AN ABSTRACT OF THE THESIS OF

Joshua A. Palotay for the degree of Master of Science in Radiation Health Physics presented on January 10, 2006.

Title: Post-Accident Radiocesium Uptake in Eastern Oregon Wheat Crops: A Preliminary Estimate Using a Modified "PATHWAY" Model.

Abstract approved: Redacted for Privacy

Kathryn A. Higley

An experimental environmental uptake model was developed for the purpose of estimating the final harvest concentration of contaminant following an acute accidental release of radiocesium onto an eastern Oregon winter wheat crop. The system was developed using the PATHWAY environmental uptake model as presented by Whicker and Kirchner (1987) for its basis. The experimental system was constructed and operated with the STELLA™ modeling software.

Two source terms were considered for the experiment. The first was a mixture of 62.8% ^{137}Cs and 37.2% ^{134}Cs, and the second was ^{137}Cs by itself. Both were assumed to be in the form of cesium chloride. These isotopes of cesium were chosen because of their presence within the nuclear industry and as fission products.

A primary alteration to the PATHWAY model was the incorporation of the growing degree day (GDD) concept. This allowed the model to adjust the length of the growing season based on the average temperature to which the crop was exposed. It was found that higher average growing temperatures resulted in increased radiocesium concentrations ($Bq \cdot kg^{-1}$) in the harvested crop.

The day on which the contaminant was dispersed during the growing season also changed the final harvest concentration. The day during the growing season which results in the highest final concentration is referred to as the optimum day of dispersal (ODD). During the 261 day growing season for winter wheat, with an average temperature of 9.58°C, the ODD was on day 96 for $^{134/137}Cs$ and day 85 for ^{137}Cs. The area contamination which resulted in a harvest concentration equal to the derived intervention level for radiocesium contaminated foods ($1200\ Bq \cdot kg^{-1}$) was $1.50 \times 10^4\ Bq \cdot m^{-2}$ and $1.43 \times 10^4\ Bq \cdot m^{-2}$, respectively.

The exposure rates at 30 cm for $1.50 \times 10^4\ Bq \cdot m^{-2}$ ($^{134/137}Cs$) and $1.43 \times 10^4\ Bq \cdot m^{-2}$ (^{137}Cs) were calculated to be $5.05 \times 10^{-5}\ mR \cdot hr^{-1}$ and $6.70 \times 10^{-5}\ mR \cdot hr^{-1}$, respectively, excluding natural background. These levels suggest that conventional area surveys could not detect the level of radiocesium contamination which would require the embargo of an eastern Oregon wheat crop.

Post-Accident Radiocesium Uptake in Eastern Oregon Wheat Crops: A Preliminary Estimate Using a Modified "PATHWAY" Model

by
Joshua A. Palotay

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Joshua A. Palotay, Author

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

Post-Accident Radiocesium Uptake in Eastern Oregon Wheat Crops: A Preliminary Estimate Using a Modified "PATHWAY" Model

Chapter 1
INTRODUCTION

The extreme importance of an uninterrupted flow of foodstuffs to a populous goes without question. By mere observation of history, one can see that the total devastation of a crop can bring about local food shortages causing increased prices for the consumer and risk of severe financial loss to the grower. Food shortages or the interruption of supply can occur when its safety for consumption comes into question. Crops can be destroyed or become unfit for human consumption by several means; among them is chemical and/or radiological contamination.

This study examines the radiocesium uptake behavior of eastern Oregon wheat crops using the "PATHWAY" model (Whicker and Kirchner 1987) with alterations made by the author. In particular, the study estimates the total surface deposition of ^{134}Cs and ^{137}Cs necessary to cause the wheat crop to reach a Derived Intervention Level (DIL) of 1200 becquerels per kilogram ($\mathrm{Bq} \cdot \mathrm{kg}^{-1}$) of fresh wheat grain, as determined by the U.S. Food and Drug Administration (2005). Once this limit is reached, the crop is considered no longer suitable for consumption. Research was conducted with three primary objectives in mind: 1) Model the radiocesium uptake of a wheat crop resulting from an acute deposition. 2) Estimate the area contamination to yield the $^{134/137}$Cs Derived Intervention Level (DIL). 3) Predict immediate post-dispersal event radiation fields.

The U.S. Food and Drug Administration (FDA) adopted updated guidelines for restricting domestic foods contaminated with radioactivity. The Compliance Policy Guide (CPG) publicized in 1998 suggests limits for radioactive contamination levels in foodstuffs to minimize health risks to the consumer. The new Protective Action Guidelines (PAG) limit a total committed effective dose equivalent (CEDE) of 5 mSv or 50 mSv to any tissue or organ. At this dose, the chance for an individual to contract cancer is approximately 1 in 4400. By comparison, the chance of contracting cancer during a lifetime is roughly 1 in 5 (U.S. Food and Drug Administration 2005). Therefore, a food commodity must not deliver a dose greater than the established PAG if it is to be released for public consumption.

In the event of a radiologic accident (i.e., reactor event, weapon detonation, or radiological dispersion device), if materials such as radiocesium are deposited over agricultural crops it will become necessary to evaluate the contaminated crops in comparison to the DILs for each contributing nuclide to ensure the health and safety of the consumer. Also, the possibility of a massive financial loss to the grower and local economy must be evaluated and prepared for in the case of a total crop embargo. Both scenarios have the potential to cause great disturbance among a population. In such a situation, public authorities must decide on the fate of contaminated crops by carefully weighing both the health and economic impacts associated with the available options: to embargo, or release to market.

The Food and Agriculture Organization (FAO) of the United Nations identifies six sources from which a radiological accident could pose a threat to agriculture. These sources are listed below in the order of importance (Food and Agriculture Organization of the United Nations 1989, pp. 11):

1) Land-based nuclear power reactors.
2) Mobile marine nuclear power reactors and air or space-vehicles carrying nuclear facilities.
3) Reactors used for research, teaching, and radioisotope production.
4) Fuel processing plants, waste discharges, etc. (especially into aquatic or marine ecosystems).
5) Mining, storage and transport of radioactive materials as part of the nuclear fuel cycle (excluding 4).
6) Nuclear-medical, industrial irradiation, and research facilities.

Another threat that must also be considered in the post 9/11 era is purposely released nuclides onto agricultural crops in an act of terrorism.

In nearly all of the above items listed by the FAO, ^{134}Cs and/or ^{137}Cs can be found as a common component in the overall nuclide profile. Due to the relatively long half lives of the nuclides, 2.062 and 30.0 years respectively, and the highly soluble nature of the cesium ion, these isotopes are important contaminants to consider (Environmental Protection Agency 1988, National Council on Radiation Protection 1977, White and Broadley 2000).

Estimating the contamination concentration of a crop after harvest as a function of total surface contamination immediately after a radiological event can be of help to gauge remedial actions. The local emergency management authorities, community, and growers can forecast the safety of a crop in reference to a dispersal event which may have occurred during the growth period. Such foresight may reduce a premature economic downturn resulting from unnecessary fear of a lightly contaminated crop or provide an early warning for growers in preparation for loss in harvest revenue due to a probable mandatory embargo.

Throughout history wheat has been an important source of nourishment for most people. “Today, wheat is grown on more land than any other commercial crop and continues to be the most important food grain source for humans. Its production leads all crops, including rice, maize and potatoes (Food and Agriculture Organization of the United Nations 2002, pp. 1).” “It is the best of the cereal foods and provides more nourishment for humans than any other food source (Food and Agriculture Organization of the United Nations 2002, pp.2).” Since 1990, the world wheat utilization has remained near 550 million tons with the United States, Canada, France and Australia being the major exporting countries in recent years (Food and Agriculture Organization of the United Nations 2002). Making such a large contribution to the modern diet and agricultural economy, it is for this reason that wheat was selected for the subject of the uptake study.

Wheat can be classified into two categories: spring wheat and winter wheat. The difference is determined by the climatic season in which it is grown. A spring wheat crop is planted during the spring and harvested in late summer. Winter wheat on the other hand is planted in the fall or autumn months and is harvested around mid-summer (Food and Agriculture Organization of the United Nations 2002). The total time in which the winter wheat crop is in contact with the soil, or total growing time, is noticeably longer as compared to spring wheat. This is due to the fact that wheat grows most efficiently in temperatures near to 25 °C and will cease to grow in temperatures of 0 °C or less (Food and Agriculture Organization of the United Nations 2002, Cook et al. 2005). Winter wheat, being the most common type of wheat grown in Oregon, is used specifically in this study[1] (National Information Service for the Regional IMP Centers 2005).

The PATHWAY model is based on a compartment-type system which estimates the flow of contaminants from one compartment to another through a series of differential equations. The model expresses the change in time in units of days (Whicker and Kirchner 1987). This unit is useful when average rates of uptake and migration for a contaminant are known. However, the growth and development of a plant depends highly on the climatic temperatures to which it is exposed (Wikipedia 2005). This becomes important since the PATHWAY model only considers plant growth as an average rate in units of day^{-1}.

The use of an average growth rate becomes problematic because of the temperature differences that can be observed from one agricultural region to another. The average growth rates for any crop or plant species will only reflect the characteristics of the sample group. Since growth rate can be considered a function of ambient temperature, it becomes necessary to address a specific climate if a particular agricultural region is being considered.

As stated earlier, wheat will stop actively growing at or below 0 °C. Depending on the climatic trend and season, wheat growth can be affected and change from one day to the next. Therefore, the author has incorporated the concept of growing degree days (GDD) into the model. By doing so, the model is made more adaptable to the growth characteristics of a given crop in a specific temperature

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[1] In the year 1998, "Soft white winter, Oregon's major variety, comprises 81.9% of all wheat planted in the state (National Information Service for the Regional IMP Centers 2005, pp. 1)."

climate. The growing degree day is a unit of accumulated heat over a given time period (Cook et al. 2005). Every plant or crop species has a unique number of total growing degree days necessary for it to reach physical maturity. With this addition, the output values of the PATHWAY model can be viewed as a function of temperature as it relates to nuclide uptake and plant growth. Though the base unit of (days) remains as the change in time for the overall equation, the integrated parameter of temperature regulates the speed of growth and the total time in which the plant remains in contact with the contaminant by dictating the length of the growing season.

Foliar absorption has been recognized as a significant, if not the most significant, contributor of radionuclide uptake in plants especially for ^{134}Cs and ^{137}Cs (White and Broadley 2000). The added parameter of temperature will determine when, how long, and to what magnitude the plant surfaces (i.e. leaves and foliage) are available for contaminant interception based on the amount of above-ground biomass that has emerged from the soil at a given point in time as is allowed by the rate of growth.

The ability to adjust for climate in an uptake model is important for concentration predictions of crops grown in a geographically diverse state such as Oregon. Growing conditions can vary greatly from one area of the state to another like those of the temperate Willamette Valley to the high desert environment of eastern Oregon. Standardized variables are good reference points for an initial estimation; however, once the point of study becomes specific, so too must the input variables be specific to that point. Uptake models should be constantly revised to allow for greater flexibility and ease of use. By making the length of the growing season a function of temperature, much of the guess work is removed for estimating the growing period of a crop if the number of growing degree days required to reach physical maturity is known. This allows for a better estimate of the total time in which the plant is in contact with the contaminant before harvest.

Chapter 2
LITERATURE REVIEW

2.1 The PATHWAY Model

The work of F. Ward Whicker and T. B. Kirchner (1987), has resulted in the development of a radionuclide uptake model for food crops using a "dynamic" compartment-type transfer methodology. Each environmental component such as the surface soil, vegetation tissues, and deep soil are treated as compartments or basins in which the contaminant collects. The PATHWAY model uses a set of numerical constants such as plant growth, weathering, foliar absorption and soil leaching to determine the movement of the contaminant from one compartment to the other. The concentration of the radioactive contaminant in any compartment can be determined at a given time by applying the constants to groups of differential equations, which are related by a series of linear operations to represent the system as a whole (Whicker and Kirchner 1987).

The PATHWAY model (Figure 2.1) uses many average input constants to give generic values for a number of different crops with a variety of source terms. Although the parameters provided by the authors of the PATHWAY model can offer a prediction for crop concentrations, they are only truly representative of the environment in which they were modeled. Though the PATHWAY model, as published, was tuned to a specific geographical region (the Nevada Test Site), it has the flexibility to be adapted to other regions with differing environmental conditions (Whicker and Kirchner 1987).

The PATHWAY model can be adjusted for a variety of diverse agricultural situations by merely changing the numerical constants within the compartmental equations to be representative of the area in question. By allowing for such flexibility inherent in the model, Whicker and Kirchner (1987), provide an excellent tool to the scientific community for evaluating a variety of agricultural contamination situations and new modeling techniques. This thesis research takes the flexible nature of the PATHWAY model and adapts is to a specific agricultural environment.

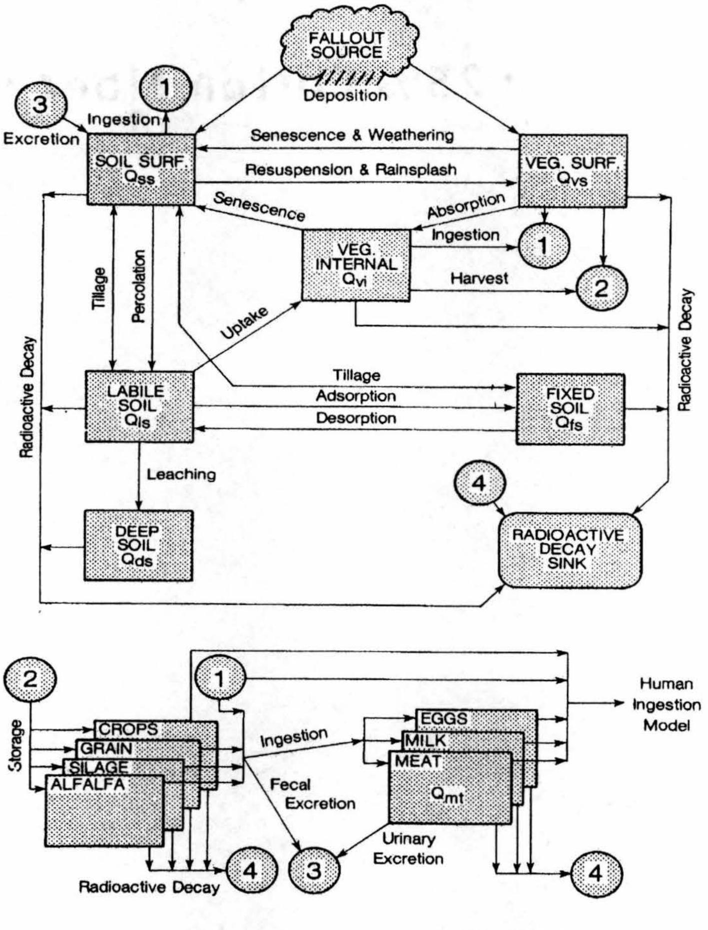

Figure 2.1 PATHWAY model. Reprinted with permission (Whicker and Kirchner 1987, pp. 719)

2.2 Wheat and the SPADE Model

A similar work (Jackson et al. 1987) to PATHWAY use the Soil Plant Animal Dynamic Evaluation (SPADE) model, a compartmental-type uptake model, to simulate a variety of deposition scenarios and predict the concentration of various radionuclides in a number of crops and other foodstuffs. Among these scenarios is an acute release, deposition, and uptake of ^{137}Cs in a generic cereal crop (Jackson et al. 1987).

In one example the authors examined a "spike deposition" (Jackson et al. 1987, pp.146) scenario totaled 3.15×10^{7} Bq · m^{-2} of ^{137}Cs onto the surface. In this simulation the contaminating event is acute and discrete, occurring at time equals zero of the model which represents the beginning of the growing season. At the end of 120 days the model resulted in a concentration of 4.8×10^{6} Bq · kg^{-1} (fresh weight) in cereals (Jackson et al. 1987).

According to Jackson et al. (1987), results generated from the ^{137}Cs simulation corresponded well to field data of concentration ratios in a variety of food products. The authors stated there was some discrepancy between the data for cereal crops. However, they note that this could be due to assumptions made about the contribution from the husk. The authors conclude, based on the comparative date between the generated results and the field data that the model appears to have credibility (Jackson et al. 1987). Therefore, the values given by the SPADE model in the previous simulation seem to make a reasonable point of reference from which to evaluate the results of the experimental model.

2.3 General Application of the Model

The PATHWAY model by Whicker and Kirchner (1987), was used as the framework for the experimental model developed by this author. In essence, it is nearly identical to PATHWAY with some slight variation to suit the specific situation being simulated. Some of the PATHWAY parameters and flow dynamics were altered for this purpose. One of the more pronounced changes to the PATHWAY model was the incorporation of growing degree days (GDD). This parameter adjusts the total length of the growing season, providing the day which the crop will reach full maturity as a function of the average temperature during the growing season. In this way, the expected duration of crop uptake becomes elastic and dependent on climate trend as compared to using a more rigid crop-specific average growing time. The details of this and other adjustments to the model will be discussed in detail later on in the document.

The general approach used in the SPADE model is very similar to that used in the PATHWAY model. The exact parameters used for the numerical constants utilized by Jackson et al. (1987), were unknown to the author of this thesis. However, due to its agreement with field observations and similarities to the PATHWAY methodology, the output of the SPADE model was used as a benchmark for the outputs generated by the experimental model.

It is the author's opinion that through the use of the PATHWAY model and the reference output provided by the SPADE model, as utilized by Jackson et al. (1987), a fairly accurate prediction for the behavior of cesium in eastern Oregon wheat crops can be made. This is done by altering the PATHWAY parameters to more closely match the conditions likely to be observed in the eastern Oregon climate. With the new experimental model tuned to agricultural conditions of the area in question, the total surface deposition required to cause the wheat grain to reach the DIL can then be determined.

2.4 Other Environmental Modeling

There are several other environmental uptake and transport models being used in experimental settings. Starting in 1996, a large scale effort was made to assess and improve several models being developed around the globe. The International Atomic Energy Agency began a program called the Biosphere Modeling Assessment (BIOMASS) for this purpose. The program ran a scenario simulating the 1986 Chernobyl accident, releasing ^{137}Cs into the environment. The program evaluated ^{137}Cs distribution, transport, and several pathways for human internal and external dose. The simulation also considered the uptake of ^{137}Cs in several crops (International Atomic Energy Agency, 2003).

The program incorporated various models developed by scientists from around the world. The models used slightly different means to provide a dynamic simulation of the source term moving through the environment and assorted pathways. The IAEA report gives somewhat of a cross section for the current state of radiologic modeling and showcases the performance of several models. Some of the models involved in this work were:

- RadCon (Radiological Consequences) model from the Australian Nuclear Science and Technology Organization.
- TAMDYN-UV model from the University of Veszprém , Hungary.
- CLRP (Concentration Levels Rapid Predictions) model from the Central Laboratory for Radiological Protection, Department of Radiation Hygiene, Warsaw, Poland.
- SPADE (Soil Plant Animal Dynamic Evaluation) model from the group presently known as the Food Standards Agency, United Kingdom.
- ECOMOD model from the SPA, "Typhoon," Obninsk, Russia.

This collaboration of environmental transport models provide a summary of current and developing tools for radiologic assessment and allows one to compare and contrast the results generated by each. (International Atomic Energy Agency, 2003)

In general, the majority of the parameter categories used in the above models appeared analogous to those used in the PATHWAY model. The models used similar compartment-based, differential processes to evaluate the extent of contamination with different software codes. The information given in the IAEA report about the various models illustrated that though computational technology has changed over time, the general compartmental or layered approach to environmental modeling remains somewhat constant within the realm of uptake analysis. (International Atomic Energy Agency, 2003)

2.5 Wheat and the Growing Degree Days Concept

Due to the agricultural nature of this study it was necessary for the author to understand the development of wheat crops and how they are grown for purposes of consumption. Several works specific to the cultivation of wheat crops were consulted. The text “Bread Wheat” published by the Food and Agriculture Organization of the United Nations (1989), provided a wealth of information on the subject. This information is helpful not only to better comprehend wheat cultivation, but also to give perspective on wheat production in the state of Oregon.

Wheat is grown all over the world, in a wide variety of environments. In general, wheat is grown in two seasons: spring and winter. In eastern Oregon, it is the winter variety that is most commonly grown. The winter wheat crop is planted in fall or autumn. During the cold months the growth of the wheat slows down and comes to a halt once 0 °C is reached (Cook et al. 2005, Food and Agriculture Organization of the United Nations 2002). During this time the wheat remains in a vegetative state until the ambient temperature increases. Typically, a winter wheat crop will reach full physical maturity sometime around mid-summer (Food and Agriculture Organization of the United Nations 2002).

Plant growth is a cumulative process, contingent upon the surrounding temperature climate (Wikipedia 2005). This makes the rate of growth and time to maturity variable, depending on the local climatic trends of the agricultural region in question. Yearly trends and fluctuation in average temperature can alter the total time of growth from one season to the next, introducing error into a standard growth coefficient. This is where the concept of growing degree days can aid in estimating contamination uptake while taking into consideration regional and trend-based temperature changes.

The growing degree day is a unit of accumulated heat over a given time period (Cook et al. 2005). Every plant or crop species has a unique number of total growing degree days necessary for it to reach physical maturity. Rao et al. (2000), reported that wheat takes an average of 2500 growing degree days (GDD) to become fully mature. It also can be used to mark different stages of development. For example, it takes an accumulated 180 °C after planting for a wheat plant to emerge from the soil (or time to emergence) (Cook et al. 2005).

However, this accumulation of heat only considers the contributing temperatures. These temperatures are those whose value is greater than the temperature at which a specific plant becomes vegetative. This temperature is known as the baseline temperature and must be subtracted from the calculated average temperature per unit time (Wikipedia 2005). As with the GDD required to reach maturity, each plant species has its own unique temperature where growth will not occur or is severely reduced. Baseline temperatures used for wheat range from 0 °C to 10 °C (Cook et al. 2005, Food and Agriculture Organization of the United Nations 2002, Wikipedia 2005). In the work prepared by Cook et al. (2005), a baseline temperature of 0 °C is used for the GDD calculations for wheat grown in northeastern Oregon; therefore, this baseline temperature is used for the study.

$$GDD = \frac{High\ temperature\ (°C) + Low\ temperature\ (°C)}{2} - Baseline$$

Equation 2.1 Growing degree days (GDD).

The GDD is an average of temperatures which contribute to the growth of the plant. The accumulated number of growing degree days is the integral of the average contributing temperature with respect to time. As stated above, wheat requires a standard 2500 GDD to reach maturity. If the average daily temperature is low, the total time to reach maturity will be greater than if the average temperature were higher. Thus, the higher average ambient temperatures result in a shorter growing period from planting to maturity, and vice versa.[2]

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[2] For the purposes of this study, harvest is assumed to occur one day after the plant has reached physical maturity.

Chapter 3
MATERIALS and METHODS

3.1 Model Functions

This section discusses the general operation of the PATHWAY model and the software used to generate the PATHWAY-based experimental model. A more detailed description of the parameters and constants used will be discussed in section 3.2. The mathematical expressions generated by the STELLA$^{\text{TM}}$ software representing the experimental model and its components can be reviewed in Appendix B. This includes a map of the model circuitry for visual reference.

3.1.1 The PATHWAY Concept

The PATHWAY model uses the compartment concept to account for and simulate the movement of radionuclides from one environmental compartment to another (Whicker and Kirchner 1987). An example would be the movement of radionuclides down through the soil system. As shown in figure 3.1, radioactivity from the initial contaminating event settles onto the surface soil. From there it will begin to accumulate into the labile soil as indicated by the direction of the arrow (direction of flow) where it becomes available for root uptake. Once in the labile compartment, the radioactivity splits its movement into two directions. It can go into either the fixed soil where it binds minerals or into the deep soil where it is beyond the physical reach of the root system. The movement of contaminant between the labile and fixed compartments is a cyclical process. In such case, radioactivity is simultaneously and continuously transferred between these compartments at specified rates (Whicker and Kirchner 1987).

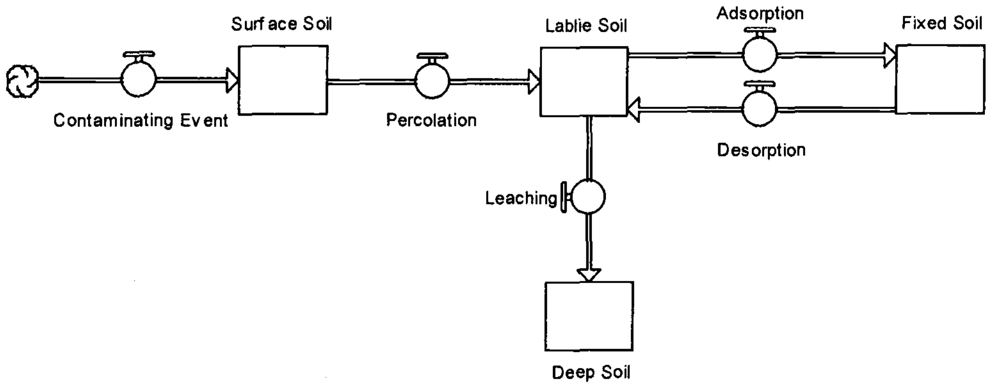


Figure 3.1 Example of compartmental flow.

The movement of radioactivity between compartments is a continual process characterized by sets of first order differential equations (Whicker and Kirchner 1987). The mathematical description for the movement between individual compartments as described by Whicker and Kirchner (Whicker and Kirchner 1987, pp. 720) is shown below in equation 3.1.

$$Q'h = \sum_{i=1}^{n} R_{in,i} - \sum_{j=1}^{m} R_{out,j}$$

where,
(Q'h) is "the time derivative of the radionuclide in compartment *h(Q'h)*"
$R_{in,i}$ = "*i*th inflow rate to compartment, *h*, Bq m^{-2} d^{-1}"
$R_{out,j}$ = "*j*th outflow rate from compartment *h*, Bq m^{-2} d^{-1}"

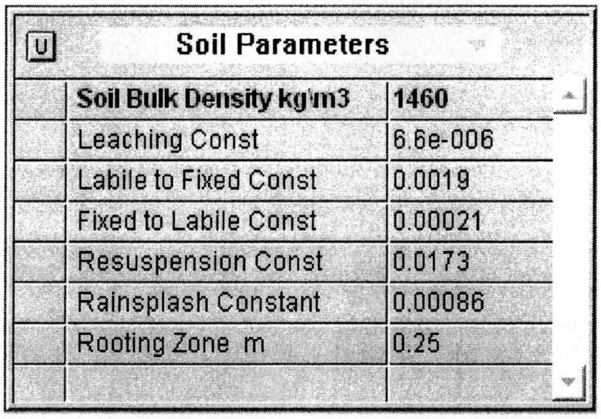
Equation 3.1 Mathematical relationship between compartments.

PATHWAY considers all the inter-compartmental flow processes as a series of interlocked differential equations. The equations are solved based on a change in time with units of (d^{-1}). The solution yields a contaminant inventory for each compartment ($Bq \cdot m^{-2}$) at a given point in time (Whicker and Kirchner 1987). The 4th order Runge-Kutta algorithm is used by Whicker and Kirchner (1987), to compute the activity within the various compartments of the system. This algorithm was also used as the computational basis in the experimental model.

3.1.2 The STELLA® Modeling Tool

The experimental model was built and operated in a modeling software package called STELLA™ version 8.1.4 from isee™ systems. The software allows compartment-type models (such as PATHWAY) to be built on a user interface called the model construction layer, using a menu of construction tools. The tools allow a model to be designed through graphic representations (Appendix B). In addition, the software has a high-level mapping layer which allows the user to break the total model up into usable sections. This layer also allows the user to interact with the model through a series of available input tools such as input tables, on-off buttons, and adjustment knobs. The user can also view the calculated outputs and specified results through dynamic tables and graphical displays.

STELLA™ allows models using ordinary first order differential processes to be calculated using the Euler, Runge-Kutta 2 and Runge-Kutta 4 methods. As the model is constructed, it generates a mathematical expression for each compartment characterizing the incoming and outgoing flow of contamination (Appendix B: Mathematical Relationships) (isee™ systems, Inc. 2005a, isee™ systems, Inc. 2005b).



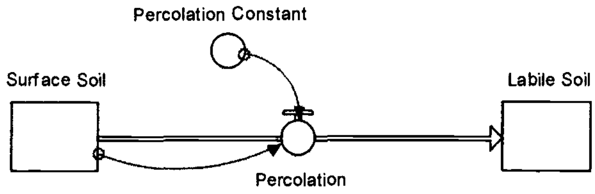
Soil Parameters

Soil Bulk Density kg/m3	**1460**
Leaching Const	6.6e-006
Labile to Fixed Const	0.0019
Fixed to Labile Const	0.00021
Resuspension Const	0.0173
Rainsplash Constant	0.00086
Rooting Zone m	0.25

Figure 3.2 Soil parameters input table created in STELLA^{TM}.

Above in figure 3.2 is an image of an input table used for the experimental model as generated in the high-level mapping layer of the STELLA^{TM} software (isee^{TM} systems, Inc. 2005a). In the left-hand column are the names of various input constants. The right-hand column contains the corresponding input value in units of (d^{-1}) with the exception of the rooting zone (meters). A specific table was generated for four groups of input constants: source term, plant variables, soil parameters, and ingestion.

A basic construction diagram using the STELLA^{TM} software is shown below in figure 3.3 along with the corresponding mathematical equation as automatically generated by the software. The process illustrated is that of radioactivity migrating from the surface soil compartment to the labile soil compartment. STELLA^{TM} refers to the compartments as "stocks," the flow arrow as a "flow," and the circle containing the rate constant as a "converter". The smaller arrows called "connectors," indicates mathematical relationships between values, where as the larger flow arrow indicates the direction of exchange between compartments (isee^{TM} systems, Inc. 2005a).



```
Labile_Soil(t) = Labile_Soil(t - dt) + (Percolation) * dt
INIT Labile_Soil = 0

INFLOWS:
Percolation = Surface_Soil*Percolation_Constant
Surface_Soil(t) = Surface_Soil(t - dt) + (- Percolation) * dt
INIT Surface_Soil = 100

OUTFLOWS:
Percolation = Surface_Soil*Percolation_Constant
Percolation_Constant = 6.6E-6
```

Figure 3.3 Percolation model created in STELLA™.

In the example set forth in figure 3.3, the stock (or compartment) representing the surface soil is the origin of the radioactivity. The unit for stock values is arbitrary in the software but must always be consistent from one to another, unless a specific converter is used to change the unit in a way that does not conflict with the mathematical process. The initial value is set to 100 atoms, all others are empty, or equal to zero, at time(t) = 0. The percolation constant is 0.0198 d^{-1}, therefore at the end of 1 day the following migration of atoms has occurred:

$$Surface\ Soil = 100 - \left[100\left(1\ day \times 0.0198\ day^{-1}\right)\right] = 98.02\ atoms$$

$$Labile\ Soil = 0 + \left[100\left(1\ day \times 0.0198\ day^{-1}\right)\right] = 1.98\ atoms$$

Equation 3.2 Surface to labile transfer.

When modeling with radioactivity, the associated radioactive decay of the nuclide must be considered. The atoms decay away with respect to time in addition to stock (or compartment) migration. Because of this, an additional flow must be added to each stock to account for the removal of atoms through the decay process. Therefore, the numerical value of each compartment in the experimental model is represented in units of Becquerels (atomic disintegrations per second).

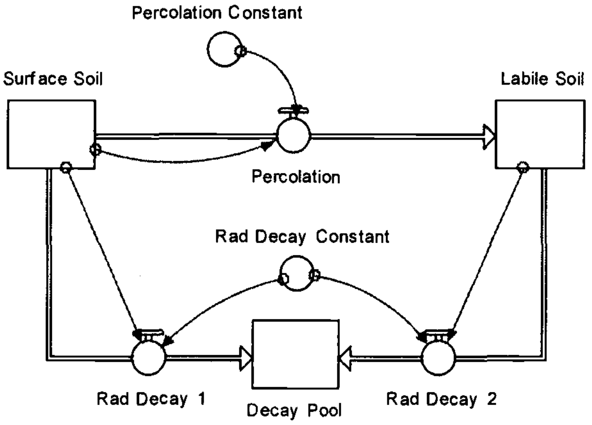


Figure 3.4 Percolation model with radioactive decay.

Using compartmental modeling as applied in the experimental model, the radioactive decay of the nuclide is simulated with the addition of an outflow from each stock as shown in figure 3.4. Each of the decay outflows is funneled to a common decay pool. Once the atoms are in the decay pool they essentially disappear from the active model by being isolated from further migration, giving the effect of decayed atoms no longer in physical existence.

Complex mathematical models with as many variables and partial differential equations as in the experiment can be prone to error mainly from the accountability of all compartmental values. The STELLA^{TM} model allows for values (atoms) to be purged from a stock without linkage to another. In essence, the atoms can be removed from the model completely and literally disappear from circulation. This method could have been applied in the experimental model to simulate radioactive decay. However, the author chose to link all decay flows to a common stock for accounting purposes, which made for a convenient check and balance technique. The function of the model can be evaluated by summing the values of all stocks (or compartments) in the system and comparing that sum to the value in the decay pool. As long as the difference between the system and the decay pool is zero, or the sum of the two equals the initial system input value, one can assume that all stocks are linked appropriately, indicating that the program is functioning as intended.

3.1.3 GDD Model Adaptation

The output data given by the generic PATHWAY model is a function of time requiring the mathematical range to be in units of days (Whicker and Kirchner 1987). However, when applying the growing degree day concept to the model, an additional input variable of temperature becomes necessary. A growing degree day is the accumulated heat which contributes to plant growth per day, wheat requiring 2500 GDD to reach maturity (Wikipedia 2005, Rao et al. 2000). The total time or maximum range of the experimental model pivots on the time required to accumulate 2500 GDD, the day (post planting) at which wheat becomes mature and ready for harvest. The length of the growing season thus becomes a function of temperature in degrees Celsius in the experimental model. Figure 3.5 graphically illustrates the relationship of temperature (°C) and the GDD for wheat as it influences the model. The day at which the wheat will reach maturity is calculated by simply dividing the GDD to maturity by the average temperature (°C), and likewise for the day of emergence, which will be further explained in section 3.2.4 of this document.

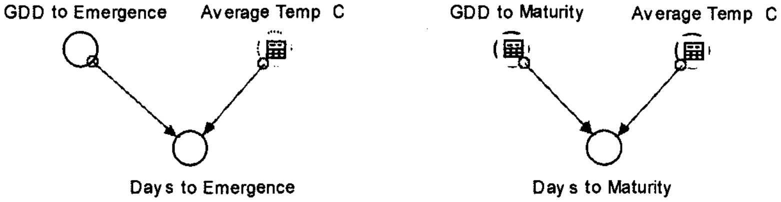


Figure 3.5 GDD relationship to emergence and maturity in STELLA®.

One item to keep in mind when evaluating the relationships of the parameters established in the experimental model is the flexibility that the STELLA™ software allows in adjusting the mathematical constants. The author used the software input tools in a way that provided immediate updating to the remainder of the model which was affected by the alteration. Therefore, when an experimental adjustment in the input parameters were made, the STELLA™ program would immediately update any processes affected by the change so that output values would be reflective of the new mathematical constants.

This flexibility is best illustrated with the GDD parameters in figure 3.5. The small boxes within the converters indicate that the value of that converter is adjustable from the input tables on the user interface. If the value of the GDD to Maturity converter is adjusted, the software will automatically adjust the value of the Days to Maturity converter to reflect the change. By setting up the equation circuitry in this manner, the error that could be incurred from multiple hand calculations was eliminated. Once the circuitry is set and checked for accuracy, no further tampering with the format is needed and only the values in the input tables need to be changed during the experiment. This allows for greater confidence in outputs when multiple variables are being changed at a given time.

3.2 Input Constants and Parameters

A listing of the numerical constants and variable parameters used in the experimental model can be viewed in Appendix A. The listed values are considered the default values of the experimental model.

3.2.1 Source Term (Cesium)

The naturally occurring isotope of cesium is ^{133}Cs. It is found in ores and soil (Environmental Assessment Division 2005). The ^{133}Cs isotope is the stable form of cesium, however several radioactive isotopes can be produced during neutron bombardment and the fission of heavy elements such as uranium, plutonium, and thorium. For example, approximately every 6 of 100 atoms produced during a fission event are the ^{137}Cs isotope, making it a fairly prominent fission product (Agency for Toxic Substances and Disease Registry 2005).

Most important in environmental contamination scenarios are the ^{134}Cs and ^{137}Cs isotopes. These isotopes are relatively long-lived, decay via β and γ emission, and readily absorbed by biological systems (White and Broadley 2000). The physical half lives of ^{134}Cs and ^{137}Cs are fairly long, 2.062 and 30.0 years respectively[3]; however, the biological half live is relatively short for humans. The average biological half-life of cesium is 105 (± 25) days for the adult male between the ages of 23 and 55 years of age (National Council on Radiation Protection 1977).

For the purposes of this study, the dose and activity characteristics of ^{134}Cs and ^{137}Cs are considered separately while the chemical form of the cesium isotopes are assumed to be in the salt or cesium chloride form, as it is in the Environmental Protection Agency's Federal Guidance Report No. 11 (Environmental Protection Agency 1988).

Cesium and its isotopes are important in the consideration of radioactive contamination events, not only because of their linkage to fission and long half-life (^{134}Cs and ^{137}Cs), but also because cesium is readily absorbed by plants and by humans through consumption. In plants, the most important component of uptake is the absorption of cesium through the plant surface or leaves, commonly referred to as foliar absorption (Greger 2004, White and Broadley 2000). For cases of acute deposition, the immediate contribution of foliar absorption has shown to be an even more significant route of incorporation than that of the root system. As the total time of environmental contamination compounds, the contribution of root uptake becomes increasingly important (Maraziotis 1992).

Cesium is an alkali metal and the second heaviest among the group I elements of the periodic table. It is chemically analogous to potassium (K) and also shares

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[3] Physical half lives: ^{134}Cs = 2.062 years (752.6 days), ^{137}Cs = 30.0 years (10950 days) (Environmental Protection Agency 1988).

similar chemical characteristics with the other group I metals (White and Broadley 2000). To date, cesium is not considered essential to the growth and development of plants (White and Broadley 2000). However, due to its chemical similarities with potassium (an essential element), it can be taken up by root systems and distributed throughout the plant in parallel with the potassium pathway (Zhu 2000, Greger 2004, Food and Agriculture Organization of the United Nations 1989).

After the Chernobyl accident, radionuclides were dispersed into the atmosphere causing contamination to settled all over Eastern Europe. Among the radionuclides were ^{134}Cs and ^{137}Cs. Samples were collected shortly after the event. The relative ratio of ^{134}Cs to ^{137}Cs was 0.372 to 0.628 respectively, based on percentage of specific activity (Senate Department of Urban Development 2005). This ratio was used as a source term parameter to simulate the relative contributions in the case of another such contamination event. The 134/137 ratio can be different from one event to the other. Therefore, this ratio can act as a fingerprint to identify its source and link it to a specific contamination event such as the Chernobyl accident (Food and Agriculture Organization of the United Nations 1989).

3.2.2 Wheat and Oregon Crops

In the United States, the per capita consumption of wheat flour averages 144.3 lbs. (65.6 kg) per year between the years 1996 and 2001 (National Agricultural Statistics Service 2005c). In 2004 growers in the state of Oregon produced 55,980,000 bushels of wheat (1 bushel of wheat = 27.215 kg) over 955,000 acres at a total value of $201,669,000. In the year 1998, eastern Oregon represented 92.5% of the winter wheat growing acreage (National Information Service for the Regional IMP Centers 2005). Of the different wheat producing regions, Umatilla County produced the most in 2004 totaling 19,578,000 bushels (National Agricultural Statistics Service 2005b). Between the years of 1990 and 2005 Oregon growers average an annual production yield of approximately 57 bushels of wheat grain per acre, translating to a state-wide average yearly crop density of 0.383 kg · m^{-2} of fresh wheat grain[4] (Dictionary.LaborLawTalk.com 2005, National Agricultural Statistics Service 2005a).

The value 0.383 kg · m^{-2} is used to represent the total fresh mass of the harvested wheat grain in the experimental model. From this value, the biomass of the remaining portions of the plant was estimated by using some generic ratios. The first was the mass of the remaining wheat straw removed from the harvesting process. One source, Wysocki (2005), suggested that a good ratio to use when making this estimate was to assume that 1 bushel of wheat would yield 80 pounds of straw.

A bushel of wheat yields 60 pounds of grain or approximately 27.2 kg (Dictionary.LaborLawTalk.com 2005). From this information, the total mass of the cut straw can be calculated.

$$\frac{0.383\,kg\,(grain)}{m^2} \times \frac{80\,lbs\,(straw)}{60\,lbs\,(grain)} = \frac{0.511\,kg\,(straw)}{m^2}$$

Equation 3.3 Biomass of straw per unit surface area.

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[4] The term "fresh" is used to describe materials whose natural moisture has not been artificially altered or removed. The term "dry" is used to describe materials whose natural moisture has been removed.

From the above equation 3.3, an estimate is made for the total biomass removed during harvest by adding this value to the original mass of harvest grain per square meter, or yield.

$$\frac{0.383\,kg\;(grain)}{m^2}+\frac{0.511\,kg\;(straw)}{m^2}=\frac{0.894\,kg\;(harvested)}{m^2}$$

Equation 3.4 Harvested biomass per unit surface area.

Once the value for the total harvested biomass is known, it becomes necessary to account for the remaining biomass of the wheat stubble to approximate the total biomass of the entire plant. The work by Whicker and Kirchner (1987), in the "PATHWAY" model suggests a value of 0.015 dry kg · m^{-2} for the remaining biomass after harvest for grain crops. Due to the previous being a dry value, it is necessary to apply a conversion factor to account for the intrinsic moisture of a fresh harvest. Till and Meyer (1983), give a fresh to dry ratio (FDR) of 1.1 for wheat. It is assumed that this ratio will apply to both the wheat grain and the remainder of the vegetation for purposes of mass estimation. The product of the FDR and the suggested remaining biomass is approximately 0.0165 fresh kg · m^{-2} after the wheat is harvested.

Now that the harvested and non-harvested biomasses are known, the estimated total biomass of the wheat plant can be calculated by summing the two values.[5]

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[5] The biomass of the root system is not considered in this model and is assumed to be in unity with the soil for the purposes of this study. Therefore, all references to biomass should be considered above-ground values.

$$\frac{0.894\ kg\ (harvested)}{m^2} + \frac{0.0165\ kg\ (remaining)}{m^2} = \frac{0.911\ kg\ (total\ fresh\ biomass)}{m^2}$$

Equation 3.5 Total fresh above-ground biomass.

The total fresh biomass is used in the model to calculate a growth rate for the wheat. The average biomass of the wheat grain per square meter (crop density) will be used to calculate the activity concentration ($Bq \cdot kg^{-1}$) of both the harvested grain and the activity concentration of the processed wheat flour. The final activity concentration in the fresh harvested wheat grain will be the value which is compared to the derived intervention levels (1200 $Bq \cdot kg^{-1}$) (U.S. Food and Drug Administration 2005).

3.2.3 Eastern Oregon Average Temperatures

Before proceeding to other parameters of the experimental model, the issue of the average seasonal growing temperatures must be addressed in order to properly illustrate the relationship of climate and the growth characteristics of a wheat crop. As will be explained later, the ambient temperatures to which a plant is exposed has a great impact on the final crop and the overall time in which it takes to reach full physical maturity. This fact brings forth the concept of growing degree days which is an accumulation of the total heat from the ambient climate to which a crop is exposed (Wikipedia 2005). This is an important component of the experimental model described in this document. The concept of growing degree days will be discussed at length in the following Section 3.2.4.

The area of eastern Oregon was selected for the subject of this model; specifically, the area of Umatilla county. The closest point at which regular climatic data are collected and archived was the NOAA station based at the Pendleton airport (Oregon Climate Service 2005). The temperature data was an average mean temperature per month from the year 1971 through 2000. The temperatures were averaged between the months of October and July, the typical growing period of a winter wheat crop (Christensen and Hart 2005, Food and Agriculture Organization of the United Nations 2002).

Monthly Mean Temperatures at Pendleton Airport (WSO), Years 1971 - 2000

Month	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**Jun.**	**Jul.**
Mean Temp (F)	52.3	41.2	33.9	33.8	38.7	45.1	51.0	58.1	65.4	72.6
Mean Temp (C)	11.3	5.1	1.1	1.0	3.7	7.3	10.6	14.5	18.6	22.6
Days per Month	31	30	31	31	28	31	30	31	30	31
DD (C X Days)	350.3	153.3	32.9	31.0	104.2	225.7	318.0	449.5	558.0	700.6
Average Temp C = 9.58			Total GDD = 2923.5							

Table 3.1 Monthly mean temperatures.

By multiplying the average temperature (°C) for each month by the number of days in the respective month, the total number of growing degree days for the growing season can be determined. Between the months of October and July, the total number of accumulated growing degree days is approximately 2924. This illustrates that a wheat crop requiring 2500 GDD (Rao et al. 2000) will reach maturity around early to mid-July if planted in October. The calculated data in the above table also yield an average temperature of 9.58 °C. This will be the standard temperature used in the experimental model. Some of the effects produced with variation of the set temperature will be discussed later in the document.

3.2.4 Growing Degree Days and Wheat Development

The experimental model is highly dependent on the day that the wheat crop reaches maturity, which is a function of the specific GDD value to maturity and the average ambient temperature. To begin, the number of growing degree days for the plant in question to reach maturity must be known. This number will lay the foundation for the entire model since the model considers only the time between planting and harvesting for the purposes of cesium uptake. Next, the average ambient temperature must also be known. Using the following relationship, the total number of days required to reach maturity (NDM) can be generated.

$$Total\ number\ of\ days\ to\ maturity = \frac{GDD\ to\ Maturity\ (^{\circ}C \cdot Days)}{Average\ Temperature\ (^{\circ}C)}$$

Equation 3.6 Total number of days to maturity.

From the above relationship, the total number of days to reach maturity is automatically generated and applied to the model. In this way, the GDD adaptation remains compatible with the original PATHWAY model where (t) remains in units of days, and time zero refers to the day of planting. Also, the maximum functional range is the day of harvest (DOH), assuming harvest will occur one day after the NDM. For example, if the average temperature was 10 °C, the NDM would be at day 250 and the DOH would be at day 251. Likewise, if the average temperature were the optimum growing temperature for wheat of 25 °C (Food and Agriculture Organization of the United Nations 2002), the NDM would be at day 100 and the DOH would be at day 101.

For the Umatilla county area in eastern Oregon the average temperature for the winter wheat growing season averaged to 9.58 °C between the years 1971 and 2000 (Oregon Climate Service 2005). After applying the relationship described above in equation 3.6, the values as shown in table 3.2 were calculated and used as a basis for the experimental model in the simulation of an eastern Oregon wheat crop.

Wheat Crop Time Scale		
Average Temp (°C)	9.58	
	GDD	Day
Planting	-	0
Emergence	180	18.8
Maturity	2500	261.0
Harvest	-	262

Table 3.2 Wheat crop time scale.

Temperature also affects the total height of the mature wheat plant. From the data given in the Food and Agriculture Organization of the United Nations (FAO) publication "Bread Wheat (Food and Agriculture Organization of the United Nations 2002)", the total height of the wheat stalk increases as the mean seasonal temperature decreases (Table 3.3). These FAO data were plotted, a linear relationship was determined, and the experimental temperature 9.58 °C was applied to the fitted line.

Wheat Height		
Mean Seasonal Temp C		Plant Height cm
Extrapolation	**9.58**	**90.5**
	12.2	82.9
	20.7	57.6
	23.9	48.6

Table 3.3 Wheat height as a function of temperature.

The output of the fitted line in figure 3.6 resulted in a height of approximately 90.5 cm with a temperature of 9.58 °C. This height is close to an average height of 86.9 for various eastern Oregon wheat crops during the growing season 1990-1991 (Karow et al. 2005). Though this value is slightly less than the extrapolated value, consideration must be given to the year to year temperature fluctuation and various other environmental and agricultural variables which can become difficult to account for. For the sake of this study, a height of 90 cm appears to be a good conservative value for the sake of exposure estimations and will be utilized in a later section.

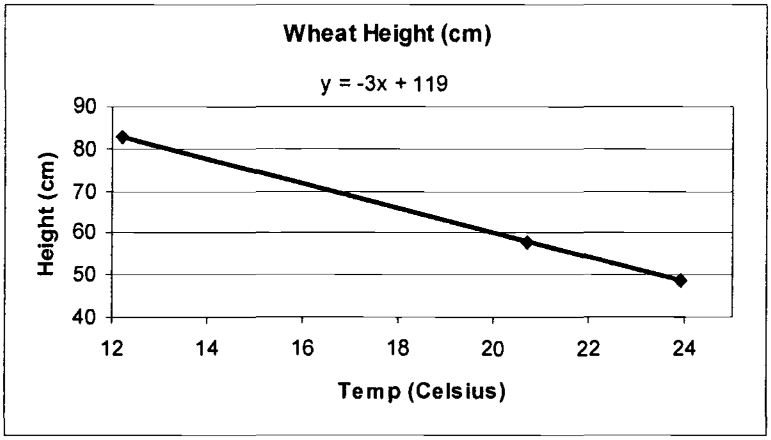

Figure 3.6 Wheat height extrapolation.

An item of great importance in the experimental model is the total amount of above-ground plant biomass present at the time of the contaminating (dispersal) event. This will affect the fraction of the contaminant which will land on the soil and onto the plant surfaces. The above ground biomass is a function of time in days (d) which is made a function of average temperature (°C) by the experimental model.

The above-ground biomass begins to accumulate after the day of emergence. This is the day when the plant begins to poke through the soil following germination (Food and Agriculture Organization of the United Nations 2002). The experiment uses this point in time as related to the GDD value of 180. The experimental temperature of 9.58 °C yields a day of emergence of approximately 18.8 days following planting. Therefore, the rate of above-ground dry biomass accumulation is described by the following relationship which also includes the fresh to dry ratio (FDR).

$$\frac{0.911\ Fresh\ kg}{m^2} \times \frac{1}{1.1\ FDR} \times \frac{1}{261\,d - 18.8\,d} = \frac{0.00342\ Dry\ kg}{day}$$

Equation 3.7 Above-ground growth rate.

The dry above-ground biomass can then be determined by multiplying the dry growth rate given in equation 3.7 by the total number of days from the day of emergence to the point of interest. Based on this principle, the value for the above-ground biomass will remain to be zero until the day of emergence.

Whicker and Kirchner (1987), provide a method for calculating the fraction of the total source term which will falls onto the soil and onto vegetation. This method is shown below in equation 3.8. The value for (B) is calculated using the principles described in the previous paragraph.

$$f_s = e^{-\alpha B} \qquad f_v = 1 - e^{-\alpha B}$$

Where,
f_s = fraction to soil
f_v = fraction to vegetation
α = foliar interception constant, (0.39 $m^2 \cdot kg^{-1}$)
B = above ground biomass of the vegetation (dry kg $\cdot$ m^2)

Equation 3.8 Source term fraction to soil and vegetation.

Below in figure 3.7 is a mathematical circuitry developed by the author in the STELLA™ modeling software. This graphic represents the relationship of all factors which contribute to the calculation of the contaminant fraction to soil. The program then subtracts this fraction from a value of 1.00 to automatically generate the fraction of the contaminant which reaches the surfaces of the wheat plant.

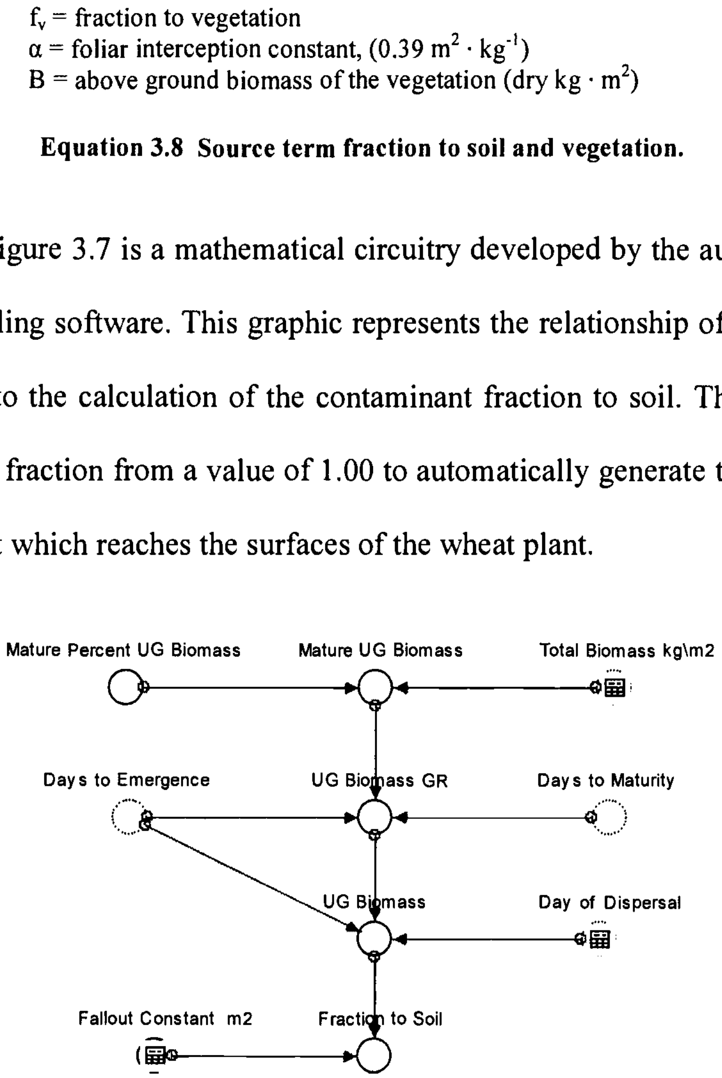

Figure 3.7 Fraction to soil modeled in STELLA™.

The PATHWAY model requires a growth rate of the plant in units of (d^{-1}). Since the experimental model is attempting to simulate the cesium uptake in a specific location, the generic growth rate constant suggested for grains by Whicker and Kirchner (1987), was substituted for one calculated to represent a wheat crop in eastern Oregon. This was done by dividing the total biomass of the wheat plant by the number of days required for the plant to reach maturity. The PATHWAY model puts the growth rate in units of (kg · m^{-2} · d^{-1}) (Whicker and Kirchner 1987). The value for the average wheat biomass per unit area calculated in equation 3.9 can be applied to the total number of days required for the wheat to reach maturity at the average temperature of 9.58 °C as shown in table 3.2. This method is used since the biomass of the root system is not considered.

$$\frac{0.911\,kg}{m^2} \times \frac{1}{261\,days} = \frac{0.00349\,kg}{m^2 \cdot d}$$

Equation 3.9 Wheat plant growth rate.

It is generally known that the growth and development of plants is not a totally linear process. However, the concentration of contaminant in the wheat crop is evaluated at the end of the growing period in this experiment. Therefore, only a linear relationship was needed to estimate values at the end point.

3.2.5 Soil Parameters

The type and nature of the soil will dramatically influence radionuclide uptake within a plant. Soils differ greatly from region to region. This is probably the most complex variable when dealing with an uptake model within a terrestrial ecosystem. A soil's physical and chemical traits can make great differences in the way a contaminant migrates through it and is taken up by roots. A soil's physical properties can range from very fine silt to large course gravel. Soil also contains varying degrees of clay, minerals, and organic material (Davidson and Springman 2005, Greger 2004, Food and Agriculture Organization of the United Nations 1989).

To maintain as much consistency as possible with the generic PATHWAY model, the default values given in PATHWAY for soil-based parameters were not altered (Whicker and Kirchner 1987). These parameters are as follows:

Model Constant	Value
1) Soil bulk density	$1.46\ \mathrm{g} \cdot \mathrm{cm}^{-1}$
2) Percolation	$1.98 \times 10^{-2}\ \mathrm{d}^{-1}$
3) Leaching	$6.6 \times 10^{-6}\ \mathrm{d}^{-1}$ (specific to cesium)
4) Adsorption (labile to fixed)	$1.9 \times 10^{-3}\ \mathrm{d}^{-1}$ (specific to cesium)
5) Desorption (fixed to labile)	$2.1 \times 10^{-4}\ \mathrm{d}^{-1}$ (specific to cesium)
6) Resuspension	$1.73 \times 10^{-2}\ \mathrm{d}^{-1}$
7) Rainsplash	$8.6 \times 10^{-4}\ \mathrm{d}^{-1}$
8) Rooting zone	25 cm

The percolation constant refers to the movement of contaminant from the soil surface to the intermediate layer (0.0 – 0.1 cm). The leaching constant describes the movement from the intermediate layer (0.1 – 25 cm), composed of the labile and fixed soil compartments, to the compartment representing deep soil (>25 cm). Once the contaminant has seeped down to the intermediate layer it is first collected in the labile compartment. Here, the contaminant is available to be taken up by the root. While in the labile compartment it can also leach to the deep soil or move to the fixed soil compartment through a process called adsorption. The fixed soil is a figurative compartment in the intermediate soil layer where the contaminant is essentially locked in place and can no longer migrate. However, contaminants can return to the labile soil through the process of desorption where it again becomes available to migrate (Whicker and Kirchner 1987).

The rooting zone provided in the PATHWAY model is 25 cm. The roots of a wheat plant are primarily concentrated in the top 30 cm of the soil (Food and Agriculture Organization of the United Nations 2002). The difference between these two values are relatively small. Since it is known that uptake decreases with depth, the rooting zone was left at 25 cm in the experimental model for the sake of consistency with the original parameters. This decision can be further justified by the low sensitivity of this parameter within the model, having little impact on the final results. This will be discussed later section 4.4.

Concentration ratios (CR) are standardized values for the amount of contaminant that is expected to concentrate within a given plant over the concentration of the contaminant within the soil (Till and Meyer 1983). The PATHWAY model requires this term as part of the calculation of root uptake and transference to the internal plant tissues. A value of 0.019 was selected for the CR in the experimental model. This number is provided in the work by Till and Meyer (1983), for ^{137}Cs in wheat grain kernels. The previous value was also applied to the ^{134}Cs component of the experimental model. This is justified by the understanding that isotopes generally maintain nearly identical chemical properties. Though the half-life of ^{134}Cs is much shorter than ^{137}Cs, the range of the experiment is less than half of one ^{134}Cs half-life. Finally, the sensitivity of the CR component in the model was not among the most significant parameters as shown by the sensitivity analysis (Figure 4.7).

After research into the reference material used by Whicker and Kirchner (1987), the author could not justify changing the above parameters from the default values as given in the PATHWAY model for the purposes of this study, with the exception of three parameters: tillage, resuspension, and senescence. These parameters where either omitted from the experimental model or adjusted to suit the scenario.

The first parameter that was adjusted from the original PATHWAY model was that of tillage. The reasons were threefold. The first is that since the experimental model is considering a wheat crop, the author assumes that no additional field cultivation will occur after the wheat seed has been planted (time zero) until after the crop has been harvested. In the experimental model, the contaminating dispersal event can only occur between the time of planting and harvest.

The second reason is that tillage can reduce the uptake of contaminants in crops. The uptake of a contaminant is highest where the root system is most concentrated. The root system of plants is most concentrated near the soil surface and decreases with depth. Thus, the ability of a plant to absorb contamination also decreases with soil depth. The method of mechanical mixing of the top soil with the deeper soil dilutes the surface contaminants, thus reducing the overall soil concentration available to the roots. In light of this fact, tilling or ploughing soil is considered a type of countermeasure by reducing a crop's access to the contamination (Food and Agriculture Organization of the United Nations 1989). In an attempt to make the estimation for radiocesium uptake more conservative, this countermeasure was removed from the experimental model.

Finally, the third reason was that the PATHWAY model assumes tillage for a grain crop to take place in the month of April (Whicker and Kirchner 1987), which is during the growing season of a winter wheat crop. Therefore, this parameter could not be incorporated during the time suggested by Whicker and Kirchner (1987) and was omitted from the experimental model.

Resuspension in the PATHWAY model describes the rate at which ground contaminants are removed from the ground by air turbulence and subsequently deposited onto plants (Whicker and Kirchner 1987). Resuspension is characterized by the ratio of the airborne contamination ($Bq \cdot m^{-3}$) over the amount of ground surface contamination ($Bq \cdot m^{-2}$) (Sehmel 1980). This ratio is known as the resuspension factor (RF). The RF is multiplied by the deposition velocity (V) of the contaminant in question, and the area concentration of the ground contamination (as is done by the PATHWAY model). The resulting value (R_{res}) represents the fraction of ground contamination which is expected to migrate to the plant surfaces over a given period of time (Whicker and Kirchner 1987).

$$R_{res}\ (Bq \cdot d^{-1}) = Activity\ on\ soil\ surface\ (Bq) \times RF\ (m^{-1}) \times V(m \cdot d^{-1})$$

Equation 3.10 Resuspension.

Selecting an appropriate value for resuspension in an environmental model is problematic. This stems from the RF being very difficult to accurately predict (Sehmel 1980). Many reported values range over ten orders of magnitude (Sehmel 1980, Whicker and Kirchner 1987). Due to this issue, the parameters selected in the experimental model were done so in attempt to maintain congruency with the original PATHWAY model. The value for deposition velocity was kept to the recommended 173 $m \cdot d^{-1}$. The value used for the RF was 1.0×10^{-4} m^{-1}. This value is not the default value in the PATHWAY model, but was said to be fitting for desert environments (Whicker and Kirchner 1987). Considering the area modeled in the experiment (an acute deposition in eastern Oregon), the value appears to suit the situation.

Another factor of the PATHWAY model which contributes to the recycling of contamination to the soil is that of senescence. The model uses this term to account for the death and shedding of the contaminated plant. Senescence then reincorporates radioactivity from the internal plant tissue and the remaining surface contamination back into the soil. PATHWAY specifically applies this process between the dates of August and December 31 (Whicker and Kirchner 1987). However, the experimental model applies only from the time of wheat planting to the date of maturity and harvest. It does not consider a perpetual growth cycle nor the total natural lifetime of the wheat plant since it is an agricultural crop being simulated. Therefore, the experiment assumes that senescence would contribute very little to the cycling of contaminant and was omitted.

3.2.6 Plant Surface Parameters

Other than resuspension, there are two additional parameters that are related to the contamination of the plant surface: foliar absorption and weathering. The foliar absorption factor is one of the most influential components in an acute dispersal event. Foliar absorption is the movement of contaminant into the plant tissue through direct contact with the plant surface. It is presumed that the absorption of cesium by leaves is mainly due to metabolic processes. It has been reported that leaves are capable of absorbing 5-30% of the cesium deposited onto their surface. Once absorbed, the cesium can move to other parts of the plant (Greger 2004). The constant for the foliar absorption of cesium suggested in the original PATHWAY model is $5.5 \times 10^{-3}\ d^{-1}$ (Whicker and Kirchner 1987).

The process of weathering is the removal of contaminant from the plant surface to the ground through environmental processes such as wind and rain. The PATHWAY model uses the value of $4.95 \times 10^{-2}\ d^{-1}$ for radionuclides other than the isotopes of iodine. This number equates to a half-life of approximately 14 days which appears to be a readily accepted weathering value within the field of radioecology (Whicker and Kirchner 1987). At the day of harvest all remaining surface contamination is assumed to be removed from the grain through the threshing of the wheat husk.

3.2.7 Wheat Ingestion

When considering the contamination of food crops, the average consumption of that crop must be factored in if one is to estimate the dose received from eating that food item. According to the National Agricultural Statistics Service (2005c), Americans consumed an average of 144.3 lbs. (65.6 kg) of wheat flour per year between the years of 1996 and 2001.

The direct mixing of contaminated foodstuffs with uncontaminated stores is outlawed according to the Federal Food, Drug and Cosmetic Act (U.S. Department of Health and Human Services 2005). However, it is assumed that an individual's diet is somewhat diversified and one will not receive all of a particular food group from any one agricultural region. When assessing the dose to an individual it is predicted that only 30% of dietary intake will be contaminated (U.S. Department of Health and Human Services 2005). Therefore, this study applies a factor of 0.30 to the final yearly contaminated intake calculation to give a more realistic dose estimate for an adult male.

Lastly, a factor was incorporated into the final contaminated intake estimate. It is understood that a portion of the contaminant in grain (wheat) is lost during the refining process. One source suggests that when dealing with a cesium contamination to a grain crop, 50% of the cesium in the grain will be lost when it is milled into flour (Simmonds and Linsley 1982). The author has then introduced a factor of 0.50 into the calculation of cesium concentrations within the final edible product.

3.2.8 Ingested Dose CEDE

Cesium is readily absorbed into biologic systems (National Council on Radiation Protection 1977). The ingestion of radiocesium by humans can result in a significant committed dose. The committed effective dose equivalent (CEDE) conversion factors for ^{134}Cs and ^{137}Cs are 1.98 x 10^{-5} mSv · Bq^{-1} and 1.35 x 10^{-5} mSv · Bq^{-1} respectively (Environmental Protection Agency 1988). The CEDE can then be calculated by multiplying the total activity consumed by the above conversion factors.

In the experimental model, the grain (flour) is removed for the contamination at harvest where it remains in a "harvested" compartment. The radioactivity in this compartment is only affected by physical radioactive decay. As a result, the activity concentration (Bq · kg^{-1}) decreases over time. In recent years, the average American consumes approximately 65.6 kg of wheat flour per year (National Agricultural Statistics Service 2005c). This can be averaged to approximately 0.180 kg per day. If one consumes flour from the contaminated crop being held in the "harvested" compartment, assuming the mass consumed per day remains constant, the total activity consumed per day will decrease due to radioactive decay over time.

The experimental model estimates an ingested CEDE for an individual based off the assumption that 50% of the contamination is lost in milling the grain to flour and that only 30% of the dietary flour intake comes from a contaminated crop. This implies that only 15% of an individual's annual flour intake would be contaminated. This reduction is applied to the activity concentration in the "harvested" compartment (Appendix B: Source Term 1 Diagram) to represent a store of flour which is being consumed by the individual, keeping in mind that the activity in the compartment is decaying with time. The calculation considers the individual to consume this flour over the course of one year at a rate of 0.180 kg per day. Due to the decay process, each daily serving of flour has a reduced activity concentration (Bq · kg^{-1}) as the number of days between the contamination event and consumption increases. At the end of the year the total activity, or integrated activity, of each isotope which has been consumed is calculated by the model. This value (Bq · yr^{-1}) is then applied to the EPA dose conversion factors for ingested radioactivity giving a CEDE for that year (Environmental Protection Agency 1988). When two isotopes were consumed, the CEDE calculated for each is summed giving a total CEDE.

3.2.9 External Exposure

When a contamination even occurs, the quickest way to determine its magnitude is with an exposure rate meter, measuring in uR · hr^{-1} or mR · hr^{-1}. When taking this approach several factors come into play. The first, and probably the most important, is the level of background radiation present at the site to be measured. In the United State the average person receives a CEDE of approximately 1 mSv per year due to naturally occurring radiation, both cosmic and terrestrial (Martin 2000). If one assumes a radiation weighting factor (W_R) of one for gamma and x-ray contribution (Cember 1996), the corresponding exposure rate in (mR · hr^{-1}) can be calculated from the CEDE.

$$H_T = W_R \times D_T \quad \Rightarrow \quad 1\,mSv = 1 \times 1\,mGy$$

$$\frac{0.001\,Gy}{yr} \times \frac{1\,R}{8.76 \times 10^{-3}\,Gy} \times \frac{1000\,mR}{1\,R} \times \frac{1\,yr}{365\,d} \times \frac{1\,d}{24\,hr} = \frac{0.0130\,mR}{hr}$$

Equation 3.11 Background exposure rate.

The exposure rate from the contaminated area must be high enough to make a significant contribution to the total exposure rate to cause a statistically visible change on the detection device. Otherwise, the contamination would remain undetected. When the contamination level becomes this low, the most accurate method for quantification purposes would be laboratory analysis using equipment with high sensitivity and specificity.

The distance which the detector is placed from the source can dramatically affect the indicated exposure rate on the survey meter, especially in the case of a point source. With a point source, the intensity of the radiation field is a function of distance according the inverse-square law. However, when using an infinite plane source the change in exposure rate with distance is not as severe due to the angular contribution of the radiation distributed across the plane. Therefore, the inverse-square law does not apply and another relationship must be used to calculate the radiation intensity at a given distance from the source.

In the wheat crop contamination event being modeled by this experiment, the author has chosen an infinite plane concept to describe the source. This approach was used due to the complexities of modeling non-uniform three-dimensional sources. In this model, there are actually two plane sources to consider when the wheat is near to maturity and has reached an appreciable height. In this case the planes are positioned to represent the soil surface and the surface contamination of the wheat plant.

A reasonable assumption would be that the contamination of mature wheat is at greatest concentration near the top of the wheat head and decreases exponentially moving downward toward the ground as the contaminants are filtered out by foliage. However, this makes for a complex arrangement if considered as a volume source. In light of this assumption, the plane source describing the wheat was placed at a point two-thirds the total estimated height of the wheat plant (90cm). At approximately 60 cm above ground the assumption is made that the exposure contribution of both halves of the plant are roughly equal.

A typical rule of thumb for measuring exposure rates from a source is at distances of 30 cm or 100 cm. Both these distances become problematic when attempting to measure a contaminated wheat crop. At 30 cm from the ground source, a pancake-type meter would miss most contribution from the contaminant on the wheat plant. At 100 cm, the survey meter is very close to the tops of the wheat head giving a gap of only 10 cm. Therefore, for the purposes of this study the exposure estimates were made at a distance of 120 cm from the ground, which equates to 60 cm from the plane source describing the wheat contamination (Figure 3.8).

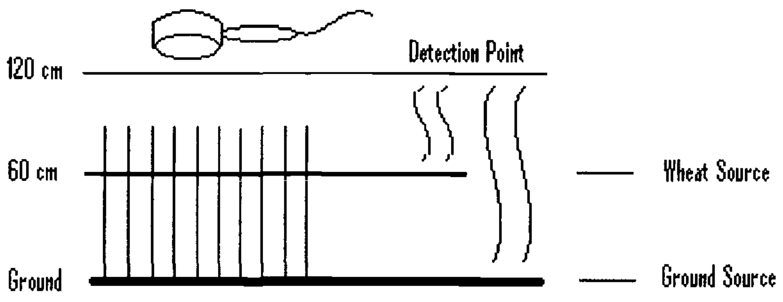

Figure 3.8 Radiation detection of a wheat crop.

For purpose of radiation protection, the guidelines provided by the Environmental Protection Agency (EPA) are typically used when calculated dose to the general public. Conversion factors are available in the EPA Federal Guidance Report No. 12 for ground contamination of radionuclides which converts surface area activity (Bq · m^{-2}) into an effective dose equivalent rate (Sv · s^{-1}) at one meter (Environmental Protection Agency 1993). These values need to be adjusted for the increased distance from 100 cm to 120 cm. Since the sources in question are plane sources, a particular equation needs to be applied to account for the change in distance, which alters the values of the dose factors. The text by Cember provides an equation for such cases (Cember 1996, pp. 424).

$$\frac{H_1}{H_2} = \frac{\ln\left[\left(r^2 + h_1^2\right)/ h_1^2\right]}{\ln\left[\left(r^2 + h_2^2\right)/ h_2^2\right]}$$

Where,
H_1 = Original dose factor
H_2 = New dose factor
h_1 = Original distance (1.00 m)
h_2 = New distance (1.20 cm)
r = Radius of plane source (1000 m)

Equation 3.12 Adjustment for detection distance from a plane source.

The plane sources in the model are best described as infinite plane sources. Therefore, a large arbitrary radius of 1000 meters was applied in equation 3.12 to simulate an infinitely large plane representing a wheat field. The equation reduced the original dose factors to 97.3% of their original values with an increase of 20 cm distance from the source.

FGR No. 12 Dose Rate Factors

Units = (Sv m2)/(Bq s)

% Change from 1 meter:		1.00		0.973		1.07		1.17
Soil Depth	Surface	1 cm	Surface	1 cm	Surface	1 cm	Surface	1 cm
Distance	1.00 m	1.00 m	1.20 m	1.20 m	0.60 m	0.60 m	0.30 m	0.30 m
Cs - 134	1.52E-15	9.78E-18	1.48E-15	9.52E-18	1.63E-15	1.05E-17	1.78E-15	1.14E-17
Ba - 137m (Cs - 137)	5.86E-16	3.76E-18	5.70E-16	3.66E-18	6.27E-16	4.02E-18	6.86E-16	4.40E-18

Table 3.4 FGR No. 12 Dose rate factors with adjustment for distance.

The EPA Federal Guidance Report No. 12 gives effective dose factors at a one meter distance for ground surface contamination and soil contaminated to a depth of 1 cm, in units of $(Sv \cdot m^2 \cdot Bq^{-1} \cdot s^{-1})$ (Environmental Protection Agency 1993). Surface contamination factors are used to describe the radioactivity on the wheat plant, while the factors for 1 cm soil depth are used to describe the ground contribution. Because the primary gamma (0.6617 MeV) characteristic of ^{137}Cs comes from the decay of its daughter ^{137m}Ba (Martin 2000), the FGR No. 11 value for ^{137m}Ba is used (Environmental Protection Agency 1993).

Chapter 4
RESULTS

4.1 Purpose and Introduction of the Experiments

The purpose of the experimental model is to simulate the uptake behavior of ^{134}Cs and ^{137}Cs in eastern Oregon wheat crops following an acute dispersal event. Therefore, the focus of the experiment will assume instantaneous deposition of the total source term onto the soil and wheat surface. No time-dependent accumulation is considered, which is typically the case regarding a fallout event.

At first glance this approach may seem flawed due to the time dependency of fallout deposition. However, it is the aim of the author to perform a type of back-calculation to determine the amount of deposited contamination required to reach the derived intervention level (DIL) of 1200 ($Bq \cdot kg^{-1}$) for ^{134}Cs and ^{137}Cs in a freshly harvest, mature crop of eastern Oregon wheat (U.S. Food and Drug Administration 2005, U.S. Department of Health and Human Services 2005). Due to the nature of the back-calculation and the scenario of an acute deposition, time-integrated accumulation of the contaminant of interest is not considered.

The experiments of this study were conducted using the general PATHWAY model for the transfer of radioactive contamination within the environment as it relates to the food-chain (Whicker and Kirchner 1987). The construction of the model and the ensuing experimental adjustments to input values was accomplished using the modeling software STELLA® version 8.1.4 (isee™ systems, Inc. 2005a). As explained in earlier sections, some slight variations to the PATHWAY model were made to take into account specific crops and agricultural regions.

The input values that were selected for the experiment are listed in appendix A. Of the values listed under "Constants," only the fractions of ^{134}Cs and ^{137}Cs of the total source term were ever changed during the course of experimentation. This was done when the source term was made to consist only of ^{137}Cs, where the fractions of ^{134}Cs and ^{137}Cs were changed to 0.00 and 1.00 respectively. Otherwise, the fractions of 0.372 (^{134}Cs) and 0.628 (^{137}Cs) were used as the standard constants and the remaining constants were not tampered with as their category name implies. Under the category "Variables" in appendix A are those parameters which were adjusted during experimentation to observe the related outcomes in the output values of interest. These variables were: Total Source Term (Bq), Day of Dispersal, Average Temperature (°C), Fraction to Soil, and Fraction to Vegetation.

The total source term is the total activity in becquerels per square meter of surface ($Bq \cdot m^{-2}$), or the sum of the contributing contaminates. The total source term was divided between the surface soil and the above-ground surfaces of the wheat plant which is represented by the Fraction to Soil and Fraction to Vegetation parameters. The source term and corresponding output used as a benchmark for the study were $3.15 \text{ X } 10^7 \ Bq \cdot m^{-2}$ and $4.8 \text{ X } 10^6 \ Bq \cdot kg^{-1}$ respectively. These values are given by Jackson et al. (1987), in an experiment using the SPADE model to estimate the concentration of ^{137}Cs in general cereal crops following an acute deposition. In their experiment, the contaminating event occurs at time equals zero which represents the beginning of the growing season, or the time of planting (Jackson et al. 1987).

The values for the fraction to soil and vegetation are dynamic variables. The values of each were proportional to the dry above-ground biomass of the wheat plant. The above-ground biomass of the plant is a function of time in days (d), which is a function of average temperature (°C). Therefore, the fraction of the contaminant to the soil and vegetation will change depending on the day of the dispersal event and the average temperature used.

The temperature used as a reference point in the experiment was 9.58 °C which corresponded to the average temperature of the growing season in eastern Oregon. In one of the experiments, the temperature is adjusted above and below the experimental standard to observe how a change in the ambient temperature would affect the uptake of cesium.

The day of dispersal (DOD) is the day in which the contaminant is added to the model. The DOD can occur at any time from planting (time = 0) to the day of maturity. Experiments were conducted where the DOD was set to different points along growing period to observe the affect of DOD on the final cesium concentrations in the wheat.

A manual sensitivity analysis was performed in the model. The author adjusted the individual input constants and variables to somewhat extreme values. This was done to evaluate the relative importance of each parameter within the total model equation. The sensitivity analysis is discussed in greater detail in section 4.4.

4.2 Experiments and Results: The Harvest Concentration

4.2.1 Comparison and Performance Standard

The first experiment was performed to make a direct comparison of the output results with those given by the SPADE model. The total source term was set to 3.15×10^7 Bq · m^{-2} with the DOD at time zero and a growing period of 120 days as given by Jackson et al. (1987), for the simulation of a contaminated cereal crop. The Source term fraction was set to 1.00 for ^{137}Cs and 0.00 for ^{134}Cs so that only ^{137}Cs would be considered, making a single isotope[6] simulation. The DT (or Δt) time step for the calculation intervals was set to 0.01 days. The calculation run resulted in a harvest concentration of 1.74×10^6 Bq · kg^{-1}. This is reasonably close to the concentration of 4.8×10^6 Bq · kg^{-1} given by the SPADE model. The experimental model is within a factor of 3 in comparison to the work by Jackson et al. (1987).

Below in figure 4.1 is a graphical representation of the movement of ^{137}Cs through the primary compartments of the experimental model. The initial deposition of contaminant occurs with the total amount going to the surface soil and none to the plant surface since the deposition was at time zero and the day of emergence on day 8.7. The amount in the surface soil begins to decrease. On day 8.7 the plant is now able to receive external contamination from resuspension and rainsplash. At this point on the graph a rise can be seen in the amount of contamination on the plant surface. This amount steadily decreases due to foliar absorption and removal by the weathering process.

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[6] "Single isotope" refers to a simulation using only ^{137}Cs. The term "dual isotope" indicates a simulation where both ^{134}Cs and ^{137}Cs are used in the proportions of 0.372 and 0.628, respectively.

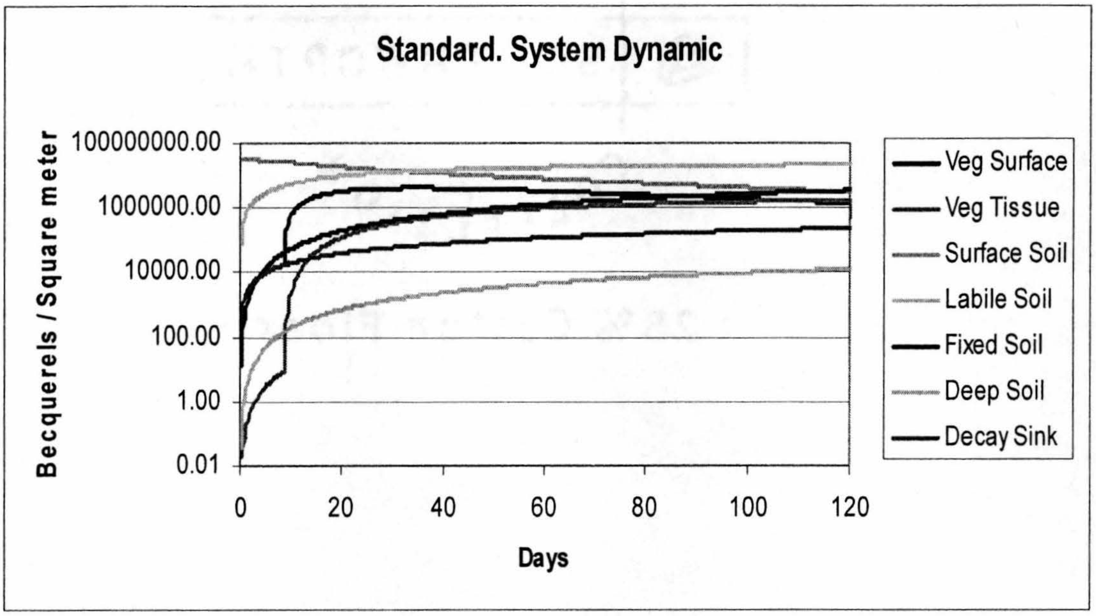

Figure 4.1 System dynamic with experimental standard.

As the contaminant starts to build up into the labile soil as it moves down from the surface soil, the root systems then begin to absorb and translocated the contaminant to the wheat tissue. Correspondingly, the wheat tissue begins to build as a result of this process and from the contribution of foliar absorption (Figure 4.2).

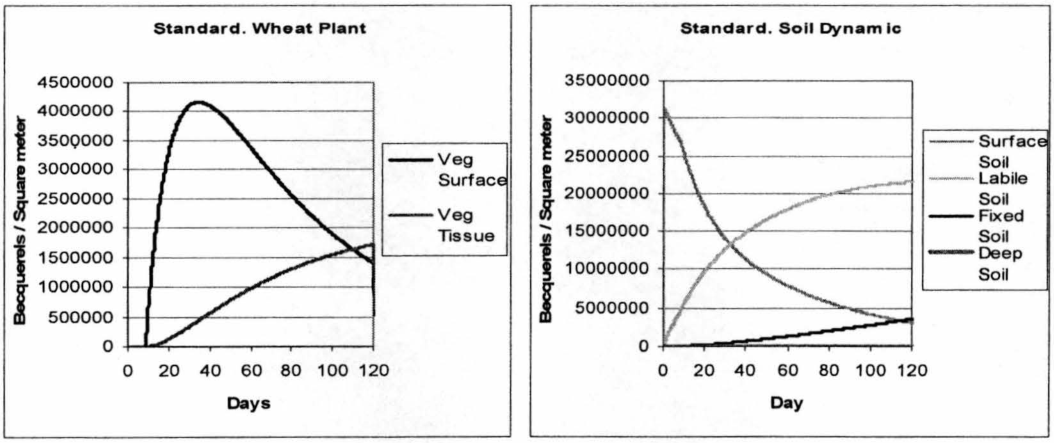

Figure 4.2 Compartmental comparisons using experimental standard. A dynamic comparison of the vegetation surface and tissue (Left). A dynamic compassion soil compartments (Right).

The quantity of atoms in the decay sink gradually builds as the atoms within the system are shunted to the decay compartment after having gone through the mathematical statistic for physical decay as described by the decay constant. Once in this compartment, the atoms are considered to no longer exist and cannot translocate to any other system compartment.

4.2.2 Dual Isotope System Performance Standard

The dual isotope system performance standard tested the function of the model when two isotopes are introduced simultaneously and summed. This run used the same parameters as in the previous test with the addition of ^{134}Cs. Therefore, the source term fractions were set to 0.372 for the ^{134}Cs component and 0.628 for the ^{137}Cs component.

The harvest concentration was 1.68×10^6 Bq · kg^{-1}. The graph in figure 4.3 illustrates the dynamics of the two isotopes on the surface of the wheat plant. Once the plant emerges from the soil (day 8.7), a sharp rise in contamination is observed followed by a decline due to foliar absorption and weathering. Both isotopes behave similarly with the exception of magnitude, resulting from the difference in source term fraction. ^{137}Cs contributes a greater amount of the total activity in the compartment since its fraction of the total source term is greater than half (0.628). Likewise, the magnitude of contamination from ^{134}Cs is less with a source term fraction of 0.372. Similar behavior can be observed in each system compartment when the simulation is run under dual isotope conditions.

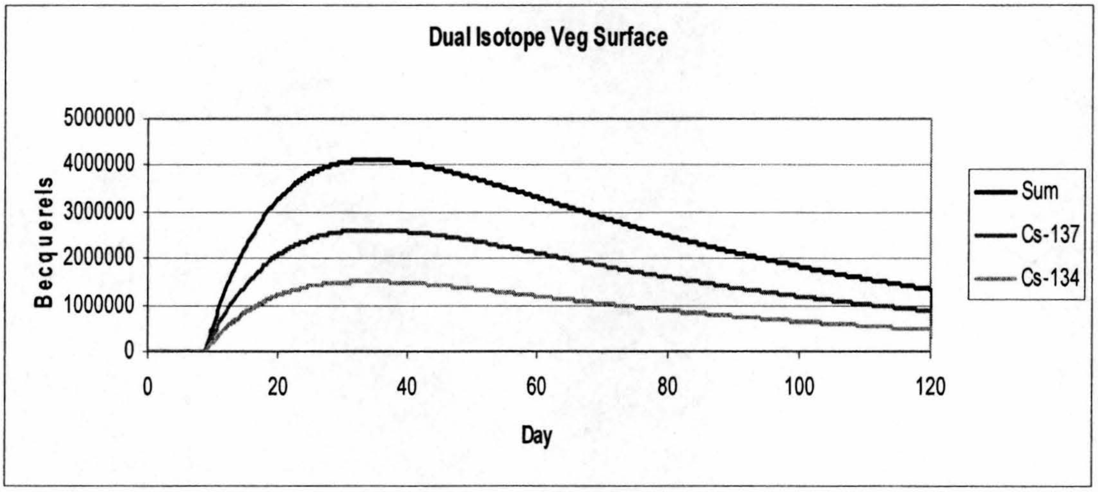

Figure 4.3 Dual isotope dynamic comparison on vegetation surface.

4.2.3 Temperature Standard

The Temperature Standard experiment set the model to an average temperature of 9.58 °C, simulating the seasonal growing conditions found in eastern Oregon. The experiment was performed in both the single isotope and dual isotope modes. The source term was set to 3.15 x 10^7 Bq · m^{-2}. The day of dispersal was at time zero which resulted in all the contaminant going directly to the soil surface (fraction to soil = 1.00). The (Δt) time step for calculation was set to 0.01 days.

The temperature of 9.58 °C equated to plant emergence at day 18.8 and physical maturity at day 261.0. The single isotope run resulted in a harvest concentration of 1.77 x 10^6 Bq · kg^{-1}. The dual isotope run produced a harvest concentration of 1.64 x 10^6 Bq · kg^{-1}.

4.2.4 Optimum Day of Dispersal

This experiment was meant to find which day along the growing season would result in the highest accumulation of radioactivity in the harvested grain (optimal day of uptake). The temperature was set to 9.58 °C, yielding a 261 day growing season and emergence at day 18.8. A source term of 3.15×10^6 Bq · m^{-2} remained the standard magnitude of contamination. The fraction of contaminant to the soil and plant surface is a function of the plant biomass, which is a function of the day of dispersal within the growing season. Hence, this fraction is dependent on the day of dispersal and changes from one day to another as the plant grows and gains surface area.

The harvest concentration was greatest when the contaminant was dispersed on day 85 of the growing period, if the contaminant was purely ^{137}Cs. On that day, the harvest concentration was approximately 2.66×10^6 Bq · kg^{-1}. The dual isotope demonstrated a maximal concentration on day 96 which approximated to 2.52×10^6 Bq · kg^{-1}.

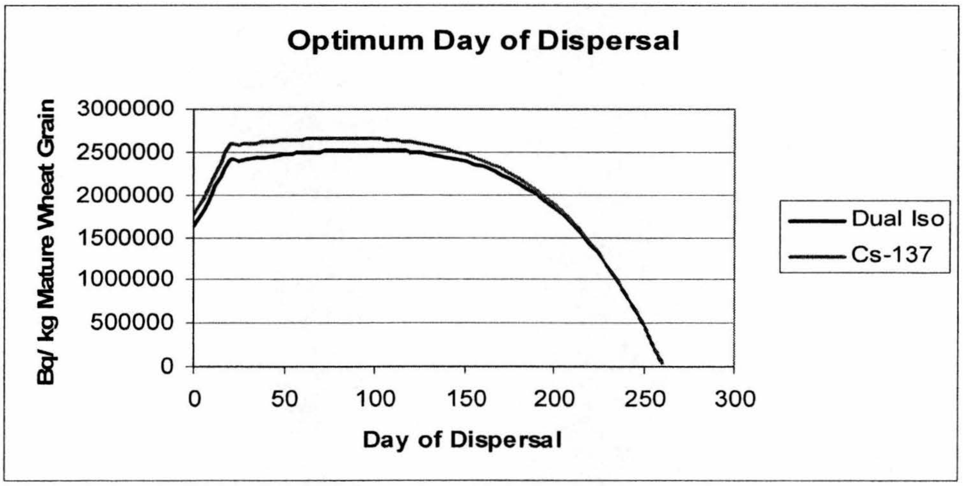

Figure 4.4 Optimum day of dispersal.

4.2.5 Maximum Source Term to Reach the DIL: Optimum DOD

The following experiment was run to find what source term value would be required to reach the DIL of 1200 Bq · kg^{-1} of wheat. The standard temperature of 9.58 °C was used yielding a day of emergence equal to 18.8 days and maturity at 261 days. The DODs of 85 and 96 were used for single and dual isotope modes, respectively. Using the optimal DOD for each mode, the minimum source term needed to reach the DIL can be found. In addition, the harvest concentration was also evaluated with the DOD at time equals zero. The experiment was a trial and error process due to the nature of the model. The source term was adjusted and fine-tuned until the harvest concentration was approximately 1200 Bq · kg^{-1}.

From a contaminating event involving only ^{137}Cs on the optimal day of uptake, the source term needed to reach the DIL is approximately 1.43×10^4 Bq · m^{-2}. Under dual isotope conditions, the source term must be approximately 1.50×10^4 Bq · m^{-2} to reach the DIL. Theses values represent the minimum estimated area contamination need to reach the DIL in a typical eastern Oregon growing climate.

When the DOD occurred at time zero, the magnitude of the source term required to reach the DIL under both source term compositions increased. The required source term for single isotope was approximately 2.15×10^4 Bq · m^{-2}. With the dual isotope condition, the source term required was approximately 2.33×10^4 Bq · m^{-2}. The tabulated compartment values and behavior graphics are shown in Appendix C and D.

4.2.6 Change in Dual Isotope Composition

A set of runs were conducted to assess the effect of the ^{137}Cs / ^{134}Cs ratio in the dual isotope source term. The total source term was set to 1.50 x 10^4 Bq · m^{-2} with a temperature of 9.58 °C. The day of dispersal was set to day 90 in the growing season. This value was decided by roughly averaging the day of maximal uptake found for the dual and single isotope modes. The ratio was then adjusted to both extremes from 100% ^{137}Cs to 100% ^{134}Cs.

The results of the experiment found that as the fraction of ^{137}Cs went down and the fraction of ^{134}Cs went up, the harvest concentration in the wheat grain decreased. The harvest concentration decreases by approximately 13.6% when the source term ratio is reduced from a 100% ^{137}Cs composition to a 100% ^{134}Cs composition.

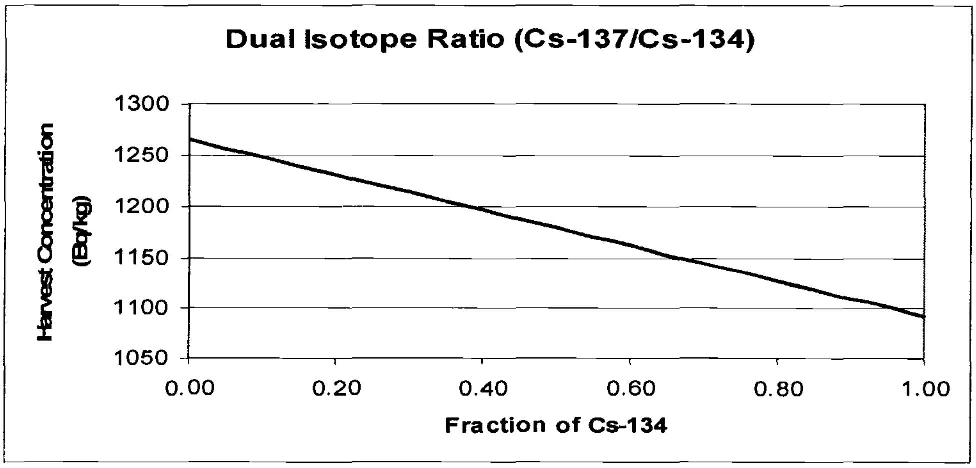

Figure 4.5 Dual isotope ratio (^{137}Cs/^{134}Cs).

4.2.7 Effect of Seasonal Temperature

The factor of average seasonal temperature fluctuation was examined for effects on the harvest concentration. A temperature range about the experimental standard (9.58 °C) was arbitrarily selected from 8.0 °C to 12.0 °C.[7] The model was set to 2.33 x 10^4 Bq · kg^{-1} under dual isotope parameters. The day of dispersion was set at time equals zero to allow contact with the contaminant during the total growing period.

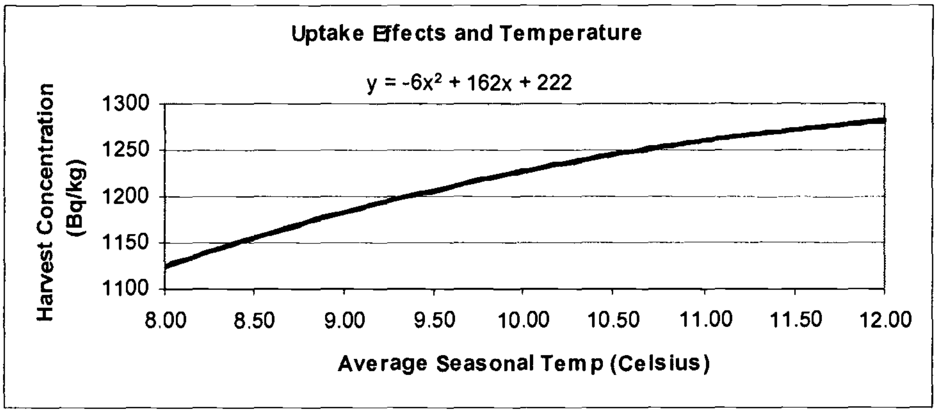

Figure 4.6 Effects of temperature on radiocesium uptake.

The results demonstrate an increased total uptake with increasing average seasonal growing temperature. Figure 4.6 shows a gradual curve increasing at a decreasing rate, suggesting a maximum uptake at approximately 13.2 °C, the maximum of the fitted quadratic.

4.3 Experiments and Results: Dose and Exposure

4.3.1 CEDE from Consumption

Given the results of the previous experiments, the CEDE from the consumption of the contaminated wheat grain can be estimated. The values are

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[7] Average temperatures much below 8 °C or above 12 °C in the model would result in growing periods far outside the expected range of a typical winter wheat crop.

generated automatically in the model as described earlier in the text. Dual and single isotope scenarios are simulated at the standard temperature of 9.58 °C with a 261 day growing period.

Two activity concentrations (Bq · kg^{-1}) are given for the activity in the harvested grain and in the milled flour. The milling is assumed to occur on the same day for the purposes of the model. Dose conversion factors were applied directly to the grain immediately after harvest (Grain) and after milling (Immediate). Dose was also calculated using a dynamic consumption method. This method simulates daily consumption of flour over a one year time period beginning after harvest, while taking radioactive decay of the flour bulk into consideration as described in section 3.2.8.

Dose and Contamination Limits

Temperature = 9.58 °C

DIL = 1200 Bq/kg) PAG = 5 mSv

Source Term (Bq/m^2)	*Harv. Con. (Bq/kg)*	*Grain (mSv/yr)*	*Flour Con. (Bq/kg)*	*Immediate (mSv/yr)*	*Dynamic (mSv/yr)*
Dual Isotope (DOD = 96)					
1.50E+04	**1202**	1.07	164	0.168	0.148
6.70E+04	5655	**5.01**	771	0.683	0.642
1.10E+05	8810	7.85	**1202**	1.23	1.09
4.46E+05	35730	36.7	4872	**5.00**	4.41
5.05E+05	40456	39.0	5517	5.66	**5.00**
Single Isotope (DOD = 85)					
1.43E+04	**1207**	1.23	165	0.146	0.137
6.81E+04	4871	**5.00**	664	0.681	0.602
1.05E+05	8862	41.5	**1208**	1.07	1.01
4.91E+05	41439	36.7	5651	**5.00**	4.71
5.22E+05	44055	9.04	6008	5.32	**5.00**

Table 4.1 Dose and contamination limits. Area contamination compared to DIL and CEDE.

4.3.2 Exposure from Contamination

Two deposition scenarios were considered for both a dual and single isotope contamination event: deposition at time zero, and deposition 7 days before harvest. The DCF for surface and 1 cm soil contamination for each nuclide were each adjusted for changes in elevation above ground from the standard 1 meter, as described in section 3.2.9. They were adjusted again according to the percent contribution of their respective isotope.

The conversion factors (Sv · m^2 · s^{-1} · Bq^{-1}) and assumed background value of 0.013 mR · hr^{-1} were used to find the expected exposure rate associated with a contamination event resulting in a harvest concentration at the DIL. These values were also used to calculated the total source term (Bq · m^{-2}) and associated harvest concentration that would create an exposure rate equaling the background level. The results of these calculations as listed in table 4.2.[8] The methods of calculation for the tabulated values are illustrated in the equations below (Equation 4.1, 4.2).

$$Source\ Term\ \frac{Bq}{m^2} \Rightarrow \frac{s \cdot Bq}{Sv \cdot m^2} \times \frac{1\,hr}{3600\,s} \times \frac{8.764 \times 10^{-3}\ Sv}{R} \times \frac{1\,R}{1000\,mR} \times \frac{0.013\,mR}{1\,hr}$$

Equation 4.1 Source term to equal the background exposure rate.

$$Exposure\ Rate\ \frac{mR}{hr} \Rightarrow \frac{Bq}{m^2} \times \frac{Sv \cdot m^2}{s \cdot Bq} \times \frac{1\,R}{8.764 \times 10^{-3}\ Sv} \times \frac{1000\,mR}{R} \times \frac{3600\,s}{1\,hr}$$

Equation 4.2 Exposure rate for a given source term.

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[8] Values for the calculated exposures are only a result of the contamination itself. The natural background field (0.013 mR · hr^{-1}) is not added to these values.

Exposure Rates From Contaminated Crops				**BKG Assumed = 0.013 mR/hr**			
DOD	Plant Height	Detect. Elev.	Harv. Con.	Exp. Rate	Source Term	Source Term	(Sv m2)
(day)	(meters)	(meters)	(Bq/kg)	(mR/hr)	(Bq/m2)	(mCi/acre)	(s Bq)
Duel Isotope (Cs - 134/137)							
0	0.00	0.30	1.20E+03	7.77E-05	2.31E+04	2.53	8.19E-18
0	0.00	0.30	2.01E+05	1.30E-02	3.86E+06	442	8.19E-18
254	0.879	1.20	1.21E+03	1.39E-02	1.25E+05	13.7	2.71E-16
254	0.879	1.20	1.13E+03	1.30E-02	1.17E+05	12.8	2.71E-16
96	**0.289**	**0.30**	**1202**	**5.05E-05**	**1.50E+04**	**1.64**	**8.19E-18**
Single Isotope (Cs - 137)							
0	0.00	0.30	1.21E+03	1.01E-04	2.15E+04	2.35	1.14E-17
0	0.00	0.30	1.45E+05	1.30E-02	2.78E+06	304	1.14E-17
254	0.879	1.20	1.20E+03	8.71E-03	1.24E+05	13.6	1.71E-16
254	0.879	1.20	1.79E+03	1.30E-02	1.85E+05	20.2	1.71E-16
85	**0.248**	**0.30**	**1207**	**6.70E-05**	**1.43E+04**	**1.56**	**1.14E-17**

Table 4.2 Exposure rates from contaminated crops.

Contamination events which could occur on the optimal day of uptake for dual and single isotope (day 96 and 85, respectively) were also considered. For both these days, the height of the wheat would be less than 30 cm. The adjustment to the DCFs for such a small difference in height is negligible when surveying at 30 cm. Therefore, when the DOD results in a plant height less than 30 cm one can assume a single plane source, treating the exposure calculation as an event occurring at time equals zero.

4.4 Sensitivity Analysis

A sensitivity analysis of the model was conducted to assess the importance of each parameter in the system. The input variables were made constant during the analysis. The model was run in dual isotope mode with a source term of 1.50 x 10^4 Bq · m^{-2}, the temperature at 9.58 °C, and the DOD at day 96.

The analysis was conducted manually by adjusting the input values to extremes of ±10% and ±10X the standard values. The high and low values for each parameter were substituted for the standard value and run through the model. The harvest concentration was used as the platform to observe change in the model due to the parameter adjustments. The resulting harvest concentration values were recorded and then applied to equation 4.3 to determine the relative sensitivity of each parameter in the model.

$$Sensitivity = \frac{\Delta\ Paramter\ Value}{\Delta\ Output\ Value}$$

Equation 4.3 Parameter sensitivity.

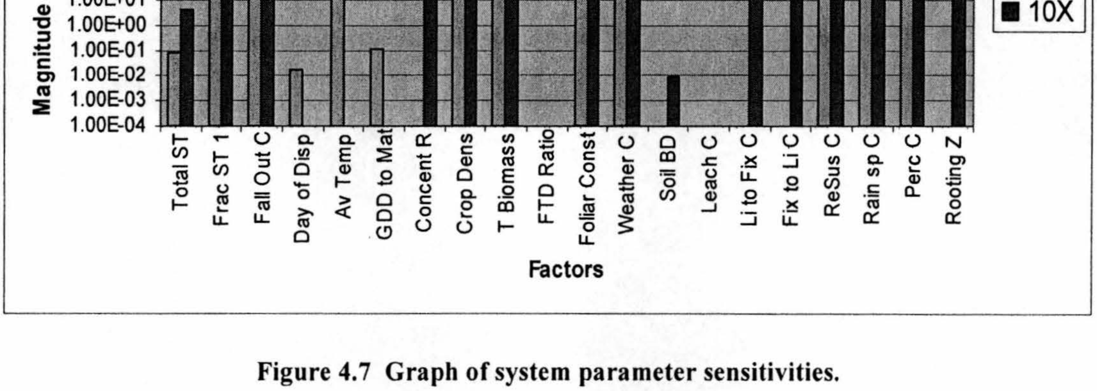

Figure 4.7 Graph of system parameter sensitivities.

Six parameters were found to be of great significance to the system. The foliar, rainsplash, resuspension, percolation, and weathering constants, along with the crop density each indicated a sensitivity magnitude greater than 10^4. The leaching constant, fresh to dry (FTD) ratio, and soil bulk density had little to no effect on the model. The DOD, average temperature, and GDD to maturity could only be evaluated with 10% differences since these affect the range of the model. Altering these parameters by a factor of 10 would result in an unrealistic change to the model, such as creating a growing season spanning a time period greater than one year.

Chapter 5
DISCUSSION

The experimental model was very similar to the general PATHWAY model. A few of the parameters given by Whicker and Kirchner (1987), were either altered or removed to allow higher specificity to an eastern Oregon winter wheat crop, such as adjusting the resuspension factor to represent a more arid climate. However, most of the standard values provided in the PATHWAY model were used for the experimental parameters. Many of these values provide a reasonable global average or are in common use for environmental modeling. An example is the weathering factor which yields a wash-off half-life for contaminants on plants of approximately 14 days. This value is widely accepted when approaching a problem of environmental contamination.

The initial outputs of the experimental model were compared with the results of a similar contamination event simulated by Jackson et al. (1987). This group used the SPADE model to estimate the concentration of ^{137}Cs in a mature cereal crop from an acute contamination 3.15×10^7 Bq $\cdot$ m^{-2} at time zero of the growing period. When this scenario was run in the experimental model, the results were only a factor of approximately 2.76 less than the values generated in SPADE. Therefore, it appears the experimental model can provide reasonable estimates for various contamination events. Some of the discrepancy between the experimental result and SPADE result are most likely due to some difference in the compartment exchange and rate of migration parameters used by Jackson et al. (1987), since most of these were unknown to the author. Also, this group was simulating a generic cereal crop rather than a more specific category such as winter wheat.

The experimental model ran smoothly and behaved as one might expect for a compartment-style environmental system. The contents of individual compartments (or stocks) collected and eliminated contaminants akin to expected terrestrial and biological processes. The graphical curve generated for each compartment and source term configuration illustrate these behaviors. Anomalies were present in some curves but can be easily accounted for and explained when acknowledging any competing or contributing processes. The most notable anomaly in the curves presented at the day of emergence. When the plant grows enough to poke through the ground soil it becomes physically exposed to the atmosphere. As a result, the plant surfaces become available to incorporate contamination through foliar absorption with increasing surface area of the growing foliage. Since foliar absorption is one of the most sensitive parameters in the model, dramatic change in many of the behavior curves could be observed after the plants' day of emergence. Such change in the curves is expected when discrete events occur.

The output value of primary concern in the model is the harvest concentration ($Bq \cdot kg^{-1}$). This is the amount of radioactivity from the nuclide(s) in question within the mature harvested crop. In this case it is the concentration within the harvested wheat grain. The derived intervention level for ^{134}Cs and ^{137}Cs is 1200 $Bq \cdot kg^{-1}$ of foodstuffs. The purpose of the experiment was to estimate the amount of settled surface contamination of ^{137}Cs or $^{134/137}Cs$ that is required to cause a harvest concentration in a typical eastern Oregon winter wheat crop to equal the DIL. According to the experimental model, it requires 1.50 x 10^4 Bq · m^{-2} ($^{134/137}Cs$) or 1.43 x 10^4 Bq · m^{-2} (^{137}Cs) to achieve a harvest concentration of approximately 1200 Bq · kg^{-1}, given the dispersal event occurs on the optimal day of uptake for the nuclide with an average temperature of 9.58 °C during the growing season.

The adaptation of the growing degree day concept to the model allows for climatic flexibility in consideration of seasonal trends. This has proven to be important since it was shown that an increase in uptake occurs as the average temperature increases. Therefore, the area contamination resulting in an embargo of crops in one agricultural region may not create embargo conditions in a different agricultural region, depending on the ambient temperature to which the crop has been exposed.

When a radioactive contamination event occurs, an analysis of the contaminated area must be performed to assess the magnitude and scope of the situation. Through the extrapolation of dose conversion factors, an estimate can be made of the exposure rate (mR · hr^{-1}), less natural background, which would be expected from a given nuclide, assuming a plane-source geometry. It was found that the exposure rate originating from an area contamination of 1.50 x 10^4 Bq · m^{-2} $^{134/137}Cs$ would yield approximately 5.05 x 10^{-5} mR · hr^{-1} at 30 cm from the surface. An event involving only ^{137}Cs with a magnitude of 1.43 x 10^4 Bq · m^{-2} would result in a 6.70 x 10^{-5} mR · hr^{-1} at 30 cm above the surface. Both these exposure rates are well below the average background rate of 0.0130 mR · hr^{-1}. These calculated exposure rates correspond to area contamination concentrations which result in a wheat crop reaching the DIL. If only conventional area surveys were used to asses such an event, it is very likely that the contamination would go unnoticed allowing the wheat products to go onto market.

The sensitivity analysis proved the importance of contamination on plant surfaces and foliar absorption. The foliar uptake constant was the most significant factor in the model with a relative sensitivity of 10^6. Other factors which play a role in the surface contamination of a plant, such as rainsplash and resuspension, immediately followed in importance. This explains the reason as to why the final uptake concentration in wheat was not at maximum levels when the dispersal event occurred at time zero. At this point, all the contamination settles to ground with little to none directly reaching the plant surface. During the early stages of wheat growth, the surface area of the plant is at a minimum in comparison to its total biomass. As the wheat develops, the wheat accrues more exterior surface area allowing a greater fraction of contaminant to be intercepted and absorbed by the foliage. Therefore, the point at which maximum harvest concentration occurs is a balance between the efficiencies of foliar absorption and root uptake.

Chapter 6
CONCLUSION

This study illustrated that relatively little radiocesium contamination is needed to result in the embargo of a wheat crop, given the appropriate environmental conditions. The contamination levels resulting in a final harvest concentration approximately equal to the DIL yields a very low exposure rate in comparison to average natural background levels. Such low radiation fields become problematic to detect with conventional survey meters.

Assessing agricultural cash crops is difficult due to inconsistent geometries, varying distances to the source plane, and very low radiation intensities. Therefore, it is the author's opinion that the analysis of a contaminated crop should be performed with more advance laboratory sampling techniques, utilizing specialized equipment with high specificity. If analysis is performed with only conventional survey methods two situation could occur:

1) The contamination is missed altogether, resulting in a release of significantly contaminated crops to market.
2) The true magnitude of the event is misinterpreted due to uncertainty, resulting in the embargo of a crop which might otherwise be deemed safe for consumption.

Methods need to be put in place which reduce the likelihood of either two situations occurring; the former causing increased health risk to the public, and the latter possibly causing financial devastation to a producer and the local economy.

Good laboratory techniques are one component in prevention of the above scenarios. Another is accurate and reliable modeling.

Incorporating an uptake model to agricultural contamination analysis which is adaptable to climatic trends, a variety of crops, and geographic agricultural regions will give greater confidence in the estimation of health risk. Such a model can help predict the final disposition of a crop which is contaminated anytime during the growth period. This will not only assist those responsible in making decisions on the fate of such crops, but also allow the grower to prepare for the expected fate of the contaminated crop.

There are several items that should be further examined in regard to this study. The first is the need for a more accurate sub-model to better describe wheat growth. This can further aid in the understanding of contaminant uptake in a wheat crop throughout its development. Another is to research and incorporate more input variables to take soil pH, analogue elements, and other detailed root uptake parameters into consideration. Lastly is study of transport accidents and intentional dispersal events which could cause agricultural crops (or portions of) to reach embargo levels.

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Appendices

Appendix A: Model Parameters

Variables:

Total Source Term (Bq/m^2)		**Fraction to Soil**	
Day of Dispersal*		**Fraction to Vegetation**	
Average Temperature (°C)*			

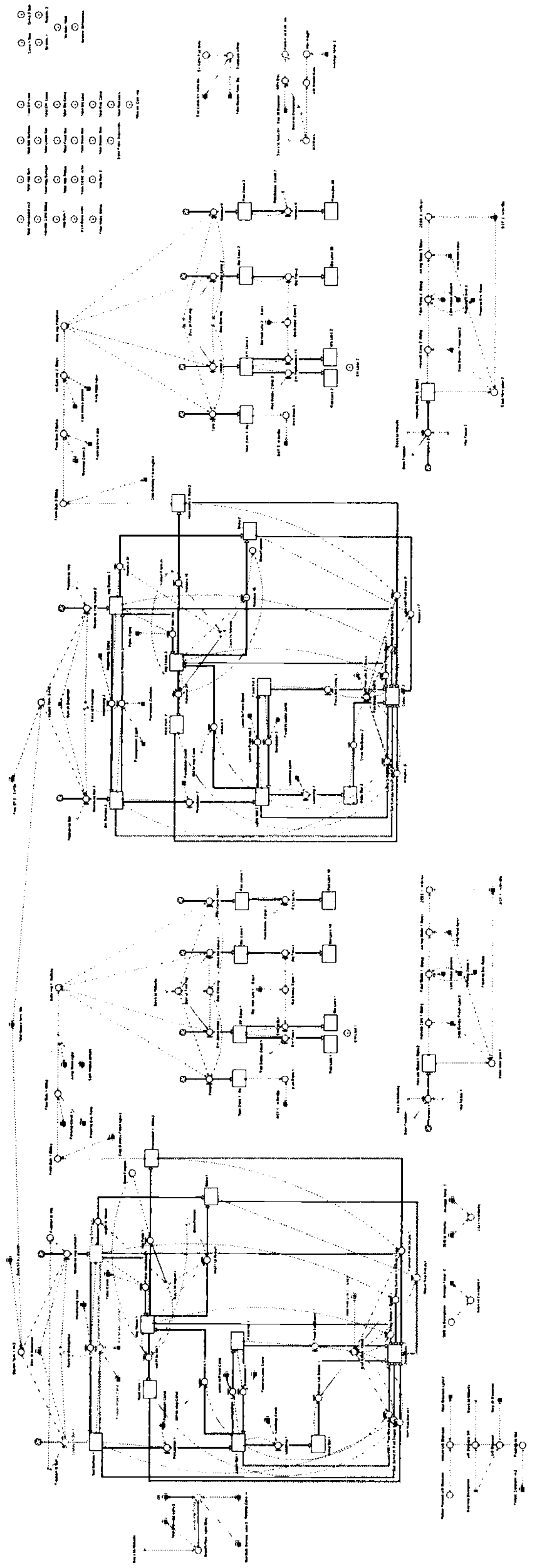
Constants:

Source Term		**Soil Parameters**	
Fraction ST 1 Cs-137	0.628	Soil Bulk Density (kg/m3)	1460
Rad Half Life 1 (Days)	10950	Leaching Const*	6.60E-06
Bio Half Life 1 (Days)	105	Labile to Fixed Const*	0.0019
DCF 1 (mSv/Bq)	1.35E-05	Fixed to Labile Const*	0.00021
Fraction ST 2 Cs-134	0.372	Resuspension Const	0.0173
Rad Half Life 2 (Days)	752.6	Rainsplash Const	0.00086
Bio Half Life 2 (Days)	105	Percolation Const	0.0198
DCF 2 (mSv/Bq)	1.98E-05	Rooting Zone (m)	0.25
Fallout Const	0.39		

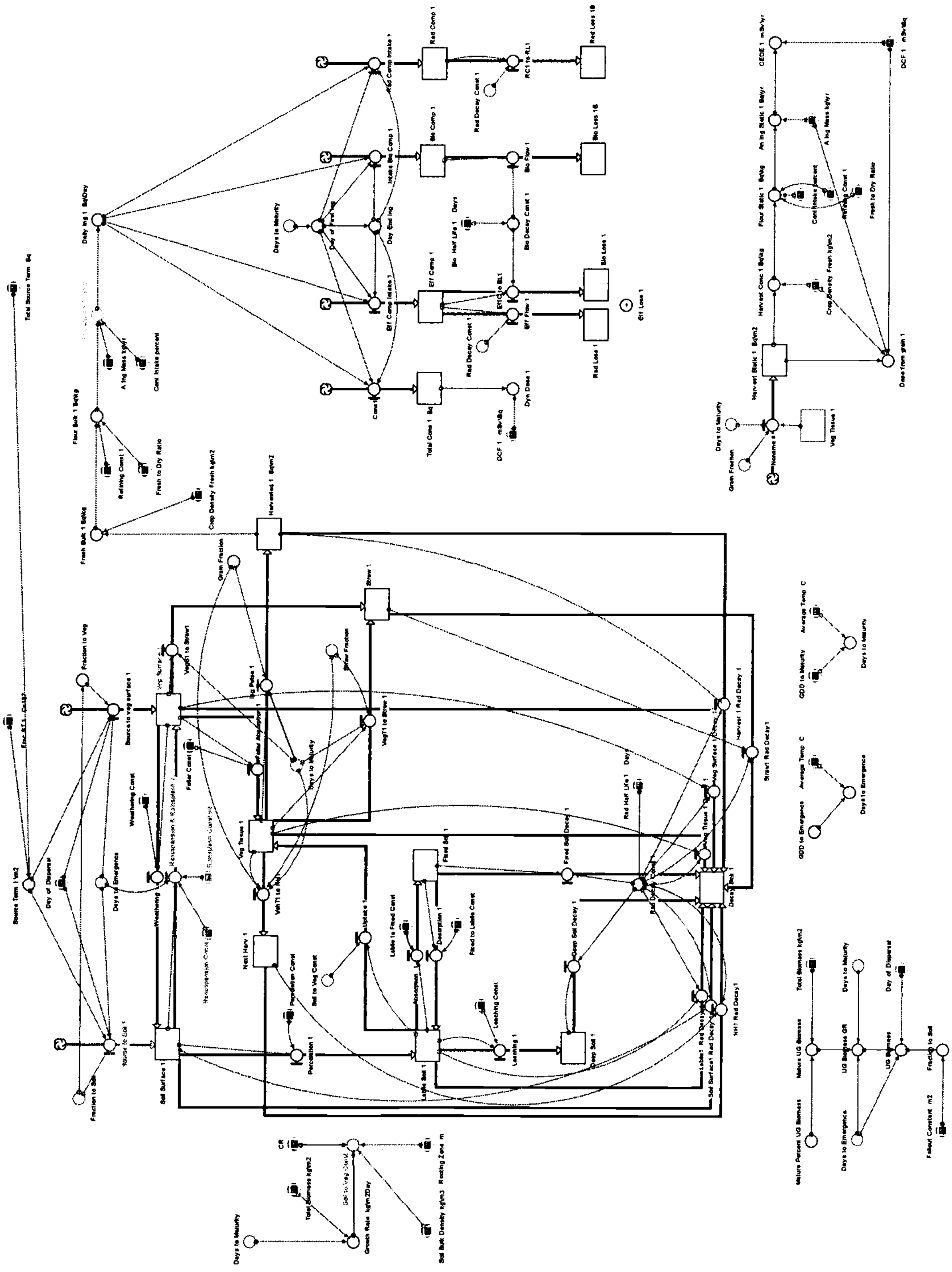
Plant Parameters		**Ingestion**	
GDD to Maturity	2500	An Ing Mass (kg/yr)	65.6
CR	0.019	Contam Intake percent	0.3
Crop Density Fresh (kg/m2)	0.383	Refining Const 1	0.5
Total Biomass (kg/m2)	0.911	Refining Const 2	0.5
Fresh to Dry Ratio	1.1		
Foliar Constant*	0.0055		
Weathering Constant	0.0495		

(*) Cesium-specific

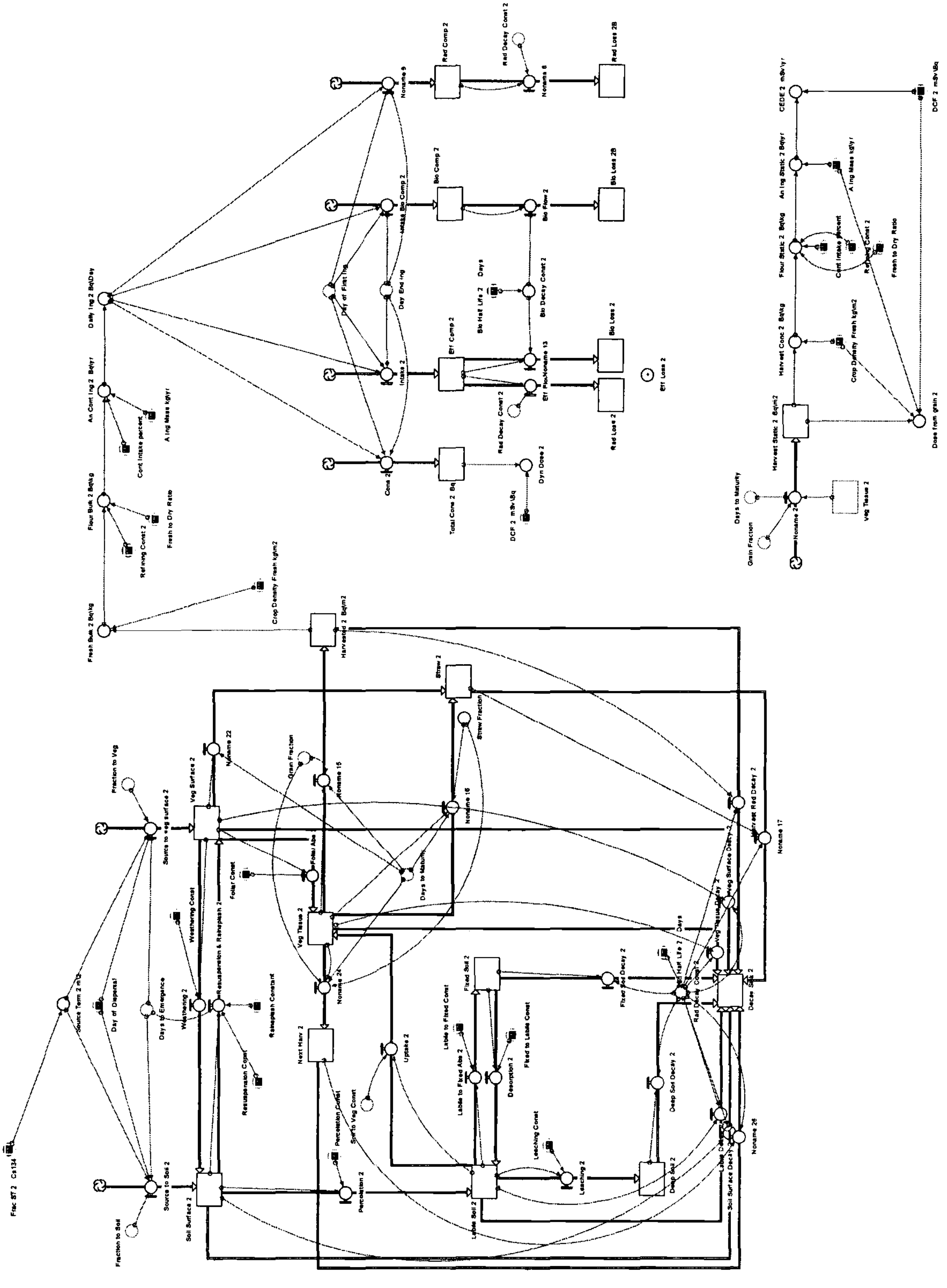
APPENDIX B: Experimental Model Diagram



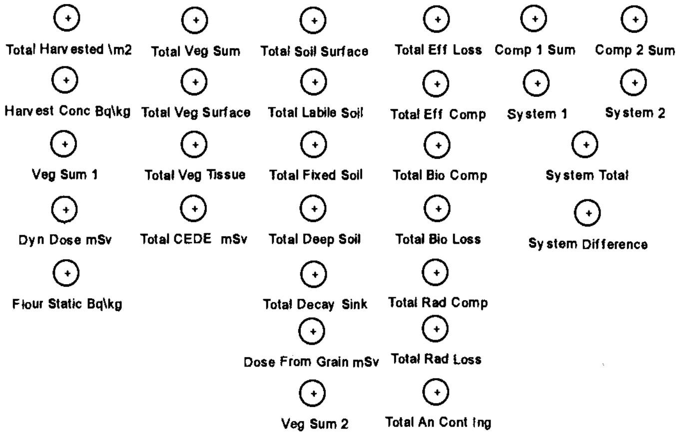
Appendix B: Source Term 1 Diagram

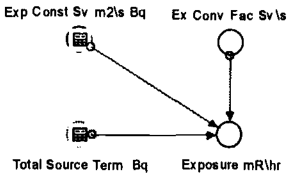


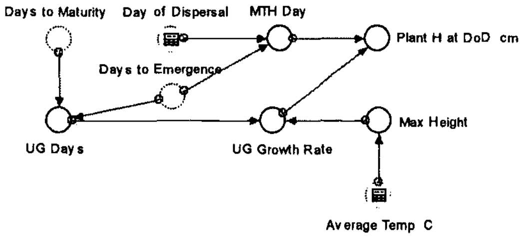
Appendix B: Source Term 2 Diagram



Appendix B: Compartment Summations, Exposure, Plant Height Diagram







Appendix B: Mathematical Relationships

```
Bio_Comp_1(t) = Bio_Comp_1(t - dt) + (Intake_Bio_Comp_1 - Bio_Flow_1) * dt
INIT Bio_Comp_1 =
(Eff_Comp_Intake_1*An_Cont_Ing_1__Bq\yr)/Crop_Density_Fresh_kg\m2

INFLOWS:
Intake_Bio_Comp_1 =
IF(TIME<=Day_End_Ing)THEN(PULSE(Daily_Ing_1__Bq\Day,Day_of_First_Ing,1)
)ELSE(0)
OUTFLOWS:
Bio_Flow_1 = Bio_Comp_1*Bio_Decay_Const_1
Bio_Comp_2(t) = Bio_Comp_2(t - dt) + (Intake_Bio_Comp_2 - Bio_Flow_2) * dt
INIT Bio_Comp_2 = 0

INFLOWS:
Intake_Bio_Comp_2 =
IF(TIME<=Day_End_Ing)THEN(PULSE(Daily_Ing_2_Bq\Day,Day_of_First_Ing,1))
ELSE(0)
OUTFLOWS:
Bio_Flow_2 = Bio_Comp_2*Bio_Decay_Const_2
Bio_Loss_1(t) = Bio_Loss_1(t - dt) + (EffC_to_BL1) * dt
INIT Bio_Loss_1 = 0

INFLOWS:
EffC_to_BL1 = Eff_Comp_1*Bio_Decay_Const_1
Bio_Loss_1B(t) = Bio_Loss_1B(t - dt) + (Bio_Flow_1) * dt
INIT Bio_Loss_1B = 0

INFLOWS:
Bio_Flow_1 = Bio_Comp_1*Bio_Decay_Const_1
Bio_Loss_2(t) = Bio_Loss_2(t - dt) + (Noname_13) * dt
INIT Bio_Loss_2 = 0

INFLOWS:
Noname_13 = Eff_Comp_2*Bio_Decay_Const_2
Bio_Loss_2B(t) = Bio_Loss_2B(t - dt) + (Bio_Flow_2) * dt
INIT Bio_Loss_2B = 0

INFLOWS:
Bio_Flow_2 = Bio_Comp_2*Bio_Decay_Const_2
Decay_Sink_1(t) = Decay_Sink_1(t - dt) + (Labile1__Rad_Decay_1 +
Fixed_Soil_Decay_1 + Veg_Tissue_1_Decay_1 + Veg_Surface_1_Decay_1 +
```

```
Deep_Soil_Decay_1 + Soil_Surface1_Rad_Decay_1 + Harvest_1_Rad_Decay_1 +
Straw1_Rad_Decay1 + NH1_Rad_Decay1) * dt
INIT Decay_Sink_1 = 0
INFLOWS:
Labile1__Rad_Decay_1 = Labile_Soil_1*Rad_Decay_Const_1
Fixed_Soil_Decay_1 = Fixed_Soil_1*Rad_Decay_Const_1
Veg_Tissue_1_Decay_1 = Veg_Tissue_1*Rad_Decay_Const_1
Veg_Surface_1_Decay_1 = Veg_Surface_1*Rad_Decay_Const_1
Deep_Soil_Decay_1 = Deep_Soil_1*Rad_Decay_Const_1
Soil_Surface1_Rad_Decay_1 = Soil_Surface_1*Rad_Decay_Const_1
Harvest_1_Rad_Decay_1 = Harvested_1__Bq\m2*Rad_Decay_Const_1
Straw1_Rad_Decay1 = Straw_1*Rad_Decay_Const_1
NH1_Rad_Decay1 = Next_Harv_1*Rad_Decay_Const_1
Decay_Sink_2(t) = Decay_Sink_2(t - dt) + (Fixed_Soil_Decay_2 +
Deep_Soil_Decay_2 + Labile_Decay_2 + Soil_Surface_Decay_2 +
Veg_Tissue_Decay_2 + Veg_Surface_Deacy_2 + Harvest_Rad_Decay_2 +
Noname_17 + Noname_26) * dt
INIT Decay_Sink_2 = 0

INFLOWS:
Fixed_Soil_Decay_2 = Fixed_Soil_2*Rad_Decay_Const_2
Deep_Soil_Decay_2 = Deep_Soil_2*Rad_Decay_Const_2
Labile_Decay_2 = Labile_Soil_2*Rad_Decay_Const_2
Soil_Surface_Decay_2 = Soil_Surface_2*Rad_Decay_Const_2
Veg_Tissue_Decay_2 = Veg_Tissue_2*Rad_Decay_Const_2
Veg_Surface_Deacy_2 = Veg_Surface_2*Rad_Decay_Const_2
Harvest_Rad_Decay_2 = Harvested_2__Bq\m2*Rad_Decay_Const_2
Noname_17 = Straw_2*Rad_Decay_Const_2
Noname_26 = Next_Harv_2*Rad_Decay_Const_2
Deep_Soil_1(t) = Deep_Soil_1(t - dt) + (Leaching_1 - Deep_Soil_Decay_1) * dt
INIT Deep_Soil_1 = 0

INFLOWS:
Leaching_1 = Labile_Soil_1*Leaching_Const
OUTFLOWS:
Deep_Soil_Decay_1 = Deep_Soil_1*Rad_Decay_Const_1
Deep_Soil_2(t) = Deep_Soil_2(t - dt) + (Leaching_2 - Deep_Soil_Decay_2) * dt
INIT Deep_Soil_2 = 0

INFLOWS:
Leaching_2 = Labile_Soil_2*Leaching_Const
OUTFLOWS:
Deep_Soil_Decay_2 = Deep_Soil_2*Rad_Decay_Const_2
```

```
Eff_Comp_1(t) = Eff_Comp_1(t - dt) + (Eff_Comp_Intake_1 - Eff_Flow_1 -
EffC_to_BL1) * dt
INIT Eff_Comp_1 =
(Eff_Comp_Intake_1*An_Cont_Ing_1__Bq\yr)/Crop_Density_Fresh_kg\m2

INFLOWS:
Eff_Comp_Intake_1 =
IF(TIME<=Day_End_Ing)THEN(PULSE(Daily_Ing_1__Bq\Day,Day_of_First_Ing,1)
)ELSE(0)
OUTFLOWS:
Eff_Flow_1 = Eff_Comp_1*Rad_Decay_Const_1
EffC_to_BL1 = Eff_Comp_1*Bio_Decay_Const_1
Eff_Comp_2(t) = Eff_Comp_2(t - dt) + (Intake_2 - Eff_Flow_2 - Noname_13) * dt
INIT Eff_Comp_2 = 0

INFLOWS:
Intake_2 =
IF(TIME<=Day_End_Ing)THEN(PULSE(Daily_Ing_2_Bq\Day,Day_of_First_Ing,1))
ELSE(0)
OUTFLOWS:
Eff_Flow_2 = Eff_Comp_2*Rad_Decay_Const_2
Noname_13 = Eff_Comp_2*Bio_Decay_Const_2
Fixed_Soil_1(t) = Fixed_Soil_1(t - dt) + (Absorption__1 - Desorption_1 -
Fixed_Soil_Decay_1) * dt
INIT Fixed_Soil_1 = 0

INFLOWS:
Absorption__1 = Labile_Soil_1*Labile_to_Fixed_Const
OUTFLOWS:
Desorption_1 = Fixed_Soil_1*Fixed_to_Labile_Const
Fixed_Soil_Decay_1 = Fixed_Soil_1*Rad_Decay_Const_1
Fixed_Soil_2(t) = Fixed_Soil_2(t - dt) + (Labile_to_Fixed_Abs_2 - Desorption_2 -
Fixed_Soil_Decay_2) * dt
INIT Fixed_Soil_2 = 0

INFLOWS:
Labile_to_Fixed_Abs_2 = Labile_Soil_2*Labile_to_Fixed_Const
OUTFLOWS:
Desorption_2 = Fixed_Soil_2*Fixed_to_Labile_Const
Fixed_Soil_Decay_2 = Fixed_Soil_2*Rad_Decay_Const_2
Harvested_1__Bq\m2(t) = Harvested_1__Bq\m2(t - dt) + (Ing_Pulse_1 -
Harvest_1_Rad_Decay_1) * dt
INIT Harvested_1__Bq\m2 = 0
```

```
INFLOWS:
Ing_Pulse_1 = PULSE((Veg_Tissue_1*Grain_Fraction),Days_to_Maturity,0)
OUTFLOWS:
Harvest_1_Rad_Decay_1 = Harvested_1__Bq\m2*Rad_Decay_Const_1
Harvested_2__Bq\m2(t) = Harvested_2__Bq\m2(t - dt) + (Noname_15 -
Harvest_Rad_Decay_2) * dt
INIT Harvested_2__Bq\m2 = 0
INFLOWS:
Noname_15 = PULSE((Veg_Tissue_2*(Grain_Fraction)),Days_to_Maturity,0)
OUTFLOWS:
Harvest_Rad_Decay_2 = Harvested_2__Bq\m2*Rad_Decay_Const_2
Harvest_Dyn_1__Bq\m2(t) = Harvest_Dyn_1__Bq\m2(t - dt) + (Noname_7) * dt
INIT Harvest_Dyn_1__Bq\m2 = 0

INFLOWS:
Noname_7 = PULSE(Harvested_1__Bq\m2,Day_of_First_Ing,0)
Harvest_Dyn_2__Bq\m2(t) = Harvest_Dyn_2__Bq\m2(t - dt) + (Noname_5) * dt
INIT Harvest_Dyn_2__Bq\m2 = 0

INFLOWS:
Noname_5 = PULSE(Harvested_2__Bq\m2,Day_of_First_Ing,0)
Harvest_Static_1__Bq\m2(t) = Harvest_Static_1__Bq\m2(t - dt) + (Noname_4) * dt
INIT Harvest_Static_1__Bq\m2 = 0

INFLOWS:
Noname_4 = PULSE((Veg_Tissue_1*Grain_Fraction),Days_to_Maturity,0)
Harvest_Static_2__Bq\m2(t) = Harvest_Static_2__Bq\m2(t - dt) + (Noname_2) * dt
INIT Harvest_Static_2__Bq\m2 = 0

INFLOWS:
Noname_2 = PULSE((Veg_Tissue_2*Grain_Fraction),Days_to_Maturity,0)
Labile_Soil_1(t) = Labile_Soil_1(t - dt) + (Percolation_1 + Desorption_1 -
Absorption__1 - Uptake_1 - Leaching_1 - Labile1__Rad_Decay_1) * dt
INIT Labile_Soil_1 = 0

INFLOWS:
Percolation_1 = Soil_Surface_1*Percolation_Const
Desorption_1 = Fixed_Soil_1*Fixed_to_Labile_Const
OUTFLOWS:
Absorption__1 = Labile_Soil_1*Labile_to_Fixed_Const
Uptake_1 = Labile_Soil_1*Soil_to_Veg_Const
Leaching_1 = Labile_Soil_1*Leaching_Const
Labile1__Rad_Decay_1 = Labile_Soil_1*Rad_Decay_Const_1
```

```
Labile_Soil_2(t) = Labile_Soil_2(t - dt) + (Percolation_2 + Desorption_2 - Uptake_2 -
Labile_to_Fixed_Abs_2 - Leaching_2 - Labile_Decay_2) * dt
INIT Labile_Soil_2 = 0

INFLOWS:
Percolation_2 = Soil_Surface_2*Percolation_Const
Desorption_2 = Fixed_Soil_2*Fixed_to_Labile_Const
OUTFLOWS:
Uptake_2 = Labile_Soil_2*Soil_to_Veg_Const
Labile_to_Fixed_Abs_2 = Labile_Soil_2*Labile_to_Fixed_Const
Leaching_2 = Labile_Soil_2*Leaching_Const
Labile_Decay_2 = Labile_Soil_2*Rad_Decay_Const_2
Next_Harv_1(t) = Next_Harv_1(t - dt) + (VehT1_to_NH1 - NH1_Rad_Decay1) * dt
INIT Next_Harv_1 = 0

INFLOWS:
VehT1_to_NH1 =
PULSE((Veg_Tissue_1*(Grain_Fraction+Straw_Fraction)),Days_to_Maturity+365,36
5)
OUTFLOWS:
NH1_Rad_Decay1 = Next_Harv_1*Rad_Decay_Const_1
Next_Harv_2(t) = Next_Harv_2(t - dt) + (Noname_24 - Noname_26) * dt
INIT Next_Harv_2 = 0

INFLOWS:
Noname_24 =
PULSE((Veg_Tissue_2*(Grain_Fraction+Straw_Fraction)),Days_to_Maturity+365,36
5)
OUTFLOWS:
Noname_26 = Next_Harv_2*Rad_Decay_Const_2
Rad_Comp_1(t) = Rad_Comp_1(t - dt) + (Rad_Comp_Intake_1 - RC1_to_RL1) * dt
INIT Rad_Comp_1 = 0

INFLOWS:
Rad_Comp_Intake_1 =
IF(TIME<=Day_End_Ing)THEN(PULSE(Daily_Ing_1__Bq\Day,Day_of_First_Ing,1)
)ELSE(0)
OUTFLOWS:
RC1_to_RL1 = Rad_Comp_1*Rad_Decay_Const_1
Rad_Comp_2(t) = Rad_Comp_2(t - dt) + (Noname_9 - Noname_8) * dt
INIT Rad_Comp_2 = 0

INFLOWS:
```

```
Noname_9 =
IF(TIME<=Day_End_Ing)THEN(PULSE(Daily_Ing_2_Bq\Day,Day_of_First_Ing,1))
ELSE(0)
OUTFLOWS:
Noname_8 = Rad_Comp_2*Rad_Decay_Const_2
Rad_Loss_1(t) = Rad_Loss_1(t - dt) + (Eff_Flow_1) * dt
INIT Rad_Loss_1 = 0

INFLOWS:
Eff_Flow_1 = Eff_Comp_1*Rad_Decay_Const_1
Rad_Loss_1B(t) = Rad_Loss_1B(t - dt) + (RC1_to_RL1) * dt
INIT Rad_Loss_1B = 0

INFLOWS:
RC1_to_RL1 = Rad_Comp_1*Rad_Decay_Const_1
Rad_Loss_2(t) = Rad_Loss_2(t - dt) + (Eff_Flow_2) * dt
INIT Rad_Loss_2 = 0

INFLOWS:
Eff_Flow_2 = Eff_Comp_2*Rad_Decay_Const_2
Rad_Loss_2B(t) = Rad_Loss_2B(t - dt) + (Noname_8) * dt
INIT Rad_Loss_2B = 0

INFLOWS:
Noname_8 = Rad_Comp_2*Rad_Decay_Const_2
Soil_Surface_1(t) = Soil_Surface_1(t - dt) + (Weathering_1 + Source_to_Soil_1 -
Resuspension_&_Rainsplash_1 - Percolation_1 - Soil_Surface1_Rad_Decay_1) * dt
INIT Soil_Surface_1 = 0

INFLOWS:
Weathering_1 = Veg_Surface_1*Weathering_Const
Source_to_Soil_1 =
IF(TIME>=Days_to_Emergence)THEN(PULSE(Source_Term_1_\m2*Fraction_to_S
oil,Day_of_Dispersal,0))ELSE(PULSE(Source_Term_1_\m2,Day_of_Dispersal,0))
OUTFLOWS:
Resuspension_&_Rainsplash_1 =
IF(TIME>=Days_to_Emergence)THEN(Soil_Surface_1*(Rainsplash_Constant+Resu
spension_Const))ELSE(0)
Percolation_1 = Soil_Surface_1*Percolation_Const
Soil_Surface1_Rad_Decay_1 = Soil_Surface_1*Rad_Decay_Const_1
Soil_Surface_2(t) = Soil_Surface_2(t - dt) + (Source_to_Soil_2 + Weathering_2 -
Resuspension_&_Rainsplash_2 - Percolation_2 - Soil_Surface_Decay_2) * dt
INIT Soil_Surface_2 = 0
```

```
INFLOWS:
Source_to_Soil_2 =
IF(TIME>=Days_to_Emergence)THEN(PULSE(Source_Term_2_m\2*Fraction_to_S
oil,Day_of_Dispersal,0))ELSE(PULSE(Source_Term_2_m\2,Day_of_Dispersal,0))
Weathering_2 = Veg_Surface_2*Weathering_Const
OUTFLOWS:
Resuspension_&_Rainsplash_2 =
IF(TIME>=Days_to_Emergence)THEN(Soil_Surface_2*(Rainsplash_Constant+Resu
spension_Const))ELSE(0)
Percolation_2 = Soil_Surface_2*Percolation_Const
Soil_Surface_Decay_2 = Soil_Surface_2*Rad_Decay_Const_2
Straw_1(t) = Straw_1(t - dt) + (VegT1_to_Straw_1 + VegS1_to_Straw1 -
Straw1_Rad_Decay1) * dt
INIT Straw_1 = 0

INFLOWS:
VegT1_to_Straw_1 = PULSE((Veg_Tissue_1*Straw_Fraction),Days_to_Maturity,0)
VegS1_to_Straw1 = PULSE(Veg_Surface_1,Days_to_Maturity,0)
OUTFLOWS:
Straw1_Rad_Decay1 = Straw_1*Rad_Decay_Const_1
Straw_2(t) = Straw_2(t - dt) + (Noname_16 + Noname_22 - Noname_17) * dt
INIT Straw_2 = 0

INFLOWS:
Noname_16 = PULSE((Veg_Tissue_2*Straw_Fraction),Days_to_Maturity,0)
Noname_22 = PULSE(Veg_Surface_2,Days_to_Maturity,0)
OUTFLOWS:
Noname_17 = Straw_2*Rad_Decay_Const_2
Veg_Surface_1(t) = Veg_Surface_1(t - dt) + (Resuspension_&_Rainsplash_1 +
Source_to_veg_surface_1 - Weathering_1 - Foliar_Absorption_1 -
Veg_Surface_1_Decay_1 - VegS1_to_Straw1) * dt
INIT Veg_Surface_1 = 0

INFLOWS:
Resuspension_&_Rainsplash_1 =
IF(TIME>=Days_to_Emergence)THEN(Soil_Surface_1*(Rainsplash_Constant+Resu
spension_Const))ELSE(0)
Source_to_veg_surface_1 =
IF(TIME>=Days_to_Emergence)THEN(PULSE(Source_Term_1_\m2*Fraction_to_V
eg,Day_of_Dispersal,0))ELSE(0)
OUTFLOWS:
Weathering_1 = Veg_Surface_1*Weathering_Const
Foliar_Absorption_1 = Veg_Surface_1*Foliar_Const
Veg_Surface_1_Decay_1 = Veg_Surface_1*Rad_Decay_Const_1
```

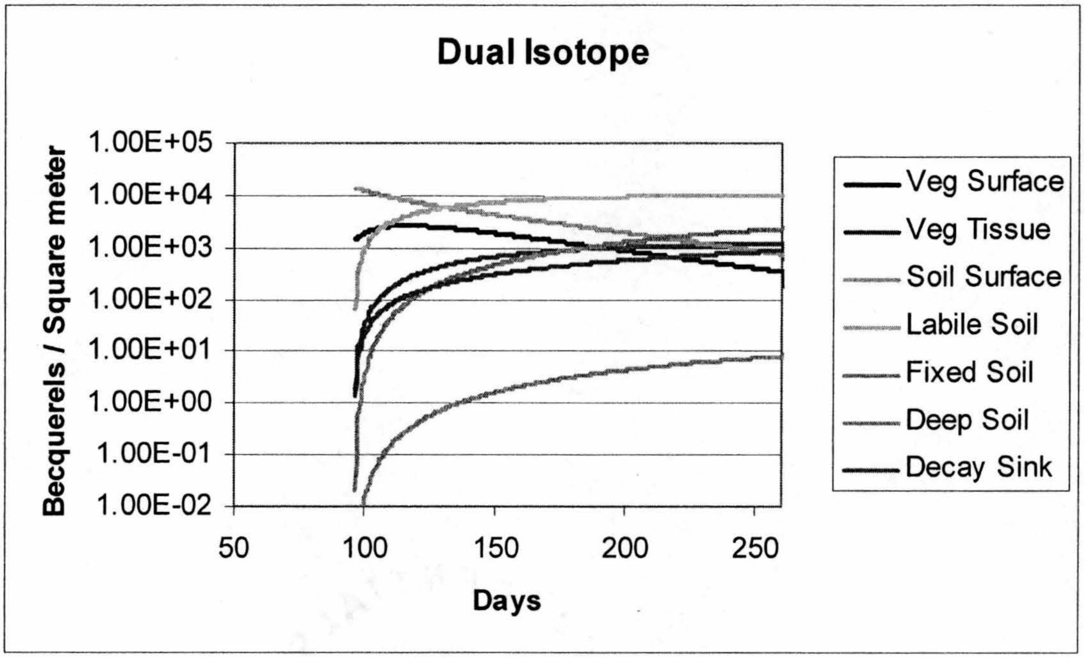
```
VegS1_to_Straw1 = PULSE(Veg_Surface_1,Days_to_Maturity,0)
Veg_Surface_2(t) = Veg_Surface_2(t - dt) + (Source_to_veg_surface_2 +
Resuspension_&_Rainsplash_2 - Weathering_2 - Foliar_Abs_2 -
Veg_Surface_Deacy_2 - Noname_22) * dt
INIT Veg_Surface_2 = 0

INFLOWS:
Source_to_veg_surface_2 =
IF(TIME>=Days_to_Emergence)THEN(PULSE(Source_Term_2_m\2*Fraction_to_V
eg,Day_of_Dispersal,0))ELSE(0)
Resuspension_&_Rainsplash_2 =
IF(TIME>=Days_to_Emergence)THEN(Soil_Surface_2*(Rainsplash_Constant+Resu
spension_Const))ELSE(0)
OUTFLOWS:
Weathering_2 = Veg_Surface_2*Weathering_Const
Foliar_Abs_2 = Veg_Surface_2*Foliar_Const
Veg_Surface_Deacy_2 = Veg_Surface_2*Rad_Decay_Const_2
Noname_22 = PULSE(Veg_Surface_2,Days_to_Maturity,0)
Veg_Tissue_1(t) = Veg_Tissue_1(t - dt) + (Foliar_Absorption_1 + Uptake_1 -
Veg_Tissue_1_Decay_1 - Ing_Pulse_1 - VegT1_to_Straw_1 - VehT1_to_NH1) * dt
INIT Veg_Tissue_1 = 0

INFLOWS:
Foliar_Absorption_1 = Veg_Surface_1*Foliar_Const
Uptake_1 = Labile_Soil_1*Soil_to_Veg_Const
OUTFLOWS:
Veg_Tissue_1_Decay_1 = Veg_Tissue_1*Rad_Decay_Const_1
Ing_Pulse_1 = PULSE((Veg_Tissue_1*Grain_Fraction),Days_to_Maturity,0)
VegT1_to_Straw_1 = PULSE((Veg_Tissue_1*Straw_Fraction),Days_to_Maturity,0)
VehT1_to_NH1 =
PULSE((Veg_Tissue_1*(Grain_Fraction+Straw_Fraction)),Days_to_Maturity+365,36
5)
Veg_Tissue_2(t) = Veg_Tissue_2(t - dt) + (Uptake_2 + Foliar_Abs_2 -
Veg_Tissue_Decay_2 - Noname_15 - Noname_16 - Noname_24) * dt
INIT Veg_Tissue_2 = 0

INFLOWS:
Uptake_2 = Labile_Soil_2*Soil_to_Veg_Const
Foliar_Abs_2 = Veg_Surface_2*Foliar_Const
OUTFLOWS:
Veg_Tissue_Decay_2 = Veg_Tissue_2*Rad_Decay_Const_2
Noname_15 = PULSE((Veg_Tissue_2*(Grain_Fraction)),Days_to_Maturity,0)
Noname_16 = PULSE((Veg_Tissue_2*Straw_Fraction),Days_to_Maturity,0)
```

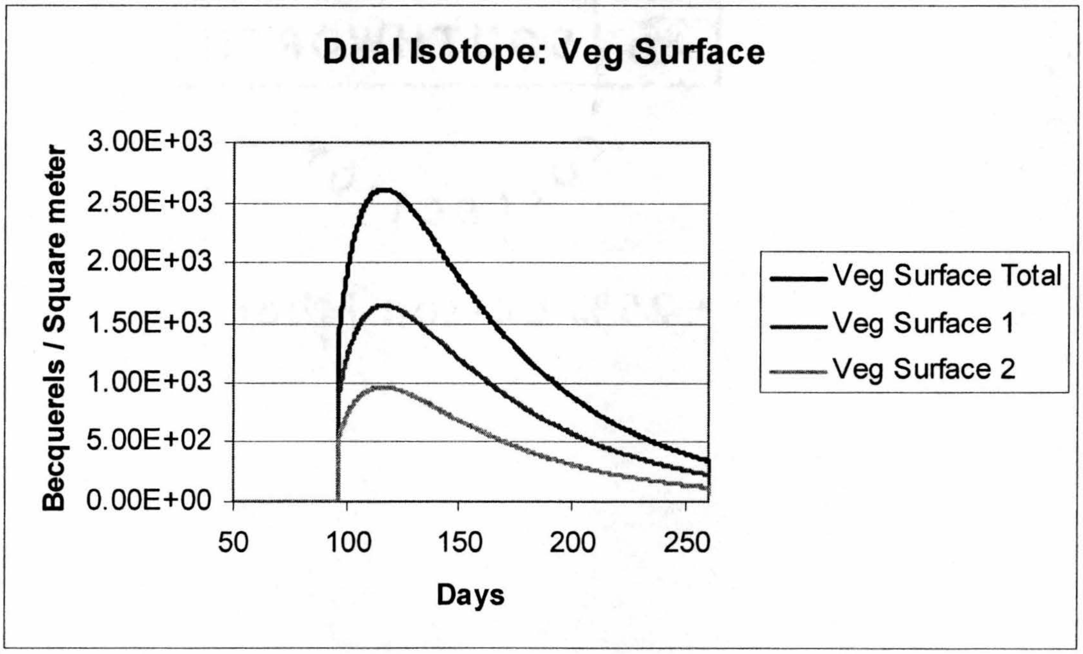
```
Noname_24 =
PULSE((Veg_Tissue_2*(Grain_Fraction+Straw_Fraction)),Days_to_Maturity+365,36
5)
An_Cont_Ing_1__Bq\yr =
Flour_Bulk_1_Bq\kg_*A_Ing_Mass_kg\yr*Cont_Intake_percent
An_Cont_Ing_2__Bq\yr =
Flour_Bulk_2_Bq\kg*A_Ing_Mass_kg\yr*Cont_Intake_percent
An_Ing_Dyn_1__Bq\yr = Flour_Dyn_1_Bq\kg*A_Ing_Mass_kg\yr
An_Ing_Dyn_2__Bq\yr = Flour_Dyn_2__Bq\kg*A_Ing_Mass_kg\yr
An_Ing_Static_1_Bq\yr = A_Ing_Mass_kg\yr*Flour_Static_1__Bq\kg
An_Ing_Static_2_Bq\yr = Flour_Static_2__Bq\kg*A_Ing_Mass_kg\yr
Average_Temp__C = 20
A_Ing_Mass_kg\yr = 143.3
Bio_Decay_Const_1 = (LOGN(2)/Bio__Half_Life_1____Days)
Bio_Decay_Const_2 = (LOGN(2)/Bio_Half_Life_2_____Days)
Bio_Half_Life_2_____Days = 105
Bio__Half_Life_1____Days = 105
CEDE_1__mSv\yr = An_Ing_Static_1_Bq\yr*DCF_1___mSv\Bq
CEDE_2__mSv\yr = An_Ing_Static_2_Bq\yr*DCF_2__mSv\Bq
Comp_1_Sum = Deep_Soil_1 + Fixed_Soil_1 + Harvested_1__Bq\m2 +
Labile_Soil_1 + Soil_Surface_1 + Straw_1 + Veg_Surface_1 + Veg_Tissue_1+
Next_Harv_1
Comp_2_Sum = Deep_Soil_2 + Fixed_Soil_2 + Harvested_2__Bq\m2 +
Labile_Soil_2 + Soil_Surface_2 + Straw_2 + Veg_Surface_2 + Veg_Tissue_2+
Next_Harv_2
Cont_Intake_percent = .30
CR = .019
Crop_Density_Fresh_kg\m2 = .383
Daily_Ing_1__Bq\Day = (An_Cont_Ing_1__Bq\yr)/365
Daily_Ing_2_Bq\Day = (An_Cont_Ing_2__Bq\yr)/365
Days_to_Emergence = GDD_to_Emergence/Average_Temp__C
Days_to_Maturity = GDD_to_Maturity/Average_Temp__C
Day_End_Ing = Day_of_First_Ing+365
Day_of_Dispersal = 0
Day_of_First_Ing = Days_to_Maturity+1
DCF_1___mSv\Bq = .000013
DCF_2__mSv\Bq = 1
Eff_Loss_1 = Rad_Loss_1 + Bio_Loss_1
Eff_Loss_2 = Rad_Loss_2 + Bio_Loss_2
Fallout_Constant__m2 = .39
Fixed_to_Labile_Const = .00021
Flour_Bulk_1_Bq\kg_ =
(Fresh_Bulk_1_Bq\kg*Refining_Const_1)/(Fresh_to_Dry_Ratio)
```

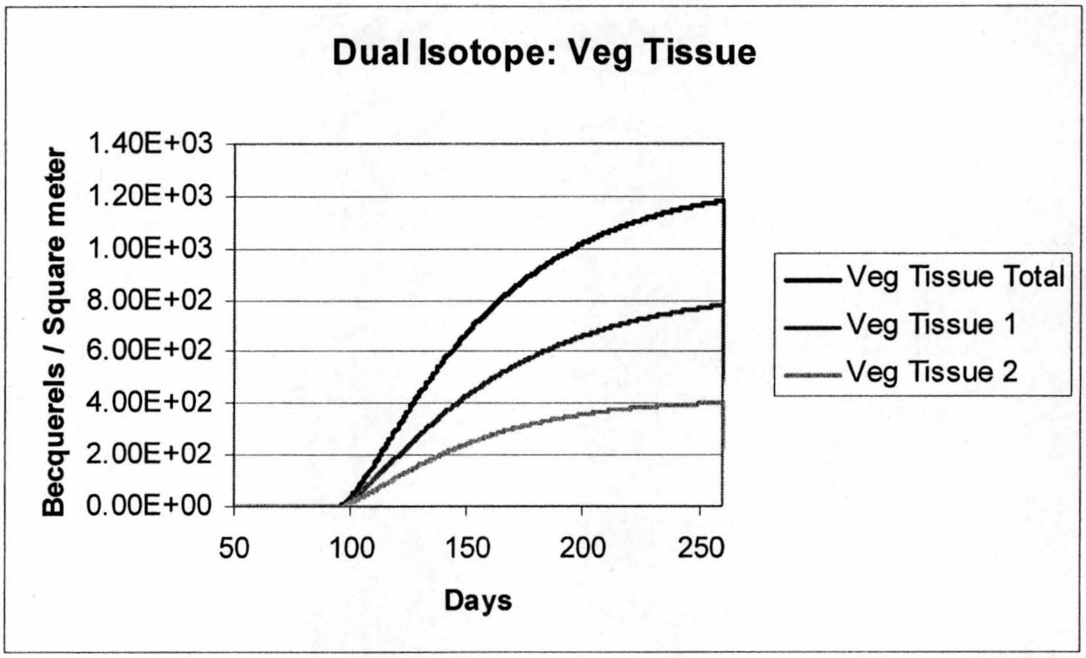
Flour_Bulk_2_Bq\kg = (Fresh_Bulk_2_Bq\kg*Refining_Const_2)/(Fresh_to_Dry_Ratio)
Flour_Dyn_1_Bq\kg = (Harvest_Conc_Dyn_1__Bq\kg*Cont_Intake_percent*Refining_Const_1)/(Fresh_to_Dry_Ratio)
Flour_Dyn_2__Bq\kg = (Harvest_Conc_Dyn_2__Bq\kg*Cont_Intake_percent*Refining_Const_2)/(Fresh_to_Dry_Ratio)
Flour_Static_1__Bq\kg = (Harvest_Conc_1_Bq\kg*Refining_Const_1*Cont_Intake_percent)/(Fresh_to_Dry_Ratio)
Flour_Static_2__Bq\kg = (Harvest_Conc_2__Bq\kg*Cont_Intake_percent*Refining_Const_2)/(Fresh_to_Dry_Ratio)
Foliar_Const = .0055
Fraction_to_Soil = EXP(-(Fallout_Constant__m2*UG_Biomass))
Fraction_to_Veg = 1-Fraction_to_Soil
Frac_ST_1___Cs137 = .5
Frac_ST_2___Cs134 = .5
Fresh_Bulk_1_Bq\kg = (Harvested_1__Bq\m2)/(Crop_Density_Fresh_kg\m2)
Fresh_Bulk_2_Bq\kg = (Harvested_2__Bq\m2)/(Crop_Density_Fresh_kg\m2)
Fresh_to_Dry_Ratio = 1.15
GDD_to_Emergence = 180
GDD_to_Maturity = 2500
Grain_Fraction = 0.389
Growth_Rate__kg\m2Day = Total_Biomass_kg\m2/Days_to_Maturity
Harvest_Conc_1_Bq\kg = (Harvest_Static_1__Bq\m2)/Crop_Density_Fresh_kg\m2
Harvest_Conc_2__Bq\kg = (Harvest_Static_2__Bq\m2)/Crop_Density_Fresh_kg\m2
Harvest_Conc_Bq\kg = Harvest_Conc_1_Bq\kg + Harvest_Conc_2__Bq\kg
Harvest_Conc_Dyn_1__Bq\kg = (Harvest_Dyn_1__Bq\m2)/(Crop_Density_Fresh_kg\m2)
Harvest_Conc_Dyn_2__Bq\kg = (Harvest_Dyn_2__Bq\m2)/(Crop_Density_Fresh_kg\m2)
Labile_to_Fixed_Const = .0019
Leaching_Const = .0000066
Mature_Percent_UG_Biomass = .844
Mature_UG_Biomass = Mature_Percent_UG_Biomass*Total_Biomass_kg\m2
Percolation_Const = .0198
Rad_Decay_Const_1 = (LOGN(2)/Rad_Half_Life_1____Days)
Rad_Decay_Const_2 = (LOGN(2)/Rad_Half_Life_2____Days)
Rad_Half_Life_1____Days = 10950
Rad_Half_Life_2____Days = 753.725
Rainsplash_Constant = .00086
Refining_Const_1 = .5

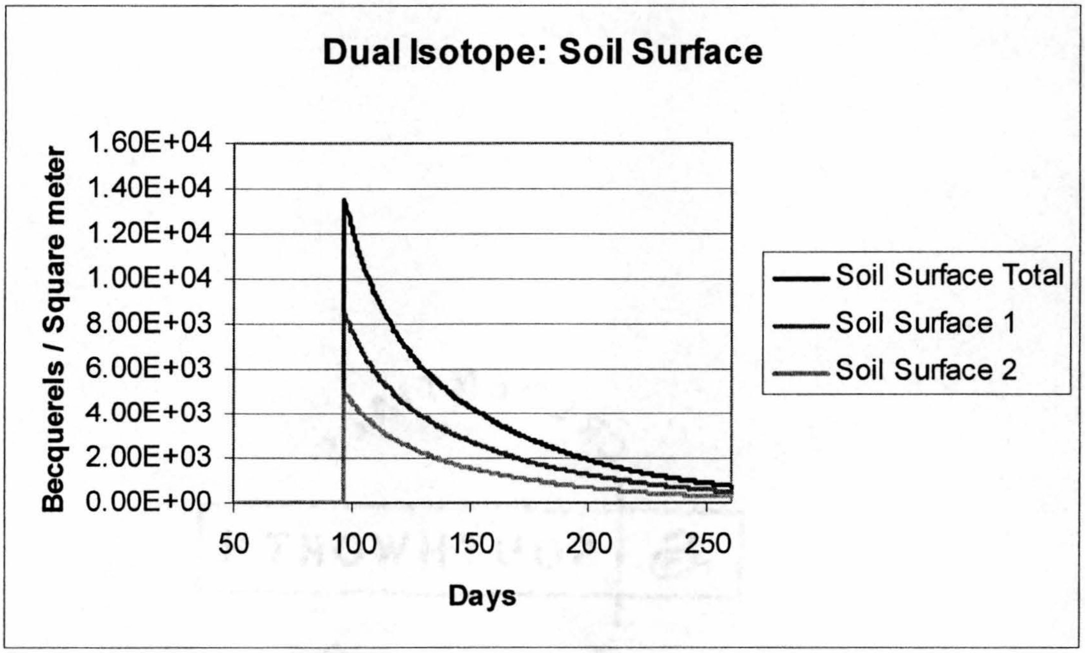
Refining_Const_2 = .5
Resuspension_Const = 1
Rooting_Zone__m = .25
Soil_Bulk_Density_kg\m3 = 1460
Soil_to_Veg_Const =
(Growth_Rate__kg\m2Day*CR)/(Rooting_Zone__m*Soil_Bulk_Density_kg\m3)
Source_Term_1_\m2 = Total_Source_Term__Bq*Frac_ST_1___Cs137
Source_Term_2_m\2 = Total_Source_Term__Bq*Frac_ST_2___Cs134
Straw_Fraction = .511
System_1 = Decay_Sink_1 + Comp_1_Sum
System_2 = Decay_Sink_2 + Comp_2_Sum
System_Difference = Total_Source_Term__Bq - System_Total
System_Total = System_1 + System_2
Total_An_Cont_Ing = An_Cont_Ing_1__Bq\yr + An_Cont_Ing_2__Bq\yr
Total_An_Ing_Dyn_Bq\yr = An_Ing_Dyn_1__Bq\yr + An_Ing_Dyn_2__Bq\yr
Total_Biomass_kg\m2 = .984
Total_Bio_Comp = Bio_Comp_1 + Bio_Comp_2
Total_Bio_Loss = Bio_Loss_1B + Bio_Loss_2B
Total_CEDE__mSv = CEDE_1__mSv\yr + CEDE_2__mSv\yr
Total_Decay_Sink = Decay_Sink_1 + Decay_Sink_2
Total_Deep_Soil = Deep_Soil_1 + Deep_Soil_2
Total_Eff_Comp = Eff_Comp_1 + Eff_Comp_2
Total_Eff_Loss = Eff_Loss_1 + Eff_Loss_2
Total_Fixed_Soil = Fixed_Soil_1 + Fixed_Soil_2
Total_Flour_Bulk_Bq\kg = Flour_Static_1__Bq\kg + Flour_Static_2__Bq\kg
Total_Harvested_\m2 = Harvested_1__Bq\m2 + Harvested_2__Bq\m2
Total_Labile_Soil = Labile_Soil_1 + Labile_Soil_2
Total_Rad_Comp = Rad_Comp_1 + Rad_Comp_2
Total_Rad_Loss = Rad_Loss_1B + Rad_Loss_2B
Total_Soil_Surface = Soil_Surface_1 + Soil_Surface_2
Total_Source_Term__Bq = 100
Total_Veg_Sum = Veg_Surface_1 + Veg_Surface_2 + Veg_Tissue_1 +
Veg_Tissue_2
Total_Veg_Surface = Veg_Surface_1 + Veg_Surface_2
Total_Veg_Tissue = Veg_Tissue_1 + Veg_Tissue_2
UG_Biomass = UG_Biomass_GR*((Day_of_Dispersal)-(Days_to_Emergence))
UG_Biomass_GR = Mature_UG_Biomass/(Days_to_Maturity-Days_to_Emergence)
Veg_Sum_1 = Veg_Tissue_1+ Veg_Surface_1
Veg_Sum_2 = Veg_Tissue_2 + Veg_Surface_2
Weathering_Const = .0495

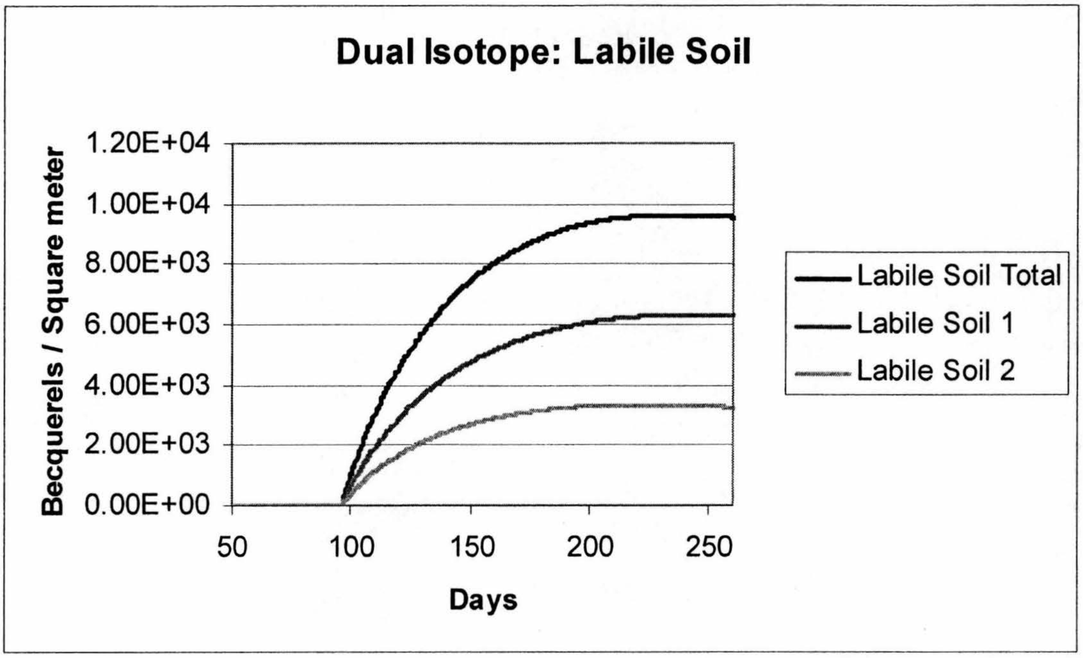
Appendix C: Dual Isotope Compartment Behavior (Graph)

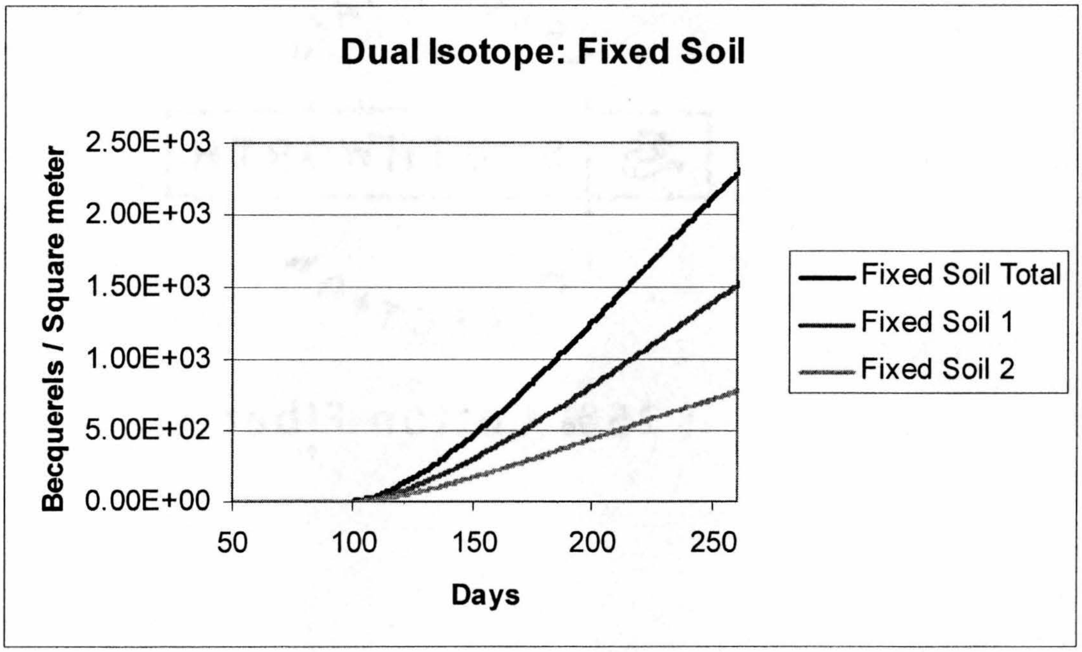


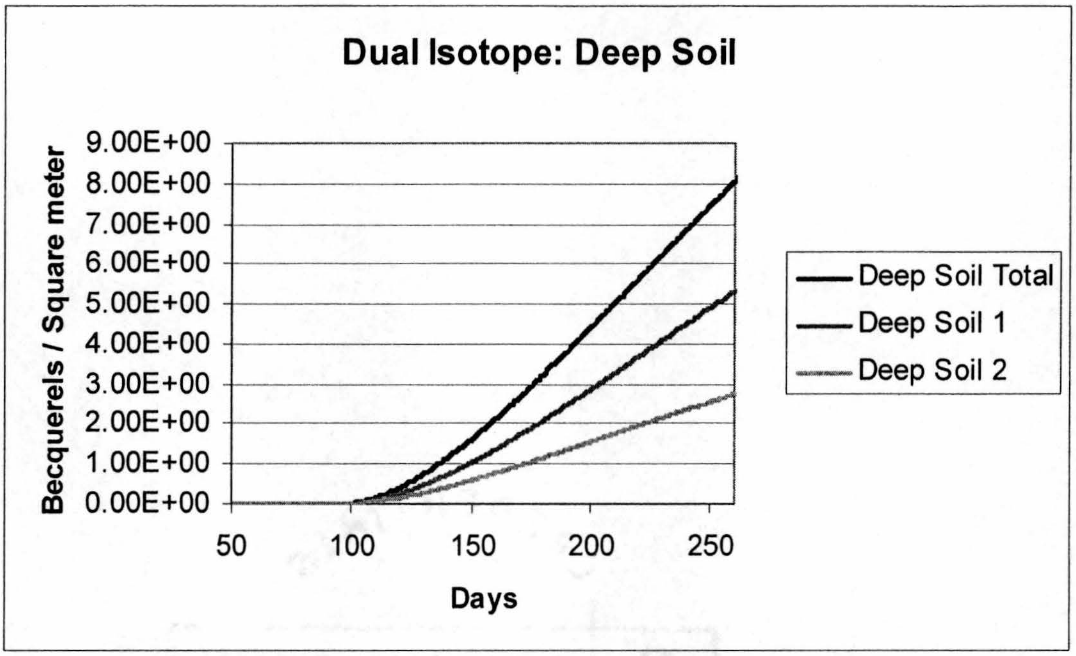


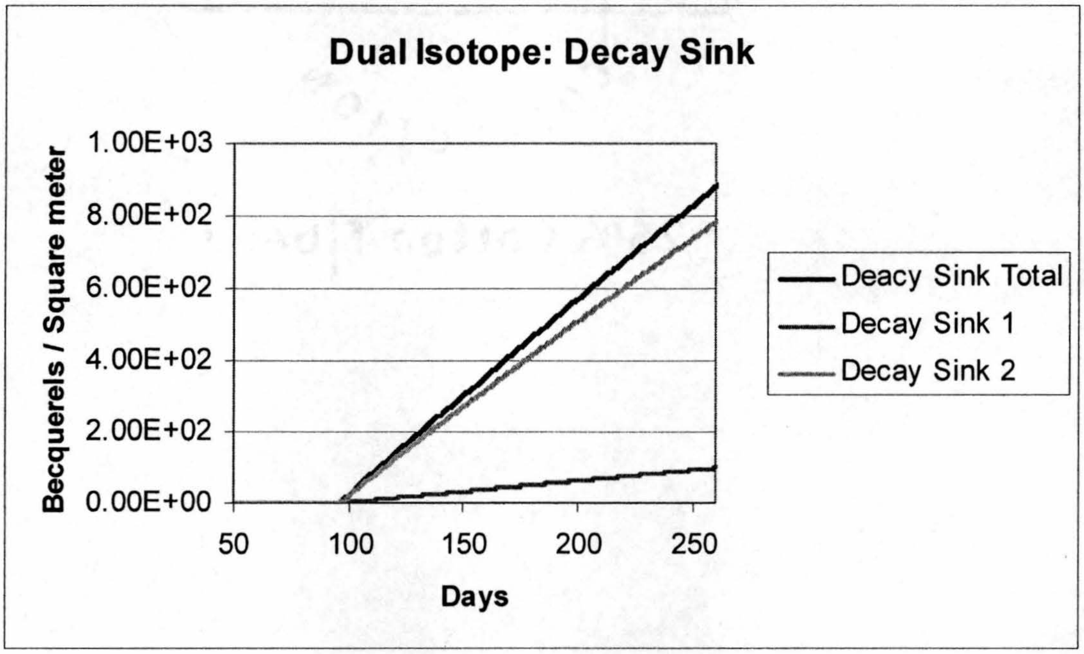

Dual Isotope: Veg Tissue
Becquerels / Square meter
1.40E+03
1.20E+03
1.00E+03
8.00E+02
6.00E+02
4.00E+02
2.00E+02
0.00E+00
50
100
150
200
250
Days
Veg Tissue Total
Veg Tissue 1
Veg Tissue 2


Dual Isotope: Soil Surface
Becquerels / Square meter
1.60E+04
1.40E+04
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
50
100
150
200
250
Days
Soil Surface Total
Soil Surface 1
Soil Surface 2


Dual Isotope: Labile Soil
Becquerels / Square meter
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
50
100
150
200
250
Days
Labile Soil Total
Labile Soil 1
Labile Soil 2


Dual Isotope: Fixed Soil
Becquerels / Square meter
2.50E+03
2.00E+03
1.50E+03
1.00E+03
5.00E+02
0.00E+00
50
100
150
200
250
Days
Fixed Soil Total
Fixed Soil 1
Fixed Soil 2


Dual Isotope: Deep Soil
Becquerels / Square meter
9.00E+00
8.00E+00
7.00E+00
6.00E+00
5.00E+00
4.00E+00
3.00E+00
2.00E+00
1.00E+00
0.00E+00
50
100
150
200
250
Days
Deep Soil Total
Deep Soil 1
Deep Soil 2


Dual Isotope: Decay Sink
Becquerels / Square meter
1.00E+03
8.00E+02
6.00E+02
4.00E+02
2.00E+02
0.00E+00
50
100
150
200
250
Days
Deacy Sink Total
Decay Sink 1
Decay Sink 2

Appendix C: Dual Isotope Compartment Tabular Values - Sum

Dual Isotope (Cs-137/134) **Cs-137 Cs-134 Summation**

Day of Dispersal = 96 Base Unit = Bq/m2 Source Term = 15000 Bq/m2
Temperature = 9.58 C Time Step = 0.50 Days Harvest Concentration = 1201.4 Bq/kg

Days	Veg Surface	Veg Tissue	Soil Surface	Labile Soil	Fixed Soil	Deep Soil	Decay Sink
90.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
91.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
92.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
93.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
94.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
95.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
96.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
97.0	1.49E+03	5.91E+00	1.33E+04	2.00E+02	1.50E-01	0.00E+00	4.30E+00
98.0	1.64E+03	1.45E+01	1.29E+04	4.58E+02	7.70E-01	0.00E+00	1.00E+01
99.0	1.78E+03	2.39E+01	1.25E+04	7.08E+02	1.88E+00	1.00E-02	1.58E+01
100.0	1.90E+03	3.40E+01	1.21E+04	9.49E+02	3.46E+00	1.00E-02	2.15E+01
101.0	2.01E+03	4.48E+01	1.17E+04	1.18E+03	5.48E+00	2.00E-02	2.72E+01
102.0	2.10E+03	5.61E+01	1.14E+04	1.41E+03	7.94E+00	3.00E-02	3.29E+01
103.0	2.19E+03	6.78E+01	1.11E+04	1.63E+03	1.08E+01	4.00E-02	3.86E+01
104.0	2.26E+03	8.01E+01	1.08E+04	1.84E+03	1.41E+01	5.00E-02	4.43E+01
105.0	2.33E+03	9.27E+01	1.05E+04	2.04E+03	1.78E+01	6.00E-02	5.00E+01
106.0	2.39E+03	1.06E+02	1.02E+04	2.24E+03	2.19E+01	8.00E-02	5.57E+01
107.0	2.43E+03	1.19E+02	9.92E+03	2.44E+03	2.63E+01	9.00E-02	6.14E+01
108.0	2.48E+03	1.32E+02	9.67E+03	2.63E+03	3.11E+01	1.10E-01	6.71E+01
109.0	2.51E+03	1.46E+02	9.42E+03	2.81E+03	3.62E+01	1.30E-01	7.27E+01
110.0	2.54E+03	1.60E+02	9.19E+03	2.99E+03	4.17E+01	1.50E-01	7.84E+01
111.0	2.56E+03	1.74E+02	8.97E+03	3.16E+03	4.75E+01	1.70E-01	8.41E+01
112.0	2.58E+03	1.88E+02	8.76E+03	3.33E+03	5.37E+01	1.90E-01	8.98E+01
113.0	2.60E+03	2.02E+02	8.55E+03	3.49E+03	6.01E+01	2.10E-01	9.54E+01
114.0	2.61E+03	2.16E+02	8.36E+03	3.65E+03	6.68E+01	2.30E-01	1.01E+02
115.0	2.61E+03	2.30E+02	8.17E+03	3.81E+03	7.39E+01	2.60E-01	1.07E+02
116.0	2.61E+03	2.45E+02	7.99E+03	3.96E+03	8.12E+01	2.80E-01	1.12E+02
117.0	2.61E+03	2.59E+02	7.82E+03	4.10E+03	8.88E+01	3.10E-01	1.18E+02
118.0	2.61E+03	2.73E+02	7.65E+03	4.25E+03	9.67E+01	3.40E-01	1.24E+02
119.0	2.60E+03	2.88E+02	7.49E+03	4.39E+03	1.05E+02	3.60E-01	1.29E+02
120.0	2.59E+03	3.02E+02	7.33E+03	4.52E+03	1.13E+02	3.90E-01	1.35E+02
121.0	2.58E+03	3.16E+02	7.18E+03	4.66E+03	1.22E+02	4.20E-01	1.41E+02
122.0	2.57E+03	3.30E+02	7.04E+03	4.79E+03	1.31E+02	4.60E-01	1.46E+02
123.0	2.55E+03	3.44E+02	6.90E+03	4.91E+03	1.40E+02	4.90E-01	1.52E+02
124.0	2.54E+03	3.58E+02	6.76E+03	5.04E+03	1.49E+02	5.20E-01	1.57E+02
125.0	2.52E+03	3.71E+02	6.63E+03	5.16E+03	1.59E+02	5.50E-01	1.63E+02
126.0	2.50E+03	3.85E+02	6.50E+03	5.28E+03	1.69E+02	5.90E-01	1.69E+02
127.0	2.48E+03	3.99E+02	6.38E+03	5.39E+03	1.79E+02	6.20E-01	1.74E+02
128.0	2.45E+03	4.12E+02	6.26E+03	5.51E+03	1.89E+02	6.60E-01	1.80E+02
129.0	2.43E+03	4.25E+02	6.14E+03	5.62E+03	1.99E+02	6.90E-01	1.85E+02
130.0	2.41E+03	4.38E+02	6.03E+03	5.72E+03	2.10E+02	7.30E-01	1.91E+02
131.0	2.38E+03	4.51E+02	5.92E+03	5.83E+03	2.21E+02	7.70E-01	1.96E+02
132.0	2.36E+03	4.64E+02	5.81E+03	5.93E+03	2.32E+02	8.10E-01	2.02E+02
133.0	2.33E+03	4.77E+02	5.71E+03	6.03E+03	2.43E+02	8.50E-01	2.08E+02
134.0	2.31E+03	4.90E+02	5.60E+03	6.13E+03	2.55E+02	8.90E-01	2.13E+02
135.0	2.28E+03	5.02E+02	5.50E+03	6.23E+03	2.66E+02	9.30E-01	2.19E+02
136.0	2.26E+03	5.14E+02	5.41E+03	6.32E+03	2.78E+02	9.70E-01	2.24E+02

137.0	2.23E+03	5.27E+02	5.31E+03	6.41E+03	2.90E+02	1.01E+00	2.30E+02
138.0	2.20E+03	5.38E+02	5.22E+03	6.50E+03	3.02E+02	1.05E+00	2.35E+02
139.0	2.17E+03	5.50E+02	5.13E+03	6.59E+03	3.14E+02	1.10E+00	2.41E+02
140.0	2.15E+03	5.62E+02	5.04E+03	6.67E+03	3.27E+02	1.14E+00	2.46E+02
141.0	2.12E+03	5.74E+02	4.96E+03	6.76E+03	3.39E+02	1.18E+00	2.52E+02
142.0	2.09E+03	5.85E+02	4.87E+03	6.84E+03	3.52E+02	1.23E+00	2.57E+02
143.0	2.07E+03	5.96E+02	4.79E+03	6.92E+03	3.65E+02	1.27E+00	2.63E+02
144.0	2.04E+03	6.07E+02	4.71E+03	7.00E+03	3.78E+02	1.32E+00	2.69E+02
145.0	2.01E+03	6.18E+02	4.63E+03	7.07E+03	3.91E+02	1.36E+00	2.74E+02
146.0	1.98E+03	6.29E+02	4.55E+03	7.15E+03	4.04E+02	1.41E+00	2.80E+02
147.0	1.96E+03	6.39E+02	4.48E+03	7.22E+03	4.18E+02	1.46E+00	2.85E+02
148.0	1.93E+03	6.50E+02	4.40E+03	7.29E+03	4.31E+02	1.50E+00	2.91E+02
149.0	1.90E+03	6.60E+02	4.33E+03	7.36E+03	4.45E+02	1.55E+00	2.96E+02
150.0	1.88E+03	6.70E+02	4.26E+03	7.43E+03	4.59E+02	1.60E+00	3.02E+02
151.0	1.85E+03	6.80E+02	4.19E+03	7.50E+03	4.73E+02	1.65E+00	3.07E+02
152.0	1.82E+03	6.90E+02	4.12E+03	7.56E+03	4.87E+02	1.70E+00	3.12E+02
153.0	1.80E+03	7.00E+02	4.06E+03	7.63E+03	5.01E+02	1.75E+00	3.18E+02
154.0	1.77E+03	7.09E+02	3.99E+03	7.69E+03	5.15E+02	1.80E+00	3.23E+02
155.0	1.75E+03	7.19E+02	3.92E+03	7.75E+03	5.29E+02	1.85E+00	3.29E+02
156.0	1.72E+03	7.28E+02	3.86E+03	7.81E+03	5.44E+02	1.90E+00	3.34E+02
157.0	1.70E+03	7.37E+02	3.80E+03	7.87E+03	5.58E+02	1.95E+00	3.40E+02
158.0	1.67E+03	7.46E+02	3.74E+03	7.92E+03	5.73E+02	2.00E+00	3.45E+02
159.0	1.65E+03	7.55E+02	3.68E+03	7.98E+03	5.88E+02	2.05E+00	3.51E+02
160.0	1.62E+03	7.64E+02	3.62E+03	8.03E+03	6.03E+02	2.10E+00	3.56E+02
161.0	1.60E+03	7.72E+02	3.56E+03	8.09E+03	6.18E+02	2.16E+00	3.62E+02
162.0	1.57E+03	7.81E+02	3.50E+03	8.14E+03	6.33E+02	2.21E+00	3.67E+02
163.0	1.55E+03	7.89E+02	3.45E+03	8.19E+03	6.48E+02	2.26E+00	3.72E+02
164.0	1.53E+03	7.97E+02	3.39E+03	8.24E+03	6.63E+02	2.32E+00	3.78E+02
165.0	1.51E+03	8.05E+02	3.34E+03	8.29E+03	6.78E+02	2.37E+00	3.83E+02
166.0	1.48E+03	8.13E+02	3.29E+03	8.33E+03	6.94E+02	2.42E+00	3.89E+02
167.0	1.46E+03	8.21E+02	3.23E+03	8.38E+03	7.09E+02	2.48E+00	3.94E+02
168.0	1.44E+03	8.29E+02	3.18E+03	8.42E+03	7.25E+02	2.53E+00	4.00E+02
169.0	1.42E+03	8.36E+02	3.13E+03	8.47E+03	7.40E+02	2.59E+00	4.05E+02
170.0	1.40E+03	8.44E+02	3.08E+03	8.51E+03	7.56E+02	2.64E+00	4.10E+02
171.0	1.37E+03	8.51E+02	3.03E+03	8.55E+03	7.72E+02	2.70E+00	4.16E+02
172.0	1.35E+03	8.58E+02	2.99E+03	8.59E+03	7.88E+02	2.75E+00	4.21E+02
173.0	1.33E+03	8.65E+02	2.94E+03	8.63E+03	8.04E+02	2.81E+00	4.26E+02
174.0	1.31E+03	8.72E+02	2.89E+03	8.67E+03	8.20E+02	2.86E+00	4.32E+02
175.0	1.29E+03	8.79E+02	2.85E+03	8.71E+03	8.36E+02	2.92E+00	4.37E+02
176.0	1.27E+03	8.86E+02	2.80E+03	8.74E+03	8.52E+02	2.98E+00	4.43E+02
177.0	1.25E+03	8.92E+02	2.76E+03	8.78E+03	8.68E+02	3.03E+00	4.48E+02
178.0	1.23E+03	8.99E+02	2.72E+03	8.81E+03	8.84E+02	3.09E+00	4.53E+02
179.0	1.22E+03	9.05E+02	2.67E+03	8.84E+03	9.00E+02	3.15E+00	4.59E+02
180.0	1.20E+03	9.12E+02	2.63E+03	8.88E+03	9.17E+02	3.21E+00	4.64E+02
181.0	1.18E+03	9.18E+02	2.59E+03	8.91E+03	9.33E+02	3.26E+00	4.69E+02
182.0	1.16E+03	9.24E+02	2.55E+03	8.94E+03	9.49E+02	3.32E+00	4.75E+02
183.0	1.14E+03	9.30E+02	2.51E+03	8.97E+03	9.66E+02	3.38E+00	4.80E+02
184.0	1.12E+03	9.36E+02	2.47E+03	9.00E+03	9.82E+02	3.44E+00	4.85E+02
185.0	1.11E+03	9.42E+02	2.43E+03	9.03E+03	9.99E+02	3.49E+00	4.91E+02
186.0	1.09E+03	9.47E+02	2.39E+03	9.05E+03	1.02E+03	3.55E+00	4.96E+02
187.0	1.07E+03	9.53E+02	2.36E+03	9.08E+03	1.03E+03	3.61E+00	5.01E+02
188.0	1.06E+03	9.58E+02	2.32E+03	9.11E+03	1.05E+03	3.67E+00	5.07E+02
189.0	1.04E+03	9.64E+02	2.28E+03	9.13E+03	1.07E+03	3.73E+00	5.12E+02
190.0	1.02E+03	9.69E+02	2.25E+03	9.16E+03	1.08E+03	3.79E+00	5.17E+02
191.0	1.01E+03	9.74E+02	2.21E+03	9.18E+03	1.10E+03	3.85E+00	5.23E+02

192.0	9.93E+02	9.79E+02	2.18E+03	9.20E+03	1.12E+03	3.91E+00	5.28E+02
193.0	9.78E+02	9.85E+02	2.14E+03	9.22E+03	1.13E+03	3.97E+00	5.33E+02
194.0	9.63E+02	9.89E+02	2.11E+03	9.25E+03	1.15E+03	4.03E+00	5.39E+02
195.0	9.48E+02	9.94E+02	2.08E+03	9.27E+03	1.17E+03	4.08E+00	5.44E+02
196.0	9.33E+02	9.99E+02	2.04E+03	9.29E+03	1.18E+03	4.14E+00	5.49E+02
197.0	9.19E+02	1.00E+03	2.01E+03	9.31E+03	1.20E+03	4.20E+00	5.54E+02
198.0	9.05E+02	1.01E+03	1.98E+03	9.32E+03	1.22E+03	4.26E+00	5.60E+02
199.0	8.91E+02	1.01E+03	1.95E+03	9.34E+03	1.23E+03	4.32E+00	5.65E+02
200.0	8.77E+02	1.02E+03	1.92E+03	9.36E+03	1.25E+03	4.38E+00	5.70E+02
201.0	8.63E+02	1.02E+03	1.89E+03	9.38E+03	1.27E+03	4.44E+00	5.75E+02
202.0	8.50E+02	1.03E+03	1.86E+03	9.39E+03	1.29E+03	4.51E+00	5.81E+02
203.0	8.37E+02	1.03E+03	1.83E+03	9.41E+03	1.30E+03	4.57E+00	5.86E+02
204.0	8.24E+02	1.03E+03	1.80E+03	9.42E+03	1.32E+03	4.63E+00	5.91E+02
205.0	8.11E+02	1.04E+03	1.77E+03	9.44E+03	1.34E+03	4.69E+00	5.96E+02
206.0	7.98E+02	1.04E+03	1.75E+03	9.45E+03	1.35E+03	4.75E+00	6.02E+02
207.0	7.86E+02	1.05E+03	1.72E+03	9.46E+03	1.37E+03	4.81E+00	6.07E+02
208.0	7.74E+02	1.05E+03	1.69E+03	9.48E+03	1.39E+03	4.87E+00	6.12E+02
209.0	7.62E+02	1.05E+03	1.67E+03	9.49E+03	1.41E+03	4.93E+00	6.17E+02
210.0	7.50E+02	1.06E+03	1.64E+03	9.50E+03	1.42E+03	4.99E+00	6.23E+02
211.0	7.38E+02	1.06E+03	1.62E+03	9.51E+03	1.44E+03	5.05E+00	6.28E+02
212.0	7.27E+02	1.07E+03	1.59E+03	9.52E+03	1.46E+03	5.11E+00	6.33E+02
213.0	7.16E+02	1.07E+03	1.57E+03	9.53E+03	1.47E+03	5.17E+00	6.38E+02
214.0	7.05E+02	1.07E+03	1.54E+03	9.54E+03	1.49E+03	5.23E+00	6.43E+02
215.0	6.94E+02	1.08E+03	1.52E+03	9.55E+03	1.51E+03	5.30E+00	6.49E+02
216.0	6.83E+02	1.08E+03	1.49E+03	9.56E+03	1.53E+03	5.36E+00	6.54E+02
217.0	6.72E+02	1.08E+03	1.47E+03	9.57E+03	1.54E+03	5.42E+00	6.59E+02
218.0	6.62E+02	1.09E+03	1.45E+03	9.57E+03	1.56E+03	5.48E+00	6.64E+02
219.0	6.52E+02	1.09E+03	1.42E+03	9.58E+03	1.58E+03	5.54E+00	6.69E+02
220.0	6.41E+02	1.09E+03	1.40E+03	9.59E+03	1.60E+03	5.60E+00	6.75E+02
221.0	6.31E+02	1.10E+03	1.38E+03	9.59E+03	1.61E+03	5.66E+00	6.80E+02
222.0	6.22E+02	1.10E+03	1.36E+03	9.60E+03	1.63E+03	5.72E+00	6.85E+02
223.0	6.12E+02	1.10E+03	1.34E+03	9.60E+03	1.65E+03	5.78E+00	6.90E+02
224.0	6.02E+02	1.10E+03	1.32E+03	9.61E+03	1.67E+03	5.85E+00	6.95E+02
225.0	5.93E+02	1.11E+03	1.30E+03	9.61E+03	1.68E+03	5.91E+00	7.00E+02
226.0	5.84E+02	1.11E+03	1.28E+03	9.62E+03	1.70E+03	5.97E+00	7.06E+02
227.0	5.75E+02	1.11E+03	1.26E+03	9.62E+03	1.72E+03	6.03E+00	7.11E+02
228.0	5.66E+02	1.12E+03	1.24E+03	9.62E+03	1.73E+03	6.09E+00	7.16E+02
229.0	5.57E+02	1.12E+03	1.22E+03	9.63E+03	1.75E+03	6.15E+00	7.21E+02
230.0	5.48E+02	1.12E+03	1.20E+03	9.63E+03	1.77E+03	6.21E+00	7.26E+02
231.0	5.40E+02	1.12E+03	1.18E+03	9.63E+03	1.79E+03	6.28E+00	7.31E+02
232.0	5.32E+02	1.13E+03	1.16E+03	9.63E+03	1.80E+03	6.34E+00	7.36E+02
233.0	5.23E+02	1.13E+03	1.14E+03	9.63E+03	1.82E+03	6.40E+00	7.42E+02
234.0	5.15E+02	1.13E+03	1.13E+03	9.64E+03	1.84E+03	6.46E+00	7.47E+02
235.0	5.07E+02	1.13E+03	1.11E+03	9.64E+03	1.86E+03	6.52E+00	7.52E+02
236.0	4.99E+02	1.14E+03	1.09E+03	9.64E+03	1.87E+03	6.58E+00	7.57E+02
237.0	4.92E+02	1.14E+03	1.07E+03	9.64E+03	1.89E+03	6.64E+00	7.62E+02
238.0	4.84E+02	1.14E+03	1.06E+03	9.64E+03	1.91E+03	6.70E+00	7.67E+02
239.0	4.76E+02	1.14E+03	1.04E+03	9.64E+03	1.92E+03	6.77E+00	7.72E+02
240.0	4.69E+02	1.15E+03	1.03E+03	9.64E+03	1.94E+03	6.83E+00	7.77E+02
241.0	4.62E+02	1.15E+03	1.01E+03	9.63E+03	1.96E+03	6.89E+00	7.82E+02
242.0	4.54E+02	1.15E+03	9.93E+02	9.63E+03	1.98E+03	6.95E+00	7.87E+02
243.0	4.47E+02	1.15E+03	9.78E+02	9.63E+03	1.99E+03	7.01E+00	7.93E+02
244.0	4.40E+02	1.15E+03	9.63E+02	9.63E+03	2.01E+03	7.07E+00	7.98E+02
245.0	4.34E+02	1.16E+03	9.48E+02	9.63E+03	2.03E+03	7.13E+00	8.03E+02
246.0	4.27E+02	1.16E+03	9.33E+02	9.62E+03	2.04E+03	7.19E+00	8.08E+02

247.0	4.20E+02	1.16E+03	9.19E+02	9.62E+03	2.06E+03	7.25E+00	8.13E+02
248.0	4.14E+02	1.16E+03	9.04E+02	9.62E+03	2.08E+03	7.31E+00	8.18E+02
249.0	4.07E+02	1.16E+03	8.90E+02	9.61E+03	2.10E+03	7.38E+00	8.23E+02
250.0	4.01E+02	1.17E+03	8.76E+02	9.61E+03	2.11E+03	7.44E+00	8.28E+02
251.0	3.95E+02	1.17E+03	8.63E+02	9.61E+03	2.13E+03	7.50E+00	8.33E+02
252.0	3.89E+02	1.17E+03	8.49E+02	9.60E+03	2.15E+03	7.56E+00	8.38E+02
253.0	3.83E+02	1.17E+03	8.36E+02	9.60E+03	2.16E+03	7.62E+00	8.43E+02
254.0	3.77E+02	1.17E+03	8.23E+02	9.59E+03	2.18E+03	7.68E+00	8.48E+02
255.0	3.71E+02	1.17E+03	8.10E+02	9.59E+03	2.20E+03	7.74E+00	8.53E+02
256.0	3.65E+02	1.18E+03	7.98E+02	9.58E+03	2.21E+03	7.80E+00	8.58E+02
257.0	3.59E+02	1.18E+03	7.85E+02	9.58E+03	2.23E+03	7.86E+00	8.63E+02
258.0	3.54E+02	1.18E+03	7.73E+02	9.57E+03	2.25E+03	7.92E+00	8.68E+02
259.0	3.48E+02	1.18E+03	7.61E+02	9.56E+03	2.27E+03	7.98E+00	8.73E+02
260.0	3.43E+02	1.18E+03	7.49E+02	9.56E+03	2.28E+03	8.04E+00	8.78E+02
261.0	3.38E+02	1.18E+03	7.38E+02	9.55E+03	2.30E+03	8.10E+00	8.83E+02
262.0	1.34E+02	4.49E+02	7.18E+02	9.54E+03	2.32E+03	8.16E+00	8.88E+02
263.0	1.28E+03	4.49E+02	6.98E+02	9.54E+03	2.33E+03	8.22E+00	8.93E+02
264.0	1.28E+03	4.50E+02	6.79E+02	9.53E+03	2.35E+03	8.28E+00	8.98E+02
265.0	1.29E+03	4.51E+02	6.60E+02	9.52E+03	2.37E+03	8.34E+00	9.03E+02

Appendix C: Dual Isotope Compartment Tabular Values – ST 1

Dual Isotope (Cs-137/134) **Cs-137 Component (Source Term 1)**

Day of Dispersal = 96 Base Unit = Bq/m2 Source Term 1 = 9420 Bq/m2
Temperature = 9.58 C Time Step = 0.50 Days Harvest Concentration 1 = 793.4 Bq/kg

Days	Veg Surface	Veg Tissue	Soil Surface	Labile Soil	Fixed Soil	Deep Soil	Decay Sink
90.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
91.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
92.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
93.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
94.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
95.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
96.0	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
97.0	9.37E+02	3.71E+00	8.35E+03	1.25E+02	9.00E-02	0.00E+00	4.50E-01
98.0	1.03E+03	9.13E+00	8.09E+03	2.88E+02	4.90E-01	0.00E+00	1.04E+00
99.0	1.12E+03	1.50E+01	7.84E+03	4.45E+02	1.18E+00	0.00E+00	1.64E+00
100.0	1.19E+03	2.14E+01	7.60E+03	5.97E+02	2.17E+00	1.00E-02	2.24E+00
101.0	1.26E+03	2.82E+01	7.38E+03	7.44E+02	3.45E+00	1.00E-02	2.83E+00
102.0	1.32E+03	3.53E+01	7.17E+03	8.86E+02	4.99E+00	2.00E-02	3.43E+00
103.0	1.38E+03	4.27E+01	6.97E+03	1.02E+03	6.81E+00	2.00E-02	4.02E+00
104.0	1.42E+03	5.04E+01	6.77E+03	1.16E+03	8.88E+00	3.00E-02	4.62E+00
105.0	1.47E+03	5.84E+01	6.59E+03	1.29E+03	1.12E+01	4.00E-02	5.22E+00
106.0	1.50E+03	6.65E+01	6.42E+03	1.41E+03	1.38E+01	5.00E-02	5.81E+00
107.0	1.53E+03	7.49E+01	6.25E+03	1.54E+03	1.66E+01	6.00E-02	6.41E+00
108.0	1.56E+03	8.34E+01	6.09E+03	1.66E+03	1.96E+01	7.00E-02	7.00E+00
109.0	1.58E+03	9.20E+01	5.94E+03	1.77E+03	2.28E+01	8.00E-02	7.60E+00
110.0	1.60E+03	1.01E+02	5.80E+03	1.88E+03	2.63E+01	9.00E-02	8.20E+00
111.0	1.62E+03	1.10E+02	5.66E+03	1.99E+03	3.00E+01	1.00E-01	8.79E+00
112.0	1.63E+03	1.19E+02	5.53E+03	2.10E+03	3.39E+01	1.20E-01	9.39E+00
113.0	1.64E+03	1.28E+02	5.40E+03	2.20E+03	3.79E+01	1.30E-01	9.98E+00
114.0	1.65E+03	1.37E+02	5.28E+03	2.31E+03	4.22E+01	1.50E-01	1.06E+01
115.0	1.65E+03	1.46E+02	5.16E+03	2.40E+03	4.67E+01	1.60E-01	1.12E+01
116.0	1.65E+03	1.55E+02	5.05E+03	2.50E+03	5.13E+01	1.80E-01	1.18E+01
117.0	1.65E+03	1.64E+02	4.94E+03	2.59E+03	5.62E+01	2.00E-01	1.24E+01
118.0	1.65E+03	1.73E+02	4.84E+03	2.69E+03	6.12E+01	2.10E-01	1.30E+01
119.0	1.65E+03	1.82E+02	4.74E+03	2.78E+03	6.63E+01	2.30E-01	1.36E+01
120.0	1.64E+03	1.91E+02	4.64E+03	2.86E+03	7.17E+01	2.50E-01	1.42E+01
121.0	1.63E+03	2.00E+02	4.55E+03	2.95E+03	7.72E+01	2.70E-01	1.48E+01
122.0	1.63E+03	2.09E+02	4.46E+03	3.03E+03	8.28E+01	2.90E-01	1.53E+01
123.0	1.62E+03	2.18E+02	4.37E+03	3.11E+03	8.86E+01	3.10E-01	1.59E+01
124.0	1.61E+03	2.27E+02	4.28E+03	3.19E+03	9.46E+01	3.30E-01	1.65E+01
125.0	1.60E+03	2.35E+02	4.20E+03	3.27E+03	1.01E+02	3.50E-01	1.71E+01
126.0	1.58E+03	2.44E+02	4.12E+03	3.35E+03	1.07E+02	3.70E-01	1.77E+01
127.0	1.57E+03	2.53E+02	4.04E+03	3.42E+03	1.13E+02	3.90E-01	1.83E+01
128.0	1.56E+03	2.61E+02	3.97E+03	3.49E+03	1.20E+02	4.20E-01	1.89E+01
129.0	1.54E+03	2.70E+02	3.90E+03	3.56E+03	1.27E+02	4.40E-01	1.95E+01
130.0	1.53E+03	2.78E+02	3.83E+03	3.63E+03	1.33E+02	4.60E-01	2.01E+01
131.0	1.51E+03	2.87E+02	3.76E+03	3.70E+03	1.40E+02	4.90E-01	2.07E+01
132.0	1.50E+03	2.95E+02	3.69E+03	3.77E+03	1.47E+02	5.10E-01	2.13E+01
133.0	1.48E+03	3.03E+02	3.63E+03	3.83E+03	1.55E+02	5.40E-01	2.19E+01
134.0	1.47E+03	3.11E+02	3.56E+03	3.90E+03	1.62E+02	5.60E-01	2.25E+01
135.0	1.45E+03	3.19E+02	3.50E+03	3.96E+03	1.69E+02	5.90E-01	2.31E+01
136.0	1.43E+03	3.27E+02	3.44E+03	4.02E+03	1.77E+02	6.20E-01	2.37E+01

137.0	1.42E+03	3.35E+02	3.38E+03	4.08E+03	1.84E+02	6.40E-01	2.43E+01
138.0	1.40E+03	3.43E+02	3.32E+03	4.14E+03	1.92E+02	6.70E-01	2.49E+01
139.0	1.38E+03	3.50E+02	3.27E+03	4.19E+03	2.00E+02	7.00E-01	2.55E+01
140.0	1.37E+03	3.58E+02	3.21E+03	4.25E+03	2.08E+02	7.20E-01	2.61E+01
141.0	1.35E+03	3.65E+02	3.16E+03	4.30E+03	2.16E+02	7.50E-01	2.67E+01
142.0	1.33E+03	3.73E+02	3.10E+03	4.36E+03	2.24E+02	7.80E-01	2.72E+01
143.0	1.32E+03	3.80E+02	3.05E+03	4.41E+03	2.33E+02	8.10E-01	2.78E+01
144.0	1.30E+03	3.87E+02	3.00E+03	4.46E+03	2.41E+02	8.40E-01	2.84E+01
145.0	1.28E+03	3.94E+02	2.95E+03	4.51E+03	2.49E+02	8.70E-01	2.90E+01
146.0	1.27E+03	4.01E+02	2.90E+03	4.56E+03	2.58E+02	9.00E-01	2.96E+01
147.0	1.25E+03	4.08E+02	2.86E+03	4.61E+03	2.67E+02	9.30E-01	3.02E+01
148.0	1.23E+03	4.15E+02	2.81E+03	4.66E+03	2.75E+02	9.60E-01	3.08E+01
149.0	1.21E+03	4.22E+02	2.77E+03	4.70E+03	2.84E+02	9.90E-01	3.14E+01
150.0	1.20E+03	4.28E+02	2.72E+03	4.75E+03	2.93E+02	1.02E+00	3.20E+01
151.0	1.18E+03	4.35E+02	2.68E+03	4.79E+03	3.02E+02	1.05E+00	3.26E+01
152.0	1.17E+03	4.41E+02	2.63E+03	4.83E+03	3.11E+02	1.08E+00	3.32E+01
153.0	1.15E+03	4.47E+02	2.59E+03	4.88E+03	3.20E+02	1.12E+00	3.38E+01
154.0	1.13E+03	4.54E+02	2.55E+03	4.92E+03	3.29E+02	1.15E+00	3.44E+01
155.0	1.12E+03	4.60E+02	2.51E+03	4.96E+03	3.39E+02	1.18E+00	3.50E+01
156.0	1.10E+03	4.66E+02	2.47E+03	5.00E+03	3.48E+02	1.21E+00	3.56E+01
157.0	1.09E+03	4.72E+02	2.43E+03	5.04E+03	3.57E+02	1.25E+00	3.62E+01
158.0	1.07E+03	4.78E+02	2.39E+03	5.07E+03	3.67E+02	1.28E+00	3.68E+01
159.0	1.05E+03	4.84E+02	2.36E+03	5.11E+03	3.77E+02	1.31E+00	3.73E+01
160.0	1.04E+03	4.89E+02	2.32E+03	5.15E+03	3.86E+02	1.35E+00	3.79E+01
161.0	1.02E+03	4.95E+02	2.28E+03	5.18E+03	3.96E+02	1.38E+00	3.85E+01
162.0	1.01E+03	5.01E+02	2.25E+03	5.22E+03	4.06E+02	1.42E+00	3.91E+01
163.0	9.95E+02	5.06E+02	2.21E+03	5.25E+03	4.15E+02	1.45E+00	3.97E+01
164.0	9.80E+02	5.11E+02	2.18E+03	5.28E+03	4.25E+02	1.49E+00	4.03E+01
165.0	9.66E+02	5.17E+02	2.14E+03	5.32E+03	4.35E+02	1.52E+00	4.09E+01
166.0	9.52E+02	5.22E+02	2.11E+03	5.35E+03	4.45E+02	1.56E+00	4.15E+01
167.0	9.38E+02	5.27E+02	2.08E+03	5.38E+03	4.55E+02	1.59E+00	4.21E+01
168.0	9.24E+02	5.32E+02	2.04E+03	5.41E+03	4.66E+02	1.63E+00	4.27E+01
169.0	9.10E+02	5.37E+02	2.01E+03	5.44E+03	4.76E+02	1.66E+00	4.33E+01
170.0	8.97E+02	5.42E+02	1.98E+03	5.47E+03	4.86E+02	1.70E+00	4.39E+01
171.0	8.83E+02	5.47E+02	1.95E+03	5.50E+03	4.96E+02	1.73E+00	4.45E+01
172.0	8.70E+02	5.52E+02	1.92E+03	5.52E+03	5.07E+02	1.77E+00	4.51E+01
173.0	8.57E+02	5.57E+02	1.89E+03	5.55E+03	5.17E+02	1.81E+00	4.57E+01
174.0	8.44E+02	5.61E+02	1.86E+03	5.58E+03	5.27E+02	1.84E+00	4.63E+01
175.0	8.32E+02	5.66E+02	1.83E+03	5.60E+03	5.38E+02	1.88E+00	4.68E+01
176.0	8.19E+02	5.70E+02	1.80E+03	5.63E+03	5.48E+02	1.92E+00	4.74E+01
177.0	8.07E+02	5.75E+02	1.78E+03	5.65E+03	5.59E+02	1.95E+00	4.80E+01
178.0	7.95E+02	5.79E+02	1.75E+03	5.68E+03	5.70E+02	1.99E+00	4.86E+01
179.0	7.83E+02	5.83E+02	1.72E+03	5.70E+03	5.80E+02	2.03E+00	4.92E+01
180.0	7.71E+02	5.88E+02	1.70E+03	5.72E+03	5.91E+02	2.07E+00	4.98E+01
181.0	7.60E+02	5.92E+02	1.67E+03	5.74E+03	6.02E+02	2.10E+00	5.04E+01
182.0	7.48E+02	5.96E+02	1.64E+03	5.77E+03	6.12E+02	2.14E+00	5.10E+01
183.0	7.37E+02	6.00E+02	1.62E+03	5.79E+03	6.23E+02	2.18E+00	5.16E+01
184.0	7.26E+02	6.04E+02	1.59E+03	5.81E+03	6.34E+02	2.22E+00	5.22E+01
185.0	7.15E+02	6.08E+02	1.57E+03	5.83E+03	6.45E+02	2.26E+00	5.28E+01
186.0	7.04E+02	6.12E+02	1.55E+03	5.85E+03	6.56E+02	2.29E+00	5.34E+01
187.0	6.94E+02	6.16E+02	1.52E+03	5.87E+03	6.67E+02	2.33E+00	5.40E+01
188.0	6.83E+02	6.19E+02	1.50E+03	5.88E+03	6.78E+02	2.37E+00	5.46E+01
189.0	6.73E+02	6.23E+02	1.48E+03	5.90E+03	6.89E+02	2.41E+00	5.51E+01
190.0	6.63E+02	6.27E+02	1.45E+03	5.92E+03	7.00E+02	2.45E+00	5.57E+01
191.0	6.53E+02	6.30E+02	1.43E+03	5.94E+03	7.11E+02	2.49E+00	5.63E+01

192.0	6.43E+02	6.34E+02	1.41E+03	5.95E+03	7.22E+02	2.53E+00	5.69E+01
193.0	6.33E+02	6.37E+02	1.39E+03	5.97E+03	7.33E+02	2.57E+00	5.75E+01
194.0	6.23E+02	6.41E+02	1.37E+03	5.99E+03	7.44E+02	2.61E+00	5.81E+01
195.0	6.14E+02	6.44E+02	1.34E+03	6.00E+03	7.55E+02	2.65E+00	5.87E+01
196.0	6.05E+02	6.47E+02	1.32E+03	6.02E+03	7.67E+02	2.68E+00	5.93E+01
197.0	5.95E+02	6.51E+02	1.30E+03	6.03E+03	7.78E+02	2.72E+00	5.99E+01
198.0	5.86E+02	6.54E+02	1.28E+03	6.04E+03	7.89E+02	2.76E+00	6.05E+01
199.0	5.77E+02	6.57E+02	1.26E+03	6.06E+03	8.00E+02	2.80E+00	6.11E+01
200.0	5.69E+02	6.60E+02	1.25E+03	6.07E+03	8.12E+02	2.84E+00	6.17E+01
201.0	5.60E+02	6.63E+02	1.23E+03	6.08E+03	8.23E+02	2.88E+00	6.23E+01
202.0	5.52E+02	6.66E+02	1.21E+03	6.10E+03	8.34E+02	2.92E+00	6.29E+01
203.0	5.43E+02	6.69E+02	1.19E+03	6.11E+03	8.46E+02	2.96E+00	6.34E+01
204.0	5.35E+02	6.72E+02	1.17E+03	6.12E+03	8.57E+02	3.00E+00	6.40E+01
205.0	5.27E+02	6.75E+02	1.15E+03	6.13E+03	8.69E+02	3.04E+00	6.46E+01
206.0	5.19E+02	6.78E+02	1.14E+03	6.14E+03	8.80E+02	3.08E+00	6.52E+01
207.0	5.11E+02	6.80E+02	1.12E+03	6.15E+03	8.91E+02	3.12E+00	6.58E+01
208.0	5.03E+02	6.83E+02	1.10E+03	6.16E+03	9.03E+02	3.17E+00	6.64E+01
209.0	4.95E+02	6.86E+02	1.08E+03	6.17E+03	9.14E+02	3.21E+00	6.70E+01
210.0	4.88E+02	6.89E+02	1.07E+03	6.18E+03	9.26E+02	3.25E+00	6.76E+01
211.0	4.80E+02	6.91E+02	1.05E+03	6.19E+03	9.37E+02	3.29E+00	6.82E+01
212.0	4.73E+02	6.94E+02	1.03E+03	6.20E+03	9.49E+02	3.33E+00	6.88E+01
213.0	4.66E+02	6.96E+02	1.02E+03	6.21E+03	9.60E+02	3.37E+00	6.94E+01
214.0	4.59E+02	6.99E+02	1.00E+03	6.21E+03	9.72E+02	3.41E+00	7.00E+01
215.0	4.52E+02	7.01E+02	9.88E+02	6.22E+03	9.83E+02	3.45E+00	7.05E+01
216.0	4.45E+02	7.04E+02	9.73E+02	6.23E+03	9.95E+02	3.49E+00	7.11E+01
217.0	4.38E+02	7.06E+02	9.58E+02	6.24E+03	1.01E+03	3.53E+00	7.17E+01
218.0	4.32E+02	7.08E+02	9.44E+02	6.24E+03	1.02E+03	3.57E+00	7.23E+01
219.0	4.25E+02	7.11E+02	9.29E+02	6.25E+03	1.03E+03	3.61E+00	7.29E+01
220.0	4.18E+02	7.13E+02	9.15E+02	6.26E+03	1.04E+03	3.65E+00	7.35E+01
221.0	4.12E+02	7.15E+02	9.01E+02	6.26E+03	1.05E+03	3.70E+00	7.41E+01
222.0	4.06E+02	7.17E+02	8.87E+02	6.27E+03	1.06E+03	3.74E+00	7.47E+01
223.0	4.00E+02	7.20E+02	8.74E+02	6.27E+03	1.08E+03	3.78E+00	7.53E+01
224.0	3.94E+02	7.22E+02	8.60E+02	6.28E+03	1.09E+03	3.82E+00	7.59E+01
225.0	3.88E+02	7.24E+02	8.47E+02	6.28E+03	1.10E+03	3.86E+00	7.65E+01
226.0	3.82E+02	7.26E+02	8.34E+02	6.29E+03	1.11E+03	3.90E+00	7.71E+01
227.0	3.76E+02	7.28E+02	8.22E+02	6.29E+03	1.12E+03	3.94E+00	7.76E+01
228.0	3.70E+02	7.30E+02	8.09E+02	6.29E+03	1.13E+03	3.98E+00	7.82E+01
229.0	3.64E+02	7.32E+02	7.97E+02	6.30E+03	1.15E+03	4.03E+00	7.88E+01
230.0	3.59E+02	7.34E+02	7.85E+02	6.30E+03	1.16E+03	4.07E+00	7.94E+01
231.0	3.53E+02	7.36E+02	7.73E+02	6.30E+03	1.17E+03	4.11E+00	8.00E+01
232.0	3.48E+02	7.38E+02	7.61E+02	6.31E+03	1.18E+03	4.15E+00	8.06E+01
233.0	3.43E+02	7.40E+02	7.49E+02	6.31E+03	1.19E+03	4.19E+00	8.12E+01
234.0	3.38E+02	7.41E+02	7.38E+02	6.31E+03	1.20E+03	4.23E+00	8.18E+01
235.0	3.32E+02	7.43E+02	7.27E+02	6.32E+03	1.22E+03	4.27E+00	8.24E+01
236.0	3.27E+02	7.45E+02	7.15E+02	6.32E+03	1.23E+03	4.31E+00	8.30E+01
237.0	3.22E+02	7.47E+02	7.05E+02	6.32E+03	1.24E+03	4.36E+00	8.36E+01
238.0	3.17E+02	7.48E+02	6.94E+02	6.32E+03	1.25E+03	4.40E+00	8.42E+01
239.0	3.13E+02	7.50E+02	6.83E+02	6.32E+03	1.26E+03	4.44E+00	8.47E+01
240.0	3.08E+02	7.52E+02	6.73E+02	6.32E+03	1.27E+03	4.48E+00	8.53E+01
241.0	3.03E+02	7.53E+02	6.62E+02	6.32E+03	1.29E+03	4.52E+00	8.59E+01
242.0	2.98E+02	7.55E+02	6.52E+02	6.33E+03	1.30E+03	4.56E+00	8.65E+01
243.0	2.94E+02	7.57E+02	6.42E+02	6.33E+03	1.31E+03	4.60E+00	8.71E+01
244.0	2.89E+02	7.58E+02	6.33E+02	6.33E+03	1.32E+03	4.65E+00	8.77E+01
245.0	2.85E+02	7.60E+02	6.23E+02	6.33E+03	1.33E+03	4.69E+00	8.83E+01
246.0	2.81E+02	7.61E+02	6.13E+02	6.33E+03	1.34E+03	4.73E+00	8.89E+01

247.0	2.76E+02	7.63E+02	6.04E+02	6.33E+03	1.36E+03	4.77E+00	8.95E+01
248.0	2.72E+02	7.64E+02	5.95E+02	6.33E+03	1.37E+03	4.81E+00	9.01E+01
249.0	2.68E+02	7.66E+02	5.86E+02	6.33E+03	1.38E+03	4.85E+00	9.07E+01
250.0	2.64E+02	7.67E+02	5.77E+02	6.33E+03	1.39E+03	4.90E+00	9.12E+01
251.0	2.60E+02	7.68E+02	5.68E+02	6.32E+03	1.40E+03	4.94E+00	9.18E+01
252.0	2.56E+02	7.70E+02	5.59E+02	6.32E+03	1.41E+03	4.98E+00	9.24E+01
253.0	2.52E+02	7.71E+02	5.51E+02	6.32E+03	1.43E+03	5.02E+00	9.30E+01
254.0	2.48E+02	7.72E+02	5.42E+02	6.32E+03	1.44E+03	5.06E+00	9.36E+01
255.0	2.44E+02	7.74E+02	5.34E+02	6.32E+03	1.45E+03	5.10E+00	9.42E+01
256.0	2.41E+02	7.75E+02	5.26E+02	6.32E+03	1.46E+03	5.14E+00	9.48E+01
257.0	2.37E+02	7.76E+02	5.18E+02	6.32E+03	1.47E+03	5.18E+00	9.54E+01
258.0	2.33E+02	7.78E+02	5.10E+02	6.31E+03	1.48E+03	5.23E+00	9.60E+01
259.0	2.30E+02	7.79E+02	5.02E+02	6.31E+03	1.50E+03	5.27E+00	9.66E+01
260.0	2.26E+02	7.80E+02	4.95E+02	6.31E+03	1.51E+03	5.31E+00	9.71E+01
261.0	2.23E+02	7.81E+02	4.87E+02	6.31E+03	1.52E+03	5.35E+00	9.77E+01
262.0	8.83E+01	2.96E+02	4.74E+02	6.30E+03	1.53E+03	5.39E+00	9.83E+01
263.0	9.18E+01	2.97E+02	4.61E+02	6.30E+03	1.54E+03	5.43E+00	9.89E+01
264.0	9.49E+01	2.97E+02	4.48E+02	6.30E+03	1.55E+03	5.47E+00	9.95E+01
265.0	9.76E+01	2.98E+02	4.36E+02	6.30E+03	1.56E+03	5.52E+00	1.00E+02

Appendix C: Dual Isotope Compartment Tabular Values – ST 2

Dual Isotope (Cs-137/134) **Cs-134 Component (Source Term 2)**

Day of Dispersal = 96 Base Unit = Bq/m2 Source Term 2 = 5580 Bq/m2
Temperature = 9.58 C Time Step = 0.50 Days Harvest Concentration 2 = 408.0 Bq/kg

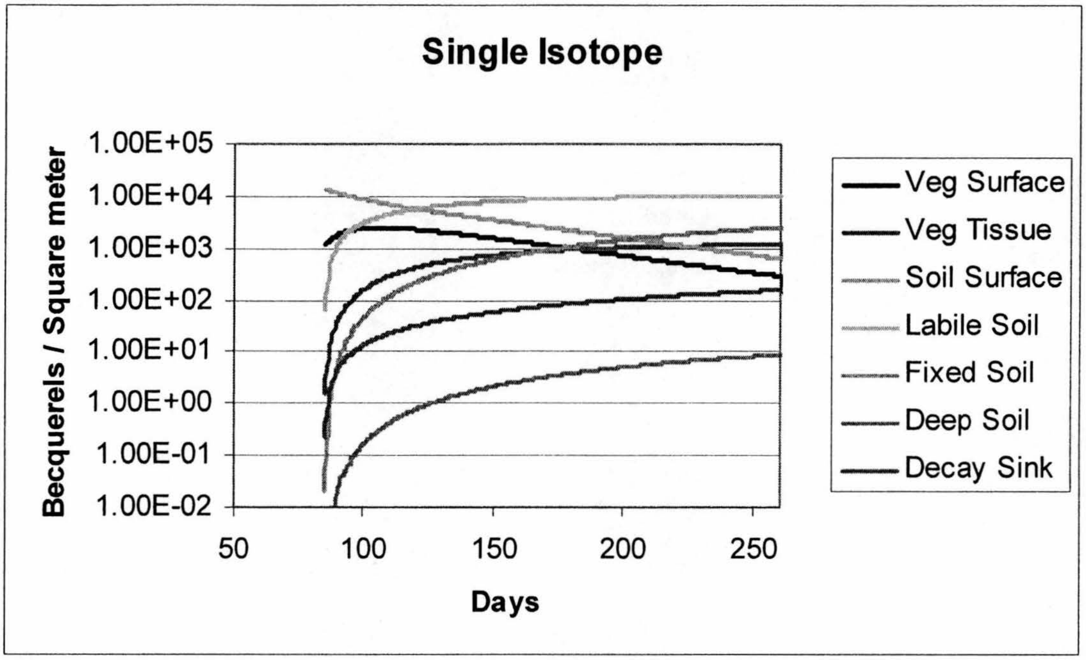
Days	Veg Surface	Veg Tissue	Soil Surface	Labile Soil	Fixed Soil	Deep Soil	Decay Sink
90.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
91.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
92.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
93.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
94.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
95.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
96.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
97.00	5.55E+02	2.20E+00	4.95E+03	7.43E+01	6.00E-02	0.00E+00	3.85E+00
98.00	6.10E+02	5.40E+00	4.78E+03	1.70E+02	2.90E-01	0.00E+00	8.99E+00
99.00	6.60E+02	8.89E+00	4.63E+03	2.63E+02	7.00E-01	0.00E+00	1.41E+01
100.00	7.05E+02	1.26E+01	4.49E+03	3.52E+02	1.28E+00	0.00E+00	1.92E+01
101.00	7.45E+02	1.66E+01	4.35E+03	4.39E+02	2.03E+00	1.00E-02	2.44E+01
102.00	7.80E+02	2.08E+01	4.22E+03	5.22E+02	2.94E+00	1.00E-02	2.95E+01
103.00	8.11E+02	2.51E+01	4.10E+03	6.03E+02	4.01E+00	1.00E-02	3.46E+01
104.00	8.38E+02	2.97E+01	3.99E+03	6.81E+02	5.22E+00	2.00E-02	3.97E+01
105.00	8.62E+02	3.43E+01	3.88E+03	7.57E+02	6.58E+00	2.00E-02	4.48E+01
106.00	8.83E+02	3.91E+01	3.77E+03	8.31E+02	8.08E+00	3.00E-02	4.99E+01
107.00	9.00E+02	4.39E+01	3.67E+03	9.02E+02	9.72E+00	3.00E-02	5.50E+01
108.00	9.15E+02	4.89E+01	3.57E+03	9.71E+02	1.15E+01	4.00E-02	6.01E+01
109.00	9.28E+02	5.39E+01	3.48E+03	1.04E+03	1.34E+01	5.00E-02	6.51E+01
110.00	9.38E+02	5.90E+01	3.39E+03	1.10E+03	1.54E+01	5.00E-02	7.02E+01
111.00	9.46E+02	6.41E+01	3.31E+03	1.17E+03	1.75E+01	6.00E-02	7.53E+01
112.00	9.53E+02	6.93E+01	3.23E+03	1.23E+03	1.98E+01	7.00E-02	8.04E+01
113.00	9.57E+02	7.45E+01	3.15E+03	1.29E+03	2.22E+01	8.00E-02	8.54E+01
114.00	9.60E+02	7.97E+01	3.08E+03	1.35E+03	2.46E+01	9.00E-02	9.05E+01
115.00	9.62E+02	8.49E+01	3.01E+03	1.40E+03	2.72E+01	9.00E-02	9.55E+01
116.00	9.62E+02	9.01E+01	2.94E+03	1.46E+03	2.99E+01	1.00E-01	1.01E+02
117.00	9.61E+02	9.53E+01	2.88E+03	1.51E+03	3.27E+01	1.10E-01	1.06E+02
118.00	9.59E+02	1.00E+02	2.81E+03	1.56E+03	3.56E+01	1.20E-01	1.11E+02
119.00	9.56E+02	1.06E+02	2.75E+03	1.61E+03	3.85E+01	1.30E-01	1.16E+02
120.00	9.52E+02	1.11E+02	2.69E+03	1.66E+03	4.16E+01	1.40E-01	1.21E+02
121.00	9.47E+02	1.16E+02	2.64E+03	1.71E+03	4.48E+01	1.60E-01	1.26E+02
122.00	9.42E+02	1.21E+02	2.58E+03	1.76E+03	4.80E+01	1.70E-01	1.31E+02
123.00	9.36E+02	1.26E+02	2.53E+03	1.80E+03	5.13E+01	1.80E-01	1.36E+02
124.00	9.29E+02	1.31E+02	2.48E+03	1.85E+03	5.47E+01	1.90E-01	1.41E+02
125.00	9.22E+02	1.36E+02	2.43E+03	1.89E+03	5.82E+01	2.00E-01	1.46E+02
126.00	9.14E+02	1.41E+02	2.38E+03	1.93E+03	6.18E+01	2.20E-01	1.51E+02
127.00	9.06E+02	1.46E+02	2.33E+03	1.97E+03	6.54E+01	2.30E-01	1.56E+02
128.00	8.98E+02	1.51E+02	2.29E+03	2.01E+03	6.91E+01	2.40E-01	1.61E+02
129.00	8.89E+02	1.55E+02	2.24E+03	2.05E+03	7.29E+01	2.50E-01	1.66E+02
130.00	8.80E+02	1.60E+02	2.20E+03	2.09E+03	7.68E+01	2.70E-01	1.71E+02
131.00	8.70E+02	1.65E+02	2.16E+03	2.13E+03	8.07E+01	2.80E-01	1.76E+02
132.00	8.61E+02	1.69E+02	2.12E+03	2.16E+03	8.47E+01	2.90E-01	1.81E+02
133.00	8.51E+02	1.74E+02	2.08E+03	2.20E+03	8.87E+01	3.10E-01	1.86E+02
134.00	8.41E+02	1.78E+02	2.04E+03	2.23E+03	9.28E+01	3.20E-01	1.91E+02
135.00	8.31E+02	1.83E+02	2.01E+03	2.27E+03	9.70E+01	3.40E-01	1.96E+02
136.00	8.21E+02	1.87E+02	1.97E+03	2.30E+03	1.01E+02	3.50E-01	2.01E+02

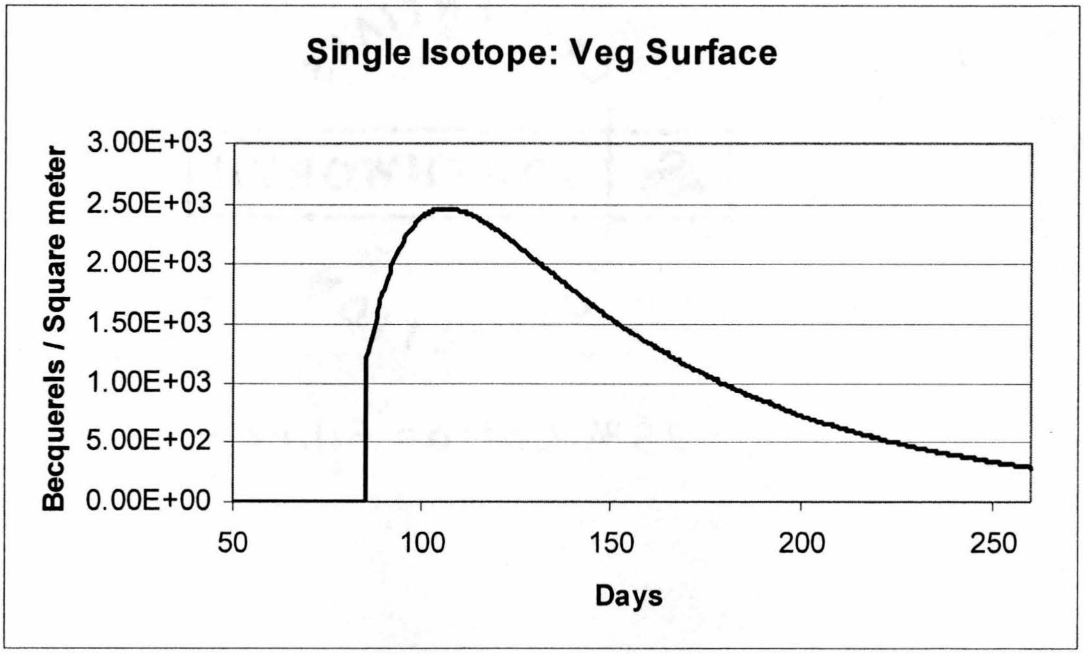
137.00	8.11E+02	1.92E+02	1.93E+03	2.33E+03	1.05E+02	3.70E-01	2.06E+02
138.00	8.01E+02	1.96E+02	1.90E+03	2.36E+03	1.10E+02	3.80E-01	2.10E+02
139.00	7.90E+02	2.00E+02	1.86E+03	2.39E+03	1.14E+02	4.00E-01	2.15E+02
140.00	7.80E+02	2.04E+02	1.83E+03	2.42E+03	1.19E+02	4.10E-01	2.20E+02
141.00	7.70E+02	2.08E+02	1.80E+03	2.45E+03	1.23E+02	4.30E-01	2.25E+02
142.00	7.59E+02	2.12E+02	1.77E+03	2.48E+03	1.28E+02	4.50E-01	2.30E+02
143.00	7.49E+02	2.16E+02	1.74E+03	2.51E+03	1.32E+02	4.60E-01	2.35E+02
144.00	7.39E+02	2.20E+02	1.71E+03	2.54E+03	1.37E+02	4.80E-01	2.40E+02
145.00	7.28E+02	2.24E+02	1.68E+03	2.56E+03	1.42E+02	4.90E-01	2.45E+02
146.00	7.18E+02	2.28E+02	1.65E+03	2.59E+03	1.46E+02	5.10E-01	2.50E+02
147.00	7.08E+02	2.31E+02	1.62E+03	2.61E+03	1.51E+02	5.30E-01	2.55E+02
148.00	6.98E+02	2.35E+02	1.59E+03	2.64E+03	1.56E+02	5.40E-01	2.60E+02
149.00	6.88E+02	2.39E+02	1.57E+03	2.66E+03	1.61E+02	5.60E-01	2.65E+02
150.00	6.78E+02	2.42E+02	1.54E+03	2.69E+03	1.66E+02	5.80E-01	2.70E+02
151.00	6.68E+02	2.46E+02	1.51E+03	2.71E+03	1.71E+02	6.00E-01	2.74E+02
152.00	6.58E+02	2.49E+02	1.49E+03	2.73E+03	1.76E+02	6.10E-01	2.79E+02
153.00	6.48E+02	2.52E+02	1.46E+03	2.75E+03	1.81E+02	6.30E-01	2.84E+02
154.00	6.39E+02	2.56E+02	1.44E+03	2.77E+03	1.86E+02	6.50E-01	2.89E+02
155.00	6.29E+02	2.59E+02	1.41E+03	2.79E+03	1.91E+02	6.70E-01	2.94E+02
156.00	6.20E+02	2.62E+02	1.39E+03	2.81E+03	1.96E+02	6.80E-01	2.99E+02
157.00	6.10E+02	2.65E+02	1.37E+03	2.83E+03	2.01E+02	7.00E-01	3.04E+02
158.00	6.01E+02	2.68E+02	1.34E+03	2.85E+03	2.06E+02	7.20E-01	3.08E+02
159.00	5.92E+02	2.71E+02	1.32E+03	2.87E+03	2.11E+02	7.40E-01	3.13E+02
160.00	5.83E+02	2.74E+02	1.30E+03	2.89E+03	2.17E+02	7.60E-01	3.18E+02
161.00	5.74E+02	2.77E+02	1.28E+03	2.90E+03	2.22E+02	7.70E-01	3.23E+02
162.00	5.65E+02	2.80E+02	1.26E+03	2.92E+03	2.27E+02	7.90E-01	3.28E+02
163.00	5.56E+02	2.83E+02	1.24E+03	2.94E+03	2.32E+02	8.10E-01	3.33E+02
164.00	5.48E+02	2.86E+02	1.22E+03	2.95E+03	2.38E+02	8.30E-01	3.38E+02
165.00	5.39E+02	2.89E+02	1.20E+03	2.97E+03	2.43E+02	8.50E-01	3.42E+02
166.00	5.31E+02	2.91E+02	1.18E+03	2.98E+03	2.48E+02	8.70E-01	3.47E+02
167.00	5.23E+02	2.94E+02	1.16E+03	3.00E+03	2.54E+02	8.90E-01	3.52E+02
168.00	5.15E+02	2.96E+02	1.14E+03	3.01E+03	2.59E+02	9.10E-01	3.57E+02
169.00	5.07E+02	2.99E+02	1.12E+03	3.03E+03	2.65E+02	9.20E-01	3.62E+02
170.00	4.99E+02	3.01E+02	1.10E+03	3.04E+03	2.70E+02	9.40E-01	3.66E+02
171.00	4.91E+02	3.04E+02	1.08E+03	3.05E+03	2.76E+02	9.60E-01	3.71E+02
172.00	4.83E+02	3.06E+02	1.07E+03	3.07E+03	2.81E+02	9.80E-01	3.76E+02
173.00	4.75E+02	3.09E+02	1.05E+03	3.08E+03	2.87E+02	1.00E+00	3.81E+02
174.00	4.68E+02	3.11E+02	1.03E+03	3.09E+03	2.92E+02	1.02E+00	3.86E+02
175.00	4.61E+02	3.13E+02	1.01E+03	3.10E+03	2.98E+02	1.04E+00	3.90E+02
176.00	4.53E+02	3.15E+02	9.98E+02	3.11E+03	3.03E+02	1.06E+00	3.95E+02
177.00	4.46E+02	3.18E+02	9.82E+02	3.12E+03	3.09E+02	1.08E+00	4.00E+02
178.00	4.39E+02	3.20E+02	9.66E+02	3.13E+03	3.15E+02	1.10E+00	4.05E+02
179.00	4.32E+02	3.22E+02	9.50E+02	3.14E+03	3.20E+02	1.12E+00	4.09E+02
180.00	4.25E+02	3.24E+02	9.35E+02	3.15E+03	3.26E+02	1.14E+00	4.14E+02
181.00	4.19E+02	3.26E+02	9.20E+02	3.16E+03	3.31E+02	1.16E+00	4.19E+02
182.00	4.12E+02	3.28E+02	9.05E+02	3.17E+03	3.37E+02	1.18E+00	4.24E+02
183.00	4.05E+02	3.30E+02	8.90E+02	3.18E+03	3.43E+02	1.20E+00	4.28E+02
184.00	3.99E+02	3.32E+02	8.76E+02	3.19E+03	3.48E+02	1.22E+00	4.33E+02
185.00	3.93E+02	3.34E+02	8.62E+02	3.20E+03	3.54E+02	1.24E+00	4.38E+02
186.00	3.86E+02	3.36E+02	8.48E+02	3.21E+03	3.60E+02	1.26E+00	4.43E+02
187.00	3.80E+02	3.37E+02	8.34E+02	3.21E+03	3.65E+02	1.28E+00	4.47E+02
188.00	3.74E+02	3.39E+02	8.20E+02	3.22E+03	3.71E+02	1.30E+00	4.52E+02
189.00	3.68E+02	3.41E+02	8.07E+02	3.23E+03	3.77E+02	1.32E+00	4.57E+02
190.00	3.62E+02	3.42E+02	7.94E+02	3.24E+03	3.83E+02	1.34E+00	4.62E+02
191.00	3.56E+02	3.44E+02	7.81E+02	3.24E+03	3.88E+02	1.36E+00	4.66E+02

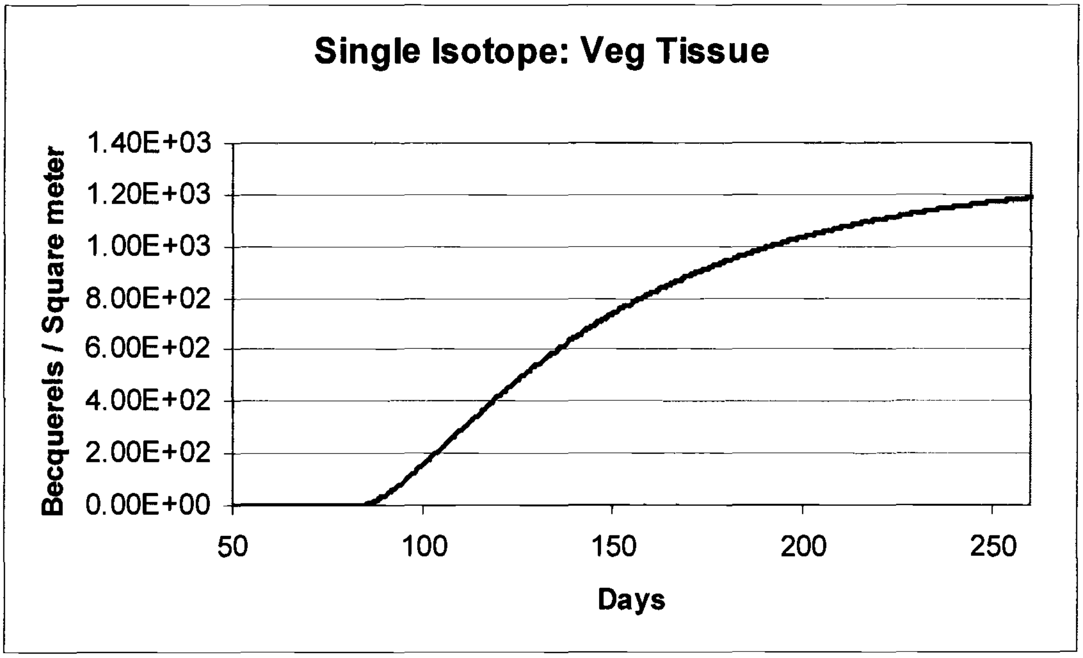
192.00	3.51E+02	3.46E+02	7.69E+02	3.25E+03	3.94E+02	1.38E+00	4.71E+02
193.00	3.45E+02	3.47E+02	7.56E+02	3.25E+03	4.00E+02	1.40E+00	4.76E+02
194.00	3.40E+02	3.49E+02	7.44E+02	3.26E+03	4.05E+02	1.42E+00	4.80E+02
195.00	3.34E+02	3.50E+02	7.32E+02	3.27E+03	4.11E+02	1.44E+00	4.85E+02
196.00	3.29E+02	3.52E+02	7.20E+02	3.27E+03	4.17E+02	1.46E+00	4.90E+02
197.00	3.24E+02	3.53E+02	7.08E+02	3.28E+03	4.23E+02	1.48E+00	4.94E+02
198.00	3.18E+02	3.55E+02	6.97E+02	3.28E+03	4.28E+02	1.50E+00	4.99E+02
199.00	3.13E+02	3.56E+02	6.86E+02	3.29E+03	4.34E+02	1.52E+00	5.04E+02
200.00	3.08E+02	3.58E+02	6.75E+02	3.29E+03	4.40E+02	1.54E+00	5.09E+02
201.00	3.03E+02	3.59E+02	6.64E+02	3.29E+03	4.46E+02	1.56E+00	5.13E+02
202.00	2.98E+02	3.60E+02	6.53E+02	3.30E+03	4.51E+02	1.58E+00	5.18E+02
203.00	2.94E+02	3.62E+02	6.43E+02	3.30E+03	4.57E+02	1.60E+00	5.23E+02
204.00	2.89E+02	3.63E+02	6.32E+02	3.30E+03	4.63E+02	1.62E+00	5.27E+02
205.00	2.84E+02	3.64E+02	6.22E+02	3.31E+03	4.69E+02	1.64E+00	5.32E+02
206.00	2.80E+02	3.65E+02	6.12E+02	3.31E+03	4.74E+02	1.66E+00	5.36E+02
207.00	2.75E+02	3.67E+02	6.02E+02	3.31E+03	4.80E+02	1.68E+00	5.41E+02
208.00	2.71E+02	3.68E+02	5.92E+02	3.32E+03	4.86E+02	1.70E+00	5.46E+02
209.00	2.66E+02	3.69E+02	5.83E+02	3.32E+03	4.92E+02	1.72E+00	5.50E+02
210.00	2.62E+02	3.70E+02	5.73E+02	3.32E+03	4.97E+02	1.74E+00	5.55E+02
211.00	2.58E+02	3.71E+02	5.64E+02	3.32E+03	5.03E+02	1.76E+00	5.60E+02
212.00	2.54E+02	3.72E+02	5.55E+02	3.32E+03	5.09E+02	1.78E+00	5.64E+02
213.00	2.50E+02	3.73E+02	5.46E+02	3.33E+03	5.15E+02	1.80E+00	5.69E+02
214.00	2.46E+02	3.74E+02	5.37E+02	3.33E+03	5.20E+02	1.83E+00	5.73E+02
215.00	2.42E+02	3.75E+02	5.29E+02	3.33E+03	5.26E+02	1.85E+00	5.78E+02
216.00	2.38E+02	3.76E+02	5.20E+02	3.33E+03	5.32E+02	1.87E+00	5.83E+02
217.00	2.34E+02	3.77E+02	5.12E+02	3.33E+03	5.38E+02	1.89E+00	5.87E+02
218.00	2.30E+02	3.78E+02	5.04E+02	3.33E+03	5.43E+02	1.91E+00	5.92E+02
219.00	2.27E+02	3.79E+02	4.95E+02	3.33E+03	5.49E+02	1.93E+00	5.96E+02
220.00	2.23E+02	3.80E+02	4.87E+02	3.33E+03	5.55E+02	1.95E+00	6.01E+02
221.00	2.19E+02	3.81E+02	4.80E+02	3.33E+03	5.60E+02	1.97E+00	6.06E+02
222.00	2.16E+02	3.82E+02	4.72E+02	3.33E+03	5.66E+02	1.99E+00	6.10E+02
223.00	2.12E+02	3.82E+02	4.64E+02	3.33E+03	5.72E+02	2.01E+00	6.15E+02
224.00	2.09E+02	3.83E+02	4.57E+02	3.33E+03	5.77E+02	2.03E+00	6.19E+02
225.00	2.06E+02	3.84E+02	4.49E+02	3.33E+03	5.83E+02	2.05E+00	6.24E+02
226.00	2.02E+02	3.85E+02	4.42E+02	3.33E+03	5.89E+02	2.07E+00	6.29E+02
227.00	1.99E+02	3.85E+02	4.35E+02	3.33E+03	5.94E+02	2.09E+00	6.33E+02
228.00	1.96E+02	3.86E+02	4.28E+02	3.33E+03	6.00E+02	2.11E+00	6.38E+02
229.00	1.93E+02	3.87E+02	4.21E+02	3.33E+03	6.06E+02	2.13E+00	6.42E+02
230.00	1.90E+02	3.88E+02	4.14E+02	3.33E+03	6.11E+02	2.15E+00	6.47E+02
231.00	1.87E+02	3.88E+02	4.08E+02	3.33E+03	6.17E+02	2.17E+00	6.51E+02
232.00	1.84E+02	3.89E+02	4.01E+02	3.33E+03	6.23E+02	2.19E+00	6.56E+02
233.00	1.81E+02	3.90E+02	3.95E+02	3.32E+03	6.28E+02	2.21E+00	6.60E+02
234.00	1.78E+02	3.90E+02	3.88E+02	3.32E+03	6.34E+02	2.23E+00	6.65E+02
235.00	1.75E+02	3.91E+02	3.82E+02	3.32E+03	6.39E+02	2.25E+00	6.69E+02
236.00	1.72E+02	3.91E+02	3.76E+02	3.32E+03	6.45E+02	2.27E+00	6.74E+02
237.00	1.69E+02	3.92E+02	3.70E+02	3.32E+03	6.51E+02	2.29E+00	6.78E+02
238.00	1.66E+02	3.93E+02	3.64E+02	3.32E+03	6.56E+02	2.31E+00	6.83E+02
239.00	1.64E+02	3.93E+02	3.58E+02	3.31E+03	6.62E+02	2.33E+00	6.87E+02
240.00	1.61E+02	3.94E+02	3.52E+02	3.31E+03	6.67E+02	2.35E+00	6.92E+02
241.00	1.59E+02	3.94E+02	3.47E+02	3.31E+03	6.73E+02	2.37E+00	6.96E+02
242.00	1.56E+02	3.95E+02	3.41E+02	3.31E+03	6.78E+02	2.39E+00	7.01E+02
243.00	1.54E+02	3.95E+02	3.36E+02	3.30E+03	6.84E+02	2.41E+00	7.05E+02
244.00	1.51E+02	3.96E+02	3.30E+02	3.30E+03	6.89E+02	2.42E+00	7.10E+02
245.00	1.49E+02	3.96E+02	3.25E+02	3.30E+03	6.95E+02	2.44E+00	7.14E+02
246.00	1.46E+02	3.97E+02	3.20E+02	3.30E+03	7.00E+02	2.46E+00	7.19E+02

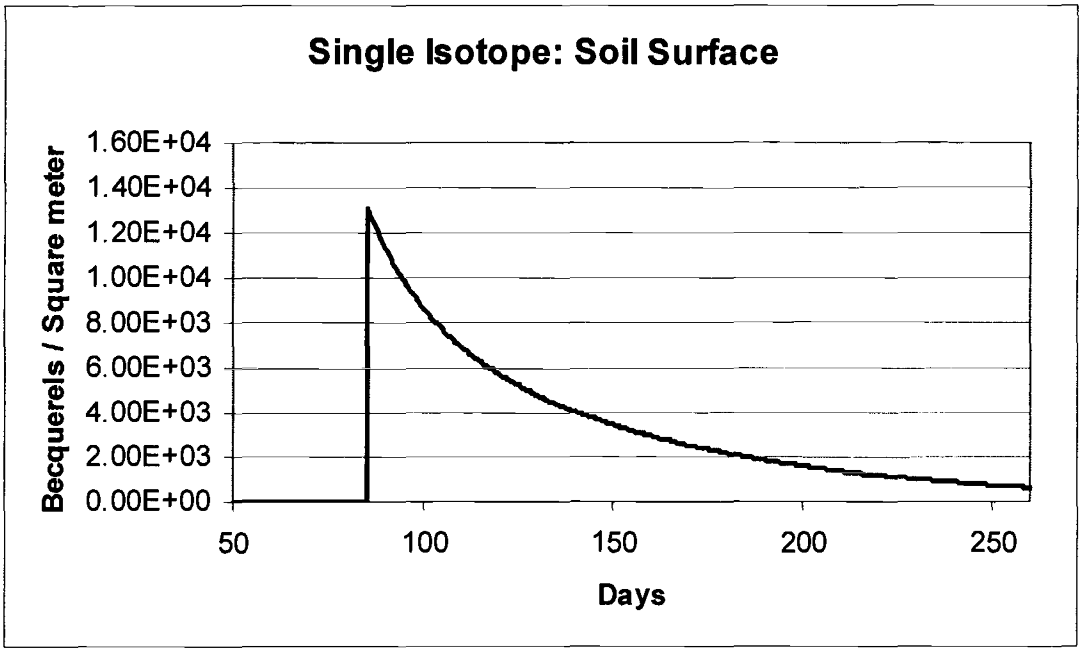
247.00	1.44E+02	3.97E+02	3.14E+02	3.29E+03	7.06E+02	2.48E+00	7.23E+02
248.00	1.42E+02	3.97E+02	3.09E+02	3.29E+03	7.11E+02	2.50E+00	7.28E+02
249.00	1.39E+02	3.98E+02	3.04E+02	3.29E+03	7.17E+02	2.52E+00	7.32E+02
250.00	1.37E+02	3.98E+02	3.00E+02	3.28E+03	7.22E+02	2.54E+00	7.37E+02
251.00	1.35E+02	3.99E+02	2.95E+02	3.28E+03	7.27E+02	2.56E+00	7.41E+02
252.00	1.33E+02	3.99E+02	2.90E+02	3.28E+03	7.33E+02	2.58E+00	7.46E+02
253.00	1.31E+02	3.99E+02	2.85E+02	3.27E+03	7.38E+02	2.60E+00	7.50E+02
254.00	1.28E+02	4.00E+02	2.81E+02	3.27E+03	7.44E+02	2.62E+00	7.55E+02
255.00	1.26E+02	4.00E+02	2.76E+02	3.27E+03	7.49E+02	2.64E+00	7.59E+02
256.00	1.24E+02	4.00E+02	2.72E+02	3.26E+03	7.54E+02	2.66E+00	7.63E+02
257.00	1.22E+02	4.01E+02	2.67E+02	3.26E+03	7.60E+02	2.68E+00	7.68E+02
258.00	1.20E+02	4.01E+02	2.63E+02	3.26E+03	7.65E+02	2.69E+00	7.72E+02
259.00	1.18E+02	4.01E+02	2.59E+02	3.25E+03	7.70E+02	2.71E+00	7.77E+02
260.00	1.17E+02	4.01E+02	2.55E+02	3.25E+03	7.76E+02	2.73E+00	7.81E+02
261.00	1.15E+02	4.02E+02	2.51E+02	3.24E+03	7.81E+02	2.75E+00	7.86E+02
262.00	4.54E+01	1.52E+02	2.44E+02	3.24E+03	7.86E+02	2.77E+00	7.90E+02
263.00	4.72E+01	1.53E+02	2.37E+02	3.24E+03	7.91E+02	2.79E+00	7.94E+02
264.00	4.87E+01	1.53E+02	2.30E+02	3.23E+03	7.97E+02	2.81E+00	7.99E+02
265.00	5.01E+01	1.53E+02	2.24E+02	3.23E+03	8.02E+02	2.83E+00	8.03E+02

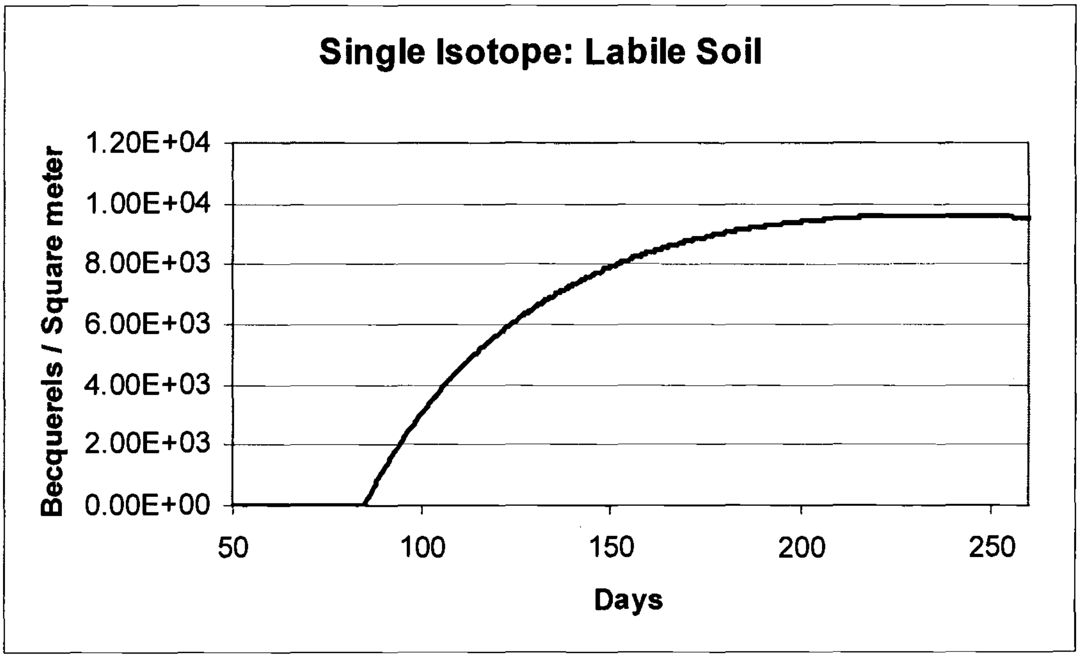
Appendix D: Single Isotope Compartment Behavior (Graph)

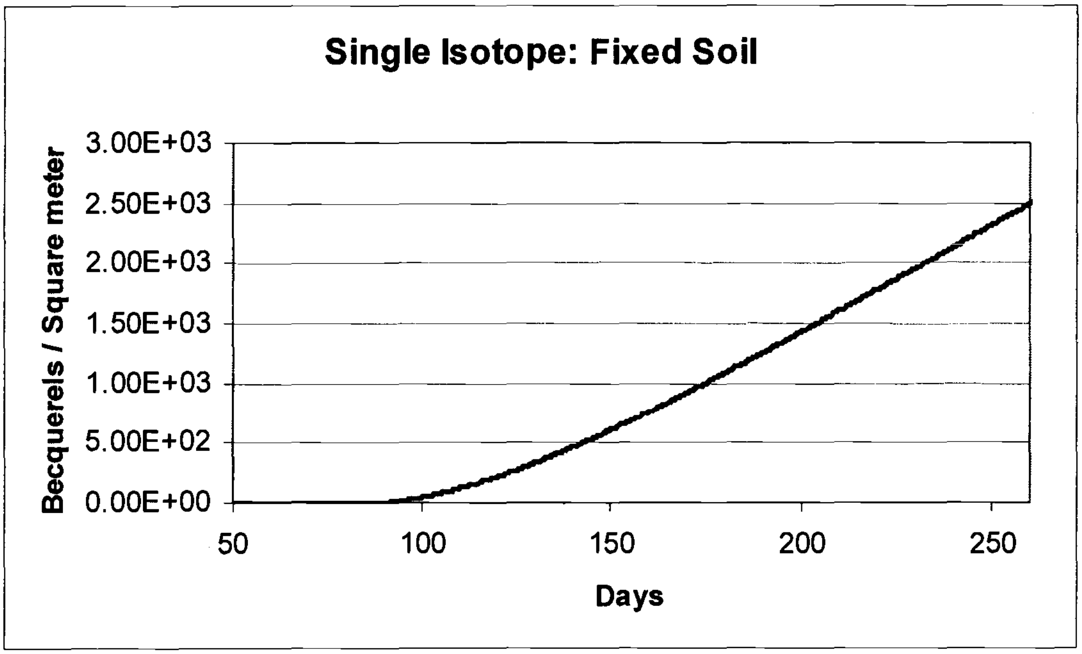


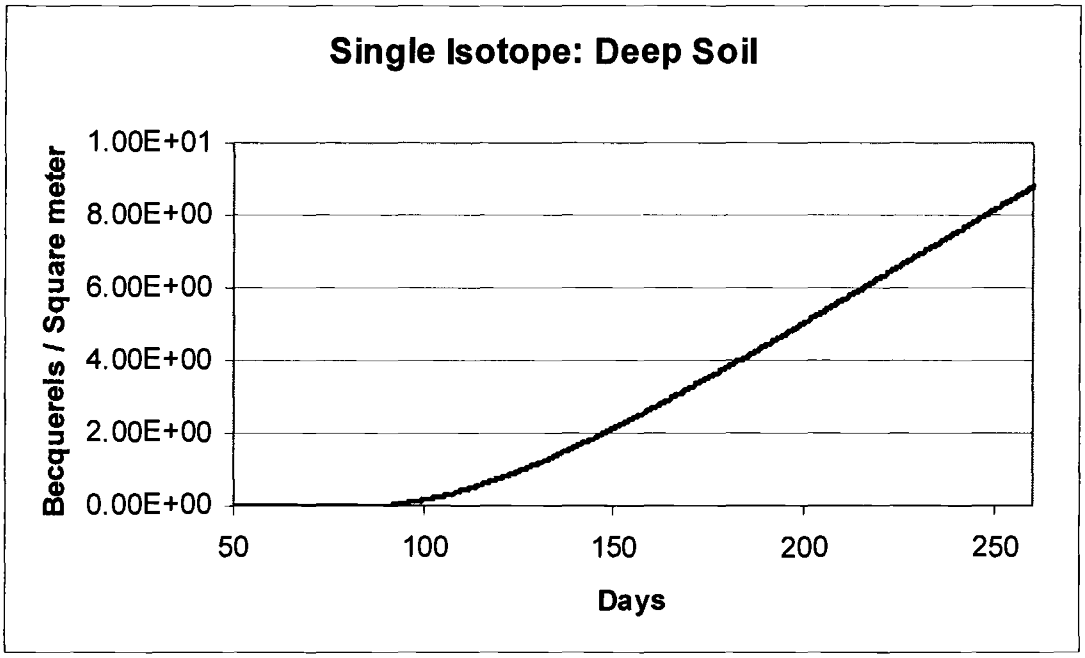


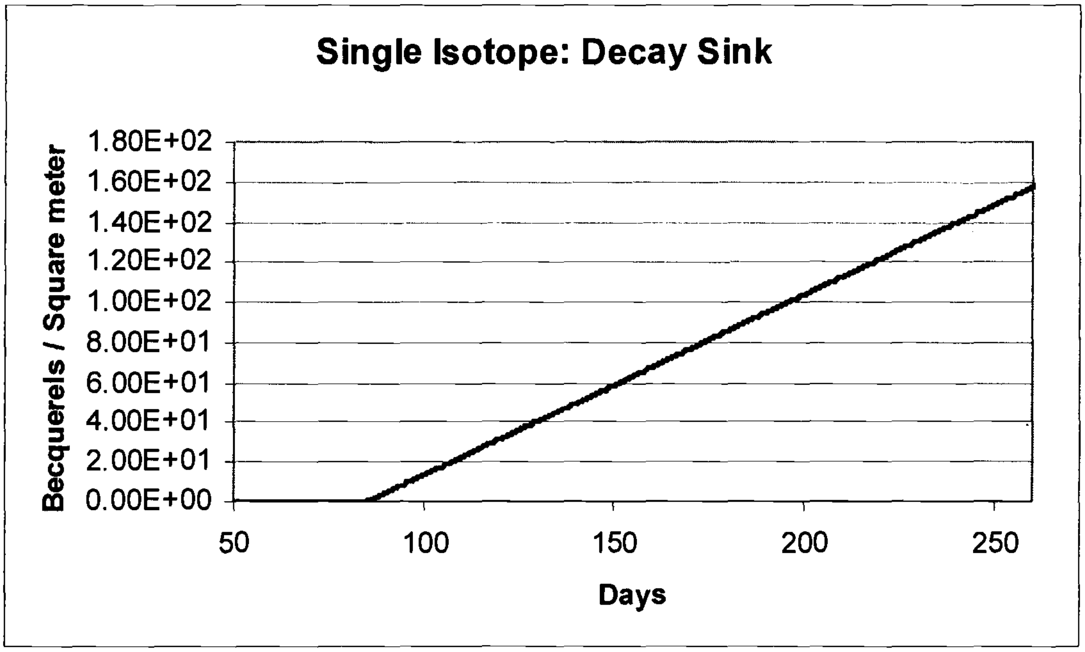

Single Isotope: Veg Tissue
Becquerels / Square meter
1.40E+03
1.20E+03
1.00E+03
8.00E+02
6.00E+02
4.00E+02
2.00E+02
0.00E+00
50
100
150
200
250
Days


Single Isotope: Soil Surface
Becquerels / Square meter
1.60E+04
1.40E+04
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
50
100
150
200
250
Days


Single Isotope: Labile Soil
Becquerels / Square meter
1.20E+04
1.00E+04
8.00E+03
6.00E+03
4.00E+03
2.00E+03
0.00E+00
50
100
150
200
250
Days


Single Isotope: Fixed Soil
Becquerels / Square meter
3.00E+03
2.50E+03
2.00E+03
1.50E+03
1.00E+03
5.00E+02
0.00E+00
50
100
150
200
250
Days


Single Isotope: Deep Soil
Becquerels / Square meter
1.00E+01
8.00E+00
6.00E+00
4.00E+00
2.00E+00
0.00E+00
50
100
150
200
250
Days


Single Isotope: Decay Sink
Becquerels / Square meter
1.80E+02
1.60E+02
1.40E+02
1.20E+02
1.00E+02
8.00E+01
6.00E+01
4.00E+01
2.00E+01
0.00E+00
50
100
150
200
250
Days

Appendix D: Single Isotope Compartment Tabular Values

Single Isotope (Cs-137)

Day of Dispersal = 85
Base Unit = Bq/m2
Source Term = 14300 Bq/m2
Temperature = 9.58 C
Time Step = 0.50 Days
Harvest Concentration = 1206.6 Bq/kg

Days	Veg Surface	Veg Tissue	Soil Surface	Labile Soil	Fixed Soil	Deep Soil	Decay Sink
80	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
81	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
82	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
84	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
85	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
86	1.25E+03	4.92E+00	1.28E+04	1.93E+02	1.40E-01	0.00E+00	6.80E-01
87	1.41E+03	1.23E+01	1.24E+04	4.43E+02	7.50E-01	0.00E+00	1.58E+00
88	1.55E+03	2.04E+01	1.20E+04	6.84E+02	1.82E+00	1.00E-02	2.49E+00
89	1.68E+03	2.93E+01	1.17E+04	9.17E+02	3.34E+00	1.00E-02	3.39E+00
90	1.79E+03	3.88E+01	1.13E+04	1.14E+03	5.30E+00	2.00E-02	4.30E+00
91	1.89E+03	4.89E+01	1.10E+04	1.36E+03	7.67E+00	3.00E-02	5.20E+00
92	1.98E+03	5.96E+01	1.07E+04	1.57E+03	1.05E+01	4.00E-02	6.11E+00
93	2.06E+03	7.07E+01	1.04E+04	1.78E+03	1.36E+01	5.00E-02	7.01E+00
94	2.13E+03	8.22E+01	1.01E+04	1.98E+03	1.72E+01	6.00E-02	7.92E+00
95	2.19E+03	9.41E+01	9.81E+03	2.17E+03	2.11E+01	7.00E-02	8.82E+00
96	2.25E+03	1.06E+02	9.56E+03	2.36E+03	2.54E+01	9.00E-02	9.73E+00
97	2.29E+03	1.19E+02	9.31E+03	2.54E+03	3.01E+01	1.00E-01	1.06E+01
98	2.33E+03	1.32E+02	9.07E+03	2.71E+03	3.51E+01	1.20E-01	1.15E+01
99	2.37E+03	1.44E+02	8.85E+03	2.89E+03	4.04E+01	1.40E-01	1.24E+01
100	2.39E+03	1.58E+02	8.64E+03	3.05E+03	4.60E+01	1.60E-01	1.34E+01
101	2.42E+03	1.71E+02	8.43E+03	3.22E+03	5.19E+01	1.80E-01	1.43E+01
102	2.43E+03	1.84E+02	8.23E+03	3.38E+03	5.82E+01	2.00E-01	1.52E+01
103	2.45E+03	1.97E+02	8.04E+03	3.53E+03	6.47E+01	2.30E-01	1.61E+01
104	2.46E+03	2.11E+02	7.86E+03	3.68E+03	7.16E+01	2.50E-01	1.70E+01
105	2.46E+03	2.24E+02	7.69E+03	3.83E+03	7.87E+01	2.70E-01	1.79E+01
106	2.46E+03	2.38E+02	7.52E+03	3.97E+03	8.61E+01	3.00E-01	1.88E+01
107	2.46E+03	2.52E+02	7.36E+03	4.11E+03	9.37E+01	3.30E-01	1.97E+01
108	2.46E+03	2.65E+02	7.21E+03	4.25E+03	1.02E+02	3.50E-01	2.06E+01
109	2.45E+03	2.79E+02	7.06E+03	4.38E+03	1.10E+02	3.80E-01	2.15E+01
110	2.45E+03	2.92E+02	6.91E+03	4.51E+03	1.18E+02	4.10E-01	2.24E+01
111	2.44E+03	3.05E+02	6.77E+03	4.63E+03	1.27E+02	4.40E-01	2.33E+01
112	2.42E+03	3.19E+02	6.64E+03	4.76E+03	1.36E+02	4.70E-01	2.42E+01
113	2.41E+03	3.32E+02	6.51E+03	4.88E+03	1.45E+02	5.00E-01	2.51E+01
114	2.40E+03	3.45E+02	6.38E+03	5.00E+03	1.54E+02	5.40E-01	2.60E+01
115	2.38E+03	3.58E+02	6.26E+03	5.11E+03	1.64E+02	5.70E-01	2.69E+01
116	2.36E+03	3.71E+02	6.14E+03	5.22E+03	1.74E+02	6.00E-01	2.78E+01
117	2.34E+03	3.84E+02	6.03E+03	5.33E+03	1.84E+02	6.40E-01	2.87E+01
118	2.32E+03	3.97E+02	5.92E+03	5.44E+03	1.94E+02	6.70E-01	2.96E+01
119	2.30E+03	4.10E+02	5.81E+03	5.55E+03	2.04E+02	7.10E-01	3.05E+01
120	2.28E+03	4.22E+02	5.70E+03	5.65E+03	2.15E+02	7.50E-01	3.14E+01
121	2.26E+03	4.35E+02	5.60E+03	5.75E+03	2.25E+02	7.90E-01	3.23E+01
122	2.23E+03	4.47E+02	5.50E+03	5.85E+03	2.36E+02	8.20E-01	3.32E+01
123	2.21E+03	4.59E+02	5.40E+03	5.95E+03	2.48E+02	8.60E-01	3.41E+01
124	2.19E+03	4.71E+02	5.31E+03	6.04E+03	2.59E+02	9.00E-01	3.50E+01
125	2.16E+03	4.83E+02	5.21E+03	6.13E+03	2.70E+02	9.40E-01	3.59E+01
126	2.14E+03	4.95E+02	5.12E+03	6.22E+03	2.82E+02	9.80E-01	3.68E+01

127	2.11E+03	5.07E+02	5.04E+03	6.31E+03	2.94E+02	1.02E+00	3.77E+01
128	2.09E+03	5.18E+02	4.95E+03	6.40E+03	3.06E+02	1.07E+00	3.87E+01
129	2.06E+03	5.30E+02	4.87E+03	6.48E+03	3.18E+02	1.11E+00	3.96E+01
130	2.04E+03	5.41E+02	4.78E+03	6.56E+03	3.30E+02	1.15E+00	4.05E+01
131	2.01E+03	5.52E+02	4.70E+03	6.65E+03	3.43E+02	1.19E+00	4.14E+01
132	1.99E+03	5.63E+02	4.63E+03	6.72E+03	3.55E+02	1.24E+00	4.23E+01
133	1.96E+03	5.74E+02	4.55E+03	6.80E+03	3.68E+02	1.28E+00	4.32E+01
134	1.94E+03	5.85E+02	4.47E+03	6.88E+03	3.81E+02	1.33E+00	4.41E+01
135	1.91E+03	5.95E+02	4.40E+03	6.95E+03	3.94E+02	1.37E+00	4.50E+01
136	1.89E+03	6.05E+02	4.33E+03	7.03E+03	4.07E+02	1.42E+00	4.59E+01
137	1.86E+03	6.16E+02	4.26E+03	7.10E+03	4.20E+02	1.47E+00	4.68E+01
138	1.84E+03	6.26E+02	4.19E+03	7.17E+03	4.34E+02	1.51E+00	4.77E+01
139	1.81E+03	6.36E+02	4.12E+03	7.23E+03	4.47E+02	1.56E+00	4.86E+01
140	1.79E+03	6.46E+02	4.06E+03	7.30E+03	4.61E+02	1.61E+00	4.95E+01
141	1.76E+03	6.55E+02	3.99E+03	7.37E+03	4.75E+02	1.66E+00	5.04E+01
142	1.74E+03	6.65E+02	3.93E+03	7.43E+03	4.89E+02	1.71E+00	5.13E+01
143	1.71E+03	6.74E+02	3.86E+03	7.49E+03	5.03E+02	1.75E+00	5.22E+01
144	1.69E+03	6.84E+02	3.80E+03	7.55E+03	5.17E+02	1.80E+00	5.31E+01
145	1.66E+03	6.93E+02	3.74E+03	7.61E+03	5.31E+02	1.85E+00	5.40E+01
146	1.64E+03	7.02E+02	3.68E+03	7.67E+03	5.46E+02	1.90E+00	5.49E+01
147	1.62E+03	7.11E+02	3.62E+03	7.73E+03	5.60E+02	1.96E+00	5.58E+01
148	1.59E+03	7.20E+02	3.57E+03	7.79E+03	5.75E+02	2.01E+00	5.67E+01
149	1.57E+03	7.28E+02	3.51E+03	7.84E+03	5.89E+02	2.06E+00	5.76E+01
150	1.55E+03	7.37E+02	3.46E+03	7.89E+03	6.04E+02	2.11E+00	5.85E+01
151	1.53E+03	7.45E+02	3.40E+03	7.95E+03	6.19E+02	2.16E+00	5.94E+01
152	1.50E+03	7.54E+02	3.35E+03	8.00E+03	6.34E+02	2.21E+00	6.03E+01
153	1.48E+03	7.62E+02	3.30E+03	8.05E+03	6.49E+02	2.27E+00	6.12E+01
154	1.46E+03	7.70E+02	3.24E+03	8.10E+03	6.64E+02	2.32E+00	6.21E+01
155	1.44E+03	7.78E+02	3.19E+03	8.14E+03	6.80E+02	2.37E+00	6.30E+01
156	1.42E+03	7.86E+02	3.14E+03	8.19E+03	6.95E+02	2.43E+00	6.39E+01
157	1.40E+03	7.93E+02	3.09E+03	8.24E+03	7.10E+02	2.48E+00	6.48E+01
158	1.38E+03	8.01E+02	3.05E+03	8.28E+03	7.26E+02	2.54E+00	6.57E+01
159	1.36E+03	8.08E+02	3.00E+03	8.33E+03	7.41E+02	2.59E+00	6.66E+01
160	1.34E+03	8.16E+02	2.95E+03	8.37E+03	7.57E+02	2.65E+00	6.75E+01
161	1.32E+03	8.23E+02	2.91E+03	8.41E+03	7.73E+02	2.70E+00	6.84E+01
162	1.30E+03	8.30E+02	2.86E+03	8.45E+03	7.89E+02	2.76E+00	6.93E+01
163	1.28E+03	8.37E+02	2.82E+03	8.49E+03	8.04E+02	2.81E+00	7.02E+01
164	1.26E+03	8.44E+02	2.77E+03	8.53E+03	8.20E+02	2.87E+00	7.11E+01
165	1.24E+03	8.51E+02	2.73E+03	8.57E+03	8.36E+02	2.92E+00	7.20E+01
166	1.22E+03	8.58E+02	2.69E+03	8.60E+03	8.53E+02	2.98E+00	7.29E+01
167	1.20E+03	8.64E+02	2.65E+03	8.64E+03	8.69E+02	3.04E+00	7.38E+01
168	1.18E+03	8.71E+02	2.61E+03	8.67E+03	8.85E+02	3.09E+00	7.47E+01
169	1.17E+03	8.77E+02	2.57E+03	8.71E+03	9.01E+02	3.15E+00	7.56E+01
170	1.15E+03	8.83E+02	2.53E+03	8.74E+03	9.17E+02	3.21E+00	7.65E+01
171	1.13E+03	8.90E+02	2.49E+03	8.77E+03	9.34E+02	3.27E+00	7.74E+01
172	1.12E+03	8.96E+02	2.45E+03	8.81E+03	9.50E+02	3.32E+00	7.83E+01
173	1.10E+03	9.02E+02	2.41E+03	8.84E+03	9.67E+02	3.38E+00	7.92E+01
174	1.08E+03	9.08E+02	2.38E+03	8.87E+03	9.83E+02	3.44E+00	8.01E+01
175	1.07E+03	9.14E+02	2.34E+03	8.90E+03	1.00E+03	3.50E+00	8.10E+01
176	1.05E+03	9.19E+02	2.30E+03	8.93E+03	1.02E+03	3.56E+00	8.19E+01
177	1.03E+03	9.25E+02	2.27E+03	8.95E+03	1.03E+03	3.62E+00	8.28E+01
178	1.02E+03	9.31E+02	2.23E+03	8.98E+03	1.05E+03	3.68E+00	8.37E+01
179	1.00E+03	9.36E+02	2.20E+03	9.01E+03	1.07E+03	3.73E+00	8.46E+01
180	9.88E+02	9.41E+02	2.17E+03	9.03E+03	1.08E+03	3.79E+00	8.55E+01
181	9.73E+02	9.47E+02	2.13E+03	9.06E+03	1.10E+03	3.85E+00	8.64E+01

182	9.58E+02	9.52E+02	2.10E+03	9.08E+03	1.12E+03	3.91E+00	8.73E+01
183	9.43E+02	9.57E+02	2.07E+03	9.11E+03	1.13E+03	3.97E+00	8.82E+01
184	9.29E+02	9.62E+02	2.04E+03	9.13E+03	1.15E+03	4.03E+00	8.91E+01
185	9.15E+02	9.67E+02	2.00E+03	9.15E+03	1.17E+03	4.09E+00	9.00E+01
186	9.01E+02	9.72E+02	1.97E+03	9.17E+03	1.19E+03	4.15E+00	9.09E+01
187	8.87E+02	9.77E+02	1.94E+03	9.19E+03	1.20E+03	4.21E+00	9.18E+01
188	8.74E+02	9.82E+02	1.91E+03	9.21E+03	1.22E+03	4.27E+00	9.27E+01
189	8.61E+02	9.87E+02	1.88E+03	9.23E+03	1.24E+03	4.33E+00	9.36E+01
190	8.48E+02	9.91E+02	1.86E+03	9.25E+03	1.25E+03	4.39E+00	9.45E+01
191	8.35E+02	9.96E+02	1.83E+03	9.27E+03	1.27E+03	4.46E+00	9.54E+01
192	8.22E+02	1.00E+03	1.80E+03	9.29E+03	1.29E+03	4.52E+00	9.63E+01
193	8.10E+02	1.00E+03	1.77E+03	9.31E+03	1.31E+03	4.58E+00	9.72E+01
194	7.97E+02	1.01E+03	1.74E+03	9.32E+03	1.32E+03	4.64E+00	9.81E+01
195	7.85E+02	1.01E+03	1.72E+03	9.34E+03	1.34E+03	4.70E+00	9.90E+01
196	7.73E+02	1.02E+03	1.69E+03	9.35E+03	1.36E+03	4.76E+00	9.99E+01
197	7.61E+02	1.02E+03	1.67E+03	9.37E+03	1.38E+03	4.82E+00	1.01E+02
198	7.50E+02	1.03E+03	1.64E+03	9.38E+03	1.39E+03	4.88E+00	1.02E+02
199	7.38E+02	1.03E+03	1.62E+03	9.40E+03	1.41E+03	4.95E+00	1.03E+02
200	7.27E+02	1.03E+03	1.59E+03	9.41E+03	1.43E+03	5.01E+00	1.04E+02
201	7.16E+02	1.04E+03	1.57E+03	9.42E+03	1.45E+03	5.07E+00	1.04E+02
202	7.05E+02	1.04E+03	1.54E+03	9.44E+03	1.46E+03	5.13E+00	1.05E+02
203	6.94E+02	1.05E+03	1.52E+03	9.45E+03	1.48E+03	5.19E+00	1.06E+02
204	6.84E+02	1.05E+03	1.50E+03	9.46E+03	1.50E+03	5.26E+00	1.07E+02
205	6.73E+02	1.05E+03	1.47E+03	9.47E+03	1.52E+03	5.32E+00	1.08E+02
206	6.63E+02	1.06E+03	1.45E+03	9.48E+03	1.53E+03	5.38E+00	1.09E+02
207	6.53E+02	1.06E+03	1.43E+03	9.49E+03	1.55E+03	5.44E+00	1.10E+02
208	6.43E+02	1.06E+03	1.41E+03	9.50E+03	1.57E+03	5.50E+00	1.11E+02
209	6.33E+02	1.07E+03	1.38E+03	9.51E+03	1.59E+03	5.57E+00	1.12E+02
210	6.24E+02	1.07E+03	1.36E+03	9.52E+03	1.60E+03	5.63E+00	1.12E+02
211	6.14E+02	1.07E+03	1.34E+03	9.53E+03	1.62E+03	5.69E+00	1.13E+02
212	6.05E+02	1.08E+03	1.32E+03	9.54E+03	1.64E+03	5.75E+00	1.14E+02
213	5.96E+02	1.08E+03	1.30E+03	9.54E+03	1.66E+03	5.82E+00	1.15E+02
214	5.87E+02	1.08E+03	1.28E+03	9.55E+03	1.67E+03	5.88E+00	1.16E+02
215	5.78E+02	1.09E+03	1.26E+03	9.56E+03	1.69E+03	5.94E+00	1.17E+02
216	5.69E+02	1.09E+03	1.24E+03	9.56E+03	1.71E+03	6.01E+00	1.18E+02
217	5.60E+02	1.09E+03	1.22E+03	9.57E+03	1.73E+03	6.07E+00	1.19E+02
218	5.52E+02	1.10E+03	1.21E+03	9.58E+03	1.75E+03	6.13E+00	1.20E+02
219	5.43E+02	1.10E+03	1.19E+03	9.58E+03	1.76E+03	6.19E+00	1.21E+02
220	5.35E+02	1.10E+03	1.17E+03	9.59E+03	1.78E+03	6.26E+00	1.21E+02
221	5.27E+02	1.10E+03	1.15E+03	9.59E+03	1.80E+03	6.32E+00	1.22E+02
222	5.19E+02	1.11E+03	1.13E+03	9.59E+03	1.82E+03	6.38E+00	1.23E+02
223	5.11E+02	1.11E+03	1.12E+03	9.60E+03	1.83E+03	6.45E+00	1.24E+02
224	5.03E+02	1.11E+03	1.10E+03	9.60E+03	1.85E+03	6.51E+00	1.25E+02
225	4.95E+02	1.12E+03	1.08E+03	9.60E+03	1.87E+03	6.57E+00	1.26E+02
226	4.88E+02	1.12E+03	1.07E+03	9.61E+03	1.89E+03	6.63E+00	1.27E+02
227	4.80E+02	1.12E+03	1.05E+03	9.61E+03	1.90E+03	6.70E+00	1.28E+02
228	4.73E+02	1.12E+03	1.03E+03	9.61E+03	1.92E+03	6.76E+00	1.29E+02
229	4.66E+02	1.13E+03	1.02E+03	9.61E+03	1.94E+03	6.82E+00	1.30E+02
230	4.59E+02	1.13E+03	1.00E+03	9.62E+03	1.96E+03	6.89E+00	1.30E+02
231	4.52E+02	1.13E+03	9.87E+02	9.62E+03	1.98E+03	6.95E+00	1.31E+02
232	4.45E+02	1.13E+03	9.72E+02	9.62E+03	1.99E+03	7.01E+00	1.32E+02
233	4.38E+02	1.14E+03	9.57E+02	9.62E+03	2.01E+03	7.08E+00	1.33E+02
234	4.31E+02	1.14E+03	9.43E+02	9.62E+03	2.03E+03	7.14E+00	1.34E+02
235	4.25E+02	1.14E+03	9.28E+02	9.62E+03	2.05E+03	7.20E+00	1.35E+02
236	4.18E+02	1.14E+03	9.14E+02	9.62E+03	2.06E+03	7.26E+00	1.36E+02

237	4.12E+02	1.14E+03	9.00E+02	9.62E+03	2.08E+03	7.33E+00	1.37E+02
238	4.06E+02	1.15E+03	8.87E+02	9.62E+03	2.10E+03	7.39E+00	1.38E+02
239	3.99E+02	1.15E+03	8.73E+02	9.62E+03	2.12E+03	7.45E+00	1.39E+02
240	3.93E+02	1.15E+03	8.60E+02	9.61E+03	2.14E+03	7.52E+00	1.39E+02
241	3.87E+02	1.15E+03	8.47E+02	9.61E+03	2.15E+03	7.58E+00	1.40E+02
242	3.81E+02	1.15E+03	8.34E+02	9.61E+03	2.17E+03	7.64E+00	1.41E+02
243	3.76E+02	1.16E+03	8.21E+02	9.61E+03	2.19E+03	7.71E+00	1.42E+02
244	3.70E+02	1.16E+03	8.08E+02	9.61E+03	2.21E+03	7.77E+00	1.43E+02
245	3.64E+02	1.16E+03	7.96E+02	9.60E+03	2.22E+03	7.83E+00	1.44E+02
246	3.59E+02	1.16E+03	7.84E+02	9.60E+03	2.24E+03	7.89E+00	1.45E+02
247	3.53E+02	1.16E+03	7.72E+02	9.60E+03	2.26E+03	7.96E+00	1.46E+02
248	3.48E+02	1.17E+03	7.60E+02	9.59E+03	2.28E+03	8.02E+00	1.47E+02
249	3.43E+02	1.17E+03	7.49E+02	9.59E+03	2.29E+03	8.08E+00	1.47E+02
250	3.37E+02	1.17E+03	7.37E+02	9.59E+03	2.31E+03	8.15E+00	1.48E+02
251	3.32E+02	1.17E+03	7.26E+02	9.58E+03	2.33E+03	8.21E+00	1.49E+02
252	3.27E+02	1.17E+03	7.15E+02	9.58E+03	2.35E+03	8.27E+00	1.50E+02
253	3.22E+02	1.18E+03	7.04E+02	9.57E+03	2.36E+03	8.33E+00	1.51E+02
254	3.17E+02	1.18E+03	6.93E+02	9.57E+03	2.38E+03	8.40E+00	1.52E+02
255	3.12E+02	1.18E+03	6.83E+02	9.57E+03	2.40E+03	8.46E+00	1.53E+02
256	3.08E+02	1.18E+03	6.72E+02	9.56E+03	2.42E+03	8.52E+00	1.54E+02
257	3.03E+02	1.18E+03	6.62E+02	9.56E+03	2.43E+03	8.58E+00	1.55E+02
258	2.98E+02	1.18E+03	6.52E+02	9.55E+03	2.45E+03	8.65E+00	1.56E+02
259	2.94E+02	1.18E+03	6.42E+02	9.54E+03	2.47E+03	8.71E+00	1.56E+02
260	2.89E+02	1.19E+03	6.32E+02	9.54E+03	2.49E+03	8.77E+00	1.57E+02
261	2.85E+02	1.19E+03	6.23E+02	9.53E+03	2.50E+03	8.83E+00	1.58E+02
262	1.13E+02	4.51E+02	6.06E+02	9.53E+03	2.52E+03	8.90E+00	1.59E+02
263	1.17E+02	4.51E+02	5.89E+02	9.52E+03	2.54E+03	8.96E+00	1.60E+02
264	1.21E+02	4.52E+02	5.73E+02	9.51E+03	2.56E+03	9.02E+00	1.61E+02
265	1.25E+02	4.53E+02	5.58E+02	9.51E+03	2.57E+03	9.08E+00	1.62E+02