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LABORATORY**

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

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Front Matter  
Introduction

**Health and Safety Research Division**

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**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

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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/ $m^3$ ).
$C_a^{H3}$	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).
$f_{ff}$	The fractional transfer of ingested activity to beef (unitless).

## PARAMETER SYMBOLS AND DEFINITIONS (Continued)

Symbol	Definition
$f_m$	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 ( $\text{yr}^{-1}$ ).
$H$	Average annual absolute humidity ( $\text{g}/\text{m}^3$ ).
$h_h$	The number of hay harvests in a year ( $\text{yr}^{-1}$ ).
$I$	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 ( $\text{mL}/\text{g}$ ).
$L_{df}$	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 $i$ ( $\text{kg}/\text{yr}$ ).
$P_e$	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 (equal 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 $\mu\text{m}$ from resuspension processes ( $\mu\text{g}/\text{m}^3$ ).
$p_c$	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 ( $^{\circ}$ W)
$Y$	Latitude ( $^{\circ}$ N)
$Y_e$	The productivity of exposed produce (kg/m <sup>2</sup> ).
$Y_{gf}$	The productivity of grain feed (kg/m <sup>2</sup> ).
$Y_{gh}$	The productivity of grain food (kg/m <sup>2</sup> ).
$Y_h$	The productivity of hay (kg/m <sup>2</sup> ).
$Y_i$	The productivity of plant $i$ based on the ratio of production to area harvested (kg/m <sup>2</sup> ).
$Y_i^a$	The area1 yield of crop $i$ (kg/yr/m <sup>2</sup> ).
$Y_{lv}$	The productivity of leafy vegetables (kg/m <sup>2</sup> ).
$Y_{pg}$	The productivity of pasture grass (kg/m <sup>2</sup> ).
$Y_{pg}^a$	The area1 yield of pasture grass (kg/yr/m <sup>2</sup> ).
$Y_{pp}$	The productivity of protected produce (kg/m <sup>2</sup> ).
$Y_s$	The productivity of silage (kg/m <sup>2</sup> ).
$z$	Altitude (m).
$\lambda_g$	The turnover rate of cattle in the “cattle on feed” category (yr <sup>-1</sup> ).
$\lambda_f$	The metabolic removal rate constant for beef (s <sup>-1</sup> ).
$\lambda_m$	The metabolic removal rate constant for milk (s <sup>-1</sup> ).
$\lambda_w$	The weathering removal constant for plant surfaces (s <sup>-1</sup> ).
$\rho$	Soil bulk density (g/cm <sup>3</sup> ).
$\theta$	Volumetric water content of the soil [mL (equal to cm <sup>3</sup> H <sub>2</sub> O) /cm <sup>3</sup> ].

## 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 uncertainty 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  $\frac{1}{2} \times \frac{1}{2}$  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<sup>1</sup> and DARTAB<sup>2</sup> 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 Specific Information on the Terrestrial Environment (SITE) computerized data base, element-specific transport parameters, and other parameters used in lieu of user input in the terrestrial transport code TERRA<sup>3</sup> or accessed by the atmospheric transport code ANEMOS<sup>4</sup> and/or the dose and risk code ANDROS.<sup>5</sup>

The terrestrial transport and agricultural parameters reviewed and documented by Moore et al.<sup>1</sup> represented an attempt to update and reevaluate parameters previously recommended in USNRC Regulatory Guide 1.109.<sup>6</sup> 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.<sup>1</sup> 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.<sup>7</sup> 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

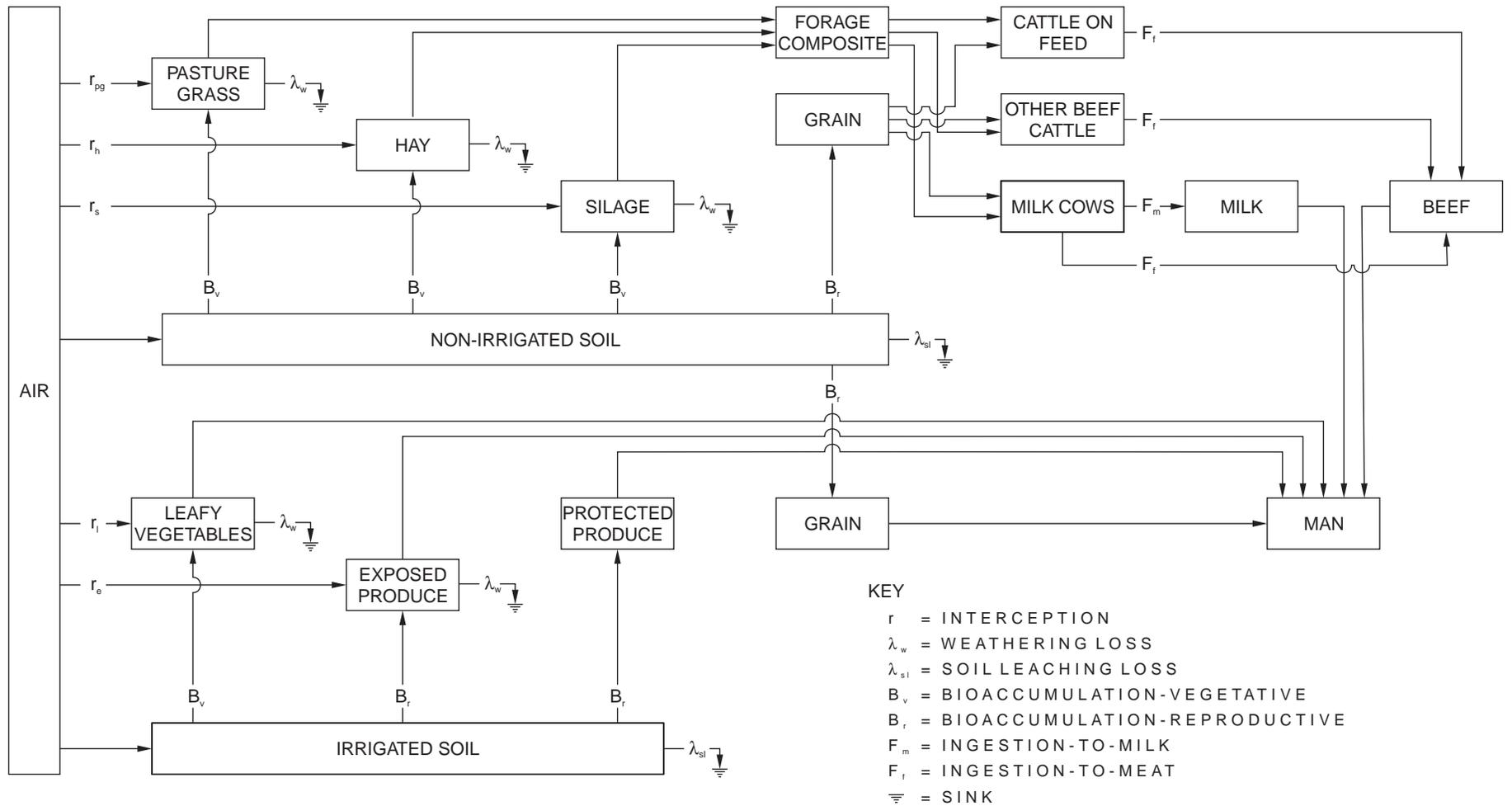


Figure 1.1. The categorization of all vegetable crops and animal feeds in the TERRA code based on radionuclide transport and agricultural pathway characteristics.

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.,<sup>1</sup> or listed in the USNRC Regulatory Guide 1.109,<sup>6</sup> have not been made capriciously, but reflect responses to limitations or inconsistencies of past approaches.