	
Carcinogen	PCB	0.3	0.1	2E-04	4000	1333	1060	10.37182	19.044957	0.2385977	0.4329049	

					Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	Stage 2	Number of	Number of
	Standard	Detection	West Site	East Site	Maximum	Average	West Site	East Site	West Site	East Site	Samples	Samples
	Contaminant	Concentraion	A1	A1	Concentration	Concentration	A hot spot	A hot spot	A1	A1	West Site	East Site
		(mg/kg)	(Acres)	(Acres)	(mg/kg)	(mg/kg)	(Acres)	(Acres)	(Acres)	(Acres)	N	N
Non-carcinogen	Beryllium	1.5	6.730	12.21							6	2
Carcinogen	PCB	50	0.2327	0.422							389	214
	PCB	10			50	16.67	19.08	34.62	12.21	22.16	2	2

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Table 3. Maximum detection limit for individual COCs.

COC	Maximum Detection Limit non-carcinogens	Maximum Detection Limit Carcinogens	Maximum Detection Limit Carcinogens Stage 2
Mercury			
Cobalt			
Lead			50 10
PCB		1.5	
Beryllium		18.75	
Chromium VI		3750	
Chromium III		18.75	
Cadmium		75	
Nickel		75	
Cyanide		187.5	
Cresols		1.5	
Antimony		26.25	
Barium		3750	
Manganese			

Table 4. Calculation of number of samples, sample density, and spacing for decision units.

Decision Unit	Contaminant type	Standard	Cd	Ades acres	%t	FV	Cind	SD	N	Spacing ft	Spacing m
West Site Exposure Unit											
Orange	non-carcinogen	Be	1.5	11.8	70.66	0.5	3.77	0.76	9	240	73
	carcinogen	PCBs	50	11.8	0.71	0.5	13.19	26.20	309	41	12
		Stage2 PCBs	10	11.8	0.71	0.5	13.19	0.97	11	212	65
R1	non-carcinogen	BE	1.5	4	23.95	0.25	5.57	1.37	5	178	54
	carcinogen	PCBs	50	4	0.24	0.25	19.45	52.27	209	29	9
		Stage2 PCBs	10	4	0.24	0.25	19.45	1.81	7	155	47
R2	non-carcinogen	BE	1.5	0.9	5.39	0.25	24.74		<1		
	carcinogen	PCBs	50	0.9	0.054	0.25	86.45	50.97	46	29	9
		Stage2 PCBs	10	0.9	0.054	0.25	86.45		<1		
East Site Exposure Unit											
Orange	non-carcinogen	BE	1.5	26.4	87.13	0.4	2.45	0.55	15	280	85
	carcinogen	PCBs	50	26.4	0.87	0.4	8.56	18.08	477	49	15
		Stage2 PCBs	10	26.4	0.87	0.4	8.56	0.70	19	249	76
R3	non-carcinogen	BE	1.5	1.3	4.29	0.2	24.86		<1		
	carcinogen	PCB's	50	1.3	0.043	0.2	86.87	35.11	46	35	11
		Stage2 PCBs	10	1.3	0.043	0.2	86.87		<1		
R4	non-carcinogen	BE	1.5	1.3	4.29	0.2	24.86		<1		
	carcinogen	PCB's	50	1.3	0.043	0.2	86.87	35.11	46	35	11
		Stage2 PCBs	10	1.3	0.043	0.2	86.87		<1		
R5	non-carcinogen	BE	1.5	1.3	4.29	0.2	24.86		<1		
	carcinogen	PCBs	50	1.3	0.043	0.2	86.87	35.11	46	35	11
		Stage2 PCBs	10	1.3	0.043	0.2	86.87		<1		

Table 5. Subscript definition

i	refers to independent point samples
q	refers to individual composite samples within an orange decision sub-unit or red decision unit.
j	refers to decision unit
r	refers to decision sub-unit
k	refers to individual contaminant
n	refers to either carcinogen or non-carcinogen normalized contaminant
p	refers to sampling stage

Table 6. Variable Definition

Cb_k The mean concentration of composite samples obtained from background plus the product of the standard deviation times a tolerance factor relative to the kth contaminant.

Cbh_k The mean concentration of point samples obtained from background plus the product of the standard deviation times a tolerance factor relative to the kth contaminant.

$Cl_{j,k,q}$ The concentration of qth composite sample in jth decision unit, rth decision subunit, relative to the kth contaminant.

$Cn_{j,n,q,p,r}$ The normalized concentration of the qth composite sample in the jth decision unit, rth decision sub-unit, for the nth normalized contaminant.

$Cm_{j,n}$ The mean normalized concentration of the composite samples in the jth decision unit for the nth normalized contaminant.

$Co_{j,n,p,r}$ The mean normalized concentration of the nth contaminant in the jth decision unit, rth decision sub-unit,in the pth sample stage.

$Ch_{i,j,n,p}$ The normalized contaminant concentration measured in ith point sample of jth decision unit,rth decision sub-unit, for the nth contaminant in stage p.

$Cind_{j,n,p}$ The normalized index concentration for the jth decision unit, pth stage, and nth contaminant. Defined in more detail in previous discussion and presented in table 4. This value represents the lowest average normalized concentration in a

decision unit which could pose a threat to human health.

$Cd_{j,n,p}$ The normalized detection concentration for the jth decision unit, stage p sampling, and the nth contaminant. Based on previous discussion, this value represents the normalized concentration, which if not detected, would assure with 95 percent confidence that a hot spot which poses a threat to human health or the environment is not present. Values are presented in table 4.

$Cu_{j,n,,r}$ The maximum expected normalized concentration of a composite sample in the jth decision unit, rth decision sub-unit, for the nth normalized contaminant if Cm<Cind.

$Ct_{j,n,r}$ The mean normalized concentration of composite samples in the jth decision unit, rth decision sub-unit, for the nth normalized contaminant which, if exceeded when Cm> Cind, would result in the investigation of adjacent yellow decision units.

$N_{j,r,p,n}$ The percentage of point samples having concentrations above Cd in the jth decision unit, rth decision sub-unit, for the nth normalized contaminant and the pth stage.

Table 7. Values of constants.

Carcinogens (normalized with respect to ppm PCB)

Decision Unit	Cind	Cd		Ct	Cu
		Stage1	Stage2		
E - Orange	9	50	10	2	70
E - Red	87	50	10		105
W - Orange	13	50	10	8	45
W - Red					
R1	19	50	10		23
R2	86	50	10		120

Noncarcinogens (normalized with respect to ppm Be)

Decision Unit	Cind	Cd	Ct	Cu
E - Orange	3	1.5	2	4
E - Red	25	1.5		32
W - Orange	3	1.5	2	4
W - Red				
R1	5	1.5		9
R2	25	1.5		32

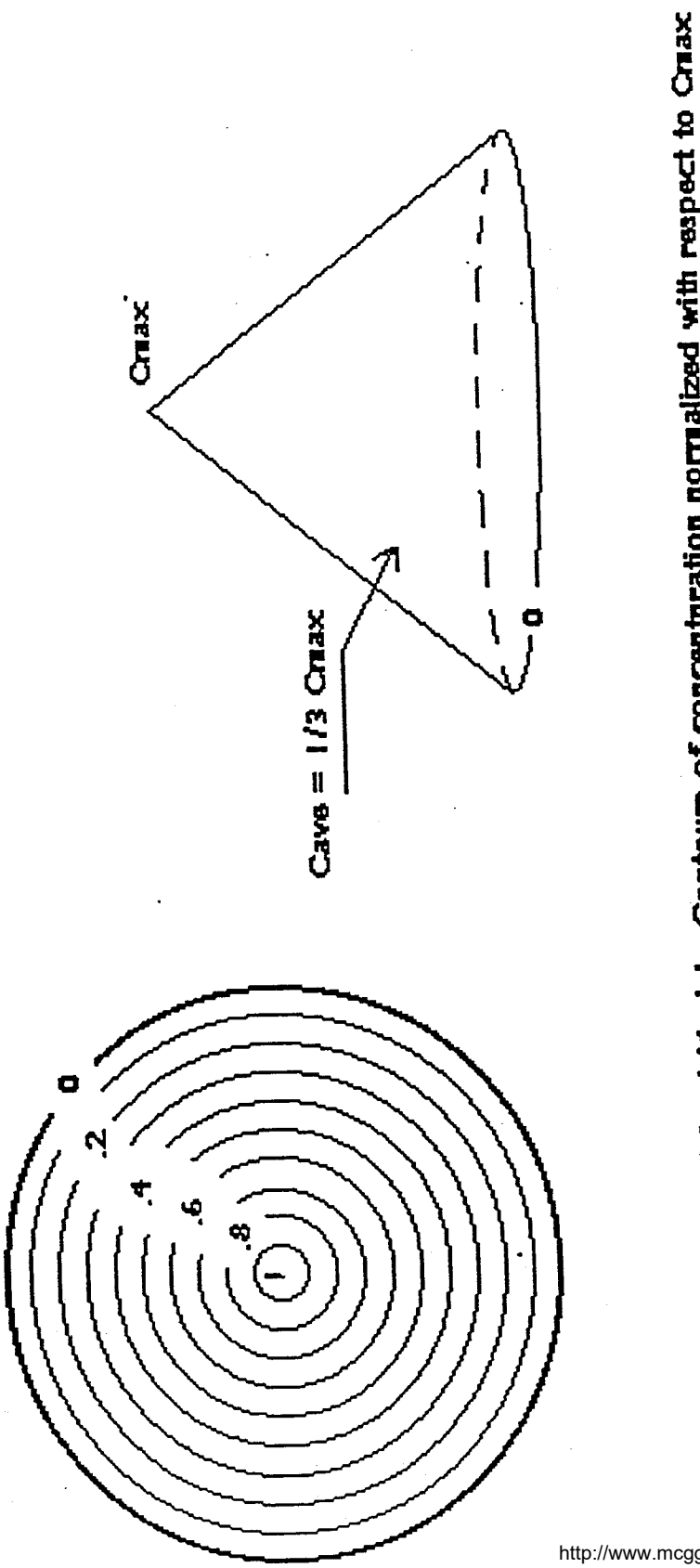

Figure 2. Conceptual Hot Spot Model - Contours of concentration normalized with respect to Cmax

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