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ORNL-5786

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture

C. F. Baes III
R. D. Sharp
A. L. Sjoreen
R. W. Shor

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL-5786

Health and Safety Research Division

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C. F. Baes III
Environmental Sciences Division

R. D. Sharp
Computer Sciences

A. L. Sjoreen
Computer Sciences

R. W. Shor
Health and Safety Research Division

Date Published: September 1984

Research Sponsored by the Office of Radiation Programs, U. S. Environmental Protection Agency under Interagency Agreement AD-89-F-2-A106 (formerly EPA-78-D-X0394)

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
operated by
Martin Marietta Energy Systems, Inc.
for the
U. S. DEPARTMENT OF ENERGY
under contract No. DE-AC05-84OR21400

DISCLAIMER

Although the research described in this report has been funded by the United States Environmental Protection Agency through Interagency Agreement Number AD-89-F-2-A106 (formerly EPA-78-D-X0394) with Oak Ridge National Laboratory, it has not been subjected to the Agency's required peer and policy review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

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PARAMETER SYMBOLS AND DEFINITIONS

Symbol	Definition
A_{hi}	The area allocated to crop *i* which is harvested or harvest area (m^2).
A_i	The inventory area allocated to crop *i* (m^2).
A_p	The area of pasture (m^2).
B_r	Soil-to-plant concentration factor which is the ratio of activity concentration in plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers, etc.) in dry weight to the dry weight activity concentration in root zone soil at edible maturity or time of harvest (unitless).
B_v	Soil-to-plant concentration factor which is the ratio of activity concentration in plant parts usually associated with vegetative functions (leaves, stems, straw, etc.) in dry weight to the dry weight activity concentration in root zone soil at edible maturity or time of harvest (unitless).
C_a^{C14}	Carbon-14 activity concentration in air (Bq or Ci/m^2).
C_a^{H3}	Tritium activity concentration in air (Bq or Ci/m^3).
C_a^r	Resuspension air concentration (Bq or Ci/m^3).
C_{cd}^{C14}	Carbon-14 activity concentration in atmospheric carbon dioxide (Bq or Ci/kg).
C_{food}^{H3}	Tritium activity concentration in food (Bq or Ci/m^3).
C_p	The annual consumption of pasture by livestock (kg/yr).
C_r	Activity concentration in plant parts usually associated with reproductive or storage functions (fruits, seeds, tubers, etc.) in dry weight (Bq or Ci/kg).
C_s	Activity concentration in dry weight in root zone soil (Bq or Ci/kg).
C_s^t	Activity concentration in dry weight in average or typical root zone soil (Bq or Ci/kg).
C_v	Activity concentration in plant parts usually associated with vegetative functions (leaves, stems, straw, etc.) in dry weight (Bq or Ci/kg).
C_{wv}^{H3}	Tritium activity concentration in atmospheric water vapor (Bq or Ci/kg).
C^{ps}	The activity concentration on the surfaces of plants (Bq or Ci/kg).
D_r^r	The deposition rate of resuspended material (Bq or $Ci/m^2/s$).
d	Depth of the soil layer of interest, e.g., root zone (cm).
d_{ff}	Average annual number of frost-free days (d).
d_l	The linear distance between a weather station and the centroid of the SITE cell (km).
d_p	The distance between plants in a row in a field of row crops (cm).
d_r	The distance between rows of plants in a field of row crops (cm).
E	Average annual evapotranspiration (cm).
F_f	The fraction of daily ingested activity concentration (from feeding) which is transferred to and remains in a kilogram of muscle at equilibrium (d/kg).
f_{gi}	The fraction of grain which is imported from outside of the assessment area (unitless).
F_m	The fraction of daily ingested activity concentration (from feeding) which is transferred to and remains in a kilogram of milk at equilibrium (d/kg).
f_{tf}	The fractional transfer of ingested activity to beef (unitless).

PARAMETER SYMBOLS AND DEFINITIONS (Continued)

Symbol	Definition
f_{tm}	The fractional transfer of ingested activity to milk (unitless).
f_w^a	The fraction of water in vegetation derived from atmospheric sources (unitless).
f^m	The fraction of maximum growth attained by plants (unitless).
g_{pg}	The number of successive grazings of pasture by cattle (yr^{-1}).
H	Average annual absolute humidity (g/m^3).
h_h	The number of hay harvests in a year (yr^{-1}).
I	Average annual irrigation (cm).
i	Identification number for each SITE cell based on the longitude and latitude of the southeastern corner of the cell (unitless).
K_d	The soil-water distribution coefficient which is the ratio of activity or elemental concentration in soil to that in water at equilibrium (mL/g).
L_{df}	Dominant land feature of the assessment area (unitless).
l	The length of a unit area (cm).
M_{am}	Average annual morning mixing height (m).
M_{pm}	Average annual afternoon mixing height (m).
m_m	The muscle mass of a cow (kg).
m_p	The quantity of milk produced from a milk cow per milking (kg).
n	The number of fruit per plant or tree (unitless).
n_a	The inventory of “all other cattle” (head).
n_b	The inventory of ‘beef cattle” (head).
n_{cc}	The inventory of cattle and calves (head).
n_g	The inventory of grain-fattened cattle (head).
n_m	The inventory of milk cows (head).
n_r	The number of plants in a row in a field of row crops (unitless).
n_s	The inventory of sheep (head).
P	Average annual total precipitation (cm).
P_{ai}	The annual yield or production of crop *i* (kg/yr).
P_e	The annual production of exposed produce (kg).
P_{gf}	The annual production of grain feed (kg).
P_{gh}	The annual production of grain food (kg).
P_h	The annual production of hay (kg).
P_{hf}	The annual production of harvested forage or hay + silage (kg).
P_{hi}	The harvest yield or production of crop *i* per harvest (kg).
P_{lv}	The annual production of leafy vegetables (kg).
P_{pg}	The annual production (equa1 to consumption by livestock inventory) of pasture grass (kg).
P_{pp}	The annual production of protected produce (kg).
P_s	The annual production of silage (kg).
P_{sl}	Pressure corrected to sea level (mb).

PARAMETER SYMBOLS AND DEFINITIONS (Continued)

Symbol	Definition
P_{sus}	Suspended particulate matter in the range of 2.0-15 µm from resuspension processes (µg/m^3).
p_c	The parameter value for a SITE cell (variable).
p_1	The parameter value for the nearest weather station to the centroid of a SITE cell (variable).
p_2	The parameter value for the second nearest weather station to the centroid of a SITE cell (variable).
p_3	The parameter value for the third nearest weather station to the centroid of a SITE cell (variable).
pop_{nf}	The fraction of the population classified as “rural-non-farm” (unitless).
pop_{rf}	The fraction of the population classified as “rural-farm” (unitless).
pop_t	The total population of the assessment area (unitless).
pop_u	The fraction of the population classified as “urban” (unitless).
Q_f^{fc}	The lifetime forage requirement of grain-fed cattle (kg/yr).
Q_{feed}	Feed ingestion rate by cattle used in meat and milk concentration calculations (k/s).
Q_g^{fc}	The lifetime grain requirement of grain-fed cattle (kg/yr).
R_f	The collective forage requirement by livestock (kg/yr).
R_g	The collective grain requirement by livestock (kg/yr).
r_f	The radius of an individual fruit or plant (cm).
r_n	The number of rows of plants in a field of row crops (unitless).
r^e	The average interception fraction for exposed produce (unitless).
r^{ef}	The average interception fraction for exposed fruit (unitless).
r^h	The interception fraction for hay (unitless).
r^i	The interception fraction for plant *i* (unitless).
r^{lv}	The interception fraction for leafy vegetables (unitless).
r^{mf}	The interception fraction for mature tree fruit (unitless).
r^{mlv}	The interception fraction for mature leafy vegetables (unitless).
r^{ms}	The interception fraction for mature silage (unitless).
r^{msb}	The interception fraction for mature snap beans (unitless).
r^{mt}	The interception fraction for mature tomatoes (unitless).
r^{pg}	The interception fraction for pasture grass (unitless).
r^s	The interception fraction for silage (unitless).
s_g	The annual sales of grain-fattened cattle (head/yr).
T_f	The metabolic half-time for material in beef (s).
T_m	The metabolic half-time for material in milk (s).
T_w	The weathering removal half-time for material deposited on plant surfaces (s).
t_i	The time of interest (d).
t_m	The time at which milk is sampled (s).

PARAMETER SYMBOLS AND DEFINITIONS (Continued)

Symbol	Definition
t_{max}	The time at which maximum plant growth occurs (d).
t_s	The time at which cattle are slaughtered (s).
V_d^r	The deposition velocity of resuspended material (cm/s).
V_i	The velocity of a migrating material in a soil column (cm/s).
V_w	The velocity of water in a soil column (cm/s).
w	The width of a unit area (cm).
w_1	The weighting factor (inversely proportional to distance) used with the nearest weather station to the centroid of a SITE cell (unitless).
w_2	The weighting factor (inversely proportional to distance) used with the second nearest weather station to the centroid of a SITE cell (unitless).
w_3	The weighting factor (inversely proportional to distance) used with the third nearest weather station to the centroid of a SITE cell (unitless).
X	Longitude (°W)
Y	Latitude (°N)
Y_e	The productivity of exposed produce (kg/m^2).
Y_{gf}	The productivity of grain feed (kg/m^2).
Y_{gh}	The productivity of grain food (kg/m^2).
Y_h	The productivity of hay (kg/m^2).
Y_i	The productivity of plant *i* based on the ratio of production to area harvested (kg/m^2).
Y_i^a	The area1 yield of crop *i* ($kg/yr/m^2$).
Y_{lv}	The productivity of leafy vegetables (kg/m^2).
Y_{pg}	The productivity of pasture grass (kg/m^2).
Y_{pg}^a	The area1 yield of pasture grass ($kg/yr/m^2$).
Y_{pp}	The productivity of protected produce (kg/m^2).
Y_s	The productivity of silage (kg/m^2).
z	Altitude (m).
λ_g	The turnover rate of cattle in the “cattle on feed” category (yr^{-1}).
λ_f	The metabolic removal rate constant for beef (s^{-1}).
λ_m	The metabolic removal rate constant for milk (s^{-1}).
λ_w	The weathering removal constant for plant surfaces (s^{-1}).
ρ	Soil bulk density (g/cm^3).
θ	Volumetric water content of the soil [mL (equal to cm^3 H_20) /cm^3].

ACKNOWLEDGMENT

We wish to express our deepest gratitude to C. B. Nelson, C. W. Miller, S. Y. Ohr, B. D. Murphy, O. W. Hermann, and C. L. Begovich for their cooperation, suggestions, help, and encouragement in producing the TERRA computer code. We also wish to acknowledge G. G. Killough for his assistance in the Monte Carlo simulations which were essential to some of our analyses and P. E. Johnson and R. C. Durfec for their assistance in creating the SITE data base. Finally, we wish to recognize Y. C. Ng, C. A. Little, D. E. Fields, A. P. Watson, and R. J. Raridon for their time and effort in reviewing this manuscript.

HIGHLIGHTS

Assessment models of radionuclide transport through terrestrial agricultural systems rely on input parameters to describe transport behavior and define interrelationships among the agricultural ecosystem compartments. Often a single set of default parameters, such as those given in the USNRC Reg. Guide I. 109, is recommended for use in generic assessments in lieu of site specific information. These parameters are often based on an incomplete knowledge of transport processes, on readily available literature references, and on generalized or idealized conceptualizations of common agricultural practice. Usually, in lieu of solid experimental, observational, or theoretical support, parameters are chosen to provide conservative results. Further, inconsistencies may occur between experimental determination of the parameter and its use in the assessment model.

The above-mentioned limitations in model input parameters are usually unavoidable and seem to be inherent in the assessment modeling process, but are usually acceptable (in many applications) within the context of overall uncertaintity in assessment methodology. However, in some assessment applications, including comparisons among various facilities and source terms in a variety of geographical locations, many of these limitations are not acceptable. This report describes an evaluation of terrestrial transport parameters designed to address many of the above-mentioned limitations and provides documentation of default parameters incorporated into the food-chain-transport assessment code TERRA.

The parameters discussed in this report are divided into five categories: agricultural, climatological, demographic, element-specific, and miscellaneous. The climatological, demographic, and many of the agricultural parameters have been determined on a location-specific basis for the conterminous United States with a resolution of ½×½ degree longitude-latitude. These parameters include various land use and geographic information, population and its distribution in rural and urban settings, agricultural production and productivity, precipitation, and estimates of evapotranspiration, morning and afternoon mixing heights, absolute humidity, and number of frost-free days. These location-specific parameters have been stored in computer readable format and are collectively referred to as the Specific-Information on the Terrestrial Environment (SITE) data base. This report describes the SITE data base and the protocols used in its generation.

The element-specific parameters include soil-to-plant concentration factors, B_v, and B_r, ingestion-to-milk and ingestion-to-beef transfer parameters, F_m and F_f, respectively, and the soil-water distribution coefficient, K_d. The report describes the available literature references, the protocols and assumptions made, and correlations between parameters used to determine these default parameters and compares concentrations predicted using them with experimentally measured concentrations.

1. INTRODUCTION

Under Task I of contract EPA-AD-89-F-2-A106 (formerly EPA-78-D-X0394), the Health and Safety Research Division (HASRD) of the Oak Ridge National Laboratory (ORNL) prepared the AIRDOS-EPA[1] and DARTAB[2] computer codes to provide the Environmental Protection Agency (EPA) with an integrated set of codes and data bases to simulate atmospheric and terrestrial transport of radionuclides routinely released to the atmosphere and to calculate resulting health impacts to man consequent from these releases. Under Task II of the project an integrated set of computer codes and data bases is being designed to replace the AIRDOS-EPA and DARTAB system. This report describes the **S**pecific **I**nformation on the **T**errestrial **E**nvironment (SITE) computerized data base, element-specific transport parameters, and other parameters used in lieu of user input in the terrestrial transport code TERRA[3] or accessed by the atmospheric transport code ANEMOS[4] and/or the dose and risk code ANDROS.[5]

The terrestrial transport and agricultural parameters reviewed and documented by Moore et al.[1] represented an attempt to update and reevaluate parameters previously recommended in USNRC Regulatory Guide 1.109.[6] Experience with the AIRDOS-EPA computer code has highlighted several problems in the modeling approach and certain limitations in the assessment methodology which are addressed under Task II. One problem occurs in the protocols used in reviewing literature values for soil-to-plant concentration factors. Other limitations apparent in the AIRDOS-EPA computer code are the absence of transport parameters for many elements and the incorporation of a single set of default agricultural parameters to describe a highly diverse agricultural system in the United States.

Much of the effort under Task II has been directed towards resolution of these problems or inconsistencies and construction of a location-specific data base of default agricultural, meteorological, and demographic parameters for use in generic assessments. Element-specific transport parameters have been reevaluated with regard to their use in the model TERRA, literature references given by Moore et al.[1] have been reevaluated, and new references have been added. For those elements for which experimental experience has been slight, systematic assumptions based on their location in the periodic table of the elements have been used to estimate default values. Theoretical models based on two- and three-dimensional geometries of food and feed crops have been used to suggest default values of the interception fraction, r.

It is beyond the scope of this report to detail the TERRA computer code, but a general understanding of the simulation of transport in vegetable and feed crops is prerequisite to interpretation of our analyses. All vegetable and feed crops have been assigned to seven categories based on their phenotypic and agricultural transport characteristics.[7] These categories are leafy vegetables, exposed produce, protected produce, grains, pasture, hay, and silage (Fig. 1.1). The first three are classed as human foods and the last three as livestock feeds. Grains are classed as both. Leafy vegetables present a broad flat leaf surface for direct interception of atmospherically depositing material. Furthermore, the edible portion of the plant is primarily concerned with vegetative growth (leaves and stems). Exposed produce (snap beans, tomatoes, apples, etc.) intercept atmospherically depositing material on edible surfaces, but surface areas for exposure are relatively small compared to leafy vegetables. Additionally, edible portions are typically concerned with reproductive functions (fruits and seeds). Protected produce (potatoes, peanuts, citrus fruits, etc.) are not directly exposed to atmospherically depositing material because their growth habit is underground, or if aboveground, the edible portions are protected by pods, shells, or nonedible skins or peels. Typically, edible portions are reproductive or storage organs.

Grains are similar to protected produce, but their use as both livestock feeds and food for man necessitates a separate category. The other three categories of livestock feeds are pasture, hay, and (corn and sorghum) silage. All of these feeds are composed, primarily, of vegetative growth. Silage is categorized separately from hay and pasture based on its interception characteristics. Hay and pasture are separated because their residence times in the field are significantly different, and therefore, parent nuclide decay and ingrowth of daughters calculated in TERRA for these two

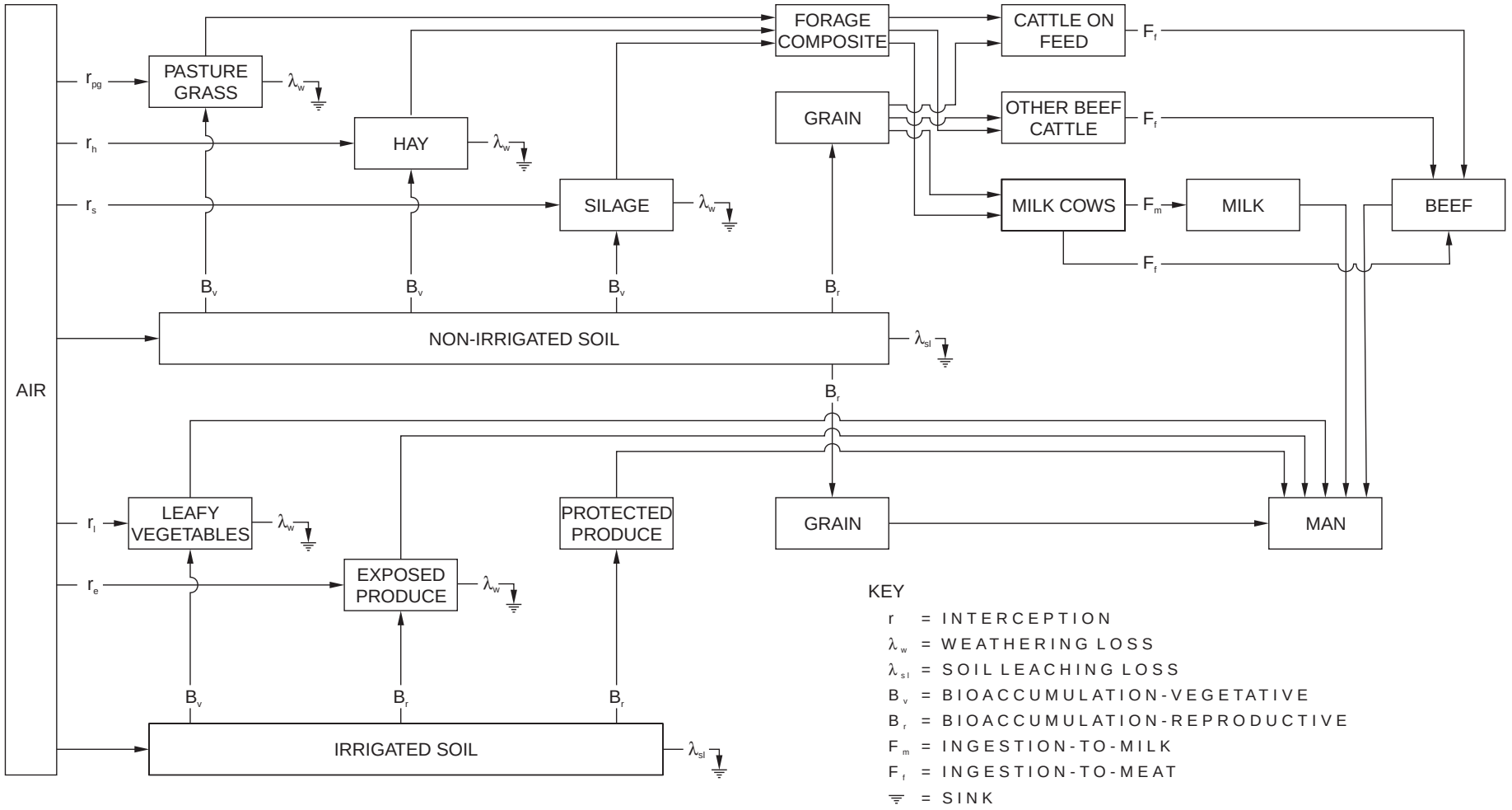

Figure 1.1. The categorization of all vegetable crops and animal feeds in the TERRA code based on radionuclide transport and agricultural pathway characteristics.

categories may be significantly different. Furthermore, hay is easily imported and exported from a location and pasture is not. This difference between the two is important in the calculation of location-specific estimates of pasture productivity and feed fractions based on livestock inventories (Section 4.1).

The elaboration of vegetation into seven categories has been determined chiefly by the protocols necessary in analyzing transport behavior, allowing for location-specific variability in agricultural practice, and simulating radiological decay in the TERRA code. Similarly, for all parameters the following analyses reflect our intent towards “reasonable estimates” based on unbiased approaches, parameter correlations, and theoretical or systematic models when available information is limited. We will attempt to estimate distributions of these parameters whenever possible to allow the reader to select more or less conservative parameter estimates than those used as default in TERRA. Finally, any changes in parameter definitions from those given by Moore et al.,[1] or listed in the USNRC Regulatory Guide l.109,[6] have not been made capriciously, but reflect responses to limitations or inconsistencies of past approaches.