HEALTH RISK EVALUATION OF SELECT METALS IN INORGANIC FERTILIZERS POST APPLICATION

Prepared for:

The Fertilizer Institute (TFI)

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EXECUTIVE SUMMARY

An evaluation of the potential human health risks from exposure to metals (primarily non-nutritive elements) found in inorganic fertilizers following their application to agricultural soil is presented in this report. This evaluation comprises one component of a program developed and funded by The Fertilizer Institute (TFI) that is intended to answer the question: are fertilizers safe? The overall program is viewed in the context of the life cycle of an inorganic fertilizer. Two additional components of the program include: (1) an assessment of risks to fertilizer applicators from exposure to metals in products[1], and (2) a whole product toxicity and occupational exposure evaluation. There are also two other recent reports, one by the United States Environmental Protection Agency (USEPA) and another by the California Department of Food and Agriculture (CDFA), that provide information to address the same questions of post application fertilizer safety. Their scopes, methodologies and conclusions are also summarized in this report.

Metals are generally present in inorganic fertilizers as byproducts or contaminants. There are however some metals, for example zinc, iron and copper, that are plant nutrients and are intentionally included in fertilizer formulations. It is acknowledged a priori that exposure to high enough levels of metals (nutrient or otherwise) could pose a health risk. This evaluation establishes safe limits of metals, referred to as risk based concentrations (RBCs), in inorganic fertilizers that are applicable under any foreseeable set of local conditions.

The methodology used to develop the RBCs is a back-calculation of health risks and is standard for a screening level risk evaluation. This approach provides the basis to screen specific fertilizers, either as groups (e.g., DAP, phosphate blends, or zinc micronutrients) or individually (e.g., a 10-30-5 blend or a 50% zinc oxide). There are three basic steps in the screening level evaluation: (1) narrow the scope to focus on the highest possible risks; (2) derive the health protective RBC values for each metal of concern; and (3) compare the RBC value for each metal to the measured concentration of that metal in fertilizer products. If the measured concentrations are below the RBC values, then there are negligible health risks. If the measured concentrations exceed the RBC values, then there may or may not be a health risk, and, a further, more in-depth evaluation is warranted.

The first step of the evaluation, narrowing the scope, involves choosing those fertilizer products, metals, and exposure scenarios that are associated with the highest potential health risks. Those that are not directly evaluated are still represented because their associated risks are even less than those that are evaluated directly. Based on the available data, on analyses from existing reports on fertilizer health risks, and consistent with accepted health risk assessment methodology, this evaluation focuses on:

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[1] Evaluation completed for metals and applicators; it was determined that risks to fertilizer applicators from metals are negligible (THE WEINBERG GROUP INC. (TWG). 1999a, *Health Risk Based Concentrations for Fertilizer Products and Fertilizer Applicators.* And TWG 1999b, *Fertilizer Applicator Health Risk Evaluation for Non-nutritive Elements in Inorganic Fertilizers*).

- phosphate fertilizers and micronutrient fertilizers;
- 12 metals (referred to as metals of potential concern [MOPC]) including: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, vanadium, zinc, and one radionuclide, radium 226;
- exposure to the farm family (including adults and children);
- ingestion of crops, unintentional ingestion of fertilized soil, and dermal contact with fertilized soil; and
- single and multi-crop farming scenarios.

The second step of the evaluation, deriving the health protective RBCs for each metal, involves estimating reasonable maximum exposures (RME) to the metals. The metals are evaluated for non-cancer and/or cancer hazards, as applicable, and the RBCs are established at accepted risk levels (i.e., a $1x10^{-5}$ cancer risk, and a non-cancer hazard index of 1.0). In general, USEPA standard approaches, assumptions and default high-end exposure values are used in developing the RBCs. Overall, the RBCs for metals are derived to be health protective to ensure that health risks are not underestimated. There are separate RBCs for phosphate fertilizers and for micronutrient fertilizers.

The third and final step of the evaluation involves comparing the RBC for each metal to the maximum measured level of that metal in fertilizer products. Using the maximum metal concentration provides the most health protective determination of a health risk. The concentration data are obtained from the published literature, from a survey of fertilizer manufacturers, and from monitoring programs being conducted by a number of states. The database is compiled by THE WEINBERG GROUP and is updated as new data become available. To date, there are approximately 925 individual phosphate fertilizer samples in 15 categories of products[2], and approximately 140 individual micronutrient fertilizer samples in four categories of products.[3]

The screening comparison indicates there are no exceedances for any of the phosphate fertilizer RBCs, and therefore, no post-application health risks from exposure to metals in NPK types of fertilizers. This same conclusion is reached by USEPA in their recent (1999b) fertilizer risk assessment.[4] The CDFA (1998) issued its own report of RBCs for arsenic, cadmium and lead in inorganic fertilizers.[5] While the report did not compare RBCs to measured levels in products, the RBCs are very similar to those in this evaluation, and therefore, would support the same conclusion of negligible risk for NPK type fertilizers if a screening comparison were conducted.

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[2] The phosphate fertilizer categories include: NPK blends, ammonium phosphate sulfate, ammonium polyphosphate, diammonium phosphate (DAP), monoammonium phosphate (MAP), nitrophosphate, orthophosphate, phosphate, phosphoric acid, superphosphate, superphosphoric acid, triple superphosphate, urea-ammonium phosphate, urea-ammonium polyphosphate, and urea-diammonium phosphate.

[3] The micronutrient fertilizer categories include: boron, iron, manganese and zinc micronutrients (no mixes).

[4] In addition to evaluating health risks, USEPA conducted a screening-level ecological risk evaluation of metals in fertilizer runoff into streams, and concludes that no exceedances of water quality criteria are projected. USEPA 1999b, *Estimating Risks from Contaminants Contained in Agricultural Fertilizers.*

[5] CDFA 1998, *Development of Risk Based Concentrations for Arsenic, Cadmium, and Lead in Inorganic Commercial Fertilizer.*

With regard to micronutrient fertilizers, there are exceedances of arsenic and lead RBCs for several micronutrient fertilizer products. These products contain relatively high levels of arsenic and lead in some samples. The USEPA (1999b) reached a similar conclusion indicating that a few micronutrient fertilizer products exceeded the acceptable risk levels for arsenic. Because of the health protective methodology employed in screening level evaluations, and because exceedances occur only at the maximum arsenic and lead concentrations, a firm conclusion regarding health risks from the micronutrient products in question requires a closer evaluation. This refined evaluation would take into account product specific information on crop uses, application rates, fraction of nutrients in the product, and metal concentrations from multiple samples of the same product. This product-specific information would replace the default, high-end exposure values used in the screening risk evaluation equation.

As with all risk assessments there is some level of uncertainty associated with this evaluation. The major uncertainties are identified and described in the report. The uncertainty is more likely to err on the side of overestimating the potential for risk rather than underestimating the potential risk for both the NPK and micronutrient fertilizer products.

In conclusion, this report, along with the recent USEPA (1999b) and CDFA (1998) evaluations, provide considerable and definitive information to answer the question: do metals in fertilizers pose a health risk following application? The answer is: these evaluations indicate that metals in inorganic fertilizers do not pose post-application harm to human health. It is clear that the risks are negligible for metals in NPK type fertilizers. For the majority of micronutrient fertilizer products for which we have data, the risks are also clearly negligible. A few samples for a few micronutrient products have concentrations of arsenic or lead that exceed the corresponding RBCs. However, no definitive conclusion regarding health risk can be made until these materials are further evaluated in a specific case-by-case manner. Screening risk evaluations are designed to identify if, and where, additional attention may be warranted. Actual risks may well be overestimated, but they are not underestimated, by the RBC values.

So where do things stand in the life cycle evaluation: are inorganic fertilizers safe? This report and the CDFA (1998) report address post application health risks; the recent USEPA (1999b) report addresses post application health and environmental risks; and the TWG (1999a,b) reports address applicator risks from metals in fertilizers. In total, these evaluations support the conclusion that these fertilizers are safe. The remaining aspect of this life cycle evaluation is an evaluation of whole product toxicity and occupational risks. This evaluation is underway at TFI. It is both prudent and responsible to conduct such an evaluation. However, the fact that there are industry and government standards in place to protect workers and the environment, and given the long history of the fertilizer industry, the answer seems obvious. The information that is being assembled is the proof.

INTRODUCTION

This document presents an evaluation of the potential human health risks from exposure to metals (primarily non-nutritive elements) found in inorganic fertilizers following their application to agricultural soil. This evaluation comprises one component of a program developed and funded by The Fertilizer Institute (TFI) that is intended to answer the question: are fertilizers safe? The overall program is viewed in the context of the entire life cycle of an inorganic fertilizer, as diagrammed in Figure 1. As seen in Figure 1, this human health risk evaluation focuses on the latter part of the life cycle, that is, post application.[6]

Metals are generally present in inorganic fertilizer as byproducts or contaminants. These non-nutritive elements are not purposely present in the fertilizer and are not needed by the plant for growth. Some metals, for example zinc, iron, and copper, are plant nutrients and their presence in fertilizers is essential for plant growth. This human health risk evaluation includes a dozen metals, both non-nutritive and nutritive, as well as radioactive elements.[7] In this report, all of the metals under evaluation are referred to as ‘metals of potential concern’ or MOPC.

The information presented in this document is intended to be easy to use by fertilizer manufacturers, regulators, and the public. There are many fertilizer products, many uses (varying by local conditions), many metals (and at varying concentrations), and a number of possible scenarios where a person could be exposed to MOPC following the application of fertilizers to agricultural soils. The intention of this document is to derive safe exposure levels for these metals that would be applicable under any foreseeable set of local conditions, rather than to determine if a given product and local conditions pose an unacceptable health risk. In the language of ‘risk assessment’, the former is called a back calculation of risk and the latter is called a forward calculation of risk. Both approaches use the same fundamental risk assessment science. The forward calculation allows a determination of whether ‘fertilizer product A’ used under ‘conditions B’ poses a health risk. The back calculation allows extrapolation to a much wider set of product and local condition combinations now and in the future. In the back calculation, the results are presented as concentrations of metals that are considered “safe” under reasonable worst case conditions. These concentrations are called ‘risk based concentrations’ or RBCs. By the nature of their derivation, RBCs are also typically called ‘screening level values’ and are intended for screening level evaluations. In a screening level evaluation, RBCs are used to determine if a given fertilizer product is safe by comparing the RBC with the metal concentration in the product.

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[6] The Weinberg Group Inc. (TWG) prepared two previous reports that evaluate the health risks to applicators of fertilizers for TFI. They are: TWG. 1999a. Health Risk Based Concentrations for Fertilizer Products and Fertilizer Applicators. and TWG. 1999b. Fertilizer Applicator Health Risk Evaluation for Non-nutritive Elements in Inorganic Fertilizers: Risk Based Concentrations (RBCs) Compared to Measured Levels of Non-nutritive Elements in Products. These reports concluded there is no significant health risk for fertilizer applicators.

[7] Due to the major difference regarding the toxic nature of radionuclides compared to metals, and thus the significant difference in evaluating risk from exposure, radionuclides are evaluated separately. The evaluation of radionuclides can be found in Section 5.0.

Since RBCs are used primarily for screening level evaluations, they are based on the exposure scenario that reflects the reasonable maximum exposure (RME), and are intended to be health protective of all other scenarios. In this way, RBCs are derived to ensure that health risks are not underestimated. In general, United States Environmental Protection Agency (USEPA) standard approaches and values are used in developing the RBCs in this evaluation of metals in fertilizers.

In addition to the development and presentation of RBCs, this report also presents a screening level health risk evaluation where the RBC for each metal is compared to the available database of measured levels of the metals in fertilizer products. Measurements of metal concentrations in fertilizer products conducted in the future could also be compared to the RBCs in order to screen for potential human health risks.

Finally, this evaluation builds upon existing reports and information on potential health risks from exposure to metals in fertilizers to answer the question: are fertilizers safe? Considerable data and analyses have been reported in recent months by the USEPA and by the California Department of Food and Agriculture.[8]

This report is organized as follows:

SECTION 1.0 – DEFINING THE SCOPE OF THIS EVALUATION. The logic and rationale that was used to define the scope of this evaluation is presented. Specifically, this section identifies the fertilizer product categories that are evaluated, the metals for which RBCs are developed, and the human exposure scenarios and the crop groups that the RBCs are based upon.

SECTION 2.0 – DERIVATION OF RISK BASED CONCENTRATIONS (RBCs). In this section, the RBC equation and the following parameters and factors are described.

SECTION 3.0 – PRESENTATION OF THE RISK BASED CONCENTRATIONS (RBCs) FOR METALS OF POTENTIAL CONCERN (MOPC). In this section, the screening level RBCs are selected and described for each MOPC.

SECTION 4.0 – SCREENING LEVEL HEALTH EVALUATION: COMPARISON OF RBCs WITH CONCENTRATIONS OF MOPC IN FERTILIZER PRODUCTS. In this section, the RBCs for each MOPC are compared to metal concentration data for each of the product categories.

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[8] The following resources provided critical information in streamlining and focusing the scope of this evaluation:

- California Department of Food and Agriculture (CDFA) and the Heavy Metal Task Force. 1998. Development of Risk-Based Concentrations for Arsenic, Cadmium, and Lead in Inorganic Commercial Fertilizer. Foster Wheeler Environmental Corporation, Sacramento, CA.
- United States Environmental Protection Agency (USEPA). 1999a. Background Report on Fertilizer Use, Contaminants and Regulations. Columbus, OH: Battelle Memorial Institute.
- United States Environmental Protection Agency (USEPA). 1999b. Estimating Risk from Contaminants Contained in Agricultural Fertilizers. Draft. Washington, D.C.: Office of Solid Waste and Center for Environmental Analysis.

SECTION 5.0 – DERIVATION OF THE RISK BASED CONCENTRATION FOR RADIONUCLUDE (RADIUM226) AND SCREENING LEVEL HEALTH EVALUATION: COMPARISON OF THE RADIUM226 RBC WITH PRODUCT DATA. In this section, a RBC for radium 226 is derived and the RBC is compared to radium226 product data.

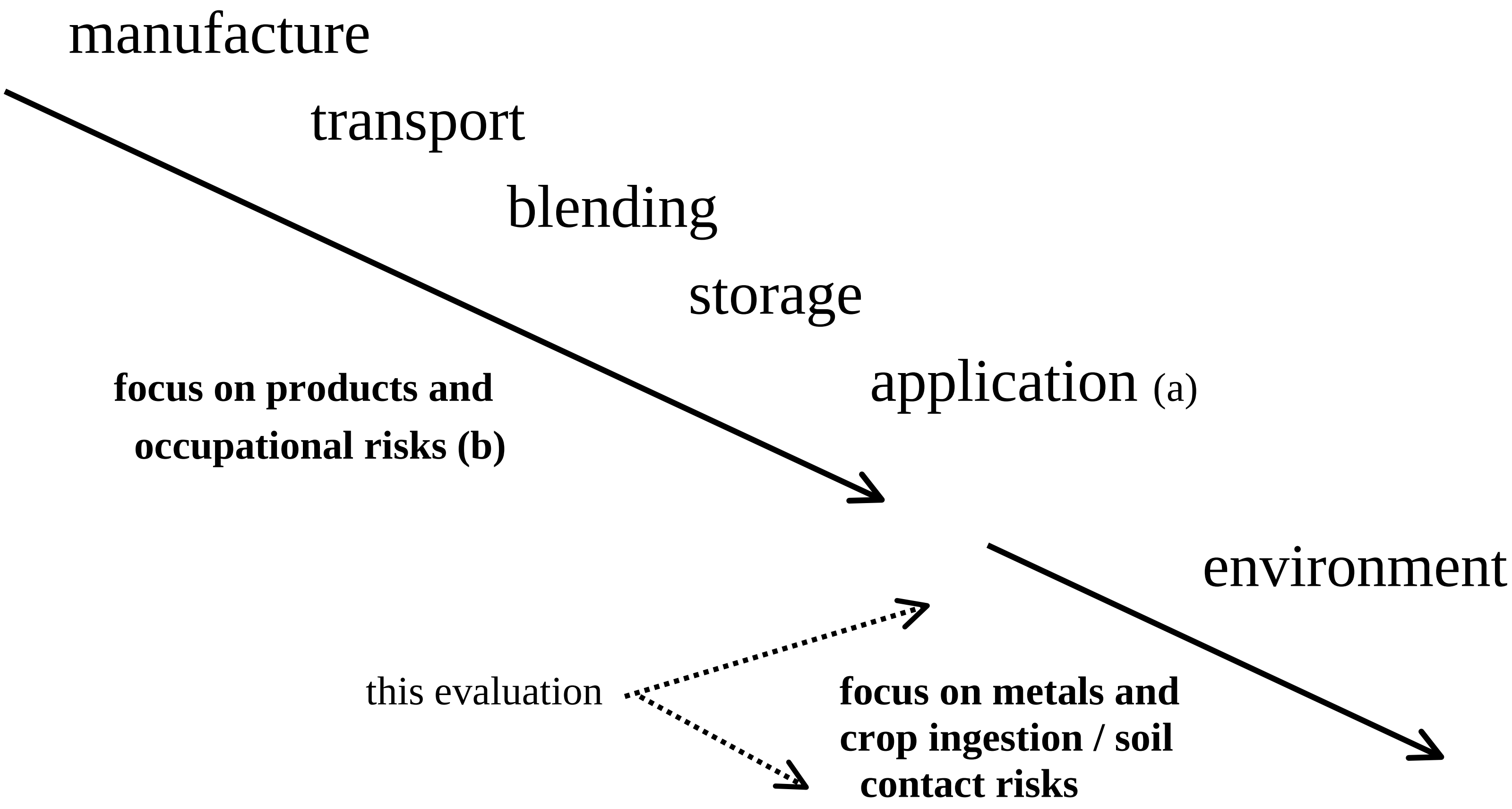
SECTION 6.0 – DISCUSSION OF UNCERTAINTY. In this section, uncertainties related to the scope of this health risk evaluation and the derivation of RBCs are presented.

SECTION 7.0 – CONCLUSIONS OF EVALUATION. In this section, conclusions are drawn from the screening-level health risk evaluation for NPK and micronutrient fertilizers.

SECTION 8.0 – COMPARISON TO OTHER EVALUATIONS. In this section, the outcome of this evaluation is compared to other health risk evaluations for fertilizers, including USEPA (1999b) and CDFA (1998).

FIGURES

FIGURE 1. RISK EVALUATION FOR THE LIFE CYCLE OF INORGANIC FERTILIZERS



(a) Occupational exposure to metals during application was determined to be safe in previous evaluation (TWG 1999a,b).

(b) Whole product toxicity and occupational exposure are being evaluated in another program.

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SECTION 1.0 — DEFINING THE SCOPE OF THIS EVALUATION

Consistent with a screening level risk evaluation[9], the scope of this evaluation is narrowed to focus on the fertilizer product categories, metals, and exposure scenarios that have the highest potential for health risks.[10] Developing RBCs that are based on "high-end" exposures results in RBCs that are protective of other less risky scenarios and results in health risks that are not underestimated. Figure 2 entitled 'Narrowing the Scope of the Evaluation - Focusing on the Fertilizer Products, Elements, and Exposure Scenario of Highest Concern' presents a summary of how each of these key components was narrowed. In addition, the narrowing of each of these components is discussed in the following sections.

Selection of Representative Fertilizer Products

As stated previously, the purpose of this assessment is to evaluate potential health risks from metals in inorganic fertilizers following their application to agricultural soils. The fertilizer products that result in the greatest addition of metals to soil are the products of highest concern. The magnitude of MOPC addition to soil is dependent on several factors including (1) the composition of the fertilizer, (2) the concentration of the metal in the fertilizer, and (3) the amount of fertilizer that is applied. By evaluating the health risks from those products whose use results in the greatest addition of metals to soil, the wide array of inorganic fertilizers is covered as well. That is, 'all' fertilizers can be evaluated by screening for health risks based on those products posing the highest potential risks. Therefore, a critical component of this evaluation is the characterization of inorganic fertilizer products and the selection of the products that will be representative of all other inorganic fertilizer products.

Table 1 presents a summary of each of the factors determining the magnitude of metal addition to soil and identifies the representative products that are selected for health risk evaluation.[11] Each of the factors is also discussed below.

Types of Inorganic Fertilizers and Use

There are three general categories of inorganic fertilizers: macronutrient (or primary) fertilizers, secondary fertilizers, and micronutrient fertilizers. Each of the general categories of inorganic fertilizers supplies plants with different nutrients. Macronutrient fertilizers supply primary nutrients, which include nitrogen (N), available phosphate (P), and soluble potash or potassium (K). There are products that supply each of the nutrients separately, as well as blends; for example NPK. Also, there are numerous phosphate fertilizers, such as, diammonium phosphate (DAP), triple super phosphate (TSP), and monoammonium phosphate (MAP). There are also many different types of macronutrient nitrogen fertilizer products (e.g., ammonium nitrate,

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[9] Narrowing the scope of a screening level evaluation to focus on the scenario that is health protective and representative of all other scenarios is standard USEPA practice [as indicated in USEPA guidance (1995), and used to assess health and environmental risks from fertilizers in USEPA (1999b) and CDFA (1998)].

[10] Based on a screening level ecological risk evaluation of metals in fertilizer runoff into streams, USEPA (1999b) concluded that no exceedances of water quality criteria are projected.

[11] Information used in this section was obtained primarily from USEPA (1999a) and TWG (1999b).

ammonium polysulfide, sodium nitrate, and urea). Macronutrient fertilizers are used the most in the US, accounting for 91% of the total inorganic fertilizer; specifically, 38%, 12%, 10%, and 31% of N, P, K, and NPK are used, respectively (USEPA 1999a).

Secondary fertilizers supply secondary nutrients to plants including calcium, magnesium, and sulfur. Examples of secondary fertilizer products include calcium chloride, calcium chelate, and magnesium chelate. Secondary and micronutrient fertilizers (discussed below) account for only 4.5% of the total inorganic fertilizer use in US agriculture (USEPA 1999a).

Micronutrient fertilizers supply plants with boron, chlorine, cobalt, copper, iron, manganese, molybdenum, sodium, and/or zinc. For example, zinc micronutrient fertilizers supply zinc, iron micronutrient fertilizers supply iron, and mixes supply one or more of the micronutrients. Examples of micronutrient products include manganese oxide, cobalt sulfate, and zinc sulfate. Among the various micronutrient fertilizers (e.g., boron, iron, manganese, and zinc), zinc is used the most throughout the US (Hignett and McClellan 1985).

Product Composition / Percent Nutrient

In addition to the nutrient composition (i.e., N, P, K and secondary and micronutrient described above), the percent of each nutrient (e.g., P_2O_5 or zinc) in a product varies. For example, as can be seen in Table 1, percent nutrient of P_2O_5 ranges from 2-70% (USEPA 1999a).

Application Rates

The application rate (AR) of any given fertilizer can vary depending on the nutrient needs of the plant and the local soil conditions. The AR is also influenced by the composition of the product and the percent nutrient content. The lower the percentage of nutrient in a product, the higher the AR required to meet the plant's nutrient needs. The ARs presented in Table 1 are high-end estimates (95th percentile) and are based on the nutrient needs of high acreage US crops (USEPA 1999a). As can be seen in Table 1, nitrogen (N) has the highest AR of each of the primary nutrients and phosphate (P) has the second highest AR. The ARs for secondary and micronutrients are generally much lower than the ARs for the primary nutrients.

Concentration of Metal in Products

Metals occur in fertilizers because of the sources of the nutrients. As a category, phosphate fertilizers have the highest levels of metals among the primary and secondary nutrients, thus, the "high" relative concentration rating. Nitrogen fertilizers (and NPK applied for N) have lower concentrations of MOPC compared to phosphate fertilizers (and NPK applied for P) and potash fertilizers generally have much lower concentrations of MOPC than nitrogen fertilizers (USEPA 1999a, b). Phosphorous is mined from phosphorous rock, and phosphorous ores naturally contain metals.[12] Depending upon their source of nutrients, micronutrient fertilizers can also have relatively high levels of metals. As presented in Table 1, iron and zinc micronutrients have

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[12] As reported in Raven and Loeppert (1997), Potash & Phosphate Institute (PPI) (1998), CDFA (1998), TWG (1999c), and USEPA (1999a).

the highest relative concentrations of MOPC (especially when considering arsenic in iron micronutrients) (USEPA 1999a,b). Micronutrient mixes can also have relatively high concentrations of select MOPC. Since the metals exist in the nutrient part of the fertilizer, the percent nutrient of the product has a direct bearing on the concentration of metal in the final product. Table 1 lists 'concentration relative ratings' for the metals evaluated in this assessment. The actual measured concentrations of metals in numerous products have been compiled in a database from industry, state and literature sources (TWG 1999c).

Representative Fertilizer Products

Considering all of the factors discussed above and the information presented in Table 1, phosphate fertilizers are selected to represent the macronutrient (primary and secondary) fertilizers in developing the health protective RBCs and comparing them to measured levels in products. The application of phosphate fertilizers is expected to result in the greatest addition of metals to soil, and therefore, the highest potential for exposure among the macronutrient fertilizers.[13] The RBCs are developed for a generic phosphate fertilizer but are then modified to account for different percent nutrient content in specific phosphate fertilizers (e.g., DAP, TSP) or phosphate blends (e.g., NPK of various percent nutrient combinations).[14]

Zinc, manganese, iron, and boron micronutrient fertilizers are selected to represent micronutrient fertilizers. Micronutrient mixes are not specifically evaluated, however, the evaluation of the other micronutrients will be health protective of potential risk from the application of micronutrient mixes because the concentrations of MOPC in micronutrient mixes is represented by the other micronutrient fertilizers. While the ARs can vary among micronutrient products, the initial screening RBCs are based on the AR for zinc products. The ARs for different micronutrient fertilizers are similar. In the health risk evaluation, the RBCs are modified to account for the different percent nutrient content in specific micronutrient fertilizers.

Other commercial fertilizer products, for example, nitrogen only, potassium only, secondary nutrient fertilizers, and the remaining micronutrient fertilizers and mixes are not specifically evaluated because the evaluation of phosphate fertilizers, and select micronutrients (as discussed above) is considered health protective of these fertilizers.

Selection of Metals of Potential Concern (MOPC)

As can be seen in Table 2, this health risk assessment begins with a list of 23 metals that are potentially found in inorganic fertilizers.[15] For similar reasons that the products of highest potential concern are selected for a screening risk evaluation, the metals selected for this assessment are also narrowed. These metals are called MOPC. MOPC selected for evaluation

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[13] The selection of phosphate fertilizers for this evaluation is further supported by estimates of MOPC loading in soil from macronutrient fertilizer application in both the USEPA (1999a) and CDFA (1998) risk assessments.

[14] This evaluation focuses on granular fertilizers. Liquid fertilizers are not considered separately in this evaluation because liquid fertilizers are generally applied at a much lower rate then granular fertilizers. Therefore, the evaluation of granular fertilizers will be health protective of liquid fertilizers (USEPA 1999a).

[15] While not exhaustive, this list is considered comprehensive. It was developed from a search of industry and published literature records (TWG 1999c). Three radionuclides (radium, thorium and uranium) were also considered in the starting list.

are intended to be representative and health protective of all the metals in inorganic fertilizer products. The factors that are considered in selecting the MOPC include (1) their relative toxicity, (2) their relative concentration in products, and (3) whether there is an evaluation precedence (e.g., a regulation or high priority) for human health concerns. Both toxicity and concentration in products are considered because they are determinants that relate directly to risk. All three factors are detailed in Table 2, along with the list of MOPC that are selected.

Relative Toxicity

Relative toxicity is determined by comparing the oral reference dose (RfD) for each metal as established by USEPA and presented in USEPA's Integrated Risk Information System (IRIS).[16] The oral RfD is particularly relevant in this evaluation because oral exposure is expected to contribute the greatest potential for health risk from metals in agricultural soil.

Relative Product Concentration

The data describing the concentration of metals in products comes from an industry and published literature survey conducted for TFI (TWG 1999c) and from the USEPA publication on fertilizers (USEPA 1999a). The MOPC concentration in the fertilizer products is rated by a qualitative evaluation of MOPC concentrations in each of the phosphate fertilizer and micronutrient fertilizer product categories relative to each other. The concentration for each MOPC is compared across product categories and rated accordingly. Products with obviously high MOPC concentrations are rated high; product categories with generally low MOPC concentrations are rated low. The relative MOPC concentrations are low (phosphate fertilizer < 10 ppm, micronutrient fertilizer < 50ppm); medium (phosphate fertilizer, 10 ppm – 100 ppm, micronutrient fertilizer, 50 ppm – 1,000 ppm); and high (phosphate fertilizer > 100 ppm, micronutrient fertilizer >1,000 ppm). Again, these qualitative ratings are based on a review of the product concentration database (TWG 1999c.)

Evaluation Precedence

As seen in Table 2, most of the 23 metals on the starting list, and all of the MOPC selected for this health risk evaluation, have been identified and/or evaluated in previous, relevant, reports.[17] Evaluation precedence is considered an important aspect in the final selection of MOPC, even when the metal was not highly toxic or was not found at particularly high concentrations in fertilizer products.

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[16] There is a detailed discussion of these values in the section of this report entitled 'Toxicity Assessment'.

[17] The following reports (or standards) have established evaluation precedence for the MOPC:

- California based RBCs for arsenic, cadmium, and lead are developed in CDFA (1998).
- Risks from arsenic, cadmium, chromium, copper, lead, mercury, nickel, vanadium and zinc contained in agricultural fertilizers was estimated in USEPA (1999b).
- Canada has established metal limits in fertilizers for arsenic, cadmium, cobalt, mercury, molybdenum, nickel, lead, selenium, and zinc as reported in the Canadian Fertilizers Act R.S., c. F-9s.l. (1003).
- Pollutant limits for arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc in biosolids applied to agricultural soils were developed by USEPA (1995).

Metals of Potential Concern (MOPC) Selected for Evaluation

The following 12 metals are selected as MOPC. Note, the elemental symbol for each metal is presented in parenthesis next to each MOPC, however, for ease in reading this document, the full name is used throughout this document. In addition, one radionuclide (discussed in Section 5.0) is selected for evaluation.

Arsenic (As)
Cadmium (Cd)
Chromium (Cr)
Cobalt (Co)
Copper (Cu)
Lead (Pb)
Mercury (Hg)
Molybdenum (Mo)
Nickel (Ni)
Selenium (Se)
Vanadium (V)
Zinc (Zn)
Radium 226 (Ra)

Selection of Health Protective Exposure Scenarios

In a similar manner to that used to focus on which fertilizer products and MOPC to include in the screening risk evaluation, the exposure scenario that would be representative and health protective of all potential exposure scenarios is identified. All of the possible exposure pathways, as well as exposure routes for potentially exposed populations, that occur post-application are considered. The exposure scenario with the greatest exposure and risk potential is then identified.

Potential Exposure Pathways

The first step in selecting the exposure scenario with the highest potential risk is to determine all of the possible exposure pathways for the MOPC in fertilizer, following application. A complete exposure pathway has a transport pathway, a potential exposure media, and a likely exposure route (mode of contact with the receptor). All of the potential exposure pathways are presented in Figure 3. Each of these exposure pathways and associated exposure routes is discussed below.

1. The first pathway is runoff of the metals into surface water, followed by incidental ingestion and dermal contact by humans, as well as, uptake into fish followed by ingestion of fish by humans. This exposure pathway and routes are eliminated as a major exposure pathway because (a) they are not expected to contribute significantly to risk (based on USEPA's previous assessment of fertilizers (1999b) and biosolids (1995)) and (b) the only MOPC that is expected to bioaccumulate in fish is a form of mercury, methyl mercury.[18] The other MOPC are not expected to bioaccumulate.

2. Leaching into groundwater followed by ingestion in drinking water is eliminated as a major exposure pathway based on the elimination of this pathway in USEPA (1999b, 1995) and CDFA (1998). Exposure from drinking water is much less than from crop consumption.

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[18] In soil, mercury is reactive and may form several different complexes. Although the transport of mercury into a nearby water body, some formation of methyl mercury, and uptake into fish may occur, it is expected that this pathway will occur less frequently, and result in less exposure than the complexing of mercury with chlorine in soil (especially since chlorine ions may be the most persistent and available complexing agent for mercury in soil) (McLaughlin et al. 1996).

3. Volatilization of metals into air followed by inhalation, and wind blown dispersion of airborne metals followed by inhalation, are eliminated as major exposure pathways based on USEPA (1999b) and CDFA (1998) as well as TWG's applicator risk assessment (1999a,b). Specifically, this exposure pathway is eliminated because MOPC are not expected to volatilize and the inhalation of particulates was found to contribute minimally to risk in these previous evaluations. Other exposure routes that are selected for inclusion in the RBC equation (e.g., unintentional ingestion of fertilized soil or ingestion crops) are the primary contributors to risk.

4. The ingestion of MOPC in fertilized soil and in crops by foraging cattle, followed by the subsequent ingestion of animals products (beef and milk) by humans, is eliminated as a major exposure pathway.[19] Instead, the direct exposure pathways (i.e., unintentional ingestion of soil and dermal contact with soil, and ingestion of crops) are considered to provide a much higher level of exposure, especially because the MOPC do not bioaccumulate in the terrestrial food chain (i.e., cattle).

5. Direct contact with soil (i.e., unintentional ingestion of fertilizers in soil and dermal contact with fertilizers in soil) and uptake of metals in the soil by plants (crops) followed by ingestion are considered the most likely and most substantial exposure pathways and therefore are the basis of the RBCs. The selection of these exposure pathways is based on information presented in USEPA (1999b and 1995), CDFA (1998) and TWG (1999a,b).

Potential Populations and Exposure Routes

The next step in defining the exposure scenario is to identify all of the potentially exposed populations and their associated exposure routes. This step is presented in Table 3. Note, exposure pathways and routes eliminated in the previous step are not included in this table. There are four potential populations considered for evaluation including a home gardener, the general public, a farm worker, and a resident farmer.

Representative and Health Protective Exposure Scenario

Compared to the other populations, the resident farmer has many more potential exposure routes and greater potential for exposure. The home gardener is not selected because of the lower exposure potential and low use of fertilizers compared to the farmer. The general public is not selected because of the low relative exposure potential from the ingestion of soil compared to the resident farmer. The farm worker has been evaluated in previous reports (TWG 1999a,b) and found not to be at risk from metals as a result of applying fertilizers. Clearly, the resident farmer (and family including children) is the population with the highest exposure potential and is selected as the population that the RBCs will be based upon.[20]

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[19] These exposure routes are eliminated in CDFA (1998) screening phase of the assessment because they contribute much less to risk than ingestion of crops.

[20] The selection of the resident farmer as the representative and health protective population is supported by the use of this population in developing RBCs in CDFA (1998) and the use of this population to estimate risk from exposure to agricultural fertilizers in USEPA (1999b).

In most risk evaluations there are populations that may be considered "sensitive or high-end" populations. These populations are at potentially higher risk from exposure compared to other populations either because the population is particularly sensitive to the toxic effect of the MOPC (e.g., children are especially sensitive to lead exposure) or because the population is considered sensitive (e.g., lactating mother or elderly). In this evaluation, children are evaluated. Elderly are not specifically evaluated because the adult farm resident scenario is considered health protective of an elder. The exposure routes and associated exposure parameters used to evaluate the adult farmer resident, represent greater exposure than an elder would encounter. The lactating mother is not evaluated because metals are not typically fat soluble, and therefore, are not expected to be at elevated concentrations in mother's milk. In addition, as discussed in the toxicity assessment, toxicity values have uncertainty factors built into them for different reasons, one of which is to protect for sensitive subpopulations.

Selection of Representative Crop Groups

As indicated above, the ingestion of crops is a significant route of exposure. The magnitude of exposure from this route varies depending on the type of crop(s) evaluated. Crops vary in how they grow (e.g., above or below ground, depth of root system), how much nutrient they need to grow (e.g., higher or lower phosphate requirement), and their ability to take up metals into edible portions of the plant. For the purposes of this assessment, crops are therefore grouped by type, and these crop groups are treated separately in the equation used to derive the RBC values for each MOPC.

In this evaluation, crops are grouped considering basic physiology ("like" crops were grouped together) as well as crop grouping and evaluation in other relevant reports.[21] The crop groups that are considered include: unexposed vegetables (root crops), exposed vegetables, grains, fruit, forage crops, and field crops. Each of these groups is further clarified and classified below:

- Vegetable crops are also called exposed crops or unprotected crops. Vegetable crop is a large, broad category of many different kinds of crops. Examples of different types of vegetables are leafy vegetables (e.g., endive, kale, lettuce, spinach, swiss chard, and water cress), head and stalk vegetables (e.g., artichokes, asparagus, broccoli, brussel sprouts, cabbage, cauliflower, celery, and peppers), and legumes (e.g., beans and peas). Several crops included in this group are technically fruits, but are cultivated as vegetables (i.e., cucumber, eggplant, and tomato). All of the above vegetables are considered in the vegetable crop group.

- Unexposed vegetables are also called protected vegetables, root crops, herbage, tubers, or bulbs. This report will refer to this group as root crops. Root crops have unique growing characteristics and are considered to have "like" physiologies; thus, they are evaluated together. Crops in this category include beets, carrots, fennel, mangel, onion, parsnip, potatoes, radish, rutabaga, and turnip.

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[21] CDFA (1998) evaluated six crop groups: vegetable, root, grain, tree, vine, and forage crops. USEPA (1999b) evaluated five crop groups: grains, forage, fruit, herbage, and roots. Grain and forage were evaluated through ingestion of these crops by cattle and subsequent human ingestion of animal products.

- Grains are also a large, general crop group. Grains can be designated as field grains, silo grains, forage grains, or small or large grains. The grains included in this group are all grains consumed by humans. Grains consumed by cattle (forage or silo grains) are not included in this evaluation because, as discussed, ingestion of animal products is not evaluated. Grains in this group include corn, barley, millet, oat, rice, rye, and wheat.

- Fruit crops can be grown on trees (i.e., tree fruits, such as, limes, lemons, and oranges) or as sweet fruits. Examples, of sweet fruits include cantaloupe, apple, rhubarb, strawberry, fig, grapes, kiwi, and pear. Vine crops (such as, grapes) are also fruits. The ingestion of fruit crops is not included in this evaluated because they are not expected to contribute significantly to exposure.[14] Nuts are also tree crops, but are not considered in this evaluation because of low exposure potential. [14]

- Field crop is a general term for crops grown on fields. Examples of field crops include corn, cotton, potatoes, soybeans, tobacco, or wheat (USEPA 1999a). Field crops that are ingested by humans are evaluated in the appropriate crop groupings (grain, root, or vegetable group).

- Forage crops are crops that are grown solely for the purpose of feeding cattle. Again, the ingestion of animal products by humans was eliminated from this evaluation. Therefore, forage crops are not considered further.[14]

For consistency, these crop groupings are retained throughout the different components of this evaluation (e.g., development of plant uptake factors, application rates, and ingestion rates) given available data. Crop groups expected to contribute significantly to exposure are selected for inclusion in the evaluation.[22] These are vegetable, root and grain crops. Crop groups and the rationale for inclusion are presented in Table 4.

Farms and their use of fertilizers vary by size, geography (including soil and climate conditions), preferred crop types, etc. USEPA (1999a) recent report on the use of fertilizers includes an overview of fertilizer consumption and the amount of crops produced in different regions of the country. For example, the following table indicates where the use of different fertilizer types is heaviest, and those states with the highest crop acreage (by crop).

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[22] CDFA (1998) eliminated tree (fruit and nut) crops, vine crops (grapes), and forage crops from the development of RBCs in the screening phase of their assessment because their associated exposure to arsenic, cadmium, and lead and subsequent risk, were determined to be considerably less than for the other crop groupings.

FERTILIZER	**REGION**	**STATES**
Phosphate	West North Central East North Central	Illinois Indiana
Multiple Nutrient	South Atlantic West North Atlantic	Florida Texas
Secondary Nutrient	Pacific South Atlantic	California North Carolina
CROP	**STATES**	**SPECIFIC CROPS**
Vegetable	California	Asparagus, bell pepper, broccoli, cabbage, cauliflower, celery, lettuce, tomatoes
	Florida	Bell peppers, legumes, snap peas, sweet corn (fresh)
	Georgia	Snap peas
	Michigan	Cucumbers (fresh)
Root	California	Carrots, onion
	Idaho	Potato
	Maine	Potato
	New York	Onion
	Oregon	Onion
	Texas	Potato, onion
Grain	Illinois	Corn (for grain), wheat
	Indiana	Corn
	Montana	Corn
	Nebraska	Corn
Fruit	California	Apples, citrus fruits
	Florida	Citrus fruits

It is also recognized that a farm may grow one crop or it may grow several different kinds of crops (i.e., multi-crop farming). The exposure scenario for a single crop farm could be quite different from the exposure scenario for a multi-crop farm. For example, on a single crop farm the application rate would be the same for every parcel of the farm, because only one crop is grown, and the application rate is dependent on the crop type. Whereas, on a multi-crop farm the application rate and crop acreage is proportioned into different crop groups (i.e., grain, 50%, vegetable, 40%, and root, 10%). Another parameter that is used to quantify exposure, and that is crop specific, is the plant uptake factor. Therefore, RBCs for both a single crop (one for each crop group) and a multi-crop (combines all 3 crop groups) are developed. The lowest of these four RBCs is used for the screening-level health risk evaluation.

Summary of Scope

The scope of this evaluation is focused in order to provide a health protective screening evaluation of risks associated with post application exposure to metals in inorganic fertilizers. Those fertilizer types, metals, receptors, and exposure routes that are associated with the highest potential health risks are identified for direct evaluation. Those that are not directly evaluated are represented because their associated risks are even less than those that are evaluated directly. Based on the available data and on analyses from existing reports, and consistent with accepted health risk assessment methodology, this evaluation focuses on:

- phosphate fertilizers and micronutrient fertilizers;
- 12 metals including: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, vanadium, zinc, and one radionuclide, radium 226;
- exposure to the farm family (including children);
- ingestion of crops, unintentional ingestion of fertilized soil, and dermal contact with fertilized soil; and
- single and multi-crop farming scenarios

TABLES

TABLE 1
SELECTION OF REPRESENTATIVE FERTILIZER PRODUCTS: CONSIDERATION OF USE IN THE U.S., APPLICATION RATE, PERCENT NUTRIENT IN PRODUCT, AND RELATIVE METAL OF POTENTIAL CONCERN (MOPC) CONCENTRATION

General Inorganic Fertilizer Category (purpose)	Nutrient	Use in US in 1996 rounded to the nearest million ton (percent of total) (a)	High-End (95th percentile) Application Rate (lb/acre-year) (b)	Range of Percent Nutrient in Product (a)	Rating of Relative MOPC Concentration (c)	Selected for Evaluation?	
						Yes (Y) or No (N)	Rationale
Macronutrient (supply primary nutrient)	N	23 (38)	206 (d)	6.3 - 82	Medium	N	Evaluation of NPK-P and P will be health protective of NPK-N and N because of the low relative MOPC concentration.
	P	**7 (12)**	**173 (e)**	**2.0 - 70.1**	**High**	**Y**	**Primarily because of the relative high MOPC concentration. Also due to the application rate and amount used in the US.**
	K	6 (10)	177 (f)	9.8 - 62.1	Low	N	Low relative MOPC concentration.
	NPK for N	19 (31)	206	3-46	Medium	N	Evaluation of NPK-P and P will be health protective of NPK-N and N because of the low relative MOPC concentrations.
	NPK for P		**173**	**11.5 - 27.4**	**High**	**Y**	**Primarily because of the relative high MOPC concentration. Also due to the application rate and amount used in the US.**
Secondary (g) (supply secondary nutrient)	Sulfur	3 (4.5)	40	14 - 100	Low (i)	N	Low use and low relative MOPC concentration.
	Calcium		4,000	NA		N	Low use and low relative MOPC concentration.
	Magnesium		100	NA		N	Low use and low relative MOPC concentration.
Micronutrients (h) (supply micronutrient)	**Boron**		**3**	**10 - 21**	**Medium/Low (i)**	**Y**	**High relative arsenic concentration.**
	Iron		**20**	**12 - 15**	**High (i)**	**Y**	**High relative arsenic and cadmium concentration.**
	Manganese		**10**	**24.7 - 29.5**	**Medium/Low (i)**	**Y**	**High relative arsenic concentration.**
	Zinc		**10**	**7 - 58**	**High (i)**	**Y**	**High relative MOPC concentration.**
	Mixes		30	NA	High/Medium (i) (j)	N	Appropriate information is not available.

Notes:

Bold = Selected as the representative and health protective product, therefore, evaluated in this assessment.
MOPC = Metal of Potential Concern
N = Nitrogen. Examples of nitrogen fertilizers include: ammonium nitrate, ammonium sulfate, ammonium sulfate-nitrate-urea, calcium ammonium nitrate, calcium cyanamide, calcium nitrate, calcium nitrate-urea, ferrous ammonium sulfate, magnesium nitrate, nitric acid, sodium nitrate, urea, urea formaldehyde, zinc manganese ammonium sulfate.
P = Available Phosphate or Phosphorous Oxide (or P_2O_5). P is not a fertilizer, but is a building block of other fertilizers (many of which are NPKs). Examples of "phosphate" fertilizers include: ammonium metaphosphate, ammonium phosphate, ammonium phosphate nitrate, ammonium phosphate sulfate, ammonium polyphosphate, basic lime phosphate, basic slag, calcium metaphosphate, diammonium phosphate (DAP), magnesium phosphate, monoammonium phosphate (MAP), nitric phosphate, phosphate rock, phosphoric acid, superphosphate (SP), and triple SP (TSP).
K = Potassium or Soluble Potash (or K_2O). Examples of potash fertilizers include: lime-potash mixtures, manure salts, muriate potash, potassium carbonate, potassium nitrate, potassium sulfate, potassium-magnesium sulfate, potassium-metaphosphate, and potassium-sodium nitrate.
NPK = Nitrogen, Phosphate, Potash blend. Generally called macronutrient agricultural blends. Some phosphate fertilizers are also NPs (e.g., DAP, TSP) or NPKs.
NA = Not Applicable
TWG = The Weinberg Group Inc.
(a) Based on information presented in USEPA (1999a). Note, total percent does not add up to 100% because liming agents (3.6%) are not included.
(b) Based on application to field crops that are planted the most (highest planting acreage) in the US (USEPA 1999a).
(c) Qualitative rating of relative MOPC concentrations among products. MOPC considered include arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, vanadium, and zinc. Based on TWG fertilizer database [(TWG 1999c) compilation of survey, literature, industry and state data], and information presented in USEPA (1999a), CDFA (1998), and USEPA (1999b).
(d) Based on application to broccoli (USEPA 1999a).
(e) Based on application to potato (USEPA 1999a).
(f) Based on application to oranges (USEPA 1999a).
(g) Examples of secondary nutrient products include: aluminum sulfate, calcium chelate, calcium chloride, Epsom salt, and gypsum.
(h) Examples of micronutrient products include: borax, copper chelate, magnesia, manganese oxide, ferric oxide, non-chelate, zinc oxide, and zinc sulfate.
(i) Concentration of MOPC in the product varies by MOPC; these ratings are based on the general trends observed. Considering all MOPCs, zinc micronutrients have the highest relative MOPC concentrations. In addition, zinc micronutrient fertilizers have the most data available. However, some MOPCs are at higher concentrations (e.g., arsenic and cadmium) in micronutrient fertilizers other than zinc (e.g., iron).
(j) Mixes are not included in the screening evaluation, because the necessary information (percent micronutrient) is not available.

TABLE 2
SELECTION OF METALS OF POTENTIAL CONCERN (MOPC): CONSIDERATION OF RELATIVE TOXICITY, RELATIVE PRODUCT CONCENTRATION, AND EVALUATION PRECEDENCE

Metal of Potential Concern (MOPC)	Relative Ratings for Determinants of Potential Health Risk			Evaluation Precedence (e)	Selected for Evaluation ?	
		MOPC Concentration (b)				
	Toxicity (a)	Phosphate Fertilizer (c)	Micronutrient Fertilizer (d)		Yes (Y) or No (N)	Primary Reason
Aluminum	■	▒	▒		N	Not expected to pose a health risk
Antimony	■	□	□		N	Not expected to pose a health risk
Arsenic	■	▓	▒	**CAL, C, E, S**	**Y**	**Relative Toxicity**
Barium	░	▓	▓		N	Not expected to pose a health risk
Beryllium	░	□	□		N	Not expected to pose a health risk
Bismuth	NA	□	□		N	Not expected to pose a health risk
Boron	░	▒	▒		N	Not expected to pose a health risk
Cadmium	░	▓	▓	**CAL, C, E, S**	**Y**	**Potential for Exposure (g)**
Chromium III (f)	■	▒	▓	**E, S**	**Y**	**Evaluation Precedence**
Cobalt	░	□	▓	**C, S**	**Y**	**Evaluation Precedence**
Copper	░	▓	▒	**E, S**	**Y**	**Evaluation Precedence**
Iron	■	▒	▒	S	N	Not expected to pose a health risk
Lead	■	▒	▒	**CAL, C, E, S**	**Y**	**Relative Toxicity**
Manganese	■	▒	▒		N	Not expected to pose a health risk
Mercury	■	□	□	**CAL, C, E, S**	**Y**	**Relative Toxicity**
Molybdenum	░	▓	▓	**C, S**	**Y**	**Evaluation Precedence**
Nickel	░	▓	▓	**C, E, S**	**Y**	**Evaluation Precedence**
Selenium	░	□	□	**C, S**	**Y**	**Evaluation Precedence**
Silver	░	□	□		N	Not expected to pose a health risk
Strontium	■	▒	▓		N	Not expected to pose a health risk
Titanium	■	▒	▓		N	Not expected to pose a health risk
Vanadium	░	▒	▓	**E**	**Y**	**Evaluation Precedence**
Zinc	■	▒	▒	**C, E, S**	**Y**	**Evaluation Precedence**

Notes:

Bold = Selected for evaluation.
Italics = Micronutrients (i.e., essential to plant growth)
■ = Relative High Toxicity
░ = Relative Medium Toxicity
■ = Relative Low Toxicity
▒ = Relative High Concentration
▓ = Relative Medium Concentration
□ = Relative Low Concentration
NA = Not Available
C = Canadian Standard. Canadian Fertilizers Act R.S., c. F-9s.1.(1003).
CAL = California Department of Food and Agriculture (CDFA) and the Heavy Metal Task Force. 1998. Development of Risk Based Concentrations for Arsenic, Cadmium, and Lead in Inorganic Commercial Fertilizers. Foster Wheeler Environmental Corporation, Sacramento, CA.
E = United States Environmental Protection Agency (USEPA). 1999b. Estimating Risks from Contaminants Contained in Agricultural Fertilizers. Draft. Washington, D.C.: Office of Solid Waste and Center for Environmental Analysis.
S = United States Environmental Protection Agency (USEPA). 1995. A Guide to the Biosolids Risk Assessments for the EPA Part 503 Rule. Washington, D.C.: Office of Wastewater Management. EPA 832-B-93-005.

(a) Toxicity rating is based on the oral reference dose (RfD), because, the oral route of exposure is expected to be the exposure route of most concern (i.e., incidental ingestion of soil and ingestion of crops), and because all of the MOPC have an oral RfD.
(b) MOPC concentration rating is based on a qualitative evaluation of the MOPC concentrations in products relative to each other.
(c) Phosphate fertilizers includes (but are not limited to) N-P-K blends, DAP, MAP, TSP, and SP.
(d) Micronutrient fertilizers include: boron, iron, manganese, and zinc.
(e) Evaluation precedence identifies existing, relevant, studies that have evaluated the MOPC.
(f) Based on the assumption that chromium III (not chromium VI) is the species that is available.
(g) Cadmium is selected for evaluation because it is easily taken up into plants and, therefore, has a high exposure potential. Relative toxicity and concentration also contributed to this selection.

TABLE 3
SELECTION OF REPRESENTATIVE AND HEALTH PROTECTIVE EXPOSURE SCENARIO

Potential Populations	Potential Exposure Routes			Selected for Evaluation?	
	Soil				
	Incidental Ingestion	Dermal Contact	Ingestion of Crops	Yes (Y) or No (N)	Rationale
Home Gardner	Y	Y	Y	N	Lower exposure potential than resident farmer. (a)
Public Consumer	N	N	Y	N	Lower exposure potential than other scenarios. (a)
Farm Worker (b)	Y	Y	N	N	Lower exposure potential than a resident farmer and evaluated in previous evaluation. (c)
Resident Farmer (d) (e)	**Y**	**Y**	**Y**	**Y**	**Highest exposure potential; representative and health protective of other scenarios.**

Notes:

Bold = Selected as the representative and health protective exposure scenario.

RBC = Risk Based Concentration

Y = Yes, a plausible exposure route and expected to contribute significantly to exposure.

N = No, not a plausible exposure route.

(a) Each of these populations has lower exposure potential compared to the farm resident because exposure to fertilized soil either (1) does not occur or (2) occurs less frequently.

(b) Exposure to an applicator, including a farm worker, was evaluated in TWG (1999a, b). No significant health risk was found for this exposure scenario.

(c) A farm worker has a much lower exposure potential than a farm resident because the ingestion of crops is not applicable (or considered) for this population.

(d) Resident farmer considers both an adult and child who lives on a farm.

(e) CDFA (1998) focused on this population in developing RBCs for arsenic, cadmium, and lead; USEPA (1999b) also focused on this population in evaluating risks from contaminants contained in agricultural fertilizers.

TABLE 4
SELECTION OF REPRESENTATIVE AND HEALTH PROTECTIVE CROP GROUPINGS

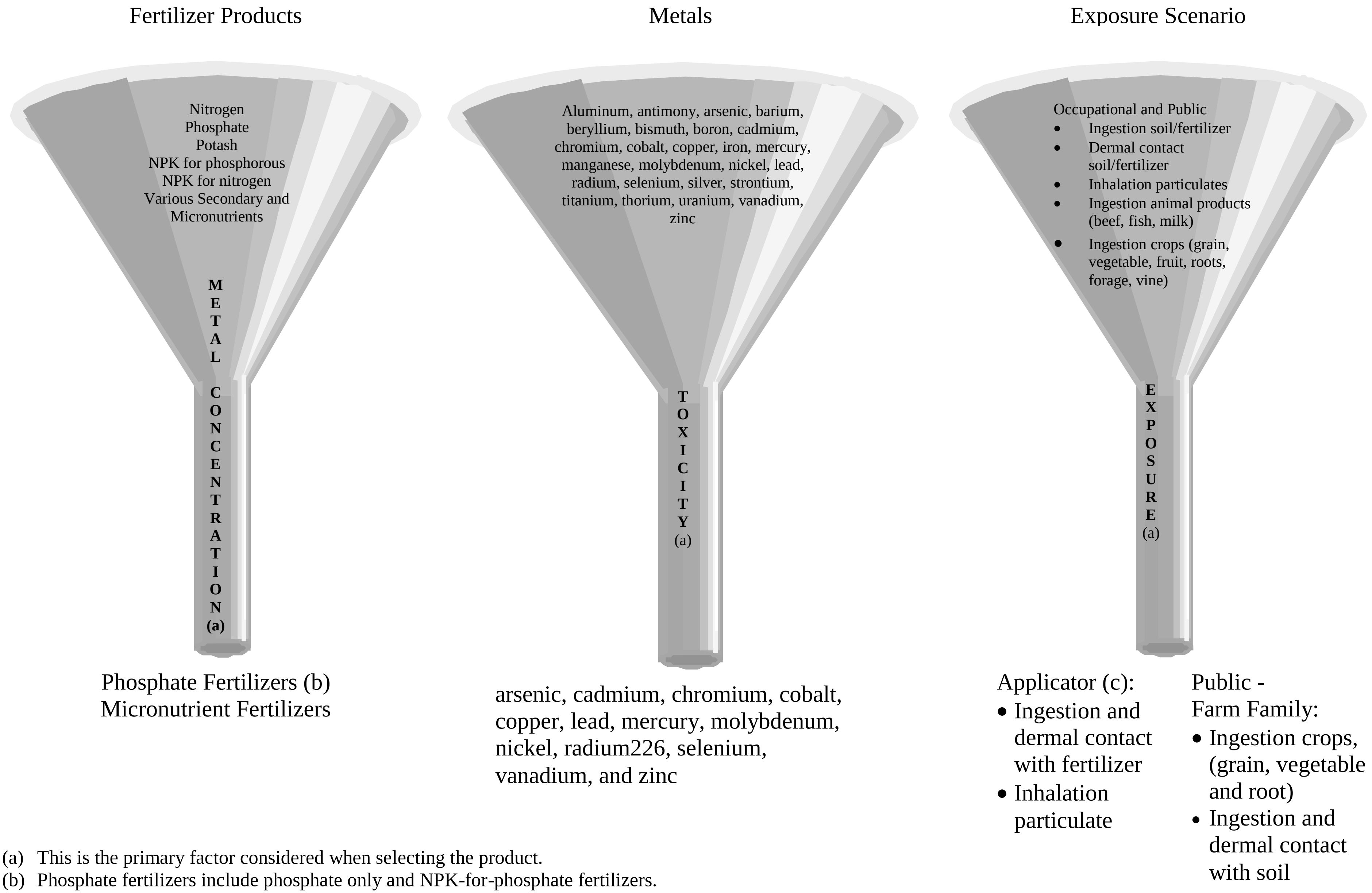
Potential Crop Groups	Selected for Evaluation?	
	Yes (Y) or No (N)	Rationale
Root (a)	**Y**	**Expected to contribute significantly to exposure.**
Vegetable (b)	**Y**	**Expected to contribute significantly to exposure.**
Grain (c)	**Y**	**Expected to contribute significantly to exposure.**
Fruit (d)	N	Much less exposure potential compared to crop groups selected for evaluation. (g)
Forage (e)	N	Ingestion of animal products eliminated from further evaluation in scoping stage. (g)
Field (f)	N	Field crops that are ingested by humans are considered in their appropriate crop groups.

Notes:

Bold = Selected as a representative and health protective crop grouping and included in the RBC equation.
RBC = Risk Based Concentration
Y = Yes, crop grouping expected to contribute significantly to exposure and included in the RBC equation.
N = No, crop grouping not expected to contribute significantly to exposure and not included in the RBC equation.
(a) Root crops are also called unexposed vegetables or protected vegetables. Root crops include: beets, carrots, fennel, onions, parsnip, potatoes, radish, rutabaga, turnip, and mangel.
(b) Vegetable crops are also called exposed or unprotected vegetables. Vegetable is a large broad category of crops. Examples of different types of vegetables are leafy (e.g., endive, kale, lettuce, swiss chard, spinach, and water cress), head and stalk (e.g., artichoke, asparagus, broccoli, brussel sprout, cabbage, cauliflower, celery, and peppers). Several fruits are also included in the vegetable category, because, they are cultivated as vegetables (i.e., cucumber, eggplant, and tomato).
(c) Grain is a large broad category of crops. Grains can be designated as field grains, silo grains, forage grains, or small or large grains. Only grains consumed by humans are included in this group. These grains include barley, corn, millet, oat, rice, rye, and wheat.
(d) Fruit crops can be designated as vine crops (grape), tree crops (nuts or lemon, lime, and orange) or sweet fruits (e.g., apple, cantaloupe, fig, grape, kiwi, rhubarb, pear, and strawberry).
(e) Forage crops are crops grown solely for the purpose of feeding cattle.
(f) Field crop is a general term for crops grown on fields. Examples of field crops include corn, cotton, potatoes, soybeans, tobacco, or wheat. Field crops that are ingested by humans are evaluated within their appropriate crop grouping (e.g., potatoes as root crops, wheat as grain).
(g) CDFA (1998) eliminated fruit and forage crops from the development of RBCs by demonstrating considerably less exposure to arsenic, cadmium, and lead, and therefore risk, for these crop groups.

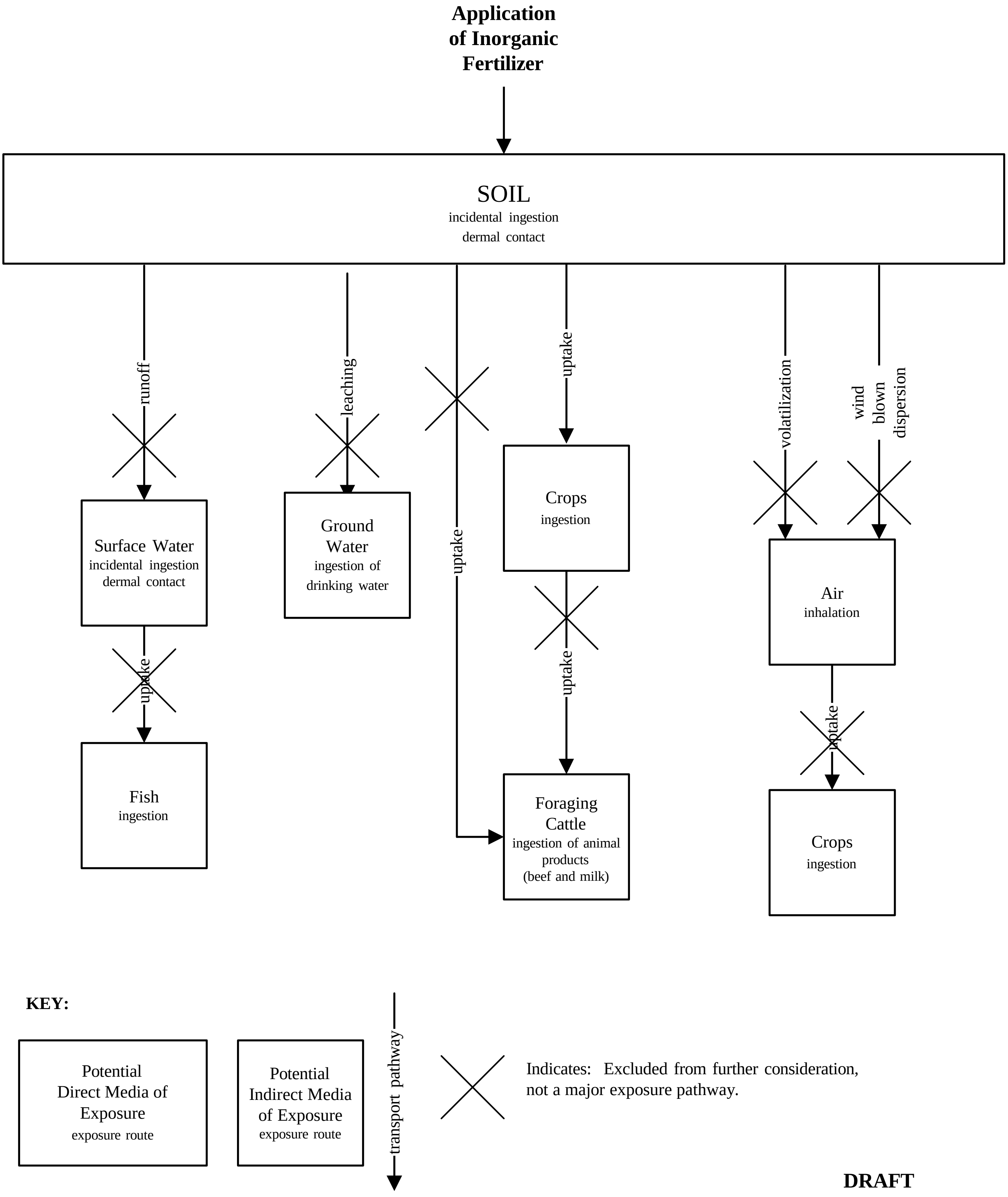
FIGURES

FIGURE 2. NARROWING THE SCOPE OF THIS SCREENING LEVEL EVALUATION - FOCUSING ON THE FERTILIZER PRODUCTS, METALS, AND EXPOSURE SCENARIO OF HIGHEST CONCERN



(a) This is the primary factor considered when selecting the product.
(b) Phosphate fertilizers include phosphate only and NPK-for-phosphate fertilizers.
(c) Occupational exposure (i.e., applicator) was evaluated in TWG (1999a,b).

FIGURE 3. POTENTIAL EXPOSURE PATHWAYS OF METALS OF POTENTIAL CONCERN (MOPC) IN INORGANIC FERTILIZER POST APPLICATION INCLUDES: TRANSPORT PATHWAYS, MEDIA OF POTENTIAL CONCERN, AND ASSOCIATED EXPOSURE ROUTES



DRAFT

SECTION 2.0 — DERIVATION OF RISK BASED CONCENTRATIONS (RBCS)

As noted in the introduction, this evaluation uses a standard, back-calculation, risk based approach to evaluate potential health risks. RBCs that are nationally representative and health protective are derived.

As defined in Section 1.0, RBCs are derived to represent and evaluate:

- 2 categories of inorganic fertilizers: phosphate fertilizers and micronutrient fertilizers;
- 12 MOPC: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, vanadium, and zinc; and 1 radionuclide, radium 226;
- Farm resident, including adult and child;
- 3 routes of exposure;
  - Unintentional ingestion of soil following fertilizer application,
  - Dermal contact with soil following fertilizer application,
  - Ingestion of crops, which are broken out into 3 crop groups: root, vegetable, and grain; and
- Both single crop and multi-crop farm scenarios.

Risk Based Concentration (RBC) Equation

The RBC equation is developed using standard USEPA risk practices and exposure parameters (USEPA 1989).[23] The standard equation to calculate risk combines 3 factors: estimated intake from exposure, toxicity of the element of interest (in this case MOPC), and concentration of the MOPC in the media of concern (i.e., fertilizer or product). In a back-calculation risk based approach, the equation is arranged to solve for the RBC using an estimate of potential exposure, toxicity, and an acceptable risk level. [24]

The RBC equation for the single crop farm is presented below. The equation integrates the 3 potential routes of exposure.

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[23] The standard USEPA exposure (intake) and risk equations were modified to fit the scenario evaluated in this report.

[24] Standard USEPA guidance presented in USEPA (1991).

Equation 1. RBC for the Single Crop Farm

$$RBC = \frac{\text{TR or THI}}{SACF * \{AR * 1 / FON * [(\frac{ED * EF * IRs * RAFs * CF}{BW * AT} * TOX) + (\frac{ED * EF * SA * AF * ABS}{BW * AT} * TOX) +}$$

$$\frac{\text{TR or THI}}{(\frac{ED * EF * IRc * RAFc}{AT} * PUF * TOX)]\}}$$

where:

$$\frac{ED * EF * SA * AF * ABS * CF}{BW * AT} = Summary\ Intake\ Factor\ (SIFd)\ Dermal\ Contact\ Soil / Fertilizer$$

$$\frac{ED * EF * IRs * RAFs * CF}{BW * AT} = Summary\ Intake\ Factor\ (SIFsi)\ Incidental\ Ingestion\ Soil / Fertilizer$$

$$\frac{ED * EF * IRc * RAFc}{AT} = Summary\ Intake\ Factor\ (SIFc)\ Ingestion\ Crop$$

where:

RBC = Risk Based Concentration (mg MOPC/kg product);
TR/THI = Acceptable Target Risk or Hazard Index (Unitless);
AR = Application Rate (g/m^2-year);
FON = Fraction of Nutrient (unitless);
SACF = Soil Accumulation Factor (m^2-year/g);
ED = Exposure Duration (years);
EF = Exposure Frequency (days/year);
BW = Body Weight (kg);
AT = Averaging Time (days);
CF = Conversion Factor (1X 10^{-6} kg/mg);
IRs = Ingestion Rate Soil (mg/day);
SA = Surface Area (cm^2/event-day);
AF = Adherence Factor (mg/cm^2);
IRc = Ingestion Rate Crops (kg/day);
RAF = Relative Absorption Factor (RAF) (unitless);
ABS = Dermal Absorption Factor (unitless);
PUF = Plant Uptake Factor (unitless); and
TOX = Toxicity Values (mg/kg-day or mg/kg-day $^{-1}$).

The RBC equation for the multi-crop farm scenario is more complicated than the RBC equation for the single crop farm, because all three-crop groups are integrated into one equation. Yet, each crop group has a different AR and PUF. The RBC equation for the multi-crop farm scenario is presented below. Note the addition of a new factor, Fraction of Land (FOL), in the equation. FOL is used to fractionate the addition of MOPC to soil by the different application rates for the different crop groups. Also note the use of SIFs in the equation. SIFs are summary intake factors that are derived for the single crop farm in Equation 1.

Equation 2. RBC for the Multi-Crop Farm

$$RBC = \frac{\text{TR or THI}}{(SACF * \{ARv * 1/FON * [(SIFs * TOX + SIFd * TOXd) * FOLv] + PUFv * SIFv * TOX\} +}$$

$$\frac{\text{TR or THI}}{\{ARr * 1/FON * [(SIFs * TOX + SIFd * TOXd) * FOLr] + PUFr * SIFr * TOX\} +}$$

$$\frac{\text{TR or THI}}{\{ARg * 1/FON * [(SIFs * TOX + SIFd * TOXd) * FOLg] + PUFg * SIFg * TOX\}}$$

where:

FOL = Fraction of Land (unitless) (discussed below)
v = Vegetable
r = Root
g = Grain

As discussed in Section 1.0, California is the largest multi-crop farming state; so, the multi-crop RBC is based on a multi-crop farm in this region. Gross estimates of the percentage of acreage dedicated to each crop group in California were made based on a rough review of agricultural data (crop acreage harvested) obtained from USDA (1999). In addition, CDFA (1998) was consulted for FOLs. FOLs of 50% grain, 40% vegetable, and 10% root are used to calculate multi-crop RBCs.[24]

Acceptable Target Risk (TR) or Hazard Index (THI)

In keeping with standard USEPA practices, a target cancer risk (TR) of 1X 10^{-5} and a target hazard index (THI) of 1 is used.[25] In general, USEPA uses an acceptable cancer risk of 1 $X10^{-5}$ (1 in 10,000) and a hazard quotient (HQ) of 1 for noncancer effects under it's hazardous waste programs. A HQ is the determination of noncancer risk for an individual MOPC. If the noncancer effects of the individual MOPC were all the same, the THI (of 1) would need to be reduced to account for the additive noncancer effects. However, since most of the MOPC are associated with different noncancer effects (i.e., different toxic endpoints) the THI does not need to be reduced below 1.[26]

Summary Intake Factor (SIF) Parameters

Summary intake factors (SIFs) combine biological exposure parameters and absorption factors to estimate intake from exposure. They are standard methods, intended to simplify the calculation

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[24] CDFA (1998) also uses these FOLs to develop RBCs for their multi-crop scenario.
[25] CDFA (1998) and USEPA (1999b) use these acceptable risk and HQ levels in their fertilizer risk assessment.
[26] Associated target organs or target effects for each noncarcinogen are presented in 'Toxicity Assessment'.

of the RBC. Biological exposure parameters are related to behavior and are age dependent. They include: exposure duration (ED), exposure frequency (EF), body weight (BW), averaging time (AT), ingestion rates (IR), skin surface area (SA), and adherence factor (AF). The values for all of these exposure parameters were developed from USEPA references and are intended to represent the reasonable maximum exposure (RME). They are presented in Table 5. As defined under USEPA (1989), RME is the highest exposure that is reasonably expected to occur and that is well above the average case, but within the bounds of the high-end exposure case. In addition, relative absorption factors (RAF) and dermal absorption factors (ABS) are developed (as appropriate). The information used to derive RAF and ABS are presented in Appendix A. RAF and ABS are presented in Appendix A, Table A-1.

Exposure Duration (ED)

The exposure duration (ED) is the length of time exposure occurs and is typically the length of residence. The ED for the farm adult is 30 years. This ED is the USEPA recommended default ED at the 95th percentile for a family to reside in a home. The central default value (50% percentile) is 9 years. There is also a central residence time estimate for a farm presented in USEPA (1997a) (about 17 –18 years), however; the upper-end estimate of general residence time is considered a better estimate for the RME scenario. The ED for the farm child is 6 years. This is the standard age frame considered when evaluating risks to children.

Exposure Frequency (EF)

Exposure frequency (EF) represents how often (days/year) the potential for exposure occurs. The exposure frequency (EF) for the farm adult and child is 350 days/year for all exposure routes, including dermal contact and incidental ingestion of soil and crop ingestion. An EF of 350 days/year is recommended when using daily ingestion rates (excluding time away from home for vacation). In addition, an EF of 350 days/year is most representative of a warm climate.

Averaging Time (AT)

Averaging time (AT) depends on the toxic effect assessed (i.e., whether cancer or non-cancer). For non-carcinogens, intake is averaged over ED. In the RBC equation for non-cancer, ED is in the numerator of the intake equation and AT is in the denominator (AT=ED*365 days/yr). Therefore, AT and ED cancel each other out. For carcinogens, intake is averaged by prorating the cumulative dose over a lifetime (i.e., 70 years = 25,550 days) (USEPA 1989).

Body Weight (BW)

USEPA standard default body weights (BW) were used for both the farm adult and child. The BW values are averages; average is the recommended statistic for BW when evaluating the RME scenario (USEPA 1989). The adult BW is 71.8 kg (represents ages 18 – 75 years) and the child BW is 15.5 kg (average BW from 6 months to 6 years for males and females) (USEPA 1997a).

Ingestion Rate (IR)

Ingestion rate (IR) is the amount of media of interest (either soil or crop) ingested and is presented as an amount per day. IR correlates with BW, because IR correlates with age, which correlates with BW. Because IR correlates with BW, and the average BW is suggested for the RME scenario, IRs are also central estimates (or averages). The IR for soil is different than the IR for crops (and the IR for each crop group is different) as discussed below.

- Soil

The incidental soil IR for an adult is 50 mg/day. This is USEPA's recommended central estimate adult soil IR (USEPA 1997a). There is no recommended high-end estimate. In the past, typical USEPA risk assessments used adult soil ingestion rates of 50 mg/day for an industrial setting and 100 mg/day for a residential and agricultural setting (USEPA 1997a). USEPA's most recent guidance (1997a) recommends an IR of 50 mg/day. Regardless, whether using a soil ingestion rate of 50 mg/day or 100 mg/day, the effect on the RBC not significant, as discussed in the uncertainty section.

The soil IR for a child is 200 mg/day. This is a conservative estimate of the mean. A high-end estimated soil IR of 400 mg/day was considered too high for this assessment, because, it is based on a short study period, and not usual daily activity (USEPA 1997a). As with the adult scenario, the use of a 200 mg/day or 400 mg/day soil ingestion does not significantly influence the RBC (as discussed in the uncertainty section).

- Crop

IRs for each crop group (i.e., vegetable, root, and grain) are developed from information presented in USEPA (1997a). Because the IR for crops varies by age group, and correlates with BW, the crop IRs are already averaged over BW. Therefore, BW does not appear as an independent parameter in the crop intake equation. In developing the crop IRs, the IRs for each crop group consider all of the data that are appropriate for that crop group (as listed in Section 1.0). The crop IRs are weighted averages of the means, across the age groups of interest, on a per capita basis. Per capita intake rates are appropriate estimates for average intake of the general population (USEPA 1997a). The IRs are based on data from the USEPA "key" and recommended study (USEPA 1997a). This study is the Continuing Survey of Food Intakes by Individuals (CSFII) from 1989-1991.

These IRs are based on "as consumed", which means fresh weight or wet weight. For children, the age groups included in the weighted average are ages 1 –5. For adults, ages 6-70+ were considered. This age group also considers teens and young adults.

Vegetable

Vegetable IRs are developed from data in Table 9-9 (Per Capita Intake of Exposed Vegetables) and Table 9-10 (Per Capita Intake of Protected Vegetables) in USEPA (1997a). Data for exposed vegetables considers all of the vegetables presented in the discussion of crop grouping in Section 1.0, plus additional vegetables not listed in this group. Protected vegetables in Table 9-10 in USEPA (1997a) are vegetables with a husk or thick skin (not vegetables that grow underground or root vegetables). Examples, of these vegetables include pumpkin, squash, lima beans, peas, and corn. Several of these vegetables do not fit into the vegetable category, as defined for this report (especially corn), however, all exposed vegetables were still included in developing the IRs for vegetables. The vegetable IR is the age weighted IR for protected plus exposed vegetables.

The vegetable IR for an adult is 1.7 g/kg-day. The vegetable IR for a child is 2.9 g/kg-day.

Root

The IRs for root crops are developed from data in Table 9-11 (Per Capita Intake of Root Vegetables) (USEPA 1997a). Examples of root vegetables considered in this table are potatoes, carrots, beets, garlic, onions, radish, turnip, and leeks.

The root IR for an adult is 1.1 g/kg-day and the root IR for a child is 2.1 g/kg-day.

Grain

The IRs for grain are developed from data presented in Table 12-1 (Per Capita Intake of Total Grains Including Mixtures) (USEPA 1997a). These IRs are developed the same way as the IRs for vegetables and roots (i.e., time weighted averaged, based on the mean, and per capita). Total grains presented in this table includes breads, sweets (cakes, pie, and pastries), breakfast foods with grains, pasta, cereals, and rice and grain mixtures.

The grain IR for an adult is 3.4 g/kg-day and the grain IR for the child is 9.4 g/kg-day.

Fraction Ingested (FI)

One parameter that is not shown in the RBC equation, but is factored in and needs to be mentioned is fraction ingested (FI). FI can apply to any media of interest (soil or crop) ingested, and is the fraction (or portion) of the soil or crop that originates from the source (in this case, soil following application of fertilizer, or crops grown on this soil). For the purposes of this screening level evaluation, all (100%) of the soil or crop is assumed to come from the farm, therefore, FI is 1. An FI of 1 is the most health protective (conservative) FI value. Since FI is 1, for simplicity, it is not presented in the RBC equation.

Skin Surface Area (SA)

Skin surface area (SA) is the area of skin that is available for dermal contact with soil/fertilizer. The skin SA is taken from the most recent USEPA (1998b) dermal guidance. Similar to IR, skin SA correlates with BW. Therefore, average or central estimates are recommended for the RME scenario.

For soil exposure, the recommended central estimate of skin SA area for an adult is 5,700 cm^2/day; the recommended central skin SA for a child is 2,900 cm^2/day (USEPA 1998b). The adult skin SA is based on a warm climate where more skin is likely to be exposed. The adult skin SA is based on the adult wearing short sleeved shirt, shorts, and shoes; the exposed areas are the head, hands, forearms, and lower legs. The child skin SA is also based on a warm climate scenario and a child wearing short sleeved shirt and shorts, but no shoes. For the child, the exposed SA area is 45% of the total skin SA (USEPA 1998b).

Adherence Factor (AF)

Adherence factor (AF) is an estimate of the amount of soil that adheres to skin. As with the skin SA, the most recent USEPA dermal guidance (1998b) was consulted for AFs. AFs vary depending on the exposure scenario. For example, AFs are available for a groundskeeper, or nursery worker, or an archeologist. The AF selected for the adult is the USEPA recommended adult, default AF, 0.08 mg/cm^2-event. This AF is for the residential scenario and is based on outdoor gardening. The recommended default AF for a child is 0.3 mg/cm^2-event (USEPA 1998b).

Absorption Parameters

As can be seen in the RBC equation, there are two additional parameters in the SIF, relative absorption factor (RAF) and percent dermal absorption (ABS). These parameters adjust the estimated intake to an actual absorbed "dose." Absorbed dose refers to the amount of the MOPC that is actually absorbed into the blood stream following exposure and intake. RAF and ABS help to develop a more realistic RBC by estimating the fraction of MOPC that is actually absorbed into the bloodstream, not just the amount of exposure (i.e., ingested or contacted). Absorption is representative of the fraction of the MOPC that is available (i.e., bioavailable). Bioavailability is the fraction of specific contaminant in a medium (e.g., soil or crop) that is absorbed into the bloodstream across physiological barriers. Without the incorporation of these factors, the RBCs may be largely overestimated. However, these parameters are only used, when appropriate and applicable data are available. Information supporting the RAFs is presented in Appendix A. For MOPC where data is not available to develop a RAF, a RAF of 100% is assumed. This is the case for most MOPC. An RAF is developed and incorporated into the RBC for arsenic and lead, as discussed below. In addition, for most MOPC, a default ABS for metals of 1% is used (USEPA 1998b).

- Relative Absorption Factor (RAF)

RAF is intended to ensure that the toxicity value and estimated intake are based on comparable estimates of intake (both based on an absorbed or administered dose, and the same or similar medium). Therefore, RAF depends on (1) whether the toxicity value is an "administered" or an actual absorbed dose and (2) the absorption from both the medium of the toxicity study and the medium of interest (i.e., soil or crop). RAF is the percent of the MOPC that is absorbed from the medium of interest [following ingestion, and absorption through the gastrointestinal tract (GI)] divided by the percent GI absorption used in the oral toxicity study.

The estimated intake and associated toxicty of arsenic from the ingestion of soil is adjusted by a RAF. The oral toxicity value for arsenic is based on an administered dose from exposure to arsenic in drinking water. An applicable and acceptable study on the bioavailability of arsenic was found. This study determined a bioavailability of arsenic in soil of 42% (Rodriquez et al. 1999). The percent absorption of arsenic in drinking water is 95% (USEPA 1999c). Therefore, a RAF for arsenic in soil of 44% (42% ÷ 95%) is incorporated into the RBC.

In addition, the estimated intake of lead into the GI tract following unintentional ingestion of lead in soil and ingestion of lead in crops, and the associated toxicity, is adjusted by a RAF. Since the toxicity of lead is based on an acceptable blood lead level, which is an absorbed level (or dose), the intake also needs to be adjusted to an absorbed dose. The GI absorption of lead in soil and crop following ingestion is 0.41, and 0.50, respectively (USDHHS 1997). The estimated intake from unintentional ingestion of soil and ingestion of crops and associated toxicity is adjusted accordingly.

A default RAF of 100% (or 1) is assumed for all other MOPC and their associated exposure routes.

- Percent Dermal Absorption (ABS)

All of the toxicity values for the dermal route of exposure are based on an absorbed dose (as described in the Toxicity Assessment Section). Therefore, intake from dermal contact needs to be in an absorbed dose. Percent dermal absorption (ABS) estimates the amount of MOPC that is absorbed across the skin into the bloodstream following dermal contact. Screening level ABS are used (1% for all MOPC, except 3% for arsenic) and were obtained from (USEPA 1998b).

Application Rate (AR) and Fraction of Nutrient (FON)

Application rate (AR) is a very important parameter in the RBC equation and can influence the RBC greatly. As defined in the scoping stage of this evaluation (Section 1.0), RBCs are developed for phosphate fertilizers and zinc micronutrient fertilizers. Application rates (ARs) for phosphate and zinc micronutrient fertilizers are presented in Table 6.

Also discussed in Section 1.0, AR is dependent on the plant nutrient needs (P or zinc) and the composition of the product, specifically, the percent nutrient (percent P or percent zinc). ARs vary for different crops and different products. ARs for each of the three crop groups (vegetable, root, and grain) are developed for phosphate and for zinc based on information presented in USEPA (1999a). However, these ARs are based on nutrient needs of crops and are not product specific (i.e., they do not consider the percent nutrient of product). These ARs (or nutrient needs) will vary depending on the percent nutrient of the product. For example, products with a higher percent of P will be applied less than a product with a low percent of P in order to meet the nutrient needs of the plant. The percent of P for phosphate fertilizers varies considerably from fertilizer to fertilizer (as can be seen in Table 1, percent of P ranges from 2.0-70.1).

RBCs are intended for screening level evaluations and need to be easy to use and flexible. Therefore, the RBCs are normalized to represent a 1 percent fraction of nutrient (FON) content. These RBCs are called unit RBCs. Unit RBCs can easily be adjusted to represent a particular product with a certain percent nutrient content (the concept of unit RBC and their adjustment is discussed in further detail in Section 4.0).

The ARs for P (and thus phosphate fertilizers) are based on the appropriate and available crop data presented in USEPA (1999a). Data for all crops and every state, regardless of geographic area, are compiled into the database used to develop the ARs for P. The data set compiled for each crop group is presented in Appendix A. The ARs are the 95 upper confidence limit (UCL) of the mean (based on the assumption that the data is normally distributed). Although this data set may not be normally distributed, the 95UCL of the mean is considered an appropriate estimate because it is sufficiently high-end. The ARs are presented in USEPA (1999a) in units of 1b/acre-yr. These ARs are converted to g/m^2-year by 0.11 g-acre/lb-m^2 (for appropriate units in the RBC) and then adjusted to reflect a 1% FON.

The high-end ARs for phosphate fertilizers are:

- Vegetable = 119 lb/acre-year (13 g/m^2-year);
- Root = 157 lb/acre-year (17 g/m^2-year); and
- Grain = 63 lb/acre-year (7 g/m^2-year).

There is limited information available on the application of micronutrients. The information and ARs presented in USEPA (1999a) are based on interviews with experts. The “high” AR for zinc micronutrient presented in USEPA (1999a) of 10 lb/acre (1 g/m^2-year) is a best estimate. This is the AR used for all micronutrient fertilizers and for all crop groups.

Soil Accumulation Factor (SACF)

The soil accumulation factor (SACF) estimates how much of an MOPC accumulates in soil following annual applications (over years of farming) and takes into account an estimated loss of MOPC in soil from transport of the MOPC into surrounding media. The accumulation and behavior of MOPC in soil from agricultural application depends essentially on (1) farming duration (years) (2) the application rate (AR) of the fertilizer (3) the concentration of the MOPC in the fertilizer and (4) the fate and transport of the MOPC in soil. Further, fate and transport depends on the soil condition, climatic conditions and MOPC specific parameters (i.e., MOPC form, soil water coefficient, etc.). USEPA has developed models that estimate the accumulation of MOPC in soil following application (USEPA 1990, 1993). These models were modified by CDFA (1998) for the purposes of developing an RBC (Equation 3.0); the resulting equation is presented below.

The modified equation (Equation 4.0) is also presented below. As can be seen in Equation 4.0, SACF is related to the duration of application, the depth of soil that is expected to accumulate MOPC, the potential loss of the MOPC from soil through potential transport (or now considered loss) pathways, and limited soil characteristics (e.g., bulk density). The fate and transport of the MOPC in soil, over years of farming, depends on the form of the MOPC, the type (i.e., sandy or silty loam) and condition of soil (e.g., the organic matter content of the soil, the pH of the soil) and the climatic conditions of the area. Because SACF depends on so many different factors, which all vary given any situation, not all situations can be represented when developing the RBC. Instead and in keeping with the intent of this screening level evaluation, a SACF is estimated that is based on nationally representative high-end (resulting in more protective RBCs) assumptions, and an SACF that is based on the most important parameters and loss pathways. The development of SACF does not consider MOPC specific factors (except Kd), such as, the form of the MOPC (speciation and complexation), and is based on general, not site specific, assumptions. All of the parameters used to calculate the SACFs are presented in Table 7. The SACFs are presented in Table 8.

Equation 3.0 Accumulated Soil Concentration

$$Sc = \frac{AR * [1 - \exp(-K_s * T\ )] * 100}{Z * BD * K_s}$$

where:

Sc = accumulated soil concentration (mg/kg);
AR = application rate (deposition rate) of metal (g/m^2-yr);
Ks = soil loss constant (yr^{-1});
T = total time period (evaluation time) over which deposition occurs (years);
100 = conversion factor (mg-m^2/kg-cm^2);
Z = soil mixing depth (cm); and
BD = soil bulk density (g/cm^3).

Equation 4.0 Soil Accumulation Factor (SACF)

$$\text{SACF} = \frac{10^{-6} * [1.0 - \exp(-K_s * T)] * 100}{Z * BD * K_s}$$

where:

SACF = soil accumulation factor (m^2/yr-g);
10^{-6} = conversion factor (kg/mg);
T = total time period over which deposition occurs (years);
Z = soil mixing depth (cm);
BD = soil bulk density (g/cm^3); and
K_s = soil loss constant (yr^{-1}).

<u>Time Period of Application (T)</u>

MOPC are added to soil over years of farming. Because of losses from the root zone, the rate of accumulation of the MOPC in soil will slow over the years. Eventually, following application year after year, on the same soil, the concentrations of the MOPC are expected to reach a steady state. The number of years it takes the MOPC to reach steady state is assumed to be 50 years, except for lead where the application duration is 200 years. These application durations are developed in CDFA (1998).

Soil Mixing Depth (Z)

Soil mixing depth (Z) is the depth of soil that is expected to be tilled. A default Z of 20 cm is used (USEPA 1998a).

Soil Bulk Density (BD)

A default BD of 1.5 g/cm^3 from USEPA (1998a) is used. This BD is based on a loam soil.

Defining Potential Fate and Transport (Loss Pathways) (Ks)

As can be seen in Figure 3, chemicals in soils can be lost through four potential transport pathways including degradation, leaching, erosion, and volatilization. The loss of the MOPC through these transport pathways decreases the amount of MOPC that accumulates in soil and that is available (1) for exposure through direct contact with soil or (2) uptake into crops. Only leaching is considered a mechanism (albeit a small amount) of metal loss from soil.[25] All of the other transport pathways are not considered in the development of SACF because they either are (1) not plausible or (2) they are inconsequential.[26] The equation that is used to determine loss due to leaching is presented below (Equation 5.0). This equation is adopted from USEPA (1993).

Equation 5.0 Metal Loss Due to Leaching from Soil

$$ksl = \frac{P + I - Ev}{\Theta * Z * (1.0 + BD * K_d / \Theta)}$$

where:

ksl = metal loss due to leaching (yr^{-1})
P = average annual precipitation (cm/yr)
I = average annual irrigation (cm/yr)
Ev = average annual evapotranspiration (cm/yr)
K_d = soil-water partitioning coefficient (mL/g)
Θ = soil volumetric water content (mL/cm^3)

Equation 5.0 was further reduced because irrigation is designed to counter loss due to evapotranspiration; therefore, evapotranspiration and irrigation are excluded from this equation.

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[25] Leaching of MOPC into groundwater, and subsequent ingestion of drinking water, was eliminated as an exposure pathway (as presented in Figure 3). Although the amount of MOPC that leaches is expected to be small, and is not considered to contribute significantly to exposure, the loss of MOPC through leaching is still greater than the loss through other transport pathways.

[26] The other 3 loss pathways, degradation, erosion, and volatilization were previously determined to (1) either not occur or (2) to be inconsequential as loss pathways for metals in agricultural soils (CDFA 1998).

Precipitation (P)

A USEPA (1998a) default precipitation (P) estimate of 28 cm/year is assumed. This precipitation is a relatively low precipitation rate from a national perspective. Precipitation rates range across the country from approximately 18 cm/year up to 165 cm/year (USEPA 1998a). The lower the precipitation rate the less potential for leaching and the more MOPC in the soil.

Soil-Water Partitioning (Kd)

Soil-water partitioning coefficients (Kd) are used to estimate how much of an MOPC is expected to move from the soil phase to the water phase. This movement of an MOPC to the liquid phase makes the MOPC more bioavailable. Bioavailable MOPC are available for movement away from soil, for example, through uptake into crops or leaching into groundwater. Kd is best determined from empirical studies and not modeled.[27] Kd is the ratio of the total soil metal concentration over the dissolved metal concentration (or metal in the water phase). Kd is highly influenced by the characteristics of the soil (e.g., organic matter content and especially pH). Generally, the lower the pH, the higher the Kd (and the more soluble and more bioavailable the MOPC).

The Kd values are taken from an article that compiled empirically derived Kds from existing literature and developed a distribution of these values. The literature presents Kds for most of the MOPC over different soil types (clays and loams) and a pH range of 4.5 – 9.0 (Baes and Sharp 1983). The Kd selected for use in the SACF is the mean value. Because there were no Kd values for mercury, nickel, and vanadium in Baes and Sharp (1983), Kds for these MOPC are adopted from USEPA (1995) and Gerriste et al. (1982). These values are also mean estimates. The soil type in Gerriste et al. (1982) is sandy soil and sandy loam with pH's of 5.0 and 8.0, respectively.

Soil Volumetric Water Content (Θ)

A default soil volumetric water content (Θ) of 0.2 mL/cm^3 is used (USEPA 1998b).

Plant Uptake Factors (PUFs)

Like AR, plant uptake factor (PUF) is a critical parameter in the RBC equation.[28] PUF estimates the amount of MOPC present in soil that is taken up by the crop.[29] PUF is MOPC specific and is determined through experimental studies that measure the concentration of MOPC in soil and then MOPC in plant tissue of plants grown on this soil. Basically, PUF is the ratio of total (not extractable, as discussed below) MOPC concentration in plant over the MOPC concentration in soil. In addition to the influence of crop type and MOPC, there are many other factors that influence PUF. These factors include study design (e.g., greenhouse or pot or field study), form of the MOPC, and the soil types and conditions of the study. Each of these factors is considered

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[27] As discussed in USEPA (1999b).

[28] In CDFA (1998) sensitivity analysis, PUF was determined to be one of the most sensitive parameters for most of the RBCs.

[29] PUF is also called transfer coefficient or transfer ratio.

when selecting studies that are used to develop PUFs. A presentation of the study selection criteria are presented in Appendix B, along with the summary statistics for each PUF data set. PUFs that are used to calculate the RBCs are presented in Table 9.

Green House, Pot, and Field Studies

Study design (i.e., green house or pot or field) will influence the PUF.   Generally, when both the plant root system and soil are confined, as in a green house or pot study, the opportunity for uptake of the MOPC by the plant is increased. The higher uptake could result from increased soil temperature and differences in evapotranspiration (Chaney et al. 1999), and in comparison, in field studies, the root system has a greater space, and more dilute soil system, allowing less potential for MOPC uptake. Nevertheless, because of the sometimes limited information from field studies, greenhouse and pot studies are included in the PUF database.[30]

Type of Fertilizer

The chemical form of the MOPC in the fertilizer influences the PUF and the MOPC form is likely to be different for different types of fertilizers. In general, the form of the MOPC in fertilizer is different in organic fertilizer compared to inorganic fertilizer. Given that this evaluation is focused on inorganic fertilizers, studies using inorganic fertilizers are of most interest.

MOPC in inorganic fertilizers are generally impurities and are usually part of a relatively immobile complex. The plant uptake of MOPC in phosphate fertilizers is generally lower than some other fertilizers, like soluble chloride or sulfate salts. MOPC in these fertilizers, which are extremely soluble, are much more available for plant uptake. MOPC in inorganic fertilizers usually have higher plant uptake than MOPC in organic fertilizer. MOPC in organic fertilizers tend to have an increased capacity to sorb to soil because of the presence of several hydrous metal oxides (aluminum, iron, and manganese) (Chaney et al. 1999). In general, studies using organic fertilizers are not appropriate for developing PUFs for inorganic fertilizer application. However, studies using organic fertilizer (sewage sludge) are included in the database if the addition of an organic fertilizer was more like the addition of an inorganic fertilizer. These studies were used only if:

1. The experiment included an untreated (control) plot with typical plant yields. Control plots with atypically low plant yields were assessed to be inadequately fertilized and, therefore, inappropriate for evaluating PUFs.
2. Sludge had been added many years ago and MOPC concentrations in soil had reached steady state.
3. Flyash was added to soil at nontoxic levels, and like sludge, was allowed to reach steady state with the surrounding soil.

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[30] USEPA (1999b) conducted a sensitivity analysis on the use of field versus pot studies for estimating fertilizer risks and found data from field studies to be the most appropriate information to use for this scenario. More specifically, the PUFs developed from pot studies are much higher than the PUFs from field studies; therefore, field studies are more appropriate for the exposure scenario.

Soil Type and Condition

PUF is also influenced by soil type (e.g., sandy-silty loam, sand) and soil conditions (e.g., pH, cation exchange capacity, temperature, and moisture content), because, these factors will affect the form and behavior of the MOPC in soil. The studies included in the PUF database represent a wide variety of soils and soil conditions covering a large range of chemical and physical soil properties. The database included information obtained throughout the US and some information from Canada, Europe, Australia and elsewhere. An evaluation of the variability of these specific soil factors was not conducted on the PUF database, however, the database is considered large enough to average out the affects of these variables. In addition, a high-end estimate of the PUF was used in developing the RBC to represent conditions where high plant uptake may occur.

Studies Excluded from Consideration

Studies were excluded from the PUF database because insufficient information was presented to be useful. In particular, studies that did not report total metal soil concentrations (or at least sufficient data to calculate total metal soil concentration) were excluded from the database. These studies typically report an extractable (or plant available) soil concentration. Plant available (i.e., extractable) MOPC concentration in soil does not correlate well with total MOPC soil concentration because of the different methods of extraction and is not considered a good value for estimating PUFs.[31] In general, PUFs developed using extractable MOPC concentrations are lower than PUFs using total MOPC concentrations.

In addition, studies where the methods were deemed to be inappropriate or not applicable for this scenario, were excluded. For example, studies where the application rates of the fertilizer were exaggerated, in comparison with practical application rates, were excluded from the database.

Presentation of PUFs

The PUFs for each MOPC and crop group are presented in Table 9. The PUFs are presented in both dry and wet (or fresh) weight. Most studies present plant and soil concentrations in dry weight; dry weights are generally more constant than fresh weight. However, PUFs need to be in the same units as the ingestion rates (IR). IRs are presented in “as consumed basis” (as consumed equals wet weight), therefore, the PUFs are converted from dry to weight wet. This conversion is done by multiplying the PUF in dry weight by a dry weight fraction for the crop over the dry weight fraction of the soil. The percent (or fraction) of dry weight is derived from the percent of wet weight (or moisture values) (i.e., 100% weight - % wet weight = % dry weight). The fraction of dry weight for vegetable, root, and grains are 10%, 11%, 90%, respectively. These values are based on standard USEPA data (USEPA 1997a). The fraction dry weight for soil is 90%. This fraction is based on sandy loam soil because this is the type of soil used in most of the studies. Regardless of soil type, the percent moisture content of soil is typically low; therefore, the dry weight fraction is usually high. The PUFs in Table 9 are the 90% upper confidence limit (UCL) of the geometric mean, which is a high-end estimate. Generally, the data for PUFs are log normally distributed.

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[31] Expert opinion from Dr. Roland Hauck of Florence, AL. Personal Communications. 1999

Toxicity Assessment

In developing the RBCs, the toxicity of the MOPC are evaluated for both cancer and non-cancer endpoints (note the exceptions for lead, as discussed below). Toxicity values were obtained from USEPA's online Integrated Risk Information System (IRIS) (USEPA 1999c), USEPA's Health Effects Assessment Summary Tables (HEAST) (USEPA 1997b) and USEPA Region III risk based concentration toxicity values (USEPA 1999c). The oral and dermal toxicity values are presented in Table 10.

For several MOPC (i.e., chromium and mercury) the toxicity values depend on the form of the MOPC. For example, toxicity values are available for chromium III and chromium VI. For mercury, toxicity values are available for elemental mercury, mercuric chloride, and methyl mercury. Assumptions about the form of the MOPC that is likely to be found in soil following years of application of inorganic fertilizer are made and the appropriate toxicity values are used to calculate the RBC. In summary, chromium III and mercuric chloride (or divalent mercury) are more likely to be found in soil and be available for uptake and potential exposure, compared to the other forms of these MOPC.

Carcinogenic Effects

For MOPC exhibiting carcinogenic potential, cancer slope factors (SF) are developed by USEPA's Carcinogen Risk Assessment Verification Endeavor Work Group (CRAVE). These slope factors are developed from chronic animal studies or, where possible, human epidemiological data, and represent the excess lifetime cancer risk associated with various levels of exposure. Cancer slope factors (SFs) are expressed as in terms of dose in units of (mg chemical/kg body weight/day)$^{-1}$. They describe the upper bound increase in an individual's risk of developing cancer over a 70-year lifetime per unit of exposure or dose, where the unit of acceptable exposure is expressed as mg chemical/kg body weight/day (mg/kg/day). In addition to developing the SF, USEPA assigns a weight of evidence classification for each carcinogen, which are also provided in Table 10.

Non-Carcinogenic Effects

Toxicity criteria for chemicals potentially causing noncarcinogenic effects are expressed as references doses (RfDs). The RfD is a threshold level of beyond which toxic effects may result. RfDs are expressed in units of dose (mg chemical/kg body weight/day). Chronic oral RfDs are developed to be protective for long-term exposure to a chemical. To derive a RfD, a series of professional judgements are made to assess the quality and relevance of the human or animal data and to identify the critical study and the toxic effect. A toxicity level from the critical study, preferably the highest no-observable-adverse-effect level (NOAEL), is used. For each uncertainty associated with the NOAEL, a standardized factor is applied to establish a margin of safety. For example, uncertainty factors are used to account for sensitive subpopulations or the extrapolation of animal data to humans. An oral RfD for cadmium in both food and water is available. The toxicity value for food is used in this evaluation.

Dermal Toxicity Values

Toxicity values are available from USEPA for the oral (i.e., ingestion) route of exposure, but are not available for the dermal route of exposure. Dermal toxicity values are developed by converting the oral toxicity values from an administered dose to an absorbed dose, following USEPA standard guidance (USEPA 1989). For RfDs, the oral value is adjusted to a dermal toxicity value by multiplying the oral RfD by the fraction of MOPC that is absorbed in the gastrointestinal tract (GI ABS). The oral SFs are converted to dermal SFs by dividing by the GI ABS. GI ABS values are also presented in Table 10. Note, if the oral toxicity value is already based on an absorbed dose (e.g., cadmium), then no adjustment is necessary. The GI ABS values are from the chemical specific Agency for Toxic Substance Disease Registry (ATSDR) toxicological profiles.

Toxicity Value for Lead

No RfD or CSF has been established for lead (USDHHS 1997). The general consensus on evaluating lead exposure and toxicity is through measuring blood lead levels (NAS 1980). USEPA and ATSDR recommend a fetal acceptable blood lead concentration of 10 µg/dL ($PbB_{fetal, 0.95, goal}$). This level is as an upper limit indicator below which no adverse effects would be expected. The USEPA approach for developing acceptable concentrations for blood lead was used in developing the acceptable blood lead concentration. The acceptable fetal blood lead level of 10 µg/dL is used to develop a target blood lead concentration ($PbB_{a,c,g}$). In addition, biokinetic slope factors (BKSF) for the different exposure routes and the child and adult are used to convert the estimated intake to a blood lead level (DTSC 1992).[32]

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[32] CDFA (1998) used the same biokinetic slope factors.

TABLES

TABLE 5
VALUES, DESCRIPTIONS, AND REFERENCES FOR BIOLOGICAL EXPOSURE PARAMETERS (a)

Parameter	Units	Adult	Descriptor	Child	Descriptor	Reference
Exposure Duration (ED)	years	30	RME default, 95th percentile length of residence	6	typical RME default	USEPA (1997a)
Exposure Frequency (EF)	days/year	350	daily contact; days/year at home	350	daily contact; days/year at home	USEPA (1989)
Averaging Time (AT)	days					
Cancer		25,550	prorated over a lifetime of 70 yrs	25,550	prorated over a lifetime of 70 yrs	USEPA (1989)
Non-cancer		10,950	averaged over ED	2,190	averaged over ED	USEPA (1989)
Body Weight (BW)	kg	71.8	default, mean	15.5	mean (b)	USEPA (1997a)
Ingestion Rates (IR)						
Soil	mg/day	50	default, mean	200	default, conservative estimate of the mean	USEPA (1997a)
Crop	g/kg-day					
Vegetable		1.7	mean (c)	2.9	mean (d)	USEPA (1997a)
Root		1.1	mean (c)	2.1	mean (d)	USEPA (1997a)
Grain		3.4	mean (c)	9.4	mean (d)	USEPA (1997a)
Fraction Ingested (FI)	unitless	1	NA	1	NA	NA
Skin Surface Area (SA)	cm^2-day	5,700	RME default (f)	2,900	RME default (f)	USEPA (1998b)
Adherence Factor (AF)	mg/cm^2-day	0.08	RME default (f)	0.3	RME default (f)	USEPA (1998b)

Notes:

NA = Not Applicable
RBC = Risk Based Concentration
RME = Reasonable Maximum Exposure
USEPA = United States Environmental Protection Agency
(a) All values are intended to result in an RBC representative of an RME scenario.
(b) Calculated average for ages 6 months to 6 years for male and female.
(c) Calculated time weighted mean developed from key study. Represents per capita intake, ages 18-70+.
(d) Calculated time weighted mean developed from key study. Represents per capita intake, ages 1-5.
(f) Skin SA and AF values are central estimates.

TABLE 6
APPLICATION RATES (ARs) FOR
PHOSPHATE FERTILIZERS AND ZINC MICRONUTRIENT FERTILIZERS

	Fertilizer Application Rate (AR) (a)			
	Phosphate		Zinc Micronutrient	
Crop Group	**lb/acre-year (b)**	**g/m^2-year (c)**	**lb/acre - year (d)**	**g/m^2-year (c)**
Vegetable	119	13	10	1.1
Root	157	17	10	1.1
Grain	63	6.9	10	1.1

(a) Developed from information presented in USEPA (1999a). Rounded to the nearest whole number.

(b) High-end estimate of data set compiled for each crop group, including all states, presented in Appendix B. The high-end estimate is the 95% upper confidence limit (UCL) of the mean, assuming a normal distribution.

(c) Converted to appropriate units for the RBC equation (g/m^2-year) by multiplying by the conversion 0.11 g-acre/lb-m^2.

(d) Limited data is available on the application of micronutrient fertilizers, therefore, this is a high-end best estimate based on industry experts, as presented in USEPA (1999a).

TABLE 7
PARAMETERS USED TO CALCULATE SOIL ACCUMULATION FACTORS (SACFs)

Parameter	Value	
Application Time Period (T) (yrs)	50	(a)
Soil Depth (Z) (cm/yr)	20	(b)
Bulk Density (BD) (g/cm^3)	1.5	(b)
Soil Loss (Ks) (yr^{-1}) (c)		
Arsenic	0.14	
Cadmium	0.14	
Chromium	0.00042	
Cobalt	0.017	
Copper	0.042	
Lead	0.0094	
Mercury	0.0028	
Molybdenum	0.046	
Nickel	0.015	
Selenium	0.33	
Vanadium	0.084	
Zinc	0.058	
Precipitation (P) (cm/year)	28	
Soil Volumetric Water Content (mL/cm^3)	0.20	
Soil Water Partition Coefficient (Kd) (L/kg)		
Arsenic	6.7	(d)
Cadmium	6.7	(d)
Chromium	2200	(d)
Cobalt	55	(d)
Copper	22	(d)
Lead	99	(d)
Mercury	330	(e)
Molybdenum	20	(d)
Nickel	63	(e)
Selenium	2.7	(d)
Vanadium	11	(e)
Zinc	16	(d)

(a) Reasonable assumption for T developed in CDFA (1998). A T of 200 yrs is used for lead.
(b) Obtained from USEPA (1998a).
(c) Calculated.
(d) Obtained from Baes and Sharp (1983).
(e) Obtained from Gerritse et al. (1982) and USEPA (1995).

TABLE 8
SOIL ACCUMULATION FACTORS (SACFs)

MOPC	SACF (a) m^2/yr-g
Arsenic	2.4E-05
Cadmium	2.4E-05
Chromium	1.6E-04
Cobalt	1.1E-04
Copper	6.9E-05
Lead	3.0E-04
Mercury	1.6E-04
Molybdenum	6.5E-05
Nickel	1.2E-04
Selenium	1.0E-05
Vanadium	3.9E-05
Zinc	5.4E-05

Notes:

MOPC = Metal of Potential Concern

(a) Calculated.

TABLE 9
PLANT UPTAKE FACTORS (PUFs) FOR EACH CROP GROUP

Metal of Potential Concern (MOPC)	PUF (mg MOPC/kg plant/mg MOPC/kg soil) (unitless) (a)					
	Dry Weight (b)			Wet Weight		
	Vegetable (c)	Root (d)	Grain (e)	Vegetable	Root	Grain
Arsenic	0.3	0.05	0.03	0.03	0.0061	0.03
Cadmium (f)	1.7	0.93	0.12	0.17	0.11	0.12
Chromium (g)	0.0014	0.0014	0.037	0.00014	0.00018	0.037
Cobalt	0.05	0.03	0.02	0.005	0.0037	0.02
Copper	0.034	0.22	0.31	0.0034	0.027	0.31
Lead	0.08	0.05	0.05	0.008	0.0061	0.05
Mercury	0.61	0.67	0.26	0.061	0.082	0.26
Molybdenum	1.1	0.15	0.22	0.11	0.018	0.22
Nickel	0.15	0.07	0.05	0.015	0.0086	0.05
Selenium	0.88	0.76	0.57	0.088	0.093	0.57
Vanadium (h)	0.007	0.007	0.007	0.0007	0.00086	0.007
Zinc	1.7	0.46	0.58	0.17	0.056	0.58

(a) PUFs are the 90% upper confidence limit (UCL) of the geometric mean, which is considered a high-end estimate.

(b) Converted to wet weight (ww) using the dry weight (dw) fraction.
Dry Weight Fractions are:
vegetable = 91% moisture, 9% dry;
root = 89% moisture, 11% dry;
grain = 10% moisture, 90% dry; and
soil (based on sandy loam) = 10 % moisture, 90% dry (USEPA 1997a).
Example of dw to ww conversion:
PUF arsenic, vegetable dw * dw fraction vegetable/dw fraction soil = 0.3 * 0.09/0.90 = 0.03

(c) Vegetable database consists of data for broccoli, brussel sprouts, cabbage, cauliflower, cucumber, eggplant, kale, lettuce, pepper, spinach, swiss chard, and tomato.

(d) Root crop database consists of data for beet, carrot, fennel, mangel, onion, parsnip, potato, radish, and rutabaga.

(e) Grains database consists of data for barley, corn, millet, oats, rice, and wheat.

(f) Cadmium PUF does not consider the presence of zinc, which can decrease the cadmium PUF.

(g) The PUFs for chromium (vegetable and root) were adopted from (USEPA 1999b).

(h) Very limited data were found that could be used to develop a PUF for vanadium.
This PUF is based on data for forage crops (obtained from USEPA (1999b)).

TABLE 10
ORAL AND DERMAL TOXICITY VALUES

	GI ABS Fraction		Noncancer Toxicity Value					Cancer Toxicity Value				
Metal of Potential Concern (MOPC)	Value	Source	Oral RfD (mg/kg-day)	Dermal RfD (a) (mg/kg-day)	Safety Factor	Target Organ or Effect	Source	Oral SF $(mg/kg-day)^{-1}$	Dermal SF (a) $(mg/kg-day)^{-1}$	Target Tissue	WOEC	Source
Arsenic	0.95	IRIS	3.0E-04	2.9E-04	3	skin	IRIS	1.5E+00	1.5E+00	skin	A	IRIS
Cadmium (b)	--	--	1.0E-03	1.0E-03	10	kidney	IRIS	--	--	--	--	--
Chromium (III) (c)	0.02	USDHHS 1993	1.5E+00	3.0E-02	1,000	none observed	IRIS	--	--	--	D	IRIS
Cobalt	0.44	USDHHS 1992	6.0E-02	2.6E-02	10	blood	RBC	--	--	--	--	--
Copper	0.97	USDHHS 1989	4.0E-02	3.9E-02	--	--	RBC	--	--	--	D	IRIS
Lead	--	--	10 ug/dL acceptable fetal blood lead level and biokinetic slope factors specific to age group and exposure route.								B2	USEPA 1996
Mercury (d)	0.07	IRIS	3.0E-04	2.1E-05	1,000	autoimmune, kidney	IRIS	--	--	--	C	IRIS
Molybdenum	1	(f)	5.0E-03	5.0E-03	30	joints, blood	IRIS	--	--	--	--	--
Nickel (e)	0.007	USDHHS 1995	2.0E-02	1.4E-04	300	decreased organ weight	IRIS	--	--	--	--	--
Selenium	--	--	5.0E-03	5.0E-03	3	liver, CNS (selenosis)	IRIS	--	--	--	D	IRIS
Vanadium	0.03	USDHHS 1990	7.0E-03	2.1E-04	100	--	HEAST	--	--	--	--	--
Zinc	0.81	USDHHS 1994	3.0E-01	2.4E-01	3	blood	IRIS	--	--	--	D	IRIS

Notes:

-- = Not Applicable or Not Available
CNS = Central Nervous System
GI ABS = Gastrointestinal Absorption Fraction
HEAST = Health Effects Assessment Summary Tables (USEPA 1997b)
IRIS = Integrated Risk Information System (USEPA 1999c)
RfD = Reference Dose
SF = Slope Factor
USDHHS = United States Department of Health and Human Services
WOEC = Weight of Evidence Classification (A = human carcinogen, B = probable human carcinogen, C = possible human carcinogen, D = not classifiable as to human carcinogenicity)

(a) Dermal toxicity values are not developed by the USEPA, so, the oral toxicity values are used. In most cases, the oral toxicity value is an administered dose and is not an absorbed dose (note the incorporation of a percent dermal absorption value), therefore, the toxicity value also needs to be in an absorbed dose. Oral toxicity values that are administered are converted to absorbed dose by multiplying the oral RfD by the GI ABS or dividing the SF by the GI ABS (USEPA 1989).

(b) Toxicity values are based on cadmium in food, which is based on an absorbed dose.

(c) Toxicity values are based on insoluble salts. As discussed in the Toxicity Assessment Section, chromium (Cr) is expected to be primarily in the form of CrIII (rather than CrVI) in soil and available for uptake.

(d) Toxicity values are based on mercuric chloride. As discussed in the Toxicity Assessment Section, mercuric chloride (or divalent mercury) is assumed to be the most likely form of mercury found in soil. Based on oral administration of mercuric chloride in mice. A 1% GI ABS value was also reported.

(e) Toxicity values are based on soluble nickel salts.

(f) No GI ABS information was found for molybdenum; therefore, a GI ABS fraction of 1 was assumed.

SECTION 3.0 — PRESENTATION OF RISK BASED CONCENTRATIONS (RBCS) FOR METALS OF POTENTIAL CONCERN (MOPC)

A summary of all of the parameters that go into deriving the risk based concentrations (RBCs) are presented in Tables 11, 12, and 13. Table 11 summarizes the parameters used to calculate the summary intake factors (SIFs); Table 12 presents the SIFs for each exposure pathway; and Table 13 provides the remaining parameters used to calculate the RBCs. The unit RBCs, based on a one percent fraction of nutrient (FON), are presented in Table 14 for phosphate fertilizers and micronutrient fertilizers.

As seen in the tables, unit RBCs are calculated for a single crop farm and a multi-crop farm for both an adult and a child. The lowest RBC for each MOPC is selected for screening human health risks and is presented in the last two columns of Table 14.

Note that for arsenic the adult farm resident has the lowest RBC because arsenic is a carcinogen and the exposure duration is much longer for an adult. The lowest RBCs for the remainder of the MOPC are for the child farm resident. The multi-crop scenario always has the lowest RBC value because exposure is coming from all crop types not just one of the crop types.

TABLES

TABLE 11
SUMMARY OF ALL OF THE PARAMETERS AND ASSUMPTIONS USED TO CALCULATE THE SUMMARY INTAKE FACTORS (SIFs) (a)

Parameter (b)		Units	Parameter Values	
Target Cancer Risk and Hard Quotient		unitless	--	
TR	Target Cancer Risk		1.0E-05	
THQ	Target Hazard Quotient		1	
Biological Exposure Parameters			**Adult**	**Child**
EF	Exposure Frequency	days/year	350	350
ED	Exposure Duration	years	30	6
AT	Averaging Time	days		
	Cancer		25,550	25,550
	Noncancer		10,950	2190
BW	Body Weight	kg	71.8	15.5
IR_s	Soil Ingestion Rate	mg/day	50	200
IR_c	Ingestion Rate	g/kg-day		
	Vegetables		1.7	2.9
	Roots		1.1	2.1
	Grains		3.4	9.4
AF	Adherence Factor	mg/cm^2	0.08	0.3
SA	Exposed Skin Surface Area	cm^2/day	5,700	2,900
RAF	**Relative Absorption Factor**	unitless	**Soil (s)**	**Crop (c)**
	Arsenic		0.42	1
	Cadmium		1	1
	Chromium		1	1
	Cobalt		1	1
	Copper		1	1
	Lead		0.41	0.5
	Mercury		1	1
	Molybdenum		1	1
	Nickel		1	1
	Selenium		1	1
	Vanadium		1	1
	Zinc		1	1
ABS	**Dermal Absorption Factor**	unitless	--	
	Arsenic		0.03	
	Cadmium		0.01	
	Chromium		0.01	
	Cobalt		0.01	
	Copper		0.01	
	Lead		1	
	Mercury		0.01	
	Molybdenum		0.01	
	Nickel		0.01	
	Selenium		0.01	
	Vanadium		0.01	
	Zinc		0.01	

Notes:

-- Not Applicable

(a) The equations used to calculate the SIFs are presented below. SIFs are calculated to simplify the calculation of the RBC, and are presented in Table 12.

(b) The development of all of these parameters is presented in Section 2.0.

SIF Calculations:

Unintentional Ingestion of Fertilized Soil Summary Intake Factor (SIFsi) = (ED*EF*IRs*RAFs*CF)/(BW*AT)

Dermal Contact with Fertilized Soil Summary Intake Factor (SIFd) = (ED*EF*SA*AF*ABS*CF)/(BW*AT)

Crop Ingestion Summary Intake Factor (SIFc) = (ED*EF*IRc*RAFc)/(AT)

TABLE 12
SUMMARY INTAKE FACTORS (SIFs) (a)

Summary Intake Factors (SIF)	Units	SIF Value	
		Adult	Child
Unintentional Ingestion of Fertilized Soil (SIF)si	day^{-1}		
Cancer			
Arsenic (a)		1.2E-07	4.5E-07
Noncancer			
Arsenic		2.8E-07	5.2E-06
Lead (b)		2.7E-07	5.1E-06
All Other MOPC (c)		6.7E-07	1.2E-05
Dermal Contact with Fertilized Soil (SIF)d			
Cancer			
Arsenic		7.8E-08	1.4E-07
Noncancer			
Arsenic		1.8E-07	1.6E-06
All Other MOPC (c)		6.1E-08	5.4E-07
Crop Ingestion			
Vegetable (SIF)v			
Cancer			
Arsenic		7.0E-04	2.4E-04
Noncancer			
Lead (b)		8.2E-04	1.4E-03
All Other MOPC (c)		1.6E-03	2.8E-03
Root (SIF)r			
Cancer			
Arsenic		4.5E-04	1.7E-04
Noncancer			
Lead (b)		5.3E-04	1.0E-03
All Other MOPC (c)		1.1E-03	2.0E-03
Grain (SIF)g			
Cancer			
Arsenic		1.4E-03	7.7E-04
Noncancer			
Lead (b)		1.6E-03	4.5E-03
All Other MOPC (c)		3.3E-03	9.0E-03

(a) Arsenic is the only MOPC that is evaluated for potential carcinogenicity.

(b) Lead SIFs are adjusted appropriately by biokinetic slope factors specific to age group and exposure route.

(c) The only parameters in the SIF equations (presented below) that are MOPC specific, and therefore, can change the SIF to be MOPC specific, are RAF or ABS. If a MOPC specific RAF or ABS is not found, a default value is used; then the SIF is not specific MOPC, and therefore, is generic, and presented in the All Other MOPC row.

SIF Calculations:

Unintentional Ingestion of Fertilized Soil Summary Intake Factor (SIFsi) = (ED*EF*IRs*RAFs*CF)/(BW*AT)

Dermal Contact with Fertilized Soil Summary Intake Factor (SIFd) = (ED*EF*SA*AF*ABS*CF)/(BW*AT)

Crop Ingestion Summary Intake Factor (SIFc) = (ED*EF*IRc*RAFc)/(AT)

TABLE 13
PARAMETERS (SACF, AR, PUF, FOL, AND TOXICITY VALUES)
USED TO CALCULATE THE RISK BASED CONCENTRATIONS (RBCs) (a,b)

Parameter (c)		**Units**	**Parameter Values**		
SACF	**Soil Accumulation Factor**	m^2-yr/g	--		
	Arsenic		2.4E-05		
	Cadmium		2.4E-05		
	Chromium		1.6E-04		
	Cobalt		1.1E-04		
	Copper		6.9E-05		
	Lead		3.0E-04		
	Mercury		1.6E-04		
	Molybdenum		6.5E-05		
	Nickel		1.2E-04		
	Selenium		1.0E-05		
	Vanadium		3.9E-05		
	Zinc		5.4E-05		
AR (d)	**Application Rate**	g/m^2-yr	**Vegetable (v)**	**Root (r)**	**Grain (g)**
	Phosphate		13	17	6.9
	Zinc Micronutrient		1.1	1.1	1.1
PUF	**Plant Uptake Factor**	unitless	**Vegetable**	**Root**	**Grain**
	Arsenic		0.03	0.0061	0.03
	Cadmium		0.17	0.11	0.12
	Chromium		0.00014	0.00018	0.037
	Cobalt		0.005	0.0037	0.02
	Copper		0.0034	0.027	0.31
	Lead		0.008	0.0061	0.05
	Mercury		0.061	0.082	0.26
	Molybdenum		0.11	0.018	0.22
	Nickel		0.015	0.0086	0.05
	Selenium		0.088	0.093	0.57
	Vanadium		0.0007	0.00086	0.007
	Zinc		0.17	0.056	0.58
FOL (e)	**Fraction of Land**	unitless	**Vegetable**	**Root**	**Grain**
			0.4	0.1	0.5
Toxicity Value			**Oral (o)**	**Dermal (d)**	
SF	Slope Factor	$(mg/kg\text{-}day)^{-1}$			
	Arsenic		1.5E+00	1.5E+00	
RfD	Reference Dose	mg/kg-day			
	Arsenic		3.0E-04	2.9E-04	
	Cadmium		1.0E-03	1.0E-03	
	Chromium		1.5E+00	3.0E-02	
	Cobalt		6.0E-02	2.6E-02	
	Copper		4.0E-02	3.9E-02	
	Lead		--	--	
	Mercury		3.0E-04	2.1E-05	
	Molybdenum		5.0E-03	5.0E-03	
	Nickel		2.0E-02	1.4E-04	
	Selenium		5.0E-03	5.0E-03	
	Vanadium		7.0E-03	2.1E-04	
	Zinc		3.0E-01	2.4E-01	

Notes:

-- Not Applicable
(a) The equations used to calculate the RBCs are presented below.
(b) Summary Intake Factors (SIFs) are presented in Table 12.
(c) All of the parameters are presented in Section 2.0.
(d) AR is adjusted so that the RBC is based on 1% fraction of nutrient (FON), resulting in unit RBCs.
The AR is inversely proportionate to the FON, therefore, AR is adjusted to 1% FON by dividing by 1%.
(e) FOL is only needed for the calculation of the multiple crop RBCs.

RBC Calculations for Single Crop Farm (equations adopted from CDFA 1998)**:**
Cancer RBC = TR/{SACF*[AR*(SIFsi*SFo*RAFs+SIFd*SFd+PUF*SIFc*SFo*RAFc)]}
Noncancer RBC = THI/{SACF*[AR*(SIFsi*1/RfDo*RAFs+SIFd*1/RfDd+PUF*SIFc*1/RfDo*RAFc)]}

RBC Calculations for Multiple Crop Farm (equations adopted from CDFA 1998)**:**
Cancer RBC =
TR/(SACF*{ARv*[((SIFsi*SFo+SIFd*SFd)*FOLv)+PUFv*SIFv*SFo]}+{ARr*[((SIFsi*SFo+
SIFsd*SFd)*FOLr)+PUFr*SIFr*SFo]}+{ARg*[((SIFsi*SFo+SIFd*SFd)*FOLg)+PUFg*SIFg*SFo]})
Noncancer RBC =
THI/(SACF*{ARv*[((SIFsi*1/RfDo+SIFd*1/RfDd)*FOLv)+PUFv*SIFv*1/RfDo]}+{ARr*[((SIFsi
*1/RfDo+SIFd*1/RfDd)*FOLr)+PUFr*SIFr*1/RfDo]}+{ARg*[((SIFsi*1/RfDo+SIFd*1/RfDd)*FOLg)+
PUFg*SIFg*1/RfDo]})

TABLE 14
UNIT RISK BASED CONCENTRATIONS (RBCs) (a) FOR ALL SCENARIOS

	Adult Farm Resident RBC				Child Farm Resident RBC				Lowest Unit RBC (b)	
MOPC	**Vegetable**	**Roots**	**Grains**	**Multi-crop**	**Vegetable**	**Roots**	**Grains**	**Multi-crop**	**Scientific Notation**	**Standard Notation**
Phosphate Fertilizer										
Arsenic (c)	9.9E+00	5.4E+01	9.4E+00	**4.5E+00**	2.7E+01	9.7E+01	1.7E+01	9.8E+00	4.5E+00	4.5
Cadmium	1.1E+02	2.0E+02	1.5E+02	4.9E+01	6.4E+01	9.8E+01	5.4E+01	**2.3E+01**	2.3E+01	23
Chromium (III)	1.8E+06	1.4E+06	1.1E+05	1.0E+05	1.7E+05	1.3E+05	3.6E+04	**3.4E+04**	3.4E+04	34,000
Cobalt	4.5E+04	6.6E+04	1.2E+04	8.4E+03	1.5E+04	1.5E+04	4.0E+03	**3.1E+03**	3.1E+03	3,100
Copper	7.0E+04	1.1E+04	8.2E+02	7.6E+02	2.0E+04	5.0E+03	3.0E+02	**2.8E+02**	2.8E+02	280
Lead	1.3E+03	2.0E+03	2.1E+02	1.6E+02	7.7E+02	9.3E+02	8.5E+01	**7.3E+01**	7.3E+01	73
Mercury	1.5E+01	1.3E+01	3.3E+00	2.2E+00	7.8E+00	6.1E+00	1.2E+00	**9.0E-01**	9.0E-01	0.9
Molybdenum	3.3E+02	2.2E+03	1.6E+02	1.0E+02	1.8E+02	9.0E+02	5.6E+01	**4.2E+01**	4.2E+01	42
Nickel	3.8E+03	5.4E+03	1.4E+03	1.0E+03	9.9E+02	9.3E+02	4.5E+02	**3.5E+02**	3.5E+02	350
Selenium	2.6E+03	2.9E+03	3.8E+02	3.0E+02	1.5E+03	1.4E+03	1.4E+02	**1.2E+02**	1.2E+02	120
Vanadium	3.6E+04	2.9E+04	1.0E+04	8.3E+03	4.2E+03	3.2E+03	2.8E+03	**2.2E+03**	2.2E+03	2,200
Zinc	1.5E+04	5.3E+04	4.2E+03	3.1E+03	8.8E+03	2.5E+04	1.5E+03	**1.2E+03**	1.2E+03	1,200
Micronutrient Fertilizer										
Arsenic (c)	1.2E+02	8.4E+02	5.9E+01	**3.8E+01**	3.2E+02	1.5E+03	1.0E+02	7.4E+01	3.8E+01	38
Cadmium	1.3E+03	3.1E+03	9.5E+02	4.7E+02	7.6E+02	1.5E+03	3.4E+02	**2.1E+02**	2.1E+02	210
Chromium (III)	2.1E+07	2.1E+07	6.7E+05	6.7E+05	2.1E+06	2.1E+06	**2.2E+05**	**2.2E+05**	2.2E+05	220,000
Cobalt	5.4E+05	1.0E+06	7.3E+04	6.2E+04	1.8E+05	2.3E+05	2.5E+04	**2.3E+04**	2.3E+04	23,000
Copper	8.3E+05	1.8E+05	5.2E+03	5.0E+03	2.3E+05	7.8E+04	1.9E+03	**1.8E+03**	1.8E+03	1,800
Lead	1.6E+04	3.1E+04	1.3E+03	1.2E+03	9.1E+03	1.5E+04	5.4E+02	**5.0E+02**	5.0E+02	500
Mercury	1.7E+02	2.0E+02	2.1E+01	1.7E+01	9.3E+01	9.5E+01	7.4E+00	**6.5E+00**	6.5E+00	6.5
Molybdenum	3.9E+03	3.5E+04	9.8E+02	7.6E+02	2.2E+03	1.4E+04	3.5E+02	**3.0E+02**	3.0E+02	300
Nickel	4.6E+04	8.4E+04	9.0E+03	7.5E+03	1.2E+04	1.4E+04	2.9E+03	**2.6E+03**	2.6E+03	2,600
Selenium	3.1E+04	4.6E+04	2.4E+03	2.1E+03	1.7E+04	2.2E+04	8.7E+02	**8.0E+02**	8.0E+02	800
Vanadium	4.2E+05	4.5E+05	6.4E+04	5.9E+04	5.0E+04	5.1E+04	**1.7E+04**	**1.7E+04**	1.7E+04	17,000
Zinc	1.8E+05	8.3E+05	2.6E+04	2.3E+04	1.0E+05	4.0E+05	9.6E+03	**8.6E+03**	8.6E+03	8,600

Notes:

Bold = Lowest RBC
MOPC = Metal of Potential Concern

(a) The units for all RBCs are mg MOPC/kg product (i.e., ppm). The lowest unit RBC for each metal is shown in the two far right columns. This is the value used for screening (presented in Section 4.0).
(b) The lowest unit RBC is the lowest for child and adult farm residents.
(c) The RBCs presented for arsenic are based on cancer. All other RBCs are based on non-cancer.

SECTION 4.0 — SCREENING HEALTH EVALUATION: COMPARISON OF THE RISK BASED CONCENTRATIONS (RBC) WITH THE CONCENTRATION OF THE METAL OF POTENTIAL CONCERN (MOPC) IN FERTILIZER PRODUCTS

A screening-level determination of whether a particular fertilizer product poses a potential health risk is accomplished by comparing the measured concentration of a MOPC (e.g. arsenic) in the product to the RBC for that same MOPC. The RBCs for this assessment are derived in this report and presented in Table 14. The lowest RBCs are the most appropriate to use in a screening-level health risk evaluation. The measured concentrations of MOPC are obtained from the published literature, from a survey of fertilizer manufacturers, and from monitoring programs being conducted by a number of states. This database has been compiled by TWG.[33]

The concentrations of the MOPC in products must be in the same units as the RBCs to make a direct comparison. The RBCs and the product concentration database are reported in mg MOPC/kg product (i.e., part per million or ppm). Comparisons can be made on a product-by-product basis, or if there are multiple reported concentrations of a MOPC for the same fertilizer (e.g., samples from different batches or from different manufacturers), the maximum MOPC concentration can be compared to the RBC as an initial screen. Comparing the lowest RBC to the maximum MOPC concentration provides the most health protective estimate of health risk. If the concentration of the MOPC in the fertilizer is below the RBC, there is no health risk. If the concentration of the MOPC in the fertilizer is above the RBC, further evaluation is warranted. An exceedence of a screening-level RBC does not necessarily indicate there is a health risk because the RBCs are health protective derived to ensure that health risks are not underestimated (but they may be overestimated). A firm conclusion regarding health risks, in the case of a RBC exceedence, therefore, requires a closer evaluation.

Before the RBCs can be compared to the measured levels of MOPC in a product, however, the unit RBCs (i.e., RBCs derived for 1% of the nutrient in a product; reported in Table 14) need to be adjusted for the actual fraction of nutrient (FON) in the product. The unit RBC is adjusted by multiplying the RBC by the percent FON. For phosphate fertilizers, the FON is the phosphate (or P2O5) component; for micronutrient fertilizers, it is the principal micronutrient component (e.g. zinc or iron). The representative FON is determined using both the TWG fertilizer database and information reported in USEPA (1999a). The FONs for each product category are best estimates and are presented in Table 15 (for phosphate) and Table 16 (for micronutrients).

The comparisons of FON adjusted RBCs to maximum measured concentrations of MOPC in products (by fertilizer type or product category) are presented in Tables 17 and 18 for phosphate and micronutrient fertilizers, respectively. Phosphate product categories include, for example, diammonium phosphate or urea-ammonium phosphate. There are also a number of product samples that were reported as ‘agricultural blends’; they contain N,P and K but with no micronutrients added. The micronutrient product categories are boron, iron, manganese, and zinc micronutrient fertilizers.

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[33] TWG fertilizer database consists of state, literature, and industry data on inorganic fertilizers. A summary of this database is presented in TWG (1999c). This database is updated as new data become available.

Results

There were no RBC exceedances for any of the 12 MOPC in phosphate fertilizers (see Table 17). There were comparisons made for 15 categories of phosphate fertilizers (including the agricultural blends) and for a total of approximately 925 individual fertilizer samples.

There were RBC exceedances among the four categories of micronutrient fertilizers, primarily for the MOPC arsenic and lead. A total of approximately 140 individual fertilizer samples were evaluated. The exceedances include:

- 2 for arsenic in boron micronutrient fertilizers;
- 8 for arsenic in iron micronutrients;
- 2 for arsenic in manganese micronutrient fertilizers;
- 1 for lead in iron micronutrient fertilizers;
- 1 for lead in manganese micronutrient fertilizers;
- 6 for lead in zinc micronutrient fertilizers;
- and 2 for zinc in zinc micronutrient fertilizers.

A closer evaluation of the exceedances, to determine if these fertilizers pose a health risk, would involve several steps, including: (1) replacing the default FON developed for the fertilizer category with the FON for the individual fertilizer sample (not always reported in the database)[34], (2) confirmation that the product is still on the market (a number of the samples reported in the database are years old), and (3) determine the exact usage (including application rate, crop types, etc.) for the product of interest, then adjust the RBC value to more closely reflect the actual exposure scenario conditions.

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[34] Six of these 22 exceedances become non-exceedances when the unit RBC is adjusted by a sample-specific FON in place of the default FON for the product category. FONs were reported for most of the samples.

TABLES

TABLE 15
PERCENT FRACTION OF NUTRIENT (FON) ESTIMATES FOR PHOSPHATE FERTILIZER PRODUCT CATEGORIES

Product Category	TWG Database (a)					USEPA (b)	Best Estimate (d)
	N (c)	Minimum	Maximum	Median	Mean	Reported % P_2O_5	
Agricultural Blends	59	2	60	15	18	--	18
Ammonium Phosphate Sulfate	1	20	20	--	--	20.0	20
Ammonium Polyphosphate	1	34	34	--	--	60.0	34
Diammonium Phosphate	4	46	53	46	48	46.0	46
Monoammonium Phosphate	8	50	52	52	51	51.8	52
Nitrophosphate	1	20	20	--	--	--	20
Orthophosphate	1	30	30	--	--	--	30
Phosphate	5	15	37	30	27	--	30
Phosphoric Acid	2	52	60	56	56	53.3	56
Superphosphate	2	18	20	19	19	20.7	20
Superphosphoric acid	4	61	70	69	67	70.1	70
Triple Superphosphate	7	44	46	46	45	45.7	46
Urea Ammonium Polyphosphate - KCl	1	19	19	--	--	--	19
Urea-Ammonium Phosphate	1	45	45	--	--	--	45
Urea-Diammonium Phosphate - KCl	1	15	15	--	--	--	15

Notes:

-- = Not Applicable
N = Number of Samples
% P_2O_5 = Phosphate (Phosphorous)
TWG = The Weinberg Group Inc.
USEPA = United States Environmental Protection Agency

(a) All values are the % P2O5 of the product category. TWG database is compiled from industry, literature, and states' monitoring data (TWG 1999c).
(b) Numbers are from Table 3-4 of USEPA (1999a).
(c) Reflects the number of samples of a product with a reported % P2O5.
(d) The best estimate is the % FON that is used to adjust the unit RBC.

TABLE 16
PERCENT FRACTION OF NUTRIENT (FON) ESTIMATES FOR MICRONUTRIENT FERTILIZER PRODUCT CATEGORIES

Product Category	**TWG Database(a)**					**USEPA (1999a) (b)**				**Best Estimate (d)**
	N (c)	**Minimum**	**Maximum**	**Median**	**Mean**	**N**	**Minimum**	**Maximum**	**Mean**	
Boron	5	10	21	15	15	2	10	21	15.5	15
Iron	16	2	58	20	24	3	12	15	14	24
Manganese	7	28	40	12	12	2	24.7	29.5	27.1	12
Zinc	29	7	89	25	27	63	7	89	26.5	27

Notes:

-- = Not Applicable
N = Number of Samples
TWG = The Weinberg Group Inc.
USEPA = United States Environmental Protection Agency

(a) TWG database is compiled from industry, literature, and states' monitoring data (TWG 1999c).
(b) All values are the % micronutrient of the product category. Statistics are calculated from the data set found in Appendix G of USEPA (1999a).
(c) Reflects the number of products for which a % micronutrient is reported.
(d) The best estimate is the % FON that is used to adjust the unit RBC.

TABLE 17

SCREENING LEVEL EVALUATION:

COMPARISON OF THE CONCENTRATION OF METAL OF POTENTIAL CONCERN (MOPC) IN PHOSPHATE FERTILIZERS TO THE ADJUSTED RISK BASED CONCENTRATION (RBC)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Agricultural Blends											
Arsenic	84	0.15	42	2.6	3.6	3.2	4.5	81	42	No	--
Cadmium	83	0.015	160	3.2	7.1	4.6	23	410	160	No	--
Chromium	84	0.25	5,100	49	4.2	64	34,000	610,000	5,100	No	--
Cobalt	35	0.65	22	3.3	2.9	4.5	3,100	56,000	22	No	--
Copper	55	0.14	540	15	5.1	22	280	5,000	540	No	--
Lead	79	0.1(h)	650	4.8	9.3	7.3	73	1,300	650	No	--
Mercury	46	0.0025	1.1	0.036	6.5	0.058	0.9	16	1.1	No	--
Molybdenum	10	0.69	6	3.4	1.9	4.9	42	760	6	No	--
Nickel	52	0.54	54	8.6	3	11	350	6,300	54	No	--
Selenium	26	0.025	5.7	0.22	2.9	0.32	120	2,200	5.7	No	--
Vanadium	52	0.28	350	42	3.7	56	2,200	40,000	350	No	--
Zinc	57	0.85	6,300	107	7.8	130	1,200	22,000	6,300	No	--
Ammonium Phosphate Sulfate											
Arsenic	2	4.1	4.2	4.1	1	--	4.5	90	4.2	No	--
Cadmium	2	150	150	150	1	--	23	460	150	No	--
Chromium	2	210	250	230	1.1	--	34,000	680,000	250	No	--
Cobalt	2	2.5	3.2	2.8	1.2	--	3,100	62,000	3.2	No	--
Copper	2	11	16	13	1.3	--	280	5,600	16	No	--
Lead	2	2.1	4.4	3	1.7	--	73	1,500	4.4	No	--
Mercury	2	0.01	0.024	0.015	1.9	--	0.9	18	0.024	No	--
Molybdenum	2	5	5.7	5.3	1.1	--	42	840	5.7	No	--
Nickel	2	200	220	208	1.1	--	350	7,000	220	No	--
Selenium	2	0.13	2	0.5	7.1	--	120	2,400	2	No	--
Vanadium	1	400	400	--	--	--	2,200	44,000	400	No	--
Zinc	2	1,500	2,400	1,900	1.4	--	1,200	24,000	2,400	No	--

Foot notes are presented at the end of the table.

TABLE 17 (continued)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Ammonium Polyphosphate											
Arsenic	7	0.6	21	7.7	3.5	19	4.5	150	21	No	--
Cadmium	11	4	56	15	2.2	23	23	780	56	No	--
Chromium	9	57	400	150	2	240	34,000	1,200,000	400	No	--
Cobalt	3	0.15	1.4	0.53	3.1	--	3,100	110,000	1.4	No	--
Copper	10	0.5	14	3	3.6	6.4	280	9,500	14	No	--
Lead	10	0.17	150	2.7	10	10	73	2,500	150	No	--
Mercury	1	0.0025	0.0025	--	--	--	0.9	31	0.0025	No	--
Molybdenum	2	3.1	6.5	4.5	1.7	--	42	1,400	6.5	No	--
Nickel	5	0.5	14	5.9	4.1	--	350	12,000	14	No	--
Selenium	2	2	2.1	2	1	--	120	4,100	2.1	No	--
Vanadium	5	49	230	94	1.8	--	2,200	75,000	230	No	--
Zinc	10	46	820	180	2.3	290	1,200	41,000	820	No	--
Diammonium Phosphate											
Arsenic	114	0.05	21	10	1.9	11	4.5	210	21	No	--
Cadmium	347	0.25	190	5.1	1.8	5.3	23	1,100	190	No	--
Chromium	117	1	620	69	1.8	76	34,000	1,600,000	620	No	--
Cobalt	106	0.25	10	3.8	1.8	4.1	3,100	140,000	10	No	--
Copper	115	0.45	98	1.8	2.9	2.1	280	13,000	98	No	--
Lead	344	0.5	150	3.4	2.5	3.7	73	3,400	150	No	--
Mercury	167	0.001	0.5	0.046	6.4	0.058	0.9	41	0.5	No	--
Molybdenum	103	2.5	47	11	1.4	11	42	1,900	47	No	--
Nickel	127	1.1	160	17	1.8	18	350	16,000	160	No	--
Selenium	103	0.025	5	1.2	5	1.6	120	5,500	5	No	--
Vanadium	78	11	280	130	1.4	130	2,200	100,000	280	No	--
Zinc	115	0.83	2,300	82	2.9	96	1,200	55,000	2,300	No	--

Foot notes are presented at the end of the table.

TABLE 17 (continued)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Monoammonium Phosphate											
Arsenic	84	0.05	25	10	2.6	12	4.5	230	25	No	--
Cadmium	233	0.15	210	6.2	2	6.6	23	1,200	210	No	--
Chromium	83	0.5	730	69	2.5	82	34,000	1,800,000	730	No	--
Cobalt	79	0.78	12	4.3	1.9	4.8	3,100	160,000	12	No	--
Copper	80	0.44	76	1.8	2.9	2.2	280	15,000	76	No	--
Lead	231	0.05	150	4.9	2.5	5.4	73	3,800	150	No	--
Mercury	98	0.002	1.5	0.044	6.5	0.061	0.9	47	1.5	No	--
Molybdenum	75	4	38	12	1.4	13	42	2,200	38	No	--
Nickel	82	1.3	240	17	1.7	19	350	18,000	240	No	--
Selenium	74	0.05	20	1.1	4.4	1.4	120	6,200	20	No	--
Vanadium	52	35	1,100	160	1.6	170	2,200	110,000	1,100	No	--
Zinc	80	10	3,400	75	2.1	86	1,200	62,000	3,400	No	--
Nitrophosphate (i)											
Arsenic	5	3.6	7.4	6.1	1.3	--	4.5	90	7.4	No	--
Cadmium	5	2.6	4.3	3.2	1.2	--	23	460	4.3	No	--
Chromium	5	39	200	66	1.9	--	34,000	680,000	200	No	--
Cobalt	5	2.7	12	6.4	1.7	--	3,100	62,000	12	No	--
Copper	5	11	71	21	2.1	--	280	5,600	71	No	--
Lead	5	2.5	20	4.5	2.3	--	73	1,100	20	No	--
Mercury	1	0.38	0.38	--	--	--	0.9	18	0.38	No	--
Nickel	5	5.7	86	15	2.9	--	350	7,000	86	No	--
Vanadium	4	65	83	71	1.1	--	2,200	44,000	83	No	--
Zinc	5	0.48	140	19	8.8	--	1,200	24,000	140	No	--

Foot notes are presented at the end of the table.

TABLE 17 (continued)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Orthophosphate (i)											
Arsenic	2	21	21	21	--	--	4.5	140	21	No	--
Cadmium	2	20	20	19	--	--	23	690	20	No	--
Lead	2	150	150	150	--	--	73	2,200	150	No	--
Phosphate (i)											--
Arsenic	5	0.2	25	2.1	10	--	4.5	130	25	No	--
Cadmium	4	3	69	10	4.6	--	23	690	69	No	--
Lead	3	1	110	11	10	--	73	2,200	110	No	--
Phosphoric Acid											
Arsenic	14	0.5	19	7.5	3.3	13	4.5	250	19	No	--
Cadmium	10	0.15	160	18	11	75	23	1,300	160	No	--
Chromium	3	62	900	160	4.4	--	34,000	1,900,000	900	No	--
Cobalt	3	0.15	4	1.2	6.2	--	3,100	170,000	4	No	--
Copper	3	0.2	0.5	0.37	1.7	--	280	16,000	0.5	No	--
Lead	10	0.5	10	1.6	2.4	2.7	73	4,100	10	No	--
Mercury	3	0.0025	0.25	0.054	14	--	0.9	50	0.25	No	--
Molybdenum	3	5.9	11	8.7	1.4	--	42	2,400	11	No	--
Nickel	3	0.5	15	4.6	6.8	--	350	20,000	15	No	--
Selenium	3	2	2.5	2.3	1.1	--	120	6,700	2.5	No	--
Vanadium	3	57	140	97	1.6	--	2,200	120,000	140	No	--
Zinc	3	31	63	45	1.4	--	1,200	67,000	63	No	--
Superphosphate											
Arsenic	4	7	21	11	1.7	--	4.5	90	21	No	--
Cadmium	4	2	4.9	3.8	1.5	--	23	460	4.9	No	--
Chromium	3	32	40	34	1.1	--	34,000	680,000	40	No	--
Cobalt	1	2.5	2.5	--	--	--	3,100	62,000	2.5	No	--
Copper	1	6.9	6.9	--	--	--	280	5,600	6.9	No	--
Lead	4	1	17	6.2	3.5	--	73	1,500	17	No	--
Mercury	1	0.0025	0.0025	--	--	--	0.9	18	0.0025	No	--
Molybdenum	2	3.9	27	10	3.9	--	42	840	27	No	--
Nickel	4	8.8	14	11	1.2	--	350	7,000	14	No	--
Selenium	1	2	2	--	--	--	120	2,400	2	No	--
Vanadium	2	49	190	97	2.7	--	2,200	44,000	190	No	--
Zinc	2	43	56	49	1.2	--	1,200	24,000	56	No	--

Foot notes are presented at the end of the table.

TABLE 17 (continued)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Superphosphoric Acid (i)											
Arsenic	9	0.2	31	6.9	4.7	18	4.5	320	31	No	--
Cadmium	9	0.5	160	33	8.3	120	23	1,600	160	No	--
Chromium	2	300	840	500	2.1	--	34,000	2,400,000	840	No	--
Copper	2	2.5	30	8.6	5.8	--	280	20,000	30	No	--
Lead	5	0.05	8.5	1.3	7.3	--	73	5,100	8.5	No	--
Molybdenum	2	6	6.8	6.4	1.1	--	42	2,900	6.8	No	--
Nickel	2	22	27	24	1.2	--	350	25,000	27	No	--
Selenium	1	4.3	4.3	--	--	--	120	8,400	4.3	No	--
Vanadium	2	52	200	100	2.6	--	2,200	150,000	200	No	--
Zinc	2	30	240	85	4.4	--	1,200	84,000	240	No	--
Triple Superphosphate											
Arsenic	68	0.05	21	9.8	2.4	10	4.5	210	21	No	--
Cadmium	204	1.8	180	8	2	8.6	23	1,100	180	No	--
Chromium	63	3.5	550	84	1.9	96	34,000	1,200,000	550	No	--
Cobalt	56	1.8	15	6.1	2	7.1	3,100	140,000	15	No	--
Copper	58	1	55	4.2	2.2	5	280	13,000	55	No	--
Lead	201	1	1,900	8.4	2	9.1	73	3,400	1,900	No	--
Mercury	85	0.0025	1.3	0.056	4.8	0.074	0.9	41	1.3	No	--
Molybdenum	53	6	72	12	1.4	13	42	1,900	72	No	--
Nickel	64	10	150	19	1.6	21	350	16,000	150	No	--
Selenium	54	0.025	21	2	3.2	2.6	120	5,500	21	No	--
Vanadium	33	87	720	140	1.4	160	2,200	100,000	720	No	--
Zinc	57	42	1,600	100	2	120	1,200	55,000	1,600	No	--
Urea-Ammonium Polyphosphate-KCl (i)											
Arsenic	4	5.2	7.8	6.7	1.2	--	4.5	86	7.8	No	--
Cadmium	5	1.6	24	4.1	2.9	--	23	440	24	No	--
Chromium	5	44	160	63	1.7	--	34,000	650,000	160	No	--
Cobalt	2	3.5	3.9	3.7	1.1	--	3,100	59,000	3.9	No	--
Copper	4	3.9	26	10	2.2	--	280	5,300	26	No	--
Lead	5	1.1	3.8	2.2	1.7	--	73	1,400	3.8	No	--
Nickel	4	9.2	27	13	1.6	--	350	6,700	27	No	--
Vanadium	5	47	98	76	1.3	--	2,200	42,000	98	No	--
Zinc	4	6.9	75	28	2.7	--	1,200	23,000	75	No	--

Foot notes are presented at the end of the table.

TABLE 17 (continued)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Urea-Ammonium Phosphate (i)											
Arsenic	1	1	1	--	--	--	4.5	200	1	No	--
Cadmium	1	110	110	--	--	--	23	1,000	110	No	--
Chromium	1	380	380	--	--	--	34,000	1,500,000	380	No	--
Lead	1	3.2	3.2	--	--	--	73	3,300	3.2	No	--
Mercury	1	0.0025	0.0025	--	--	--	0.9	41	0.0025	No	--
Selenium	1	0.15	0.15	--	--	--	120	5,400	0.15	No	--
Urea-Diammonium Phosphate-KCl (i)											
Arsenic	2	4.7	4.9	4.8	1	--	4.5	68	4.9	No	--
Cadmium	2	2	2.1	2	1	--	23	350	2.1	No	--
Chromium	2	28	43	34	1.3	--	34,000	510,000	43	No	--
Cobalt	1	7.2	7.2	--	--	--	3,100	47,000	7.2	No	--
Copper	2	3.9	7.2	5.3	1.5	--	280	4,200	7.2	No	--
Lead	2	1.8	2.1	1.9	1.1	--	73	1,100	2.1	No	--
Nickel	2	6.2	11	8.4	1.5	--	350	5,300	11	No	--
Vanadium	2	49	73	60	1.3	--	2,200	33,000	73	No	--
Zinc	2	0.3	0.55	0.41	1.5	--	1,200	18,000	0.55	No	--

Notes:

-- = Not Applicable
GM = Geometric Mean
GSD = Geometric Standard Deviation
N = Number of Samples (or Exceedances)
90% UCL = 90% Upper Confidence Limit

(a) All concentrations are in mg MOPC/kg product (or ppm). Data is from industry, literature, and states' monitoring data [compiled and maintained by The Weinberg Group Inc. (TWG 1999c)].

(b) A 90 %UCL is provided when the number of samples for the MOPC is greater than five. The 90% UCL is considered a good upper end estimate of the mean.

(c) Unit RBC is based on a 1% fraction of nutrient (FON). All RBCs are in mg MOPC/kg product.

(d) % FON for each product category is a best estimate. The determination of FON is presented in Table 15.
% FON for each product category is:
agricultural blends = 18; ammonium phosphate sulfate = 20; ammonium polyphosphate = 34; diammonium phosphate = 46; monoammonium phosphate = 52; nitrophosphate = 20; orthophosphate = 30; phosphate = 30; phosphoric acid = 56; superphosphate = 20; superphosphoric acid = 70; triple superphosphate = 46; urea ammonium polyphosphate - KCl = 19; urea ammonium phosphate = 45; and urea - diammonium phosphate - KCl = 15.

(e) Adjusted RBC equals the unit RBC multiplied by the % FON.
For example, arsenic unit RBC for agricultural blends = 4.5 and the % FON for agricultural blends is 18. Therefore, the adjusted RBC for arsenic in agricultural blends = 4.5*18 = 81 mg of arsenic/kg product.

(f) If the maximum concentration is greater than the adjusted RBC, there is an exceedance.

(g) The number of exceedances is the number of samples (within each product category) with a concentration greater than the adjusted RBC.

(h) All numbers have two significant figures. When only one digit is presented, a zero (to the right of the decimal) is the last digit. For example, 6 = 6.0 and 0.05 = 0.050.

(i) TWG (1999c) does not have data for all MOPC for the following product categories: nitrophosphate, orthophosphate, phosphate, superphosphoric acid, urea-ammonium polyphosphate - KCl, urea-ammonium phosphate, and urea-diammonium phosphate.

TABLE 18
SCREENING LEVEL EVALUATION:
COMPARISON OF THE CONCENTRATION OF METAL OF POTENTIAL CONCERN (MOPC) IN MICRONUTRIENT FERTILIZERS TO THE ADJUSTED RISK BASED CONCENTRATION (RBC)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Boron Micronutrient											
Arsenic	**8**	**1.8**	**1,000**	**42**	**8.6**	**180**	**38**	**570**	**1,000**	**Yes**	**2**
Cadmium	5	0.75	20	10	4.3	--	210	3,200	20	No	--
Chromium	1	1.3	1.3	--	--	--	220,000	3,300,000	1.3	No	--
Cobalt	1	1.8	1.8	--	--	--	23,000	350,000	1.8	No	--
Copper	1	0.5 (h)	0.5	--	--	--	1,800	27,000	0.5	No	--
Lead	7	1	150	21	12	130	500	7,500	150	No	--
Mercury	1	0.0025	0.0025	--	--	--	6.5	98	0.0025	No	--
Molybdenum	1	0.25	0.25	--	--	--	300	4,500	0.25	No	--
Nickel	3	0.5	4	1.8	3	--	2,600	39,000	4	No	--
Selenium	1	2	2	--	--	--	800	12,000	2	No	--
Vanadium	1	17	17	--	--	--	17,000	260,000	17	No	--
Zinc	1	7.7	7.7	--	--	--	8,600	130,000	7.7	No	--
Iron Micronutrient (i)											
Arsenic	**35**	**0.6**	**6,200**	**67**	**13**	**140**	**38**	**910**	**6,200**	**Yes**	**8**
Cadmium	31	0.3	3,900	17	5.4	28	210	5,000	3,900	No	--
Chromium	10	2	120	8.9	3.9	20	220,000	5,300,000	120	No	--
Lead	**37**	**0.37**	**18,000**	**330**	**12**	**660**	**500**	**12,000**	**18,000**	**Yes**	**1**
Nickel	10	3.4	210	31	4.2	71	2,600	6,200	210	No	--
Manganese Micronutrient											
Arsenic	**14**	**0.1**	**2,000**	**19**	**16**	**70**	**38**	**460**	**2,000**	**Yes**	**2**
Cadmium	13	0.16	55	3.1	6	7.4	210	2,500	55	No	--
Chromium	8	3.1	460	17	5.8	57	220,000	2,600,000	460	No	--
Cobalt	5	11	290	74	3.4	--	23,000	280,000	290	No	--
Copper	3	21	40,000	2,500	65	--	18,000	220,000	40,000	No	--
Lead	**14**	**0.55**	**13,000**	**62**	**30**	**310**	**500**	**6,000**	**13,000**	**Yes**	**1**
Mercury	5	0.0025	0.23	0.01	7.6	--	6.5	78	0.23	No	--
Molybdenum	5	2.5	850	15	12	--	300	3,600	850	No	--
Nickel	11	1.5	560	43	5.4	110	2,600	31,000	560	No	--
Selenium	5	2	20	6.2	2.9	--	800	9,600	20	No	--
Vanadium	3	0.55	33	3	8.4	--	17,000	200,000	33	No	--
Zinc	5	61	94,000	4,700	25	--	8,600	100,000	94,000	No	--

Foot notes are presented at the end of the table.

TABLE 18 (continued)

Product Category	Statistical Summary of Concentration Data (a)						Comparison			Exceed?	
	N of Samples	Minimum	Maximum	GM	GSD	90% UCL (b)	Unit RBC (c, d)	Adjusted RBC (e)	Maximum Concentration	Yes or No (f)	N (g)
Zinc Micronutrient											
Arsenic	56	0.1	130	4.5	8.8	7.4	38	1,000	130	No	--
Cadmium	74	0.095	2,300	24	8.5	36	210	5,700	2,300	No	--
Chromium	24	0.25	8,100	24	17	65	1,800,000	49,000,000	8,100	No	--
Cobalt	6	0.25	790	17	36	330	23,000	620,000	790	No	--
Copper	4	4.4	1,700	170	14	--	1,800	49,000	1,700	No	--
Lead	**72**	**0.32**	**28,000**	**180**	**23**	**320**	**500**	**14,000**	**28,000**	**Yes**	**6**
Mercury	16	0.0025	12	0.03	31	0.14	6.5	180	12	No	--
Molybdenum	5	0.25	14	1.2	5.6	--	300	8,100	14	No	--
Nickel	14	4.3	450	47	4.4	96	2,600	70,000	450	No	--
Selenium	15	0.013	25	0.77	9.1	2.1	800	22,000	25	No	--
Vanadium	4	0.5	47	14	9.3	--	17,000	460,000	47	No	--
Zinc	**6**	**22,000**	**350,000**	**160,000**	**2.8**	**380,000**	**8,600**	**230,000**	**350,000**	**Yes**	**2**

Notes:

-- = Not Applicable
GM = Geometric Mean
GSD = Geometric Standard Deviation
N = Number of Samples (or Exceedances)
90% UCL = 90 percent Upper Confidence Limit

(a) All concentrations are in mg MOPC/kg product (or ppm). Data is from industry, literature, and states' monitoring data [compiled and maintained by The Weinberg Group Inc. (TWG 1999c)].

(b) A 90 %UCL is provided when the number of samples for the MOPC is greater than five. The 90% UCL is considered a good upper end estimate of the mean.

(c) Unit RBC is based on a 1% fraction of nutrient (FON). All RBCs are in mg MOPC/kg product.

(d) % FON for each product category is a best estimate. The determination of FON is present in Table 16.
% FON for each product category is:
boron micronutrient = 15; iron micronutrient = 24; manganese micronutrient = 12; and zinc micronutrient = 27.

(e) Adjusted RBC equals the unit RBC multiplied by the % FON.
For example, arsenic unit RBC for micronutrient = 38, % FON for boron miconutrient = 15, therefore, the adjusted RBC for arsenic in boron micronutrient = 38*15 = 570 mg arsenic/kg product.

(f) If the maximum concentration is greater than the adjusted RBC, there is an exceedance.

(g) The number of exceedances is the number of samples (within each product category) with a concentration greater than the adjusted RBC.

(h) All numbers have two significant figures. When only one number is presented, a zero (to the right of the decimal) is the last digit.
For example, 6 = 6.0 and 0.05 = 0.050.

(i) TWG (1999c) does not have data for all MOPC for the iron micronutrient category.

SECTION 5.0 — DERIVATION OF THE RISK BASED CONCENTRATION (RBC) FOR RADIONUCLUDE (RADIUM226) AND SCREENING LEVEL HEALTH EVALUATION: COMPARISON OF THE RBC WITH PRODUCT DATA

Several radionuclides have been detected in phosphate fertilizers, namely uranium238, radium226, and thorium232. This section derives a RBC for one of the radionuclides, radium226. Radium226 is selected as the radionuclide to develop a RBC based on relative toxicity, relative product concentration, and evaluation precedence. The RBC for radium226 is used to conduct a screening level health evaluation.

Relative Toxicity

A radionuclide is the radioactive species of a specific element. Radionuclides exert a toxic effect by transferring energy from the electric field of their nucleus thereby destroying surrounding cells and producing free radicals. Toxicity is measured as activity. Radionuclides are classified by USEPA as Group A carcinogens (USEPA 1999d), and as such, the RBCs are developed based on carcinogenic risk. Radium226 has higher relative toxicity, based on the ingestion slope factors (USEPA 1999d), compared to the other radionuclides under consideration. The ingestion slope factors for radium226, thorium232, and uranium238 are 2.96E-10 (for radium and its short-lived decay products), 3.28E-11, and 4.27E-11, respectively. The slope factors are expressed as age-average lifetime oral radiation cancer incidence risk per unit intake or exposure; the units are risk/pCi (picoCurie, discussed below).

Relative Concentration in Product

The amount (or concentration) of a radionuclide is also measured as activity. Typically, the unit of activity is expressed as becqueral (Bq). Bq is the quantity of a radionuclide where one atom is transferred per second. In the derivation of the RBC, Bq are converted to more conventional units, picoCurie (pCi), in order to match the units of the toxicity value. There is limited data on the concentration of radionuclides in phosphate fertilizers. During processing, the concentration of uranium238 and thorium232 will generally remain in the phosphate component of the fertilizer (USEPA 1999a). Uranium238 decays to form radium226 (USEPA 1999e). The half-life for radium226 is 1,600 years. Radium226 then decays to form radon-222 gas, which has a half-life of 3.8 days (USEPA 1999e). Radium226 in phosphate ore will be contained in the phosphogypsum by-product (USEPA 1999a). Thorium232 is at lower levels in phosphate fertilizer than uranium238 and radium226 (USEPA 1999a and TWG 1999c). The level of uranium238 and radium226 measured in various phosphate fertilizers varies.

Evaluation Precedence

Radium226 is selected as a good example radionuclide to develop a RBC. This selection is based largely on evaluation precedence. Currently, the USEPA (1999e) has established strict regulatory limits on phosphogypsum, including a ban on its use in building roads in Florida due to radium content. The ban is based on the potential risk to a resident if the road is abandoned and a house is built on the road. Under USEPA regulation, the agricultural use of phosphogypsum is permitted if a stack (pile) has less than 10 pCi/g of radium226.

Derivation of the Risk Based Concentration (RBC)

A RBC is derived for radium226 for the exposure scenario defined in Section 1.0, the farm family and unintentional ingestion of fertilized soil and ingestion of crops.[35] The dermal contact exposure route is not included in the RBC because of the low risk potential from dermal exposure.

The RBC is calculated using a similar approach and many of the same parameters that are used to derive the MOPC RBCs. However, because of the difference in toxicity (e.g., slope factors are expressed as activity other than concentration) of radionuclides, the RBC for radium226 is calculated in a slightly different way than the RBCs for the MOPC. In addition, radium specific parameters are needed for several parameters. Deviations from the derivation of the RBCs for the MOPC are:

(1) radionuclide slope factors are not expressed as a function of body weight and time, therefore, these parameters are not included in the intake equation;
(2) radium226 specific parameters for PUF and Kd; and
(3) radionuclide slope factors are expressed as an activity.

Radium226 specific parameters are:

- Kd of 214 - 470 mL/g (USDHHS 1989b);
- PUF (unitless) for vegetable crops is 0.012, root crops is 0.012, and for grain is 0.001 – 0.6 (Post, Buckley, Schuh, & Jernigan, Inc. [PBS&J] 1990, Watson et al., 1983); and
- Oral Slope Factor 2.96E-10 risk/pCi (USEPA 1999d).

The PUFs values for vegetable and root crops are consistent. However, there is a wide range of PUFs for grain (Watson et al., 1983). In a report by PBS&J (1990) the authors suggest that the 0.6 PUF for grain is too high; they suggest a more realistic PUF for grain (0.01 for “control” soils or 0.001 for grain grown on phosphate clay settling areas). The grain PUF value that is similar to the PUFs for vegetable and root is used to calculate the RBC (0.01).

In addition, given the consideration of only one loss pathway, the low end Kd value is used to calculate the RBC.

The amount of radium226 that is taken into the body through unintentional ingestion of fertilized soil and ingestion of crops is adjusted by the percent of radium226 that is expected to be absorbed in the gastrointestinal tract (GI), which is 20% (USDHSS 1989b).

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[35] The decay of radium226 to radon-222 gas and potential for inhalation exposure is recognized. However, under the farm family exposure scenario, the contribution of exposure from inhalation is expected to be much lower than the other routes of exposure. The exposure for this route is expected to be low because (1) the limited time of exposure (time spent in the filed) and (2) because the exposure is not in a confined space but in open field, which will allow the radionuclide to dissipate.

Presentation of the Risk Based Concentration (RBC) and Health Screening Evaluation

The unit RBCs for radium226 are presented below, the lowest unit RBC is 21 pCi/g and is based on the multi-crop farm and the adult.

RBC (pCi/g)	Vegetable	Root	Grain	Multiple Crop
Adult	55	70	64	**21**
Child	540	520	460	200

The unit RBC is adjusted by the appropriate FON for screening and compared with the activity measured in select phosphate products. The screening evaluation is presented below. There are no exceedances of the radium226 RBC by measured activity levels of radium 226 in phosphate fertilizers.

Product	FON	Adjusted RBC	Activity Level in Product (pCi/g) (a)		Exceedances
			Minimum	Maximum	
DAP	46	966	0.7	--	None
MAP	52	1,100	0.6	12.8	None
TSP	46	970	84	--	None
SP	20	420	92	--	None
NPK	18	380	0.4	124	None

-- Indicates one sample.
(a) Activity level in phosphate products is from TWG (1999c) and several world wide samples from USEPA (1999a).

SECTION 6.0 — DISCUSSION OF UNCERTAINTY

Each step in establishing the scope of the evaluation and in developing the RBCs has some inherent uncertainty associated with it. The major uncertainties in this evaluation of fertilizers are described in this section in order to provide an indication of the relative degree to which the uncertainty may underestimate or overestimate exposure, the RBCs, and/or the conclusions of the screening evaluation. Note, an overestimate of exposure will result in a RBC that is lower, a lower RBC is more health protective. An assessment of the major uncertainties associated with establishing the scope of the evaluation and developing the RBCs is presented in Table 19. In addition, an assessment of the magnitude of relative impact in the RBC equation associated with each parameter is presented in Table 20.

The purpose of this document is to provide fertilizer manufacturers and interested regulators with an easy tool to evaluate whether the concentrations of select elements (MOPC), in a particular commercial inorganic fertilizer, may pose a health risk to the humans following its application to agricultural soil. The tool is a screening-level RBC that defines a health protective exposure limit. RBCs are calculated based on a reasonable maximum exposure (RME) and "high-end values" purposely selected to account for the inherent uncertainty associated with each parameter. RBCs are intended to be an evaluation tool. More specifically, the RBC is an evaluation threshold above which further evaluation (more product specific) are necessary to determine if there is, in fact, a risk. The RBCs are therefore, more likely to be over- rather than under-protective of human health, and the uncertainty analysis supports this conclusion.

The information presented in Tables 19 and 20 follow the organization of the information as presented in the report and are discussed below by major category.

Scope of the Evaluation

The scope of the evaluation is narrowed to focus on the products, MOPC, exposed population, and exposure pathways of greatest concern. As a result, the RBCs are focused on the highest potential exposure and are intended to be health protective of all other exposure scenarios. The RBCs may result in an overestimate of potential risk but are not likely to underestimate risk.

Based on (1) the available MOPC concentration data in a wide range of inorganic fertilizer products, (2) the relative toxicity of the MOPC, and (3) the precedence for health risk evaluation, the selection of phosphate fertilizers and micronutrient fertilizers and the 12 metals (plus radium 226) there is very little uncertainty that there are higher risks for other products or metals.

Fertilizer applicators are at minimal risk from MOPC in inorganic fertilizers (TWG 1999a,b). Ingestion is the major exposure pathway and therefore a crop consumer who lives on a farm (i.e., farm adult and child) has the highest expected exposure to MOPC (USEPA 1999b, CDFA 1998). Exposure is from both ingestion of crops plus incidental dermal and soil ingestion. The added exposure from applying fertilizer is not expected to add significantly to the risk to the farm adult.

Several exposure pathways (transport pathways and exposure routes) are not major exposure pathways and are excluded from the development of the RBCs. The exclusion of these exposure pathways is not likely to significantly underestimate risk, since the exposure pathways and exposure routes of greatest concern (the primary drivers of the RBC) are the basis of the RBC (USEPA 1999b, CDFA 1998). In particular, the ingestion of animal products is not considered in the RBC. The exclusion of this exposure route is not likely to underestimate risk because all of the MOPC that is taken up into grains is assumed to be directly consumed by humans (rather than splitting the MOPC exposure into direct consumption of crops and indirect consumption of animals that ate the crops). Similarly, the assumption that the form of mercury is mercuric chloride (that accumulates in soil), and not methyl mercury (that bioaccumulates in fish), is very unlikely to significantly change the final evaluation of risk.[36] Again, it is a matter of splitting the total MOPC added to soil into two exposure pathways versus considering the total MOPC added to soil in a single exposure pathway.

Several exposure routes that are not considered "environmental acceptable end points" (Chaney et al., 1999) for specific MOPC were included in the RBC. For example, several MOPC may be toxic (phytotoxic) to the plant (e.g. zinc) before reaching levels that could be toxic to humans that ingest the plant (or crop). The inclusion of the ingestion of crops in the RBC for these MOPC may overestimate risk.

Derivation of the Risk Based Concentration (RBC)

The RBCs are intended to represent a RME scenario; therefore, they are expected to be reasonably and maximally health protective. The lower RBC is the more health protective. Many of the parameters are statistical estimates recommended by USEPA for the RME scenario. An assessment of the magnitude of relative impact in the RBC equation for each of these parameters is presented in Table 20. The magnitude of impact considers (1) the possible range of values (e.g., EF of 350 days/year – 1 day /year, or soil ingestion for a child of 100 mg/day – 400 mg/day) and (2) the weight that each of the parameters has on the RBC (e.g., SACF, AR, and PUF can significantly influence the RBC). Two parameters in particular, AR and PUF, that have upper end estimates, are particularly influential on the RBC derivation. The use of an RME scenario and upper end estimates for AR and PUF is more likely to underestimate rather than overestimate the RBCs (i.e., overestimate rather than underestimate risk), as discussed below. Several additional assumptions are made that may further underestimate the RBC (overestimate risk); these assumptions are also discussed below.

The biological exposure parameters (e.g., BW [body weight], IR [ingestion rate], and SA [exposed skin surface area]) are recommended RME estimates. These parameters may underestimate the RBC, but are considered reasonable for a screening-level evaluation. In addition, they have a low relative impact on the RBC equation. The use of an FI of 1 assumes that 100% of the crops that a person consumes is from the farm. This is the highest FI and assumes that all of the crops that are ingested are fertilized. Also, the effect of preparing and/or cooking crops for consumption is not evaluated in the RBC. The exclusion of this factor may

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[36] In soil, mercury is reactive and may form several different complexes. Although the transport of mercury into a nearby water body, formation of methyl mercury, and uptake into fish may occur, it is expected that this pathway will occur less frequently, and result in less exposure than the complexing of mercury with chlorine in soil (especially since chlorine ions may be the most persistent complexing agent for mercury in soil) (McLaughlin et al. 1996).

overestimate risk and underestimate the RBC because it is likely that cooking will result in less concentration of a MOPC in the crop by causing the release of some of the MOPC.

The use of high-end estimates for AR and PUF may result in RBCs that are underestimated for a "typical" scenario. However, the use of high-end estimates for these parameters ensures that the RBCs are health protective of possible high-end exposures. For example, plant uptake of an MOPC is generally higher in acidic soil. The use of an upper end estimate of PUF results in RBCs that are health protective of this potential scenario. In addition, the PUFs may be further overestimated by the inclusion of greenhouse or pot studies. MOPC uptake is typically greater in pot studies than field studies; still pot studies were included in the database. Conversely, the PUFs may be underestimated by the use of total compared to extractable MOPC soil concentration in the denominator of the PUF. Lastly, the PUFs are based on all of the plant parts, not just the edible portion. The magnitude of uncertainty on the use of data from the whole plant in developing the PUFs is unknown. In general, the PUFs are probably overestimates of MOPC plant uptake rather than underestimates.

Another parameter that may further underestimate rather than overestimate the RBC is the assumption of 100% relative absorption factor (RAF) from the ingestion of MOPC in soil and crops for most of the MOPC. Again, this is selected as a conservative parameter for a screening-level evaluation. RAF adjusts the estimated intake and toxicity value to an absorbed dose resulting in a RBC that is more realistic and representative of actual exposure, intake, and absorption. The absorbed dose is likely to be less than the administered dose, especially when the MOPC is sorbed to soil or in plant tissue. For all MOPC, except arsenic, RAF is assumed to be 1. In addition, lead intake is adjusted by percent absorption values. A RAF of 1 can have different magnitudes of effect on the RBC depending on the MOPC and the basis of the toxicity value. For example, most of the toxicity values are based on an administered dose in the diet or food. The absorbed dose may be lower than the administered dose. In this case toxicity would occur at a lower dose, resulting in a lower toxicity value. Therefore, a toxicity value based on an administered dose may be greater than the a toxicity value based on an absorbed dose. Conversely, an estimated intake that is also based on an administered intake, rather than an absorbed intake, may be over estimated, especially depending on the medium of exposure. Therefore, if possible toxicity values and intake should both be based on administered dose or an absorbed dose and the same (or similar) medium of exposure.

When the toxicity value is based on an absorbed dose and the estimated intake is based on administered dose, as is the case for cadmium, the RBC may be underestimated. The toxicity value for cadmium is based on food and is derived using a pharmacokinetic model that considers the percent of cadmium that is absorbed into the blood stream from the diet. Yet, the estimated intake of cadmium from the crop and incidental soil ingestion is based on the amount of food or soil ingested and not the actual amount of cadmium absorbed into the bloodstream. The absorption of cadmium in these media is assumed to be 100%, whereas, cadmium absorption from food or soil in the gut is expected to be much lower (less than 5%).

The magnitude of the effect of soil accumulation factor (SACF) on the RBC is unknown. SACF may overestimate or underestimate accumulation and bioavailability of the MOPC in soil following application. The consideration of MOPC loss through leaching as the only loss pathway is likely to underestimate the RBC because it is likely that loss of MOPC through other loss pathways could occur. Conversely however, the Kd values used in the development of the RBC may overestimate the leaching of the MOPC into groundwater and underestimate the exposure in soil. The lower the Kd, the more available the MOPC is for leaching into groundwater and the less remains in the soil. There is a very wide range of Kd values (both measured and estimated) in the literature. The Kds selected for this evaluation are based on measured data and come from a single literature source, but are on the lower end of the Kd range.

The USEPA toxicity values used in the development of the RBCs are purposely conservative. For instance, the toxicity value for arsenic is based on a nutrient deficient population. The agency has built in considerable safety factors. In addition, for this evaluation in particular, the use of the oral cancer slope factor for arsenic may overestimate risk since the cancer toxicity value for arsenic is based on (1) inhalation and lung cancer and (2) drinking water and skin cancer, neither being directly related to the ingestion of food.

Also, toxicity values for several forms of chromium are available. In order to select the most appropriate toxicity value to use in developing the RBCs, assumptions are made about the form of the MOPC that is likely to accumulate in soil and be available for uptake into crop and human exposure. In particular, chromium III is assumed to accumulate in soil and be available for uptake, not chromium VI. This assumption about the form of chromium may underestimate risk from exposure because chromium III is less toxic than chromium VI. However, chromium III is the form expected to accumulate in soil over a long period of time.

The presence and effect of other MOPC on toxicity (synergism, antagonism) or uptake (e.g., cadmium and zinc) are not considered and may underestimate or overestimate risks. More than one MOPC is often present in a fertilizer. In addition, the contribution of MOPC in soil from natural background levels is also not accounted for in the RBC. The exclusion of contribution from background may overestimate the RBC and underestimate exposure and risk. The potential for underestimating exposure and risk from these factors is assumed to be offset by the overall high end parameters and assumptions used in the derivation of the RBCs.

Overall Assessment of Uncertainty on the RBC and Health Risk Screening Evaluation

The approach used in this evaluation is consistent with the generally accepted practice in screening-level health risk assessments. To this end, the products, MOPC, exposed population, and exposure scenario are selected and the RBCs are derived to ensure they are sufficiently health protective. Despite several uncertainties that may overestimate the RBC (underestimate risk), the scope, the RBCs and the health screening evaluation (comparison of RBCs to measured MOPC concentrations in products) are considered to be health protective. In addition, most of the parameters, in particular parameters that have a relative high impact on the RBC equation (e.g., AR, PUF), are high end estimates.

TABLES

TABLE 19
MAJOR ASSUMPTIONS AND UNCERTAINTIES ASSOCIATED WITH THE RISK BASED CONCENTRATIONS (RBCs) AND THE SCREENING LEVEL HEALTH RISK EVALUATION

Assumption	Magnitude of Uncertainty and Effect on the Risk Based Concentration (RBC) and Estimate of Risk	Rationale
Scope of the Evaluation		
Focuses on phosphate and select micronutrient fertilizers.	Low – may underestimate risk (overestimate RBC) if other classes had higher metal levels, but not likely.	These classes of inorganic fertilizers tend to contain higher levels of the metals of potential concern (MOPC). Phosphate fertilizers have the highest levels of metals compared to other macronutrient fertilizers. Also, micronutrient fertilizers that are evaluated have the highest metal concentrations.
Focuses on twelve metals of potential concern (MOPC) and one radionuclide (radium 226) considered to have toxicological significance compared to other metals found in inorganic fertilizers.	Low – may underestimate risk and overestimate the RBC if the other metals are more toxic or were at significantly higher levels, but not likely.	Other metals found in inorganic fertilizers have lower comparative toxicity. Also, since the metals with high toxicity are generally not found to a health concern (arsenic, mercury and lead), then the other metals are not expected to be a health concern.
Focuses on farmer family and select exposure pathways – unintentional ingestion of fertilized soil, dermal contact fertilized soil and ingestion of crops.	Low – may overestimate risk and underestimate the RBC.	Health protective of all other scenarios because considered the scenario with highest exposure, and therefore, expected to have the lowest RBC.
Exclusion of several exposure pathways and routes, such as, ingestion of animal products that have taken up MOPC, and bioaccumulation of methyl mercury in fish.	Low – may underestimate risk and overestimate the RBC.	Not likely to underestimate risk because the highest exposure routes are the basis of the RBC. In particular, the RBC for grains is based on the assumption that all of the MOPC that is taken up into grain is directly consumed by humans.
Lack of the consideration of environmentally acceptable endpoints. For example, MOPC may be toxic to the plant before reaching levels that could toxic to humans.	Low – Medium – may overestimate risk and underestimate RBC.	Plant toxicity is not considered in this evaluation. The RBCs are intended to be health protective of the ingestion of MOPC in crops for any scenario.
Derivation of the Risk Based Concentration (RBC)		
Development of a RME scenario.	Low – Medium – may overestimate risk and underestimate the RBC.	Standard screening level guidance to ensure the RBCs are sufficiently health protective.
Exposures are based on granular fertilizer.	Low – may under or overestimate risk and RBC.	Exposure to fertilizer in the granular form is assumed to be similar to soil and exposure to liquid fertilizer is assumed to result in similar exposure as to granular fertilizer. Sufficiently health protective.
Upper – end estimates for AR and PUF.	Low – Medium – may overestimate risk and underestimate the RBC.	Ensures the RBCs are health protective of scenario were high accumulation, uptake, and exposure may occur.

TABLE 19 (continued)

Assumption	Magnitude of Uncertainty and Effect on the Risk Based Concentration (RBC) and Estimate of Risk	Rationale
Development of PUFs (1) includes greenhouse and pot studies and (2) is based on total MOPC concentration in soil.	Low – Medium – may under or overestimate risk and RBC.	Uptake of MOPC by plants in greenhouse and pot studies is greater than in filed studies. PUFs based on total MOPC concentration in soil are lower than PUFs based on extractable MOPC concentration in soil.
RAF of 1 (or 100%).	Low – Medium – may overestimate exposure and risk and underestimate the RBC.	Conservative assumption given the lack of information needed to develop appropriate and applicable RAF. RAF is probably lower than 100%.
Development of SACF – consideration of limited loss pathways and use of low end Kds.	Low – Medium – may over or underestimate risk and RBC.	An SACF based on limited loss pathways may result in more MOPC accumulating in soil. Conversely, low end Kds may overestimate the availability of MOPC to transport and leach into groundwater.
Conservatively derived USEPA cancer slope factors, chronic reference doses, and lead biokinetic slope factor are used to evaluate risk.	Medium – may overestimate risk and underestimate RBC.	For noncancer effects, combinations of uncertainty factors along with dose-response data, often from laboratory animals, are used to derive criteria to protect the most sensitive human receptors. For cancer effects, dose-response data are used to derive slope factors that estimate an upper limit on risk associated with a given exposure. Actual risk could be much lower (especially for arsenic).
Toxicity criteria for the dermal exposure of exposure were derived using route-to-route extrapolation and an adjustment to an absorbed dose.	Medium – may over or underestimate risk and RBC.	Depending on the MOPC, the route of administration or exposure may change the toxicity.
Toxicity value for chromium III, not chromium VI is used.	Low – may underestimate risk and overestimate the RBC.	Chromium VI is more toxic than chromium, however, chromium III is expected to accumulate in soil over a long time period.
Factors not considered when developing the RBC • Contribution of MOPC from background • The presence and effect of other MOPC on toxicity (synergism antagonism) or uptake (e.g. cadmium and zinc)	Low – Medium – may over or underestimate risk and RBC.	Impossible to assess each of the factors because of lack of information that is needed. Overall conservative approach is considered health protective.

TABLE 20
MAGNITUDE OF RELATIVE IMPACT ASSOCIATED WITH EACH PARAMETER IN THE RISK EQUATION

Parameter	Statistical Descriptor	Magnitude of Relative Impact (High, Low) in Risk Equation (a)
Biological Exposure Parameters		
Exposure Duration (ED)	95th percentile, upper end estimate	High (for arsenic, the only carcinogen)
Exposure Frequency (EF)	Very high end, assumes exposure every day of the year except for 2 weeks away from home	High
Averaging Time (AT)	Standard default, but high end, based on lifetime exposure for cancer and length of exposure (exposure duration) for noncancer	High
Body Weight (BW)	Mean estimate	Low
Ingestion Rates for Soil and Crops (IR)	Mean estimates	Low
Fraction Ingested (FI)	Highest possible percent	High
Skin Surface Area (SA)	Central tendency	Low
Adherence Factor (AF)	Central tendency	Low
Crops Specific Parameters		
Application Rate (AR)	95% upper confidence limit of the arithmetic mean – upper end estimate	High
Plant Uptake Factors (PUFs)	90% confidence limit of the geometric mean – upper end estimate	High
Fraction of Land (FOL)	Reasonable estimates	Low
Soil Accumulation Factor (SACF)	Reasonable estimate, combination of high, central and low-end values	High
Metal of Potential Concern (MOPC) Specific Parameters		
Toxicity Values (Tox)	High end, standard health protective values	High
Relative Absorption Factor (RAF)	Mostly 100%, high end percent (except for arsenic and lead)	Low – High (MOPC dependent)

(a) The magnitude of impact considers (1) the possible range of values (e.g., EF of 350 days/year – 1 day /year or soil ingestion for a child of 100 mg/day – 400 mg/day) and (2) the weight that each of the parameters has in the RBC equation (e.g., SACF, AR, and PUF have significant weight).

SECTION 7.0 — CONCLUSIONS OF EVALUATION

The screening evaluation indicates there are no exceedances for any of the phosphate fertilizer RBCs and therefore no post application health risks from exposure to metals in NPK types of fertilizers. With regard to micronutrient fertilizers, there are exceedances of arsenic and lead RBCs for several micronutrient fertilizer products. These products contain relatively high levels of arsenic and lead in some samples. Because of the health protective nature of screening level evaluations, and because exceedances occur only at the maximum metal concentration in some of the samples, a firm conclusion regarding health risks from micronutrient products or product categories requires a closer, product-by-product evaluation. A refined evaluation would take into account the exact uses and use conditions of the specific products, as well as monitoring data for arsenic and lead concentrations in additional samples of these products.

As with all risk assessments there is some level of uncertainty associated with this evaluation. The major uncertainties are identified and described in the report. The uncertainty is more likely to err on the side of overestimating the potential for risk rather than underestimating the potential risk for both the NPK and micronutrient fertilizer products.

SECTION 8.0 — COMPARISON TO OTHER EVALUATIONS

In addition to this evaluation, evaluations of inorganic fertilizers have been conducted and are presented in two previous reports: CDFA (1998) and USEPA (1999b).[37] These reports are used throughout this evaluation to assist in establishing health protective assumptions and in focusing the scope of this evaluation. A comparison of the (1) purpose and general approach (2) scope (3) specific key parameters and (4) the conclusions among these three evaluations is made in this section.

Purpose and General Approach

The purpose and general approach of each of the evaluations is presented in Table 21. All three evaluations are intended to assist in answering the question: are inorganic fertilizers safe, or more specifically, does the use of inorganic fertilizer on agricultural soils pose a health risk? Each of these evaluations provides valuable information to answer this question. However, each assessment has a somewhat different approach and thus provides unique as well as complimentary information and conclusions.

The purpose of this evaluation is to develop a flexible screening tool that can be used to evaluate inorganic fertilizer products. In addition, this assessment evaluates a fairly comprehensive fertilizer product database (TWG 1999c). Because the purpose of this evaluation is to provide a flexible screening tool, that can be used to evaluate many products now and in the future, this evaluation uses a back-calculation, risk based approach and develops RBCs. This evaluation uses a deterministic and high-end exposure estimate approach to develop health protective RBCs, or levels of metals in products. In addition, this evaluation is intended to be nationwide in its application.

As stated in USEPA (1999b), the purpose of USEPA's assessment is to estimate potential risks posed to human health and the environment by contaminants in (23) fertilizer products. Such a determination of risk requires a forward risk assessment approach. That is, USEPA determines risks for a range of product types that are currently in commerce. A summary of this product database is presented in USEPA (1999a). USEPA uses a probabilistic approach to estimate the distribution of individual lifetime risk from exposure to metals in inorganic fertilizer following application. USEPA's evaluation has nationwide application.

The purpose of the CDFA (1998) evaluation is to develop RBCs for three metals in inorganic fertilizers, arsenic, mercury, and lead, that are based on application and exposure in California. Of all the metals that are present in inorganic fertilizers, these three were chosen (based on a screening evaluation) because they are considered to pose the highest risk. CDFA (1998) offers a method but does not evaluate actual product data and therefore does not make conclusions with regard to health risks. California uses a probabilistic approach to develop the RBCs.

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[37] The USEPA fertilizer risk assessment relies on the information provided in a companion report, USEPA 1999a.

Scope

The scope of each of these evaluations varies; a comparison of the scope is also presented in Table 21.

The scope of this evaluation is narrowed to focus on the products, MOPC, populations and exposure pathways of greatest concern. The products evaluated are phosphate fertilizers and select micronutrient fertilizers (boron, iron, manganese, and zinc). The MOPC for which RBCs are developed and products are evaluated are: arsenic, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, vanadium, and zinc and one radionuclide, radium 226. The exposure scenario is the farm family, including adults and children, and exposure pathways that contribute the most to risk including direct contact with fertilized soil (i.e., unintentional ingestion and dermal contact) and uptake of MOPC into crops and subsequent ingestion of crops. The RBCs are intended to be nationally representative. The crops are grouped into like physiological groups (vegetable, root, and grain); each of these groups is evaluated independently.

USEPA (1999b) evaluates all of the general categories of inorganic fertilizer products (e.g., NPK for P, NPK for N, phosphate fertilizers, nitrogen fertilizers, potash fertilizers, etc.), farm workers and farm residents (both adults and children), most of the potential exposure pathways (all three evaluations exclude drinking water), and 29 geographic locations. Crops are grouped as ingested by animals (grain and forage) and crops ingested by humans (fruit, herb or above ground vegetables, and root). USEPA (1999b) evaluates nine MOPC: arsenic, cadmium, cobalt, copper, lead, mercury, nickel, vanadium, and zinc, as well as dioxin. USEPA (1999b) also evaluates risk to the environment.

The scope of CDFA (1998) is focused on the development of RBCs for phosphate and zinc micronutrient fertilizers and three MOPC: arsenic, cadmium, and lead. In addition, as mentioned above, the CDFA (1998) evaluation focuses on California. The exposure scenario that the RBCs are based on is narrowed to focus on the exposure scenario of greatest concern through a deterministic, forward risk assessment screening evaluation. The focused exposure scenario consists of the farm family (adults and children) and direct contact with fertilized soil (i.e., unintentional ingestion and dermal contact) and the uptake of the MOPC through the ingestion of crops. Crops are grouped and evaluated similar to this evaluation.

Key Parameters

Whether the assessment uses a forward risk based approach (determination of risk for a specific group of products) or a back-calculation risk based approach (development of RBCs and a screening evaluation of current and future products), there are “key” parameters in common. Key parameters are those that can significantly influence the estimation of the RBC or risk; they are also called sensitive parameters. A comparison of the parameters used in each of the three evaluations is presented in Table 22. The key parameters include application rate (AR), soil accumulation factor (specifically related to loss and bioavailability), plant uptake factor (PUF), and representative MOPC concentration in product. Other parameters are also presented in Table 22 (i.e., biological exposure parameters and toxicity values); however, these parameters are generally similar among the three evaluations and therefore do not influence the estimation of the RBC or risk as much as the key parameters.

Application Rate (AR)

The application rates used in this evaluation are developed from information presented in USEPA (1999a). ARs for each of the three crop groups are developed for both phosphate fertilizers and zinc micronutrient fertilizers. The ARs are upper-end estimates of the data set for each crop group (they are the 95 percent upper confidence limit, 95UCL of the mean, based on a normal distribution). The ARs for phosphate fertilizers are 118, 154, and 63 lbs/acre-year for vegetable, root, and grain crops, respectively. The AR for zinc micronutrient fertilizer is 10 lbs/acre for all 3 crop groups, and is an estimate from industry experts (USEPA 1999a).

The ARs used in USEPA (1999b) are taken directly from USEPA report (1999a) where the consumption and use of inorganic fertilizers is presented. The ARs for each generic fertilizer category are based on a distribution of percentile (50th, 85th, and 95th) ARs. For the purposes of comparing, the high-end (85%) estimate from USEPA (1999a) for phosphate fertilizer is 173 lbs/acre and the maximum AR (95%) is 252 lbs/acre-year. The high-end ARs for micronutrient fertilizers are 10 lbs/acre-year for zinc and 20 lbs/acre-year for iron micronutrient fertilizers (USEPA 1999a). The distribution of ARs is combined with varying FONs in determining the distribution of risk.

ARs used in developing the RBC in CDFA (1998) are also represented as a distribution. For comparison purposes, phosphate fertilizer ARs values (mean) reported in CDFA (1998) are 60.0, 67.4, and 38.2 lb/acre-year for vegetable, root, and grain crop groups, respectively (CDFA 1998). The AR for micronutrient fertilizers is 6.1 lb/acre-year for all crop groups.

Soil Accumulation

The accumulation of MOPC soil following application is estimated in each of the three evaluations using similar models. However, assumptions that are made regarding soil accumulation, loss from soil, and the Kd values are different.

In this evaluation, SACF considers only the loss of MOPC through leaching, thereby, most of the MOPC that is applied is assumed to accumulate in soil. SACF is primarily based on generic USEPA default parameters. The Kd values are measured values published in the literature. These Kd values are on the lower end of the Kd range.

The accumulation of MOPC in soil in USEPA's evaluation is more complex because it considers the loss of MOPC through several loss pathways. Also, accumulation and loss is determined for each of the 29 geographic locations using geographic specific parameters. The Kd distributions in USEPA (1999b) are from derived from a database of Kds compiled by USEPA.

The accumulation of MOPC in soil in CDFA (1998) considers several loss pathways however only leaching is determined to contribute substantially to loss. The other loss pathways are determined to be negligible. The Kd values used in CDFA (1998) are the same as the Kd values used in this evaluation.

Plant Uptake Factor (PUF)

The plant uptake factors (PUFs) used in this evaluation are based primarily on field studies, however, some data are from greenhouse or pot studies (in the instance of insufficient field data). Also, any studies that applied organic fertilizer are generally excluded from the PUF database. The PUF data are grouped by crop: vegetable, root, and grain. PUF estimates are the 90 percent upper confidence limit (UCL) assuming a log normal distribution (or the 95% UCL, based on a normal distribution). PUFs are presented in Table 23.

The plant uptake factors (defined as Br in USEPA's evaluation) in USEPA (1999b) are presented as distributions and are developed from a comprehensive literature search. All of the PUF data used in CDFA (1998) is included in this database as well as additional data. The majority of PUF data is from field studies; however, some data is from greenhouse studies (used to supplement data set in the instance of insufficient field data). Studies that use organic fertilizer are not included in the database. PUFs are developed for herbs (exposed vegetables consumed by humans), roots, grains, fruits, and forage crops. The mean value of the distribution is presented in Table 23 for comparison purposes.

The PUF distributions developed in CDFA (1998) also exclude studies that apply organic fertilizer, however, unlike the data in USEPA or this report, most of the data in CDFA (1998) is from greenhouse and pot studies. The mean PUF is also presented in Table 23 for comparison purposes.

Other parameters, biological exposure parameters (e.g., IRs, BW, and SA), absorption values, and toxicity values, are generally developed from standard USEPA resources. Some of these parameters are represented as distributions and not point estimates in USEPA (1999b) and CDFA (1998). Nevertheless, these parameters are generally similar.

MOPC Concentration in Product

MOPC concentration in product is only considered in this evaluation and in USEPA (1999b). A comparison of MOPC concentrations is presented in Table 24. CDFA (1998) does not conduct a health evaluation of products and therefore does not consider product information.

The product database used in this evaluation is a fairly comprehensive database and consists of industry, state, and literature data (TWG 1999c). Products for which there are reported MOPC concentrations are evaluated as product groups or types, but can also be evaluated separately.

The product database for USEPA's risk assessment (1999b) is based on a recent USEPA report on inorganic fertilizers (USEPA 1999a) that summarizes the literature data. MOPC concentrations for a product type (e.g. diammonium phosphate) are evaluated as a distribution.

However, for several products, limited product data are available and distributions could not be developed.

Conclusion Regarding Determination of Risk

Only this evaluation and USEPA (1999b) evaluate potential risk from exposure to MOPC following application. However, the RBC values for arsenic, cadmium and lead are similar for this evaluation and the CDFA (1998) evaluation. Both this evaluation and USEPA (1999b) evaluation conclude that there is no significant post-application human health risk from exposure to NPK types of inorganic fertilizers. The CDFA (1998) evaluation would give the same conclusion if its RBC values were compared to MOPC concentrations in the fertilizer product database. With regard to micronutrient fertilizers, both this evaluation and USEPA (1999b) identified several micronutrient fertilizers that contain levels of certain MOPC, in particular arsenic, that pose a possible health risk. While it is a basic tenant of health risk assessment that exposure to a high enough concentration of a chemical can pose an unacceptable risk, a closer look at these relatively few micronutrient product samples is warranted before a firm conclusion of risk for these specific samples, and even more so for product types or categories, can be made. USEPA (1999b) concluded that hazardous constituents in fertilizers generally do not pose harm to human health or the environment.[38] This evaluation, and by similarity in RBCs, the CDFA (1998) evaluation are in general agreement with this conclusion.

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[38] Based on a screening level ecological risk evaluation of metals in fertilizer runoff into streams, USEPA (1999b) concluded that no exceedances of water quality criteria are projected.

TABLES

TABLE 21
COMPARISON OF THE PURPOSE, GENERAL APPROACH, AND SCOPE OF THIS EVALUATION TO USEPA (1999b) INORGANIC FERTILIZER RISK ASSESSMENT AND CDFA (1998) DEVELOPMENT OF RISK BASED CONCENTRATIONS (RBCs) FOR ARSENIC, CADMIUM, AND LEAD

Factor	**This Evaluation**	**USEPA**	**CDFA**
General			
Purpose	Develop flexible risk based screening tool and to evaluate available product data.	Estimate distribution of individual lifetime risk based on available product information.	Develop RBCs for arsenic, cadmium and lead.
Approach	Back calculation, risk based approach – development of risk based concentrations (RBCs)	Forward risk assessment	Back calculation, risk based approach – development of RBCs
	Deterministic based on a reasonable maximum exposure (RME) scenario	Probabilistic presents risks at 50, 90, 95, and 99 percentile	Probabilistic develop RBCs (protective of 90 percentile risks)
Perspective	National (health protective)	National (29 geographic locations)	California
Scope			
Fertilizers	▪ Phosphate (blends and phosphate) ▪ Select micronutrients (boron, iron, manganese, and zinc)	▪ Macronutrient (phosphate, NPK for phosphate, NPK for nitrogen, potash) ▪ Amendments (sulfur for nutrient, sulfur for pH, lime, and gypsum) ▪ Micronutrient (boron, iron, manganese, zinc, and mixes)	▪ Phosphate ▪ Zinc micronutrients
Metals of Potential Concern (MOPC)	Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium, Vanadium, and Zinc (radium 226 is also evaluated)	Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Nickel, Vanadium, and Zinc (dioxin is also evaluated)	Arsenic, Cadmium, and Lead
Populations and Exposure Routes	Farm family - adult and child ▪ unintentional ingestion of fertilized soil ▪ dermal contact with fertilized soil ▪ crop ingestion on a single and multi-crop farm (vegetable, root, and grains) note: a worker is evaluated in previous reports (TWG 1999a,b)	Farm family - adult and child ▪ inhalation ▪ ingestion of animal products (milk and beef) following ingestion of forage crops and grain ▪ ingestion of crops (fruit, vegetable, and root) (multiple only) ▪ unintentional ingestion of fertilized soil (not added to indirect pathways) ▪ ingestion fish ▪ direct ingestion fertilizer (adult worker only)	Farm family - adult and child ▪ unintentional ingestion of fertilized soil ▪ dermal contact with fertilized soil ▪ crop ingestion on a single and multi-crop farm (vegetable, root, and grain) note: focused on this exposure scenario through a deterministic risk based forward screen

TABLE 22
COMPARISON OF KEY PARAMETERS USED IN THIS EVALUATION TO THESE PARAMETERS IN USEPA (1999b) INORGANIC FERTILIZER RISK ASSESSMENT AND CDFA (1998) DEVELOPMENT OF RISK BASED CONCENTRATIONS (RBCs) FOR ARSENIC, CADMIUM, AND LEAD

Key Parameters	This Evaluation	USEPA	CDFA
Application Rate (AR)	Upper end point estimates based on information from USEPA (1999a) (a) Phosphate 118 lb/acre–yr – vegetable 154 lb/acre–yr – root 63 lb/acre–yr – grain Micronutrient 10 lbs/acre–yr	Distribution based on information from USEPA (1999a) (a) High-end estimates: Phosphate 173 lb/acre–yr – all crops Micronutrient 10 lb/acre–yr (for zinc) 20 lb/acre–yr (for iron)	Based on California data and distribution based Representative value: Phosphate 60.1 lb/acre–yr – vegetable 66.2 lb/acre–yr – root 37.4 lb/acre–yr – grain Micronutrient 6 lbs/acre–yr
Soil Accumulation Factor (SACF)	▪ Based on national default values and only one loss pathway (leaching) ▪ 50 yrs application duration (200 for lead) ▪ Low end Kd values	▪ Based on regional information and several default values and several loss pathways ▪ 100 yrs application duration (followed by 40 years of inactive use) ▪ Distribution of Kd values that includes high-end values	▪ California specific and several loss pathways ▪ 50 yrs application duration (200 for lead) ▪ Low end Kd values
Plant Uptake Factors (PUFs) (a)	▪ Upper end point estimate ▪ Database consists of field studies and limited greenhouse and potted	▪ Represented as a distribution ▪ Database consists of all data in CDFA plus additional data ▪ Primarily field studies, except when insufficient field data, then greenhouse and potted studies	▪ Represented as a distribution ▪ Mostly pot and greenhouse studies; few field studies
Toxicity Values	Standard USEPA	Standard USEPA	Standard USEPA and DTSC
General Exposure Parameters (e.g., ingestion rates, exposure duration, exposed skin surface area, and body weight and relative absorption factors and fraction ingested)	▪ Based on USEPA default, RME recommended point estimates ▪ 100% fraction ingested ▪ 100% (or 1) relative absorption factor (except for arsenic and lead)	▪ Generally based on USEPA standard default, several represented as a distribution ▪ IRs developed differently considers a fraction ingested of less than 100% ▪ Relative absorption of 100%	▪ Generally based on USEPA default, some California, Department of Toxic Substance Control (DTSC) specific information ▪ 100% fraction ingested ▪ Similar relative absorption factor as this evaluation
MOPC Concentration in Product (b)	▪ Comprehensive product database ▪ Maximum product concentration used for screening	▪ Concentration data obtained from USEPA (1999a) ▪ Represented as a distribution except for when limited number of samples available (e.g., iron micronutrient)	NA

Notes:

NA Not Applicable
(a) PUFs are presented in Table 23.
(b) MOPC concentrations in product are presented in Table 24 and Table 25.

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TABLE 23
COMPARISON OF PLANT UPTAKE FACTORS (PUFs) USED IN THIS EVALUATION TO THE PUFs DEVELOPED IN USEPA (1999b) INORGANIC FERTILIZER RISK ASSESSMENT AND CDFA (1998) DEVELOPMENT OF RISK BASED CONCENTRATIONS (RBCs) FOR ARSENIC, CADMIUM, AND LEAD

Metal of Potential Concern (MOPC)	PUFs (a)								
	This Evaluation (upper end estimate, 95 UCL)			USEPA (mean, although estimated as a distribution)			CDFA (mean, although estimated as a distribution)		
	Vegetable	**Root**	**Grain**	**Herbage**	**Root**	**Grain**	**Vegetable**	**Root**	**Grain**
Arsenic	0.30	0.05	0.03	0.065	0.099	0.005	0.024	0.011	0.02
Cadmium	1.7	0.93	0.12	0.81	0.75	0.54	0.68	0.31	0.092
Chromium	0.0014	0.0014	0.0037	0.032	0.0011	0.000093	--	--	--
Cobalt	0.05	0.03	0.02	--	--	--	--	--	--
Copper	0.034	0.22	0.31	0.28	0.45	1.7	--	--	--
Lead	0.08	0.05	0.05	0.12	0.046	0.11	0.014	0.026	0.0096
Mercury	0.61	0.67	0.26	0.52	0.036	0.57	--	--	--
Molybdenum	1.1	0.15	0.22	--	--	--	--	--	--
Nickel	0.15	0.07	0.05	0.0086	--	--	--	--	--
Selenium	0.88	0.76	0.57	--	--	--	--	--	--
Vanadium	0.007	0.007	0.007	--	--	--	--	--	--
Zinc	1.7	0.46	0.58	0.77	0.13	0.97	--	--	--

Notes:

-- Not applicable or not available

(a) PUFs are based on dry weight and are unitless.

TABLE 24
COMPARISON OF THE METAL OF POTENTIAL CONCERN (MOPC) CONCENTRATIONS IN PHOSPHATE FERTILIZER PRODUCTS USED IN THIS EVALUATION TO THE MOPC CONCENTRATIONS USED IN USEPA (1999b) INORGANIC FERTILIZER RISK ASSESSMENT

	Concentrations (a)					
	This Evaluation			USEPA		
MOPC	**Minimum**	**Maximum**	**Mean (b)**	**Minimum**	**Maximum**	**Mean**
Arsenic	0.05	42	10	0.05	155	12
Cadmium	0.015	205	13	0.03	250	44
Chromium	0.25	5,060	120	4.3	896	110
Cobalt	0.04	58	5.6	NE	NE	NE
Copper	0.14	544	14	0.2	1,170	41
Lead	0.05	1,860	13	0.1	5,425	140
Mercury	0.001	1.5	0.16	0.003	0.2	0.1
Molybdenum	0.69	72	12	NE	NE	NE
Nickel	0.5	351	22	0.5	195	28
Selenium	0.03	27	2.6	NE	NE	NE
Vanadium	0.28	1,106	128	25	721	180
Zinc	0.30	6,270	260	1	2,193	240

Notes:

NE Not Evaluated

(a) Concentrations are presented as ppm (or mg MOPC/kg product).

(b) For comparison purposes, the mean values assume a normal distribution, the mean values presented in Section 4.0 assume a log normal distribution.

TABLE 25
COMPARISON OF THE METAL OF POTENTIAL CONCERN (MOPC) CONCENTRATIONS IN MICRONUTRIENT FERTILIZER PRODUCTS USED IN THIS EVALUATION TO THE MOPC CONCENTRATIONS USED IN USEPA (1999b) INORGANIC FERTILIZER RISK ASSESSMENT

	Concentrations (a)					
	This Evaluation (b)			USEPA		
MOPC	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
Arsenic	0.1	6,200	400	0.5	4,950	560
Cadmium	0.095	3,900	120	0.75	2,165	340
Chromium	0.25	8,100	290	1.3	580	170
Cobalt	0.25	790	200	NE	NE	NE
Copper	0.5	40,000	7,700	1.5	2,050	640
Lead	0.32	28,000	2,400	5	52,000	9,400
Mercury	0.0025	12	1	0.01	3.36	1.3
Molybdenum	0.25	850	83	NE	NE	NE
Nickel	0.5	560	88	2.5	8,950	760
Selenium	0.013	25	6	NE	NE	NE
Vanadium	0.5	47	23	0.5	41	15
Zinc	8	350,000	120,000	6	60.8	33

Notes:

NE Not Evaluated

(a) Concentrations are presented as ppm (or mg MOPC/kg product).
(b) For comparison purposes, the mean values assume a normal distribution, the mean values presented in Section 4.0 assume a log normal distribution.

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GLOSSARY

Symbol	**Term**	**Definition**
ABS	Percent Dermal Absorption	Estimates the amount of MOPC that is absorbed across the skin into the bloodstream following dermal exposure. The ABS adjusts the estimated intake to an actual "dose".
AF	Adherence Factor	Estimated amount of soil that adheres to skin.
AR	Application Rate	The amount of fertilizer applied to a specified area of soil per year. AR depends on the plant nutrient needs, the composition of the product, and local soil conditions.
As	Arsenic	Symbol for arsenic.
AT	Averaging Time	Time over which intake is averaged. For non-carcinogens, intake is averaged over ED. For carcinogens, intake is averaged over a lifetime (70 years).
BIO	Bioavailability	Fraction of a specified contaminant in a medium (e.g., fertilizer) that is absorbed into the bloodstream across physiological barriers.
BW	Body Weight	Average body weight, which is recommended for evaluating the RME scenario (71.8 kg for adult; 15.5 kg for child).
BD	Bulk Density	The ratio of the mass of water-free soil to its bulk volume. It is expressed in g/cm^3 (apparent specific gravity).
Cd	Cadmium	Symbol for cadmium.
Co	Cobalt	Symbol for cobalt.
Cr	Chromium	Symbol for chromium.
Cu	Copper	Symbol for copper.
ED	Exposure Duration	Length of time over which exposure occurs (typically the length of residence). The ED for farm residents varies between children (6 years) and adults (30 years).
EF	Exposure Frequency	Represents how often (days/year) the potential for exposure occurs. The EF is 350 days/year for both farm resident children and adults.

Symbol	**Term**	**Definition**
--	Exposure Pathway	A unique mechanism by which an individual or population is exposed to a substance. A pathway has a source, a mechanism of release to the environment, an environmental transport medium, a point of potential human contact, and an exposure route and intake by a human receptor at the exposure point.
--	Fertilizer	A substance that contains one or more recognized plant nutrients that is especially designed to be used for its plant nutrient content.
FI	Fraction Ingested	Fraction of the soil or crop that originates from the source (i.e., soil following fertilizer application, or crops grown in this soil). Assumed in this evaluation to be 100%.
FOL	Fraction of Land	Portion of land dedicated to each crop type (e.g., vegetables, roots, and grains); the total of the fractions is 1.0 (or 100%).
FON	Fraction of Nutrient	Portion of fertilizer that is comprised of a specified nutrient. Used to adjust a unit RBC (RBC representing 1% FON) to represent a particular product (e.g., DAP has 46% FON for phosphate).
Hg	Mercury	Symbol for mercury.
IR	Ingestion Rate	Amount of media of interest (soil or crop) ingested per day. The IR varies between children and adults and is different for soil and for each crop.
Kd	Soil-Water Partitioning Coefficient	Used to estimate how much of an MOPC is expected to move from the soil phase to the water phase. It is the ratio of the total soil metal concentration over the dissolved metal concentration.
--	Macronutrient	Supplies primary nutrients, which include nitrogen, available phosphate, and soluble potash or potassium, and secondary nutrients, which include calcium, magnesium, and sulfur.
--	Micronutrient	Supplies plants with boron, chlorine, cobalt, copper, iron, manganese, molybdenum, sodium, and zinc.
Mo	Molybdenum	Symbol for molybdenum.

Symbol	**Term**	**Definition**
MOPC	Metal of Potential Concern	Metals present in inorganic fertilizer that are selected for this health risk evaluation.
--	Multi-Crop Scenario	Farm where more than one crop is grown. For the purposes of this evaluation, a multi-crop farm grows vegetables, roots, and grains on 40%, 10%, and 50% of the portion of the farm land, respectively.
Ni	Nickel	Symbol for nickel.
Pb	Lead	Symbol for lead.
--	Phosphate	A salt of phosphoric acid with ions such as ammonium, calcium, potassium, or sodium .
--	Phosphogypsum	The by-product of treating phosphate rock with sulfuric acid. It is referred to in Florida simply as gypsum.
PUF	Plant-Uptake Factor	Expresses the ratio of metal concentration in plant parts used for food to metal concentration in dry root-zone soil. The ratio estimates how metals in soils accumulate in plants. Also known as soil-to-plant transfer coefficient.
Ra	Radium	Symbol for radium.
--	Radiation	Energy released by the disintegration (decay) of unstable isotopes. It can be in the form of gamma rays or alpha or beta particles. The radiation referred to in this document results from the decay of natural radium226 and its radioactive decay products.
RAF	Relative Absorption Factor	Bioavailability of the MOPC in the medium of interest divided by the percent absorption used in the toxicity study. The RAF adjusts the estimated intake to an actual “dose”.
RBC	Risk Based Concentration	Concentration of a substance (e.g., MOPC) in fertilizer that is considered health protective at a given acceptable risk level (poses no significant potential for adverse effects) and a for particular exposure scenario.
R_fD	Reference Dose	Level of exposure (dosage) below which non-carcinogenic adverse health effects are unlikely. They are specific to exposure route and duration and are also referred to as “acceptable daily intake”.

Symbol	**Term**	**Definition**
RME	Reasonable Maximum Exposure	Refers to the lower portion of the plausible upper limit of the true value of the exposure distribution; an exposure level not likely to be lower than the true exposure. A health protective estimate of exposure.
SA	Exposed Skin Surface Area	The area of skin that is available for dermal contact with soil/fertilizer.
SACF	Soil Accumulation Factor	Rate of accumulation of an MOPC in soil (g/m^2-yr). When combined with a fertilizer land application rate and a MOPC concentration in a fertilizer product, yields a MOPC concentration in soil.
Se	Selenium	Symbol for selenium.
--	Single Crop Farm	Farm where only one of the three crop groups are grown (i.e., vegetable, root, or grain).
SF	Cancer Slope Factor	The 95th percent upper confidence limit of the slope representative of the cancer potency of the compound.
SIF	Summary Intake Factor	Combines biological exposure parameters and absorption factors to estimate daily intake from incidental soil ingestion, dermal contact, and crop ingestion.
THI	Target Hazard Index	Acceptable noncancer exposure level.
TR	Target Risk	Acceptable individual cancer risk of 1 in 100,000 ($1x10^{-5}$).
--	Unintentional Ingestion	Unintentional ingestion resulting typically from hand-to-mouth or from dust transfer.
Zn	Zinc	Symbol for zinc.

APPENDIX A

DEVELOPMENT OF RELATIVE ABSORPTION FACTOR (RAF) AND PERCENT DERMAL ABSORPTION (ABS)

RELATIVE ABSORPTION FACTOR (RAF)

Relative absorption factor (RAF) is intended to ensure that the toxicity value and estimated intake are based on comparable estimates of intake (both based on an absorbed or administered dose, and the same or similar medium). In addition, RAF ensures that toxicity and intake are not overestimated. RAF depends on (1) whether the toxicity value is an “administered” or an actual absorbed dose and (2) the absorption from both the medium of the toxicity study and the medium of interest (i.e., soil or crop). RAF is the percent of the MOPC that is absorbed from the medium of interest [following ingestion, and absorption through the gastrointestinal tract (GI)] divided by the percent GI absorption reported in the oral toxicity study. The information that is used to determine (1) the need to develop a RAF and (2) if sufficient information is available to develop a RAF for each MOPC is presented in Table A-1. As discussed in the report, RAFs are developed and incorporated into the RBC only for arsenic and lead (as discussed below). RAFs for all the other MOPC and exposure routes are assumed to be 100% (1).

As can be seen in Table A-1, all of the oral toxicity values, that are based on an administered dose, are derived from studies were the exposure media is diet, food, or supplements. For most MOPC, sufficient gastrointestinal absorption (GI ABS) data was not found for the medium of exposure of the toxicity study, or for soil and crops, therefore, a RAF for these MOPC could not be developed.

The oral toxicity value for arsenic is based on an administered dose from exposure to arsenic in drinking water. An applicable and acceptable study on the bioavailability of arsenic was found. This study determined a bioavailabilty of arsenic in soil of 42% (Rodriquez et al. 1999). The percent absorption of arsenic in drinking water is 95% (USEPA 1999). Therefore, a RAF for arsenic in soil of 44% (42% divided by 95%) is incorporated into the RBC.

As can be seen from Table A-1, cadmium, lead, and selenium toxicity values are based on absorbed dose (i.e., absorption in the toxicity study is 100%). Considering the medium of the toxicity study, RAFs could be developed for these MOPC. At a minimum, the intake could be adjusted to an absorbed dose.

Cadmium absorption following ingestion of cadmium in food is 0.02 or 2% (USEPA 1999). Since the toxicity study value is based on an absorbed dose, the absorption of cadmium ingested food could be incorporated into the RBC. However, this absorption value was not used in the RBC, because of the large degree of variability of cadmium absorption (as discussed in the uncertainty section).

Lead absorption from ingestion of soil and crops is 0.41 and 0.50, respectively (USDHHS 1997b). These values are used in estimating intake (RAF 0f 0.41 for unintentional ingestion of soil and 0.50 for ingestion of crops) for lead.

Sufficient information was not found for selenium.

DERMAL ABSORPTION FACTOR (ABS)

The percent dermal absorption (ABS) parameter estimates the amount of MOPC that is absorbed across the skin following dermal contact. All of the ABS are USEPA defaults (USEPA 1998).

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TABLES

TABLE A-1
DEVELOPMENT OF ABSORBED DOSE ADJUSTMENTS: (RELATIVE ABSORPTION FACTORS (RAFs) AND PERCENT DERMAL ABSORPTION (ABS)) FOR EACH METAL OF POTENTIAL CONCERN (MOPC)

	Toxicity Value as an Administered or Absorbed Dose (a)	Actual Absorption or Possible Absorption from Toxicity Study Medium			Potential Percent Gastrointestinal Absorption (GI ABS) from the Media of Interest				RAF (b)		Dermal Absorption (c)
MOPC		Medium	Percent	Reference	Soil	Reference	Crop	Reference	Soil	Crop	Percent
Arsenic	Administered	DW	95	USDHHS 1998	42	Rodriguez et al., 1999	--	--	0.44	--	0.03
Cadmium	Absorbed	Food	2.5	IRIS	low (d)	USDHHS 1997a	2.5	as food, IRIS	--	0.025	0.01
Chromium	Administered	Diet	2	USDHHS 1993	--	--	2	USDHHS 1993	--	--	0.01
Cobalt	--	--	--	--	--	--	--	--	--	--	0.01
Copper	--	--	--	--	--	--	--	--	--	--	0.01
Lead	Absorbed (e)	several	--	--	41 (f)	USDHHS 1997b	50 (f)	USDHHS 1997b (g)	--	--	--
Mercury	Absorbed	DW (h)	7	IRIS	low (i)	USDHHS 1997c	low (j)	USDHHS 1997c	--	--	0.01
Molybdenum	Administered	Diet	--	--	--	--	--	--	--	--	0.01
Nickel	Administered	Diet	0.7+/- 0.4	IRIS	--	--	0.7+/- 0.4	IRIS	--	--	0.01
Selenium	Absorbed	Diet	97	USDHHS 1994a	--	--	--	USDHHS 1994a	--	--	0.01
Vanadium	--	--	--	--	--	--	--	--	--	--	0.01
Zinc	Administered	Supplements	81	USDHHS 1994b	--	--	81	USDHHS 1994b	--	--	0.01

Notes:

-- = Not Available or Not Applicable
DW = Drinking Water
IRIS = Integrated Risk Information System (USEPA 1999)
USEPA = United States Environmental Protection Agency
(a) Determined only when toxicity value is from IRIS. Otherwise, specific information on the toxicity was not readily available and not evaluated.
(b) RAF is the absorption from the media of interest divided by the absorption from the medium in the toxicity study.
(c) Obtained from USEPA (1998).
(d) Qualitative estimate of percent absorption (or bioavailability).
(e) Toxicity of lead is based on an acceptable blood lead level, which is an absorbed level.
(f) Used to adjust intake.
(g) High-end absorption estimate, based on children, adults are expected to have lower gastrointestinal absorption.
(h) Back calculated intake from a drinking water level, which is based on a subcutaneous dose.
(i) Bioavailability of mercury in soil and crops is expected to be low, but, no quantitative estimates of absorption were found.

APPENDIX B

APPLICATION RATE DATABASE COMPILED FROM USEPA (1999) AND CALCULATION OF APPLICATION RATES FOR PHOSPHATE AND ZINC FERTILIZERS

The data sets used to calculate the application rates (ARs) for phosphate and zinc fertilizers, for each crop group, are presented in Tables B.1 – B.3. All of this data was compiled from USEPA (1999). All available data for appropriate and applicable crops were included. In addition, data reported from all states were included. The statistic that is used to calculate the risk based concentration (RBC) is the 95th upper confidence limit (UCL) of the mean (assuming a normal distribution).

Reference

United States Environmental Protection Agency (USEPA). 1999. Background Report on Fertilizer Use, Contaminants and Regulations. Columbus, OH: Battelle Memorial Institute.

TABLES

TABLE B-1
DATA SET COMPILED FOR PHOSPHATE FERTILIZER APPLICATION RATE (AR) AND CALCULATION OF THE 95% UPPER CONFIDENCE LIMIT (UCL) OF THE MEAN: VEGETABLE CROP

Crop	State	Application Rate (lb/acre-year)
Beans, snap (fresh)	CA	100
	FL	99
	GA	66
	MI	64
	NJ	68
	NY	47
	NC	69
Beans, snap (processing)	CA	96
	IL	52
	MI	40
	NJ	40
	NY	75
	NC	100
	OR	130
	WA	49
	WI	48
Broccoli	AZ	200
	CA	88
	OR	160
	TX	88
Cabbage (fresh)	CA	97
	FL	94
	GA	120
	MI	100
	NJ	120
	NY	110
	NC	150
	TX	86
	WI	110
Cabbage (processing)	NY	96
	WI	93
Cauliflower	AZ	240
	CA	85
	MI	92
	NY	100
	OR	130
	TX	96
Celery	CA	230
	FL	160
	MI	130
	TX	NA
Cucumbers (fresh)	CA	61
	FL	140
	GA	89
	MI	69
	NJ	84
	NY	93
	NC	91
	TX	47
Cucumbers (processing)	CA	56
	FL	40
	GA	55
	MI	48
	NC	47
	OR	120
	TX	100
	WA	150
	WI	54

TABLE B-1 (CONTINUED)

Crop	State	Application Rate (lb/acre-year)
Eggplant	FL	120
	NJ	140
Lettuce, head	AZ	250
	CA	150
	FL	NA
	NJ	99
	NY	84
Lettuce, other	AZ	240
	CA	110
	FL	34
Peppers (bell)	CA	410
	FL	140
	MI	73
	NJ	150
	NC	69
	TX	120
Spinach (fresh)	CA	92
	NJ	90
	TX	110
Spinach (processing)	TX	97
Tomatoes (fresh)	CA	120
	FL	200
	GA	110
	MI	64
	NJ	120
	NY	170
	NC	120
	TX	78
Tomatoes (processing)	CA	100
	MI	110
	Number	86
	Maximum	410
	Average	110
	Standard Deviation	57
	95% Confidence	12
	95 UCL	**120**
	95th Percentile	220

Notes:

NA = Not Applicable

TABLE B-2
DATA SET COMPILED FOR PHOSPHATE FERTILIZERS APPLICATION RATE (AR) AND CALCULATION OF THE 95% UPPER CONFIDENCE LIMIT (UCL) OF THE MEAN: ROOT CROP

Crop	**State**	**Application Rate (lb/acre-year)**
Carrots	AZ	NA
	CA	200
	FL	31
	MI	97
	NY	95
	OR	120
	TX	55
	WA	130
	WI	150
Fall potatoes	ID	200
	ME	170
	WA	200
	RR (ND)	78
Onions (dry)	AZ	190
	CA	160
	GA	220
	MI	150
	NY	130
	OR	150
	TX	73
	WA	140
	WI	110
	Number	21
	Maximum	220
	Average	140
	Standard Deviation	52
	95% Confidence	22
	95 UCL	**160**
	95th Percentile	200

Notes:

NA = Not Applicable

TABLE B-3

DATA SET COMPILED FOR PHOSPHATE FERTILIZER APPLICATION RATE (AR) AND CALCULATION OF THE 95% UPPER CONFIDENCE LIMIT (UCL) OF THE MEAN: GRAIN CROP

Crop	**State**	**Application Rate (lb/acre-year)**
Winter wheat	CO	21
	ID	53
	KS	28
	MT	30
	NE	32
	OK	32
	OR	30
	SD	28
	TX	44
	WA	20
Durum wheat	ND	23
Other spring wheat	MN	37
	MT	27
	ND	30
Corn (grain)	IL	85
	IN	64
	IA	60
	KS	38
	KY	78
	MI	47
	MN	53
	MO	55
	NE	34
	NC	59
	OH	87
	PA	58
	SC	57
	SD	34
	TX	37
	WI	39
Corn, Sweet (fresh)	CA	130
	FL	78
	GA	50
	IL	68
	MI	65
	NJ	100
	NY	76
	NC	68
	OR	100
	TX	83
	WA	71
	WI	40
Corn, Sweet (processing)	IL	60
	MI	47
	MN	48
	NY	68
	OR	130
	WA	68
	WI	49

Number	49
Maximum	130
Average	55
Standard Deviation	26
95% Confidence	7.2
95 UCL	**63**
95th Percentile	100

APPENDIX C

COLLECTION OF DATA AND SUMMARY STATISTICS FOR PLANT UPTAKE FACTORS (PUFs)

Plant uptake factors (PUFs) were developed with the assistance of an expert in soil chemistry, Dr. Ronald Hauck, a retired professor from University of Alabama (Hauck 1999, Hauck and Bystrom 1999). Dr. Hauck identified and selected relevant and applicable plant uptake studies and then compiled the data into a large PUF database. Dr. Hauck then organized the database into data sets by crop type for each metal of potential concern (MOPC). The following outlines (1) Dr. Hauck's procedure for identifying and selecting plant uptake studies to include in the database (2) how the database is separated into appropriate data sets and (3) the calculation of an upper end PUF estimate for each crop group.

Identification and Selection of Studies Used to Develop a Plant Uptake Factors (PUFs) Database

Figure C-1 presents how Dr. Hauck identified, evaluated, and selected studies to include in the PUF database.

Dr. Hauck performed an extensive literature search relying largely upon the Agro-law, Tennessee Valley Authority (TVA), and University of Alabama libraries. Initially, 11,700 articles (including duplicates) were identified through review articles, reference books, and bibliographic lists. Articles were eliminated if the titles did not appear to contain relevant information. Specifically, articles appearing to evaluate forage crops, nonfood crops, or food crops harvested before producing edible crops were excluded from this initial list. Approximately 1,150 citations remained for further examination as follows.

In particular, studies that evaluated the plant uptake of a waste (e.g. sludge) were considered applicable only if they met specific criteria.

1. The experiment included an untreated (control) plot with typical plant yields. Control plots with atypically low plant yields were assessed to be inadequately fertilized and, therefore, inappropriate for evaluating PUFs.
2. Sludge had been added many years ago and MOPC concentrations in soil had reached steady state.
3. Flyash was added to soil at nontoxic levels, and like sludge, was allowed to reach steady state with the surrounding soil.

In addition, studies were excluded from the PUF database if insufficient information was presented to be useful. In particular, studies that did not report total metal soil concentrations (or at least sufficient data to calculate total metal soil concentration) were excluded from the database. These studies typically report an extractable (or plant available) soil concentration. Plant available (i.e., extractable) MOPC concentration in soil does not correlate well with total MOPC soil concentration because of the different methods of extraction and is not considered a reliable value for estimating PUFs. In general, PUFs developed using extractable MOPC concentrations are lower than PUFs using total MOPC concentrations.

In addition, studies where the methods were deemed to be inappropriate or not applicable for this scenario were excluded. For example, studies where the application rates of the fertilizer were exaggerated, in comparison with practical application rates, were excluded from the database.

By using these examination criteria, the list of potentially useful studies was reduced to 178 studies and consists of data from greenhouse, lysimeter, and field studies from the U.S., Australia, Europe, and Canada. Typically, field study data are preferred because plant uptake of metals from field studies is a better representation of uptake in crops in an agricultural setting. Generally, plant uptake in a green house or pot study is greater than in a field study. Green house and potted studies were included in the database only if the information from field studies was considered limited for a particular MOPC.

The soil conditions in these studies also covers a wide range of soil chemical and physical properties, such as, soil-water partitioning coefficient (K_d), cation exchange capacity, and pH. However, the database is believed to be sufficiently large (one reason for the inclusion of some green house studies) to represent national averages. Finally, studies consisted of both unamended and unamended plus amended soils, which appeared to have similar PUFs.

For consistency purposes, all of the individual PUF data points are presented as dry weight. If the data presented in the study was presented as a wet weight, Dr. Hauck used information from the study to convert the wet weight into a dry weight.

Separation of PUF Data by Crop Group and Metal of Potential Concern (MOPC)

PUF data was separated by MOPC as well as crop group. Dr. Hauck grouped the data into data sets for leafy vegetable, head/stalk vegetable, vegetable fruit, root/tuber/bulb, legume, sweet fruit, corn, and small grains. However, to remain consistent with the crop groups identified in the exposure assessment, several crop subgroups were combined into one data set. Figure C-2 presents the grouping of PUF data into data sets for each crop group.

Upper End PUF Estimate for Each Crop Group

A statistical summary of each data set is presented in Table C-1. Generally, the data has a lognormal distribution. The underlying statistics and shape of the distribution for each of these parameters is obtained using a protocol developed in accordance with USEPA (1992) recommendations, which adhere to simple statistical procedures outlined in Gilbert (1987). The software package Statistica ® was used to perform all statistics. The 90% upper confidence limit (UCL) of the geometric mean is considered the upper end PUF estimate and is used in the calculation of the RBC. These PUFs in Table C-1 are dry weight.

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TABLES

TABLE C-1
SUMMARY STATISTICS FOR PLANT UPTAKE FACTOR (PUF) DATA SETS (a) FOR EACH CROP GROUP AND METAL OF POTENTIAL CONCERN (MOPC)

Crop Group and MOPC	Number of Data Points	Geometric Mean dw	Geometric Standard Deviation dw	Minimum Value dw	Maximum Value dw	90% Upper Confidence Limit (UCL) dw (b)
Vegetable						
Arsenic	28	0.14	11	0.00086	3	0.3
Cadmium	174	1.32	7.8	0.0012	75	1.7
Chromium (c)	95	0.001	11	0.000012	0.069	0.0014
Cobalt	11	0.028	3.3	0.0093	0.45	0.05
Copper	69	0.26	3.8	0.014	6.6	0.034
Lead	93	0.055	6.2	0.00018	6	0.08
Mercury	10	0.18	8.1	0.0071	2.3	0.61
Molybdenum	50	0.73	5.7	0.02	19	1.1
Nickel	27	0.1	3.8	0.015	0.86	0.15
Selenium	59	0.56	7.9	0.0067	120	0.88
Vanadium (d)	21	0.0048	3.2	0.0017	0.014	0.007
Zinc	135	1.3	6.8	0.067	58	1.7
Root						
Arsenic	22	0.024	6.4	0.0018	0.56	0.05
Cadmium	96	0.68	6.2	0.0046	23	0.93
Chromium (c)	6	0.00066	3.7	0.000076	0.0023	0.0014
Cobalt	12	0.016	3.2	0.0026	0.13	0.03
Copper	107	0.18	3.9	0.0095	6	0.22
Lead	142	0.039	4.3	0.00071	2.6	0.05
Mercury	14	0.23	9.6	0.003	3	0.67
Molybdenum	33	0.1	3.8	0.011	3.2	0.15
Nickel	31	0.049	3.4	0.0042	0.67	0.07
Selenium	58	0.43	13	0.0093	110	0.76
Vanadium (d)	21	0.0048	3.2	0.0017	0.014	0.007
Zinc	83	0.35	4.8	0.0093	70	0.46
Grain						
Arsenic	11	0.015	3.7	0.002	0.069	0.03
Cadmium	162	0.093	9.2	0.00013	22	0.12
Chromium	39	0.03	2.2	0.00046	0.083	0.037
Cobalt	9	0.0087	3.9	0.0013	0.093	0.02
Copper	57	0.23	3.7	0.015	16	0.31
Lead	73	0.043	3.3	0.00065	1.6	0.05
Mercury	7	0.078	5.1	0.0044	0.48	0.26
Molybdenum	13	0.14	2.5	0.025	0.48	0.22
Nickel	65	0.041	2.7	0.0017	1.4	0.05
Selenium	137	0.43	7.2	0.013	25	0.57
Vanadium (d)	21	0.0048	3.2	0.0017	0.014	0.007
Zinc	124	0.5	2.8	0.021	6.4	0.58

Notes:

dw = dry weight

(a) Each data set is generally log normally distributed. The distribution and statistics are based on a protocol developed in accordance with USEPA (1992) recommendations, which adhere to simple statistical procedures outlined in Gilbert (1987). The software package Statistica was used.

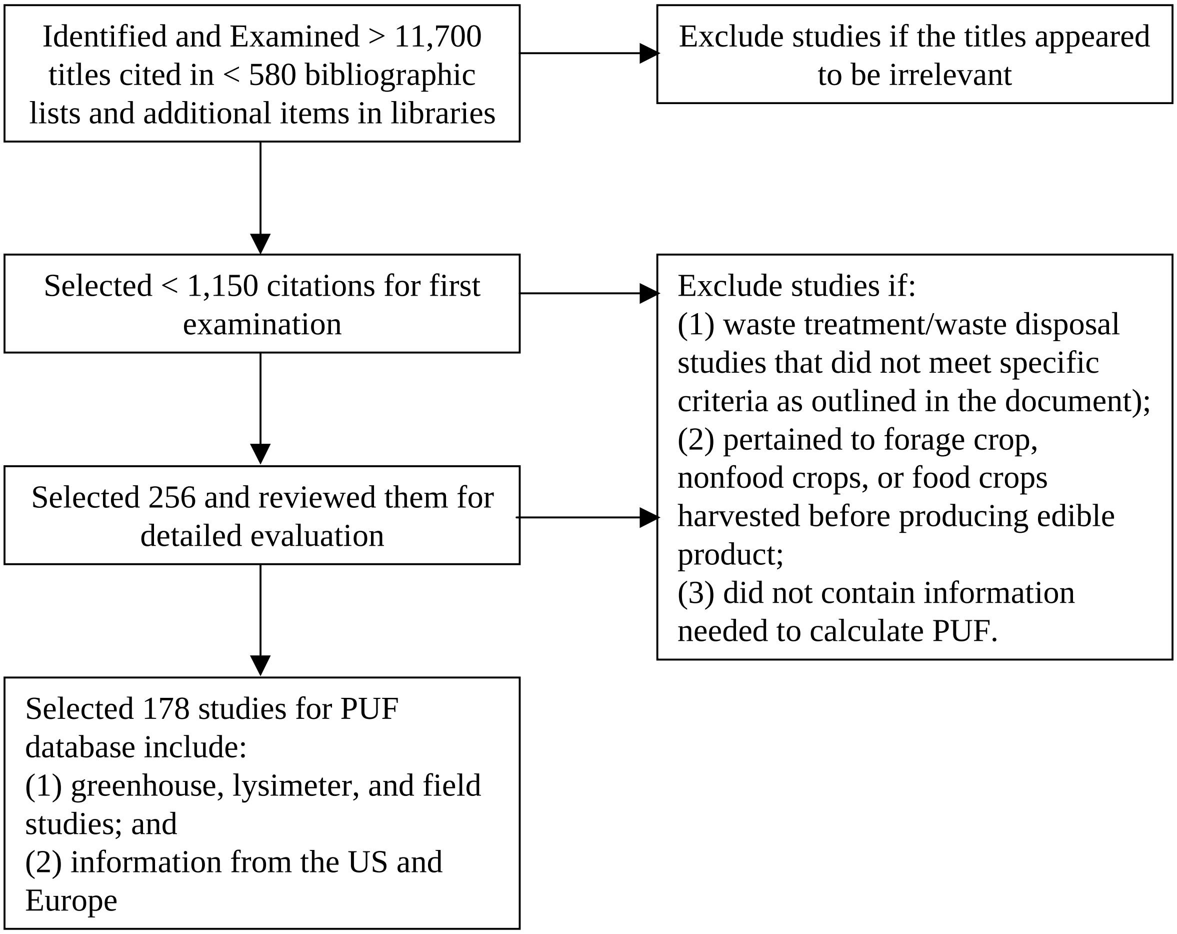
(b) The 90% upper confidence limit (UCL) of the geometric mean is considered a high end estimate of PUF.

(c) Chromium PUF data for vegetable and root are based on data from USEPA (1999).

(d) Limited applicable data are available for vanadium PUFs, therefore, data are based on forage crops from USEPA (1999).

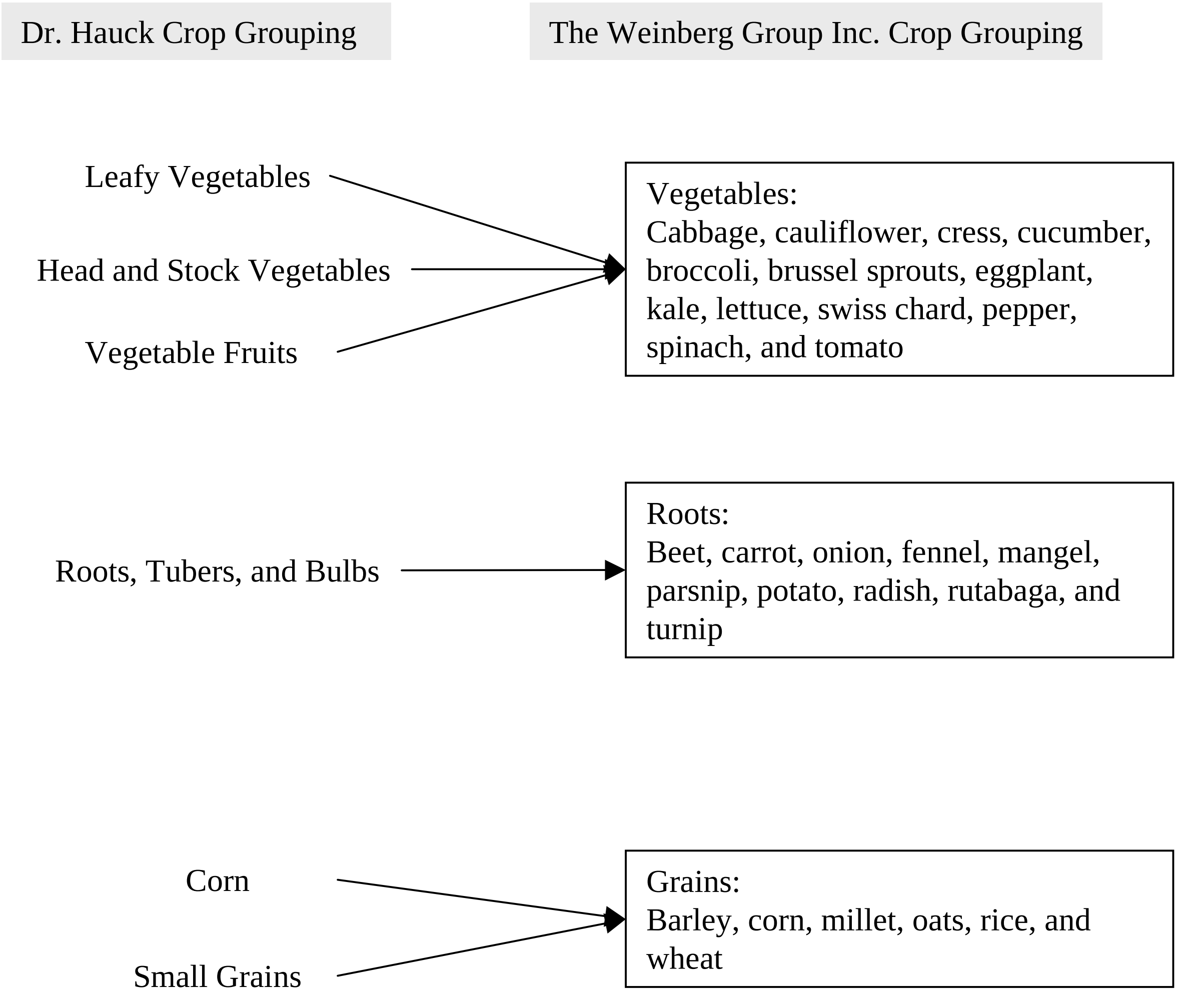
FIGURES

FIGURE C-1
PROCEDURE FOR IDENTIFYING AND SELECTING STUDIES FOR THE DEVELOPMENT OF PLANT UPTAKE FACTORS (PUFs)



Note: All data used to calculate the PUFs are in dry weight (converted to dry weight if study reports wet weight).

FIGURE C-2
REGROUPING OF CROPS TO CALCULATE PLANT UPTAKE FACTORS (PUFs)



Vegetables:
Cabbage, cauliflower, cress, cucumber, broccoli, brussel sprouts, eggplant, kale, lettuce, swiss chard, pepper, spinach, and tomato

Roots:
Beet, carrot, onion, fennel, mangel, parsnip, potato, radish, rutabaga, and turnip

Grains:
Barley, corn, millet, oats, rice, and wheat

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