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Biota Modeling in EPA's Preliminary Remediation Goal and Dose Compliance Concentration Calculators for Use in EPA Superfund Risk Assessment: Explanation of Intake Rate Derivation, Transfer Factor Compilation, and Mass Loading Factor Sources: 2021 Revision

Draft.

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June 2021

OAK RIDGE NATIONAL LABORATORY
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Environmental Sciences Division
Center for Radiation Protection Knowledge

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ERRATA

Summary of changes:

Page	Section	Description
Whole	Multiple	Any reference to 24 individual produce items has been updated to 25 to account for the addition of Peppers.
4	3.3 Soil to Plant Transfer Factory Derivation for Carbon	Section 3.3 was added to describe the specific derivation of the carbon soil to plant transfer factor that was implemented in the 2016 biota update for the PRG and DCC calculators.
6	5. Produce Contaminant Concentrations	Section 5 about plant contamination was added.
9	7. References	References for the updated Exposure Factors Handbook chapters that were used for this update have been added.
A-2	Appendix A, Figure A-1	Screenshot of Table 9-5 from the 2011 Exposure Factors Handbook was updated to Table 9-5 from the 2018 Exposure Factors Handbook Chapter 9 update.
A-5	Appendix A, Equation A-1	Equation was updated to use the new intake rates from Chapter 9 update of the Exposure Factors Handbook.
A-6	Appendix A, Equation A-2	Equation was updated to use Table 9-5 new age bins from the Chapter 9 update of the Exposure Factors Handbook and the consumer only intake rates that were calculated thereof.
A-7	Appendix A, Equation A-3	Equation was updated to use Table 9-5 new age bins from the Chapter 9 update of the Exposure Factors Handbook and the consumer only intake rates that were calculated thereof.
A-7	Appendix A, Equation A-4	Equation was updated to reflect the new intake rates calculated based on the use of Table 9-5 from the Chapter 9 update of the Exposure Factors Handbook.
A-7	Appendix A, Equation A-5	Equation was updated to reflect the new intake rates calculated based on the use of Table 9-5 from the Chapter 9 update of the Exposure Factors Handbook.
A-8	Appendix A, Equation A-6	Equation was updated to reflect the new intake rates calculated based on the use of Table 9-5 from the Chapter 9 update of the Exposure Factors Handbook.
A-8	Appendix A, Equation A-7	Equation was updated to reflect the new intake rates calculated based on the use of Table 9-5 from the Chapter 9 update of the Exposure Factors Handbook.
A-9	Appendix A, Equation A-8	Equation was updated to reflect the new intake rates calculated based on the use of Table 9-5 from the Chapter 9 update of the Exposure Factors Handbook.
A-9	Appendix A, Equation A-9	Equation was updated to reflect the new intake rates calculated based on the use of Table 9-5 from the Chapter 9 update of the Exposure Factors Handbook.
A-9	Appendix A, Proposed Intake Rates	Text was updated to reflect the new age bins used for adults in the sensitivity analysis, provided in Appendix D, and the corresponding results.

A-10	Appendix A, Table A-1	Values in table have been updated to reflect new intake rates derived from the Chapters 9 and 11 updates of the Exposure Factors Handbook. Fish intake rates have been split into fin fish and shellfish.
A-11	Appendix A, Table A-2	Values in table have been updated to reflect new intake rates derived from the Chapter11 update of the Exposure Factors Handbook
B-5	Appendix B, Table B-1	Peppers and their respective transfer factors have been added.
B-7	Appendix B, Table B-1	Shellfish and their respective transfer factors have been added. Transfer factors from EA were also added to the Fin fish hierarchy.
B-10	Appendix B, Figure B-1	Figure was updated to include peppers and redesignate onions as root vegetables. The IAEA TRS-472 guidance lists onions as both root vegetables and non-leafy vegetables. The environment agency (EA), however, only lists onions as root vegetables. When the ORNL/TM-2016/328-R1 was originally released, onion was listed as a non-leafy vegetable. For consistency with EA and due to root vegetable BVs being generally more protective, the onion BV designation was updated from non-leafy vegetable to root vegetable.
B-11	Appendix B, Figure B-2	Figure was updated to include Shellfish. Transfer factors from EA were also added to the Fin fish hierarchy.
C-3	Appendix C, Table C-1	A row for peppers has been added.
D-2	Appendix D	Text has been updated to reflect the results of the new sensitivity analysis that was done based on updates for Chapters 9 and 11 of the Exposure Factors Handbook.
D-3	Appendix D, Table D-1	A row for peppers has been added, fish was split into fin fish and shellfish, and new intake rates derived from the Chapters 9 and 11 updates of the Exposure Factors Handbook were added.
D-4	Appendix D, Table D-2	A row for peppers has been added, fish was split into fin fish and shellfish, and new adult age bins and intake rates derived from the Chapters 9 and 11 updates of the Exposure Factors Handbook were added.
D-5	Appendix D, Table D-3	Text and table have been updated to reflect the results of the new sensitivity analysis.
E-3	Appendix E, Table E-1	A row for peppers has been added. Tomato produce category has been corrected from protected to exposed.
G-1	Appendix G	Appendix G about plant contamination from non-irrigation scenarios was added.
H-1	Appendix H	Appendix H about plant contamination from irrigation scenarios was added.

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ACRONYMS, INITIALISMS, AND ABBREVIATIONS

BV	Soil to plant transfer factor
BW	Body Weight
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	Contaminated Fraction
CPW	Cooking/Preparation Loss
CR	Consumption Rate
DCC	Dose Compliance Concentration
DOE	U.S. Department of Energy
EA	Environment Agency of the U.K.
EFH	Exposure Factors Handbook
EPA	U.S. Environmental Protection Agency
HHRAP	Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities
IAEA	International Atomic Energy Agency
IAG	Interagency Agreement
IR	Intake Rate
MLF	Mass Loading Factor
NCRP	National Council on Radiation Protection and Measurements
NPL	National Priorities List
ORNL	Oak Ridge National Laboratory
OSWER	Office of Solid Waste and Emergency Response
P&M	Pinder and McLeod
PRG	Preliminary Remediation Goal
Qp	fodder intake by farm animals
Qs	soil intake by farm animals
Qw	water intake by farm animals
RADSSL	Radionuclide Soil Screening Levels
RCRA	Resource Conservation and Recovery Act
SL	Soil Loading

SSG	Soil Screening Guidance
TF	Transfer Factor
TRS	Technical Report Series
TWA	Time Weighted Average

ABSTRACT

The Preliminary Remediation Goal (PRG) and Dose Compliance Concentration (DCC) calculators are screening level risk assessment tools that set forth the Environmental Protection Agency's (EPA) recommended approaches and currently available risk assessment guidance for response actions at Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) sites, commonly known as Superfund. The environmental screening levels derived by the PRG and DCC calculators are used to identify isotopes contributing the highest risk and dose as well as establish preliminary remediation goals. Each calculator has residential gardening and subsistence farmer exposure scenarios that model transfer of contaminants from soil and water into various types of biota (crops and animal products). New publications of human intake rates of biota; farm animal intakes of water, soil, and fodder; and soil to plant interactions require updates be implemented into the PRG and DCC calculators. Recent improvements in the biota modeling for these calculators include newly derived biota intake rates, enhanced soil mass loading factors (MLFs), and more comprehensive soil to plant transfer factors (BV's) and soil to tissue transfer factors (TFs) for animals. New biota have been added in both the produce and animal products categories that greatly improve the accuracy and utility of the PRG and DCC calculators and encompass greater geographic diversity on a national and international scale.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

There is a need for advancement in risk assessment modeling regarding the consumption of produce and animal products that are cultivated on contaminated land and/or land irrigated with contaminated water. The EPA, in conjunction with Oak Ridge National Laboratory (ORNL), have developed a hierarchal selection process of biota modeling in the PRG and DCC calculators to address this need. The PRG and DCC calculators are a product of ORNL via an IAG with OSRTI. These risk assessment web tools are free to the public and set forth EPA's recommended approaches for response actions at CERCLA sites (commonly known as Superfund), and the screening level equations are based upon currently available guidance and information with respect to risk assessment. ORNL provides these web tools to perform risk assessments on DOE sites that are on the CERCLA National Priorities List (NPL) in addition to many other sites for private and governmental organizations. The NPL is EPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial action under Superfund (RAIS, 2016).

The recent improvements in biota modeling parameters for EPA's PRG and DCC calculators are presented in this technical memorandum (TM). Each of these calculators (online tools) provides fact sheets in the welcome section of their respective homepages that describe the purpose of these tools in more detail. To provide the users of these tools the most accurate risk assessment possible, an update to biota modeling parameters was necessary to follow recent guidance from the International Atomic Energy Agency (IAEA) and the U.S. EPA 2011 Exposure Factors Handbook (EFH). The updates in biota modeling include newly derived human consumption rates and more comprehensive and diverse BVs, TFs, and MLFs. These updates will greatly improve the accuracy and utility of the PRG and DCC calculators and encompass greater geographic diversity on a national and international scale.

Formerly, the BVs used in these risk assessment tools were applied generically to all produce types. Now, the BVs are element-specific, biota-specific, climate zone-specific, and soil type-specific, where applicable. These new BVs and TFs include contributions from the recent IAEA TRS-472 and TRS-479 as well as Science Report: SC030162/SR2 from the Environment Agency (EA) of the U.K. and were used to supersede most of the older generic values from the National Council on Radiation Protection and Measurements (NCRP), Radionuclide Soil Screening Levels (RADSSL), RESidual RADioactive (RESRAD), and *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture* (Baes et. al., 1984). MLFs were also improved from a single MLF, that was applied to all produce, to now include individual MLFs that correspond with the individual produce items of each new produce. Previously, produce intake rates were based on generic fruit and generic vegetables. The new produce intake rates are based on 25 individual produce items, found in the 2011 EFH, that contribute to the overall produce ingestion PRG and DCC calculations. New animal products have also been added to the site-specific modes of these calculators. Finally, the intake rates for produce and animal products can be implemented in screening level calculations as raw weight or weight after cooking/preparation loss. Prior to these updates, raw weight was the only option.

2. INTAKE RATE DERIVATION

2.1 METHOD OF DERIVATION

The updated intake rates were derived following the Office of Solid Waste and Emergency Response's (OSWER) method outlined in the 2005 Human Health Risk Assessment Protocol (HHRAP) for Hazardous Waste Combustion Facilities. HHRAP provides guidance for regional and state Resource Conservation and Recovery Act (RCRA) waste programs (HHRAP, 2005). HHRAP uses consumer only intake rates, from chapter 13 of the 2011 EFH and the intake rate derivation method found on pages 6-12 through 6-13 of HHRAP, to determine consumption rates of homegrown produce for Farmer Child, Farmer Adult, Resident Child, Resident Adult, Fisher Child, and Fisher Adult scenarios. RCRAs consumption rates are shown in table C-1-2 of the HHRAP. Consumer only intake rates are the amount of homegrown produce consumed from a singular site. In the case of a contaminated site, it is conservatively assumed that 100% of produce grown on-site is contaminated, yielding a contaminated fraction (CF) of 1. Per capita intake rates are based on the average consumer intakes and, therefore, the contaminated fraction of food consumed is less than 1 because only a portion of the produce consumed may come from a contaminated site. Further, per capita data from EFH chapter 9 (Figure A-1, Appendix A) was used to fill in data gaps in the consumer only intake rate tables from EFH chapter 13 (Figure A-2, Appendix A). An example derivation is shown in Equations A-1 through A-9 in Appendix A, using the method found on page 6-12 of HHRAP. Although the HHRAP uses the term consumption rate; this document uses the term intake rate instead of consumption rate for consistency with the PRG and DCC calculators. Both consumption rate and intake rate refer to the amount of food consumed.

2.2 DIFFERENCES IN INTAKE RATE DERIVATION (PRG & DCC VS. HHRAP)

HHRAP provides three produce categories: Exposed Aboveground Produce, Protected Aboveground Produce, and Belowground Produce. These are combined from the 5 produce categories provided in EFH 1997, which include exposed fruit, protected fruit, exposed vegetables, protected vegetables, and root vegetables. The HHRAP method was used to simplify the default biota intake equations in the PRG and DCC calculators by using a CF of 1 (100%), assuming all 'consumer only' produce is harvested from contaminated land on-site. In site-specific mode of the PRG and DCC tools, users are given the option to change the CF along with child and adult intake rates. There were some key alterations made to the HHRAP process of deriving intake rates for use in the PRG and DCC calculators, including:

1. Both Fisher Child and Fisher Adult were excluded from the intake rate derivation, since subsistence fisher produce ingestion is the same as resident produce ingestion in the PRG and DCC calculators.
2. The default intake rates are based on raw biota, which does not include cooking and preparation loss. In site-specific mode of the PRG and DCC calculators, the user can select fresh weight or cooked weight. This will change the intake rates populated in the tool between raw intake rates and intake rates that include preparation and cooking loss. All of these proposed intake rates can be found in Table A-1 in Appendix A. Table A-2 in Appendix A lists biota that will only be available in site-specific mode of the PRG and DCC calculators.

3. The intake rates derived for the PRG and DCC calculators are given in g/day instead of kg/kg-day. A body weight conversion factor of 15kg for children and 80 kg for adults were used, as per the OSWER directive 9200.1-120. See Appendix D for more information on why these body weights were chosen.
4. In the HHRAP, the age segment used to calculate intake rates for adults was 6-70 years and for children was 1-6 years. To calculate new intake rates, a more protective age segment of 21-70 years for adults was used, as per OSWER directive 9200.1-120. For children, the age segment 0-6 was used for consistency with other land use exposure equations from the PRG, DCC, and Regional Screening Level (RSL) calculators, as well as OSWER directive 9200.1-120. See Appendix D for more information on why these age segments were chosen.
5. Per capita intake rates from chapter 9, 10, and 11 of EFH 2011 and EFH 1997 and consumer only intake rates from chapter 13 of EFH 2011 and EFH 1997 as well as page 6-12 of the HHRAP were used to derive individual biota intake rates, such as apples and potatoes. Although HHRAP follows that same derivation method, the HHRAP biota categories are more general (i.e., exposed, protected, and root).

3. TRANSFER FACTOR SOURCE COMPILATION

3.1 USE OF TRANSFER FACTORS IN THE PRG AND DCC CALCULATORS

TFs are used in the PRG and DCC calculators. The TFs used for animals are called transfer coefficients. The transfer coefficient has been widely adopted for quantifying radionuclide transfer to both milk (Fm, d L^{-1} or d kg^{-1}) and meat (Ff, d kg^{-1}) as the equilibrium ratio of the radionuclide activity concentration in milk/meat to the daily dietary radionuclide intake (IAEA, TRS-472, 2010). For animal product modeling, it is also necessary to address grazing habits by finding Qw (quantity of water), Qs (quantity of soil), and Qp (quantity of fodder) intake rates by farm animals. The intake rates by farm animals used in the PRG and DCC tools can be found in Table F-1 in Appendix F. Soil to plant TFs, called BVs, are used to determine the quantity of a radionuclide that is transferred to a plant. These TFs and BVs are used in the PRG and DCC to model radionuclide transfer to animal products and produce, respectively, before human consumption.

3.2 TRANSFER FACTOR HIERARCHY

Table B-1 in Appendix B of this document outlines the TF and BV sources and hierarchy for each individual produce and farm animal product that is available in the PRG and DCC calculators. The source hierarchy is as follows:

1. IAEA
2. EA
3. NCRP-123
4. RADSSL
5. RESRAD
6. Baes paper

Previously, the DCC and PRG calculators only modeled generic overall produce consumption for fruits and vegetables because BVs were only available for generic plants. Currently, IAEA presents BVs for specific plant parts (i.e., fruit, seeds, etc.). It is for this reason that the PRG and DCC calculators can now model transfer to specific produce. When a potato is selected for produce output, for instance, the BV category that is used from IAEA is specifically for the edible tuber portion of the plant. IAEA TRS-472 has also divided BVs into climate zones and soil types, which has been implemented into the PRG and DCC calculators as well. The available climate zones include temperate, tropical, and subtropical. The available soil types include all (default), sand, loam, clay, organic, coral sand, and other. So, the BV used for a tuber plant in a temperate climate zone with sandy soil may differ from a BV used for a tuber plant in temperate climate zone with loamy soil or tropical climate zone with sandy soil, etc.

If there is not a BV available from IAEA that fits into the particular climate zone and soil type parameters that a user has chosen, then the hierarchy will move to EA. EA does not break down their BVs in as much detail as IAEA; however, they do offer more detail than the rest of the hierarchy. EA divides BVs into 3 different plant types, including fruit, green vegetables, and root vegetables. Therefore, if produce output is selected for a potato grown in a tropical climate with loamy soil and there is no BV available from IAEA, then the BV selected from EA would overlook the climate zone and soil type selected and look in EA for a BV for a root vegetable for whichever radionuclide was chosen.

If a BV is not available in either IAEA or EA for the chosen inputs, then the hierarchy continues to NCRP-123, RADSSL, and RESRAD, respectively. These sources only provide BVs based on the radionuclide selected. They do not take produce type, climate type, or soil type into account.

Finally, the soil to plant transfer factors that come from the Baes paper are divided into two categories, B_v and B_r. According to Baes, B_v values are used for vegetative growth (leaves and stems) and B_r values are used for non-vegetative growth (fruits, seeds, and tubers). Figure E-1 from Appendix E lists how the B_v and B_r values should be applied, and Table E-1 from Appendix E outlines how BVs from Baes are applied in the PRG and DCC tools.

TFs are applied using the same hierarchy as BVs; however, climate zone and soil type are not taken into consideration for TFs. New TFs have been introduced for animal products in IAEA that have not previously been incorporated in the PRG and DCC calculators. These include sheep meat, sheep milk, goat meat, and goat milk.

3.3 CARBON AND HYDROGEN SOIL TO PLANT TRANSFER FACTORS

3.3.1 CARBON

Carbon in plants primarily comes from the process of photosynthesis. Carbon can also volatilize into the sub-canopy from soil. Depending on atmospheric conditions, plants may absorb some of this volatilized carbon from atmospheric deposition.

It is typically estimated 2% of plant carbon comes from soil (either directly or by uptake from the sub-canopy atmosphere). The other 98% of plant carbon comes from the above-canopy atmosphere, which is assumed not to contain carbon from the contaminated site.

When evaluating soil to plant transfer factors for carbon, it is important to consider that most transfer factor sources include atmospheric deposition and soil uptake. The model used by the PRG and DCC calculators is specifically for modeling root uptake. It is for this reason that the BV for carbon was derived as follows. The initial BV value of 5.5 that the PRG and DCC use is from RESRAD. It is for all plants and assumes that all carbon in the plant is from root uptake. This value is derived from data in Ng et al 1968; where the carbon composition in terrestrial plants, 1.10E+05 ppm, from Table 10A is divided by the carbon composition in typical agricultural soil, 2.00E+04 ppm, from Table 4.

Consider that a plant is about 90% water and of the 10% dry matter about 40% is carbon. Therefore, plants comprise about 4% carbon on a fresh weight basis. A mineral soil is typically about 2% to 5% organic matter, which corresponds to 0.8% to 2% carbon on a dry mass basis. Thus, taking the ratio of carbon contents results in a transfer factor of 4%/(0.8% to 2%) = 5.0 to 2.0 g fresh plant/g dry soil. The next step is to apply the 2% fraction of plant carbon derived from soil. The resulting range of transfer factors is 0.1 to 0.04; (2%*(5.0 to 2.0)). The value of 0.1 is chosen for the calculation of PRGs and is used for all the BV_{wet} values. BV_{dry} values are derived for each plant type based on individual plant moisture content. For comparison purposes, the 5.5 value from RESRAD gives a transfer factor of 0.11 if the 2% fraction of plant carbon derived from soil assumption is made. The derivation of this default transfer factor came from personal email communication with a carbon expert which is presented in Appendix I of this document.

The above derivation assumes that all soil to plant carbon uptake is radioactive. In situations where radioactive carbon is mixing with stable carbon (C-12), a site-specific transfer factor can be derived using a model called, "specific activity". Essentially, specific activity is the concentration ratio of the radioactive form to the stable form of carbon. Specific activity assumes, that within a compartment (i.e., soil), the radioactive contaminant mixes with the stable form both chemically and physically. Plant's uptake the carbon element in the same ratio as it exists in the soil compartment, resulting in the same ratio in the plant as in the soil compartment.

To determine a site-specific soil to plant transfer factor, actual site data must be available. Further, the flux rate of the element must be in a steady-state condition. The environmental compartments must be well defined and the fluxes between compartments well understood. For further information, refer to the following: AMEC/004041/007 section 5, ANL/EAD-4 Appendix L, and IAEA TECDOC 1616 page 550.

3.3.2 HYDROGEN

Coming Soon

4. MASS LOADING FACTOR SOURCE COMPILATION

4.1 MASS LOADING FACTOR HIERARCHY

Another aspect that has been added to the PRG and DCC calculators is plant-specific soil mass loading factors. Previously, a MLF of 0.26 was provided for generic fruits and vegetables and a MLF of 0.25 was provided for pasture. Listed in Table C-1 of Appendix C are the proposed MLFs to be implemented for each individual produce in the PRG and DCC tools. The MLF hierarchy is as follows:

1. Hinton
2. EA
3. Pinder and McLeod

The MLFs that Hinton provide are in units of mg soil/g dry plant. In order to get these MLFs in the units required for the PRG and DCC tools, they were converted to g soil/g dry plant. Then, a moisture content conversion factor from Table G-1 of the soil screening guidance (SSG) was used to convert the MLF to g soil/g fresh plant. To provide the best accuracy possible, there were a few surrogate Hinton values used for other produce, provided they were in a similar family. Bush beans were a surrogate for lima beans and snap beans. If a produce-specific moisture content conversion factor was not available in Table G-1, either a known conversion factor was used from another source or the average for a corresponding group of vegetables or fruits was used.

The document "Updated Background to the CLEA Model", SC050021/SR3, is the second MLF source. Similar to Hinton, the MLFs were provided in g dry soil/g dry plant. These are labeled as SL in Table 6.3 of EA Document SC050021/SR3. To convert these MLFs to g dry soil / g fresh plant, conversion factors were used from Table 7.1 of EA Document SC050021/SR3. If the individual produce was not listed, the average moisture content conversion factor was used from the respective produce category.

Pinder and McLeod was only used for corn, as an MLF for corn was not found in any of the previous sources.

The pasture MLF of 0.25 was derived based on Hinton. In the Hinton document, the pasture MLF ranges from <1 mg soil/g dry plant to 500 mg soil/g dry plant. Given the large range, the median was taken and converted into units of g soil/g dry plant, or 250/1000 = 0.25. This MLF is applied to pasture, rice, and cereal grain.

5. PRODUCE CONTAMINANT CONCENTRATIONS

To estimate contaminant concentrations in produce, a complete food chain analysis for contaminants moving from soil to plants to humans is necessary. Plants are primarily exposed to contaminants by root uptake from soil, atmospheric deposition onto plant surfaces, resuspension of contaminants in soil deposited on plant surface, and irrigation with contaminated water. Resuspension mechanisms include wind blowing contaminants in the air, water splashing from rain or irrigation, and mechanical activities disturbing soil. When possible, samples of plants or

plant products should be used to estimate exposure concentrations for risk assessment. In the absence of measured plant concentrations, however, exposure models are appropriate for estimating these concentrations for risk assessment.

The models presented in Appendices G and H are applicable for vegetation consumed by farm animals and humans. For farm animal consumption, specific adaptations to the models may be necessary if the vegetation is wet or dry. Moisture of the pasture would dictate the use of an uptake factor based on a wet soil to plant transfer factor (BV_{wet}) or a dry soil to plant transfer factor (BV_{dry}). Additionally, an appropriate soil mass loading (MLF) would need to be applied for animal fodder. Appendix C provides the default MLF that should be used for pasture (0.25 g dry soil / g dry plant). Appendix F provides farm animal intake rates of water, soil, and fodder. Appendix A provides human intake rates of farm animal products.

6. CONCLUSION

There is a need for advancement in risk assessment modeling regarding the consumption of produce and animal products that are cultivated on contaminated land and/or land irrigated with contaminated water. The increased diversity of biota now included in the PRG and DCC calculators addresses this need. Previously, these tools only offered human intake rate data for a generic fruit and a generic vegetable in the overall produce equations. Users are now able to select from 25 specific produce types to include in the total produce consumption calculations. In site-specific calculation mode, users can now add sheep meat, sheep milk, goat meat, and goat milk to their assessment in addition to the 7 animal products that the PRG and DCC tools already provide. The user-provided option now allows users to choose between chicken, duck, turkey, and goose for poultry output. The intake rates for produce and animal products can now be implemented in screening level calculations as raw weight or weight after cooking/preparation loss. Prior to these updates, raw weight was the only option.

Enhancements and diversity of BVs and TFs have also been implemented in the PRG and DCC calculators. Previously, BVs that applied to produce were generic for all produce types. Now, the BVs encompass 25 individual produce types, 4 climate zones, and 7 soil types. New TFs have also been introduced for animal products that have not previously been incorporated. These include sheep meat, sheep milk, goat meat, and goat milk.

Use of MLFs have been enhanced from a single MLF applied to all produce to 25 individual MLFs that correspond with the 25 individual produce items that have new produce intake rates. Also, the dry weight MLFs provided in the literature were converted to a wet weight using moisture content values specific to the plant type. This refinement allows the MLFs and BVs to be in consistent units.

These improvements will greatly expand the use and applicability of the PRG and DCC calculators in the field of risk assessment with respect to CERCLA sites as well as many other sites for private and governmental organizations. The newly derived biota intake rates, MLFs, and TFs encompass greater geographic diversity.

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APPENDIX A. INTAKE RATE DERIVATION & PROPOSED INTAKE RATES IN THE PRG & DCC CALCULATOR

INTAKE RATE DERIVATION EXAMPLE

The example set of equations in Appendix A shows the step-by-step process used to estimate the intake rate of apples for farmer child in g/day and farmer adult in g/day for fresh weight and prepared/cooked weight. Although these examples are for apples, this process was used to determine all of the intake rates presented in Table A-1 below. The values used in the example equations can be found in Table 9-5 of the 2018 EFH chapter 9 update and Table 13-31 of the 2011 EFH; both of which are shown below as Figure A-1 and Figure A-2, respectively. Both CP-loss and CP post-loss are taken from Figure A-3 below.

First, as seen in Figure A-2, there are missing consumer-only mean intake rates for age groups 1-2, 3-5, and 12-19. To fill in these data gaps in chapter 13 for consumer only intake rates, per capita intake rates from chapter 9, Figure A-1, were used. An example of this process can be found in Equation A-1 below. Second, the age groups used in table 9-5 are different than those used in table 13-31. When a missing consumer only value from EFH 2011 chapter 13 needed to be extrapolated based on chapter 9 per capita intake rates and age segments from the per capita 2018-chapter 9 update did not match the age segments from the 2011-chapter 13 consumer only intakes, the average was calculated from the chapter 9 age segments (e.g., $IR_{con\text{-}apple\ 1<3}$ in Equation A-1).

Figure A-1 is Table 9-5 from the 2018 Chapter 9 update of the Exposure Factors Handbook.

Table 9-5. Per Capita 2-Day Average[a] Intake of Individual Fruits and Vegetables Based on the 2005–2010 National Health and Nutrition Examination Survey (NHANES) (g/kg-day, edible portion, uncooked weight)[b]

Population Group	*N*	PC	Mean	SE	PC	Mean	SE	PC	Mean	SE	PC	Mean	SE
		Apples[c]			Asparagus[d]			Bananas[e]			Beans[f]		
Whole population	24,673	35	0.48	0.02	2	0.01	<0.005	57	0.39	0.01	45	0.23	<0.005
Age group													
Birth to <1 month	87	0	0	0	0	0	0	0	0	0	0	0	0
1 to <3 months	233	3	0.18	0.08	0	0	0	4	0.08	0.03	<0.5	<0.005	<0.005
3 to <6 months	282	30	1.96	0.43	0	0	0	31	1.26	0.17	15	0.25	0.04
6 to <12 months	588	62	3.45	0.21	1	<0.005	<0.005	75	2.71	0.22	46	0.92	0.13
Birth to <1 year	1,190	39	2.23	0.15	1	<0.005	<0.005	46	1.68	0.12	27	0.53	0.07
1 to <2 years	728	56	2.53	0.25	2	0.02	0.01	77	2.52	0.35	49	0.79	0.08
2 to <3 years	751	50	1.96	0.17	1	0.05	0.03	81	1.83	0.13	48	0.69	0.08
3 to <6 years	1,418	45	1.57	0.14	1	<0.005	<0.005	76	1.1	0.10	45	0.58	0.05
6 to <11 years	2,292	41	0.93	0.06	1	0.01	<0.005	73	0.48	0.03	38	0.28	0.02
11 to <16 years	2,551	32	0.46	0.05	1	0.01	<0.005	56	0.18	0.02	33	0.16	0.01
16 to <21 years	2,191	26	0.29	0.04	<0.5	<0.005	<0.005	49	0.17	0.02	33	0.13	0.01
21 to <30 years	2,082	27	0.25	0.03	1	0.01	<0.005	47	0.22	0.02	42	0.16	0.01
30 to <40 years	2,282	29	0.24	0.02	2	0.02	0.01	51	0.22	0.01	49	0.19	0.01
40 to <50 years	2,378	31	0.26	0.02	1	0.01	<0.005	51	0.25	0.02	49	0.21	0.01
50 to <60 years	2,103	39	0.34	0.03	3	0.03	0.01	59	0.32	0.02	47	0.21	0.01
60 to <70 years	2,214	38	0.30	0.02	4	0.02	<0.005	60	0.33	0.02	51	0.23	0.01
70 to <80 years	1,578	42	0.35	0.03	4	0.03	<0.005	63	0.36	0.02	51	0.21	0.01
80+ years	915	44	0.32	0.02	5	0.03	0.01	72	0.47	0.03	50	0.24	0.02
21 to <50 years	6,742	29	0.25	0.01	2	0.01	<0.005	50	0.23	0.01	47	0.19	0.01
50+ years	6,810	39	0.33	0.02	4	0.03	<0.005	61	0.35	0.01	49	0.22	0.01
Race													
Mexican American	5,787	36	0.67	0.03	1	<0.005	<0.005	57	0.58	0.03	57	0.29	0.01
Non-Hispanic Black	5,337	28	0.40	0.03	1	<0.005	<0.005	55	0.25	0.01	42	0.25	0.01
Non-Hispanic White	10,294	36	0.45	0.03	3	0.02	<0.005	57	0.37	0.01	42	0.22	0.01
Other Hispanic	2,082	33	0.57	0.05	1	<0.005	<0.005	59	0.50	0.04	55	0.27	0.02
Other race—including multiple	1,173	36	0.51	0.04	2	0.02	0.01	61	0.48	0.04	51	0.24	0.02

FIGURE A-1. EFH CHAPTER 9 PER CAPITA INTAKE RATES

Figure A-2 is Table 13-31 from Chapter 13 of the 2011 Exposure Factors Handbook.

Table 13-31. Consumer-Only Intake of Home-Produced Apples (g/kg-day)

Population Group	Nc wgtd	Nc unwgtd	% Consuming	Mean	SE	*p*1	*p*5	*p*10	*p*25	*p*50	*p*75	*p*90	*p*95	*p*99	MAX
Total	5,306,000	272	2.82	1.19	0.08	0.08	0.23	0.28	0.45	0.82	1.47	2.38	3.40	5.42	10.10
Age															
1 to 2	199,000	12	3.49	*	*	*	*	*	*	*	*	*	*	*	*
3 to 5	291,000	16	3.59	*	*	*	*	*	*	*	*	*	*	*	*
6 to 11	402,000	25	2.41	1.28	0.19	0.47	0.47	0.56	0.74	0.96	1.29	2.98	4.00	4.00	4.00
12 to 19	296,000	12	1.44	*	*	*	*	*	*	*	*	*	*	*	*
20 to 39	1,268,000	61	2.06	0.80	0.11	0.19	0.23	0.26	0.30	0.60	0.92	1.55	1.97	5.42	5.42
40 to 69	1,719,000	90	3.03	0.96	0.14	0.06	0.09	0.26	0.40	0.65	1.08	1.59	2.38	9.83	9.83
≥ 70	1,061,000	52	6.68	1.45	0.14	0.20	0.26	0.45	0.63	1.18	1.82	3.40	3.62	4.20	4.20
Season															
Fall	1,707,000	60	3.58	1.28	0.12	0.26	0.30	0.32	0.58	1.03	1.66	2.69	3.40	4.25	4.25
Spring	639,000	74	1.38	0.95	0.11	0.19	0.24	0.28	0.38	0.57	1.10	2.00	2.78	5.87	5.87
Summer	1,935,000	68	4.25	1.12	0.17	0.06	0.09	0.19	0.40	0.69	1.41	2.29	2.98	9.83	9.83
Winter	1,025,000	70	2.10	1.30	0.18	0.19	0.23	0.32	0.57	0.88	1.59	2.75	3.40	10.10	10.10
Urbanization															
Central City	912,000	30	1.62	1.24	0.26	0.23	0.26	0.39	0.51	0.92	1.59	2.19	2.26	10.10	10.10
Non-metropolitan	2,118,000	122	4.70	1.27	0.13	0.06	0.12	0.25	0.41	0.90	1.55	2.92	3.48	9.83	9.83
Suburban	2,276,000	120	2.63	1.09	0.09	0.19	0.24	0.29	0.44	0.77	1.29	2.29	3.40	5.42	5.42
Race															
Black	84,000	4	0.39	*	*	*	*	*	*	*	*	*	*	*	*
White	5,222,000	268	3.31	1.18	0.08	0.08	0.23	0.28	0.45	0.80	1.41	2.38	3.40	5.42	10.10
Region															
Midwest	2,044,000	123	4.41	1.38	0.15	0.22	0.29	0.30	0.52	0.92	1.61	2.69	3.40	9.83	10.10
Northeast	442,000	18	1.07	*	*	*	*	*	*	*	*	*	*	*	*
South	1,310,000	65	2.04	1.10	0.11	0.20	0.24	0.30	0.44	0.92	1.38	1.90	2.98	4.00	4.91
West	1,510,000	66	4.19	1.20	0.13	0.06	0.19	0.26	0.47	0.79	1.82	2.75	3.62	4.25	4.25
Response to Questionnaire															
Households who garden	4,707,000	246	6.91	1.21	0.08	0.13	0.25	0.30	0.47	0.82	1.47	2.38	3.40	5.87	10.10
Households who farm	1,299,000	68	17.72	1.39	0.13	0.06	0.36	0.54	0.70	0.96	1.58	2.99	4.00	4.91	5.87

* Intake data not provided for subpopulations for which there were less than 20 observations.

SE = Standard error.
p = Percentile of the distribution.
Nc wgtd = Weighted number of consumers.
Nc unwgtd = Unweighted number of consumers in survey.

Source: Based on EPA's analyses of the 1987–1988 NFCS.

FIGURE A-2. EFH CHAPTER 13 CONSUMER ONLY INTAKE RATES

Figure A-3 is Table 13-69 from Chapter 13 of the 2011 Exposure Factors Handbook.

Table 13-69. Percent Weight Losses From Food Preparation

Food Group	Mean Net Preparation/Cooking Loss (%)	Mean Net Post Cooking (%)
Meats[a]	29.7[b]	29.7[c]
Fish and shellfish[d]	31.5[b]	10.5[c]
Fruits	25.4[e]	30.5[f]
Vegetables[g]	12.4[h]	22[i]

[a] Averaged over various cuts and preparation methods for various meats including beef, pork, chicken, turkey, lamb, and veal.

[b] Includes dripping and volatile losses during cooking.

[c] Includes losses from cutting, shrinkage, excess fat, bones, scraps, and juices.

[d] Averaged over a variety of fish and shellfish to include bass, bluefish, butterfish, cod, flounder, haddock, halibut, lake trout, mackerel, perch, porgy, red snapper, rockfish, salmon, sea trout, shad, smelt, sole, spot, squid, swordfish steak, trout, whitefish, clams, crab, crayfish, lobster, oysters, and shrimp and shrimp dishes.

[e] Based on preparation losses. Averaged over apples, pears, peaches, strawberries, and oranges. Includes losses from removal of skin or peel, core or pit, stems or caps, seeds, and defects. Also includes losses from removal of drained liquids from canned or frozen forms.

[f] Averaged over apples and peaches. Include losses from draining cooked forms.

[g] Averaged over various vegetables to include asparagus, beets, broccoli, cabbage, carrots, corn, cucumbers, lettuce, lima beans, okra, onions, green peas, peppers, pumpkins, snap beans, tomatoes, and potatoes.

[h] Includes losses due to paring, trimming, flowering the stalk, thawing, draining, scraping, shelling, slicing, husking, chopping, and dicing and gains from the addition of water, fat, or other ingredients. Averaged over various preparation methods.

[i] Includes losses from draining or removal of skin. Based on potatoes only.

Source: Derived from USDA (1975)

FIGURE A-3. FOOD PREPARATION LOSS

EQUATION A-1. DERIVATION OF CONSUMER ONLY INTAKE RATE

$$IR_{\text{con-apple }<1}\left(\frac{5.53\text{ g}}{\text{kg-day}}\right) = TP_{\text{con-apple-mean}}\left(\frac{1.19\text{ g}}{\text{kg-day}}\right) \times \left(\frac{IR_{\text{per-apple }<1}\left(\frac{2.23\text{ g}}{\text{kg-day}}\right)}{TP_{\text{per-apple-mean}}\left(\frac{0.48\text{ g}}{\text{kg-day}}\right)}\right)$$

$$IR_{\text{con-apple }1<3}\left(\frac{5.57\text{ g}}{\text{kg-day}}\right) = TP_{\text{con-apple-mean}}\left(\frac{1.19\text{ g}}{\text{kg-day}}\right) \times \left(\frac{\left(\left(\frac{IR_{\text{per-apple }1<2}\left(\frac{2.53\text{ g}}{\text{kg-day}}\right)}{TP_{\text{per-apple-mean}}\left(\frac{0.48\text{ g}}{\text{kg-day}}\right)}\right) + \left(\frac{IR_{\text{per-apple }2<3}\left(\frac{1.96\text{ g}}{\text{kg-day}}\right)}{TP_{\text{per-apple-mean}}\left(\frac{0.48\text{ g}}{\text{kg-day}}\right)}\right)\right)}{2}\right)$$

$$IR_{\text{con-apple }3<6}\left(\frac{3.89\text{ g}}{\text{kg-day}}\right) = TP_{\text{con-apple-mean}}\left(\frac{1.19\text{ g}}{\text{kg-day}}\right) \times \left(\frac{IR_{\text{per-apple }3<6}\left(\frac{1.57\text{ g}}{\text{kg-day}}\right)}{TP_{\text{per-apple-mean}}\left(\frac{0.48\text{ g}}{\text{kg-day}}\right)}\right)$$

where :

$TP_{\text{con-apple}}$ = Mean apple consumer-only intake for total population (EFH 2011 Table 13-31).

$TP_{\text{per-apple}}$ = Mean apple per capita intake for total population (EFH 2018 Table 9-5).

$IR_{\text{con-apple}}$ = Mean apple consumer-only intake of population for a particular age segment (i.e. <1) (derived in this equation).

$IR_{\text{per-apple}}$ = Mean apple per capita intake of population for a particular age segment (i.e. <1) (EFH 2018 Table 9-5).

Note: When a missing consumer only value from EFH 2011 chapter 13 needed to be extrapolated based on chapter 9 per capita intake rates and age segments from the per capita 2018 chapter 9 update did not match the age segments from the 2011 chapter 13 consumer only intakes, the average was calculated from the chapter 9 age segments (e.g., $IR_{\text{con-apple }1<3}$).

EQUATION A-2. FARMER CHILD: APPLE CONSUMER ONLY INTAKE RATE DERIVATION

Consumer Only Intake Rate of Apples for Farmer Child in Fresh Weight:

$$IR_{\text{apple-child}}\left(\frac{5.52\ g}{kg\text{-}day}\right) = \text{Intake Rate of Households Who Farm}\left(\frac{1.39\ g}{kg\text{-}day}\right) \times \left(\frac{TWA_{\text{apple-child}}\left(\frac{4.72\ g}{kg\text{-}day}\right)}{\text{Mean Consumer Only Intake}\left(\frac{1.19\ g}{kg\text{-}day}\right)}\right)$$

where:

$$TWA_{\text{apple-child}}\left(\frac{4.72\ g}{kg\text{-}day}\right) = \frac{\left(\left(IR_{\text{con-apple }<1}\left(\frac{5.53\ g}{kg\text{-}day}\right) \times ED_{(<1)}(1\ \text{years})\right) + \left(IR_{\text{con-apple }1<3}\left(\frac{5.57\ g}{kg\text{-}day}\right) \times ED_{(1<3)}(2\ \text{years})\right) + \left(IR_{\text{con-apple }3<6}\left(\frac{3.89\ g}{kg\text{-}day}\right) \times ED_{(3<6)}(3\ \text{years})\right) + \right)}{ED_{\text{child}}(6\ \text{years})}$$

EQUATION A-3. FARMER ADULT: APPLE CONSUMER ONLY INTAKE RATE DERIVATION

Consumer Only Intake Rate of Apples for Farmer Adult in Fresh Weight:

$$IR_{\text{apple-adult}}\left(\frac{1.06\ \text{g}}{\text{kg-day}}\right) = \text{Intake Rate of Households Who Farm}\left(\frac{1.39\ \text{g}}{\text{kg-day}}\right) \times \left(\frac{TWA_{\text{apple-adult}}\left(\frac{0.91\ \text{g}}{\text{kg-day}}\right)}{\text{Mean Consumer Only Intake}\left(\frac{1.19\ \text{g}}{\text{kg-day}}\right)}\right)$$

where:

$$TWA_{\text{apple-adult}}\left(\frac{0.91\ \text{g}}{\text{kg-day}}\right) = \frac{\left(\begin{array}{l}\left(IR_{\text{apple}(20<40)}\left(\frac{0.88\ \text{g}}{\text{kg-day}}\right) \times ED_{(20<40)}(19\ \text{years})\right) + \\ \left(IR_{\text{apple}(40<70)}\left(\frac{0.96\ \text{g}}{\text{kg-day}}\right) \times ED_{(20<40)}(29\ \text{years})\right) + \\ \left(IR_{\text{apple}(70+)}\left(\frac{1.45\ \text{g}}{\text{kg-day}}\right) \times ED_{(50+)}(1\ \text{years})\right)\end{array}\right)}{ED_{\text{adult}}(49\ \text{years})}$$

EQUATION A-4. FARMER CHILD: APPLE CONSUMER ONLY INTAKE RATE INCLUDING BODY WEIGHT

Final Consumer Only Intake Rate of Apples for Farmer Child in Fresh Weight:

$$IR_{\text{apple-child}}\left(\frac{82.7\ \text{g}}{\text{day}}\right)(\text{FW}) = \left[IR_{\text{apple-child}}\left(\frac{5.52\ \text{g}}{\text{kg-day}}\right)(\text{FW})\right] \times 15\ \text{kg}$$

EQUATION A-5. FARMER ADULT: APPLE CONSUMER ONLY INTAKE RATE INCLUDING BODY WEIGHT

Final Consumer Only Intake Rate of Apples for Farmer Adult in Fresh Weight:

$$IR_{\text{apple-adult}}\left(\frac{84.8\ \text{g}}{\text{day}}\right)(\text{FW}) = \left[IR_{\text{apple-adult}}\left(\frac{1.06\ \text{g}}{\text{kg-day}}\right)(\text{FW})\right] \times 80\ \text{kg}$$

EQUATION A-6. FARMER CHILD: APPLE CONSUMER ONLY INTAKE RATE INCLUDING PREPARATION AND COOKING LOSS

Consumer Only Intake Rate of Apples for Farmer Child Including Preparation and Cooking Loss:

$$IR_{apple\text{-}child}\left(\frac{2.86\ g}{kg\text{-}day}\right)(CPW) = IR_{apple\text{-}child}\left(\frac{5.52\ g}{kg\text{-}day}\right)(FW) \times \left(1 - CP_{loss}\left(0.254\right)\right) \times \left(1 - CP_{post\text{-}loss}\left(0.305\right)\right)$$

where:

CPW = Cooking/Preparation Loss Weight

CP_{loss} = Cooking/Preparation Loss Ratio

$CP_{post\text{-}loss}$ = Post Cooking/Preparation Loss Ratio

*Note: Both CP_{loss} and $CP_{post\text{-}loss}$ values were taken from EFH 2011 table 13-69.

EQUATION A-7. FARMER ADULT: APPLE CONSUMER ONLY INTAKE RATE INCLUDING PREPARATION AND COOKING LOSS

Consumer Only Intake Rate of Apples for Farmer Adult Including Preparation and Cooking Loss:

$$IR_{apple\text{-}adult}\left(\frac{0.55\ g}{kg\text{-}day}\right)(CPW) = IR_{apple\text{-}adult}\left(\frac{1.06}{kg\text{-}day}\right)(FW) \times \left(1 - CP_{loss}\left(0.254\right)\right) \times \left(1 - CP_{post\text{-}loss}\left(0.305\right)\right)$$

where:

CPW = Cooking/Preparation Loss Weight

CP_{loss} = Cooking/Preparation Loss

$CP_{post\text{-}loss}$ = Post Cooking/Preparation Loss

*Note: Both CP_{loss} and $CP_{post\text{-}loss}$ values were taken from EFH 2011 table 13-69.

EQUATION A-8. FARMER CHILD: APPLE CONSUMER ONLY INTAKE RATE INCLUDING PREPARATION AND COOKING LOSS AND BODY WEIGHT

Final Consumer Only Intake Rate of Apples for Farmer Child Including Preparation and Cooking Loss:

$$IR_{apple\text{-}child}\left(\frac{42.9\ g}{day}\right)(CPW) = \left[IR_{apple\text{-}child}\left(\frac{2.86\ g}{kg\text{-}day}\right)(CPW)\right] \times 15\ kg$$

EQUATION A-9. FARMER CHILD: APPLE CONSUMER ONLY INTAKE RATE INCLUDING AND COOKING LOSS AND BODY WEIGHT

Final Consumer Only Intake Rate of Apples for Farmer Adult Including Preparation and Cooking Loss:

$$IR_{apple\text{-}adult}\left(\frac{44.0\ g}{day}\right)(CPW) = \left[IR_{apple\text{-}adult}\left(\frac{0.55\ g}{kg\text{-}day}\right)(CPW)\right] \times 80\ kg$$

INTAKE RATES

This section clarifies assumptions utilized in calculating intake rates based on recent guidance, data, and analyses. . A sensitivity test was performed to determine which age segment should be used to determine adult intake rates and whether a single or age-specific body weight should be used to determine both child and adult intake rates. Standard guidance and documentation have used the following exposure duration age segments: 6-26 (currently used in the PRG and DCC calculators) or 6-30 (previously used in the PRG and DCC calculators), 6-70, and 21+. The results of this analysis can be found in Appendix D. For the child intake rates, the age segment remains 0-6 for most previous documentation. Therefore, child intake rates for this study were calculated based on the 0-6 age segment. A general and age-specific body weight were applied in the sensitivity analysis to determine which body weight was more protective for children. The analysis showed that intake rates for children were not greatly affected by which body weight was used. Therefore, the general child body weight was chosen as it is consistent with what is already used in the PRG and DCC tools.

Generally, the adult intake rates were more protective when the age segment 21+ was used. Additionally, using a general body weight for adults yielded a more protective intake rate more often than not. Table A-1 lists the final intake rates that were calculated. There are both fresh weight (FW) intake rates and cooking/preparation loss (CPW) intake rates. As mentioned in section 2 of this document, these intake rates were determined using consumer only intake rates of homegrown produce provided in the EFH. Table A-1 also provides Total Fruit, Total Vegetables, and Total Meat and Dairy intake rates. These intake rates are highly conservative since the intake rates for each individual fruit, vegetable, meat, and dairy food product rate is a high-end value for homegrown consumption of that particular food product. Site-specific biota intake rates should be used when available.

TABLE A-1. DEFAULT PROPOSED INTAKE RATE

	IR Farmer Child (g/day) (FW)	IR Farmer Adult (g/day) (FW)	IR Resident Child (g/day) (FW)	IR Resident Adult (g/day) (FW)	IR Farmer Child (g/day) (CPW)	IR Farmer Adult (g/day) (CPW)	IR Resident Child (g/day) (CPW)	IR Resident Adult (g/day) (CPW)
Apples[2]	82.7	84.8	72.0	73.9	42.9	44.0	37.3	38.3
Citrus Fruits[2]	206.0	306.5	206.0	306.5	106.8	158.9	106.8	158.9
Berries[2]	24.2	35.2	24.2	35.2	12.5	18.2	12.5	18.2
Peaches	98.2	103.1	110.2	115.7	50.9	53.5	57.1	60.0
Pears	79.6	59.8	69.4	52.1	41.3	31.0	36.0	27.0
Strawberry	27.5	40.6	27.5	40.6	14.2	21.1	14.2	21.1
Total Fruit	518.2	630.0	509.3	624.0	268.6	326.7	263.9	323.5
Asparagus	11.9	40.1	11.9	40.1	8.1	27.4	8.1	27.4
Beets	6.0	34.4	6.0	34.4	4.1	23.5	4.1	23.5
Broccoli	14.8	34.1	13.2	30.5	10.1	23.3	9.0	20.8
Cabbage[2]	11.0	79.5	11.8	85.1	7.5	54.3	8.0	58.1
Carrots	13.1	24.4	14.5	27.1	8.9	16.6	9.9	18.5
Corn	31.6	82.1	23.2	60.2	21.6	56.1	15.8	41.1
Cucumbers	16.3	54.9	24.5	82.3	11.2	37.5	16.7	56.2
Lettuce[2]	3.4	36.7	3.4	36.7	2.3	25.0	2.3	25.0
Lima Beans[1]	22.0	33.9	22.0	33.9	15.0	23.2	15.0	23.2
Okra[1]	9.4	30.4	9.4	30.4	6.4	20.8	6.4	20.8
Onions	7.5	27.3	5.9	21.5	5.1	18.6	4.0	14.7
Peas	20.4	31.6	22.6	35.0	13.9	21.6	15.5	23.9
Peppers	7.4	23.9	5.9	19.1	5.1	16.3	4.1	13.0
Pumpkins[1]	21.2	63.5	21.2	63.5	14.5	43.4	14.5	43.4
Snap Beans[1]	28.7	54.5	28.3	53.8	19.6	37.2	19.3	36.8
Tomatoes	42.2	94.0	36.0	80.1	28.9	64.2	24.6	54.7
White Potatoes[2]	52.4	141.8	47.3	127.8	35.8	96.9	32.3	87.3
Total Vegetables	319.3	887.1	307.1	861.5	218.1	605.9	209.6	588.4
Dairy	1116.4	1438.0	n/a	n/a	n/a	n/a	n/a	n/a
Beef	64.6	270.1	n/a	n/a	31.9	133.5	n/a	n/a
Swine	32.2	151.1	n/a	n/a	15.9	74.7	n/a	n/a
Poultry	48.8	175.5	n/a	n/a	24.1	86.7	n/a	n/a
Egg	25.1	97.3	n/a	n/a	n/a	n/a	n/a	n/a
Finish	36.1	155.9	n/a	n/a	22.1	95.6	n/a	n/a
Shellfish	21.3	208.9	n/a	n/a	13.0	128.1	n/a	n/a
Total Meat and Dairy	1344.5	2496.8			107.0	518.6		

1. Data taken from EFH 1997 because it was not available in EFH 2011.
2. **Apples:** with/without peel & crabapples. **Citrus:** all **Berries**: blackberry, blueberry, boysenberry, cranberry, elderberry, loganberry, mulberry, & raspberry (other than strawberry). **Cabbage:** brussel sprout, red, savoy, & Chinese celery (bok choy). **Lettuce:** whole, iceberg, & romaine. **White Potatoes:** peeled/whole.

Table A-2 lists biota categories that will be available for the user to select in the site-specific mode of the PRG and DCC calculators only. There was limited or no data available for most of these biota and, therefore, most do not have default intake rates presented. The default poultry inputs used in the PRG and DCC calculators are for chicken only. In the poultry section of site-specific mode, the user will be able to select the poultry type (chicken, duck, turkey, goose) for output. The human intake rates of poultry will remain the same regardless of which poultry type is selected; however, soil, water, and fodder intake rates by poultry type will change. The consumer-only data for rice and cereal grain comes from Table 12-6 in the 2011 EFH. Both are based on edible, uncooked weight so intake rates for these are only proposed in dry weight. These dry intake rates for rice and grain are not included in the produce totals if the calculator is run in default mode. Each of the biota in Table A-2 will only be included in their respective biota total if they are selected in site-specific mode, and the additional data required is provided by the user.

TABLE A-2. ADDITIONAL SITE-SPECIFIC PROPOSED INTAKE RATES

	IR Farmer Child (g/day) (FW)	IR Farmer Adult (g/day) (FW)	IR Resident Child (g/day) (FW)	IR Resident Adult (g/day) (FW)	IR Farmer Child (g/day) (CPW)	IR Farmer Adult (g/day) (CPW)	IR Resident Child (g/day) (CPW)	IR Resident Adult (g/day) (CPW)
Goat Milk	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Sheep Milk	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Mutton	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Goat Meat	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Duck	48.8	175.5	n/a	n/a	24.1	86.7	n/a	n/a
Turkey	48.8	175.5	n/a	n/a	24.1	86.7	n/a	n/a
Goose	48.8	175.5	n/a	n/a	24.1	86.7	n/a	n/a
Rice Grains	n/a	n/a	n/a	n/a	49.6	98.9	41.0	81.9
Cereal Grains	n/a	n/a	n/a	n/a	48.1	84.8	39.8	70.2

APPENDIX B. TRANSFER FACTOR SOURCE COMPILATION AND APPLICATION

Table B-1 lists all biota available in the PRG and DCC calculators, which TF or BV category will be used for each biota from each source, and the hierarchy used for each biota. The red text elements are on the 'Common Isotopes' list from the PRG and DCC calculators which include Am, Co, Cs, H, I, Pu, Ra, Rn, Sr, Tc, Th, and U. Transfer Factors from NCRP-123, RADSSL, and RESRAD, are universal soil to plant BVs that are not specific to a particular plant category or type, but rather the element itself. The Baes paper breaks produce BVs into 2 categories. These categories are explained in Appendix E.

TABLE B-1. TRANSFER FACTOR HIERARCHY

	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Apples[5]	Woody Tree	IAEA TRS 472	4- Am, Cs, Pu, Sr	Fruit	EA	39-Ag, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Er, Eu, Fe, Ga, I, In, La, Lu, Mo, Na, Nb, Np, P, Pm, Po, Ra, Rb, Ru, S, Sb, Se, Sm, Tc, Th, Tl, U, V, Y, Zn, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Citrus Fruits[5]	Woody Tree	IAEA TRS 472	4- Am, Cs, Pu, Sr	Fruit	EA	39-Ag, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Er, Eu, Fe, Ga, I, In, La, Lu, Mo, Na, Nb, Np, P, Pm, Po, Ra, Rb, Ru, S, Sb, Se, Sm, Tc, Th, Tl, U, V, Y, Zn, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Berries[5]	Shrub	IAEA TRS 472	2-Cs, Sr	Fruit	EA	15- Au, Ca, Cm, Er, Ga, I, In, Nb, Np, P, Pm, S, Tc, Tl, Y	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including Am, Co, H, Pu, Ra, Rn, Th, U.

TABLE B-1. TRANSFER FACTOR HIERARCHY

	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Peaches	Woody Tree	IAEA TRS 472	4- Am, Cs, Pu, Sr	Fruit	EA	39-Ag, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Er, Eu, Fe, Ga, I, In, La, Lu, Mo, Na, Nb, Np, P, Pm, Po, Ra, Rb, Ru, S, Sb, Se, Sm, Tc, Th, Tl, U, V, Y, Zn, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Pears	Woody Tree	IAEA TRS 472	4- Am, Cs, Pu, Sr	Fruit	EA	39-Ag, Au, Ba, Br, Ca, Ce, Cl, Co, Cr, Er, Eu, Fe, Ga, I, In, La, Lu, Mo, Na, Nb, Np, P, Pm, Po, Ra, Rb, Ru, S, Sb, Se, Sm, Tc, Th, Tl, U, V, Y, Zn, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Strawberry	Herbaceous	IAEA TRS 472	4- Am, Cs, Pu, Sr	Fruit	EA	20-Au, Ca, Cm, Er, Ga, I, In, Mn, Mo, Nb, Np, P, Pm, Ru, S, Sb, Tl, V, Y, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including Co, H, Ra, Rn, Tc, Th, and U.
Asparagus	Leafy Vegetable	IAEA TRS 472	35-Ag, Am, Ba, Ce, Cl, Cm, Co, Cr, Cs, Fe, I, K, La, Mn, Mo, Na, Nb, Np, P, Pb, Po, Pr, Pu, Ra, Rb, Ru, Sb, Sr, Tc, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	15-Au, Br, Ca, Er, Eu, Ga, In, Lu, Ni, Pm, S, Se, Sm, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.

TABLE B-1. TRANSFER FACTOR HIERARCHY

	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Beets	Root	IAEA TRS 472	34-Ag, Am, Ba, Ce, Cl, Cm, Co, Cr, Cs, Fe, I, La, Mn, Mo, Na, Nb, Np, P, Pb, Pm, Po, Pr, Pu, Ra, Rb, Ru, Sb, Sr, Tc, Te, Th, U, Y, Zr	Root Vegetable	EA	15- Au, Br, Ca, Er, Eu, Ga, In, Lu, Ni, S, Se, Sm, Tl, V, Zn	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Broccoli	Non-Leafy Vegetable	IAEA TRS 472	26-Ag, Am, Cm, Co, Cr, Cs, Fe, I, La, Mn, Na, Nb, Np, P, Pb, Pu, Ra, Ru, Sb, Sr, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	22- Au, Ba, Br, Ca, Ce, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Cabbage[5]	Leafy Vegetable	IAEA TRS 472	35-Ag, Am, Ba, Ce, Cl, Cm, Co, Cr, Cs, Fe, I, K, La, Mn, Mo, Na, Nb, Np, P, Pb, Po, Pr, Pu, Ra, Rb, Ru, Sb, Sr, Tc, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	15-Au, Br, Ca, Er, Eu, Ga, In, Lu, Ni, Pm, S, Se, Sm, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Carrots	Root	IAEA TRS 472	34-Ag, Am, Ba, Ce, Cl, Cm, Co, Cr, Cs, Fe, I, La, Mn, Mo, Na, Nb, Np, P, Pb, Pm, Po, Pr, Pu, Ra, Rb, Ru, Sb, Sr, Tc, Te, Th, U, Y, Zr	Root Vegetable	EA	15- Au, Br, Ca, Er, Eu, Ga, In, Lu, Ni, S, Se, Sm, Tl, V, Zn	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Corn	Maize Grain	IAEA TRS 472	14-Cd, Co, Cs, Mn, Np, Pb, Po, Pu, Ra, Sr, Tc, Th, U, Zn	Green Vegetable	EA	34-Ag, Am, Au, Ba, Br, Ca, Ce, Cl, Cm, Cr, Er, Eu, Fe, Ga, I, In, La, Lu, Mo, Na, Nb, Ni, P, Pm, Rb, Ru, S, Sb, Se, Sm, Tl, V, Y, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.

TABLE B-1. TRANSFER FACTOR HIERARCHY

	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Cucumbers	Non-Leafy Vegetable	IAEA TRS 472	26-Ag, Am, Cm, Co, Cr, Cs, Fe, I, La, Mn, Na, Nb, Np, P, Pb, Pu, Ra, Ru, Sb, Sr, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	22- Au, Ba, Br, Ca, Ce, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Lettuce[5]	Leafy Vegetable	IAEA TRS 472	35-Ag, Am, Ba, Ce, Cl, Cm, Co, Cr, Cs, Fe, I, K, La, Mn, Mo, Na, Nb, Np, P, Pb, Po, Pr, Pu, Ra, Rb, Ru, Sb, Sr, Tc, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	15-Au, Br, Ca, Er, Eu, Ga, In, Lu, Ni, Pm, S, Se, Sm, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Lima Beans	Legume Seed	IAEA TRS 472	24-Am, Cd, Ce, Cl, Cm, Co, Cs, Fe, I, La, Mn, Np, Pb, Pm, Po, Pu, Ra, Ru, Sb, Sr, Tc, Th, U, Zn	Green Vegetable	EA	24-Ag, Au, Ba, Br, Ca, Cr, Er, Eu, Ga, In, Lu, Mo, Na, Nb, Ni, P, Rb, S, Se, Sm, Tl, V, Y, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Okra	Non-Leafy Vegetable	IAEA TRS 472	26-Ag, Am, Cm, Co, Cr, Cs, Fe, I, La, Mn, Na, Nb, Np, P, Pb, Pu, Ra, Ru, Sb, Sr, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	22- Au, Ba, Br, Ca, Ce, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Onions	Root	IAEA TRS 472	34-Ag, Am, Ba, Ce, Cl, Cm, Co, Cr, Cs, Fe, I, La, Mn, Mo, Na, Nb, Np, P, Pb, Pm, Po, Pr, Pu, Ra, Rb, Ru, Sb, Sr, Tc, Te, Th, U, Y, Zr	Root Vegetable	EA	22- Au, Ba, Br, Ca, Ce, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Peas	Legume Seed	IAEA TRS 472	24-Am, Cd, Ce, Cl, Cm, Co, Cs, Fe, I, La, Mn, Np, Pb, Pm, Po, Pu, Ra, Ru, Sb, Sr, Tc, Th, U, Zn	Green Vegetable	EA	24-Ag, Au, Ba, Br, Ca, Cr, Er, Eu, Ga, In, Lu, Mo, Na, Nb, Ni, P, Rb, S, Se, Sm, Tl, V, Y, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.

TABLE B-1. TRANSFER FACTOR HIERARCHY

	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Peppers	Non-Leafy Vegetable	IAEA TRS 472	26-Ag, Am, Cm, Co, Cr, Cs, Fe, I, La, Mn, Na, Nb, Np, P, Pb, Pu, Ra, Ru, Sb, Sr, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	22- Au, Ba, Br, Ca, Ce, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Pumpkins	Non-Leafy Vegetable	IAEA TRS 472	26-Ag, Am, Cm, Co, Cr, Cs, Fe, I, La, Mn, Na, Nb, Np, P, Pb, Pu, Ra, Ru, Sb, Sr, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	22- Au, Ba, Br, Ca, Ce, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Snap Beans	Legume seed	IAEA TRS 472	24-Am, Cd, Ce, Cl, Cm, Co, Cs, Fe, I, La, Mn, Np, Pb, Pm, Po, Pu, Ra, Ru, Sb, Sr, Tc, Th, U, Zn	Green Vegetable	EA	24-Ag, Au, Ba, Br, Ca, Cr, Er, Eu, Ga, In, Lu, Mo, Na, Nb, Ni, P, Rb, S, Se, Sm, Tl, V, Y, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Tomatoes	Non-Leafy Vegetable	IAEA TRS 472	26-Ag, Am, Cm, Co, Cr, Cs, Fe, I, La, Mn, Na, Nb, Np, P, Pb, Pu, Ra, Ru, Sb, Sr, Te, Th, U, Y, Zn, Zr	Green Vegetable	EA	22- Au, Ba, Br, Ca, Ce, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
White Potatoes[5]	Tuber	IAEA TRS 472	30-Am, Ba, Cd, Ce, Cm, Co, Cr, Cs, Fe, I, La, Mn, Na, Nb, Np, P, Pb, Pm, Po, Pu, Ra, Ru, Sr, Tc, Te, Th, U, Y, Zn, Zr	Root Vegetable	EA	19-Ag, Au, Br, Ca, Cl, Er, Eu, Ga, In, Lu, Mo, Ni, Rb, S, Sb, Se, Sm, Tl, V	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Dairy	Beef Milk	IAEA TRS 472	31-Am, Ba, Be, Ca, Cd, Ce, Co, Cr, Cs, Fe, I, Mn, Mo, Na, Nb, Ni, P, Pb, Po, Pu, Ra, Ru, S, Sb, Se, Sr, Te, U, W, Zn, Zr	Beef Milk	EA	20-Ag, Au, Br, Cl, Cm, Er, Eu, Ga, In, La, Lu, Np, Pm, Rb, Sm, Tc, Th, Tl, V, Y	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.

TABLE B-1. TRANSFER FACTOR HIERARCHY

	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Beef	Beef	IAEA TRS 472	26-Am, Ba, Ca, Cd, Cl, Co, Cs, Fe, I, La, Mn, Mo, Na, Nb, P, Pb, Pu, Ra, Ru, Sb, Sr, Te, Th, U, Zn, Zr	Beef	EA	23-Ag, Au, Br, Ce, Cm, Cr, Er, Eu, Ga, In, Lu, Ni, Np, Pm, Po, Rb, S, Se, Sm, Tc, Tl, V, Y	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.
Swine	Swine	IAEA TRS 472	20-Ag, Am, Ca, Cd, Ce, Co, Cs, Cu, Fe, I, Mn, Nb, P, Pu, Ru, Se, Sr, Tc, U, Zn	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.	None	None	None
Poultry	Poultry	IAEA TRS 472	30-Ag, Am, Ba, Ca, Cd, Co, Cs, Cu, Fe, Hg I, K, Mn, Mo, Na, Nb, Nd, Pm, Po, Pr, Pu, Ru, Se, Sr, Tc, Te, U, Y, Zn, Zr	None	None	None	None	None	None
Egg	Egg	IAEA TRS 472	31-Am, Ba, Ca, Cd, Ce, Co, Cs, Cu, Fe, I, K, La, Mn, Mo, Na, Nb, Nd, P, Pm, Po, Pr, Pu, Ru, Se, Sr, Tc, Te, U, Y, Zn, Zr	None	None	None	None	None	None
Fin fish	Fish whole body	IAEA TRS 472	49-Ag, Al, Am, As, Au, Ba, Br, C, Ca, Ce, Cl, Co, Cr, Cs, Cu, Dy, Eu, Fe, Hf, Hg, I, K, La, Mg, Mn, Mo, Na, Ni, P, Pb, Po, Pu, Ra, Rb, Ru, Sb, Sc, Se, Sr, Tb, Te, Th, Ti, Tl, U, V, Y, Zn, Zr	Fresh Water Fish Whole Body	IAEA TRS 479	2-Cd, Sn	Fish	EA	Cm, Er, Ga, H, In, Lu, Nb, Np, Pm, S, Sm, Tc

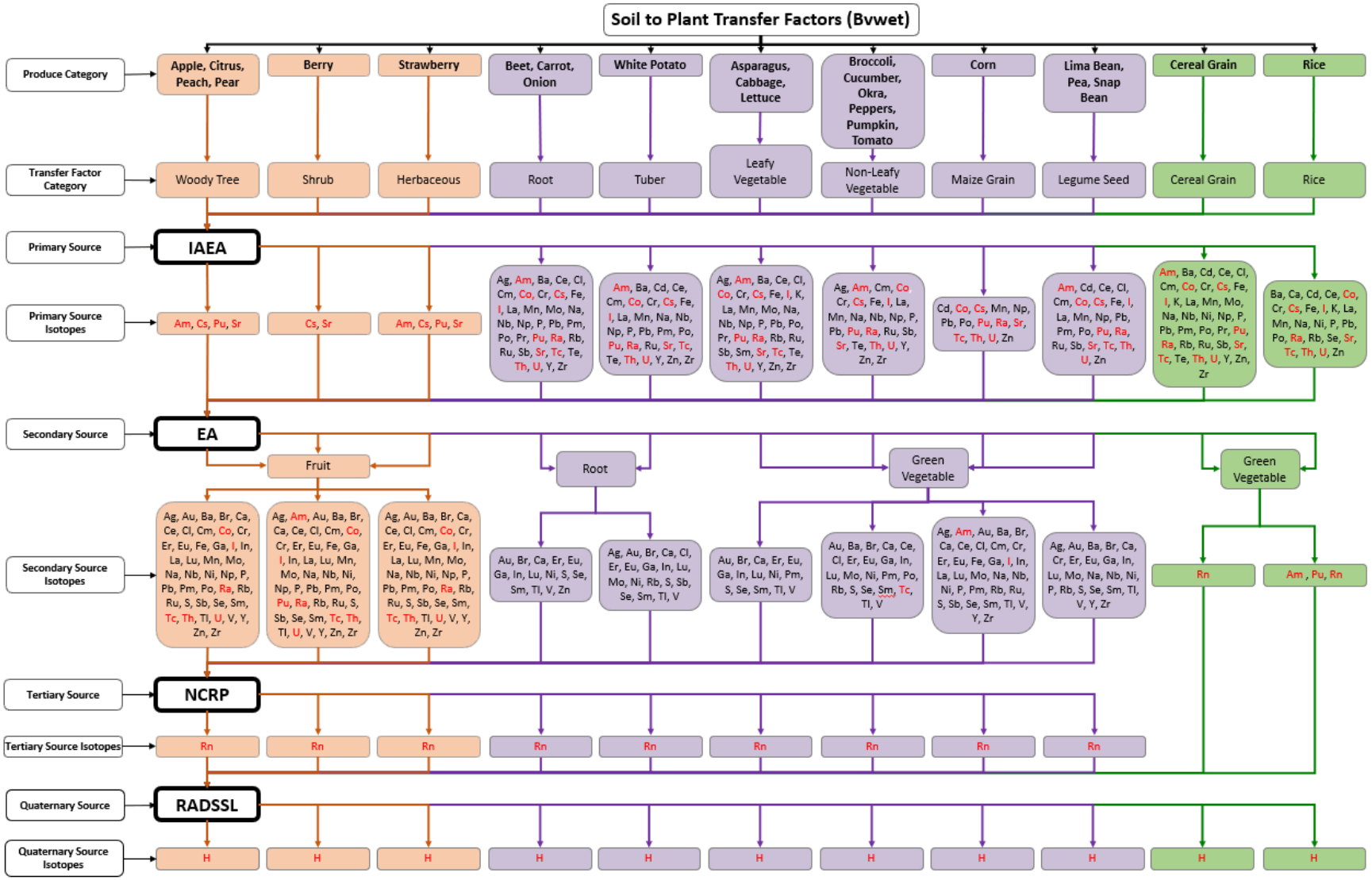
TABLE B-1. TRANSFER FACTOR HIERARCHY

	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Shellfish	Freshwater Invertebrates	IAEA TRS 472	Ag, Al, Am, As, Au, Ba, Br, C, Ca, Cd, Ce, Cl, Cm, Co, Cr, Cs, Cu, Eu, Fe, Hf, Hg, I, K, La, Lu, Mg, Mn, Mo, Na, Np, Pb, Pu, Ra, Rb, Ru, Sb, Sc, Se, Sm, Sr, Tc, Th, U, V, V, Zn	None	None	None	None	None	None
Goat Milk	Goat Milk	IAEA TRS 472	27-Am, Ba, Ca, Cd, Ce, Co, Cr, Cs, Fe, I, Mn, Mo, Na, Nb, Ni, Np, P, Pb, Pm, Po, S, Se, Sr, Te, U, Zn, Zr	None	None	None	None	None	None
Sheep Milk	Sheep Milk	IAEA TRS 472	18-Ba, Ca, Cd, Co, Cr, Cs, Fe, I, Mn, Na, Ni, P, Pb, Pu, S, Sr, Te, Zn	None	None	None	None	None	None
Sheep Meat	Mutton	IAEA TRS 472	15-Ag, Am, Cd, Ce, Co, Cs, I, Mn, Na, Pb, Pu, Ru, S, Sr, Zn	Sheep	UK-EA	33-Au, Ba, Br, Ca, Cl, Cm, Cr, Er, Eu, Fe, Ga, In, La, Lu, Mo, Nb, Ni, Np, P, Pm, Po, Ra, Rb, Sb, Se, Sm, Tc, Th, Tl, U, V, Y, Zr	None	None	None
Goat Meat	Goat	IAEA TRS 472	7-Ba, Cs, Nb, Sr, Te, Y, Zr	None	None	None	None	None	None
Rice[4]	Rice	IAEA TRS 472	25- Ba, Ca, Cd, Ce, Co, Cr, Cs, Fe, I, K, La, Mn, Na, Ni, P, Pb, Po, Ra, Rb, Se, Sr, Tc, Th, U, Zn	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including Am, H, Pu, and Rn.	None	None	None

TABLE B-1. TRANSFER FACTOR HIERARCHY

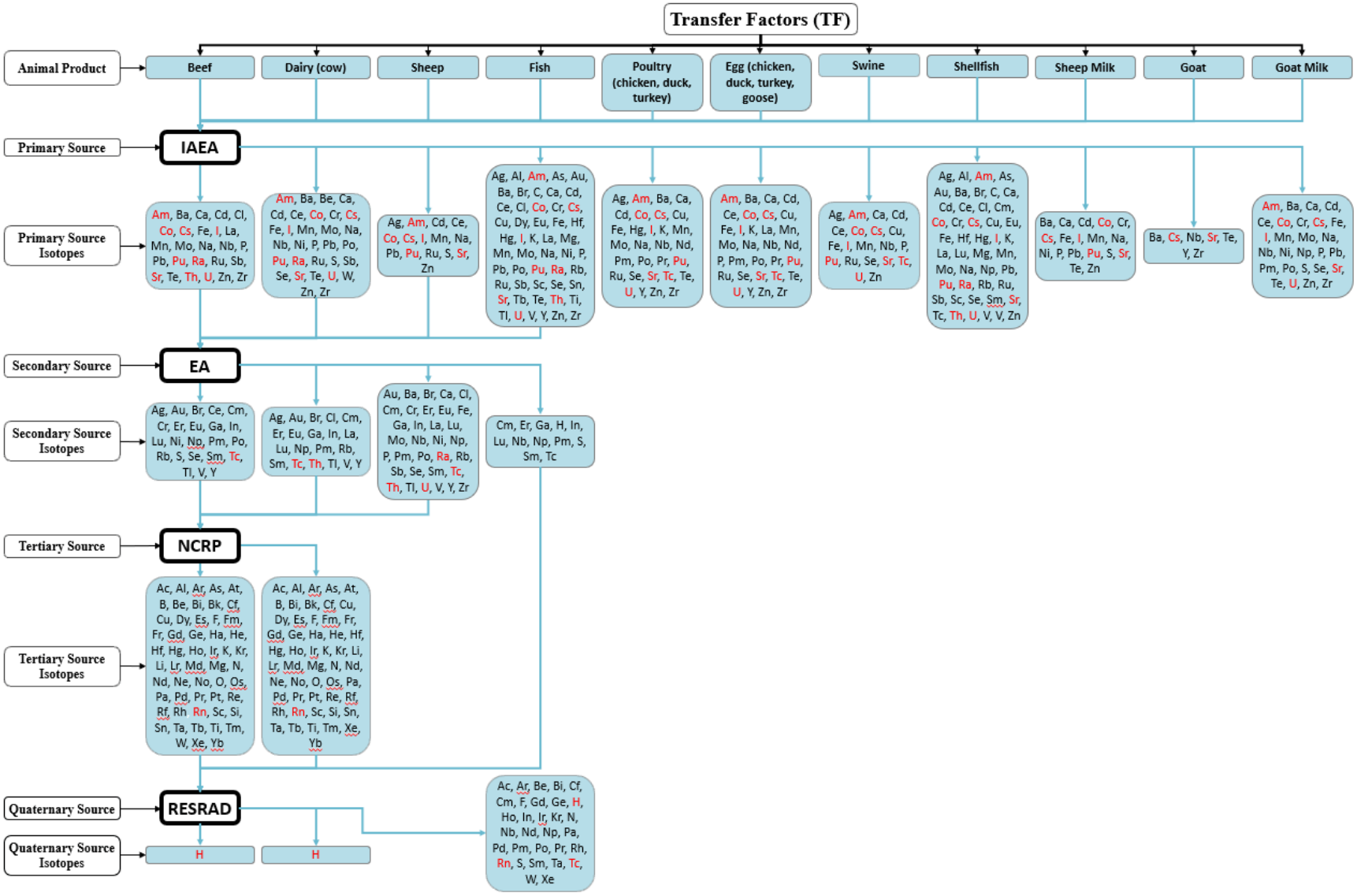
	Primary Transfer Factor Category	Primary Transfer Factor Source	Number of Transfer Factors from Primary Source[1]	Secondary Transfer Factor Category	Secondary Transfer Factor Source	Number of Transfer Factors from Secondary Source[1,2]	Tertiary Transfer Factor Category	Tertiary Transfer Factor Source	Number of Transfer Factors from Tertiary Source[1,2,3]
Cereal Grains	Cereal Grain	IAEA TRS 472	37- Am, Ba, Cd, Ce, Cl, Cm, Co, Cr, Cs, Fe, I, K, La, Mn, Mo, Na, Nb, Ni, Np, P, Pb, Pm, Po, Pr, Pu, Ra, Rb, Ru, Sb, Sr, Tc, Te, Th, U, Y, Zn, Zr	None	NCRP-123, RADSSL, RESRAD, Baes paper	Any elements not previously listed, including H and Rn.	None	None	None

1. Red elements are on the 'Common Isotopes' list of EPA calculator webpages. (Am, Co, Cs, H, I, Pu, Ra, Rn, Sr, Tc, Th, U)
2. Transfer Factors from NCRP-123, RADSSL, and RESRAD are universal soil to plant Transfer Factors that are not specific to a particular plant category or type, but rather the element itself.
3. The Baes paper BVs are divided into two categories. Appendix E shows how these categories are applied to produce.
4. TRS-472 provides two differing transfer factor derivations for rice. The values derived from radionuclide studies are given in Table 22; the values derived from stable element data are presented in Table 23 (TRS-472, pg. 78). In the event that a transfer factor was provided for the same element in both tables, the most protective transfer factor was used.
5. **Apples:** with/without peel & crabapples. **Citrus:** all **Berries**: blackberry, blueberry, boysenberry, cranberry, elderberry, loganberry, mulberry, & raspberry (other than strawberry). **Cabbage:** brussel sprout, red, savoy, & Chinese celery (bok choy). **Lettuce:** whole, iceberg, & romaine. **White Potatoes:** peeled/whole.



- The red text elements are on the from the 'Common Isotopes' list on the calculator page.

FIGURE B-1: SOIL TO PLANT TRANSFER FACTOR (BV) FLOW CHART



- The red text elements are on the from the 'Common Isotopes' list on the calculator page.

FIGURE B-2: ANIMAL TRANSFER FACTOR (TF) FLOW CHART

APPENDIX C. APPLICATION OF MASS LOADING FACTORS

Table C-1 below lists the MLFs that are applied to each individual produce as well as pasture. Columns 2, 3 and 4 list the initial MLF, the initial MLF units, and its respective source. The unit conversion column shows the initial MLF in units of grams. If the initial MLF was already given in grams, then the column lists none. Once all the MLFs were converted to grams, a moisture content conversion factor was applied to convert the dry plant MLFs to fresh plant MLFs. The last two columns list the final MLFs and their units that are used in the PRG and DCC calculators.

TABLE C-1. MASS LOADING FACTORS

	Initial MLF	Initial MLF units	Initial MLF Source	Unit Conversion	Units After Mass Conversion	Moisture Content Conversion Factor	Moisture Content Conversion Factor Source	Final MLF (Soil Mass Loading Factor)	Final MLF Units
Apples[2]	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.160	EA (2009)	1.60E-04	g dry soil / g fresh plant
Citrus Fruits[2]	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.157	EA (2009)	1.57E-04	g dry soil / g fresh plant
Berries[2]	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.166	EA (2009)	1.66E-04	g dry soil / g fresh plant
Peaches	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.150	EA (2009)	1.50E-04	g dry soil / g fresh plant
Pears	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.160	EA (2009)	1.60E-04	g dry soil / g fresh plant
Strawberry	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.080	EA (2009)	8.00E-05	g dry soil / g fresh plant
Asparagus	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.079	EA (2009)	7.90E-05	g dry soil / g fresh plant
Beets	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.138	EA (2009)	1.38E-04	g dry soil / g fresh plant
Broccoli	10	mg dry soil / g dry plant	Hinton (1992)	0.01	g dry soil / g dry plant	0.101	SSG	1.01E-03	g dry soil / g fresh plant
Cabbage[2]	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.105	EA (2009)	1.05E-04	g dry soil / g fresh plant
Carrots	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.097	EA (2009)	9.70E-05	g dry soil / g fresh plant
Corn	1.7	mg dry soil / g dry plant	Pinder & McLeod	0.0017	g dry soil / g dry plant	0.085	SSG	1.45E-04	g dry soil / g fresh plant
Cucumbers	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.040	EA (2009)	4.00E-05	g dry soil / g fresh plant
Lettuce[2]	260	mg dry soil / g dry plant	Hinton (1992)	0.26	g dry soil / g dry plant	0.052	SSG	1.35E-02	g dry soil / g fresh plant
Lima Beans	45	mg dry soil / g dry plant	Hinton (1992)	0.045	g dry soil / g dry plant	0.085	SSG	3.83E-03	g dry soil / g fresh plant

TABLE C-1. MASS LOADING FACTORS

	Initial MLF	Initial MLF units	Initial MLF Source	Unit Conversion	Units After Mass Conversion	Moisture Content Conversion Factor	Moisture Content Conversion Factor Source	Final MLF (Soil Mass Loading Factor)	Final MLF Units
Okra	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.080	EA (2009)	8.00E-05	g dry soil / g fresh plant
Onions	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.097	EA (2009)	9.70E-05	g dry soil / g fresh plant
Peas	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.178	EA (2009)	1.78E-04	g dry soil / g fresh plant
Peppers[3]	30	mg dry soil / g dry plant	Hinton (1992)	0.030	g dry soil / g dry plant	0.074	SSG	2.22E-03	g dry soil / g fresh plant
Pumpkins	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.058	EA (2009)	5.80E-05	g dry soil / g fresh plant
Snap Beans[1]	45	mg dry soil / g dry plant	Hinton (1992)	0.045	g dry soil / g dry plant	0.111	SSG	5.00E-03	g dry soil / g fresh plant
Tomatoes	30	mg dry soil / g dry plant	Hinton (1992)	0.030	g dry soil / g dry plant	0.059	SSG	1.77E-03	g dry soil / g fresh plant
White Potatoes[2]	0.001	g dry soil / g dry plant	EA (2009)	None	g dry soil / g dry plant	0.210	EA (2009)	2.10E-04	g dry soil / g fresh plant
Pasture	250	mg dry soil / g dry plant	Hinton (1992)	0.25	g dry soil / g dry plant	N/A	N/A	N/A	N/A
Cereal Grains[1]	250	mg dry soil / g dry plant	Hinton (1992)	0.25	g dry soil / g dry plant	N/A	N/A	N/A	N/A
Rice[1]	250	mg dry soil / g dry plant	Hinton (1992)	0.25	g dry soil / g dry plant	N/A	N/A	N/A	N/A

1. Bush beans were a surrogate for lima beans and snap beans. Pasture was a surrogate for cereal grains and rice.
2. **Apples:** with/without peel & crabapples. **Citrus:** all **Berries**: blackberry, blueberry, boysenberry, cranberry, elderberry, loganberry, mulberry, & raspberry (other than strawberry). **Cabbage:** brussel sprout, red, savoy, & Chinese celery (bok choy). **Lettuce:** whole, iceberg, & romaine. **White Potatoes:** peeled/whole.
3. The tomato initial mass loading factor was used as a surrogate for peppers.

APPENDIX D. AGE SEGMENT AND BODY WEIGHT SENSIVITY ANALYSIS

To support selection of the most appropriate age segment used to derive adult intake rates and whether a single body weight or age-specific body weight should be used to derive both child and adult intake rates, a sensitivity analysis was conducted. The purpose of the analysis was to determine whether a particular age segment or body weight had a significant effect on intake rates.

Biota specific intake rates were calculated for each age segment provided in the Exposure Factors Handbook. Both a general, representative of children and adults, and age-specific body weights were then applied to each calculated intake rate. Figure D-1 shows the general and age-adjusted body weights that were used for each age segment. Figure D-1 below displays the body weights used for each age segment in the sensitivity analysis. Age is in years and body weight is in kg. The values in the adjusted column are calculated average body weights for the given age segment based on EFH 2011 table 8-11. The values in the general column come from OSWER directive 9200.1-120.

	Body Weight	
Age	General	Adjusted
00<01	15	7.8
01<03	15	11.4
03<06	15	17.0
06<12	15	31.8
06<12	80	31.8
12<20	80	62.4
20<40	80	79.6
40+	80	80.0
Mean	68.7	68.7

FIGURE D-1. BODY WEIGHTS

Table D-1 demonstrates the effect of using different body weights to determine intake rates in children. The sensitivity analysis indicated that the effect of using an age adjusted child body weight in place of a general child body weight for farmer was slightly more protective 53% of the time. For resident, using a general child body weight was slightly more protective 52% of the time.

Table D-2 demonstrates the effect of using both a general and age-adjusted body weight and different age segments for adults. It was determined that using a general body weight was the most protective 83.6% of the time for adults. The most protective intake rates came from the age segment 21+. This aligns with the OSWER Directive 9200.1-120, where an adult is 21+ years.

Table D-1: Green cells represent the most protective intake rates across all age segments and body weights.

TABLE D-1. CHILD INTAKE RATE SENSITIVITY TEST

	Child Body Weight (kg)	Farmer Child (g/day) (FW)	Resident Child (g/day) (FW)	Child Body Weight (kg)	Farmer Child (g/day) (FW)	Resident Child (g/day) (FW)
Apples	General	77.9	67.8	Age Adjusted	71.0	61.8
Citrus Fruits	General	179.2	179.2	Age Adjusted	183.3	183.3
Berries	General	21.5	21.5	Age Adjusted	21.7	21.7
Peaches	General	96.9	108.7	Age Adjusted	85.6	96.0
Pears	General	75.8	66.0	Age Adjusted	66.1	57.6
Strawberries	General	23.2	23.2	Age Adjusted	23.9	23.9
Asparagus	General	10.9	10.9	Age Adjusted	10.3	10.3
Beets	General	6.0	6.0	Age Adjusted	6.4	6.4
Broccoli	General	14.2	12.7	Age Adjusted	13.8	12.3
Cabbage	General	12.3	13.1	Age Adjusted	12.4	13.3
Carrots	General	11.9	13.3	Age Adjusted	12.0	13.3
Corn	General	27.1	19.9	Age Adjusted	26.0	19.1
Cucumbers	General	13.9	20.9	Age Adjusted	15.2	22.9
Lettuce	General	3.2	3.2	Age Adjusted	3.6	3.6
Lima Beans	General	21.7	21.7	Age Adjusted	19.6	19.6
Okra	General	8.5	8.5	Age Adjusted	8.9	8.9
Onions	General	6.7	5.3	Age Adjusted	7.0	5.5
Peas	General	20.2	22.4	Age Adjusted	16.6	18.4
Peppers	General	8.0	6.4	Age Adjusted	8.7	6.9
Pumpkins	General	22.1	22.1	Age Adjusted	17.8	17.8
Snap Beans	General	24.2	23.9	Age Adjusted	22.2	21.9
Tomatoes	General	32.8	28.0	Age Adjusted	32.7	27.9
White Potatoes	General	48.2	43.5	Age Adjusted	48.3	43.5
Dairy	General	944.6	n/a	Age Adjusted	933.2	n/a
Beef	General	62.1	n/a	Age Adjusted	65.1	n/a
Swine	General	29.4	n/a	Age Adjusted	31.1	n/a
Poultry	General	45.6	n/a	Age Adjusted	46.3	n/a
Egg	General	28.4	n/a	Age Adjusted	26.7	n/a
Fin fish	General	36.1	n/a	Age Adjusted	34.6	n/a
Shellfish	General	21.3	n/a	Age Adjusted	21.3	n/a

Table D-2: Green cells represent the most protective intake rates across all age segments and body weights.

TABLE D-2. ADULT INTAKE RATE SENSITIVITY TEST

	General Adult Body Weight (kg)						Age Adjusted Adult Body Weight (kg)					
	Farmer 6-40 (g/day) (FW)	Farmer 6-50+ (g/day) (FW)	Farmer 21+ (g/day) (FW)	Resident 6-26 (g/day) (FW)	Resident 6-50+ (g/day) (FW)	Resident 21+ (g/day) (FW)	Farmer 6-40 (g/day) (FW)	Farmer 6-50+ (g/day) (FW)	Farmer 21+ (g/day) (FW)	Resident 6-26 (g/day) (FW)	Resident 6-50+ (g/day) (FW)	Resident 21+ (g/day) (FW)
Apples	97.7	94.1	82.5	89.1	81.9	71.8	80.1	80.8	82.5	69.2	70.4	82.5
Citrus Fruits	361.9	357.6	344.1	367.4	357.6	344.1	287.7	301.5	344.1	270.4	301.5	344.1
Berries	42.4	40.6	34.6	44.9	40.6	34.6	33.1	33.5	34.6	32.7	33.5	34.6
Peaches	123.3	118.1	101.3	146.0	132.5	113.7	96.0	97.5	101.3	105.9	109.3	101.3
Pears	75.2	71.4	59.4	69.8	62.2	51.8	57.8	58.2	59.4	50.0	50.7	59.4
Strawberries	50.0	47.3	38.2	53.7	47.3	38.2	38.4	38.5	38.2	38.5	38.5	38.2
Asparagus	35.5	35.5	35.6	35.4	35.5	35.6	29.9	31.3	35.6	28.1	31.3	35.6
Beets	33.6	33.7	33.7	33.6	33.7	33.7	28.5	29.8	33.7	26.9	29.8	33.7
Broccoli	36.7	36.7	36.7	32.8	32.8	32.8	30.8	32.2	36.7	25.9	28.8	36.7
Cabbage	75.8	78.9	88.5	76.9	84.4	94.7	65.9	71.5	88.5	63.1	76.5	88.5
Carrots	27.2	26.3	23.4	31.5	29.2	26.0	21.7	22.1	23.4	23.5	24.6	23.4
Corn	80.2	80.2	79.2	59.2	58.8	58.1	67.8	70.8	79.2	47.3	51.9	79.2
Cucumbers	53.9	53.5	51.0	82.5	80.2	76.5	44.0	46.1	51.0	63.2	69.1	51.0
Lettuce	32.9	33.9	37.2	31.6	33.9	37.2	29.7	31.5	37.2	27.4	31.5	37.2
Lima Beans	32.9	33.1	33.3	32.8	33.1	33.3	27.7	29.1	33.3	26.1	29.1	33.3
Okra	32.5	32.0	30.4	33.2	32.0	30.4	27.3	28.1	30.4	26.4	28.1	30.4
Onions	27.3	27.3	27.3	21.5	21.5	21.5	23.5	24.4	27.3	17.6	19.2	27.3
Peas	33.8	33.2	31.4	38.3	36.8	34.9	28.3	29.1	31.4	30.3	32.2	31.4
Peppers	23.1	23.3	23.6	18.4	18.6	18.8	20.1	21.0	23.6	15.2	16.8	23.6
Pumpkins	58.5	59.9	64.0	56.8	59.9	64.0	51.0	54.2	64.0	47.1	54.2	64.0
Snap Beans	56.7	56.0	53.3	57.1	55.3	52.7	47.7	49.1	53.3	45.4	48.5	53.3
Tomatoes	101.9	99.6	91.8	89.6	84.9	78.2	83.1	85.4	91.8	68.7	72.8	91.8
White Potatoes	143.4	142.4	137.6	131.1	128.4	124.1	119.7	124.5	137.6	103.2	112.2	137.6
Dairy	1341.8	1182.6	692.6	n/a	n/a	n/a	993.7	919.6	692.6	n/a	n/a	n/a
Beef	199.7	191.6	167.1	n/a	n/a	n/a	160.9	162.3	167.1	n/a	n/a	n/a
Swine	110.5	106.4	94.0	n/a	n/a	n/a	91.0	91.6	94.0	n/a	n/a	n/a
Poultry	128.3	122.9	105.6	n/a	n/a	n/a	104.0	104.6	105.6	n/a	n/a	n/a
Egg	67.1	65.3	60.1	n/a	n/a	n/a	55.5	56.6	60.1	n/a	n/a	n/a
Fish	149.7	159.7	155.9	n/a	n/a	n/a	116.4	142.6	155.6	n/a	n/a	n/a
Shellfish	160.6	187.0	208.9	n/a	n/a	n/a	139.0	175.9	208.5	n/a	n/a	n/a

Table D-3: As indicated by the yellow cells, generally, the most protective intake rates are those calculated using a general body weight and age segment of 21+.

TABLE D-3. RESULTS OF SENSITIVITY TESTS

	Total # of Green Cells	% Green Cells in Each Body Weight Category	# of Green Cells in Age Segments 6-26 and/or 6-40	% Green Cells in Age Segments 6-26 and/or 6-40	# of Green Cells in Age Segment 6-50+	% Green Cells in Age Segment 6-50+	# of Green Cells in Age Segment 21+	% Green Cells in Age Segment 21+	Most Protective Age Segment
General BW	52	83.6%	31	100.0%	5	100.0%	16	45.7%	**6-50+**
Age-Adjusted BW	19	16.4%	0	0.0%	0	0.0%	19	54.29%	**21+**
Both BW	71	100.0%	31	43.7%	5	7.0%	35	49.3%	**21+**
Most Protective BW		**General**		**General**		**General**		**Age-Adjusted**	

APPENDIX E. BAES PRODUCE CATEGORIES

Figure E-1: The flow chart below illustrates how Leafy Vegetables use B_v whereas Exposed Produce, Protected Produce, and Grains use B_r.

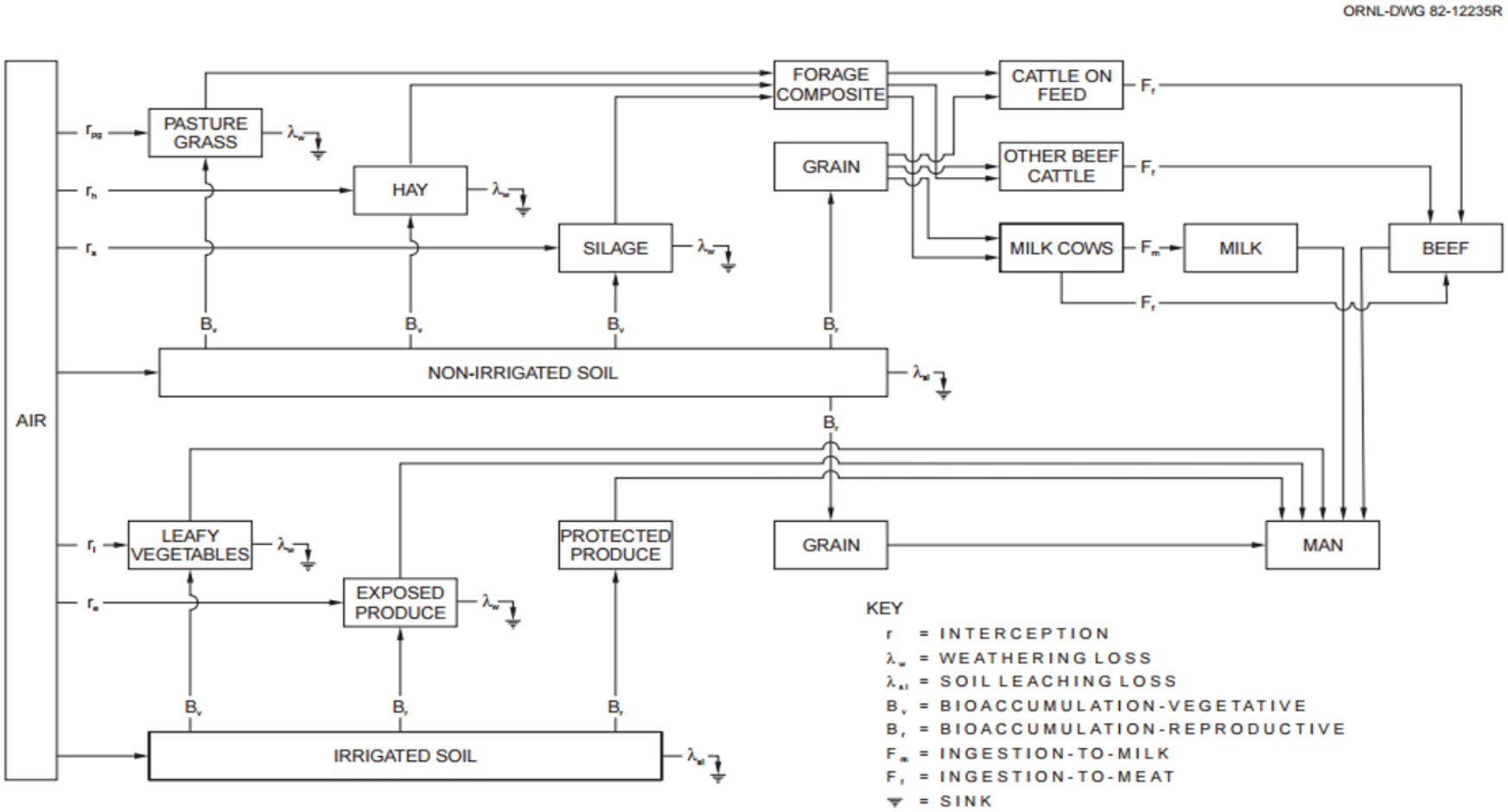


FIGURE E-1. BAES SOIL TO PLANT TRANSFER FACTOR FLOW CHART

Table F-1 below shows how these values are applied to the 25 produce types that are now available in the PRG and DCC calculators. For simplicity, the PRG and DCC calculators refer to all soil to plant transfer factors as B_v.

TABLE E-1. PRODUCE DELINEATION FOR BAES BV'S

	Produce Category	Bv or Br
Apples[1]	Exposed	B_r (exposed produce)
Citrus Fruits[1]	Protected	B_r (protected produce)
Berries[1]	Exposed	B_r (exposed produce)
Peaches	Exposed	B_r (exposed produce)
Pears	Exposed	B_r (exposed produce)
Strawberry	Exposed	B_r (exposed produce)
Asparagus	Exposed	B_r (exposed produce)
Beets[3]	Protected	B_r (protected produce)
Broccoli	Leafy	B_v (leafy vegetable)
Cabbage[1]	Leafy	B_v (leafy vegetable)
Carrots	Protected	B_r (protected produce)
Corn	Grain	B_r (protected produce)
Cucumbers	Exposed	B_r (exposed produce)
Lettuce[1]	Leafy	B_v (leafy vegetable)
Lima Beans	Protected	B_r (protected produce)
Okra	Exposed	B_r (exposed produce)
Onions	Protected	B_r (protected produce)
Peas	Protected	B_r (protected produce)
Peppers	Exposed	B_r (exposed produce)
Pumpkins[2]	Exposed	B_r (exposed produce)
Snap Beans	Exposed	B_r (exposed produce)
Tomatoes	Exposed	B_r (exposed produce)
White Potatoes[1]	Protected	B_r (protected produce)
Cereal Grains	Grain	B_r (grain)
Rice	Grain	B_r (grain)

1. **Apples:** with/without peel & crabapples. **Citrus:** all **Berries**: blackberry, blueberry, boysenberry, cranberry, elderberry, loganberry, mulberry, & raspberry (other than strawberry). **Cabbage:** brussel sprout, red, savoy, & Chinese celery (bok choy). **Lettuce:** whole, iceberg, & romaine. **White Potatoes:** peeled/whole.
2. In the BAES document page 13, paragraph 7, sentence 2 refers to a B_r for pumpkin. Pumpkin is also considered a squash, which is an exposed produce according to Table 2.3.
3. According to Table 2.3, Sugarbeets are protected produce. Since sugarbeets are the same species as table beets (Beta Vulgaris L), the same BV is used.

Figure E-2 is Table 2.3 from BAES. This table was used to determine which of the produce categories each of the individual produce, offered in the PRG and DCC calculators, belongs to and, therefore, which BAES soil to plant BV to use.

Table 2.3. Dry-to-wet weight conversion factors for exposed produce, protected produce, and grains

Vegetable	Conversion factor[a]	Weighting factor[b]	Reference
Exposed produce			
Apple	0.159	15.4	14
Asparagus	0.070	0.6	14
Bushberries	0.151	1.6	14
Cherry	0.170	0.7	14
Cucumber	0.039	4.0	14
Eggplant	0.073	0.1	14
Grape	0.181	20.2	14
Peach	0.131	6.9	14
Pear	0.173	3.5	14
Plums and prunes	0.540	3.1	14
Sweet pepper	0.074	1.3	14
Snap bean	0.111	0.7	14
Squash	0.082	1.8	14
Strawberry	0.101	1.3	14
Tomato	0.059	38.8	14
Weighted average	0.126		
Protected produce			
Bean (dry)	0.878	2.2	14
Cantaloupe	0.060	1.1	14
Carrot	0.118	2.4	14
Grapefruit	0.112	5.5	14
Lemon	0.107	2.4	14

Vegetable	Conversion factor	Weighting factor	Reference
Protected produce			
Onion	0.125	3.6	14
Orange	0.128	22.8	14
Peanut	0.920	3.4	38
Peas	0.257	0.4	14
Potato	0.222	33.7	14
Sugarbeet	0.164	6.5	13
Sugarcane	0.232	5.5	13
Sweet corn	0.261	6.0	14
Sweet potato	0.315	1.5	14
Tree nuts	0.967	0.4	14
Watermelon	0.079	2.6	14
Weighted average	0.222		
Grains			
Barley	0.889	10.1	14
Corn (for meal)	0.895	37.7	38
Oats	0.917	2.3	14
Rye	0.890	0.5	14
Soybean	0.925	5.3	14
Wheat	0.875	44.0	14
Weighted average	0.888		

FIGURE E-2. BAES PRODUCE CATEGORIES

Figure E-3 is Table 3.1 from BAES. This table was used to determine which of the produce categories each of the individual produce, offered in the PRG and DCC calculators, belongs to and, therefore, which soil to plant BV to use from the Baes paper.

Table 3.1. Weighting factors for leafy vegetable interception fraction model simulation

Leafy vegetable	Quantity planted (km^2)	Percent	Weight factor
Lettuce	948	42	
cos			14
head			14
leaf			14
Cabbage	367	16	
early			6
late			5
Chinese			5
Greens	246	11	
collards			3
kale			3
spinach			3
New Zealand spinach			2
Broccoli	176	8	
sprouting			4
raab			4
Mint	160	7	7
Celery	140	6	6
Cauliflower	113	5	5
Green onions	59.3	3	3
Escarole	33.6	2	
chicory			1
endive			1
Brussels sprouts	24.8	1	1
Total	2267.7	100	100

FIGURE E-3. BAES LEAFY VEGETABLE CATEGORY

Figure E-4 is Table 3.2 from BAES. This table was used to determine which of the produce categories each of the individual produce offered in the PRG and DCC calculators belongs to and, therefore, which soil to plant BV to use from the Baes paper.

Table 3.2. Relative importance of various exposed produce in the U.S.

Vegetable	Quantity planted (km^2)	Percent of category	Percent of sub-category
Non-citrus tree fruits			
Apple	1960	27.2	57.3
Apricot	6.00	0.1	0.2
Cherry	429	6.0	12.5
Date	0.101	≤0.1	≤0.1
Fig	0.0647	≤0.1	≤0.1
Mango	4.86	≤0.1	0.1
Nectarine	3.63	≤0.1	0.1
Peach	644	9.0	18.8
Pear	229	3.2	6.7
Hot Pepper	48.2	0.7	1.4
Plum	36.6	0.5	1.1
Prune	61.4	0.9	1.8
Total	3423	47.6	
Berries & vine fruits			
Blackberry	94.5	1.3	10.6
Blueberry	154	2.1	17.3
Boysenberry	4.75	≤0.1	0.5
Cranberry	91.2	1.3	10.2
Currant	1.12	≤0.1	0.1
Gooseberry	0.348	≤0.1	≤0.1
Grape	411	5.7	46.1
Pimento	1.64	≤0.1	0.2
Rasberry	29.9	0.4	3.4
Strawberry	104	1.5	11.7
Total	892	12.4	
Field crops			
Asparagus	269	3.7	9.3
Cucumber	380	5.3	13.2
Eggplant	16.0	0.2	0.6
Okra	16.7	0.2	0.6
Rhubarb	6.80	0.1	0.2
Sweet pepper	155	2.2	5.4
Snap bean	1250	17.4	43.4
Squash	133	1.9	4.6
Tomato	655	9.1	22.7
Total	2880	40.0	

FIGURE E-4. BAES EXPOSED PRODUCE CATEGORY

Figure E-5 is Figure 2.1 from the Baes paper and provides B_v values that should be used for leafy vegetables. B_v whereas Exposed Produce, Protected Produce, and Grains use B_r.

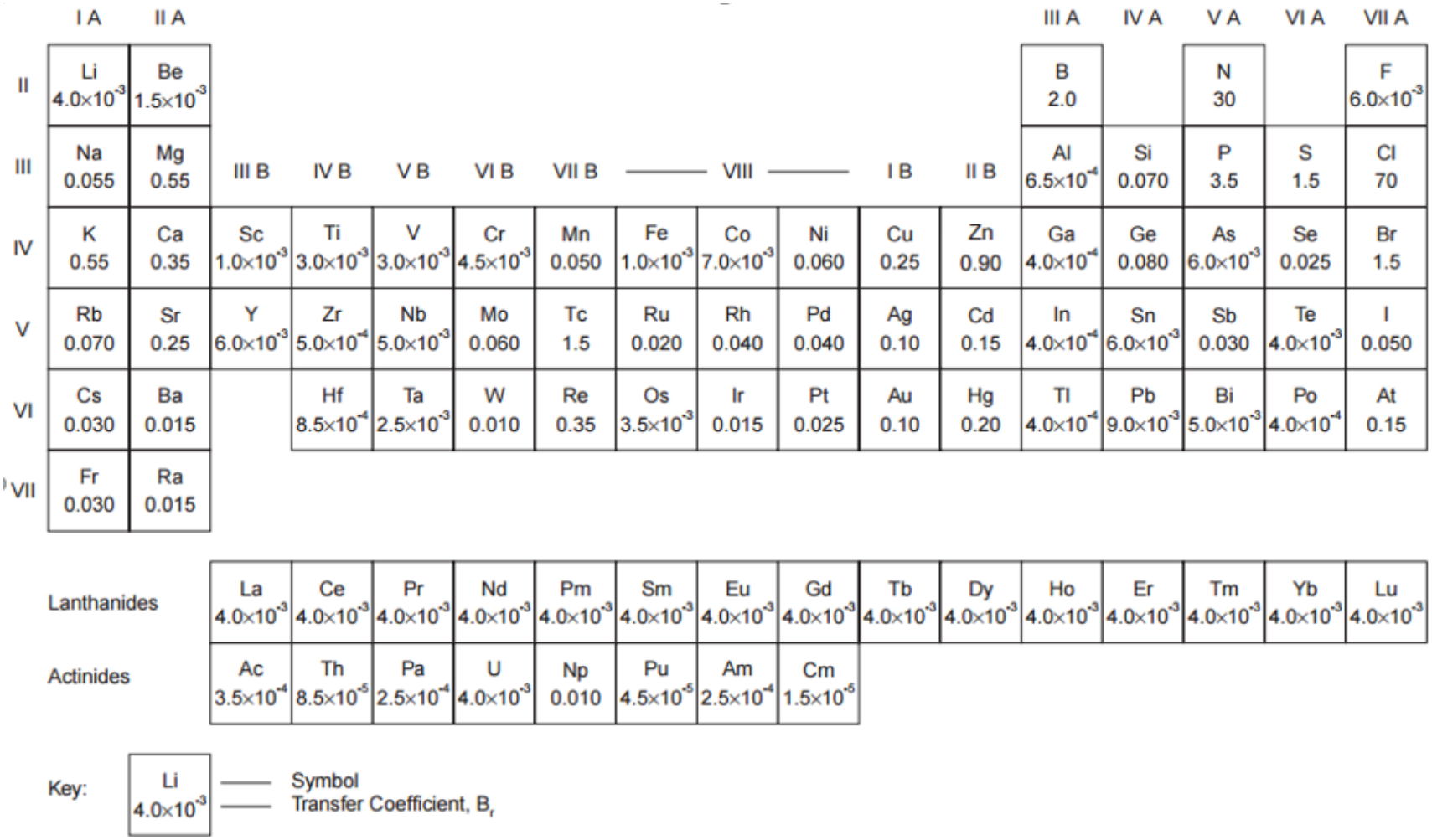
	I A	II A											III A	IV A	V A	VI A	VII A
II	Li 0.025	Be 0.010											B 4.0		N 30		F 0.060
III	Na 0.075	Mg 1.0	III B	IV B	V B	VI B	VII B	——	VIII	——	I B	II B	Al 4.0×10^{-3}	Si 0.35	P 3.5	S 1.5	Cl 70
IV	K 1.0	Ca 3.5	Sc 6.0×10^{-3}	Ti 5.5×10^{-3}	V 5.5×10^{-3}	Cr 7.5×10^{-3}	Mn 0.25	Fe 4.0×10^{-3}	Co 0.020	Ni 0.060	Cu 0.40	Zn 1.5	Ga 4.0×10^{-3}	Ge 0.40	As 0.040	Se 0.025	Br 1.5
V	Rb 0.15	Sr 2.5	Y 0.015	Zr 2.0×10^{-3}	Nb 0.020	Mo 0.25	Tc 9.5	Ru 0.075	Rh 0.15	Pd 0.15	Ag 0.40	Cd 0.55	In 4.0×10^{-3}	Sn 0.030	Sb 0.20	Te 0.025	I 0.15
VI	Cs 0.080	Ba 0.15		Hf 3.5×10^{-3}	Ta 0.010	W 0.045	Re 1.5	Os 0.015	Ir 0.055	Pt 0.095	Au 0.40	Hg 0.90	Tl 4.0×10^{-3}	Pb 0.045	Bi 0.035	Po 2.5×10^{-3}	At 1.0
VII	Fr 0.030	Ra 0.015															

Lanthanides	La 0.010	Ce 0.010	Pr 0.010	Nd 0.010	Pm 0.010	Sm 0.010	Eu 0.010	Gd 0.010	Tb 0.010	Dy 0.010	Ho 0.010	Er 0.010	Tm 0.010	Yb 0.010	Lu 0.010
Actinides	Ac 3.5×10^{-3}	Th 8.5×10^{-4}	Pa 2.5×10^{-3}	U 8.5×10^{-3}	Np 0.10	Pu 4.5×10^{-4}	Am 5.5×10^{-3}	Cm 8.5×10^{-4}						

Key: Li 0.025 —— Symbol —— Transfer Coefficient, B_v

FIGURE E-5. BAES LEAFY VEGETABLE BVS

Figure E-6 is Figure 2.2 from the Baes paper and provides B_r values that should be used for protected produce, exposed produce, and grains.



	I A	II A											III A	IV A	V A	VI A	VII A
II	Li 4.0×10^{-3}	Be 1.5×10^{-3}											B 2.0		N 30		F 6.0×10^{-3}
III	Na 0.055	Mg 0.55	III B	IV B	V B	VI B	VII B	—— VIII ——			I B	II B	Al 6.5×10^{-4}	Si 0.070	P 3.5	S 1.5	Cl 70
IV	K 0.55	Ca 0.35	Sc 1.0×10^{-3}	Ti 3.0×10^{-3}	V 3.0×10^{-3}	Cr 4.5×10^{-3}	Mn 0.050	Fe 1.0×10^{-3}	Co 7.0×10^{-3}	Ni 0.060	Cu 0.25	Zn 0.90	Ga 4.0×10^{-4}	Ge 0.080	As 6.0×10^{-3}	Se 0.025	Br 1.5
V	Rb 0.070	Sr 0.25	Y 6.0×10^{-3}	Zr 5.0×10^{-4}	Nb 5.0×10^{-3}	Mo 0.060	Tc 1.5	Ru 0.020	Rh 0.040	Pd 0.040	Ag 0.10	Cd 0.15	In 4.0×10^{-4}	Sn 6.0×10^{-3}	Sb 0.030	Te 4.0×10^{-3}	I 0.050
VI	Cs 0.030	Ba 0.015		Hf 8.5×10^{-4}	Ta 2.5×10^{-3}	W 0.010	Re 0.35	Os 3.5×10^{-3}	Ir 0.015	Pt 0.025	Au 0.10	Hg 0.20	Tl 4.0×10^{-4}	Pb 9.0×10^{-3}	Bi 5.0×10^{-3}	Po 4.0×10^{-4}	At 0.15
VII	Fr 0.030	Ra 0.015															

Lanthanides	La 4.0×10^{-3}	Ce 4.0×10^{-3}	Pr 4.0×10^{-3}	Nd 4.0×10^{-3}	Pm 4.0×10^{-3}	Sm 4.0×10^{-3}	Eu 4.0×10^{-3}	Gd 4.0×10^{-3}	Tb 4.0×10^{-3}	Dy 4.0×10^{-3}	Ho 4.0×10^{-3}	Er 4.0×10^{-3}	Tm 4.0×10^{-3}	Yb 4.0×10^{-3}	Lu 4.0×10^{-3}
Actinides	Ac 3.5×10^{-4}	Th 8.5×10^{-5}	Pa 2.5×10^{-4}	U 4.0×10^{-3}	Np 0.010	Pu 4.5×10^{-5}	Am 2.5×10^{-4}	Cm 1.5×10^{-5}							

Key: Li 4.0×10^{-3} —— Symbol —— Transfer Coefficient, B_r

FIGURE E-6. BAES OTHER THAN LEAFY VEGETABLE BV'S

APPENDIX F. WATER, SOIL, AND FODDER INTAKE RATES BY ANIMALS

Table F-1 below lists the fodder, water, and soil intake rates of the farm animals that are offered in the PRG and DCC calculators.

TABLE F-1. ANIMAL FODDER, WATER, AND SOIL INTAKE RATES

	Fodder Intake (Qp) kg/day	Fodder Intake Source	Water Intake (Qw) L/day	Water Intake Source	Soil Intake (Qs) kg/day	Soil Intake Source
Dairy (Cow)	20.3	f	92	i	0.4	f
Beef	11.77	f	53	i	0.5	f
Swine	4.7	f	11.4	g,h	0.37	f
Poultry (Chicken)	0.2	f	0.4	a,f	0.022	f
Goat Milk	1.59	b,e	8.75	e	0.29	d
Sheep Milk	3.15	b,c	10.4	c	0.57	d
Sheep Meat	1.75	b,c	5.2	c	0.32	d
Goat Meat	1.27	b	3.81	e	0.23	d
Duck	0.24	a	0.48	a	0.024	a
Turkey	0.68	a	1.36	a	0.068	a
Goose	0.33	a	0.66	a	0.033	a

a. NRC 1994: (Qw = 2 x Qp) and (Qs = 10% of Qp)
b. Lyons et. al. 1999. Mutton Qp = 3.5% of body weight; Goat Qp = 4% of body weight; Dairy Sheep Qp = 1.5% x Mutton Qp; Dairy Goat Qp = 1.5% x Goat Qp.
c. OMAFRA Water Requirements of Livestock Factsheet (body weight for dairy sheep 90kg, body weight for feeder lamb 50kg)
d. Handbook of Ecotoxicology 2002: Qs = 18% of Qp for sheep. Due to lack of sufficient data for soil intake of goats, this figure was also used to determine Qs for goats.
e. Guidelines to Feeding and Management of Dairy Goats (Goat Qw = 3 x Qp; Dairy Goat Qw = average production milk x average consumption of water per 1 L of milk produced)
f. HHRAP 2005
g. NEC Swine Nutrition Guide
h. HHRAP 1998
i. Data Collection for the Hazardous Waste Identification Rule, U.S. EPA 1999

APPENDIX G. PLANT UPTAKE IN NON-IRRIGATION SCENARIOS

When crops are grown in contaminated soil the primary mechanisms for the contaminant to assimilate in the produce are through root uptake and soil mass loading onto the plant surface. Equation G-1 depicts the application of the BV_{wet} and the MLF in a PRG and/or DCC. See references NCRP (1996) and University of Tennessee (1999) for more information.

EQUATION G-1. CONSUMPTION OF PRODUCE BACK CALCULATED TO SOIL

$$PRG_{res\text{-}soil\text{-}produce\text{-}ing\text{-}tot}\,(pCi/g) = \frac{1}{\left(\sum_{i=1}^{n} \frac{1}{PRG_{res\text{-}soil\text{-}produce\text{-}ing}\,(pCi/g)_i}\right)}$$

where:

n = total number of produce items included

and:

$$PRG_{res\text{-}soil\text{-}produce\text{-}ing}\,(pCi/g) = \frac{PRG_{res\text{-}produce\text{-}ing}\,(pCi/g)}{\left(R_{upv} + R_{es}\right)}$$

where:

$$R_{upv} = Bv_{wet}\left(\frac{pCi\ /\ g\text{-fresh plant}}{pCi\ /\ g\text{-dry soil}}\right);\ R_{es} = MLF_{produce}\left(\frac{g\text{-dry soil}}{g\text{-fresh plant}}\right)$$

Root Uptake (R_{upv})

Plants are exposed to contaminants in soil through root uptake. The model used to account for this exposure involves dividing a PRG, derived to give a protective concentration in produce consumed by human, by a contaminant-specific soil to plant transfer factor (BV_{wet}) as shown in Equation G-1. A BV_{wet} is defined as the ratio of the concentration of the contaminant in fresh plant tissue to the concentration in dry soil (pCi/g-fresh plant per pCi/g-dry soil) and are a measure of how much of the soil contamination is transferred to plant tissues by root uptake. Site-specific BV_{wet} values are preferred but in the absence of site-specific values, default values can be applied. Section 3.2 describes the transfer coefficient hierarchy used for animal products and produce calculations in the PRG and DCC calculators.

Resuspension (R_{es})

When crops are grown in contaminated soil the primary mechanisms for the contaminant to assimilate in the produce are through root uptake and soil mass loading onto the plant surface. Equation G-1 depicts the application of the BV_{wet} and the MLF in a PRG and/or DCC. Contaminants in surface soil layers can be resuspended by wind or mechanical disturbances such as rain, irrigation, or farm equipment. Resuspended soil particles may then be deposited on plant surfaces. Contaminant concentrations are usually higher in soil than in plants, so even small amounts of soil on plant surfaces can make a significant contribution to exposure through ingestion. For relatively insoluble metals, greater quantities may be ingested with soil particles on plant surfaces than those that have been incorporated into the internal tissues of the plant. In

environments where resuspension prevails, direct deposition on plant foliage may exceed root uptake. All forms of resuspension are accounted for in the MLF.

MLFs can be multiplied by the contaminant concentration in the resuspended soil fraction to derive the contaminant concentration in the plant. The PRG for the direct consumption of produce is divided by the MLF as shown in Equation G-1. Many plant-specific MLFs are given in Appendix C of this TM.

APPENDIX H. PLANT UPTAKE IN IRRIGATION SCENARIOS

When crops are irrigated with contaminated water, the soil becomes contaminated and root uptake occurs into the plant. Additionally, resuspension of soil onto the plant and direct deposition onto the plant occurs. BV_{wet}'s, MLFs, and interception fractions are used to account for root uptake, resuspension, and deposition, respectively, in determining the mass or activity of a contaminant in plants.

The irrigation rate and irrigation frequency define the amount and duration of water, and subsequently contaminant, applied to crops. Irrigation of produce, either for human or farm animal consumption, should be evaluated for appropriateness at a site. Generally, in areas with high rainfall, irrigation is less common. Additionally, irrigation of pasture for farm animal fodder is even less common. Ideally, site-specific data on irrigation rates and frequency should be used. Equation H-1 depicts the use of the three ways contaminants can get in and/or on plants from irrigation. See references NCRP (1996) and University of Tennessee (1999) for more information.

EQUATION H-1. CONSUMPTION OF PRODUCE BACK CALCULATED TO WATER

$$PRG_{water\text{-}res\text{-}produce\text{-}ing\text{-}tot}\,(pCi/L) = \frac{1}{\left(\sum_{i=1}^{n} \frac{1}{PRG_{water\text{-}res\text{-}produce\text{-}ing}\,(pCi/L)_i}\right)}$$

where:

n = total number of produce items included

and:

$$PRG_{water\text{-}res\text{-}produce\text{-}ing}\,(pCi/L) = \frac{PRG_{res\text{-}produce\text{-}ing}\,(pCi/g)}{\left(\frac{1\ kg}{1000\ g}\right) \times \left(Irr_{rup}\left(\frac{L}{kg}\right) + Irr_{res}\left(\frac{L}{kg}\right) + Irr_{dep}\left(\frac{L}{kg}\right)\right)}$$

Root Uptake (Irr_{rup})

Root uptake occurs within the root zone depth of soil. Over time (t_b), the soil will become contaminated from the contaminants in the irrigation water due to deposition and buildup. This value is based on 30 years for resident and farmer but could be set to a site-specific or default exposure duration. The depth of the root zone (0.15 m) is multiplied by the soil density (1600 kg/m³) to give an aerial soil density (P) in kg/m². Over time, the contaminant will also be removed (λ_B) from the soil by radioactive decay, harvest, and leaching through the root zone. A 70-year removal half-time of 0.000027/d for harvesting and leaching is used. Equation H-2 depicts root uptake from irrigation considering long-term deposition and removal rates.

EQUATION H-2. ROOT UPTAKE FROM IRRIGATION

$$Irr_{rup}\left(\frac{L}{kg}\right) = \frac{Ir\left(\frac{L}{m^2\text{-day}}\right) \times F \times Bv_{wet}\left(\frac{pCi/g\ plant}{pCi/g\ soil}\right) \times \left[1\text{-}exp\left(-\left(\frac{\lambda_B}{day}\right) \times t_b\ (days)\right)\right]}{P\left(\frac{kg}{m^2}\right) \times \left(\frac{\lambda_B}{day}\right)}$$

where:

$Ir\left(\frac{L}{m^2\text{-day}}\right)$ = irrigation rate;

F = irrigation period = fraction of year plants are irrigated $(unitless)$;

$Bv_{wet}\left(\frac{pCi/g\ plant}{pCi/g\ soil}\right)$ = soil to plant transfer factor;

λ_B = the effective removal constant for given constituent from soil $(per\ day)$, $\lambda_B = \lambda_i + 0.000027$;

λ_i = decay $(per\ day) = 0.693 / T_R$;

T_R = half-life $(days)$;

t_b = long-term deposition and buildup $(days)$;

$P\left(\frac{kg}{m^2}\right)$ = root zone soil density = $1600\left(\frac{kg}{m^3}\right) \times 0.15\ (m) = 240\left(\frac{kg}{m^2}\right)$.

Resuspension (Irr_{res})

The MLF is defined as the ratio of the mass of soil on vegetation per mass of dry (or fresh) vegetation. It is multiplied by the contaminant concentration in surface soil to determine the concentration of the contaminant deposited on the plant via resuspension. Site-specific and plant-specific mass loading factors are preferred. Appendix C presents the default MLFs used in the PRG and DCC calculators for each produce. Equation H-3 depicts resuspension from irrigation considering long-term deposition and removal rates.

EQUATION H-3. RESUSPENSION FROM IRRIGATION

$$Irr_{res}\left(\frac{L}{kg}\right)=\frac{Ir\left(\frac{L}{m^2\text{-day}}\right)\times F\times MLF_{produce}\left(\frac{\text{g dry soil}}{\text{g soil fresh plant}}\right)\times\left[1\text{-}\exp\left(-\left(\frac{\lambda_B}{day}\right)\times t_b\,(\text{days})\right)\right]}{P\left(\frac{kg}{m^2}\right)\times\left(\frac{\lambda_B}{day}\right)}$$

where:

$Ir\left(\frac{L}{m^2\text{-day}}\right)$ = irrigation rate;

F = irrigation period = fraction of year plants are irrigated (unitless);

$MLF_{produce}\left(\frac{\text{g dry soil}}{\text{g soil fresh plant}}\right)$ = soil to plant transfer factor;

λ_B = the effective removal constant for given constituent from soil (per day), $\lambda_B = \lambda_i + 0.000027$;

λ_i = decay (per day) = $0.693 / T_R$;

T_R = half-life (days);

t_b = long-term deposition and buildup (days);

$P\left(\frac{kg}{m^2}\right)$ = root zone soil density = $1600\left(\frac{kg}{m^3}\right) \times 0.15\ (m) = 240\left(\frac{kg}{m^2}\right)$.

Aerial Deposition from Irrigation (Irr_{dep})

Irrigation water deposited on the plant surface can result in contaminated plant tissue. The irrigation rate, irrigation frequency, and the ability of the plant to intercept the water are the primary factors considered in ariel deposition from irrigation. The interception fraction (I_r) accounts for the proportion of aerial deposition that is intercepted by plant surfaces. Different plants have different interception fractions. The density (proximity of other plants) and size throughout the growing season can impact the interception fraction. A value of 0.42 (unitless) is used for all plant types in the PRG and DCC, however, a site-specific interception fraction can be substituted if available.

The translocation factor (T) is used to account for movement of contaminants from plant surfaces on which they were deposited to the edible portions of plants. The edible portion of leafy vegetables and pasture grasses are the leaf surfaces, so the translocation factor is set to 1.0 for these plant types and used as a default for all other plants. The plant yield (Y) is issued in the deposition model to represent the mass produced per area. The plant yield, combined with the irrigation rate, estimates the amount of contaminant on the plant. Different plant types have different plant yields and site-specific values are encouraged. Weathering and radioactive removal (λ_E) account for the removal of deposited material from the plant and radioactive decay. The time for weathering half-life (t_w) is set at 14 days. Most crops are planted as seeds and after germination are above ground and then exposed to deposition. This time (t_v) varies by plant type and growing season conditions. Equation H-3 depicts interception from irrigation considering soil yield, weathering, and growing season conditions.

EQUATION H-3. AERIAL DEPOSITION FROM IRRIGATION

$$Irr_{dep}\left(\frac{L}{kg}\right) = \frac{Ir\left(\frac{L}{m^2\text{-day}}\right) \times F \times I_f \times T \times \left[1\text{-}\exp\left(-\left(\frac{\lambda_E}{day}\right) \times t_v\,(days)\right)\right]}{Y_v\left(\frac{kg}{m^2}\right) \times \left(\frac{\lambda_E}{day}\right)}$$

where:

$Ir\left(\frac{L}{m^2\text{-day}}\right)$ = irrigation rate;

F = irrigation period, fraction of year plants are irrigated $(unitless)$;

I_f = interception fraction; fraction of deposited material intercepted and retained on foliage $(unitless)$;

T = translocation factor; translocation of externally deposited contaminants to edible plant parts $(unitless)$;

λ_E = the effective removal constant for given constituent from plant $(per\ day)$, $\lambda_E = \lambda_i + 0.693 / T_w$

T_w = weathering half-life, time required for half of the originally deposited material to be lost from the plant;

λ_i = radioactive decay constant $(per\ day) = 0.693 / T_R$;

T_R = half-life $(days)$;

t_v = time of above-ground exposure of plant to contamination during the growing season $(days)$;

$Y_v\left(\frac{kg}{m^2}\right)$ = standing plant biomass at harvest above a unit surface area or yield of crop.

APPENDIX I. DERIVATION OF CARBON SOIL TO PLANT TRANSFER FACTOR

The derivation of the default transfer factor for carbon came from personal email communication with carbon expert, Mike Thorne. The email exchange is presented on the following pages.

Manning, Karessa

From: Mike Thorne <mikethorneltd@aol.com>
Sent: Friday, March 24, 2017 4:38 AM
To: Manning, Karessa L.; Walker.Stuart@epa.gov
Cc: Dolislager, Fredrick G.
Subject: Re: C-14 Soil-plant transfers

Follow Up Flag: Follow up
Flag Status: Flagged

Karessa

I can hardly criticize your UK secondary reference source, since I wrote it with Barbara Lambers. I agree that TRS 472 itself is not helpful, but the chapter on specific activity models in underpinning IAEA-TECDOC-1616 is useful. However, I think you are right that the best approach is for you to use the argument that I developed for you and to reference the AMEC document. I am pleased that this exchange seems to have been useful.

Regards

Mike Thorne
mikethorneltd@aol.com

-----Original Message-----
From: Manning, Karessa L. <manningkl@ornl.gov>
To: Mike Thorne <mikethorneltd@aol.com>; Walker.Stuart <Walker.Stuart@epa.gov>
CC: Dolislager, Fredrick G. <dolislagerf1@ornl.gov>
Sent: Thu, 23 Mar 2017 13:50
Subject: RE: C-14 Soil-plant transfers

Mike,

We recently implemented TRS-472 and updated a lot of elements. Unfortunately, in TRS-472 the only information provided are concentrations of stable carbon in plants (Table 66), but these cannot be compared with the transfer factor (or concentration ratio) of 5.5 we currently use. Our secondary source after TRS-472 is UK Science Report: SC030162/SR2 which is attached to this email. This briefly mentions the specific activity method, but is mainly focused on atmospheric deposition. The AMEC document you sent originally is the best description of the specific activity method we've seen so far. I think we would like to use a transfer factor of 0.1, per your delineation in a previous email and create a section in our user guide that references the AMEC document so our users can derive their own transfer factor provided they have collected the appropriate data.

Does this sound reasonable to you?

Thanks!

-Karessa

-----Original Message-----
From: Mike Thorne [mailto:mikethorneltd@aol.com]

Sent: Wednesday, March 22, 2017 5:13 PM
To: Manning, Karessa L. <manningkl@ornl.gov>; Walker.Stuart@epa.gov
Cc: Dolislager, Fredrick G. <dolislagerf1@ornl.gov>
Subject: Re: C-14 Soil-plant transfers

Karessa

Table E-1 of the 1977 document confirms that it is based on stable element data, i.e. the total stable carbon concentration in the plant ratioed with the total stable carbon concentration in the soil. This is as I suspected. The compilations of Ng et al. were standard references in the 1970s, but they have been replaced by reports such as IAEA Technical Reports Series No. 472 (2010).

Regards

Mike Thorne
mikethorneltd@aol.com

-----Original Message-----
From: Manning, Karessa L. <manningkl@ornl.gov>
To: Walker, Stuart <Walker.Stuart@epa.gov>; Mike Thorne <mikethorneltd@aol.com>
CC: Dolislager, Fredrick G. <dolislagerf1@ornl.gov>
Sent: Wed, 22 Mar 2017 17:31
Subject: RE: C-14 Soil-plant transfers

Hi Mike,

I have attached the original document that Argonne Lab referenced from 1977. The transfer factor of 5.5 can be found in table E-1. I have also found the document from 1968 that the 1977 document was referencing. This may shed some light on how the 5.5 transfer factor was derived.

Thanks!

-Karessa

-----Original Message-----
From: Walker, Stuart [mailto:Walker.Stuart@epa.gov]
Sent: Thursday, March 16, 2017 10:35 AM
To: Mike Thorne <mikethorneltd@aol.com>; Manning, Karessa L. <manningkl@ornl.gov>
Cc: Dolislager, Fredrick G. <dolislagerf1@ornl.gov>
Subject: RE: C-14 Soil-plant transfers

Mike,

Thanks for the further information. I will take a look at the IAEA chapter.

Stuart

-----Original Message-----
From: Mike Thorne [mailto:mikethorneltd@aol.com]
Sent: Thursday, March 16, 2017 4:52 AM
To: Walker, Stuart <Walker.Stuart@epa.gov>; manningkl@ornl.gov

Cc: dolislagerf1@ornl.gov
Subject: Re: C-14 Soil-plant transfers

Stuart

Thanks. I have downloaded the report on consumption of produce and farm animals and will have a look at it later. The issue of C-14 is always complex, as there are a variety of 'pools' of organic carbon in any environment and you have to ask the question 'Which of these pools will become labelled with C-14 and to what extent will the organism of interest access those pools?' This is where specific activity models can be misleading, as you may get the amount of C-14 correct, but then dilute it into the wrong carbon pool. Incidentally, similar issues arise with other elements. Some years ago, I looked into suitable models for Cl-36. In this case, care is needed to distinguish between Cl-36 in the chloride pool (which is available for uptake to plants) and Cl-36 incorporated in organic matter in soils (which is much less available). On these matters, the specific activity chapter in IAEA-TECDOC-1616 (pages 549 to 576) is worth a read.

Regards

Mike Thorne
mikethorneltd@aol.com

-----Original Message-----
From: Walker, Stuart <Walker.Stuart@epa.gov>
To: Mike Thorne <mikethorneltd@aol.com>; manningkl <manningkl@ornl.gov>
CC: dolislagerf1 <dolislagerf1@ornl.gov>
Sent: Wed, 15 Mar 2017 18:25
Subject: Re: C-14 Soil-plant transfers

Hi Mike,

Thanks for the explanation. It is helpful.

The 5.5 transfer factor is a carryover from a 2000 document "Soil Screening Guidance for Radionuclides." This was a joint project between my Superfund site remediation office and our radiation office. The staffer in the radiation office that worked on the transfer factors has been long retired. The 2000 document cited an earlier document from Argonne National lab for the 5.5 transfer factor.

Earlier this year staff from Argonne complained the 5.5 was a misinterpretation of their document. Looking over the Argonne document has shown a couple of other issues which is why we reached out to you via Brenda to see how others were addressing C-14. This probably came to their attention since we did a big update last December to how human consumption of produce and farm animals is addressed in our risk assessment model which if you are interested is discussed in this document https://epa-prgs.ornl.gov/radionuclides/20161130_Biota_TM_KLM_Final_printable_version.pdf

We were looking for supportable conservative default value for a transfer factor and also hopefully a methodology that someone could use get a more site-specific value. I think your explanation below is quite helpful on a default value and the UK EA document you sent has formula that we may reference for coming up with a site-specific value if desired. We will be discussing further when Fred returns next week.

Stuart

From: Mike Thorne <mikethorneltd@aol.com>
Sent: Wednesday, March 15, 2017 12:13 PM
To: manningkl@ornl.gov
Cc: Walker, Stuart; dolislagerf1@ornl.gov
Subject: Re: C-14 Soil-plant transfers

Karessa

Your current transfer factor is 5.5 pCi/g-fresh plant/pCi/g-dry soil. The units of activity do not matter, provided that they are consistent, so this is better expressed as 5.5 g-dry soil/g-fresh plant. I argued that for a soil concentration of 0.02 Bq/kg-dry soil, the plant concentration expressed on a dry mass basis would be about 0.008 Bq/kg. As plants are typically about 90% water, this corresponds to 0.0008 Bq/kg-fresh plant. Thus, the transfer factor defined identically to your approach is 0.0008/0.02 = 0.04 kg-dry soil/kg-fresh plant = 0.04 g-dry soil/g fresh plant. This indicates that the transfer factor that you should be using is 0.04 not 5.5. Incidentally, this is a best estimate, as I used central estimates for uptake via roots and during passage through the canopy atmosphere and a reasonable carbon content of soil. It is interesting to see how a value of around 5.5 originated. Consider that a plant is about 90% water and that of the 10% of dry matter about 40% is carbon. Therefore, plants comprise about 4% carbon on a fresh weight basis. A mineral soil is typically about 2% to 5% organic matter, which corresponds to 0.8% to 2% carbon on a dry mass basis. Thus, if you take the ratio of carbon contents you get a transfer factor of 4%/(0.8 to 2%) = 5.0 to 2.0 g-dry soil/g-fresh plant. Thus, your transfer factor would be a reasonably cautious estimate if all plant carbon was obtained from soil. However, as I have argued, only 2% of plant carbon comes from soil (either directly or by uptake from the sub-canopy atmosphere). The other 98% of plant carbon comes from the above-canopy atmosphere, which is assumed not to contain C-14. Therefore, a reasonable estimate of the transfer factor is 0.02*(5.0 to 2.0) = 0.1 to 0.04. The key uncertainties are the fraction of plant carbon derived from soil (values of up to 5% have been suggested, but these are extreme and 1-2% is more usual) and the fraction of carbon in mineral soil (as noted above 2-5% is reasonable).

I hope that this helps. The bottom line is that the only change that you need to make to your model is to change 5.5 to 0.04 as a realistic value, but you could use 0.1 if you wish to be cautious (allowing for either a mineral soil low in carbon or a mineral soil with a normal level of carbon and somewhat enhanced root uptake of that carbon). Alternatively, you could make the transfer factor 0.11, which would be your current value of 5.5 multiplied by 0.02 as the fraction of plant carbon obtained either directly or indirectly from the soil.

I hope that this helps.

Mike Thorne
mikethorneltd@aol.com

-----Original Message-----
From: Manning, Karessa L. <manningkl@ornl.gov>
To: Mike Thorne <mikethorneltd@aol.com>
CC: Walker.Stuart <Walker.Stuart@epa.gov>; Dolislager, Fredrick G. <dolislagerf1@ornl.gov>
Sent: Wed, 15 Mar 2017 15:08
Subject: RE: C-14 Soil-plant transfers

Hi Mike,

Sorry for the late response. I have a question regarding the C-14 soil to plant factor you derived. Since it is based on 1 Bq/kg, is the transfer factor of 0.4 for C-14 an average, low, or high end value? Should the calculation be based on another specific activity, or is 1 Bq/kg standard for C-14?

Our models use standards set by agency's like the EPA and IAEA, then we try to fill in the data gaps with other sources. In general, we try to use the most protective value, when possible, but we also want to provide a reasonable value as our current transfer factor overestimates the transfer from soil to plant because it includes carbon transfer from the atmosphere. Our current carbon soil to plant transfer factor, 5.5 (pCi/g-fresh plant / pCi/g-dry soil), is very old and has been carried from one paper to the next since 1977. Not to say it is inaccurate, but it is not relevant for our current model.

Essentially, we are trying to back calculate a preliminary remediation goal (PRG) in soil. I have attached a gif of our current soil to plant transfer model. Here is a link to our PRG sitehttps://epa-prgs.ornl.gov/radionuclides/ . In section 4.1.1 of our user guide, you can find our produce back calculated to soil equation, which is the same as the screenshot I have attached to this email in case you have trouble opening the attachment.

Databases and Tools| Waste and Cleanup Risk Assessment ...
epa-prgs.ornl.gov
PRG Home Society for Risk Analysis Meeting Posters New Biota Factors and Integration Complex Decay Chain Solver for Assessment and Cleanup Welcome

Here is a list of what each variable is from our model:
Direct ingestion equation:
IRres-c = human child intake rate
IRres-a = human adult intake rate
EDres-c = human child exposure duration
EDres-a = human adult exposure duration
EFres-c = human child exposure frequency EFres-a = human adult exposure frequency

Back calculated to soil:
Bvwet = soil to plant transfer factor
MLF = mass loading factor (soil stuck to plant)

Do you think that our current model to back calculate a PRG in soil works for C-14? Please forgive my ignorance as I am not a nuclear physicist and do not fully understand specific activity.

I really appreciate your assistance!
Thank you!

-Karessa

-----Original Message-----
From: Mike Thorne [mailto:mikethorneltd@aol.com]
Sent: Thursday, February 9, 2017 10:28 AM
To: Manning, Karessa L. <manningkl@ornl.gov>; bjho@ceh.ac.uk
Cc: Walker.Stuart@epa.gov; Dolislager, Fredrick G. <dolislagerf1@ornl.gov>

Subject: Re: C-14 Soil-plant transfers

Karessa

No problem. I am around throughout the next three weeks then on vacation for a week from 4th March.

Regards

Mike Thorne
mikethorneltd@aol.com

-----Original Message-----
From: Manning, Karessa L. <manningkl@ornl.gov>
To: Mike Thorne <mikethorneltd@aol.com>; bjho <bjho@ceh.ac.uk>
CC: Walker, Stuart <Walker.Stuart@epa.gov>; Dolislager, Fredrick G. <dolislagerf1@ornl.gov>
Sent: Thu, 9 Feb 2017 15:21
Subject: RE: C-14 Soil-plant transfers

Mike,

Thank you for responding to our inquiry. We will review this information and may contact you with questions.

We really appreciate your time.

-Karessa

-----Original Message-----
From: Mike Thorne [mailto:mikethorneltd@aol.com]
Sent: Tuesday, February 7, 2017 12:41 PM
To: Manning, Karessa L. <manningkl@ornl.gov>; bjho@ceh.ac.uk
Subject: C-14 Soil-plant transfers

Karessa and Brenda

My apologies for the delay in replying, but I was away last week in Snowdonia and am just catching up with my actions. If I was starting from scratch, I would not define a soil to plant transfer factor for carbon. This is because there are several different pools of carbon in soil (incorporated in organic matter, dissolved in soil solution, and present mainly as carbon dioxide in the gas phase). The specific activities of C-14 relative to stable carbon can be very different in these various pools and uptake occurs primarily from two of them. There is direct uptake from soil solution via the roots. This seems to be passive, since the observed amount of uptake can be accounted for by the flux of water observed to pass through plants in the transpiration stream. Also, the soil gas diffuses through the soil surface into the sub-canopy atmosphere where its carbon dioxide content is available for plant uptake by photosynthesis. I attach a detailed assessment model for C-14 entering the soil from below as carbon dioxide or methane that gives detailed information on the representation of these processes. However, to simplify, about 1% of plant uptake of carbon arises as passive uptake via the transpiration stream and a similar fraction arises from soil gas as it passes through the sub-canopy atmosphere. Therefore, about 2% of plant carbon arises directly or indirectly from the soil and 98% from photosynthesis of carbon delivered to the plant in above-canopy air that then interacts with and penetrates through the canopy.

If soil organic matter is in equilibrium with soil solution and carbon dioxide in soil gas and all three have the same specific activity of C-14, then the specific activity of C-14 in plants will be 2% of the specific activity of C-14 in soil organic matter. This would be my preferred, simple basis of modelling. However, you want a conventional soil to plant transfer

factor. Consider a mineral soil that comprises 5% organic matter (i.e. about 2% carbon by mass). Thus, if the specific activity of the carbon is 1 Bq/kg[C], the activity concentration in the soil, expressed on a dry mass basis, will be about 0.02 Bq/kg. However, if the specific activity of the soil solution and soil gas carbon is 1 Bq/kg[C], then the specific activity of plant carbon will be 0.02 Bq/kg[C], since only 2% of plant carbon comes directly or indirectly from the soil. As carbon comprises about 40% of the dry mass of plants, the C-14 concentration expressed on a dry mass basis is about 0.008 Bq/kg. Thus, the soil to plant transfer factor, as conventionally defined is 0.008/0.02 = 0.4.

I hope that this is helpful.

Regards

Mike Thorne
mikethorneltd@aol.com