DEVELOPMENT OF A RADIOECOLOGICAL MODEL FOR ACCIDENTAL RELEASE OF RADIONUCLIDES: AKKUYU AND SİNOP NUCLEAR POWER PLANTS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

LATİFE ÖZGE ÜNVER

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
IN
ENVIRONMENTAL ENGINEERING

SEPTEMBER 2014

Approval of the thesis:

DEVELOPMENT OF A RADIOECOLOGICAL MODEL FOR ACCIDENTAL RELEASE OF RADIONUCLIDES: AKKUYU AND SİNOP NUCLEAR POWER PLANTS

submitted by **LATİFE ÖZGE ÜNVER** in partial fulfillment of the requirements for the degree of **Doctor of Philosophy in Environmental Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ____________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. F. Dilek Sanin ____________
Head of Department, **Environmental Engineering**

Prof. Dr. Gürdal Tuncel ____________
Supervisor, **Environmental Engineering Dept., METU**

Assoc. Prof. Dr. Cemil Kocar ____________
Co-Supervisor, **Nuclear Engineering Dept., Hacettepe University**

Examining Committee Members:

Assoc. Prof. Dr. Ayşegül Aksoy ____________
Environmental Engineering Dept., METU

Prof. Dr. Gürdal Tuncel ____________
Environmental Engineering Dept., METU

Assoc. Prof. Dr. İpek İmamoğlu ____________
Environmental Engineering Dept., METU

Prof. Dr. Gülen Güllü ____________
Environmental Engineering Dept., Hacettepe University

Prof. Dr. Tolga Elbir ____________
Environmental Engineering Dept., Dokuz Eylül University

Date: 05.09.2014

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Latife Özge Ünver

Signature:

ABSTRACT

DEVELOPMENT OF RADIOECOLOGICAL MODEL FOR ACCIDENTAL RADIONUCLIDE RELEASE: AKKUYU AND SİNOP NUCLEAR POWER PLANTS

Ünver, Latife Özge
Ph.D., Department of Environmental Engineering
Supervisor: Prof. Dr. Gürdal Tuncel
Co-Supervisor: Assoc. Prof. Dr. Cemil Kocar

September 2014, 192 pages

A dynamic dose model has been developed to estimate radiation doses and stochastic risks due to atmospheric discharges of radionuclides in the case of a nuclear reactor accident. In addition to individual doses from different pathways for different age groups, collective doses and stochastic risks can be calculated by the model. The model can be coupled to any long-range atmospheric dispersion model which can calculate radionuclide concentrations in air and on the ground at predetermined time intervals or measurement data. Since the Chernobyl accident, there had been an increase in real world data to assess the capabilities of software, which are developed to calculate radionuclide concentrations in the environment and doses to human. Therefore, data related to Chernobyl accident was used to validate the developed software. The validated software was then used to calculate radiological consequences in the case of hypothetical severe accidents at Akkuyu and Sinop NPPs in Turkey. The accident scenario was based on Fukushima Daiichi NPP accident. The newly developed software was run for different release times, and it was turned out that meteorological pattern as well as vegetation cycles of the plants were influencing doses to humans. The doses incurred due to a severe accident at Akkuyu NPP were calculated as 3.374 mSv 1 year after the accident, and the lifetime doses will be 9.706 for adults having average habits; the doses in the case of Sinop NPP accident have been found out to be more than that of Akkuyu NPP accident. Cs-134, Cs-137 and I-131 were identified as the most dose contributing isotopes, and cereals, cow milk, chicken, fruits, lamb, beef, fruit vegetables and root vegetables were the most dose contributing foods respectively. For the maximum deposited grit found out as a result of simulation of Akkuyu NPP accident, and for the related parameters of most dose contributing isotopes and foodstuffs, uncertainty analysis was performed by LHS to predict uncertainties in the doses and activity concentrations. Furthermore, sensitivity analysis was also conducted by again LHS of the aforementioned parameters and the outputs were processed by correlation techniques to find out most influencing parameters on lifetime and short-term doses. It can be concluded that soil-plant transfer factors for Cs have a big influence on the lifetime dose results, feed-animal transfer factor for Cs for cow milk and reduction factors for external radiation, beef and grain consumption amounts have also the high effect on lifetime doses. For the short term doses, cow milk transfer factor for iodine and interception factor for the grass are also influential parameters.

Keywords: Dynamic software, environmental transfer, radionuclide, nuclear accident, Chernobyl, dose, risk, uncertainty, sensitivity.

ÖZ

KAZA SONRASI RADYONÜKLİT SALIMI İÇİN RADYOEKOLOJİK BİR MODEL GELİŞTİRİLMESİ: AKKUYU VE SİNOP NÜKLEER SANTRALLERİ

Ünver, Latife Özge
Doktora, Çevre Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Gürdal Tuncel
Ortak Tez Yöneticisi: Doç. Dr. Cemil Kocar

Eylül 2014, 192 sayfa

Bir nükleer reaktör kazası sonrası atmosfere yayılan salımlar nedeniyle maruz kalınacak radyasyon dozunu ve stokastik riskleri hesaplayan dinamik bir yazılım geliştirilmiştir. Bu model ile farklı radyasyon taşınım yollarından farklı yaş grupları için bireysel dozlar, kolektif dozlar ve stokastik riskler hesaplanabilir. Model belirli zaman aralıklarında hava konsantrasyonları ya da birikim hesaplayabilen herhangi bir uzun dönemli atmosferik taşınım modeli ile birleştirilebilir ya da ölçüm verileri modelde girdi olarak kullanılabilir. Çernobil kazasından sonra çevrede radyonüklit konsantrasyonlarının tespitine ve doz hesaplayan yazılımların kabiliyetlerini değerlendirmeye yönelik çalışmalar oldukça artmıştır. Bu nedenle Çernobil kazası sonrası ölçülen radyoaktivite verileri ile benzer modellerin doğrulama çalışmaları geliştirilen yazılımın doğruluğunu sınamak için kullanılmıştır. Doğrulanmış yazılım sonrasında, Türkiye'de kurulacak Akkuyu ve Sinop nükleer santrallerinde olabilecek ciddi bir kazanın radyolojik sonuçlarını modellemek için kullanılmıştır. Seçilen kaza senaryosu Fukuşhima Daiichi nükleer santral kazasına dayanmaktadır. Geliştirilen yazılım farklı zamanlarda çalıştırılmış ve dozlar üzerinde meteorolojik koşullar kadar bitkilerin vejetasyon döngülerinin de önemli olduğu belirlenmiştir. Akkuyu NGS'de olabilecek ciddi bir kaza senaryosuna göre, ortalama alışkanlıklara sahip yetişkinlerin dozları kazadan 1 yıl sonrasında 3.374 mSv ve ömür boyu ise 9.706 mSv olarak hesaplanmıştır. Sinop NGS'de olabilecek ciddi kazada ise dozlar daha yüksek bulunmuştur. Cs-134, Cs-137 ve I-131 doza en cok katkı yapan izotoplar olarak, tahıllar, inek sütü, tavuk eti, meyveler, koyun eti, dana eti, meyveli ve köklü sebzeler doza en çok katkı yapan gıdalar olarak tanımlanmıştır. Akkuyu nükleer santralinde meydana gelebilecek ciddi bir kaza için en fazla birikimin olduğu grit, en fazla doza katkıda bulunan radyoizotoplar ve gıda maddeleri için LHS metodu ile dozlardaki ve aktivite konsantrasyonlarındaki belirsizlikler hesaplanmıştır. Ayrıca, yukarıda bahsedilen parametreler arasından LHS metodu ile kısa dönem ve yaşam boyu dozlar üzerindeki en çok etkin olan parametreleri ortaya çıkarmaya yönelik korelasyon teknikleri kullanılarak hassasiyet analizleri de yapılmıştır. Yaşam boyu dozların üzerinde Cs'nin toprak-bitki ve inek sütündeki transfer faktörleri, harici radyasyon için azaltım faktörü, dana eti ve tahıl tüketim miktarının oldukça etkili olduğu görülmüştür. Kısa dönemli dozlar üzerinde ise iyodun inek sütündeki transfer faktörü ve çimenin radyonüklitleri tutma katsayısı da etkindir.

Anahtar sözcükler: Dinamik yazılım, çevrede taşınım, radyonüklit, nükleer kaza, Çernobil, doz, risk, belirsizlik, hassasiyet.

To my son and parents…..

ACKNOWLEDGMENTS

I would like to express my sincere appreciation to my advisor Prof. Dr. Gürdal Tuncel for his insightful guidance, limitless patience and encouragement throughout the years, even in the hard times and tackling problems seem unresolved in my studies. Being a student of his is an incredible experience and I hope I have gained at least some of his research and human attitudes and can apply into my life. I would like to thank my co-supervisor Assoc.Prof. Dr. Cemil Kocar for his guidance, advice, criticism and insight throughout the research.

I want to thank my follow-up committee members, Prof. Dr. Gülen Güllü and Assoc. Prof. Dr. Ayşegül Aksoy for enriching scientific discussions and sharing their experiences throughout thesis progress meetings and other times of my study as well.

The technical assistance of Mr. Ali Sönmez is gratefully acknowledged. He has given lots of his time to develop the structure of my software.

I extend my sincere thanks to my mother to make my life easier and to give continuous support and motivation over the years. I would like to thank my dear son for his patience and tolerance. I would like to express my deepest appreciation to my late father who had given me full support and encouragement in his life to continue my doctorate. I also would like to thank my brother Prof.Dr. Utku Ünver for his encouragement and technical support to my thesis. I would also like to express my content for all my friends being with me and believing in me to accomplish my PhD during all these long years.

Many apologies to others whom I may have inadvertently forgotten to mention.

TABLE OF CONTENTS

LIST of TABLES

TABLES

LIST of FIGURES

FIGURES

LIST OF ABBREVIATIONS

Bq: Becquerel

CB: Crystal Ball

Cs: Cesium

DCF: Dose conversion factor

ECMWF: The European Centre for Medium-Range Weather Forecasts

EUR: European Utility Requirement

I: Iodine

IAEA: International Atomic Energy Agency

IAEA TECDOC: International Atomic Energy Agency Technical Document

IAEA TRS: International Atomic Energy Agency Technical Repot Series

ICRP: International Commission on Radiation Protection

LHS: Latin hybercube sampling

MSL: Mean sea level

NOAA: National Oceanographic and Atmospheric Administration

NPP: Nuclear power plant

NRPB: National Radiation Protection Board

OECD NEA: The Organization for Economic Co-operation and Development Nuclear Energy Agency

RDR: Relative Deviation Ratio

PCC: Partial Correlation Coefficients

PRCC: Partial Rank Correlation Coefficient

PWR: Pressurized water reactor

SANAEM: Sarayköy Nuclear Research and Training Center

Sv: Sievert

USDOE: U.S. Department of Energy

USEPA FGR: U.S. Environmental Protection Agency Federal Government Report

USNRC: U.S. Nuclear Regulatory Authority

TAEK: Turkish Atomic Energy Authority

Te: Tellurium

TF: Transfer factor

TUIK: Turkish Statistics Institute

U&S: Uncertainty and sensitivity

Xe: Xenon

CHAPTER 1

INTRODUCTION

1.1. General

Though nuclear power is a good source of energy and is not generally a threat, a major reactor accident can lead to a catastrophe for people and the environment. The major health and environmental threat would be due to the escape of the fission products into the atmosphere.

There have been instances of nuclear reactor accidents like the heavy water cooled and moderated reactor at Chalk River in Canada in 1952, the graphite moderated gas cooled reactor at Sellafield in Britain in 1957, the boiling water reactor at Idaho Falls in US in 1961, the pressurized water reactor on Three Mile Island in the US in 1979, the graphite moderated water cooled reactor at Chernobyl in Ukraine in 1986, the sodium cooled fast breeder reactor at Monju in Japan in 1995 (Makhijani, 1996) and the boiling water reactor at Fukushima Daiichi NPP in Japan following an earthquake and tsunami in 2011. Among them, Chernobyl and Fukushima completely changed the human perception of radiation risk.

On April 26, 1986, USSR suffered a major accident, which was followed by a extensive release to the atmosphere of large quantities of radioactive materials. An explosion and fire released huge quantities of radioactive particles into the atmosphere, which spread over much of the western USSR and Europe. The Chernobyl disaster was one of two maximum classified event (level 7) on the International Nuclear Event Scale (the other being the Fukushima Daiichi nuclear disaster happened in 2011) and was the worst nuclear power plant accident in history in terms of cost and the resulting deaths. The battle to contain the contamination and avert a greater catastrophe ultimately involved over 500,000 workers and cost an estimated 18 billion rubles. During the accident itself, 31 people died, and long-term effects such as cancers and deformities are still being accounted for. Unfortunately, the other severe accident happened on March 11, 2011; a powerful earthquake (magnitude 9.0) hit off the east coast of Japan. A tsunami triggered by the earthquake surged over the east coast of the Tohoku region, including Fukushima. The Fukushima Daiichi NPP's cooling ability was lost and reactors were heavily damaged. Owing to controlled venting and an unexpected hydrogen explosion, a large amount of radioactive material was released into the environment. Consequently, many residents living around the NPP were exposed to radiation. In almost every respect, the consequences of the Chernobyl accident clearly exceeded those of the Fukushima accident. In both accidents, most of the radioactivity released was due to volatile radionuclides (noble gases, iodine, cesium, and tellurium) (G.Steinhauser, A. Brandl, T. E. Johnson, 2014).

Unfortunately, Turkey is surrounded by the world's oldest designed and threatening nuclear power plants: Kozloduy in Bulgaria, Metsamor in Armenia, Paks in Hungary, Dukovany in the Czech Republic, Bohunice in Slovakia, and Ignalina in Lithuania of which the first three are the closest ones. In addition, Turkey has plans to generate electricity from nuclear power plants in the near future; intergovernmental agreements on the construction of NPPs in the Akkuyu and Sinop sites were signed between the Russian Federation and Japan in 2010 and 2013, respectively. Having been seriously affected by the Chernobyl and Fukushima nuclear accidents, the countries with nuclear power plants have been made aware of the significance of having emergency preparedness systems and prediction tools for radiological effects. Those countries have signed agreements for the early notification and exchange of information in the case of nuclear accidents, and mutual agreements with close countries having nuclear programmes, as well. Furthermore, they have established good monitoring systems that are able to detect any increase in a timely manner. Capable computer codes were also developed in the nuclear emergency preparedness area. These codes have the capability to perform not only radiological consequences and risk estimates, but also cost estimation of the accidents to help in the decision making process. The effort to develop the Environmental Emergency Preparedness System started in 1999 in Turkey. The system, which is to predict the activity concentrations in the air and on the ground in the case of any nuclear emergency in the country or abroad, has already included calculation of long-range atmospheric transport and dispersion, and trajectory prediction. A nationwide monitoring system had already been developed in 1986 and has been operational since then.

1.2. The Context

The objective of the study is to develop a radiological dose model for accidental atmospheric release of radionuclides from a nuclear facility, which has been coupled with a long-range atmospheric transport and dispersion model. The research in this study is based on (i) atmospheric dispersion of radionuclides, (ii) dose and risk model development, (iii) validation of the model and (iv) an uncertainty and sensitivity analyses.

Models to represent the transport of radionuclides following atmospheric tests of nuclear weapons were developed during the 1950s and 1960s. Though radionuclides have been released into the environment during routine operational conditions of nuclear facilities, accidents and nuclear weapons tests, the model that was developed for this study was planned to predict radiation doses and risks in the case of a nuclear accident. In this study, only the accidental release of radionuclides was focused on, since the uncertainty analysis, which is a part of the software developed, makes sense for high activities observed solely in the accidental conditions. For routine release conditions, uncertainties are relatively small.

The novelties in this study are to couple a dynamic dose and risk model with a long-range atmospheric transport model to predict the radiological consequences due to accidental releases, and to perform the model simulation for NPP sites in Turkey and with Turkey specific data as far as it can be acquired. Most of the mechanisms and phenomena considered in each of the existing dose and risk calculation and environmental transfer models have been compiled in the newly developed single software to lead detailed modeling. An uncertainty and sensitivity analysis are also part of the study to determine the most influential parameters and their uncertainties on the results.

A huge amount of data, such as radioactivity concentration in foodsuffs, pasture and doses, regarding the consequences of nuclear power plants' accidents in literature was used for model development and its validation.

1.3. The Novelty of the Thesis

The main features of this software and study can be summarized as follows.

- Exposure from all pathways is included.
- Ingestion pathways are modeled in such a detailed way that, translocation, transfer between soil-plant, and feed-animal, food processing and storage, weathering, and dilution in the plant are all taken into account.
- Time dependency in radionuclide transfer in the environment considering food harvesting, sowing times, feeding regimes, and the growing up of a person are all taken into account.
- Individual doses for maximum and average individuals and for four age groups are calculated.
- Doses in the case of implementation of countermeasures are calculated.
- Collective doses for big cities can be calculated.
- Two different methods for stochastic risk modeling are applied.
- A probabilistic module has also been developed; namely, uncertainty analysis can be performed.
- Sensitivity analysis is also part of the study.

This study is regarded as unique since;

- The model algorithm, which the software developed for this study was based on (Müller, H. and Pröhl, G., 1993), has been modified;
  - to be able to calculate inhalation doses from resuspension, individual doses in terms of both average and maximum habits, collective doses and late risks, and
  - to utilise the recent knowledge in the dose and risk assessment area to the extent possible, such as dose conversion factors and risk coefficients etc.
- The long-range transport model, which the software developed for this study was coupled with, was also upgraded to increase the number of pollutants modeled to provide us easiness.
- Besides, extensive uncertainty and sensitivity analyses associated with 96 parameters have been performed for this study.

- Furthermore, with these features this software can be used as a part of the Turkish real time dose assessment system. The meteorological module in the existing environmental emergency response system is associated with 3-day-ECMWF forecast meteorological data acquired through the State Meteorological Directorate. The dispersion model is the HYSPLIT model that has the capability to predict trajectories, concentration, and deposition patterns in the case of nuclear accidents. However, doses, risks, and activities in the food chain are not calculated with the existing system in Turkey. Since the newly developed software for this study is compatible with the existing system's dispersion code, it can easily be integrated to it.

1.4. Organization of the Thesis

The thesis consists of five chapters and two appendices.

- Chapter one introduces the context and defines the research subject with its scope and objectives.
- Chapter two reviews related research on the dose and risk calculation models and the methodologies, uncertainty, and sensitivity analysis.
- Chapter three describes the dose and risk model developed for this study, its validation, the methodology chosen for coupling this model to a long range transport model, case studies for the Sinop and Akkuyu NPP using the newly developed model, and the uncertainty and sensitivity analysis performed for the Akkuyu case study in detail.
- Chapter four is devoted to the results on the validation of the code, the case studies, and the uncertainty and sensitivity analysis. Results on the case studies are presented for two different cases respectively; results on the uncertainty and sensitivity analysis are given only for the Akkuyu NPP case study.
- Chapter five presents the conclusions of the study and summarizes the contribution of this research. Possibilities for further investigation are also provided in this chapter.

After the bibliography, in the Appendix A the source code of new program is given in CD. Appendix B, which consists of the atmospheric dispersion, activity, dose and risk calculation results of hypothetical accidents at Akkuyu and Sinop NPP occurring at different times, is presented.

CHAPTER 2

RELATED RESEARCH

2.1 Background Overview

This chapter includes literature review of atmospheric dispersion models, dose and health risk modeling, and sensitivity and uncertainty analysis.

2.2. Atmospheric Dispersion Models

Numerous radiation dose calculation tools have been developed over the years. They calculate trajectories, atmospheric transport and dispersion, age-dependant radiation doses, early and late health risks, monetary costs of the accidents, doses in the case of implementation of emergency actions, collective health risk, uncertainty analysis etc. Atmospheric dispersion methods in these tools can be based on simple Gaussian or numerical approaches.

Short-range dispersion models usually use straight-line Gaussian plume model. These models are appropriate if the release is from a source that has dimensions, which are small compared to the distances at which concentrations are to be estimated. For example, for the distances out to 5-10 km from the source point, if the terrain is relatively flat and has uniform surface conditions in all directions and if the atmospheric conditions at the time and location of the release completely control the transport and diffusion of material in the atmosphere short-range atmospheric dispersion models are preferred.

Gaussian dispersion equations should not be used to estimate concentrations further than 80 km from the source under ideal conditions of flat terrain and no spatial variations of the wind field. Consequently, for a countrywide dispersion simulation, due to topography and dispersion area, the straight-line Gaussian models can not be appropriate tools. Therefore, long-range atmospheric dispersion models are used in this study.

Dose assessment methodology in some aforementioned short range codes neglect ingestion pathway and calculation of doses in the late phase of the accident. These are coupled with simple radiation dose modeling algorithm including only inhalation and external radiation pathways i.e. HotSpot, RASCAL and RTARC (Homann, S. G., 2010, Mcguire, S. A., Ramsdell, Jr., J. V. and Athey, G. F., 2007, Stubna M. and Kusovska Z., 1993). All radiation dose exposure pathways can be seen in Figure 2.1. Since short-range codes generally calculate short-term doses incurred immediately after the accident and recommend emergency protective actions, such as intervention, sheltering and iodine pills, and long-term effects incurred from ingestion pathway are not generally calculated with these types of codes. Some of the codes having Gaussian plume methodology calculates ingestion doses but not in a dynamic or comprehensive way for real time releases, i.e. GENII (Napier 2002).

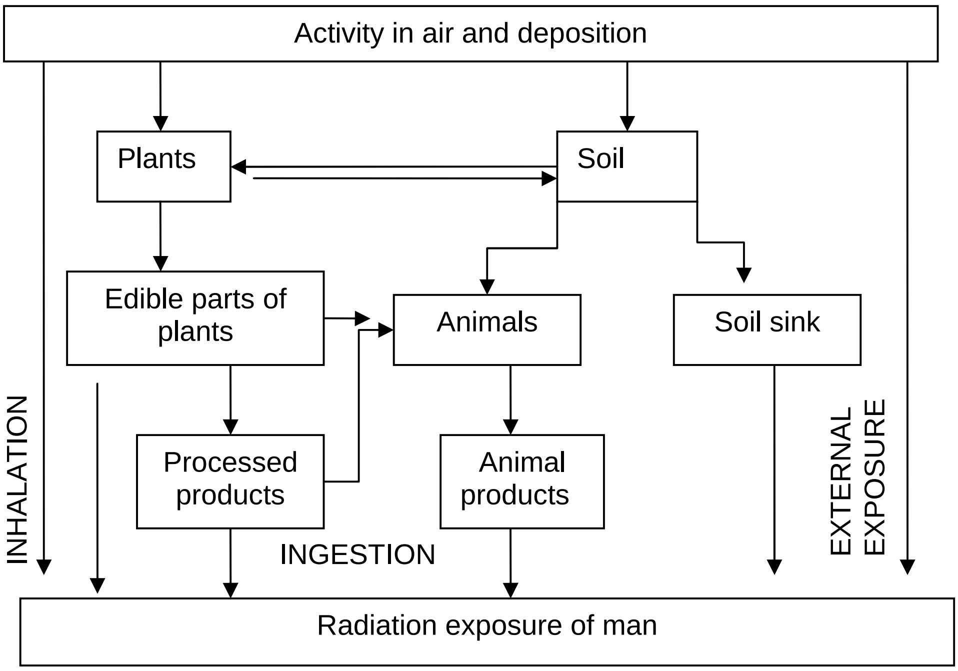

Figure 2.1. Radiation Dose Exposure Pathways

Long-range atmospheric transport models, on the other hand, generally focus on calculation of the trajectories, atmospheric transport and dispersion, and are used for real time emergency preparedness purposes. These are three-dimensional models, which use lagrangian, and eulerian approaches. These numerical models use multiple wind measurements in both the horizontal and vertical directions, and include terrain effects and vertical and horizontal wind shear. They also treat the parameter variables more realistically, such as surface roughness, deposition and variable atmospheric stability. Numerical modeling is widely used to study long-range airborne transport and deposition of radioactive matter after a hypothetical accident. Eulerian models solve the advection-diffusion equation on a fixed grid; whereas advection and diffusion components are calculated independently in Lagrangian models. When complex emission scenarios are considered, Eulerian methods are generally used, requiring solutions at all grid points. Lagrangian methods are typically favored when single point source emissions restrict computations to a few grid points. Furthermore, Eulerian models generally require emissions to be defined on a scale comparable to the models computational grids, whereas Lagrangian models can define the emissions at any resolution. Both methods have been applied successfully to lots of different scenarios. HYSPLIT, Ladas, Mesos and Derma are those having long-range atmospheric transport and dispersion algorithm (Draxler, R.R., and G.D. Hess, 1997, Suh et al., 2006, 2008, 2009, Apsimon, H.M.; Goddard, A.J.H.; Wrigley, J., 1985 and Sørensen, 1998; Sørensen et al., 2007). Generally, these types of long-range dispersion codes are integrated with environmental transfer models to predict activity in the environment and the resulting doses.

Long-range transport models have been selected to be used in this study, as long-range dispersion modeling is better to depict the wide scale of the radiological effects of nuclear accidents. The long-range transport code has been upgraded to calculate activities in the environment, human doses and risks in the case of nuclear accidents, by the usage of detailed environmental transfer modeling.

2.3. Radioecological Models

Two general classes of radioecological models have evolved; dynamic (transient) and equilibrium (steady state). Both describe the environment in terms of various “compartments” such as plant types, animal food products’ types and soil layers. Some environmental media may be described in terms of more than one compartment, such as the roots, branches and trunk.

When the equations are evaluated for sufficiently long times with unvarying values of the inputs and rate constants, the ratios of the concentrations of the radionuclides in the various compartments approach constant values. The system is then considered to be in equilibrium or in a steady state. These “quasi-equilibrium models” do not account for changes in plant biomass, livestock feeding regimes, or in growth and differential uptake of radioactive progeny during food chain transport. They are generally not appropriate for the assessment of critical short-term impacts from acute fallout events that may occur during the different times of the year and for applications related to the development of criteria for the implementation of actions.

In the late 1970’s the dynamic radioecological models started to emerge and led to a number of different such models. Since dynamic food chain transport models themselves are normally rather complex and require significant computing times most of the codes (e.g. Slaper et al., 1994, Hermann et al., 1984, Napier et al., 1988) neglect radiation exposure changes due to seasonal variations of radionuclides in the environment and human behaviors. For more realistic dose calculations, time dependency of the radionuclide transfer processes should be taken into account, leading to a dynamic modeling. Lots of radioecological data is necessary for dynamic ingestion pathway modeling. After the significant parameters are determined with respect to their effects on the results by sensitivity analysis these data may be derived locally to lead to realistic modeling. PARATI, PATWHWAY, Ecosys-87, SPADE (quasi-equilibrium), COMIDA and DYNACON are some dynamic dose models for modeling environmental transfer of radionuclides in the food chain (Rochedo et.al. 1996, Whicker and Kirchner, 1987, Müller, H., Pröhl, G., 1993, Johnson and Mitchell, 1993; Mitchell, 1999, Abbott, M.L., Rood, A.S., 1993, Hwang, W.T., Lee, G.C. Suh, K.S. E.H.Kim, Choi, Y.G. Han, M.H., Cho,G.S., 1998). Since equilibrium in the model compartments (between vegetation, soil, and animal products) is not reached for a long time, it is essential to consider seasonality in the growing cycles of crops, feeding practices of domestic animals, and dietary habits. However, because of the temporal resolution demanded for the output, a great deal of information is required as input to this type of model, and extensive computer resources are required for the implementation. By using assumptions of quasi-equilibrium (that is, relatively small changes from year to year in local conditions), the dynamic models may be simplified into equilibrium models. The equilibrium models lose the ability to answer certain temporally based questions, but are generally simpler to use, because many of the detailed rate constants required by the dynamic models can be treated as lumped parameters.

Knowledge of the contamination level of radionuclides in foodstuffs including crops and animal products is essential information for deciding the implementation of protective actions. The degree of contamination can be evaluated through a model prediction from the amount of radionuclides deposited on the ground, as well as through direct measurements of radionuclides in foodstuffs. In developing systems for emergency preparedness as well as providing for rapid decision-making relating to foodstuffs, the characterization of action plans based on model predictions are likely to be appropriate. In the case of short-term deposition of radionuclides after a nuclear accident, the radionuclide concentration in foodstuffs is strongly dependent on the date (or season) when the deposition occurs, and on the time after the deposition due to factors such as crop growth and biokinetics of radionuclides ingested by the animals. Therefore, these dynamic environmental transfer models are generally implemented in a real time emergency or decision support systems, which are used before and during an ongoing emergency and provide sound basis countermeasures. For example, DYNACON was developed to be implemented in a Korean real-time dose assessment system FADAS (Following Accident Dose Assessment System). Food chain module of decision support systems, RODOS and ARGOS (http://www.rodos.fzk.de/, http://www.pdc-argos.com/), are mainly based on radioecological model Ecosys-87. COMIDA was developed to be implemented in the new Department of Energy (DOE) version of the MELCOR Accident Consequence Code System for evaluation of accidental releases from nuclear power plants (Sandia National Laboratory, 1990).

Some codes can model only a few nuclides, such as DYNACON (Hwang, W.T., Lee, G.C. Suh, K.S. E.H.Kim, Choi, Y.G. Han, M.H., Cho,G.S., 1998), some only can produce outputs of radioactivity concentration in plants or animal products, not the doses such as FARMLAND, COMIDA and DYNACON (Brown, J. and Simmonds, J., R.,1995, Abbott, M.L., Rood, A.S., 1993, Hwang, W.T., Lee, G.C. Suh, K.S. E.H.Kim, Choi, Y.G. Han, M.H., Cho,G.S., 1998). A few can also calculate the risks, for example RESRAD and RODOS (ANL/EAD-4, 2001, http://www.rodos.fzk.de); the food chain model of which is based on Ecosys-87. In some radioecological models, such as

COMIDA, CRLP and TERNIRBU (Brown, J. and Simmonds, J., R.,1995, Krcgewski P.,1989, Kanyar, B., Fulop N., TERNIRBU, 1996) soil compartment is modeled in such a way that it is divided into many layers: surface layer, root layer, and deep soil layer, etc.

The code developed for this study took Ecosys-87 model as reference. The differences from Ecosys-87 were stated in Chapter 1.3. The data library for 53 isotopes is avalaible in the new software. All natural phenonema important for ingestion pathway modeling is taken into consideration in the new model. Whereas, time dependent translocation, layered soil compartment, wet interception, and mushroom pathway are not avaliable in the current model. Detailed informaton is given in Chapter 3.1 and 3.2.

Generally, the computer models developed for the prediction of routine releases from NPPs are based on the annual average concentrations of radionuclides in air and on the ground. However, for NPP routine atmospheric releases a dynamic model coupled with a long-range transport code was developed in another study (Kocar, C., 2003). In that study, to address the unique features of modeling operational radiological consequences of nuclear power plants, a new software based on the dynamic radio-ecological model (Müller, H. and Pröhl, G., 1993) was coded. Different from aformentioned dynamic model (Müller, H. and Pröhl, G., 1993), transfer mechansims of C-14 and H-3 were coded and multi-location food supply and interregional moves of people in the computational domain were permitted.

Main differences between this study and the previous one, which are both based on Ecosys-87, are as follows;

- In this study, accidental releases are simulated, but the previous one is for operational releases
- H-3 and C-14 releases which are of great significance for operational releases are modeled in the previous one,
- Uncertainty analysis which is meaningful for high doses incurred as a result of an accident, is part of this study,
- In this study, inhalation doses from both passage of the cloud and resuspension of deposited activity are calculated, whereas in the previous one, only inhalation dose from the cloud passage is calculated,

- In this study late risks are calculated with both USEPA FGR-13 and ICRP-103 coefficients, on the other hand in the previous study, risks are calculated only with USEPA FGR-13 risk coefficients,
- In this study individual doses are calculated for two different habits of the people in term of food consumption and gamma reduction
- Sensitivity analysis is also part of this study, whereas it is not part of the previous study.

2.4. Health Risks

Radiation health effects are classified as deterministic effects and stochastic effects, which are referred to as early effects and late effects, respectively.

Rapid and noncompansetable cell death at high doses leads to early deleterious radiation effects that become evident within days or weeks and in the close proximity of the accident site are known as “deterministic health effects”. In Table 2.1, some acute effects of radiation are indicated with the dose range values of their occurrences and time of death after exposure (Hobbie, K., 1997).

Table 2.1 Acute Effects of Radiation (Hobbie, K., 1997)

Acute effects	Occurrences within the range of dose	Time of death after the exposure
Cerebrovasculer syndrome	100 Gy	24-48 hrs
Gastrointestinal syndrome	5-12 Gy	Days later
Bone marrow death (hematopoietic syndrome)	2.5 –5 Gy	Weeks later

In this study, deterministic risks were not studied, since these effects can only be observed in very close vicinity and very early phase of the accident, which are not considered in our model.

Lower doses and dose rates don’t produce these acute early effects, because the available cellular repair mechanisms are able to compensate for the damage. These late effects, cancer induction and hereditary defects are known as “stochastic health effects”.

It is a common practice to estimate the cancer risk from intake of a radionuclide or external exposure to its emitted radiations as the simple product of a "probability coefficient" and an estimated "effective dose" to a typical adult. A nominal cancer fatality probability coefficient of 0.04 Sv^{-1} is given in ICRP 103 for all cancer types combined and given in Table 2.2. This value is referred to as nominal because of the uncertainties inherent in the radiation risk estimates and because it is based on idealized population receiving a uniform dose over the whole body. The risk estimates of ICRP 103, as well as in the previous ICRP recommendations, are based on the the quantity that links dose with radiation induced risk, and is called the risk coefficient. It depends on age, sex and organ or tissue, respectively. For estimating the risk coefficients, the ICRP 103 uses a model based on weighted incidence data from epidemiological studies (especially the studies on atomic-bomb survivors) instead of weighted mortality data as in ICRP 60. When a tumor is diagnosed, the weighting procedure takes into account the probability of survival, the loss of life expectancy and loss of quality of life. The resulting relative contributions of the various organs give the tissue-weighting factors for the effective dose. The calculated so-called nominal risk coefficients of ICRP 103 are about 25% lower than the previous estimates from ICRP 60 (1990). There are two main reasons for these changes. Firstly, the cancer risk estimates in 2007 were derived from the incidence data, while in 1990 mortality data was used for derivation. It was believed that, the use of incidence data was more reliable, because the incidence is more certainly diagnosed whereas in the case of mortality, cancer may be the underlying cause of death, but not the primary cause and some cancers may be missed in the reporting. The mortality fraction of cancers is also thought to be more certain when derived from initial incidence data. Secondly, there was a major revision of the estimates of hereditary diseases induced by radiation exposure. The major results were that the total hereditary risk is 0.3-0.5 % /gray for the first generation after irradiation. This is less than one tenth of the risk of fatal carcinogenesis following radiation exposure. Since it is now believed taking some hundreds of generations for defects to reach equilibrium, the risk to the first few generations is still about 10 % of the carcinogenic risk to the parents. (NEA/OECD, 2011)

This simple set of average risk coefficients is appropriate for regulatory purposes and generic system of radiation protection (HPA, 2009). ICRP argues that its nominal risk coefficients should apply to the whole population not to the individuals. It is noted by the ICRP that the differences exist in risks to males and females and that age-at-exposure can also have an impact on the risk. While presenting risk data specific for male and female, sex and age-averaged risk coefficients are continue to be recommended.

Table 2.2. Nominal Probability Coefficients for Stochastic Effects (Sv^{-1}) ICRP-103

Effect	Cancer	Severe hereditary effects	Total
Adult	$4.1x10^{-2}$	$0.1x10^{-2}$	$4.2x10^{-2}$
Whole	$5.5x10^{-2}$	$0.2x10^{-2}$	$5.7x10^{-2}$

USEPA FGR-13 risk coefficients are age and gender averaged. Absorption types for particulate aerosols are considered as in ICRP 72 (1996) for inhalation risk coefficients. For particulates of which the absorption types were not critically reviewed by ICRP the highest risk conversion value is applied.

The USEPA risk coefficients are characterized as the best estimate values of the age-averaged lifetime excess cancer incidence risk or cancer fatality risk per unit of intake or exposure for the particular radionuclide. These risk coefficients are estimates of risk per unit of exposure to radiation or intake of radionuclides that use age-and sex specific coefficients for individual organs, along with organ-specific dose conversion factors. Detailed information on the derivation of USEPA risk coefficients and their usage can be found in many USEPA documents (USEPA 1989, 1991, 1994, 1997 and FGR-11). The risk coefficients given in USEPA FGR-11 apply to an average member of public, in the sense that estimates of risk are averaged over the age and gender distributions of a hypothetical population whose survival functions and cancer mortality rates are based on recent data for the U.S. Specifically, the total mortality rates in this population are defined by U.S. cancer mortality data for the same period. This hypothetical population's gender-specific birth rates and survival functions are assumed to remain constant over time. For a given radionuclide and exposure pathway, mortality and morbidity risks are calculated as in the case of dose calculations, where proper risk coefficients are used in lieu of dose conversion factors in the equations. A mortality risk coefficient is an estimate of risk to an average member of the US population, per unit activity inhaled or ingested for internal exposure or per unit time-integrated activity concentration in air or soil for external exposure, of dying from cancer as a result of intake of radionuclide or external exposure to its emitted radiations. A morbidity risk coefficient is a comparable estimate of the average total risk of experiencing a radiaton related cancer, whether or not the cancer is fatal. Total mortality and total morbidity for four age groups are calculated as demonstrated in Equation 2.1 and Equation 2.2, respectively.

$$Mortality_{total} = Mortality_{inhalation} + Mortality_{ingestion} + Mortality_{cloudshine} + Mortality_{groundshine} \quad (2.1)$$

Mortality $_{total}$; total mortality risk

Mortality $_{inhalation}$; inhalation mortality risk

Mortality $_{ingestion}$; ingestion mortality risk

Mortality $_{cloudshine}$; cloudshine mortality risk

Mortality $_{groundshine}$; groundshine mortality risk

$$Morbidity_{total} = Morbidity_{inhalation} + Morbidity_{ingestion} + Morbidity_{cloudshine} + Morbidity_{groundshine} \quad (2.2)$$

Morbidity $_{total}$; total morbidity risk

Morbidity $_{inhalation}$; inhalation morbidity risk

Morbidity $_{ingestion}$; ingestion morbidity risk

Morbidity $_{cloudshine}$; cloudshine morbidity risk

Morbidity $_{groundshine}$; groundshine morbidity risk

2.5. Uncertainty and Sensitivity Analyses

Uncertainties of model predictions are resulted from variety of sources, for instance simplification of reality within a model, uncertainties of model parameters (due to lack of knowledge and variability of natural processes), or uncertainties of input data describing the contamination of air, deposition, etc. The input parameters of a model are always affected by uncertainties coming from different sources. If an input parameter has an uncertainty and this uncertainty will propagate through the output; then the output is influenced by this uncertainty, as well. Models have in general several (many) input parameters that are uncertain and those uncertainties will propagate through the models and affect the output uncertainty. This type of uncertainty is called parameter-driven uncertainty and it is this one (and the related parameter sensitivities) that was addressed in this thesis study. Uncertainty analysis involves specifying uncertain parameters, upper and lower bounds, and probability distributions for uncertain parameters specified, sampling sets of values from those distributions and propagating them through the model to give information on the uncertainty in the model outputs. Those parameters whose uncertainties make major contributions to the overall uncertainty can then be identified using correlation coefficients between the input values and the model outputs.

Uncertainty analysis is very often followed by sensitivity analysis. It is not unusual that confusion arises between the two analyses. There is a necessary distinction between uncertainty and sensitivity analyses in such a way that uncertainty analysis involves parameter importance and sensitivity analysis is used for understanding parameter sensitivity. An important parameter is always sensitive because parameter variability will not appear in the output unless the model is sensitive to the input. A sensitive parameter, however, is not necessarily significant to add uncertainty in the results, since it may be known precisely.

Sensitivity analysis involves manipulating model input values and quantifying the resulting impact on some model end point. Sensitivity analysis are conducted for many reasons by the modelers, including the need to determine: (1) which parameters require additional research for strengthening the knowledge base, thus reducing the uncertainty in the output; (2) which parameters are not important and can be removed from the final model; (3) which inputs contribute most to output variability; (4) which parameters are most strongly correlated with the output; and (5) once the model is in production use, what consequence results from changing the value of input parameter. There are many different ways of performing sensitivity analysis; however, in answering these questions these various analyses may not produce identical results (Iman and Helton, 1988). The methods for sensitivity and uncertainty analysis are based on either deterministic or probabilistic procedures also called local and global methods respectively.

2.5.1. Deterministic Techniques

If the model is too complex to be run in a Monte Carlo fashion, then a deterministic approach to sensitivity studies is more common. One may run the model a few times with different parameter combinations varying one at a time for a crude analysis of their impact on the output, or one may use adjoint methods to study the impact of the parameter space through examination of the derivatives of those parameters. In this case, it is possible to obtain simultaneously the results and the influence of the parameters quantified by the information given by the partial derivatives.

i. Differential Sensitivity Analysis: A sensitivity coefficient is basically the ratio of the change in output to the change in input while all other parameters remain constant (Krieger et al., 1977). The model result while all parameters are held constant is defined as the 'base case'. Differential techniques are structured on the behavior of the model given a specific set of parameter values, e.g. assuming the base-case scenario is with all parameter values set to their mean. Differental analysis of parameter sensitivity is based on partial differentiation of the model in an aggregated form. It can be thought of as the propagation of uncertainties. Sensitivity analyses using partial differentiation techniques are computationally efficient (Helton et al., 1985); however, the effort required in solving these equations can be quite intensive.

ii. One-at-a-Time Sensitivity Measures: Conceptually, the simplest method to sensitivity analysis is to repeatedly vary one parameter at a time while holding the others fixed (Gardner et aI., 1980; O'Neill et aL, 1980; Downing et al., 1985; Breshears, 1987; Crick et aL, 1987; Yu et al.,1991). A sensitivity ranking can be obtained quickly by increasing each parameter by a given percentage while leaving all others constant, and quantifying the change in the model output. This type of analysis has been referred to as a 'local' sensitivity analysis (Crick et al., 1987) since it only addresses sensitivity relative to the point estimates chosen and not for the entire parameter distribution.

iii. Factorial Design: Factorial analysis involves choosing a given number of samples for each parameter and running the model for all combinations of the samples (Box *et al.,* 1978; Rose, 1983). The results obtained in this fashion are then utilized to estimate parameter sensitivity. The factorial design is easy to conceptualize, but its procedure can become quite intensive with larger models.

iv. The Sensitivity Index: Another simple method of determining parameter sensitivity is to calculate the output % difference when varying one input parameter from its minimum value to its maximum value (Hoffman and Gardner, 1983; Bauer and Hamby, 1991) which gives sensitivity index. Hoffman and Gardner (1983) advocate utilizing each parameter's entire range of possible values in order to assess the true parameter sensitivities. The sensitivity index can be calculated by using;

$$SI = \frac{D_{\max} - D_{\min}}{D_{\max}} \tag{2.3}$$

where D_{min} and D_{max} represent the minimum and maximum output values, respectively, resulting from varying the input over its entire range (Hoffman and Gardner, 1983).

v. Importance Factors: Downing et *al.* (1985) have introduced three importance factors. Their measures are calculated from data collected after a five-point one-at-a-time analysis; the model output is recorded for each parameter at its mean value, 4-2 standard deviations, and -t-4 standard deviations. The first importance factor is defined as parameter uncertainty (defined as two standard deviations of the input) multiplied by parameter sensitivity (defined as the change in the output divided by change in the input). The second is the positive difference in the maximum output value and the minimum output value. And, third, they estimate importance utilizing the output sample variance.

vi. Subjective Method: Another sensitivity method based on analysis of individual parameters is the subjective method (Downing *et al.,* 1985). The method is rather simple and only qualitative since it relies on the opinions of experienced investigators to determine, a priori, which parameters can be discarded due to lack of influence on model results. One advantage is that, for large models, where most other methods are impractical, the subjective method can be used as a first cut to reduce the number of input parameters to a manageable size.

2.5.2. Probabilistic Techniques (Parameter value sampling)

To this point, sensitivity has been assessed on individual parameters regardless of the combined variability resulting from considering all input parameters simultaneously. Random sampling (e.g. simple random sampling, Monte Carlo, Latin Hypercube, etc.) of input parameters generates input and output distributions useful in assessing model and parameter uncertainties in a 'global' sense. Simple random sampling (crude or Monte Carlo sampling) method implies that the input parameters of the model are sampled from probability density functions. The variance of the probability density functions of each parameter expresses the uncertainty on the respective input parameter. The model is run in a sequential way tens, hundreds or thousands of times with different sets of sampled parameters each time. Monte Carlo sampling techniques are entirely random, that is, any given sample may fall anywhere within the range of the input distribution. Samples, of course, are more likely to be drawn in areas of the distribution, which have higher probabilities of occurrence. Latin Hypercube Sampling (LHS) is a recent development in sampling technology designed to accurately recreate the input distribution through sampling in fewer iterations when compared with the Monte Carlo method. The key to LHS is stratification of the input probability distributions. Stratification divides the cumulative curve into equal intervals on the cumulative probability scale (0 to 1.0). A sample is then randomly taken from each interval or "stratification" of the input distribution. Sampling is forced to represent values in each interval, and thus, is forced to recreate the input probability distribution. With LHS, the samples more accurately reflect the distribution of values in the input probability distribution. It should be evident that LHS converges faster on the true distributions when compared with Monte Carlo sampling. After the sampling simulations have been performed using one of the sampling methods mentioned (simple random sampling, LHS etc.) post-processing analysis can be preceded. There are several statistical tests to identify the most important parameters and how to rank them.

i. Scatter Plots: Parameter sensitivity can be determined qualitatively by plots of input vs. output values or quantitatively by calculations of correlation coefficients or regression analysis. Scatter plots of input vs. output are useful for quick determinations of the degree of correlation and the linearity of the input/output relationship (Helton et al., 1986; Crick et al., 1987; Iman and Helton, 1988; Helton et al., 1991; Helton et al.,1993). They may also reveal unexpected relationships between input and output variables that can provide insight as to how other investigations (e.g. regression analysis) might be performed.

ii. <u>Importance Index</u>: Hoffman and Gardner (1983) have also introduced an 'importance index', I_i, which is equal to the variance of the parameter value s^2_{Xi}, divided by the variance of the dependent values s^2_Y.

$$I_i = \frac{S_{Xi}^2}{S_Y^2} \tag{2.4}$$

Where s refers to the variance of the raw data for additive models and to the variance of the log-transformed data for multiplicative models. This measure of importance is based on the paramemr's fractional contribution to total variability, or uncertainty. Variable importance is estimated by Cunningham et al. (1980) through the use of a combination of the fractional contribution to output variability and the resulting change in output given individual change in input.

iii. <u>Relative Deviation Method:</u> One sensitivity ranking method uses random sampling techniques and gives the amount of variability in the model output while changing each input parameter, one-at-a-time, according to its probability density function. This method is similar to the local sensitivity method; however a much larger sampling is made of the input distribution in this method. The sensitivity figure-of-merit is the 'relative deviation' (RD), the ratio of the standard deviation to the mean of the output density function (Hamby, 1993), and is similar to the coefficient of variation (standard deviation x 100 / mean). This method provides an indication of each parameter's contribution to the variability present in the model output and the extent of correlation between the model input and output, to a degree.

iv. <u>Relative Deviation Ratio:</u> Given two input distributions, one narrow and one wide, producing identical output distributions, a model will be more sensitive to the input parameter of the narrow distribution. Accordingly, this statistical method will be the ratio of the output distribution's relative deviation to the input distribution's relative deviation and is similar to the importance index proposed by Hoffman and Gardner (1983). A large value of this 'relative deviation ratio' (RDR) indicates that either the output distribution varies widely or that the input distribution is relatively narrow. Furthermore, information on the amount of variability added to the total output variability by the model itself is gained from this statistic. A value greater than 1 indicates that uncertainty propagated through the model is increased due to the model's structure and its high sensitivity to that variable of concern. An RDR of 1 indicates that all input uncertainty is passed through the model and appears as output uncertainty, whereas a value less than 1 indicates that the model is less sensitive to the parameter, thus contributing little to output uncertainty.

v. Rank transformation: One of the problems came accross in calculating test statistics, e.g. correlation coefficients, from raw data is that the data are not necessarily linear. A method of decreasing the effects of nonlinear data is to utilise the rank transformation (Iman and Conover, 1979). The transformation of raw data into ranks has been shown to work quite well if the dependent variable is a monotonic function of the independent variables (Iman and Conover, 1979). Rank transformation linearizes monotonic nonlinear relationships between variables and reduces the effects of extreme values (Helton and Iman, 1982). This transformation converts the sensitivity measure from one of linearity to one of monotonicity.

vi. The Partial Correlation Coefficient: Strong correlations between input parameters may influence input/output correlations. Partial correlation coefficients (PCC) are calculated to account for correlations among other input variables (Gardner et aI., 1980; Gardner et al., 1981; Iman et al., 1981a; Iman and Conover, 1982; Otis, 1983; Downing et al., 1985; Iman and Helton, 1985; Breshears, 1987; Whicker and Kirchner, 1987; Iman and Helton, 1988; IAEA, 1989; Whicker et al., 1990; Iman and Helton, 1991; Helton et al., 1993). Given random variables X_1 and X_2 as input and the output variable Y, a partial correlation coefficient is a measure of the correlation between X_1 and Y, for example, while eliminating indirect correlations due to relationships that may exist between X_1 and X_2 or)/2 and Y. The PCC is defined as (Conover, 1980);

$$r_{X_1Y|X_2} = \frac{r_{X_1Y} - r_{X_1X_2} r_{X_2Y}}{\sqrt{\left(1 - r^2_{X_1X_2}\right)\left(1 - r^2_{X_2Y}\right)}} \quad (2.5)$$

The notation $rX_1Y \mid X_2$ represents the partial correlation coefficient for X_1 and Y while accounting for the affects of X_2. The parameters of the generic model considered in this report are assumed independent and no correlations have been assigned,

i.e. $r_{X1X2} = 0$. Therefore, $rX_1Y \mid X_2$ reduces to

$$r_{X_1Y\ |X_2} = \frac{r_{X_1Y}}{\sqrt{\left(1 - r^2 X_2 Y\right)}} \quad (2.6)$$

where, again, X_1 and X_2 represent any two input variables and Y represents the output variable. The square of the partial correlation coefficient is useful in determining the percentage of variability in Y accounted for by variability in X_i (Gardner *et al.,* 1981). Sensitivity rankings based on the relative values of the partial correlation coefficients will not change from the rankings determined based on the simple correlation coefficients. Therefore, with no correlations existing between input parameters, there is no need for calculating partials to determine sensitivity rankings. The rank transformation can also be applied to partial correlation as a test of monotonicity between input and output variables while accounting for relationships between input parameters. The partial rank correlation coefficient (PRCC) is widely utilized for sensitivity studies (Iman *et al.,* 1981a, b; Crick *et al.,* 1987; Iman and Helton, 1988; IAEA, 1989; Iman and Helton, 1991). Downing *et al.* (1985) compared parameter sensitivity rankings determined using partial rank correlation with orders from their three importance rankings (see section above on Importance Factors). They report the PRCC to be more powerful at indicating the sensitivity of a parameter that is strongly monotonic yet highly nonlinear.

vii. Pearson's r: A quantitative estimate of linear correlation can be determined by calculating a simple correlation coefficient on the parameter values of input and output. Gardner et al. (1981) recommend using simple correlation coefficients, derived from Monte Carlo simulations, as a reasonable way to rank model parameters according to their contribution to prediction uncertainty. Pearson's product moment correlation coefficient is denoted by r and is defined as;

$$r = \frac{\sum_{j=1}^{n}\left(X_{ij} - \bar{X}_i\right)\left(Y_j - \bar{Y}\right)}{\left[\sum_{j=1}^{n}\left(X_{ij} - \bar{X}_i^2\right)\sum_{j=1}^{n}\left(Y_j - \bar{Y}\right)^2\right]^{1/2}} \tag{2.7}$$

for the correlation between X_i and Y (Conover, 1980). The larger the absolute value of r the stronger the degree of linear relationship between the values of input and output (IAEA, 1989). A negative value of r indicates the output is inversely related to the input. A linear regression on the data can be used to determine the correlation coefficient from the square root of the coefficient of determination, R^2. Major drawbacks of utilizing the correlation coefficient for sensitivity ranking include the inherent assumption that the input/output relationship is linear and the possibility that input parameters strongly correlated to one another may result in apparent input/output correlations (Hoffman and Gardner, 1983; Crick et al., 1987; IAEA, 1989). In addition, a large number of trials may prohibit hand calculations of the correlation coefficient.

viii. Spearman ñ: If the input/output relationships are monotonic then rank transformations of the input and output values (i.e. replacing the values with their ranks) will lead to linear relationships and the rank correlation coefficient will give the degree of monotonicity between the input and output values (IAEA, 1989). The rank correlation coefficient, or Spearman's rho, can be calculated utilising the equation for Pearson's r with the exception of operating on the rank transformed data (Iman and Conover, 1979).

ix. Standardized Regression Techniques: Standardization takes place in the form of a transformation by ranks or by the ratio of the parameter's standard deviation to its mean. The effect of the standardization is to eliminate the effect of units and place all parameters on an equal level. Standardized regression analyses are conducted by Iman and Helton (Helton et al., 1985; Iman and Helton, 1988, 1991). The calculation of a rank regression coefficient, i.e. standardization by the rank transformation, is a simple procedure requiring less computation. Utilizing means and standard deviations of input and output data sets (the standardized regression coefficient), however, are slightly more rigorous and achieved by:

$$\frac{\left(\hat{Y}-\bar{Y}\right)}{s}=\sum_{k}\left[\frac{b_k s_k}{s}\right]\frac{\left(Z_k-\bar{Z}_k\right)}{s_k} \qquad (2.8)$$

Where each Z_k is a function of (X_1 . . . . . X_n) , *s* is the standard deviation of the output, and s_k is the standard deviation of the input (Helton *et al.,* 1985, 1986). If each Z_k is a function of only one parameter in X, then the value of $b_k s_k X_s$ is the standardized regression coefficient for parameter X_k, where k = 1 to n. The PRCC estimated in the section above and the standardized regression coefficient are essentially the same when using ranks; the numerical values may be different but both exhibit the same pattern of sensitivity ranking (Iman and Helton, 1988).

x. Regression Techniques: Regression techniques are often used to replace a highly complex model with a simplified 'response surface' (Cox, 1977; Iman et al., 1978; Iman et al., 1981a, b; Helton and Iman, 1982; Downing et al., 1985; Kim et al., 1988; Iman and Helton, 1988; Helton etal., 1991). The response surface is simply a regression equation that approximates model output using only the most sensitive model input parameters. Stepwise regression procedures are utilized to ensure that the final regression model provides for the best fit of raw data (Iman et al., 1978; Iman and Conover, 1980; Iman et al., 1981b; Iman and Conover, 1982; Helton and Iman, 1982; Reed et al., 1984; Helton et al., 1985, 1986; IAEA, 1989; Iman and Helton, 1991; Zimmerman et al., 1991; Helton et al., 1991, 1993). The stepwise regression may involve higher ordered equations, quadratic terms, and parameters as functions of other parameters. Regression coefficients provide a means of applying sensitivity rankings to input parameters and have been used in several investigations (Iman and Conover, 1980; Iman et al., 1981b; Helton et al., 1985; Kim et al., 1988; Helton et al., 1986; Whicker and Kirchner, 1987; Whicker et al., 1990; Margulies et al., 1991; Zimmerman et al., 1991; Kleijnen et al., 1992; Helton et al., 1993). A model with lots of sensitive parameters may lead to a complex regression equation. Matrix techniques have been utilized in such cases to calculate the regression coefficients (Krieger et al., 1977).The generalized form of a simple regression equation is,

$$Y = b_o + \sum_k b_k Z_k \tag{2.9}$$

where each Z_k is a predictor variable and a function of (X_1 ..... X_n) and each b_k is a regression coefficient (Helton et al., 1985, 1986). The use of the regression technique allows the sensitivity ranking to be determined based on the relative magnitude of the regression coefficient. This value is indicative of the amount of influence the parameter has on the whole model. Because of units and the relative magnitudes of parameters, a standardization process is sometimes warranted, however.

xi. Sensitivity Tests Including Segmented Input Distributions: These statistical methods include dividing or segmenting input parameter distributions into two or more empirical distributions based on an associated partitioning of the output (Crick et al., 1987). The methods are used to compare the characteristics of the input distributions created by the segmentation. For instance, if a dose distribution is calculated and the median value of the distribution is chosen as the dividing point, all input values for the parameter in question associated with the calculation of a dose value below the median are said to belong to one random sample while the input values associated with dose estimates above the median belong to a second random sample. Means, medians, variances, and other characteristics of the independent random samples are statistically compared to determine whether the samples originated from the same population. Division of the output distribution can occur at any value or percentile, but should be based on the statistical question to be replied; e.g. 'Is the model more sensitive to the parameter when determining the mean value or when estimating maximum values'. If the input distributions produced by this process are statistically identical then the model is not sensitive to that parameter. Nonetheless, if the distributions are different then the output distribution is indeed affected by the input and the absolute value of the test statistic can be used to conduct the sensitivity ranking. Standard parametric tests are not reasonable on input data sets produced by random sampling techniques since knowledge of the input variables and their associated distributions are limited (Iman et al., 1981b). Nonparametric statistical tests, on the other hand, are used where the data are considered distribution-free (Conover, 1980). The four nonparametric statistical tests that include Smirnov, Cramer-von Mises, Mann-Whitney, and Squared Ranks are used to determine whether the null hypothesis can be accepted. The Smirnov and Cramer-von Mises tests compare empirical distributions with a null hypothesis of 'the distributions originate from the same population'. The Mann-Whitney test and the Squared Ranks test compare means and variances, respectively, of the empirical distributions. These test statistics are calculated for the sensitivity ranking purpose, however, and not for accepting or rejecting null hypotheses. The convention stated earlier, that Y is a function of $X(Y = f\{X_1, ..., X_n\})$, is no longer appropriate; a new notation is used and specified for each test. The following tests operate on ranks of the raw data. Tied values are assumed not to exist because the input and output values can be determined to several significant figures (although this feature does not necessarily reflect a high degree of precision). By exempting the possibility of ties, equations for calculating the test statistics are largely simplified (Conover, 1980).

A few of the sensitivity analysis techniques currently in the literature are recommended for rather complex or very large models and are only stated here: These cover structural identifiability (Bellman and Astrom, 1970) and methods using adjoint equations (Oblow, 1978), Fourier analysis (Cukier et al. 1973; Helton et al. 1991), and Green's functions (Demiralp and Rabitz, 1981).

In respect to sensitivity and uncertainty analyses, the sampled-based analyses; the Simple Monte Carlo and the Latin Hypercube techniques were preferred or found superior over the deterministic or local methods in radiological risk assessment and environmental protection (Pereira, A., Boraed, 2006). The deterministic method has shortcomings in evaluating the effect of simultaneous changes in a large number of input parameters on the model output results. The probabilistic method easily identifies the most sensitive parameters and considers variation in more than one parameter simultaneously. The choice of sensitivity analysis method depends on the availability of site-specific data. (ANL, RESRAD Offsite Code, EMRAS II, 2011)

CHAPTER 3

METHODOLOGY

3.1. Model Developed for this Study

A deterministic dose calculation model called as DoseCAL has been developed for this study. For the dose assessment, all exposure pathways have been implemented as follows:

- Transfer of radionuclides through food chains and the subsequent internal exposures of humans due to ingestion of contaminated foodstuffs.
- Internal exposure due to inhalation of radionuclides during passage of cloud and from resuspension of deposited radionuclides
- External exposure from radionuclides in the passing cloud
- External exposure from radionuclides deposited on the ground.

Developed software is implemented in Visual Basic. Editable parameters are number of radionuclides, latitude and longitude of the whole area modeled, size of each grid where calculations are done, concentration and deposition outputs of an atmospheric dispersion model or measured air concentration and deposition data in days, and time interval of dose calculation in days and in years. All model parameters are kept in external editable data files, so that they can easily be exchanged or modified without changing the program. Such an approach introduces flexibility to simulate different release conditions, environments, and numbers of feedstuffs and foodstuffs. Current software can perfrom modeling well for 53 isotopes, 23 grids, 70 years, 13 food stuffs and pasture, 8 animal products, 4 different age groups, i.e. infant, child, teen and adult, maximum and average individuals in terms of food consumption habits, correction coefficients for gamma dose rate and time spent outdoors. If the number of these parameters increases, the software may have computer memory limitations. The model can produce individual dose results annually for each isotope and pathway, and the sum for all isotopes and pathways as well, collective total dose results. The model can also produce monthly activity results in grass and animal food products, activity concentrations results of agricultural food products at each harvest year after the accident, and total risk results as well. External input data files include age dependant food consumption rates, breathing rates and reduction factors for external radiation for maximum and average individuals, feedstuff intake rate of animals, storage times and processing factors of food products, translocation factors for plants, plant yields, distribution coefficients and fixation rates of radionuclides, soil-plant and feed-animal transfer factors, biological transfer rate for animal products.

Fixed input parameters for DoseCAL are radioisotopes' decay time, age and pathway dependant dose conversion factors, and mortality and morbidity risk coefficients for each pathway and for each radionuclide.

Gridded concentration and deposition output values for each time step of HYSPLIT are used as initial input parameters to DoseCAL. DoseCAL can use the concentration and deposition values in the text files.

The design of the DoseCAL is flexible such that it can be adopted anywhere for any nuclear power plant site with suitable modifications to the database.

3.1.1. Code Structure

Code Algorithm: Code algorithm is given in Figure 3.1.

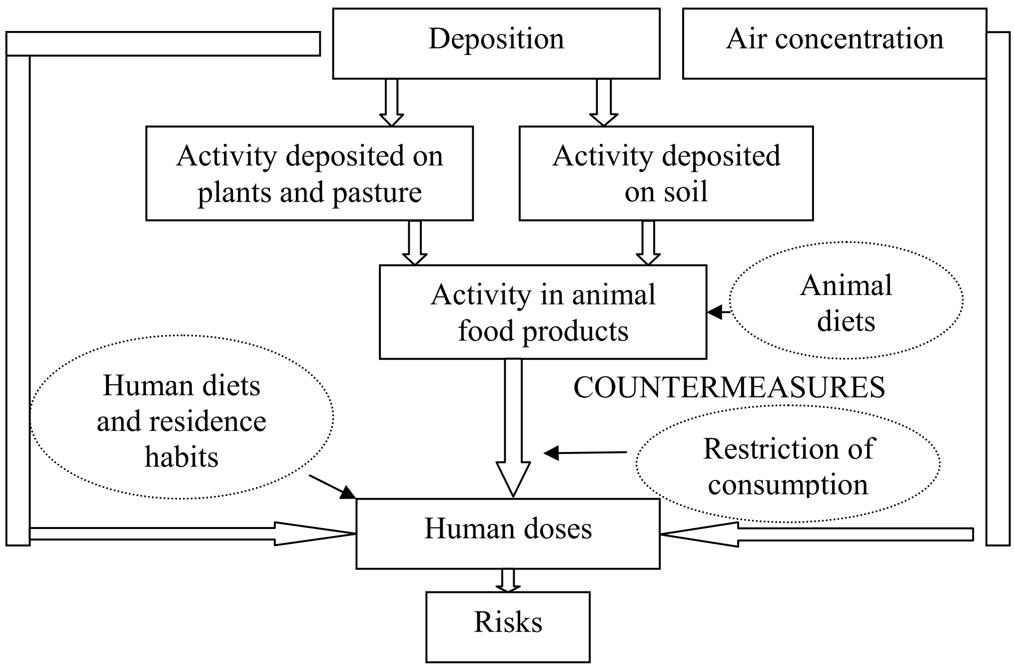

Figure 3.1. Code Algorithm

Input files: There are seven input files necessary to run DoseCAL:

1. Worksheet1;
    a. start and end date of simulation (in Julian days)
    b. simulation time (in years)
    c. size of grid space where the calculations are perfomed
    d. dimensions of each grid
    e. simulation time (in days) of atmospheric dispersion model or time interval (in days) of measurement data
2. Worksheet2;
    a. fixation rate, distribution coefficient, decay rate, DCF, RCF of radioisotopes,
    b. TF of grass, plants and animals for radioisotopes,
    c. biological turnover rate of radioisotopes for animals
3. Worksheet3;
    a. food consumption amount for each age group (maximum and average),
    b. breathing rate for each age group,
    c. reduction factor for shielding for each age group (average and maximum individual),
    d. growth dilution of grass,
    e. fraction of activity translocated to the root zone,
    f. interception fraction for grass and other plants,
    g. translocation for each plant,
    h. soil density,
    i. water percolation velocity
    j. weathering rate for grass and leafy vegetables,
    k. depth of root zone,
    l. storage times and processing factors for each foodstuff.
4. Worksheet4;
    a. population data of big cities,
5. Worksheet5;
    a. yields of different plants

    b. sowing, vegetation and harvesting times of different plants,
6. Worksheet6;
    a. montly feeding rates of each animal,
7. A text file;
    a. air concentration data (in days) of each grid for each isotopes,
    b. deposition data (in days) of each grid for each isotopes.

Output files: There are 11 output files produced by DoseCAL:

1. Extground Results: External ground dose (in Sv) for each grid for infant and others (max-avg.) age group for each radioisotope for each year after the accident,
2. Extcloud Results: External cloud dose (in Sv) for each grid for infant and others (max-avg.) age group for each radioisotope,
3. Inhalation Results: Inhalation dose and inhalation dose from resuspension (in Sv) for each grid for each age group for each radioisotope,
4. Ingestion Results: Ingestion dose (in Sv) for each grid for each age (max-avg.) group for each isotope for each year after the accident, and ingetsion dose (in Sv) incurred via consumption of each foodstuff,
5. Total Dose Results: Total dose (in Sv) for each grid for each age (max-avg.) group for each isotope for each year after the accident,
6. Foliar Activity: Activity concentration for each plant for each grid for each year after the accident,
7. AnimalProd Activity Results: Activity concentration for each animal food product and pasture for each grid for each month after the accident,
8. AgricProd Activity Results: Activity concentration for each plant for each grid for each harvest year after the accident,
9. ICRP-103 Late Risks: Cancer and hereditary risks for each age group and each grid,
10. FGR-13 Late Risks: Mortality and morbidty risks for each age group and each grid,
11. Collective Dose Risk: Collective dose, collective mortality and morbidity risks for each city for each age group.

User interface has not been developed, yet. An example output file for infant's external cloud dose, which is the output of Akkuyu accident case study, is given in Table A.1. Since DoseCAL is reading input parameters from six different worksheets and a text file, an example input file cannot be provided. Source code is given in CD in Appendix A.

Computer Requirements: This program requires Windows 95 or later, Microsoft excel 2000 or later, Pentium-compatible processor, 100 MB of disk space and 8 GB RAM of memory size. 2.5 GHz of CPU speed is sufficient. Average runtime of the program is 30 minutes depending on the input parameters.

3.2. Dose Calculation Algorithm in DoseCAL

3.2.1 Inhalation Pathway

Inhalation dose conversion factors for four age groups public are taken from ICRP 119 (2012). Dose conversion factors for 3 months old infant, 5 years old child, 15 years old teen and adult are used. ICRP inhalation dose conversion factors take into account integration period of 50 year for adults and 70 year for children. Inhalation dose coefficients are given for different lung clearnce types of particulate aerosols, i.e. slow, moderate and fast clearance. Absorption types for particulate aerosols are taken as recommended in ICRP 72 (1996) for these coefficients in DoseCAL. For particulates whose absorption types were not critically rewiewed by ICRP the highest dose conversion value is applied.

For internal exposure, the usual assumption is that daughter products produced in vivo adopts the absorption parameters of their parent, if they are produced in the respiratory or gastrointestinal tract, and the biokinetics of their parent, if they are produced after absorption to blood. In all cases, the dose coefficients corresponding to the intakes of the parent radionuclide include contributions from the parents and their daughters (ICRP 72, 1996). These aggregated DCFs correspond to ingestion or inhalation of the principal radionuclide together with its associated decay product radionuclides, which are assumed to be in secular equilibrium at the time of intake.

Inhalation from cloud and resuspension of deposited activity are both considered in DoseCAL.

Inhalation from cloud

Inhalation doses are calculated for each incremental time step (in days) of HYSPLIT simulation as follows:

$$D_{inh} = C_A.V_B.DC_{inh}.R_{inh} \quad (3.1)$$

D_{inh}; total inhalation dose (Sv),

C_A; time-integrated air concentration ($Bq.m^{-3}.d$),

V_B; age dependant breathing rate ($m^3.d^{-1}$),

DC_{inh}; age dependant radionuclide specific dose conversion factor for inhalation ($Sv.Bq^{-1}$),

R_{inh}; age dependant reduction factor for staying in different locations.

$$R_{inh} = F_{in}.c_{in} + F_{out}.c_{out} \quad (3.2)$$

F_{in} and F_{out}; fraction of time spent indoor and outdoor,

c_{in} and c_{out}; indoor and outdoor reduction factors.

Age dependant breathing rates, given in Table 3.1, are taken from ICRP 71 (1995b).

Table 3.1. Age Dependent Breathing Rates (ICRP 71, 1995b)

Age group	Infant	Child	Teen	Adult
Breathing rate ($m^3.d^{-1}$)	2.86	8.72	20.1	22.2

Inhalation from resuspension

Resuspension occurs when the wind exerts a force exceeding the adherence of particles to the surface material. The forces in action are the weight of the particle, the adherence and the aerodynamic loads related to the flow of wind. According to wind erosion models, three types of process are used to describe the dispersion of particular contaminants deposited on surface soil (Arger et. al, 1997, Anspaugh et.al, 1975, Van Heerden et.al, 1967), surface creep, saltation and (re)suspension. Another process for resuspension is the mixed effect of wind and rain on particle detachment. Rain splash transport of soil particles in windless conditions has been studied in detail. The overall result of these studies is that the contribution of rain splash transport alone is small compared with that of overland flow transport (Poesen, J., 1985, Wright, A.C., 1987, Langham, W.H., 1971). Following the accident after the cloud passage, air concentrations are assumed to be originated from resuspension. Resuspension factor approach was adapted to calculate the inhalation doses from resuspension in DoseCAL. Resuspension factor is the ratio between activity concentration in the air and initial surface concentration onto the soil. In HYSPLIT air concentrations are calculated already taking into account resuspension; i.e. default resuspension factor is 10^{-6} m^{-1}. (Draxler et.al, 2012) Therefore, when only measured data are used as input to DoseCAL, the aforementioned resuspension factor is applied in the model.

3.2.2. External Radiation Pathway

The radioactivity in air can also directly affect the population even if they do not inhale it or ingest the foods contaminated by the isotopes. This is referred to as external exposure and it can occur through exposure to the radioactive cloud or exposure to the activity deposited onto surfaces. Both of these pathways are included in the total dose acquired by humans. The relationships derived in literature were used in calculations of external dose. Radionuclide-specific dose coefficients for external irradiation from radionuclides distributed in the environment have not yet been published by the ICRP. These for radionuclides are taken from USEPA FGR-12 (USEPA, 1993). They apply for 5 years to adults. They are multiplied by correction factor of 1.5 for infant, which is 3-month-old age group. Therefore, doses incurred from external radiation pathways are calculated for two age groups, infants and all others.

External cloud doses are calculated for each incremental time step (in days) of HYSPLIT simulation as inhalation dose calculation. Cloudshine and groundshine doses are calculated as follows:

$$D_c = C_a.DCF_{cshine}.R_c \qquad (3.3)$$

D_c; total cloudshine dose (Sv),

C_a; time-integrated air concentration ($Bq.m^{-3}.s$),

DCF_{cshine}; age dependant cloudshine dose conversion factor ($Sv.m^3.Bq^{-1}.s^{-1}$),

R_c; reduction factor for staying at different locations.

$$R_c = \sum f_i.c_{c,i} \qquad (3.4)$$

f_i; age dependant fraction of time staying at location i,

$c_{c,i}$;correction coefficient for the gamma dose rate at location i relative to that in a semi-infinite homogenous cloud.

$$D_{gshine}(T) = GC(t).R_g.DC_{gshine}.\exp(-\lambda_r t) \quad (3.5)$$

$D_{gshine}(T)$; total groundshine dose (Sv) from gamma radiation of deposited nuclides from time of deposition up to time T,

GC(t); deposition to grassland ($Bq.m^{-2}$),

R_g; age dependant reduction factor for staying indoors,

y(t); corrective function for shielding,

DC_{gshine}; age dependant groundshine dose conversion factor ($Sv.m^2.Bq^{-1}.s^{-1}$),

λ_r; decay constant (d^{-1}).

Shielding due to migration of the radionuclides into deep soil is considered. The migration model and its constants are taken from Müller and Pröhl (1993). Radionuclide concentrations accumulated on the ground and corrected for decay are calculated by the following formula (Kocar, C. Sökmen, N, 2009):

$$GC(t_j) = GC(t_{j-1})e^{\lambda(t_j - t_{j-1})}(a_1 e^{\lambda_1 t} + a_2 e^{\lambda_2 t}) + GD(t_j) \quad (3.6)$$

GC = ground concentration at time step j (Bq m^{-2}),

GD = deposition output from atmospheric dispersion software at time step j (Bq m^{-2}),

λ_i = radioactive decay constant of the radionuclide i (d^{-1}),

t_j = time at jth step (day),

λ_1 = migration rate (λ_1 = 0.0046 d^{-1}),

λ_2 = migration rate (λ_2 = 0.0000387 d^{-1}),

a_1 = contribution fraction of the migration rate (a_1 = 0.36),

a_2 = contribution fraction of the migration rate (a_2 = 0.64).

Table 3.2. Correction Coefficients For External Exposure (Meckbach et.al., 1988)

Location		Cloud	Ground
Outdoors	Suburban	1.0	1.0
	Urban	0.6	0.3
Single family houses	Above ground	0.3	0.1
	Basement with windows	0.05	0.01
	Basement, no windows	0.01	0.001
Large buildings	Above ground	0.05	0.01
	Basement	0.001	0.0005

Table 3.3. Reduction Factors For Maximum and İndividual Doses for Different Age Groups		
	$R_{c,max}$	$R_{c,avg}$
Infant	0.33	0.10
Child	0.42	0.14
Teen	0.7	0.35
Adult	0.5	0.27

Reduction factors for external radiation given in Table 3.3 were calculated by making some assumptions regarding the time spent in different locations (i.e. suburban, large buildings, single-family houses) for each age group and multiplying these with the correction coefficients in Table 3.2, which are based on Meckbach and Jacobs 1988.

It is almost always reasonable to assume that secular equilibrium between parent and progeny is maintained both in the plume and following deposition, due to the short half-lives of the daughters (less than a few hours). External dose coefficients for the parent radionuclides of these four decay chains were obtained by multiplying the dose coefficient for the progeny by the decay-branching fraction and adding to the coefficient for the parent. The following daughter-parent decay chains are taken into account for external dose coefficients; Ru-106 & Rh-106, Te-132& I-132, Cs-137 & Ba-137m and Ce-144 & Pr-144/144m (Health Canada, 1999).

3.2.3. Ingestion Pathway

Ingestion pathway calculations in DoseCAL take into account the following process and data;

- Yield of grass and agricultural food products
- Harvesting and sowing time of grass and agricultural products
- Translocation within plants
- Interception
- Weathering from plant surfaces
- Dilution of radionuclide concentrations due to plant growth
- Uptake by plant roots
- Migration within the soil and

- Plant contamination due to resuspended soil
- Different livestock feeding regimes
- Storage times for fodder and human food products
- Changes in radionuclide concentrations due to food processing.

Age dependant ingestion dose coefficients for public are taken from ICRP 72 (1996). Dose coefficients for 3 months infant, 5 year old child, 15 years old teen and adult are used.

ICRP ingestion dose conversion factors take into account integration period of 50 year for adults and 70 year for children.

Input data to the ingestion modeling is the time integrated air concentrations, and deposited activity from any dispersion model or measured data.

Ingestion of tap water and aquatic food products are not considered in DoseCAL.

Activity concentration of plant products

The contamination of plant products as a function of time results from the direct contamination of the leaves and the activity transfer from the soil by root uptake and resuspension:

$$C_i(t) = C_{i,f}(t) + C_{i,r}(t) \tag{3.7}$$

$C_i(t)$; total contamination of plant type i,

$C_{i,f}(t)$; contamination of plant type i due to foliar uptake,

$C_{i,r}(t)$; contamination of plant type i due to root uptake.

Pasture and 13 different plant products, i.e. corn cobs, spring and winter wheat, spring and winter barley, rye, fruits, berries, and root, fruit and leafy vegetables, potatoes and beet can be modeled by DoseCAL.

Foliar uptake of radionuclides:

Calculation of the contamination of plants must distinguish between plants that are used totally (leafy vegetables and grass) and plants of which only a special part is used. The activity concentration at time after the deposition is determined by the initial contamination of the plant and activity loss due to weathering effects (rain, wind) and radioactive decay and growth dilution. For plants that are totally consumed growth, excluding pasture grass, growth is implicitly considered because the activity deposited onto leaves is related to the yield at harvest.

Interception factor is defined as the ratio of the activity initially retained by the standing vegetation immediately subsequent to the deposition event to the total activity deposited. Radionuclides to agricultural plants may be intercepted by dry process, wet process, or a combination of both. The interception fraction is dependent on the plant intensity in the area, stage of development of the plant, and generally leaf area of the crops. In the present model, a single coefficient was used and interception factors for grass and other plants were taken from DETRA code; the interception factor for grass and, fruits and vegetables is assumed to be 0.3 and for the grain and cereals it is 0.005. (Korhonen, R., Suolanen, V., 1984).The activity concentration at the time of harvest is given by:

$$C_{i,f}(\Delta t) = f_i \frac{A_i}{Y_i} \exp\left[-\left(\lambda_r + \lambda_w\right)\Delta t\right] \tag{3.8}$$

$C_{i,f}(t)$; concentration of activity in plant type i at time of harvest,

f_i; interception factor for plant type i,

A_i; total deposition ($Bq.m^{-2}$) onto plant type i due to the plants leaf area index at time of deposition,

Y_i; yield ($kg.m^{-2}$) of plant type i at time of harvest,

λ_w; loss rate (d^{-1}) due to weathering,

λ_r; decay rate (d^{-1}),

Δt; time span between deposition and harvest (d).

The approach for pasture grass is different because of its continuous harvest. Here, the decrease in activity due to growth dilution is explicitly considered.

$$C_{g,f}(t) = f_g \frac{A_g}{Y_g} \left\{\left(1-a\right)\exp\left[-\left(\lambda_b + \lambda_w + \lambda_r\right)t\right] + a\exp\left[-\left(\lambda_t + \lambda_r\right)t\right]\right\} \tag{3.9}$$

$C_{g,f}(t)$; activity concentration ($Bq.kg^{-1}$) in grass at time t after deposition,

f_g; interception factor for grass,

A_g; total activity deposited onto grass ($Bq.m^{-2}$),

Y_g; yield of grass at time of deposition ($kg.m^{-2}$),

a; fraction of activity translocated to the root zone,

λ_b; dilution rate by increase of biomass (d^{-1}),

λ_t; rate of activity decrease (d^{-1}) due to translocation to the root zone, t; time after deposition (d).

For the weathering rate constant λ_w; a value equivalent to a half life 14 d is taken from Farmland code (NRPB, 1995) and for rate of activity decrease due to translocation to the root zone λ_t; $1.16x10^{-2}$ d^{-1} with a contribution fraction a= 0.05 using different measurement of grass contamination after the Chernobyl accident are assumed (Pröhl, 1990). For plants that are only partly used for animal feeding or human consumption the translocation from leaves to the edible part of the plant has to be considered. This process strongly depends on the physiological behavior of the element considered. It is important for mobile elements such as cesium, iodine, tellurium whereas for immobile elements including strontium, barium, zirconium, niobium, ruthenium, cerium, plutonium only direct deposition onto edible parts of the plants play role. Translocation process is quantified by translocation factor T_i, which is defined as the fraction of the activity deposited on the foliage being transferred to the edible parts of the plant until harvest. It is dependant on the element, plant type and time between deposition and harvest. Translocation factors for agricultural food products for cesium, strontium and other elements were taken from IAEA TRS-472 (2010). Translocation factors for only the ripening stage is applied in DoseCAL.

$$C_{i,f}(\Delta t) = \frac{A_i}{Y_i} T_i \exp(-\lambda_r \Delta t) \quad (3.10)$$

T_i; translocation factor for plant type i,

Y_i; yield of edible parts of plant type i ($kg.m^{-2}$).

Root uptake of radionuclides

The estimation of the root uptake of radionuclides assumes that the radionuclides are well mixed within the entire rooting zone. The concentration of activity due to root uptake is calculated from the concentration of activity in the soil using transfer factor TF_i that gives ratio of concentration of activity in plants (fresh weight) and soil (dry weight) as follows:

$$C_{i,r}(t) = TF_i C_s(t) \quad (3.11)$$

$C_{i,r}(t)$; concentration of activity (Bq/kg) in plant type i due to root uptake at time t after the deposition,

TF_i; soil-plant transfer factor for plant type i,

$C_s(t)$; concentration of activity (Bq/kg) in the root zone of soil at time t.

Soil-plant transfer factors, soil density, percolation velocity, water content of soil, distribution coefficients, fixation rates of radionuclides, were taken from ECOSYS-87 (Pröhl, G., and Müller, H., 1993). Soil-transfer factors and distribution coefficients are given in Table 3.4.

The soil conditions which soil-plant transfer factors are based are often characterised by a low pH value together with a high organic content, and low contents of clay, potassium and calcium. Such soils are frequently found in upland areas, Scandinavia, and parts of Eastern Europe. (Pröhl, G., and Müller, H., 1993)

The concentration of activity in the root zone of soil is given by;

$$C_s(t) = \frac{A_s}{L.\delta} \exp\left[-\left(\lambda_s + \lambda_f + \lambda_r\right)t\right] \tag{3.12}$$

A_s; total deposition to soil ($Bq.m^{-2}$)

L; depth of root zone (m)

ρ; density of soil ($kg.m^{-3}$)

λ_s; rate of activity decrease due to migration out of the root zone

λ_r; rate of fixation (d^{-1})

The migration rate λ_s is estimated according to;

$$\lambda_s = \frac{V_a}{L.\left(1 + K_d.\delta/\theta\right)} \tag{3.13}$$

v_a; velocity of percolation water in soil ($m.a^{-1}$)

K_d; distribution coefficient ($cm^3.g^{-1}$)

θ; water content of soil ($g.g^{-1}$)

Depth of root zone is 0.1 meter. The soil density is 1400 $kg.m^{-3}$ and the mean water content is assumed to be 20%. Mean annual percolation water velocity is assumed to be 2 $m.a^{-1}$. The fixation is especially important for cesium and strontium. The fixation rate is assumed as 2.2E-04 d^{-1} for cesium and 9E-05 d^{-1} for strontium. Fixation is of minor importance and is not considered for the other elements in DoseCAL (Pröhl, G., and Müller, H., 1993).

Country specific data on sowing and harvesting times, and plant yields have been used to lead to realistic modeling.

Plant contamination due to resuspension

Plant contamination due to resuspension is proportional to the activity in the soil. Assuming a deposition velocity of 1 mms^{-1}, a grass yield of 1 kgm^{-2}, and a weathering half life 14 d, the resuspension factors as assumed in ECOSYS-87 is equivalent to a soil-plant transfer about 0.001 and used in DoseCAL. Due to the lack of plant-specific data, this value can be applied to all plant species considered (Pröhl, G. and Müller, H., 1993).

Contamination of animal products

The contamination of animal products results from the activity intake of the animals and the kinetics of the radionuclides within the animals. Inhalation of radionuclides by the animals is not considered; this pathway may be relevant for milk contamination in certain cases, but it is unimportant for resulting doses. The amount of activity ingested by the animals is calculated from the concentration of activity in the different feedstuffs and the feeding rates;

$$A_{a,m}(t) = \sum_{k=1}^{K_m} C_k(t).I_{k,m}(t) \qquad (3.14)$$

$A_{a,m}(t)$; activity intake rate of the animal m ($Bq.d^{-1}$),

K_m; number of different feedstuffs fed to the animal m,

$C_k(t)$; activity concentration ($Bq.kg^{-1}$) in feedstuffs k,

$I_{k,m}(t)$; feeding rate ($kg.d^{-1}$) for feedstuffs k and animal m.

Soil ingestion is also considered in DoseCAL. Soil intake of animals varies widely depending on the grazing management and the condition of the pasture. If the feeding of mechanically prepared hay and silage during winter and an intensive grazing regime on well fertilized pasture are assumed a mean annual intake of 2.5% of the grass dry matter intake seems to be appropriate. This nuclide independent value is equivalent to soil-plant transfer factor of $5x10^{-3}$ and it is added to the transfer and resuspension factor in DoseCAL. This means that for all elements with a transfer factor lower than this value, soil eating is the dominating long term pathway for the contamination for milk and meat from grazing cattle, presuming that resorption in the gut is the same for soil-bound and plant incorporated radionuclides.

Table 3.4. Soil-Plant Transfer Factors (Bq/kg Plant Fresh Weight per Bq/kg Soil Dry Weight) Used in DoseCAL (Pröhl, G., and Müller, H., 1993)

Element	Cesium	Strontium	Iodine	Zirconium	Niobium	Tellurium	Ruthenium	Barium	Cerium	Plutonium
Grass	5E-02	5E-01	1E-01	4E-04	4E-03	5E-03	2E-02	3E-02	2E-03	2E-04
Corn cobs	1E-02	2E-01	1E-01	6E-04	6E-03	1E-01	1E-02	5E-02	3E-03	2E-03
Rye	2E-02	1E-01	1E-01	4E-04	4E-03	3E-03	1E-02	1E-02	3E-03	1E-04
Wheat/Barley	2E-02	1E-01	1E-01	4E-04	4E-03	3E-03	1E-02	1E-02	3E-03	1E-04
Beet	5E-03	4E-01	1E-01	1E-04	1E-03	1E-03	1E-02	4E-03	4E-03	1E-04
Potatoes	1E-01	5E-02	1E-01	1E-04	1E-03	1E-03	1E-02	4E-03	4E-03	1E-04
Root vegetables	1E-01	3E-01	1E-01	5E-05	5E-04	4E-04	1E-02	2E-03	4E-04	1E-04
Fruit vegetables	1E-01	2E-01	1E-01	5E-05	5E-04	4E-04	1E-02	2E-03	4E-04	1E-04
Fruits/Berries	2E-02	1E-01	1E-01	5E-05	5E-04	4E-04	1E-02	2E-03	4E-04	1E-04
Leafy vegetables	2E-02	1E-01	1E-01	5E-05	5E-04	4E-04	1E-02	2E-03	4E-04	1E-04
Distribution coeff. (g cm^{-3})	1000	100	100	1000	1000	1000	1000	100	100	100

Country specific data on feeding regimes and feedstuff intake rate of animals have been used to lead to realistic modeling.

Seven different animal products, namely cow, sheep and goat milk, and lamb, beef cattle, egg and chicken, can be modeled by DoseCAL.

Transfer of radionuclides from fodder into animal products is calculated as follows:

$$C_m(t) = TF_m \sum_{j=1}^{J} \left\{ a_{mj} \int_0^t A_{a,m}(t) \lambda_{b,mj} \exp\left[-\left(\lambda_{b,mj} + \lambda_r \right) t \right] dt \right\} \quad (3.15)$$

$C_m(t)$; activity concentration in animal product m at time t,

TF_m; transfer factor ($d.kg^{-1}$) for animal product m,

j; number of biological transfer rates,

a_{mj}; fraction of biological transfer rates,

$\lambda_{b,mj}$; biological transfer rate j (d^{-1}) for animal product m.

Equilibrium transfer factors are chosen to be used in DoseCAL. The use of equilibrium transfer factors is based on assumption of equilibrium between concentrations in the related environmental compartments. The feed-animal transfer factors applied in DoseCAL are taken from RESRAD code package (Wang, Y.Y., B.M. Biwer, and C. Yu, 1993). For sheep and goat milk transfer factors 10 times higher than for cow milk are assumed. For lamb, goat's meat, and chicken, the transfer was estimated from the feed-beef transfer factor by applying correction factors for the lower body mass. Correction factors are 3 for lamb, and goat's meat and 100 for chicken. (Müller, H. and Pröhl, G., 1993) Biological turnover rate of animal products were taken from ECOSYS-87 (Pröhl, G., and Müller, H., 1993)

The processing and storage of foodstuffs

The processing and storage of foodstuffs in order to take advantage of the radioactive decay and dilution during these processes are taken into account in the model. The enrichment of minerals in the outer layers of grains and the fractionation in the milling products is considered. Besides, the radioactive decay during processing and storage is taken into account. The storage presumes the stability of the foodstuffs or the possibility to convert the foodstuffs into stable products. Storage times are considered to be mean time between the harvest and beginning of product consumption. Concentration of activity in products is calculated from the raw product by the following relation:

$$C_k(t) = C_{ko}(t - t_{pk})P_k \exp(-\lambda t_{pk}) \quad (3.16)$$

$C_k(t)$; activity concentration (Bq/kg) in product k ready for consumption at time t,

C_{ko}; activity concentration (Bq/kg) in raw product at time t,

P_k; processing factor for product k,

λ_r; radioactive decay constant (d^{-1}),

t_{pk}; storage and processing time (d) for product k.

Storage times and processing factors for food products and feedstuffs were taken from IAEA TRS-472 (2010) and RESRAD code package (Wang, Y.Y., B.M. Biwer, and C. Yu, 1993) and are given in Table 3.5.

Table 3.5. Storage and Processing of Food Products

(IAEA TRS-472, 2010 and Wang, Y.Y., B.M. Biwer, and C. Yu, 1993)

Processed Products	Storage times (day)	Processing Factor
Cereals	180	0.5
Potatoes	14	0.8
Fruits	90	0.8
Berries	4	0.8
Root vegetables	10	0.8
Fruit vegetables	7	0.8
Leafy vegetables	20	0.8
Cow milk	2	1
Sheep milk	2	1
Goat milk	2	1
Lamb	4	1
Beef	20	1
Chicken	4	1
Egg	14	1

Activity intake and exposure

The intake of activity by humans is calculated from the time-dependant concentrations of activity in foodstuffs and the human consumption rate:

$$A_h(t) = \sum_k C_k(t).V_k(t)$$

(3.17)

$A_h(t)$; human intake rate ($Bq.d^{-1}$) of activity,

$C_k(t)$; concentration of activity ($Bq.kg^{-1}$) of foodstuff k,

$V_k(t)$; consumption rate ($kg.d^{-1}$) of foodstuff k.

The foodstuffs are assumed to be locally produced. Food consumption data that is very important for calculating dose exposure by ingestion pathway is different depending on where people live. Country specific data on consumption of food products have been used to lead to realistic modeling.

The ratio is derived based on values average and maximum consumption habits presented in USNRC Regulatory Guide 109 (1977) and given in Table 3.6 and 3.7.

The dose $D_{ing}(t)$ due to ingestion of contaminated foodstuffs within time t after the deposition, is given by the following;

$$D_{ing}(t) = \int_0^t A_h(t).DF.dt \qquad (3.18)$$

$D_{ing}(t)$; ingestion dose (Sv),

DF; age dependent dose factor for ingestion ($Sv.Bq^{-1}$)

Table 3.6. Ratio of Maximum / Average Food Consumption

Ratio of Max/Avg Consumption	Fruits, vegetables, grain	Meat, poultry	Milk
Infant	-	-	1.94
Child	2.60	1.1	1.94
Teen	2.62	1.1	2.0
Adult	2.74	1.16	2.82

Table 3.7. Ratio of Food Consumption for Different Age Groups

Ratio of Avg/Max Consumption	Infant	Child	Teen	Adult
Grain	-	1	1.2	0.95
Fruits, vegetables,	-	1	1.2	0.95
Meat, poultry	-	1	1.59	2.57
Milk	1	1	1.59	2.57

Application of analogue isotope and element method

For the factors not given in the related literature and used in DoseCAL analogue isotopes and element method was applied (IAEA-TRS472, 2010). Application of analogue isotopes is the most common form of analogue use and is often used without any specific justification or even recognition that data for an analogue are being used. Short-lived fission products whose environmental behavior has been extensively studied in the context of reactor accidents or routine discharges may be used as analogues for long-lived isotopes of relevance for solid waste disposal. For example, data for I-131 may be used to predict the behavior of long-lived I-129, or data for the well studied Cs-134 or Cs-137 may be used to predict the behavior of long lived Cs-135. Similarly, short lived and readily available tracer radionuclides are often used in experiments as analogues for isotopes found in radioactive discharges or waste. In general, the behavior of isotopes of the same element is identical, except for light elements such as hydrogen. An important limitation and consideration when using stable analogues is whether the timescale over which behavior of a short lived radionuclide can be studied is sufficient to reveal the significance of long term processes that may influence the behavior of a long lived radioisotope or stable isotope of the same element. In particular, equilibration of a short-lived isotope in environmental media may be strongly influenced by its physical decay, whereas equilibration of a long-lived or stable isotope may be almost entirely determined by biogeochemical transfer processes.

The chemical properties of elements follow well-established patterns that can sometimes be used as a basis for identifying potential analogues. Elements in the same group (column) of the periodic table usually exhibit similar chemical behavior, because they have the same number of outer electrons available to form chemical bonds (i.e. they form compounds in the same valence state). In the case of essential macroelements for plants located in soil, the uptake and transfer of a chemically similar element (i.e. the element under study) will be influenced by any lack or excess of the essential macroelement.

3.2.4. Total Dose Calculation

DoseCAL calculates yearly doses for each age group and for each grid after the accident. Agricultural food products' activities are calculated at each year harvest, grass and animal products' activities are calculated on monthly basis. All aforementioned pathways are included in dose calculations as shown below:

$$Dose_{total} = Dose_{inhalation} + Dose_{ingestion} + Dose_{cloudshine} + Dose_{groundshine} \quad (3.19)$$

$Dose_{total}$; total dose (Sv)

$Dose_{inhalation}$; inhalation dose (Sv)

$Dose_{ingestion}$; ingestion dose (Sv)

$Dose_{cloudshine}$; cloudshine dose (Sv)

Dose $_{groundshine}$; groundshine dose (Sv)

A person is assumed to be as infant up to 1 year, as child upto 9 years, as teen upto 16 years and as adult upto 70 years; namely when calculating long term doses after the accident growing up of a person is taken into account in terms of his/her food consumption habits, sensitivity to doses and occupancy factors.

3.2.5. Modeling of Countermeasures

Restriction of consumption of contaminated foodstuffs is taken into account in DoseCAL in such a way that if the radioactivity concentration in the foodstuffs exceed the following values given in Table 3.8 (TAEK, Regulation on National Implementation in the case of Nuclear and Radiological Emergency, 2009) the consumption is restricted.

Table 3.8. Allowable Maximum Limits for Foodstuffs[a] (Bq/kg) (TAEK, 2009)

	Dairy products	Other foodstuffs
Iodine isotopes, particularly I–131	500	2 000
Other isotopes with half lifes longer than 10 days, Cs–134, Cs–137	1 000	1 250

[a]: After food processing these limits should apply.

3.2.6. Calculation of Collective Doses

The impact of an accident on the population as a whole depends not only on the deposition, atmospheric activity levels and dose obtained, but also on the population living in that particular area. For example the deposition, atmospheric activity levels, dose obtained and individual health risk, due to any NPP accident, may be very high, but these high values may not mean anything if there is no one living there. Consequently, better representation of the collecive doses or risk of an accident, nuclear and non-nuclear, can be obtained by multiplying the individual dose or health risk by the number of people living in the receptor. This parameter is called “collective dose or risk”.

3.2.7. Calculation of Health Effects

Late health effects are calculated in this study. Since early health effects occur at very high doses and close vicinity of the accident site. Though high doses are part of this study, close vicinity and very early phase of the accident cannot be modeled distinguishably; namely the calculations have been done on whole rectangular grid which has dimensions of 2.5x2.5º and where though the activity differ on, an average value applies. Therefore, early health risk modeling is not included in the study.

Two different methodologies have been applied for calculation of late effects in DoseCAL. ICRP-103 (2007) risk coefficients including cancers and hereditary effects and USEPA FGR 13 (1999) risk coefficients including mortality and morbidity risk coefficients for inhalation, ingestion, and cloudshine and groundshine pathways for isotopes can be applied separately.

3.3. The Input Parameters and Model Settings Used for the Validation of DoseCAL Software

After the Chernobyl accident, large and highly radioactive particles were found in several European countries. IAEA established a coordinated research programme in 1988 on the "The Validation of Models for the Transfer of Radionuclides in Terrestrial, Urban, and Aquatic Environments and Acquisitions of Data for That Purpose". The programme, which has been given a short title "Validation of Environmental Model Predictions (VAMP)" seeks use of information on the environmental behavior of radionuclides which became available as a result of the measurement programmes instituted in countries of the former Soviet Union and many European countries after April 1986 (IAEA TECDOC 904, 1996). Scenario S is the second exercise of the VAMP. Data sets were collected in Helsinki, Finland for Cs-137 contamination of the various environmental media following Chernobyl accident. The collected datasets can be summarized as follows;

- General information containing topographic features and climatic data
- Radionuclides concentration data in ground level air
- Soil contamination data
- Agricultural information
- Demographic information.

The STUK experts provided independent estimates based on their evaluation of the data on Cs-137 deposition density in soil and Cs-137 concentrations in soil, air, foodstuffs, and humans. For each quantity predicted, estimates of both the arithmetic mean and the 95 % confidence interval about the mean were provided for the specified time periods (IAEA TECDOC-904, 1996).

- The DoseCAL software is evaluated against the following time dependent quantities of Cs-137:
- Concentration in cow milk
- Concentration in beef
- Concentration in pasture
- Concentration in wheat
- Concentration in rye
- Concentration in leafy vegetables
- External dose (cloud and ground) to human
- Committed dose due to inhalation (cloud and resuspension) to human
- Committed dose due to ingestion to human
- Total dose to human

Outside the model validation exercise subjected to this study were potatoes, berries, fruits, poultry meat, eggs, fish, game animals, mushrooms and pork. Potatoes, garden berries, fruits, poultry meat and eggs are already outside the validation study in IAEA TECDOC-904. Fish and game animals, mushroom and pork pathways are not modeled with DoseCAL. Considering Turkish people, pork is not consumed, game animal's consumption is almost insignificant, and fish is part of aquatic pathway that is outside the DoseCAL scope.

The average deposition density for the region of southern Finland was 19900 ± 6000 Bq m^{-2}.

The local data for Finland used in the model are as follows:

-air concentrations for about 1 month beginning from 26^{th} of April measured at 2 stations (average is used),

-deposition values collected in 11 stations (average is used) for about 1 month beginning from 26th of April,

-food consumption habits for adults,

-crop yields and harvesting dates,

-feeding regimes and consumption of feedstuffs for animals,

-shielding properties and occupancy factors.

At air monitoring station the airflow rate was 150 m^3 /h, and the filter was Whatman GFA/A with an area of 0.06 m^2. The filters at the station were changed twice a week to avoid overloading the filters and to ensure the retention of particulate radionuclides. Total deposition, i.e. wet and dry, was collected continuously at 11 stations in the test region starting in early spring of 1986. The surface areas of the samplers were 0.05 or 1 m^2. Average Cs-137 air concentration and deposition data used in DoseCAL are presented in Table 3.9. The dietary habits of the people, averaged for man and woman adult in the region are given in Table 3.10.

Silage is not contaminated until September 1986. Silage is assumed to be made up of pasture grass. Sowing period covers whole of May. Rye was considered as 100% winter grain, this is the only plant on the field in the fallout time with grass. Wheat was not sown prior to accident. However, approximately 10% of production in region S is from winter-grown varieties, which would have been sown before the accident, so it was assumed 10% winter and 90% spring grain according to Scenario S and as assumed by many other codes.

Table 3.9. Cs-137 Air Concentration and Deposition Data

Date (Yr/M/D)	Deposition (Bq/m^2)	Concentration (Bq/m^3)	Date (Yr/M/D)	Deposition (Bq/m^2)	Concentration (Bq/m^3)
1986 4 28	1.70E+01	3.54E+00	1986 5 15	8.60E+00	1.11E-02
1986 4 29	9.10E+02	3.17E-02	1986 5 16	2.20E+01	1.11E-02
1986 4 30	1.90E+03	3.15E-02	1986 5 17	5.39E+03	1.14E-02
1986 5 1	8.60E+01	4.82E-02	1986 5 18	5.39E+03	1.07E-02
1986 5 2	2.90E+01	7.10E-02	1986 5 19	5.39E+03	1.00E-02
1986 5 3	3.10E+01	1.19E-01	1986 5 20	1.00E+01	1.17E-02
1986 5 4	1.80E+01	8.58E-02	1986 5 21	7.70E+00	2.30E-02
1986 5 5	1.90E+01	2.59E-02	1986 5 22	7.70E+00	1.68E-02
1986 5 6	1.80E+01	1.15E-02	1986 5 23	2.50E+01	1.06E-02
1986 5 7	1.70E+01	8.63E-03	1986 5 24	2.50E+01	1.65E-02
1986 5 8	1.30E+01	1.11E-02	1986 5 25	2.50E+01	1.65E-02
1986 5 9	5.40E+01	2.08E-02	1986 5 26	1.57E+01	2.24E-02
1986 5 10	3.00E+02	2.85E-02	1986 5 27	1.57E+01	3.29E-02
1986 5 11	1.90E+01	4.50E-02	1986 5 28	6.40E+00	3.29E-02
1986 5 12	1.10E+02	6.70E-02	1986 5 29	6.40E+00	3.29E-02
1986 5 13	2.60E+01	2.53E-02	1986 5 30	6.40E+00	1.05E-02
1986 5 14	7.40E+00	5.60E-03			

Table 3.10. Consumption Rates of Food Products for Adult in Finland

Food Products	Consumption (kg/day)	Food Products	Consumption (kg/day)
Grain (Wheat-Barley)	0.2	Eggs	0.03
Wild Mushroom	0.0036	Game Meat	0.0038
Potatoes	0.18	Pork	0.07
Berry (wild, garden)	0.052	Cow Milk	0.72
Fruits	0.25	Beef-Lamb	0.056
Root Vegetables	0.05	Chicken	0.02
Fruit Vegetables	0.044	Cheese	0.034
Leafy Vegetables	0.05	Fish	0.012
Pea and bean	0.01	Seafish	0.039

Harvesting times and yields of crops are presented in Table 3.11.

Table 3.11. Yield of Grass and Agricultural Crops in Finland

Grass & Crops	Yield (kg/m^2)	Harvesting Time (day.month)
Grass	0,29	01.06-15.08
Cereals	1,7	01.06-31.07
Beet	5,33	01.11-01.12
Potatoes	3,8	01.08-01.09
Soft fruits (berry)	6,23	01.05-30.06
Fruits (non-berry)	35,2	01.11-28.02
Root Vegetables	3,07	01.08-01.09
Fruit Vegetables	16,91	continuous
Leafy Vegetables	5,6	01.10-01.05

According to the information given in Scenario S description, most of the leafy vegetables are grown in greenhouses.

Feeding rate for the cows in the summer is 50 kg/day grass, 3.2 kg/day hay and grain, and in the winter it is 50 kg/day silage, 3.2 kg/day hay and grain. During the period of 7-26 May 1986, about one percent of dairy cows were fed with new grass. Soil grazing is not considered, since cows don't graze but fed with fresh grass. Grazing-stabling period is assumed as 25 May-25 September. The feeding rate for cows, reduced at 65%, was used for the diet of beef cows.

Buildings give good shielding for radiation from the ground. Especially in the higher storeys of blocks of flats, the dose rate is small compared to the dose rate at ground level outside. The shielding factor for a person living in a typical Finnish flat is on an average 0.18, and for low-rise residential houses, it is 0.47. An average Finn spends approximately 85 % of time indoors, and this occupancy factor is taken into account in the shielding factors. The data suggests that 66 % of the population is urban and 34 % is rural.

Accounting for shielding the urban population was assumed to spend 90 % of their time indoors and 10 % of their time outdoors. The rural population was assumed to spend 50 % of their time indoors and outdoors.

Soil-plant and feed-animal transfer factors, interception factors, weathering rate constant, translocation factors, distribution coefficients, soil density, depth of root zone, water content of soil, percolation water velocity, dilution factor, fixation factor, dose conversion factors, processing factors and storage time for food products have been kept as default for the software, since they are based on recent knowledge and make the results more realistic.

3.4. Case Studies on Simulation of Akkuyu and Sinop NPP Accident Scenarios

3.4.1. Accident Release Scenario

The reactor subject to Akkuyu NPP case study is assumed as 1200 MWe PWR type nuclear power plant. The core inventory of the 1200 MWe reactor is directly proportional to its electrical power and calculated from the inventory based on the 1000 MWe electrical power (Slaper, 1994). The core inventory of Sinop NPP has been assumed the same with Akkuyu NPP.

There are two important NPP accidents rated at international nuclear event scale (INES)-7, happened in the history, i.e. Chernobyl and Fukushima NPP accidents. The Chernobyl disaster was a catastrophic nuclear accident that occurred on 26 April 1986 at the Chernobyl NPP. Chernobly NPP was of RBMK type, which had several design shortcomings. RBMK reactors are not being constructed since Chernobyl mishap. The combination of graphite moderator and water coolant is found in no other power reactors in the world. As the Chernobyl accident showed, several of the RBMK's design characteristics in particular, the control rod design and a positive void coefficient were unsafe. RBMK reactors still operating have been those that are in Russian Federation and went into major modifications after Chernobyl accident to address these problems (WNA, 2010). Since newer reactors have been designed as light water cooled and moderated reactors, Chernobyl accident scenario was not used in this study.

The release fractions used for both Sinop and Akkuyu NPP accident case studies are based on Fukushima Daiichi NPP accident. In March 2011, resulting from a powerful earthquake, the Fukushima Daiichi NPP lost its cooling ability and its reactors were heavily damaged. Owing to controlled venting and an unexpected hydrogen explosion, a large amount of radioactive material was released into the environment. Estimates made by the Japanese authorities suggested complete release of the entire noble gas inventory and around 1–2 % of the cesium contained in the reactor cores of units 1–3. Our guess has been guided by the Japanese assessments and thus its total magnitude corresponds to 100 % of Xe-133 and about 1.7 % of Cs-137 (Stohl et.al, 2012). Iodine and tellurium release fraction in Fukushima accident were taken from the reference (Specter, H., 2013). The ratio of the tellurium to iodine release fraction was 0.022/0.020 = 1.1 and iodine release fraction averaged over unit 1, 2 and 3 was 3.3 %. Release fractions of other isotopes have been derived based on the ratio between release fraction of Cs-137 and other isotopes given in IAEA TECDOC-955 (1997) and presented in Table 3.12. These release fractions were used in HYSPLIT simulation of Akkuyu accident case study.

Table 3.12. Core Inventory Fractions Released to the Containment (IAEA TECDOC-955, 1997)

Group	Core Release Fraction
Noble gas (Xe, Kr)	1
Halogens (I)	0,033
Alkali metals (Cs, Rb)	0,017
Tellurium metals (Te, Sb)	0,036
(Ba)	0,00272
(Sr)	0,00204
Cerium Group (Ce, Np, Pu)	0,00068
Ruthenium group (Ru, Mo, Tc, Rh)	0,000544
Lanthanium group (La, Am, Y, Zr, Nd, Nb, Pr,)	0,000136

According to IRSN's estimates (2012), Fukushime releases to air mainly include;

- releases of radioactive noble gases: 6,550 PBq (the same order of magnitude as the Chernobyl accident), composed mainly of Xe-133,

- releases of radioactive iodine: 408 PBq (about ten times less than the Chernobyl accident), including 197 PBq of I-131 and 168 PBq of I-132,
- releases of radioactive tellurium: 145 PBq, including 108 PBq of Te-132 with its decay product iodine-132, and 12 PBq of Te-129m with its decay product Te-129 (initial release estimated at 8 PBq),
- releases of radioactive cesium: 58 PBq (about three times less than the Chernobyl accident), including 21 PBq of Cs-137, 28 PBq of Cs-134 and 9.8 PBq of Cs-136.

The other radionuclides released were estimated to represent a total activity of 29 PBq, less than 0.5% of all radioactive substances released. Only some of these radionuclides have actually been detected, in a low quantity, in the Japanese environment. In particular, plutonium released during the accident (tested by its isotopic composition) was measured in the deposits formed in the northwest of the Fukushima Daiichi plant, but at very low levels, difficult to distinguish from the plutonium from fallout in the atmosphere produced by nuclear weapons testing (IRSN, 2012). Aforementioned 9 isotopes detected in the environment following Fukushima accident according to IRSN estimtaes (2012); i.e. Cs-137, Cs-136, Cs-134, I-131, I-132, Te-132, Te-129, Te-129m and Xe-13 have been modeled by DoseCAL, and total 53 isotopes have also been modeled to see the other isotopes' contribution to total dose in this study. As seen from Table B.1, which presents the adult doses for the 9 and 53 isotopes, respectively, that were assumed to release to the atmosphere on 29^{th} of November 2000, due to hypothetical accident at Akkuyu NPP, the aformentioned 9 isotopes are contributing to the total dose approximately 70 %. This result also justifies the selection of 9 isotopes for the case studies.

Cs-137 release from Fukushima NPP started on 12 March, peaked on 14-15 March, and ended on 19 April. Xe release peaked on 12-13 March and ended on 15 March. The radionuclides released mainly from 12 to 25 March 2011, in about fifteen events, with the most important releases taking place before 17 March (IRSN, 2012). Release period has been assumed as 6 days in this study considering the release events during Fukushima NPP accident. I-131 concentrations in gas were higher than in aerosols released from Fukushima Daiichi NPP accident. The USEPA RadNet station measurements detected 81 % of the ambient I-131 in the gas and 19 % in the particle phase (Hoeve J., E., T., and Jacobson, M.C., 2012). In our case studies, the ratio of elemental and aerosol phase of iodine is assumed as the same with the above reference.

3.4.2. Determination of Meteorological Year and Time of Release for the Simulation

To determine the year of simulation of the case studies, representative year based on long-term meteorological conditions has to be selected. To determine the representative year resulting in worst-case concentrations in the air, 30-year-wind data has been taken from General Directorate of Meteorology. For Sinop site, Sinop meteorological station, which is 15 km away from proposed NPP site and 32 meter above MSL, for Akkuyu Site Silifke meteorological station, which is 46 km away from NPP site and 15 meter above MSL, have been considered. As demonstrated in Figures 3.2, 3.3, 3.4 and 3.5, the year of 2005 and the year of 2000 were selected as the most representative years for Sinop and Akkuyu sites, respectively, since those years' wind speed and direction resembles most to the average of the long years. The wind direction shows the locations where the subsequent deposition takes place; however, wind direction in the rainy days is also determining factor for the location of the deposition.

Hence, to determine the time of release or simulation date, the date, which leads to maximum deposition, is considered, the most rainy day is foreseen to leads to maximum deposition pattern. The rain data has been taken from General Directorate of Meteorology for Silifke and Sinop stations, for the year 2000 and 2005, respectively. According to data for Akkuyu site, 29th of November turns out to be the most rainy day, and for Sinop site 31th of October shows the highest rain pattern.

Apart from the meteorology, the vegetation and harvesing times of the plants and grazing of the animals also affect the radiological consequences, namely activity concentrations in the plants and doses to humans. To take into account the latter, the models were also run with the release time selected in different seasons seperately, i.e. on 1st of March, 1st of June and 1st of September in 2000 for Akkuyu NPP case study and on 31th of April, 30th of July and 31st of January in 2005 for Sinop NPP case study. The adult doses predicted with each model run have been compared, the release time leading to maximum doses has been selected for the subsequent modeling studies.

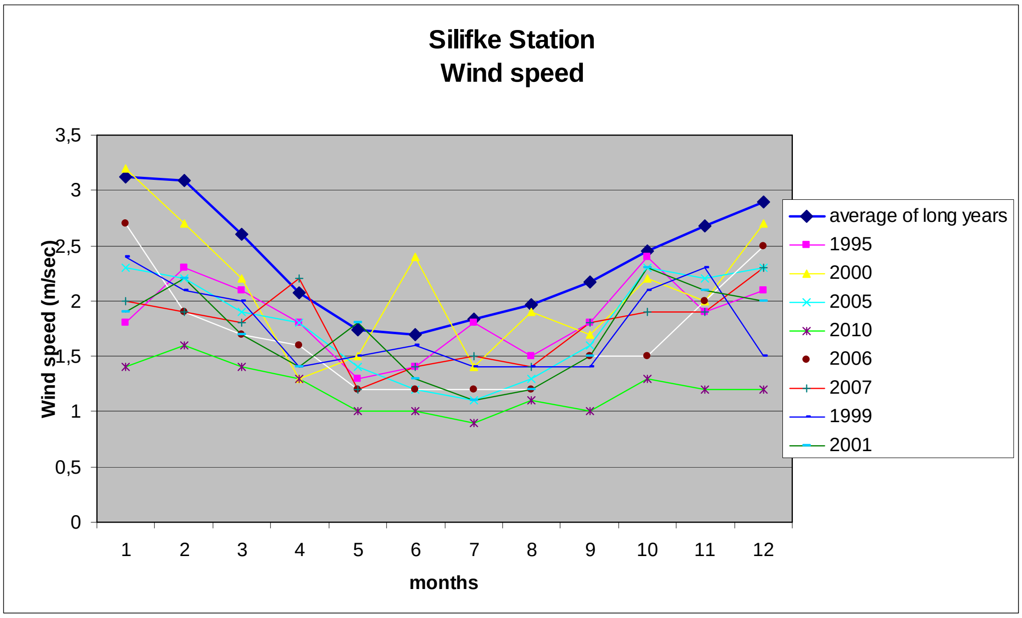

Figure 3.2. Wind Speed of Different Years for Silifke Meteorological Station

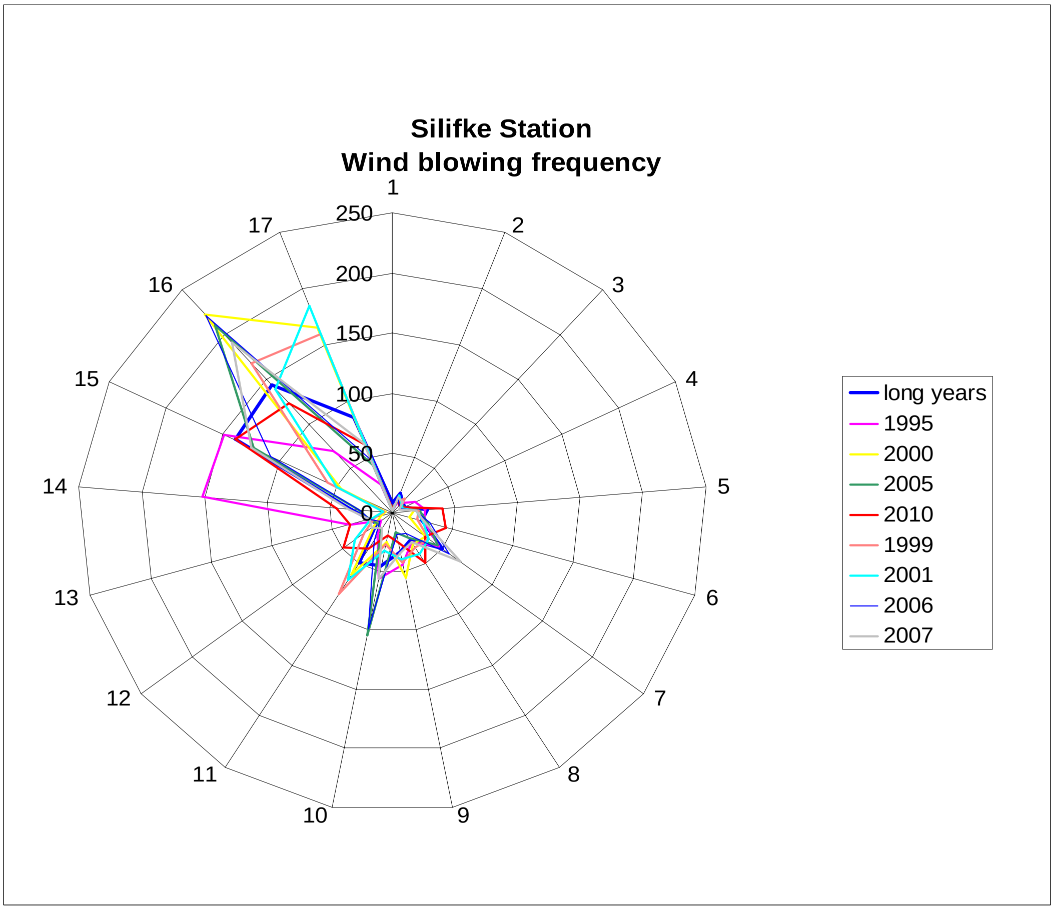

Figure 3.3. Wind Blowing Frequency of Different Years for Silifke Meteorological Station

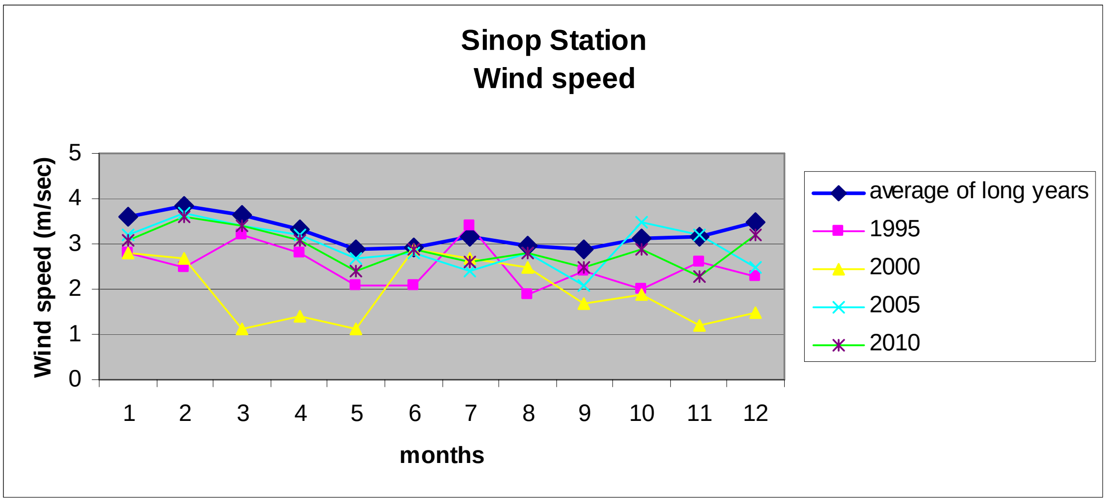

Figure 3.4. Wind Speed of Different Years for Sinop Meteorological Station

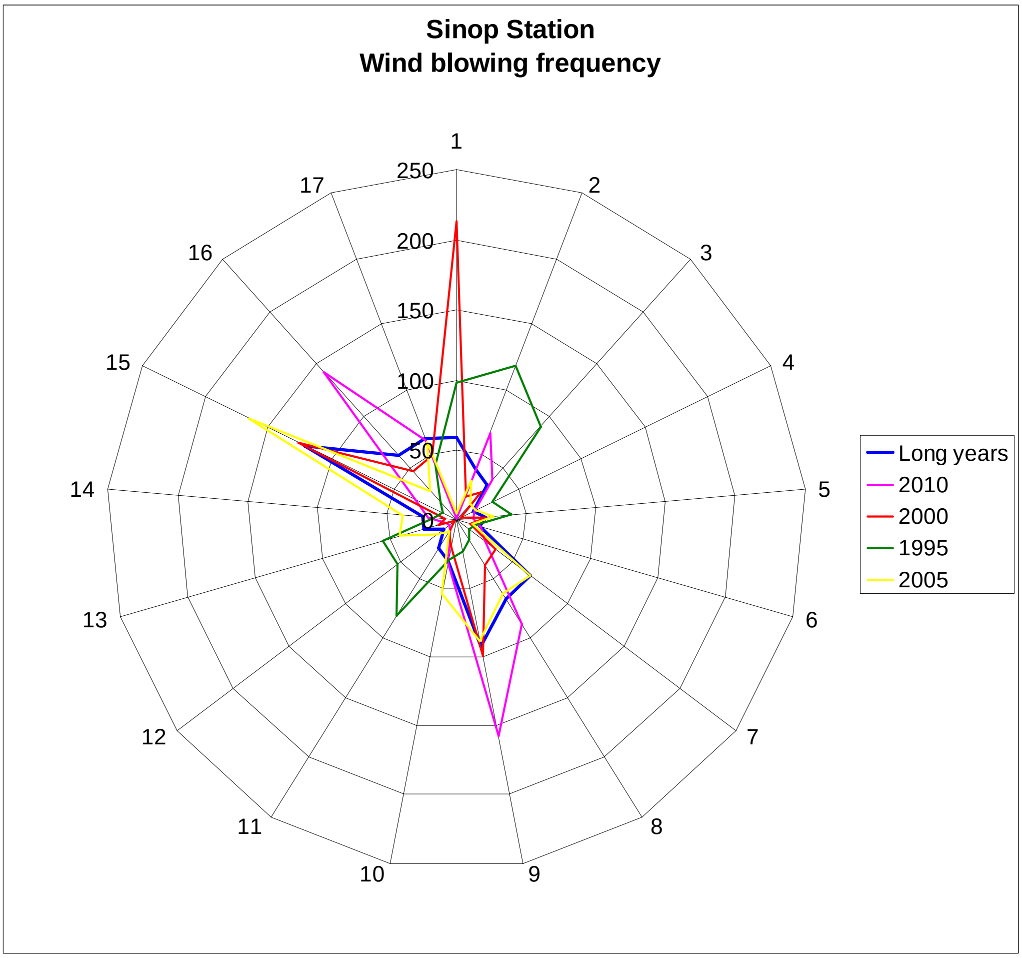

Figure 3.5. Wind Blowing Frequency of Different Years for Sinop Meteorological Station

3.4.3. Selection of the Atmospheric Dispersion Model used in the Case Studies

HYSPLIT (Hybrid Single Particle Lagrangian Integrated Transport) model developed in NOAA Air Resources Laboratory in the United States (Draxler, R.R., and Hess, G.D., 1997) has been selected to be coupled to DoseCAL model developed for this study. HYSPLIT is a model for calculating air trajectories, deposition and dispersion of pollutants. The model calculation method is hybrid between Eulerian and Lagrangian approaches. Advection and diffusion calculations are made in a Lagrangian framework while concentrations are calculated on a fixed grid. Removal processes considered in the model are wet and dry deposition, and radioactive decay. The model is used in large numbers for scientific research including pollen, ozone, fire smoke, transboundary problems etc. Dispersion of radionuclides is also an application area of HYSPLIT. User supplied inputs for HySPLIT calculations are pollutant species characteristics, emission parameters, gridded meteorological fieldsand output deposition grid definitions. The horizontal deformation of the wind field, the wind shear, and the vertical diffusivity profile are used to compute dispersion rate. Gridded meteorological data are required for regular time intervals. The meteorological data fields may be provided on one of the different vertical coordinate system: Pressure-sigma, pressure-absolute, terrain-sigma or a hybrid absolute-pressure-sigma. The model can be configured to treat the pollutant as particles, or Gaussian puffs, or as top/hat puffs. The term Hybrid refers to the additional capability of HySPLIT to treat the pollutant as Gaussian or top/hat puff in the horizontal while treating the pollutant as a particle for the purposes of calculating vertical dispersion. An advantage of the hybrid approach that is the higher dispersion accuracy of the vertical partical treatment is combined with the spatial resolution benefits of horizontal puff splitting. All model runs for this work were made in the default hybrid particle/top-hat mode.

HYSPLIT model has a capability to make simulation with seven pollutants at a time at most. Since some more radionuclides considered being most important in terms of their effects in the environment are used to represent accidental release of radionuclides in the literature, HYSPLIT model's source code has been modified to simulate more pollutants to provide us easiness for this study.

3.4.4. Input Parameters Used in HYSPLIT

Downloadable meteorological data used for HYSPLIT is only NCAR-NCEP reanalysis meteorological data, which covers 2.5 x 2.5° gridded system, so the mentioned gridded system was chosen to simulate case studies. Reanalysis data of November and December of 2000, and October and November of 2005 were downloaded into HYSPLIT for dispersion modeling. HYSPLIT model was run for 15 days, which is assumed to be reasonable period as long as accidental radiological release is concern. Figure 3.6 taken from the previous study is given to demonstrate the Cs-137 radioactivity remaining constant after a definite time (Ünver, Ö., Tuncel, G., 2004).

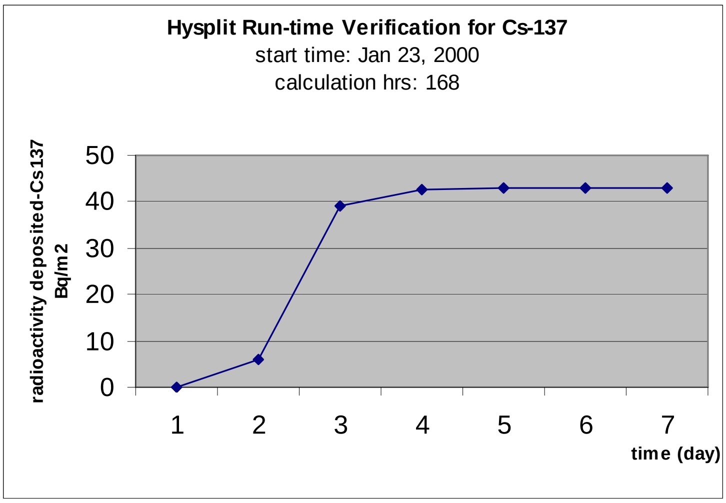

Figure 3.6. Cs-137 Activity Deposited on Turkey as a Function of Time

In this study, dry deposition velocity is assumed to be a constant for each radionuclide and surface type. Dry deposition values reported in literature for different surface types and for different isotope groups are given in Table 3.13 (Baklanov, A., Serensen, JH., 2000), to demonstrate the variability of the value. Since Turkey is mostly covered by the agricultural areas (among surface types given in Table 3.13) the dry deposition velocity values for agricultural surface type were used in our simulations. To strenghten our assumption, size of the particles released into environment in the case of a nuclear accident was also investigated. After Chernobly accident at Helsinki station at which air concentration was measured, particle size distribution (0.03-16 µm) was determined by 11 stage cascade impactors.

Table 3.13. Dry Deposition Velocities for Various Surface Types (m s^{-1})

(Baklanov, A., Serensen, JH., 2000)

Physical -chemical form	*Surface types*				
	water	*grass*	***Agricultural***	*forest*	*urban*
noble gases	0	0	**0**	0	0
aerosols	0.0007	0.0015	**0.002**	0.0075	0.0005
elemental iodine	0.001	0.015	**0.020**	0.073	0.005
organically bound iodine	0.0005	0.00015	**0.0002**	0.00075	0.00005

Table 3.14. Distribution of the Estimated Cs-137 Activity Bound to Aerosol Particles Relative to the Aerodynamic Diameter (IAEA, TECDOC 904, 1996)

Dae (ìm)	0,01	0,03	0,04	0,06	0,1	0,26	0,4	0,63	1	2,6	4	6,3	10	25	40	63	100
%	0,4	0,7	0,7	1,6	4,9	6,6	6,7	8,2	16	13	9,6	8,4	10,7	5,6	2,6	1,7	1

Distribution of the estimated Cs-137 activity bound to aerosol particles relative to the aerodynamic diameter is given in Table 3.14 (IAEA, TECDOC 904, 1996). As seen from this Table, more than half of the particles (58.8 %) have aerodynamic diamater less than and equal to 2,6 µm, less than half is above that value. If particle size is less than 2.6 µm then dry deposition velocity is assumed as 0.1 cm/sec, if it is more, dry deposition velocity is assumed as 1 cm/sec. This assumption corresponds well to dry deposition velocity of aerosols for agricultural places presented in Table 3.13.

Release height is another important parameter for subsequent dispersion modeling in HYSPLIT. Literature studies show that variations of the initial plume rise below the mixing height only slightly affect the results outside the local scale, whereas plume rise above that level led to significantly changed patterns with relatively little depositions on the local and meso-scales. Thus, a release into the atmospheric boundary level compared with a release to the free troposphere leads to large differences in the deposition patterns and lifetimes (a week or more) of radionuclides within the atmosphere. Release height was assumed as a line source between 50-250 meter considering all the accident type, release points in the reactor and plume rise. HYSPLIT input data for Cs-137 dispersion modeling is given in Table 3.15.

Table 3.15. HYSPLIT Input Data for Cs-137

Dispersion Simulation for Akkuyu NPP Accident Case Study

Starting time (yy mm dd hh)	05 10 31 00
The number of starting locations (lat, lon, m above ground)	2 42.05 34.57 50 42.05 34.57 250
Total run time (hrs)	360
Direction	forward
Top of model (m)	10.000
Vertical	Isentropic
Setup meteorological files	RP200510.gbl RP200511.gbl
Identification	C137
Emission rate (Bq/hrs)	5.25E+16
Hrs of emission (hrs)	144
Release start (yy mm dd hh min)	00 00 00 00 00
Center (lat, lon)	39.0 35.0
Spacing (lat, lon)	2.5 2.5
Span (lat, lon)	6 17
Output grid directory	./
Output grid filename	cdump
Number of vertical levels	2
Height of the levels (m)	0 10
Sampling start	00 00 00 00
Sampling stop	00 00 00 00
Interval (hrs)	00 24 00
Particel diameter, density, shape	5.0 6.0 1.0
Dry dep.vel (m/s), mol.wght(g), A-ratio, D-ratio, Henry	0.002 0.0 0.0 0.0 0.0
Henry's (M/a), In-cloud, below-cloud (1/s)	1.0E+05 3.2E+05 5.0E-05
Decay half life (day)	10976
Pollutant resuspension rate (1/m)	1.0E-06

3.4.5. Input Parameters Used in DoseCAL

Turkey specific data on feeding regimes of the animals, food consumption, and yields, and sowing and harvesting times of the crops were used to be as much realistic as possible in our case studies.

The information related to the feeding diets of the animals in Turkey has been obtained via expert judgement with personal communication in SANAEM/TAEK and given in Table 3.16.

Table 3.16. Feeding Diet of Animals in Turkey (kg/day)

Feedstuff	Beet	Hay	Silage	Pasture	Conc. feeds*	Hay	Maize silage	Pasture	Conc. feeds*
Marmara	Winter session					Summer session			
Lamb (60 kg)	-	-	-	5	0.5	-	-	5	0.5
Goat (60 kg)	-	-	-	5	0.5	-	-	5	0.5
Cow (500 kg)	-	2	15	5	4	-	-	40	7
Beef cattle	-	1.4	10	3.4	3	-	-	27	5
Black Sea	Winter session					Summer session			
Lamb	-	-	-	5	0.5	-	-	5	0.5
Goat	-	-	-	5	0.5	-	-	5	0.5
Cow(325 kg)	-	1.5	-	7	4	-	-	30	4
Beef cattle	-	-	-	-	3	-	-	20	3
Central Anatolia	Winter session					Summer session			
Lamb	-	-	-	5	0.5	-	-	5	0.5
Goat	-	-	-	-	-	-	-	-	-
Cow (500 kg)	-	3	10	4	12	-	-	30	-
Beef cattle	22.5	2	-	-	3.5	-	-	15	3.5
Mediterranean	Winter session					Summer session			
Lamb	-	-	-	5	0.5	-	-	5	0.5
Goat	-	-	-	5	0.5	-	-	5	0.5
Cow (400 kg)	-	-	-	5	11	-	1	-	11
Beef cattle	-	-	-	3.4	9	-	0.67	-	9
Aegean	Winter session					Summer session			
Lamb	-	-	-	5	0.5	-	-	5	0.5
Goat	-	-	-	5	0.5	-	-	5	0.5
Cow (500 kg)	-	-	-	20	12	-	2.5	2.5	12
Beef cattle	-	--	-	8.5	8	-	1.7	1.7	8
Eastern Anatolia	Winter session					Summer session			
Lamb	-	-	-	5	0.5	-	-	5	0.5
Goat	-	-	-	5	0.5	-	-	5	0.5
Cow (400 kg)	-	-	-	25	7	10	-	15	7
Beef cattle	-	-	-	17	5	6.7	-	10	5
Southeastern Anatolia	Winter session					Summer session			
Lamb	-	-	-	5	0.5	-	-	5	0.5
Goat	-	-	-	5	0.5	-	-	5	0.5
Cow (400 kg)	-	-	-	15	9	1	1	1	9
Beef cattle	-	-	-	10	6	0.67	0.67	0.67	6

Table 3.16. (continued)

Turkey	Winter session (November-march)					Summer session (April-October)			
Lamb				2.5	0.5	-	-	5	0.5
Goat				3.5	0.5	-	-	6	0.5
Dairy cow (400 kg)		2.07	7.14	5	5.7	1.71	0.9	20.7	6.57
Beef cattle	3.32	2	2.3	2.8	4	2.1		15.4	4.36

*Cereals (maize, wheat, barley)

Since Turkey has many climatologically different geographical regions, animal's feeding regimes, namely grazing season, type of feedstuffs and animal weight, vary from region to region; this variation is prominent particularly for dairy cow and beef cattle. For each region, a representative city was selected to provide data; data for Artvin, Şanlıurfa, Çorum, Edirne, Mersin, Muğla and Iğdır were used. In DoseCAL, average data for all regions was used, and demonstrated in the last row of Table 3.16. For beef cattle, the feeding rate is assumed to be 67 % of that of dairy cow. The feeding rate of chicken, lamb and goat is assumed same all over the regions. Chicken's feeding rate is taken as 0.110 kg/day. 30 % is soy and 70 % is maize of the feedstuffs, and 50 % of feedstuffs of chickens are assumed to be imported, the remaining is native. Lamb and goat weight and feeding regime are assumed to have same characteristics.

Yields for grouped agricultural products in Turkey have been calculated by data taken from Turkish Statistics Institute's (TUIK) web page; yields of single type of crops have been directly taken from TUIK's web page and demonstrated in Table 3.17. Food sowing and harvesting times largely depend on geographical areas of Turkey and each type of the vegetable or fruit, which are not easy to take into account in DoseCAL. This information for even the same type of fruit or vegetable may differ considering the large differences in Turkey's agricultural pattern. For example in Bursa, Akça pear is harvested in last week of June and first week of July, however Deveci pear is harvested in last week of September and first week of October. Generic approach had to be assumed to represent the whole country and given in this Table. All of the vegetables, crops and fruits have been assumed to grown in open areas, i.e. those grown in greenhouse are not considered.

Table 3.17. Yields and Harvesting Times of Grass, Agricultural Crops and Feedstuffs in Turkey

Pasture grass & Crops	Yield (kg/m^2)	Harvesting Time
Pasture grass	1.5	01.04-31.10
Cereals	0.326	01.06-31.07
Maize silage	4.6	01.06-31.07
Berry	1.24	01.05-30.06
Non-berry fruits	7.74	01.11-28.02
Beet	5.48	01.11-01.12
Potatoes	2.54	01.08-01.09
Root vegetables	4.11	01.08-01.09
Fruit vegetables	6.19	01.10-31.10
Leafy vegetables	2.42	01.10-01.05

For consumption data of the foods, most of which can be modeled by DoseCAL, questionnaires were conducted; such that approximately 20 samples from each geographical region were surveyed. The minimum, average and maximum values of the survey results are given in Table 3.18.

For this study, average values all over the geographical regions were taken into account, since data does not vary considerably over the regions. On the other hand, household interview survey for people living in all residential areas in Turkey were conducted in 2003 by TÜİK. The results of these TÜİK survey have been compared with aforementioned food consumption survey conducted and comparison results are given in Table 3.19. As seen from the table, except for cereals, consumption of other food products is approximately in the same order. Hence, the results of TÜİK statistics have been used in this study due to its reliability, except data on cereals was taken from survey conducted for this study, not from TÜİK statistics.

Transfer factors for animal-feeds and soil-plants, and fixation rates, distribution coefficients, translocation factors, dose conversion factors and metabolic turnover rates in animals for all related isotopes, and processing factors and storage days for food products, weathering rates, interception factors and soil density, water content of soil, percolation water velocity, dilution factor of the grass, depth of root zone, the references in which Cs-137 default values were taken for validation study, were used in DoseCAL during simulation of the case studies. Since most of these data are not dependent on location.

Table 3.18. Survey Results on Food Consumption for Turkish People (kg/d)

Foods	Cereal	Pulse	Cake-Pastry	Goat Milk	Cow Milk	Cheese	Yogurt-ayran	Potatoe	Root Vegetables	Leafy Vegetables	Fruit Vegetables	Non-Berry fruits	Berries	Beet	Beef	Lamb	Goat	Chicken	Egg	Butter	Fish
Central Anatolia/ # of sample:31																					
Avg.	0.193	0.046	0.045	0.214	0.216	0.079	0.155	0.038	0.067	0.148	0.133	0.283	0.054	0.004	0.074	0.011	0	0.044	0.027	0.011	0.026
Max.	0.800	0.200	0.250	0.400	0.600	0.500	0.400	0.100	0.142	0.600	0.300	0.600	0.138	0.004	0.500	0.014	0	0.171	0.060	0.043	0.107
Min.	0.014	0.005	0.003	0.100	0.029	0.003	0.007	0.003	0.008	0.005	0.014	0.005	1.4E-5	0.004	0.007	0.008	0	0.003	0.003	0.001	0.001
Egaean Region/ # of Sample: 16																					
Avg.	0.348	0.083	0.096	0.143	0.270	0.108	0.311	0.175	0.212	0.226	0.233	0.277	0.077	0.074	0.072	0.094	0.012	0.109	0.060	0.034	0.066
Max.	0.843	0.286	0.286	0.143	0.500	0.288	2.140	0.429	0.714	0.714	0.428	0.500	0.143	0.143	0.214	0.143	0.016	0.428	0.143	0.071	0.119
Min.	0.118	0.008	0.014	0.143	0.071	0.016	0.016	0.016	0.0165	0.025	0.071	0.143	0.022	0.008	0.010	0.016	0.007	0.01	0.003	0.008	0.005
Black Sea Region/# of Sample: 18																					
Avg.	0.200	0.017	0.049	0	0.042	0.043	0.107	0.074	0.120	0.073	0.380	0.230	0.289	0	0.028	0	0	0.055	0.022	0.009	0.040
Max.	0.689	0.038	0.143	0	0.067	0.057	0.200	0.143	0.229	0.334	0.593	0.345	0.480	0	0.071	0	0	0.214	0.050	0.014	0.083
Min.	0.058	0.003	0.014	0	0.033	0.007	0.029	0.021	0.066	0.02	0.24	0.188	0.188	0	0.018	0	0	0.018	0.005	0.002	0.012
Mediterrenaen Region/ # of Sample: 15																					
Avg.	0.135	0.029	0.030	0.285	0.188	0.102	0.083	0.041	0.088	0.103	0.293	0.251	0.051	0	0.057	0.032	0.033	0.071	0.033	0.054	0.035
Max.	0.516	0.071	0.120	0.285	0.367	0.428	0.400	0.143	0.330	0.400	0.800	0.750	0.072	0	0.200	0.057	0.033	0.200	0.100	0.142	0.107
Min.	0.013	0.008	0.008	0.285	0.013	0.007	0.033	0.003	0.007	0.008	0.016	0.027	0.009	0	0.017	0.013	0.033	0.014	0.007	0.001	0.006
Marmara Region/ # of Sample: 19																					
Avg.	0.182	0.075	0.077	0	0.150	0.078	0.109	0.108	0.080	0.138	0.262	0.276	0.073	0.033	0.074	0.033	0.013	0.083	0.032	0.014	0.034
Max.	0.48	0.501	0.214	0	0.400	0.285	0.250	0.714	0.228	0.857	0.663	0.900	0.186	0.033	0.167	0.071	0.014	0.248	0.06	0.025	0.107
Min.	0.03	0.007	0.010	0	0.029	0.02	0.057	0.014	0.005	0.006	0.014	0.067	0.014	0.033	0.007	0.013	0.01	0.007	0.014	0.003	0.010
Eastern Anatolia Region/ # of Sample: 20																					
Avg.	0.670	0.097	0.015	0	0.107	0.071	0.066	0.132	0.180	0.135	0.686	0.334	0.065	0	0.056	0.063	0	0.068	0.030	0.005	0.035
Max.	1.066	0.133	0.033	0	0.286	0.100	0.133	0.286	0.303	0.266	0.99	0.334	0.16	0	0.143	0.143	0	0.143	0.050	0.017	0.107
Min.	0.670	0.097	0.015	0	0.107	0.071	0.066	0.132	0.180	0.135	0.686	0.334	0.065	0	0.056	0.063	0	0.068	0.030	0.005	0.035
OVERALL																					
Avg.	0.212	0.050	0.059	0.128	0.173	0.082	0.153	0.087	0.113	0.137	0.260	2.220	0.109	0.022	0.061	0.034	0.011	0.072	0.035	0.024	0.040
Max.	0.666	0.219	0.203	0.166	0.387	0.312	0.678	0.306	0.329	0.581	0.557	57.299	0.204	0.036	0.230	0.057	0.013	0.252	0.083	0.060	0.105
Min.	0.047	0.006	0.010	0.106	0.035	0.010	0.028	0.012	0.020	0.013	0.071	0.086	0.046	0.0091	0.012	0.010	0.010	0.010	0.007	0.003	0.007

Table 3.19. Food Consumption Data (kg/d)

Survey Conducted for This Study vs. TÜİK Statistics

Food	**Cereal**	**Pulse**	**Goat milk**	**Cow milk**	**Leafy vegetables**	**Potatoes**	**Root vegetables**
TUIK	1.017	0.044	-	0.269	0.054	0.200	0.125
Survey	0.269	0.059	0.107	0.167	0.137	0.100	0.106
Food	**Fruit vegetables**	**Fruits (Non-berry)**	**Berry**	**Beet**	**Beef**	**Lamb**	**Goat**
TUIK	0.523	0.423	0.053	0.002	0.04	0.02	0.005
Survey	0.234	0.273	0.131	0.029	0.051	0.036	0.016
Food	**Butter**	**Fish**	**Yogurt-ayran**	**Cake-pastry**	**Cheese**	**Egg**	**Chicken**
TUIK	0.008	0.025	0.148	0.023	0.063	0.052	0.056
Survey	0.025	0.036	0.154	0.055	0.069	0.034	0.060

3.5. Sensitivity and Uncertainty Analyses

In uncertainty analysis, random sampling techniques have been applied in this study due to its superiority or preference over deterministic methods addressed in Chapter 2.5. Oracle Crystal Ball (CB) Program has been used for genereting n sets of random parameters by LHS method. The probability distribution type of the input parameters was the input to CB program. The uniform distribution has been assumed for all of the inputs, since in many literature studies where there is information, for most of the inputs it is given as uniform.

The probabilistic module of DoseCAL code was written in Visual Basic language for running n numbers of parameters. The applied method in this study is to vary all uncertain parameters simultaneously. Number of calculations has been determined by Wilk's formula (Wilks, S. S., 1941, 1942):

$$1 - an - n(1 - a)a(n-1) = b \qquad (3.22)$$

n is the number required calculations,

b is the confidence level (%),

a is the tolerance limit.

Because the number of calculations is independent of the number of uncertain parameters, ranking of input parameters is not necessary to reduce their number. The required number n of code runs for different confidence and tolerance limits is taken from IAEA (2008) and is given in Table 3.20. 90 % and 95 % as tolerance and confidence limits have been set, respectively for this study. The minimum number of calculation was found out to be 77. By rounding, 100 simulations have been performed for this study. The results have been statistically analyzed and processed leading to probability distributions of the model results.

For uncertainty analysis three radioisotopes, i.e. Cs-134, Cs-137 and I-131 have been studied, since their contribution to the total dose is high, more than 90 % in the first year, more than 95% during lifetime and can be seen in Table 4.7. The minimum, maximum, and various percentile doses, activity concentrations in grass and foods have been calculated among the 100 simulations. The end points of the uncertainty analysis are radionuclide concentrations in grass, foodstuffs, and adult doses.

The sensitivity analysis of input parameters associated with the transfer processes of radionuclides and dose calculation in DoseCAL is performed again using a Latine Hypercube Sampling (LHS) technique based on a Monte Carlo approach.

Minitab 17 Statistical Software was used to calculate spearman correlation coefficients for sensitivity analysis. As stated in Chapter 2.5.1 correlation coefficients provide a meaningful measure of the degree to which inputs and outputs change together, and if the relationship between an input and an output is nonlinear but monotonic, as in the case of dose modeling algotirhm in DoseCAL model, Spearman correlation coefficients based upon rank transformed values of an input and an output provides better performance compared to Pearson correlation coefficients (Gibbons 1985, Siegel and Castellan 1988, and Kendall 1990). If an input and an output have a high correlation coefficient, it means that the input has a significant impact on the ouput (through both its uncertainty and its model sensitivity). Positive coefficients indicate that an increase in the input is associated with an increase in the output. Negative coefficients imply the opposite situation. The larger the absolute value of the correlation coefficient, the greater the sensitivity. The end point of the sensitivity analysis is short-term and lifetime doses for adults.

Table 3.20. The Minimum Number of Calculations

Confidence / tolerance limit	0.90	0.95	0.99
0.90	38	77	388
0.95	46	93	473
0.99	64	130	662

It is not possible to study all of the model input parameters; instead, the parameters giving rise to most of the dose exposure were selected for both uncertainty and sensitivity (S&U) analyses. S&U analyses have been performed for only hypothetical accident occured at Akkuyu NPP for adults with average individual habits. For sensitivity and uncertainty analysis, spatial variability of the doses have not been considered, namely only one grid point where the deposition is the maximum, i.e. the source location was considered. In the sensitivity and uncertainty analyses, the starting time of the release was set as the time leading to maximum dose exposure for Akkuyu NPP accident case study, which is stated in Chapter 4.2.1.1.

According to Figure 4.24 which gives contribution of activity in foods to total dose in the case of hypothetical accident at Akkuyu NPP; cereals, fruit vegetables, fruits, beef, chicken, lamb and cow milk were studied for uncertainty analysis. These foodstuffs contribute to total dose more than 95%. Apart from these, grass, wheat and maize are also included as they are feedstuffs of cows and cattles. Furthermore, inhalation rate and reduction factor also studied. Total 96 parameters, which are related with those foodstuffs and feedstuffs and Cs-137, Cs-134 and I-131 isotopes, have been studied for their contribution to uncertainty. The references regarding the mean values of parameters used in calculating radiological consequences of a hypothetical accident at Akkuyu NPP by DoseCAL have already been described in Chapter 3.2. The choices of ranges were based on information obtained from the literature and personel judgement.

Lower and upper bounds of food consumption rates were taken from questionarry results; yield of crops were taken from TUIK statistics; fraction of activity translocated to root-zone, growth dilution rate for grass in may, weathering half life in the grass, water percolation velocity, short and long biological half life of cesium in cow milk, fraction of short life of cesium in cow milk were taken from Ecosys-87 (1993); feeding rates of the animals were evaluated by SANAEM; soil-plant transfer factors for cesium and iodine, translocation factors for plants, and distribution coefficient for cesium and iodine, transfer factors for feed-animals, storage times for food products, processing factor for fruits were taken from IAEA TRS-472 (2010), inhalation rate of adult were taken from ICRP publications (1981 and 1975), fixation rate of Cs in soil are taken from EUR-18826 (2001); soil density in plant rooting zone, water percolation velocity are taken from both Ecosys-87 (1993) and IAEA TECDOC-904 (1996); biological half life of cesium in beef were taken from ECOPATH and CRISS (Bergstrom U., Nonttinder S., 1981 and Hermann O.W., et.al, 1984); biological half life of iodine in cow milk were taken from IAEA (Report of the Chernobyl I-131 Release Working Group of EMRAS Theme 1); interception fraction of grass were taken from CRLP and SPADE (Krcgewski P., 1989, Johnson R.H. and Mitchell N.G., 1993). Since most of the Turkey's soil type, 50.49 % of the whole area, is covered by loam type of soil (Eyüpoğlu, F., 1999., Mülga Köy Hizmetleri Genel Müdürlüğü, Genel Yayın No: 220), minimum and maximum values of of soil-plant transfer factors for loam type of soil were taken from IAEA TRS-472 (2010).

Lower and upper bounds of yield of fruit vegetables were assumed to be yield of eggplant and green pepper, and minimum and maximum values of yield of fruits were assumed to be yield of apple and banana respectively.

For those parameters not mentioned above and whose upper and lower bounds cannot be found in the literature, the range given in the literature for similar parameters was used to derive their maximum and minimum values, for instance range of interception fraction for grain was derived from that of grass, range of biological half life of cesium in lamb and chicken were assumed to be derived from that of beef, reduction factor for exernal radiation etc. The lower and upper bounds of yield of grass are assumed as 50 % ± around the mean.

The correlation relationships between input parameters were not considered in both S&U analyses. Because most of the parameter values provided from the literatures are experimental results under a variety of conditions (W. T. Hwang et al., 1998). The parameters, which are not derived experimentally and still may need correlation, consist of food consumption and feeding rates. It was also assumed that the input parameters associated with natural ecosystems such as sowing and harvesting times of the plants, starting and ending of grazing season are fixed in the analysis (W. T. Hwang et al., 1998), since they strongly need to be correlated to each other. However, regarding to these parameters related to natural ecosystems, DoseCAL model was run at different times in a year for both case studies to ascertain the influence of plants' vegetation cycle and grazing season of the animals on the human doses, as stated in Chapter 4.2.1.1 and 4.2.2.1.

Probability distribution type of all uncertain parameters are assumed to be linear, since distribution of most of them found in the relevant literature; Dynacon and Ecosys-87 (Hwang et.a al., 1998, Müller, H. and Pröhl, G., 1993) is linear.

The parameters, and their mean and upper and lower bounds used in S&U analyses are given in Table 3.21.

Table 3.21. The Parameters, Their Mean, Minimum and Maximum Values Used in S&U Analyses in DoseCAL

Parameter	**Min.**	**Max.**	**Mean**
Reduction factor for adult	0.15	0.54	0.27
Inhalation rate for adult (m^3/hr)	0.616	1.2	0.913
Interception fraction for grass	0.12	0.7	0.3
Interception fraction for grain	0.002	0.0116	0.005
Interception factor for other crops	0.12	0.7	0.3
Grain consumption (kg/day)	0.1505	0.7323	0.269
Fruit (non-berry) consumption (kg/day)	0.1276	0.5715	0.423
Cow milk consumption (kg/day)	0.047	0.37	0.268
Lamb consumption (kg/day)	0.010	0.057	0.02
Beef consumption (kg/day)	0.019097	0.2179	0.04
Chicken consumption (kg/day)	0.01909	0.07142	0.0557
Transfer factor for grass for Cs	0.01	2.6	0.051
Transfer factor for silage for Cs	0.008	0.2	0.021
Transfer factor for hay for Cs	0.008	0.2	0.021
Transfer factor for cereals for Cs	0.008	0.2	0.021
Transfer factor for fruits for Cs	0.0063	0.33	0.021
Transfer factor for fruit vegetables for Cs	0.0063	0.3	1.10E-02
Transfer factor for grass for I	0.0009	0.5	1.01E-01
Transfer factor for hay for I	0.007	0.2	0.101
Transfer factor for maize silage for I	0.007	0.2	0.101
Transfer factor for cereals for I	0.007	0.2	1.01E-01
Transfer factor for fruits for I	0.0011	0.101	1.01E-01
Transfer factor for fruit vegetables for I	0.0011	0.101	1.01E-01
Fraction of activity translocated to rootzone	0.90	0.99	0.95
Fixation of Cs in soil (d^{-1})	0.0000655	0.012	0.00022
Yield of grass	2.0	1.0	1.5
Yield of maize	3.05	5.4	4.6
Yield of rye	0.265	0.416	0.326

Table 3.21. The Parameters, Their Mean, Minimum and Maximum Values Used in S&U Analyses in DoseCAL

Parameter	Min.	Max.	Mean
Yield of wheat	0.278	0.624	0.326
Yield of fruits	6.966	8.514	7.74
Yield of fruit vegetables	0.324	23.038	6.19
Yield of cereals	0.906	0.15	0.326
Transfer factor for cow milk for Cs ($d.L^{-1}$)	0.0006	0.068	0.0079
Transfer factor for lamb for Cs ($d.kg^{-1}$)	0.053	1.3	0.2
Transfer factor for cattle for Cs ($d.kg^{-1}$)	0.0047	0.096	0.051
Transfer factor for chicken for Cs ($d.kg^{-1}$)	0.3	12	12
Transfer factor for cow milk for I ($d.L^{-1}$)	0.0004	0.025	0.01
Transfer factor for lamb for I ($d.kg^{-1}$)	0.00786	0.15	0.0275
Transfer factor for beef cattle for I ($d.kg^{-1}$)	0.002	0.038	0.007
Transfer factor for chicken for I ($d.kg^{-1}$)	0.004	0.015	0.087
Translocation factor for cereals	0.0055	0.1	0.075
Translocation factor for hay	0.0055	0.1	0.075
Translocation factor for fruits	0.001	0.1	0.02
Translocation factor for fruit vegetables	0.001	0.1	0.02
Weathering half life in the grass (d)	8	25	14 d
Growth dilution rate for grass in may (d^{-1})	0.0347	0.042	0.0385
Water percolation velocity (m/yr)	1.56	15.6	2
Distribution coefficient for Cs (cm^3/gr)	370	1200	1000
Distribution coefficient for I (cm^3/gr)	0.02	580	100
Soil density in plant rooting zone (kg/m^3)	700	1650	1400
Hay feeding rate of cow in summer (kg/d)	1	3	1.71
Grass feeding rate of cow in summer (kg/d)	10	35	20.7
Silage feeding rate of cow in summer (kg/d)	0	6	0.9
Concentrates feeding rate of cow (kg/d)	3	10	6.57
Hay feeding rate of cow in winter (kg/d)	1.5	3	2.07
Grass feeding rate of cow in winter (kg/d)	3	7	5
Silage feeding rate of cow in winter (kg/d)	10	15	7.14
Concentrates feeding rate of cow (kg/d)	4	8	5.7
Grass feeding rate of sheep in summer (kg/d)	4.5	5.5	5
Concentrates feeding rate of sheep (kg/d)	0.45	0.55	0.5
Grass feeding rate of sheep in winter (kg/d)	2.25	2.75	2.5
Hay feeding rate of cattle in summer (kg/d)	2	3	2.1
Grass feeding rate of cattle in summer (kg/d)	6	27	15.4
Maize feeding rate of cattle in summer (kg/d)	0.67	1.7	0.9
Concentrates feeding rate of cattle (kg/d)	3	6	4.36
Hay feeding rate of cattle in winter (kg/d)	1.4	3	2
Grass feeding rates of cattle in winter (kg/d)	2	6	2.8
Silage feeding rate of cattle in winter (kg/d)	0	10	2.3
Concentrates feeding rate of cattle (kg/d)	2	7	4
Short biological half life of Cs in milk (d)	1.31	1.68	1.5
Long biological half life of Cs in milk (d)	10	20	15
Fraction of short biological half life of Cs in milk	0.7	0.9	0.8
Biological half life of Cs in beef (d)	14	100	30

Table 3.21. The Parameters, Their Mean, Minimum and Maximum Values Used in S&U Analyses in DoseCAL (continued)

Parameter	Min.	Max.	Mean
Biological half life of Cs in lamb (d)	9.33	66.7	20
Biological half life of Cs in chicken (d)	9.33	66.7	20
Biological half life of I in cow milk (d)	0.6	0.8	0.7
Biological half life of I in beef (d)	100	495	100
Biological half life of I in lamb (d)	100	495	100
Biological half life of I in chicken (d)	100	495	100
Storage time for rye (d)	45	365	180
Storage time for maize (d)	45	365	180
Storage time for wheat (d)	45	365	180
Storage time for fruits (d)	0	240	90
Storage time for fruit vegetables (d)	2	14	7
Storage time for cow milk (d)	1	6	2
Storage time for lamb (d)	2	7	4
Storage time for beef (d)	14	28	20
Storage time for chicken (d)	2	7	4
Processing factor for rye	0.4	0.6	0.5
Processing factor for wheat	0.4	0.6	0.5
Processing factor for fruits	0.6	1	0.8
Processing factor for fruit vegetables	0.6	1	0.8
Processing factor for cow milk	0.75	1.25	1
Processing factor for lamb	0.75	1.25	1
Processing factor for beef	0.75	1.25	1
Processing factor for chicken	0.75	1.25	1

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1. The Results of Validation of DoseCAL

The doses and time dependant radioactivity concentration values in the food products and pasture grass predicted by DoseCAL have been compared with those of different codes, which participated in VAMP assessment task, and data measured in Helsinki, Finland after Chernobyl accident. Those codes are dynamic (time-dependant), and only one of them; i.e. RESRAD, is quasi-equilibrium. Since DoseCAL is developed as dynamic software, only dynamic codes' results are presented for comparison.

The activity concentration results in the pasture, cow milk, beef and leafy vegetables, rye and wheat are given in Figure 4.1, 4.2, 4.3 and Table 4.1, 4.2 and 4.3. Validation for the individual dose results are given in Table 4.4.

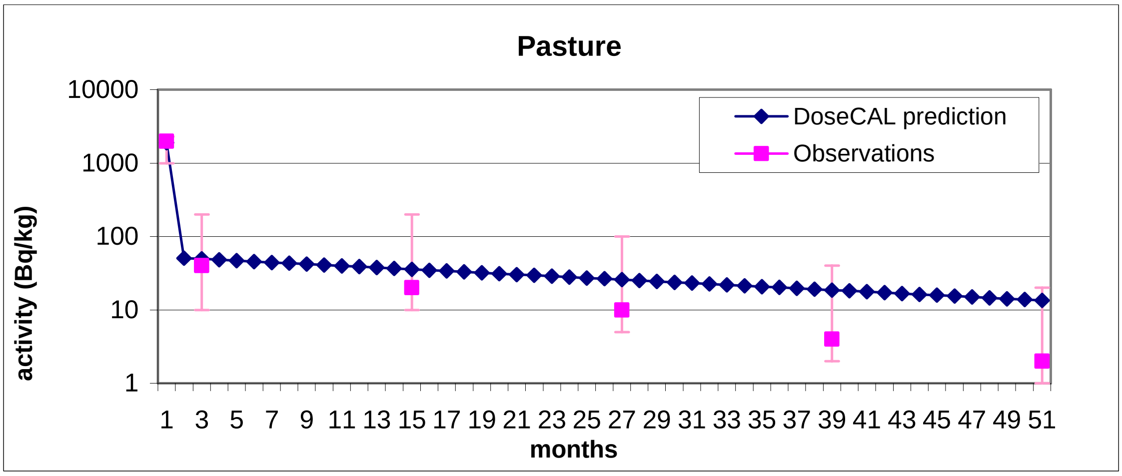

Figure 4.1. Cs-137 Activity Concentrations in Pasture

Two-tailed T-test was applied to observed and predicted values to evaluate the acceptability of the DoseCAL results. The higher the probability, the more likely it is that observed and predicted values are the same, and that any differences are just due to random chance. If the probability for T-test (p-value) is higher than 0.05 then the two sets are the same, if the p value is higher than 0.1 then there is no presumption against the null hypothesis which states that "there is no difference between observed and predicted values".

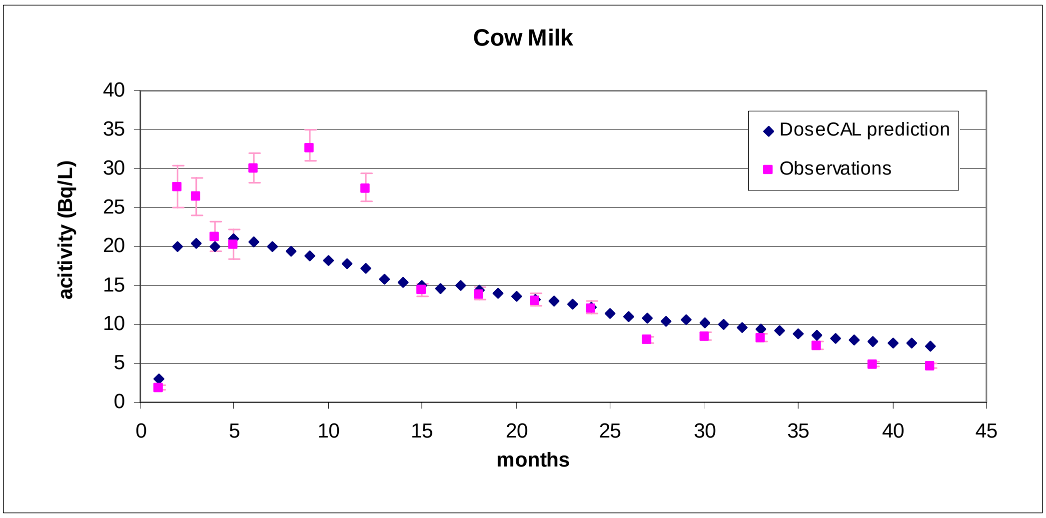

Figure 4.2. Cs-137 Activity Concentrations in Cow Milk

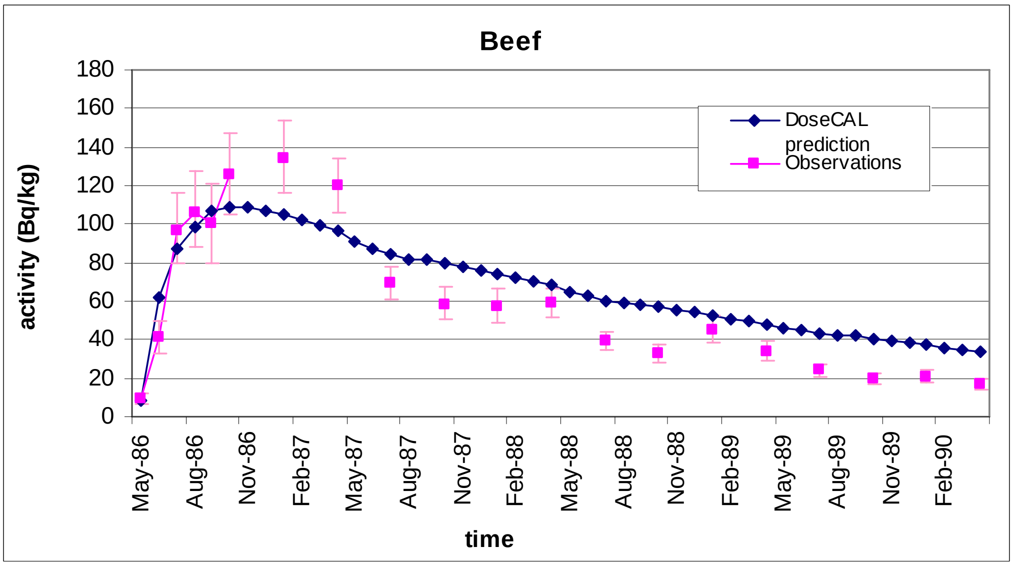

Figure 4.3. Cs-137 Activity Concentrations in Beef

The results for pasture, cow milk and beef of other codes can be seen in Figures 4.4, 4.5 and 4.6. Within Scenario S region, mean concentrations of Cs-137 in pasture range from 2300 Bq/kg in May 1986 to a low near 1 Bq/kg in July 1990. Pasture activity is very high in the first few months when the foliar uptake is dominant, then the grass is contaminated due to root uptake, and the activity decreases in time due to weathering, radioactive decay, dilution rate, rate of activity decrease translocated to the root zone.

Pasture activity is over estimated 1 year after the accident by DoseCAL compared to the measurements. In the first year, the predictions are quite convincing. Pasture vegetation was surveyed in May 1986 at sixty farms. Sampling was repeated a few times in May in most of the locations. After the spring of 1986 pasture vegetation was not surveyed in a representative way and only sporadic observations are available (IAEA TEC-DOC 904, 1996). However, the probability for T-test for pasture is 0.941, which is very close to one, and means that validation results for pasture are quite convincing.

Within Scenario S region, mean concentrations of Cs-137 in milk range from 30.47 Bq/L in June 1986 to a low near 2.73 Bq/L at the last quarter of 1990. Mean concentrations of Cs-137 in beef range from 134 Bq/kg at the first quarter of 1987 to a low near 9.96 Bq/kg at the last quarter of 1990. In the first month, after the accident, cows and cattles were still fed with uncontaminated feedstuffs. During this period, about only one per cent of dairy cows were fed new grass. In June 1986, the activity concentrations increased then steadily decreased due to radioactive and biological decay. The activity in milk and beef by DoseCAL predictions are consistent with the other code predictions given in Figure 4.4 and 4.5, the estimations of DoseCAL are comparable to the measurements, with some points outside the uncertainty band. The probability for T-test for milk and beef are 0.498 and 0.516 respectively; p-values are still higher than 0.1.

Activity concentration values in the crops and grass are given as fresh weight in DoseCAL and the observations were reported on a fresh weight basis, as well. For 1986, Cs-137 concentrations were about 5 Bq/kg for wheat and 30 Bq/kg for rye. By 1987, the mean concentrations of Cs-137 for both plant species dropped about one order of magnitude; thereafter annual mean concentrations decreased only marginally (to about 0.3 Bq/kg for wheat and 1 Bq/kg for rye by 1990).

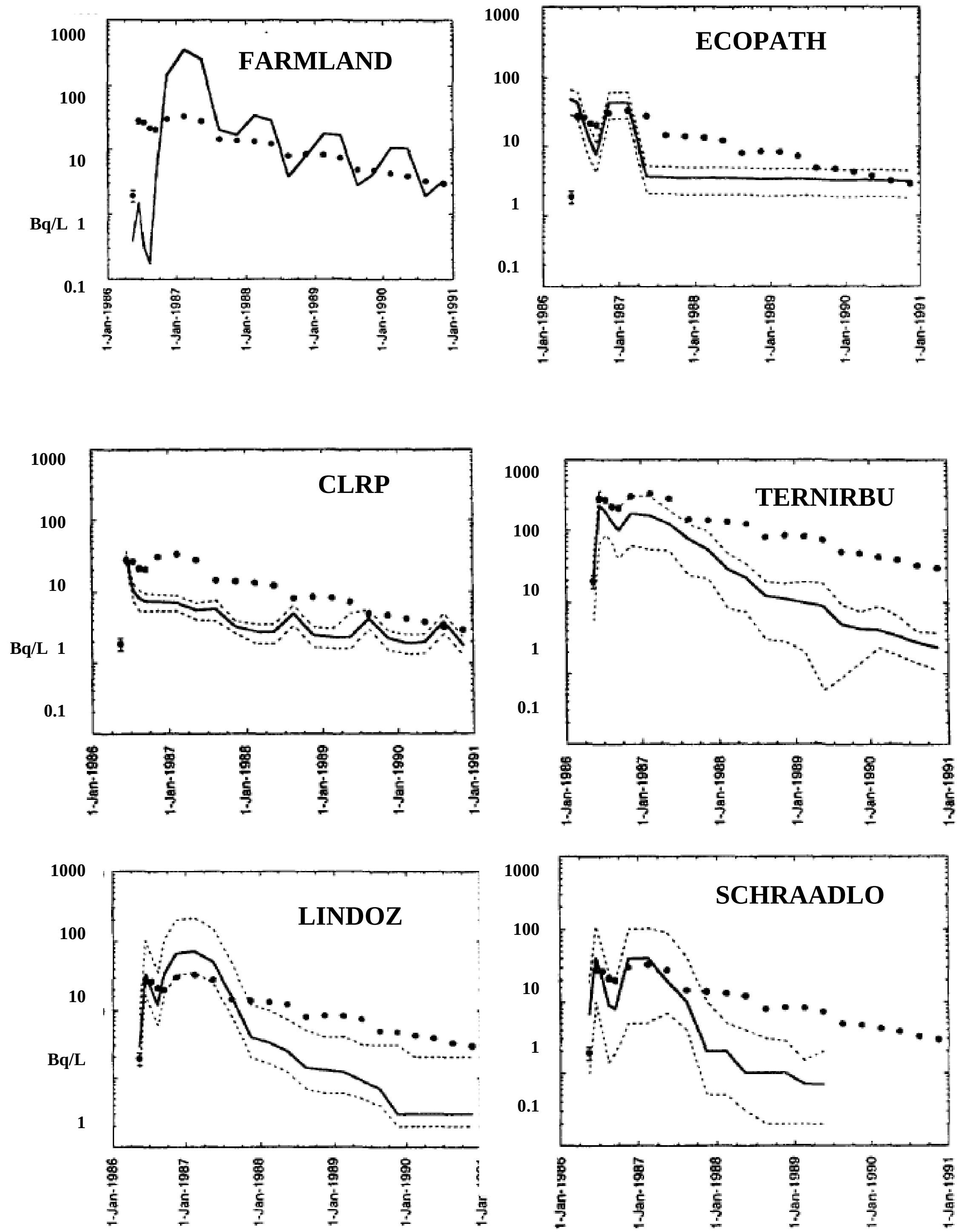

Figure 4.4. Average Activity Concentrations in Milk Predicted by Different Models Vertical bars indicate 95 % confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95 % subjective confidence interval about the mean prediction (solid line)

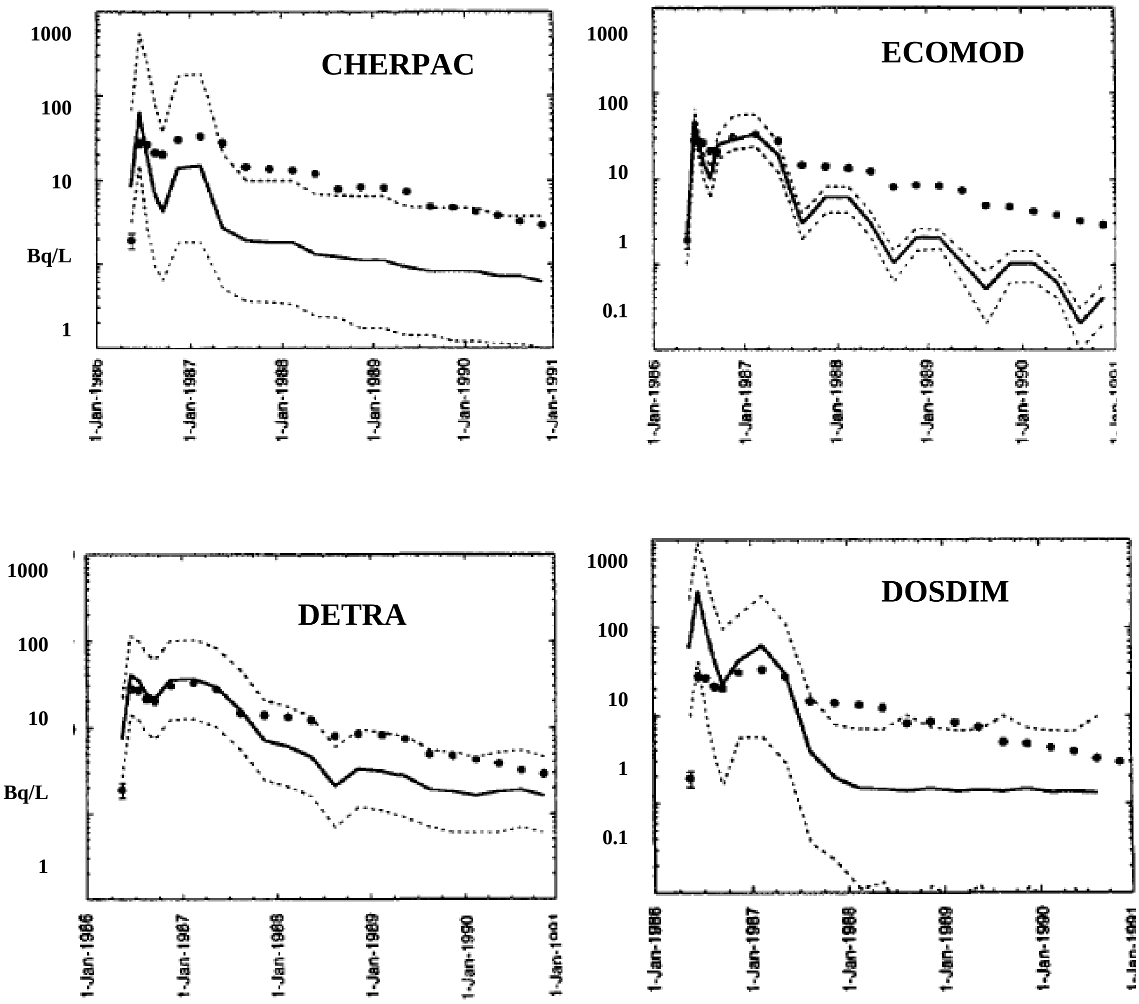

Figure 4.4. (continued)

Rye was considered as 100 % winter grain in DoseCAL according to scenario S (IAEA TECDOC-904, 1996). Since rye is the only plant on the field in the fallout time (with grass) rye concentration is higher than the other crops at the harvest time of 1986 as expected. DoseCAL predictions of rye as compared to the other code predictions are amongst the bests. The probability for T-test for rye is 0.822. Due to the assumption that no wheat was sown until 20 May and therefore the effects of direct deposition and translocation were not seen for wheat; activity is dominated only by root uptake. Wheat concentrations decrease in time due to radioactive decay, fixation in soil and migration to the root zone. Wheat concentrations predicted by DoseCAL after 1986 harvest is higher than both the measured values and the average of other code predictions. The probability for T-test for wheat is 0.290; p-value is still higher than 0.1.

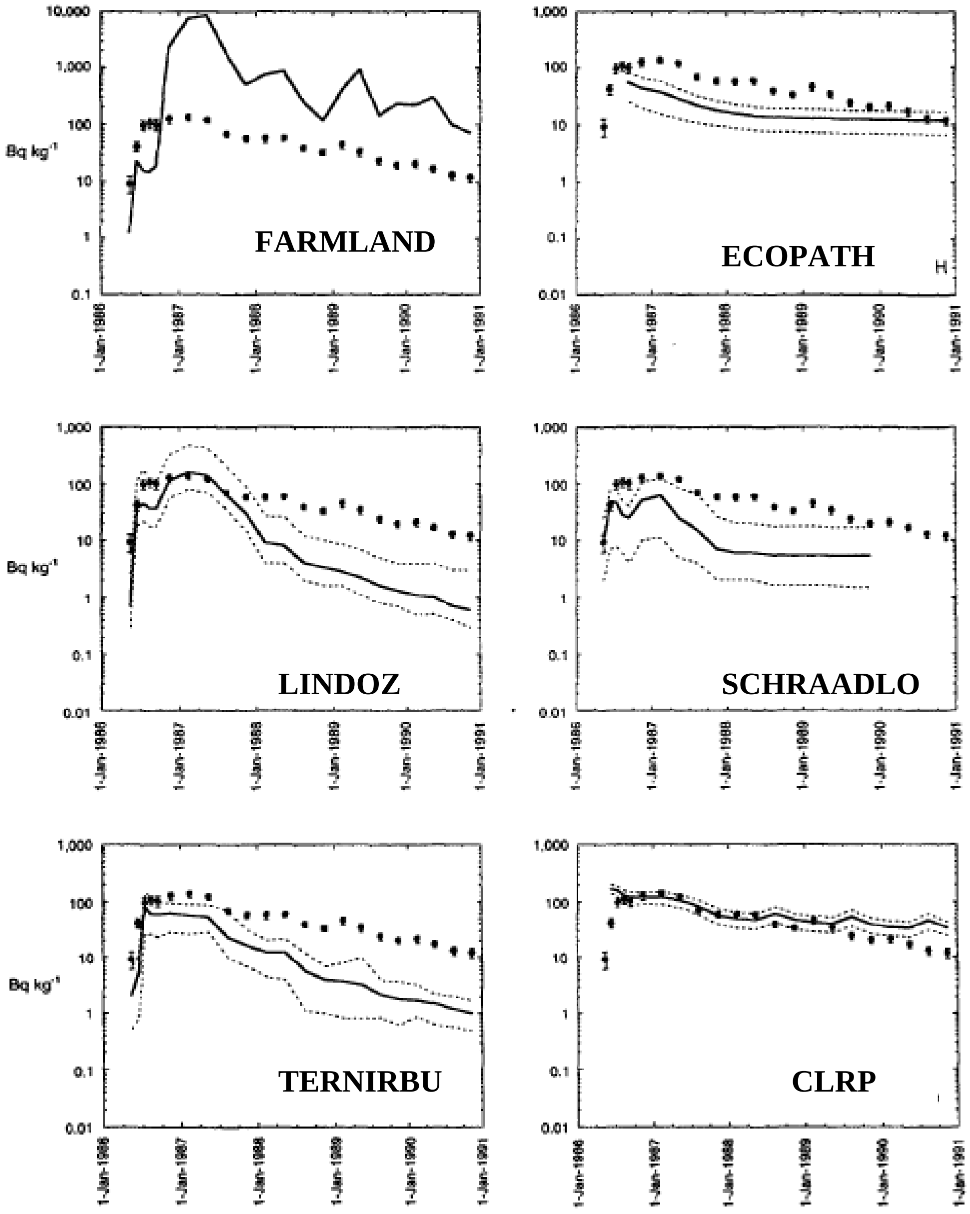

Figure 4.5. Average Concentrations in Beef Predicted by Different Models

Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line).

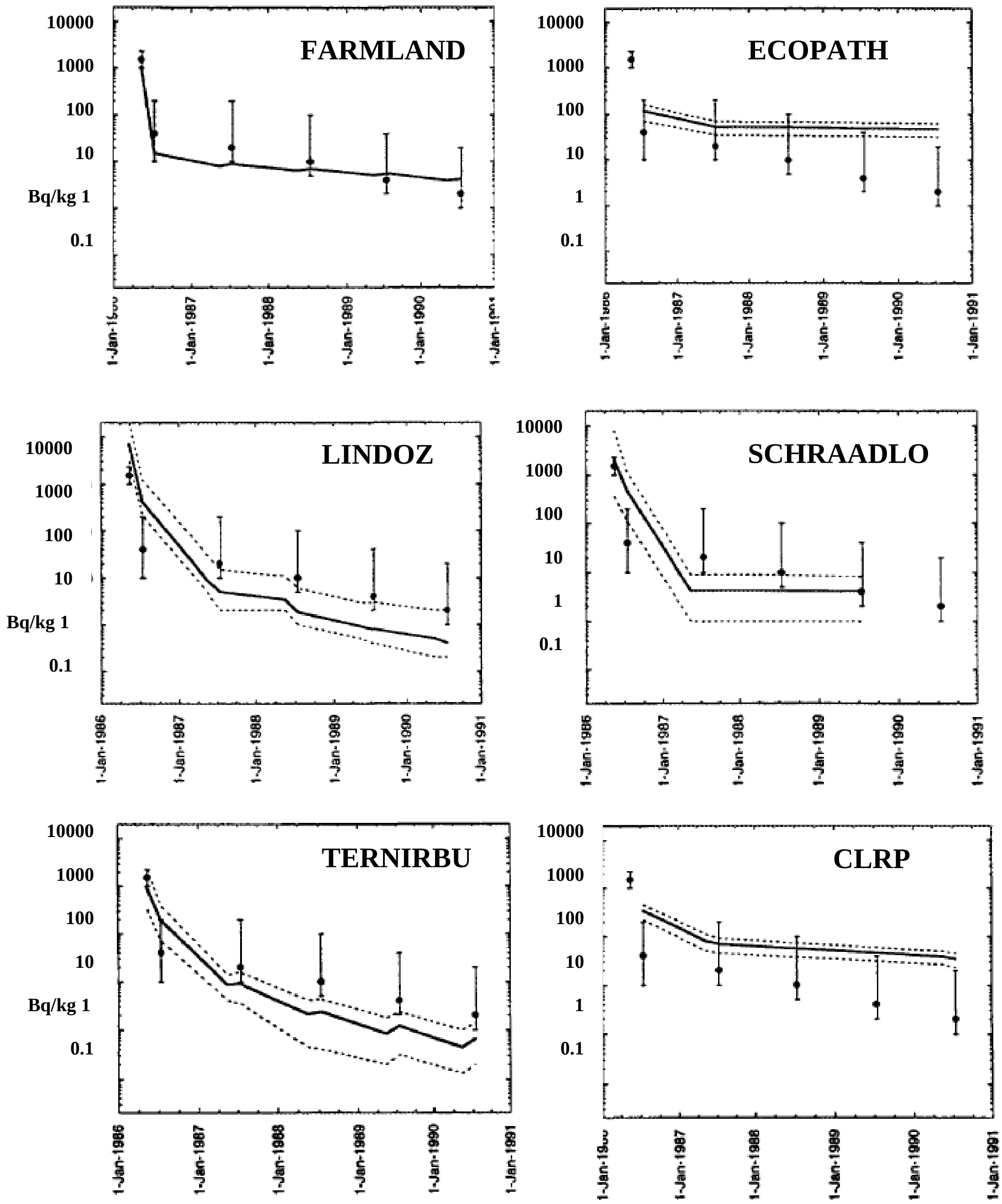

Figure 4.6. Average Concentrations in Pasture Predicted by Different Models

Vertical bars indicate 95% confidence intervals on the mean value of observations (dark circles); dashed lines indicate the 95% subjective confidence interval about the mean prediction (solid line)

Table 4.1. Concentrations of Cs-137 in Rye

Rye (Bq/kg)	Code Predictions				
Codes	1986 harvest	1987 harvest	1988 harvest	1989 harvest	1990 harvest
DoseCAL	21.1	2.2	1.95	1.8	1.6
FARMLAND	0.42	0.41	0.40	0.39	0.38
ECOMOD	4.30	3.40	3.40	2.60	1.70
LINDOZ	60.50	1.30	1.20	1.10	1.00
SCRAADLO	29	1.70	1.60	1.60	1.50
TERNIRBU	32	0.89	0.72	0.72	0.65
CRLP	34	0.50	0.30	0.25	0.21
CHERPAC	19	0.84	0.82	0.79	0.77
DETRA	28	0.40	0.38	0.36	0.34
DOSDIM	214	1.94	1.89	1.85	1.80
ECOSAFE	25.70	18.10	13.20	9.91	7.63
Observations					
Mean	28	2.8	3.5	1	1
Lower	14	1.96	2.45	0.80	0.70
Upper	44.80	3.36	4.55	1.40	1.40

Table 4.2. Concentrations of Cs-137 in Wheat

Wheat (Bq/kg)	Code Predictions				
Codes	1986 harvest	1987 harvest	1988 harvest	1989 harvest	1990 harvest
DoseCAL	4.49	2.35	2.11	1.90	1.71
FARMLAND	0.37	0.36	0.35	0.34	0.33
ECOMOD	6.90	5.20	4.30	4.30	2.60
LINDOZ	10.20	0.80	0.70	0.70	0.60
SCRAADLO	13.00	1.60	1.60	1.60	1.50
TERNIRBU	7.20	0.70	0.56	0.57	0.50
CRLP	4.90	0.40	0.30	0.20	0.20
CHERPAC	3.60	0.54	0.53	0.51	0.50
DETRA	2.40	0.30	0.29	0.27	0.26
DOSDIM	2.05	2.00	1.97	1.91	1.86
ECOSAFE	25.70	18.10	13.20	9.91	7.63
Observations					
Mean	4.9	0.53	0.57	0.4	0.26
Lower	3.43	0.37	0.40	0.32	0.18
Upper	7.35	0.74	0.80	0.60	0.39

Table 4.3. Concentrations of Cs-137 in Leafy Vegetables

Leafy vegetables (Bq/kg)	Code Predictions				
Codes	1986 harvest	1987 harvest	1988 harvest	1989 harvest	1990 harvest
DoseCAL	2.66	2.39	2.15	1.90	1.7
FARMLAND	47	0.32	0.29	0.27	0.27
ECOMOD	2.10	1.40	0.80	0.50	0.20
LINDOZ	12.00	15.00	10.00	9.00	9.00
TERNIRBU	120	2.30	0.92	1.30	1.00
CRLP	24.50	1.60	1.10	0.70	0.65
CHERPAC	5.80	0.56	0.55	0.53	0.52
DETRA	61	0.20	0.19	0.18	0.17
DOSDIM	7.00	0.039	0.015	0.014	0.014
ECOSAFE	6.70	0.92	0.89	0.86	0.83
Observations					
Mean	3.30	2.5	1.2	2.7	0.50
Lower	1.40	1.40	0.60	1.00	0.20
Upper	8.90	6.70	4.40	3.70	1.60

The annual mean concentrations in leafy vegetables are somewhat comparable from year to year, with 1989 being about the same as 1986 (3 Bq/kg fresh weight). Because most of the vegetables (all of the lettuce) were grown in greenhouses, direct deposition of Cs-137 on the plant surfaces from ventilation air was only significant pathway during 1986, when growing media were uncontaminated. Uptake of Cs-137 into the vegetables occurred later (1987-1990) from the use of contaminated peat as a growing medium. In 1986, there was a recommendation to postpone the open field sowing of lettuce, spinach and other fast growing vegetables. Although it is not clear to what extent this recommendation was implemented across all regions, the fact that DoseCAL did not account for any delay in sowing. However only root uptake for leafy vegetables was taken into account in DoseCAL. Leafy vegetables activities predicted by DoseCAL are within uncertainty band of the measured values and the best of all other code results. The probability for T-test for is 0.834, which is close to one.

The differences between predictions of the codes which participated in VAMP exercise, may be arised from misinterpretation of site-specific information; namely taking into account different assumptions, or using different soil-plant and feed-animal transfer factors as stated in IAEA TECDOC-904 (1996).

As seen from Table 4.4, inhalation and external doses predicted by DoseCAL are rather consistent compared to other codes' predictions. Ingestion doses predicted by DoseCAL, on the other hand, is lower compared to the other codes. Since in ingestion module of DoseCAL, mushroom, fish, game animals are not taken into account, whereas other food products, i.e. fruits, root and fruit vegetables, eggs have been considered as default. Since the amount of fish consumption is considerable in Finland, i.e. it is almost equal to beef consumption, and most of the ingestion doses calculated by most of the models participated in VAMP validation exercise were incurred from fish consumption. Hence, the difference in ingestion dose prediction in DoseCAL can be attributed to fish pathway.

Table 4.4. DoseCAL Validation Result for Adult Doses

Models	Inhalation Dose (mSv)				External Ground Dose (mSv)			External Cloud Dose (mSv)	Ingestion Dose (mSv)			Total Dose (mSv)		
Dose exposure	Cloud passage	Resuspension			1 year	5 year	Life time	Cloud passage	1 year	5 year	Life time	1 year	5 year	Life time
		1 year	5 year	Life time										
FARMLAND	0.0027	1.3E-5	1.5E-5	1.9E-5	0.224	0.742	2.5	2.4E-5	1.93	3.48	3.98	2.00	3.038	5.038
ECOMOD	0.0014	2.5E-5	3.0E-5	4.5E-5	0.076	0.24	1.300	1.3E-5	0.23	0.50	1.08	0.30	0.730	2.38
LINDOZ	0.00057	1.5E-4	2.0E-4	2.5E-4	0.07	0.16	0.640	-	0.24	0.584	-	0.31	-	
SCRAADLO	0.0027	-	5.0E-6	-	-	0.20	-	3.6E-5	-		-	-	-	
TERNIRBU	0.00023	3.5E-6	5.2E-6	1.0E-5	0.035	0.095	0.330	2.2E-6	0.16	0.26	0.330	0.19	0.360	0.660
CRLP	0.0011	-	-	-	0.03	0.116	0.176	6.2E-6	0.133	0.276	0.311	0.178	0.393	0.490
CHERPAC	0.00022	-	-	-	0.04	0.082	0.086	1.3E-5	0.19	0.540	0.880	0.23	0.620	0.970
DETRA	0.00012	1.2E-6	5.0E-6	3.3E-5	0.05	0.160	0.700	5.3 E-7	0.18	0.53	0.610	0.25	0.690	1.30
DOSDIM	0.015	-	-	-	0.05	0.09	-	-	0.479	0.596		0.535	0.702	
STUK estimates	0.0002	5E-5	5.8E-5	6.8E-5	0.06	0.19	0.670	5.0E-6	0.10	0.310	0.700	0.160	0.500	1.370
DOSECAL	0.00045	2.89E-5	8.78E-5	1.55E-4	0.065	0.291	0.433	1.37E-6	0.107	0.296	0.456	0.199	0.587	0.890

4.2. Case Studies

4.2.1. Case Study on Akkuyu NPP Accident Scenario

4.2.1.1. Release Time Determination for Akkuyu Accident Case Study

The HYSPLIT and DoseCAL models were run for different release times selected in each season separetely, i.e. on 29th of November, on 1st of March, 1st of June and 1st of September in 2000 for Akkuyu case study. The adult doses predicted for each season have been compared and the release time leading to the maximum doses has been selected for the case study. As seen from Figure 4.7, 1st of June, 2000 was selected as the starting time of the release for the hypothetical accident at Akkuyu NPP. Even the maximum rainy date was 29th of November in 2000; the hypothetical accident happened on 1st of June 2000 leads to maximum total, external ground and ingestion doses. This can be attributed to maximum deposition observed on 1st of June, and the maximum dose exposure by the ingestion of the all of the animal and agricultural food products, compared to accidents with the releases starting on other times. The differences between ingestion doses and the foods' contribution to the ingestion doses for four different release time can be seen in Figure 4.8 and Figure 4.10. The variation in different food's contribution to ingestion doses can be attributed to plant's sowing and harvesting time and period of grazing time of animals.

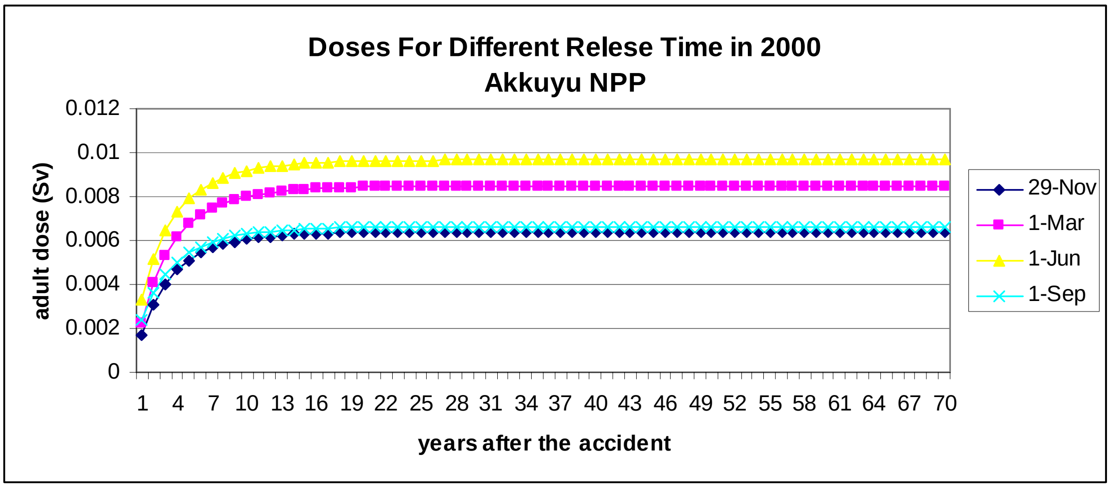

Figure 4.7. Doses for Different Release Times in 2000 for the Hypothetical Accident at Akkuyu NPP

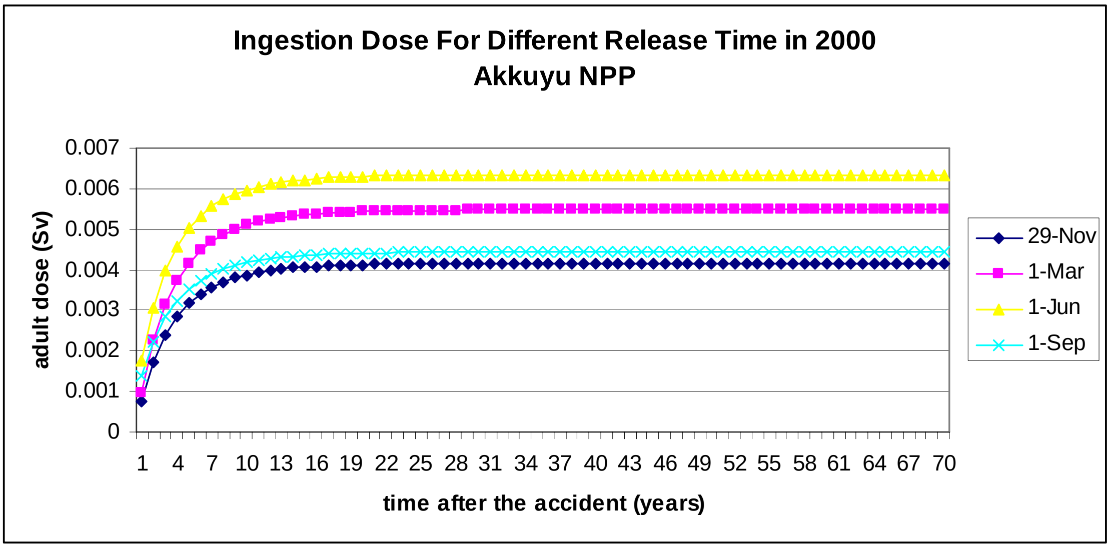

Figure 4.8. Ingestion Doses for Different Release Times in 2000 for the Hypothetical Accident at Akkuyu NPP

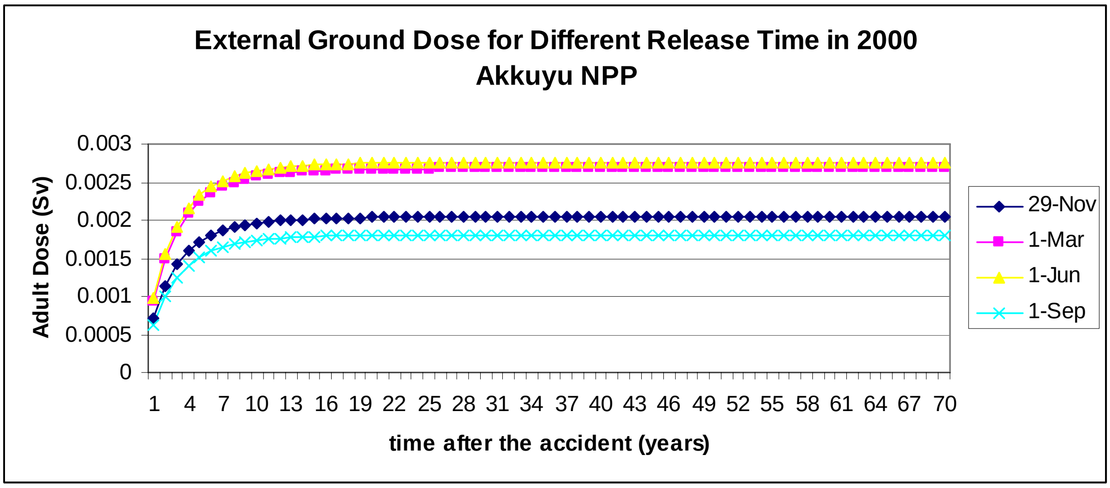

Figure 4.9. External Ground Doses for Different Release Times in 2000 for the Hypothetical Accident at Akkuyu NPP

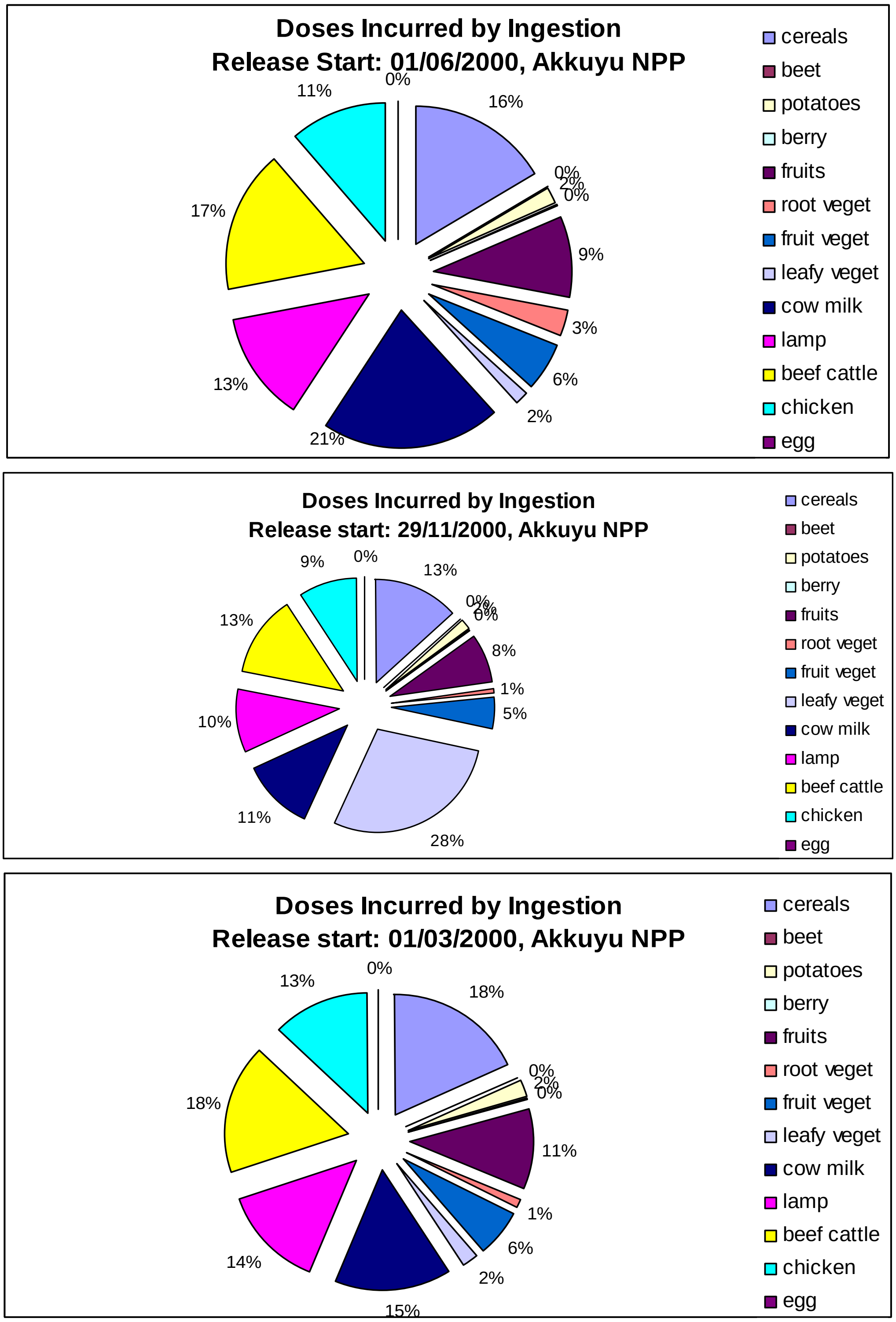

Figure 4.10. Doses Incurred by the Consumption of Different Foodstuffs for Different Release Times in 2000 for Hypothetical Accident at Akkuyu NPP

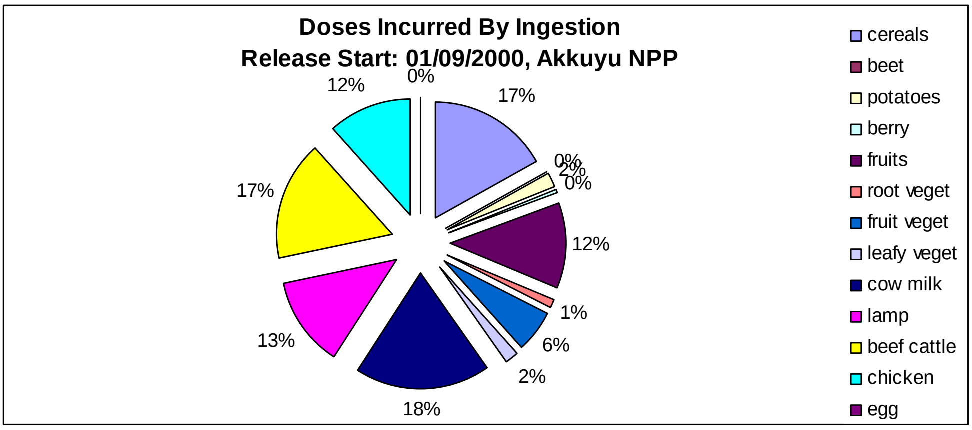

Figure 4.10. (continued)

4.2.1.2. HYSPLIT Results for Akkuyu Accident Case Study

i) For the release started on 1st of June 2000 at Akkuyu NPP, the results of HYSPLIT model for the 9 isotopes are given in Figure 4.11.

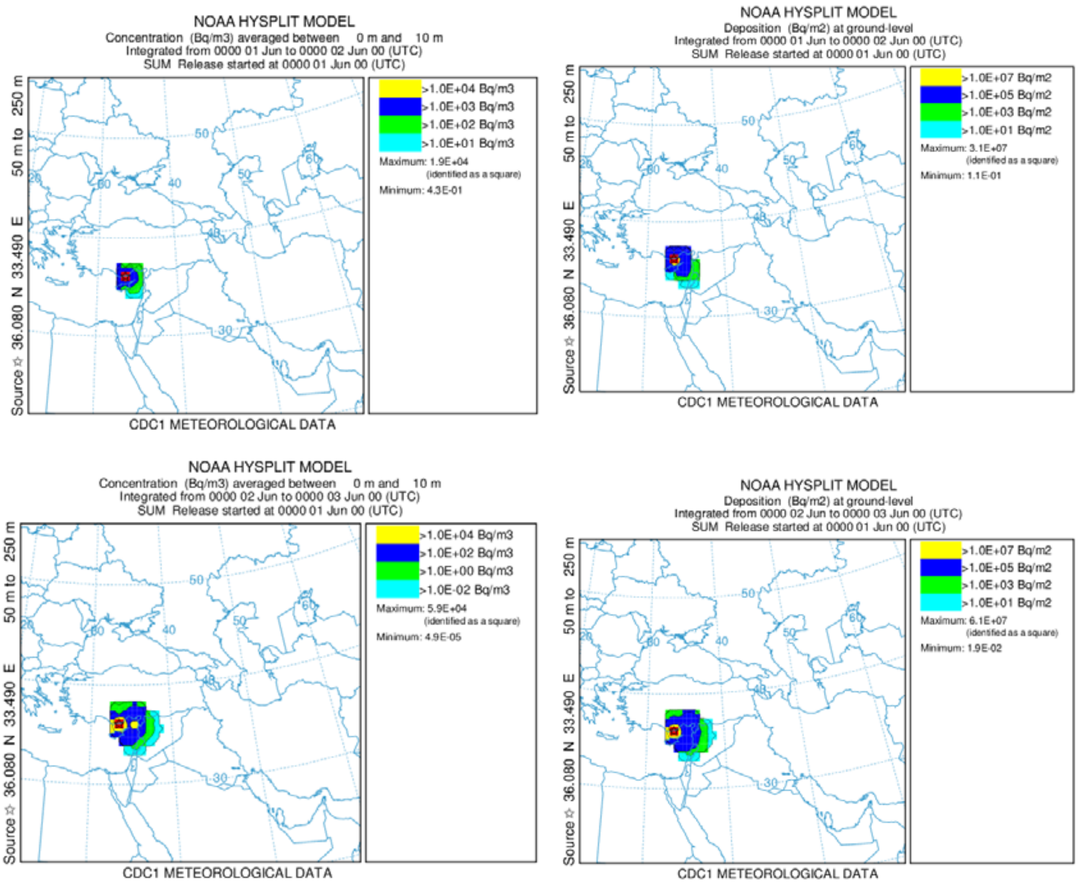

Figure 4.11. Atmospheric Dispersion Graphs of HYSPLIT for Hypothetical Accident at Akkuyu NPP

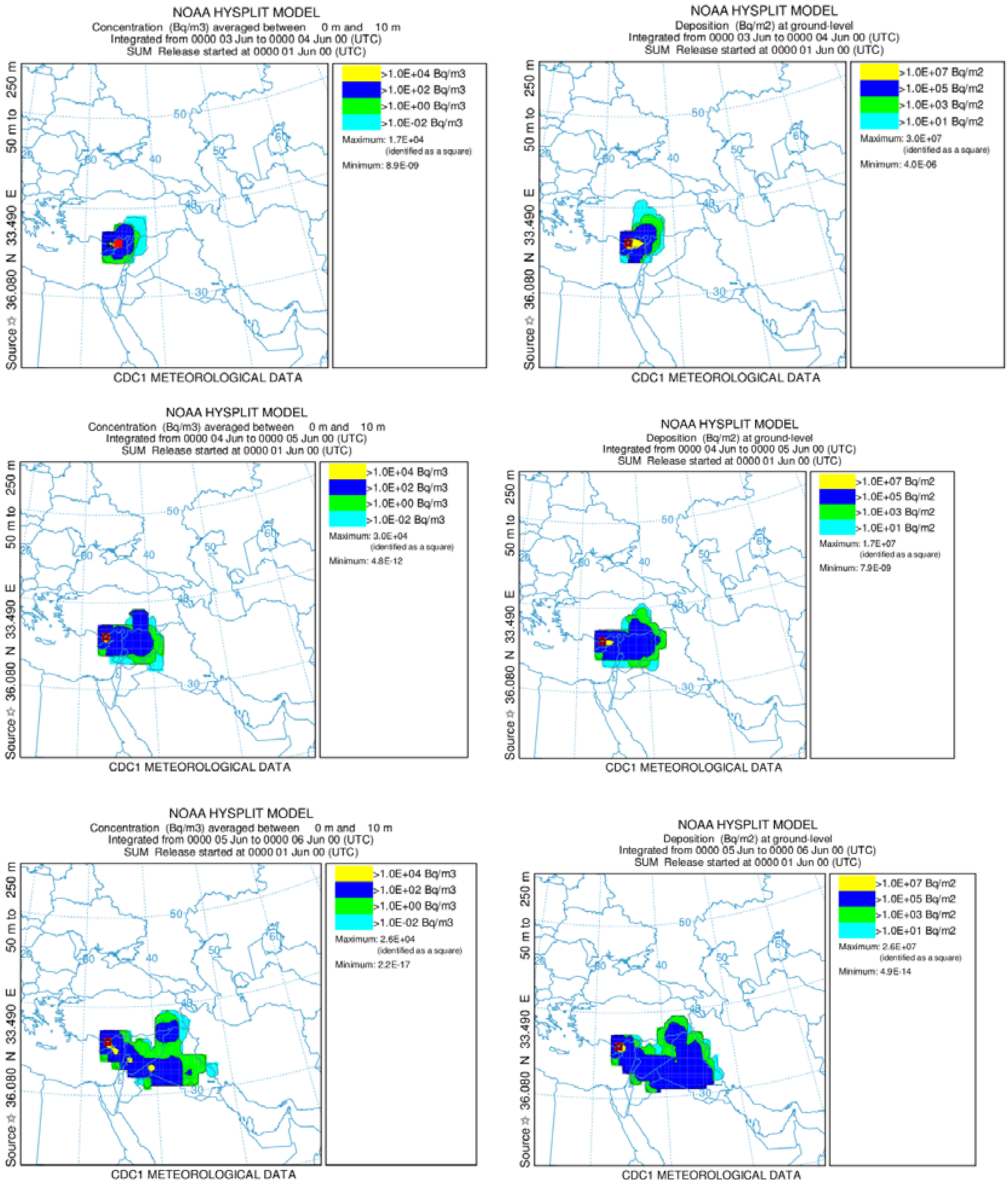

Figure 4.11. (continued)

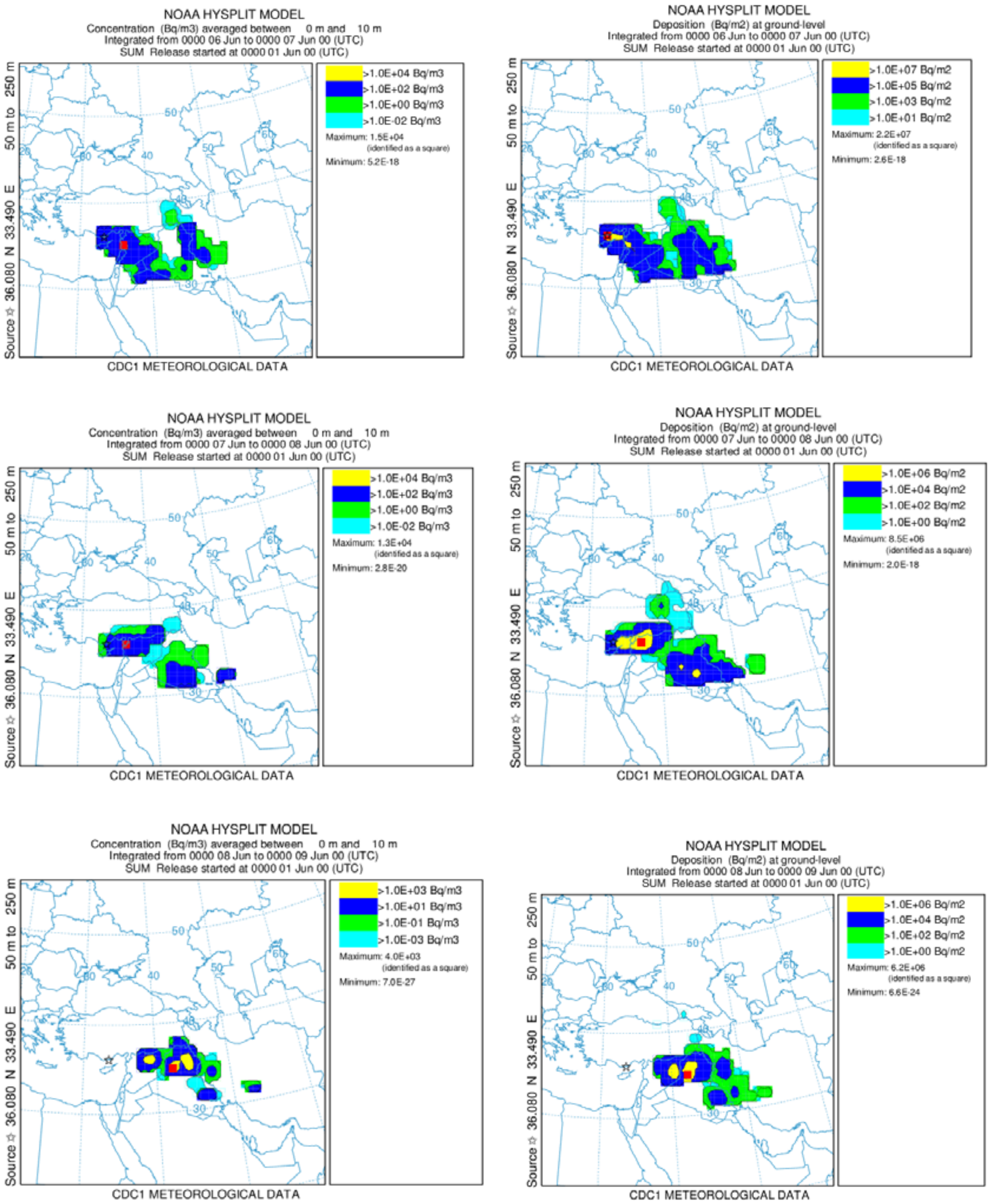

Figure 4.11. (continued)

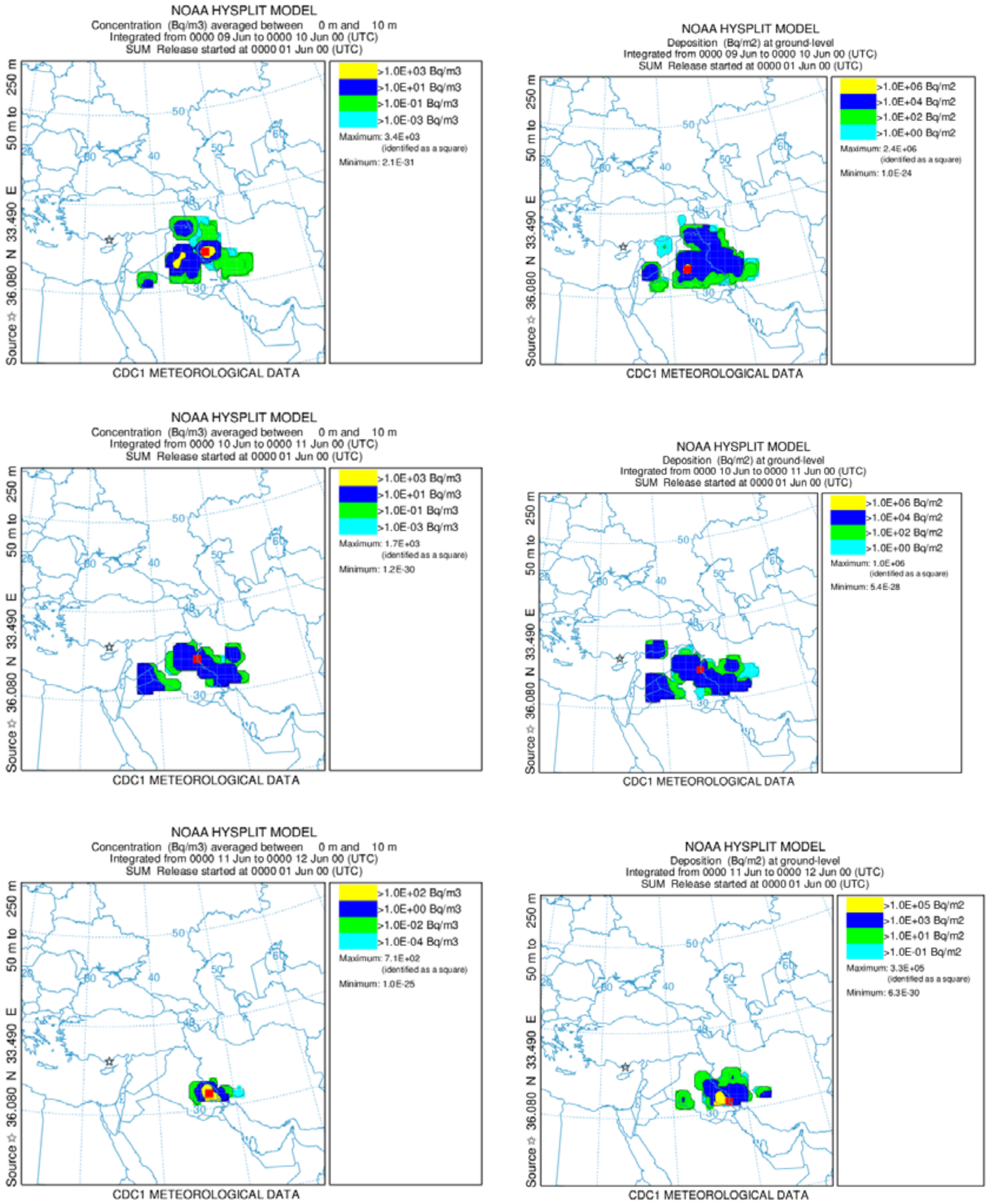

Figure 4.11. (continued)

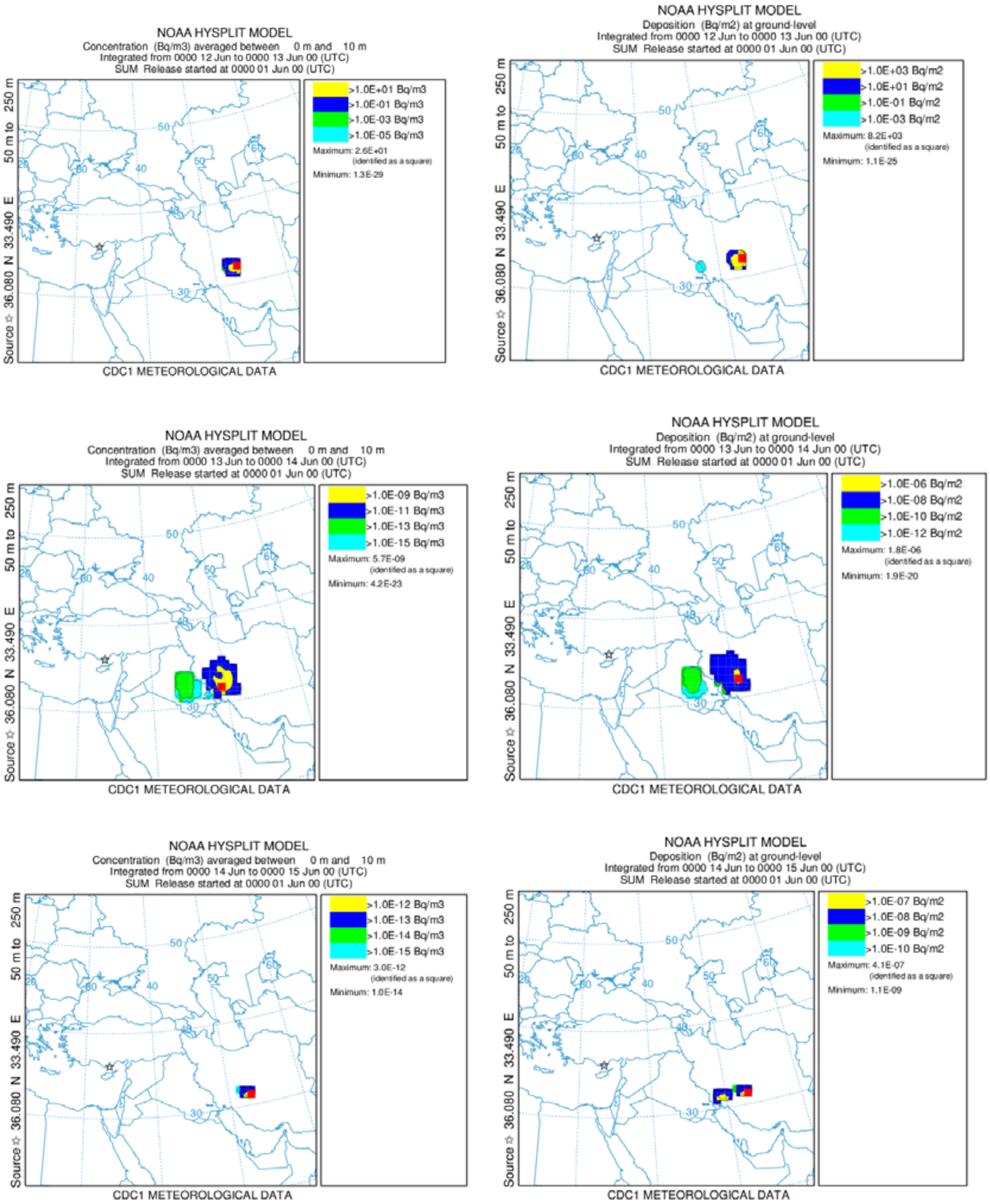

Figure 4.11. (continued)

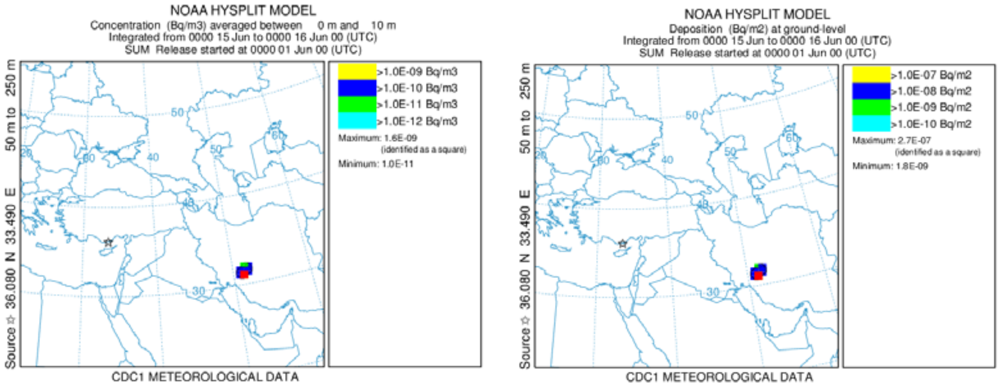

Figure 4.11. (continued)

As seen from Figure 4.11, the radioactive cloud passage can be seen after 1st of June till 8th of June, then it left Turkey on 9th of June, 2000. In the first few days after the accident north eastearn parts were seriously affected; deposited total activity on the source location reached to $1.07x10^7$ Bq/m^2 two days after the accident. The deposited activity on the source grid remained in the order of 10^6 Bq/m^2 at most for the following two days and then decreased. The area with the highest deposition was the source location for the first days, and then it moved away from Turkey.

4.2.1.3. DoseCAL Results for Akkuyu Accident Case Study

Doses incurred during 70 years, radioactivity results and risks were calculated taking into account the most important 9 isotopes mentioned in Chapter 3.4.1 are given. In the tables, the grid points where zero dose or risk values are acquired demonstrate that there is no activity in the air and on the ground. Radioactivity concentration results in the grass and food products are given in Figure 4.12-4.22.

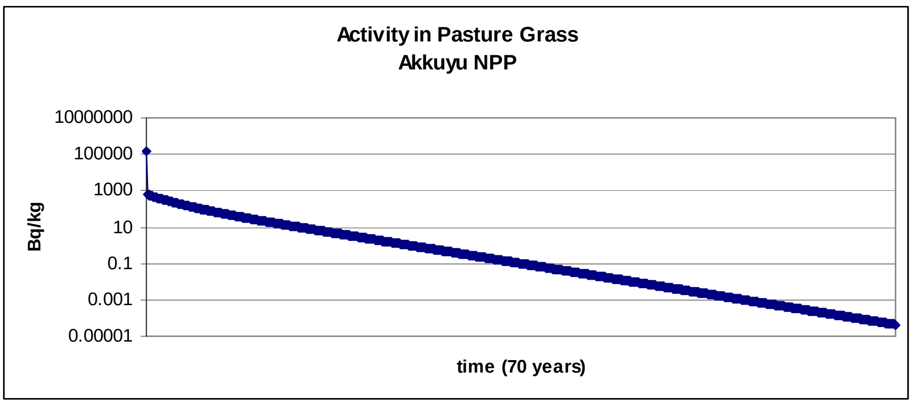

Figure 4.12.a. Annual Activity Concentrations in Pasture Grass for Hypothetical Accident at Akkuyu NPP

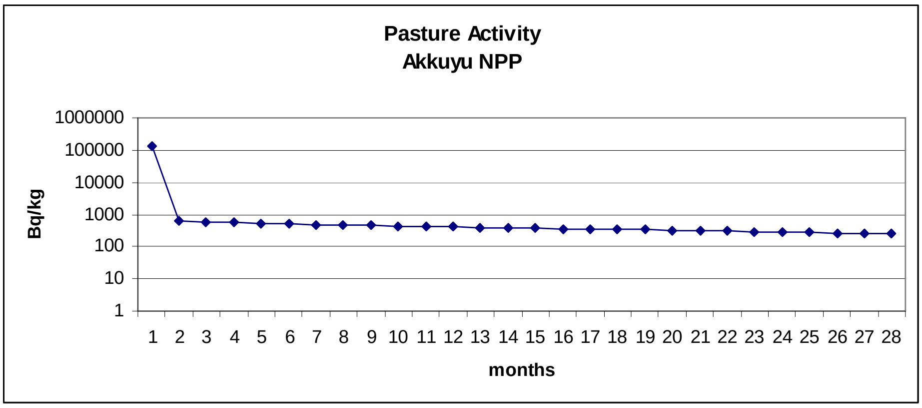

Figure 4.12.b. Monthly Activity Concentrations in Pasture Grass for Hypothetical Accident at Akkuyu NPP

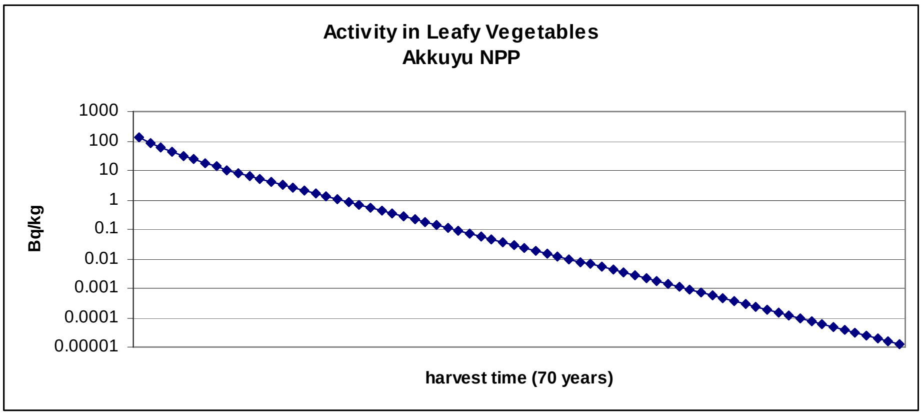

Figure 4.13. Activity in Leafy Vegetables for Hypothetical Accident at Akkuyu NPP

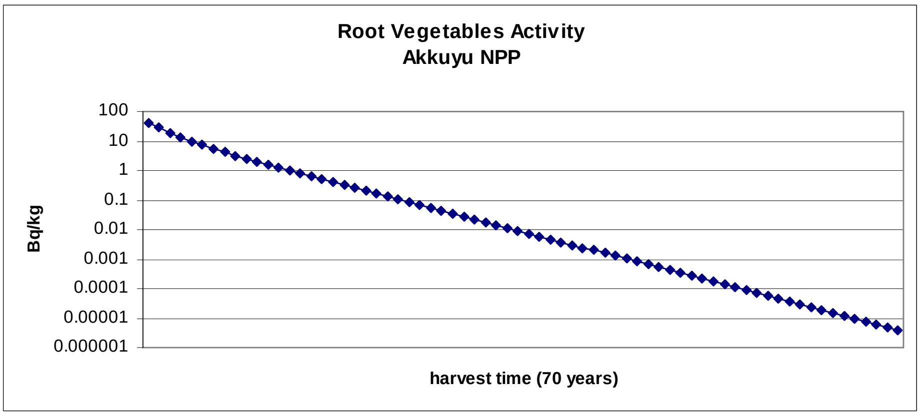

Figure 4.14. Activity in Root Vegetables for Hypothetical Accident at Akkuyu NPP

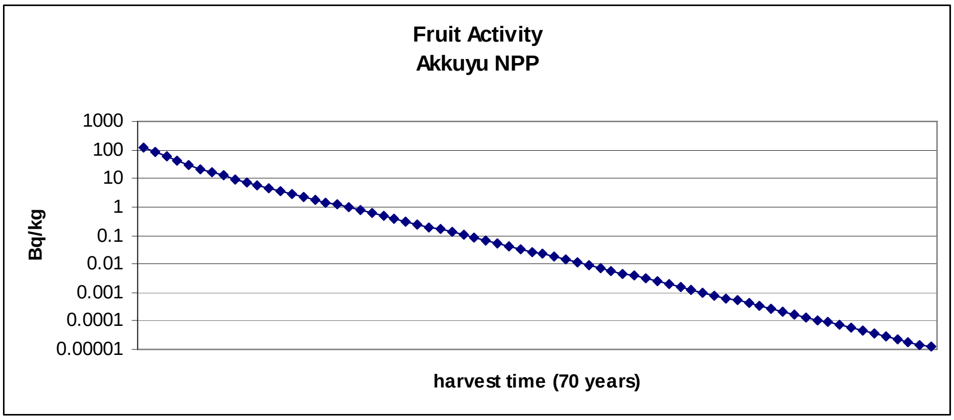

Figure 4.15. Activity in Fruits for Hypothetical Accident at Akkuyu NPP

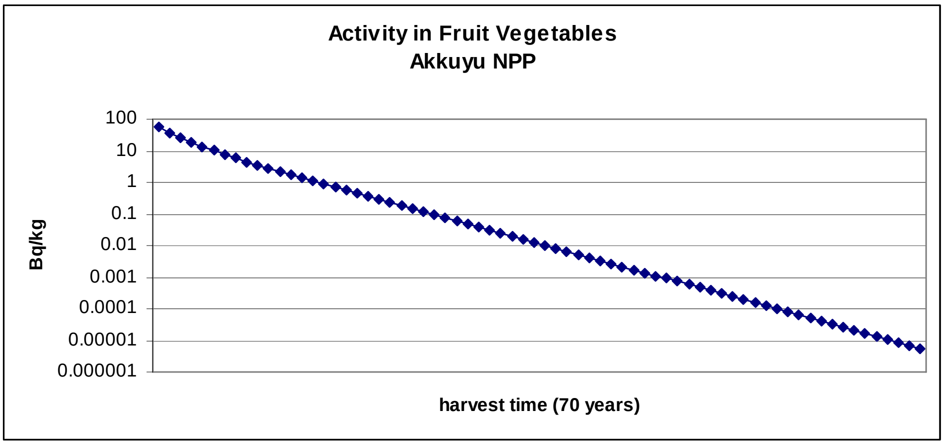

Figure 4.16. Activity in Fruit Vegetables for Hypothetical Accident at Akkuyu NPP

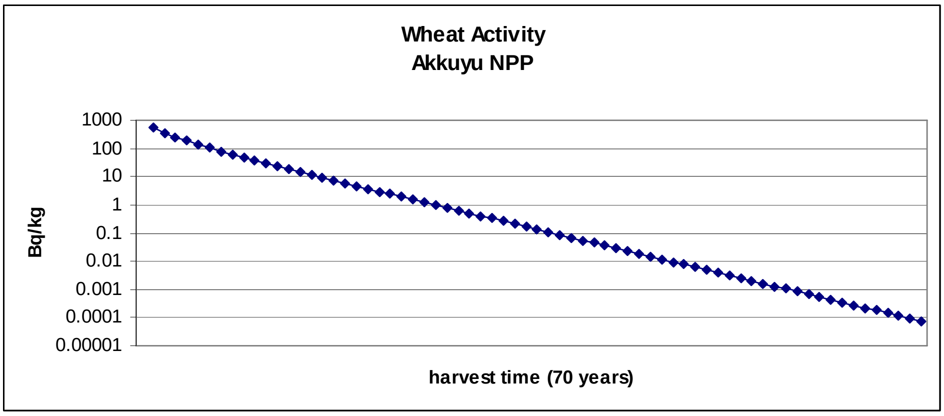

Figure 4.17. Activity in Wheat for Hypothetical Accident at Akkuyu NPP

Major contributor to the plant and pasture activity is foliar uptake during the first year, and then it is the root uptake as expected. Activity in maize and wheat are calculated on dry basis. Activity concentration in the beet and maize are higher than the other crops since these are the only crops that receive foliar uptake together with the pasture grass.

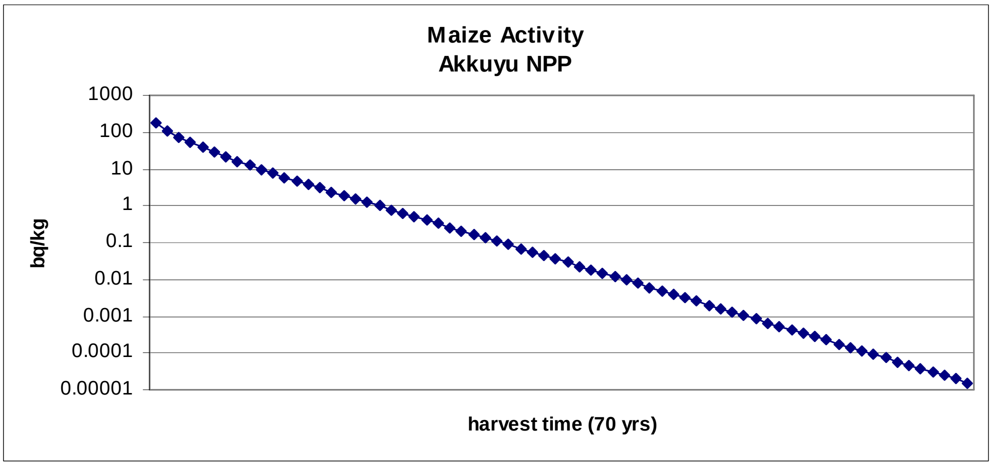

Figure 4.18. Activity in Maize for Hypothetical Accident at Akkuyu NPP

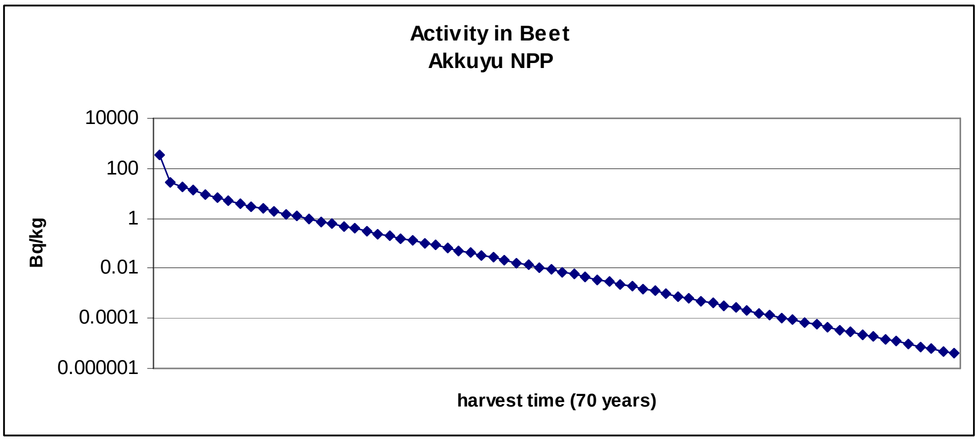

Figure 4.19. Activity in Beet for Hypothetical Accident at Akkuyu NPP

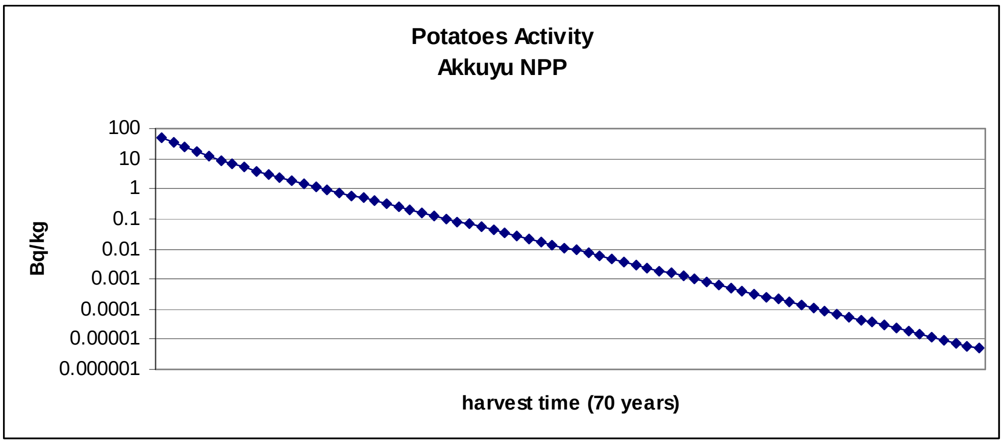

Figure 4.20. Activity in Potatoes for Hypothetical Accident at Akkuyu NPP

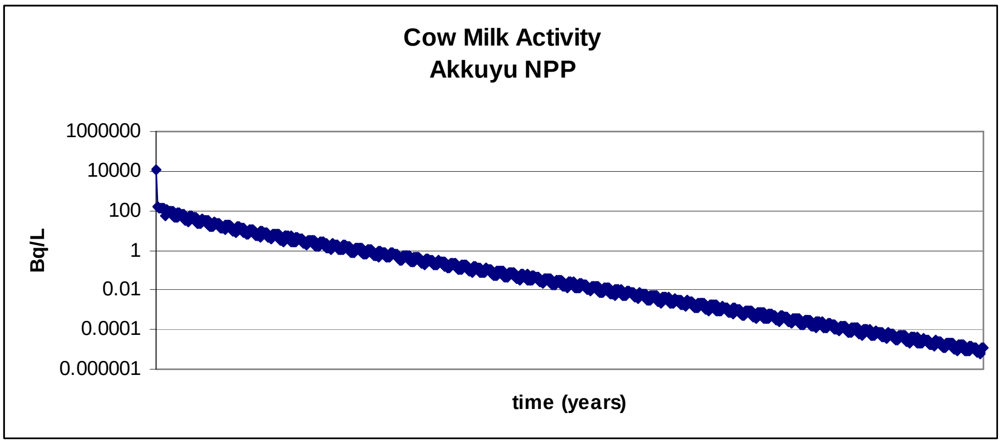

Figure 4.21.a. Annual Activity in Cow Milk for Hypothetical Accident at Akkuyu NPP

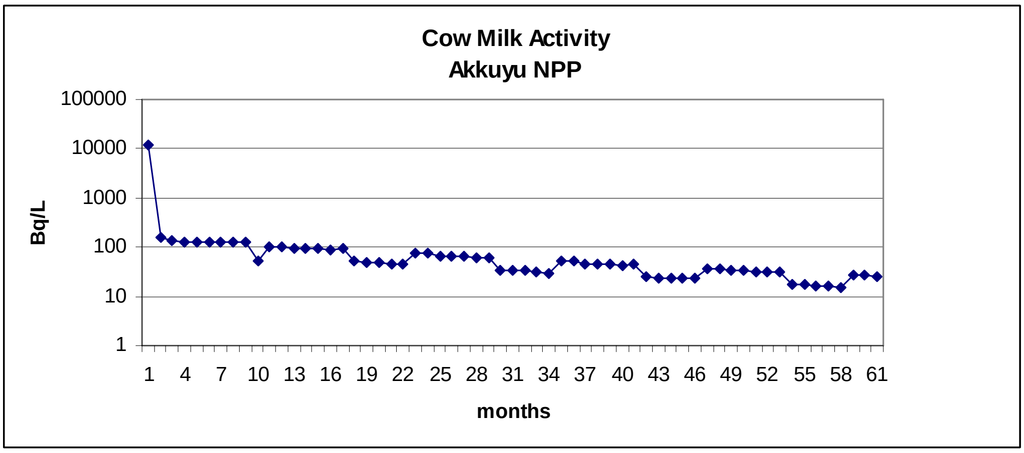

Figure 4.21.b. Monthly Activity in Cow Milk for Hypothetical Accident at Akkuyu NPP

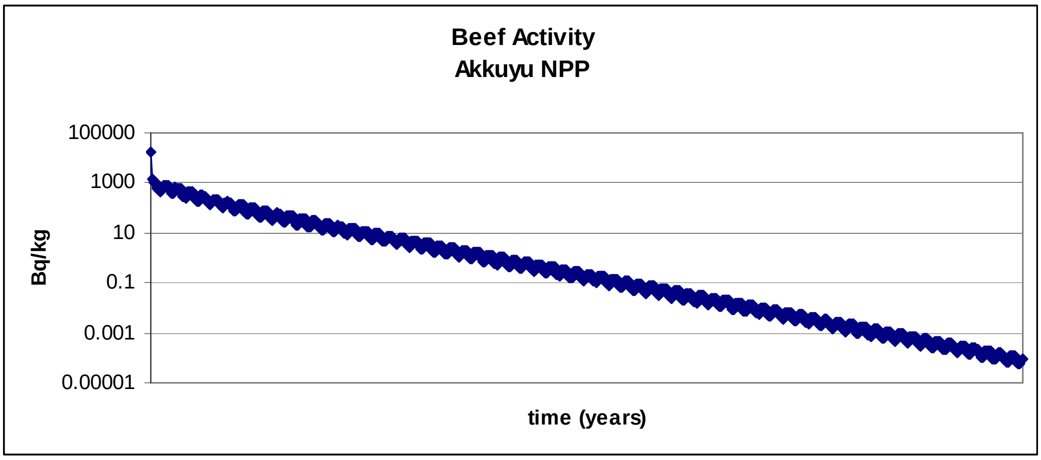

Figure 4.22.a. Annual Activity in Beef for Hypothetical Accident at Akkuyu NPP

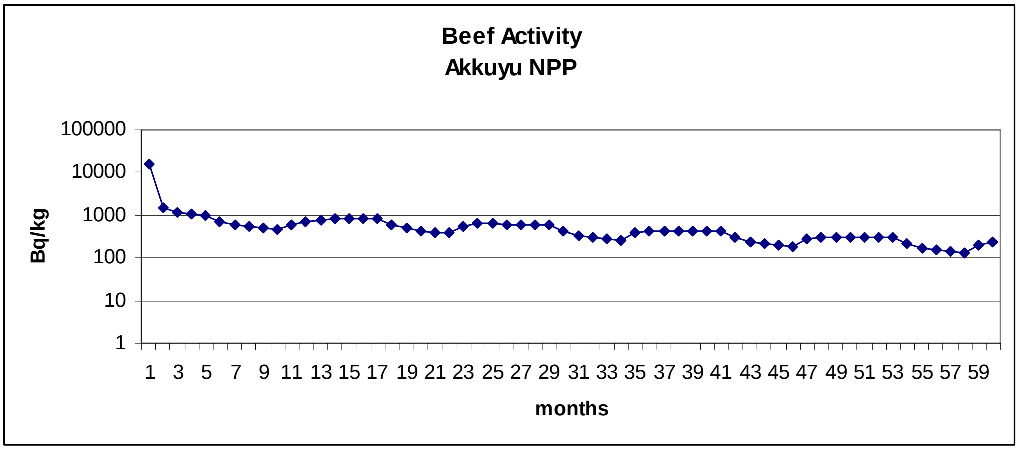

Figure 4.22.b. Montly Activity in Beef for Hypothetical Accident at Akkuyu NPP

Cow milk and beef activity are very high in the first year after the accident, particulary in the first month, then decrease fluctuately, i.e. in the grazing seasons in the springs radioactivity increases due to high activity in the grass, and then it decreases in the cold seasons. Following a few months after the accident until grazing season, the activity sharply decreases since cows and cattles are still fed with uncontaminated barley, maize and hay.

Individual doses for four age groups for the average and maximum individuals for the grid where maximum deposition occurred taking into account most important 9 isotopes, are given in Table 4.5. The doses incurred were predicted by DoseCAL regardless of any intervention measure, i.e. restriction of consumption of feedstuffs and foodstuffs, sheltering, evacuation, etc. applied. In the case of application of intervention measures, doses will be lower. Furthermore adult doses for the average individuals are presented taking into account 53 isotopes to demonstrate the contribution of other isotopes in Table B.1.

Major contributor to total effective dose is ingestion dose as understood from the Table 4.5. External ground pathway is secondary dose-contributing pathway. Ingestion doses are the highest for the infant, child, adult and teen; respectively in the first year after the accident since ingestion DCF for I-131 for the infants is the highest. Infant ingestion doses remain the highest as years pass after the accident, since infant's growing up is taken into account and their food consumption increases when they are growing.

Table 4.5. Doses from Different Pathways for 9 Isotopes Akkuyu NPP Accident (Release started on 1st of June, 2000)

Dose (mSv)		External Cloud	External Ground	Inhalation	Ingestion	Total Dose
INFANT AVG.	After 1 year	1.37E-2	0.575	0.737	5.387	6.712
	After 9 years		2.224		7.575	10.550
	After 16 years		2.339		7.882	10.972
	Lifetime		2.366		7.944	11.061
INFANT MAX.	After 1 year	4.35E-02	1.90		10.451	13.132
	After 9 years		5.42		15.415	21.615
	After 16 years		5.665		16.274	22.720
	Lifetime		5.724		16.482	22.986
CHILD AVG.	After 1 year	2.31E-02	0.97	0.863	2.037	3.893
	After 7 years		2.52		2.187	5.593
	After 15 years		2.727		2.801	6.414
	Lifetime		2.762		2.922	6.570
CHILD MAX.	After 1 year	4.93E-02	2.07		4.265	7.250
	After 7 years		5.379		8.852	15.143
	After 15 years		5.821		10.266	16.699
	Lifetime		5.89		10.526	17.328
TEEN AVG.	After 1 year	2.31E-02	0.97	0.709	1.829	3.530
	After 7 years		2.52		5.508	8.760
	Lifetime		2.762		6.292	9.786
TEEN	After 1 year	4.93E-02	2.07		3.950	6.780
	After 7 years		5.379		12.40	18.537
	Lifetime		5.89		14.085	20.733
ADULT AVG.	After 1 year	2.31E-02	0.97	0.536	1.845	3.374
	After 8 years		2.577		5.845	8.982
	After 15 years		2.727		6.336	9.622
	Lifetime		2.762		6.380	9.706
ADULT MAX.	After 1 year	4.93E-02	2.07		4.519	7.174
	After 8 years		5.501		13.072	19.158
	After 15 years		5.821		14.125	20.531
	Lifetime		5.89		14.385	20.600

Though ingestion doses of child are higher than the teen and adult in the first year, adult and teen ingestion doses that are very close, become higher than the infants as years pass after the accident, since food consumption rates for teen and adults are generally higher than for the childs (USNRC Reg. guide 1.109, 1977). Ingestion doses are highly dependant on consumption rates as seen from the differences between the doses for average and maximum individuals.

Inhalation doses are the highest for the children, though the highest inhalation DCFs are of infants, breathing rates for the children are higher than for the infants.

Inhalation dose for teens and adults are lower than childs, since DCF's for radioiosopes considered in case study for childs are higher than those for adults except cesium isotopes.

External doses are calculated for infants and others (child, teen and adult). Although DCF's for infants are 1.5 times higher than the others, correction factor for shielding is lower for infants than others, hence external doses are lower for infants. External ground doses are lower for infants too as far as the years passed after the accident is concern.

In the case of implementation of countermeasures on food consumption restrictions in the first year after the accident, the ingestion and total doses for average individuals for all age groups are given in Table 4.6. Exposure of almost all of the ingestion doses are prevented by the restriction of consumption of contaminated foodstuffs. Doses incurred by other pathways will be dominating in this case.

Table 4.6. Doses in the case of Countermeasures

Age group	Ingestion Doses (mSv)		Total Doses (mSv)	
	With countermeasure	Without countermeasure	With countermeasure	Without countermeasure
Infant	0.0496	5.387	1.376	6.712
Child	0.0446	2.037	1.901	3.893
Teen	0.0229	1.829	1.725	3.530
Adult	0.0248	1.845	1.554	3.374

As seen from the Table 4.7, the most dose contributing isotopes are Cs-134, Cs-137 and I-131 in the first year after the accident. In the long term, Cs-134 and Cs-137 remain in the environment due to their long radioactive half-lives. The dose consequence of Xe-133 is the least amongst others due to its very short half-life, i.e. 5.25 days and its inertness. Lifetime doses incurred from Cs-137, Cs-134 and I-131 are more than 95% of total doses. According to the Figure 4.24, cereals, cow milk, chicken, fruits, lamb, beef, fruit vegetables and root vegetables were the most dose- contributing foods respectively. Their ingestion causes 6.126 mSv dose exposed totally. On the other hand, potatoes, leafy vegetables, berries, egg and beet are of minor importance in terms of ingestion doses, namely their contribution to total ingestion dose is less than 5 % and 0.329 mSv.

Table 4.7. Dose Contribution of the Different Isotopes for the Hypothetical Accident at Akkuyu NPP (Sv) (Release Started on 1st of June, 2000)

yr	Cs-137	Cs-134	Cs-136	I-131 gas	I-131 particulate	I-132 gas	I-132 particulate	Te-129	Te-129m	Te-132	Xe-133	SUM
1	0.0005467	0.0015174	2E-05	5E-04	0.00037	3.71E-06	5E-06	1E-06	6E-05	3E-04	1E-06	0.003374
2	0.0006626	0.0012349	1.4E-09	4E-09	1.9E-09	0	0	0	4E-08	1E-12	0	0.001898
3	0.0005372	0.000737	3.6E-16	3E-20	1.8E-20	0	0	0	5E-11	5E-41	0	0.001274
4	0.0004312	0.0004344	1.6E-24	1E-33	5.5E-34	0	0	0	4E-14	0	0	0.000866
5	0.0003455	0.0002556	6.9E-33	0	0	0	0	0	3E-17	0	0	0.000601
6	0.0002772	0.0001506	3E-41	0	0	0	0	0	2E-20	0	0	0.000428
7	0.0002221	8.865E-05	0	0	0	0	0	0	1E-23	0	0	0.000311
8	0.0001783	5.224E-05	0	0	0	0	0	0	8E-27	0	0	0.000231
9	0.0001428	3.074E-05	0	0	0	0	0	0	5E-30	0	0	0.000174
10	0.0001146	1.812E-05	0	0	0	0	0	0	3E-33	0	0	0.000133
11	9.184E-05	1.066E-05	0	0	0	0	0	0	2E-36	0	0	0.00010
12	7.371E-05	6.284E-06	0	0	0	0	0	0	1E-39	0	0	8.000E-05
13	5.905E-05	3.697E-06	0	0	0	0	0	0	6E-43	0	0	6.275E-05
14	4.739E-05	2.179E-06	0	0	0	0	0	0	0	0	0	4.957E-05
15	3.798E-05	1.282E-06	0	0	0	0	0	0	0	0	0	3.926E-05
16	3.047E-05	7.556E-07	0	0	0	0	0	0	0	0	0	3.122E-05
17	2.441E-05	4.446E-07	0	0	0	0	0	0	0	0	0	2.485E-05
18	1.959E-05	2.62E-07	0	0	0	0	0	0	0	0	0	1.985E-05
19	1.569E-05	1.542E-07	0	0	0	0	0	0	0	0	0	1.585E-05
20	1.259E-05	9.084E-08	0	0	0	0	0	0	0	0	0	1.268E-05
21	1.009E-05	5.347E-08	0	0	0	0	0	0	0	0	0	1.015E-05
22	8.098E-06	3.151E-08	0	0	0	0	0	0	0	0	0	8.130E-06
23	6.486E-06	1.854E-08	0	0	0	0	0	0	0	0	0	6.505E-06
24	5.207E-06	1.093E-08	0	0	0	0	0	0	0	0	0	5.218E-06
25	4.172E-06	6.43E-09	0	0	0	0	0	0	0	0	0	4.178E-06
26	3.347E-06	3.789E-09	0	0	0	0	0	0	0	0	0	3.351E-06
27	2.682E-06	2.23E-09	0	0	0	0	0	0	0	0	0	2.685E-06
28	2.153E-06	1.314E-09	0	0	0	0	0	0	0	0	0	2.154E-06
29	1.725E-06	7.734E-10	0	0	0	0	0	0	0	0	0	1.726E-06

Table 4.7. Dose Contribution of the Different Isotopes for the Hypothetical Accident at Akkuyu NPP (Sv) (Release Started on 1st of June, 2000) (continued)

yr	Cs-137	Cs-134	Cs-136	I-131 gas	I-131 particulate	I-132 gas	I-132 particulate	Te-129	Te-129m	Te-132	Xe-133	SUM
30	1.384E-06	4.557E-10	0	0	0	0	0	0	0	0	0	1.385E-06
31	1.109E-06	2.682E-10	0	0	0	0	0	0	0	0	0	1.109E-06
32	8.901E-07	1.581E-10	0	0	0	0	0	0	0	0	0	8.903E-07
33	7.13E-07	9.3E-11	0	0	0	0	0	0	0	0	0	7.131E-07
34	5.721E-07	5.48E-11	0	0	0	0	0	0	0	0	0	5.722E-07
35	4.585E-07	3.225E-11	0	0	0	0	0	0	0	0	0	4.585E-07
36	3.679E-07	1.9E-11	0	0	0	0	0	0	0	0	0	3.679E-07
37	2.947E-07	1.118E-11	0	0	0	0	0	0	0	0	0	2.947E-07
38	2.365E-07	6.59E-12	0	0	0	0	0	0	0	0	0	2.365E-07
39	1.895E-07	3.878E-12	0	0	0	0	0	0	0	0	0	1.895E-07
40	1.52E-07	2.285E-12	0	0	0	0	0	0	0	0	0	1.520E-07
41	1.218E-07	1.345E-12	0	0	0	0	0	0	0	0	0	1.218E-07
42	9.778E-08	7.925E-13	0	0	0	0	0	0	0	0	0	9.778E-08
43	7.833E-08	4.663E-13	0	0	0	0	0	0	0	0	0	7.833E-08
44	6.287E-08	2.749E-13	0	0	0	0	0	0	0	0	0	6.287E-08
45	5.037E-08	1.617E-13	0	0	0	0	0	0	0	0	0	5.037E-08
46	4.043E-08	9.533E-14	0	0	0	0	0	0	0	0	0	4.043E-08
47	3.239E-08	5.609E-14	0	0	0	0	0	0	0	0	0	3.239E-08
48	2.599E-08	3.306E-14	0	0	0	0	0	0	0	0	0	2.599E-08
49	2.083E-08	1.946E-14	0	0	0	0	0	0	0	0	0	2.083E-08
50	1.671E-08	1.146E-14	0	0	0	0	0	0	0	0	0	1.671E-08
51	1.339E-08	6.745E-15	0	0	0	0	0	0	0	0	0	1.339E-08
52	1.075E-08	3.975E-15	0	0	0	0	0	0	0	0	0	1.075E-08
53	8.609E-09	2.339E-15	0	0	0	0	0	0	0	0	0	8.609E-09
54	6.906E-09	1.378E-15	0	0	0	0	0	0	0	0	0	6.906E-09
55	5.537E-09	8.114E-16	0	0	0	0	0	0	0	0	0	5.537E-09
56	4.438E-09	4.777E-16	0	0	0	0	0	0	0	0	0	4.438E-09
57	3.561E-09	2.814E-16	0	0	0	0	0	0	0	0	0	3.561E-09
58	2.854E-09	1.656E-16	0	0	0	0	0	0	0	0	0	2.854E-09

Table 4.7. Dose Contribution of the Different Isotopes for the Hypothetical Accident at Akkuyu NPP (Sv)
(Release Started on 1st of June, 2000) (continued)

yr	Cs-137	Cs-134	Cs-136	I-131 gas	I-131 particulate	I-132 gas	I-132 particulate	Te-129	Te-129m	Te-132	Xe-133	SUM
59	2.29E-09	9.761E-17	0	0	0	0	0	0	0	0	0	2.290E-09
60	1.835E-09	5.744E-17	0	0	0	0	0	0	0	0	0	1.835E-09
61	1.473E-09	3.385E-17	0	0	0	0	0	0	0	0	0	1.473E-09
62	1.18E-09	1.992E-17	0	0	0	0	0	0	0	0	0	1.180E-09
63	9.469E-10	1.174E-17	0	0	0	0	0	0	0	0	0	9.469E-10
64	7.586E-10	6.909E-18	0	0	0	0	0	0	0	0	0	7.586E-10
65	6.088E-10	4.071E-18	0	0	0	0	0	0	0	0	0	6.088E-10
66	4.879E-10	2.396E-18	0	0	0	0	0	0	0	0	0	4.879E-10
67	3.914E-10	1.412E-18	0	0	0	0	0	0	0	0	0	3.914E-10
68	3.136E-10	8.308E-19	0	0	0	0	0	0	0	0	0	3.136E-10
69	2.517E-10	4.896E-19	0	0	0	0	0	0	0	0	0	2.517E-10
70	2.013E-10	2.878E-19	0	0	0	0	0	0	0	0	0	2.013E-10

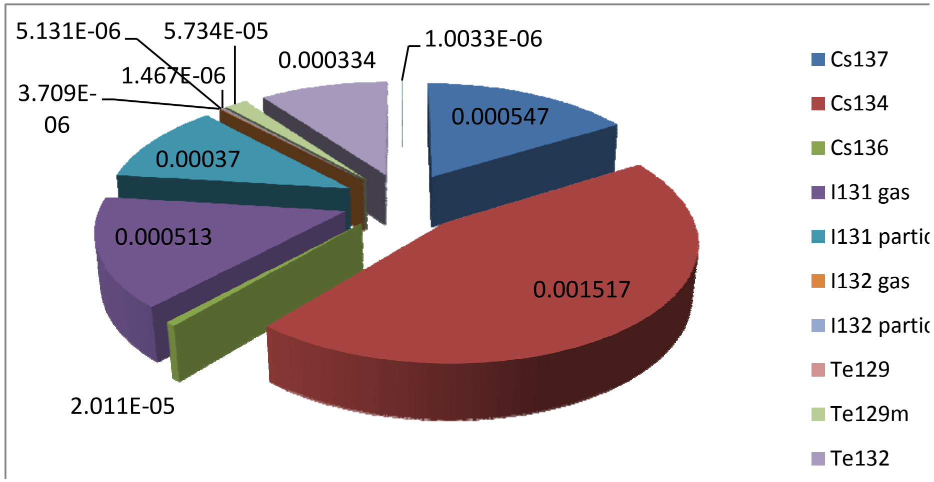

Figure 4.23. Dose Contribution (Sv) of the Different Isotopes for Akkuyu NPP Accident Case Study

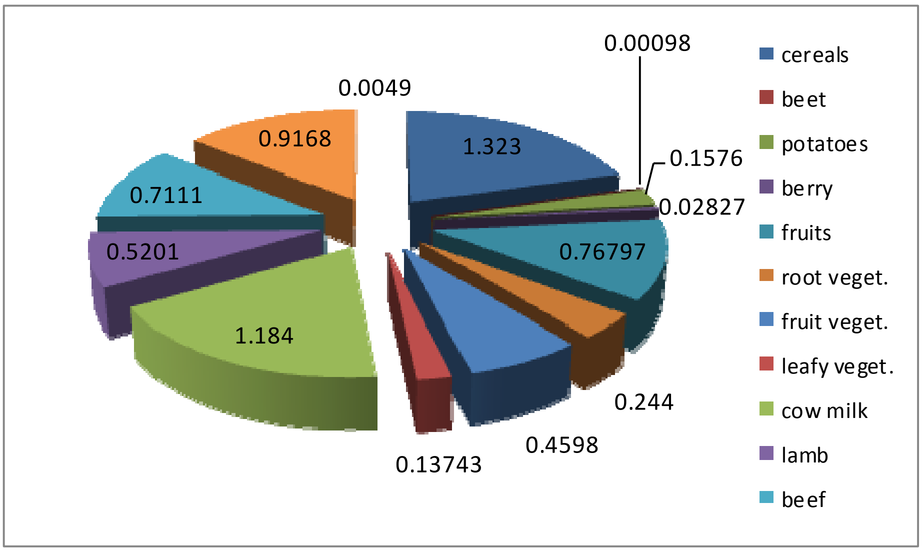

Figure 4.24. Dose (mSv) Incurred by the Consumption of Different Foods for Akkuyu NPP accident (Release started on 1st of June)

Stochastic risks were calculated based on average individual doses. Cancer and hereditary risks calculated with ICRP-103 risk coefficients are presented in Table 4.8. The grid points where there are zero risk values demonstrate that there is no any radioactivity in the air or on the ground. Mortality and morbidity risks calculated with USEPA FGR-13 coefficients are also given in Table 4.9. As seen from both tables, mortality and morbidity risks calculated with USEPA FGR-13 coefficients are higher than cancer risks calculated with ICRP-103 coefficients except for infants. Infant's cancer risk is higher than mortality-morbidity risks, and these are closer to each other than the other age groups.

The receptors in each geographical region of Turkey carrying the high population were selected to perform collective dose and risk calculations.

Table 4.8. Late Risks Calculated with ICRP-103 Risk Coefficients

Coordinates		Infant Late Risk		Child Late Risk		Teen Late Risk		Adult Late Risk	
Lat.	Lon.	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk
36	26.5	0	0	0	0	0	0	0	0
36	29	0	0	0	0	0	0	0	0
36	31.5	0	0	0	0	0	0	0	0
36	34	**0.000369**	**6.713E-06**	**0.000419**	**7.616E-06**	**0.000482**	**8.7599E-06**	**0.000401**	**1.955E-05**
36	36.5	1.925E-05	3.501E-07	5.075E-05	9.226E-07	6.006E-05	1.092E-06	5.010E-05	2.44312E-06
36	39	2.926E-06	5.321E-08	2.664E-06	4.844E-08	1.662E-06	3.022E-08	9.790E-07	4.77548E-08
36	41.5	1.501E-06	2.729E-08	1.153E-06	2.096E-08	6.452E-07	1.173E-08	3.717E-07	1.81334E-08
36	44	9.059E-07	1.647E-08	8.454E-07	1.537E-08	4.945E-07	8.990E-09	2.617E-07	1.27642E-08
38.5	26.5	0	0	0	0	0	0	0	0
38.5	29	0	0	0	0	0	0	0	0
38.5	31.5	1.532E-18	2.786E-20	1.956E-18	3.556E-20	1.665E-18	3.027E-20	1.093E-18	5.33068E-20
38.5	34	1.245E-14	2.264E-16	4.825E-14	8.772E-16	5.861E-14	1.066E-15	5.577E-14	2.72041E-15
38.5	36.5	3.570E-09	6.492E-11	6.131E-09	1.115E-10	5.840E-09	1.062E-10	4.309E-09	2.10208E-10
38.5	39	6.665E-08	1.212E-09	4.406E-08	8.010E-10	2.290E-08	4.163E-10	1.367E-08	6.66623E-10
38.5	41.5	1.122E-07	2.040E-09	7.178E-08	1.305E-09	3.602E-08	6.549E-10	2.105E-08	1.02664E-09
38.5	44	3.520E-07	6.401E-09	4.293E-07	7.805E-09	2.699E-07	4.907E-09	1.370E-07	6.68472E-09
41	26.5	0	0	0	0	0	0	0	0
41	29	0	0	0	0	0	0	0	0
41	31.5	1.448E-23	2.633E-25	1.397E-22	2.540E-24	6.535E-23	1.188E-24	3.562E-23	1.73778E-24
41	34	1.298E-14	2.359E-16	5.063E-14	9.205E-16	5.880E-14	1.069E-15	5.539E-14	2.7021E-15
41	36.5	1.720E-13	3.128E-15	1.104E-12	2.008E-14	1.473E-12	2.678E-14	1.439E-12	7.0177E-14
41	39	1.028E-12	1.869E-14	3.757E-12	6.831E-14	4.559E-12	8.289E-14	4.139E-12	2.01882E-13
41	41.5	1.474E-10	2.680E-12	1.919E-10	3.489E-12	1.507E-10	2.740E-12	1.060E-10	5.16906E-12
41	44	1.776E-10	3.229E-12	8.928E-10	1.623E-11	1.195E-09	2.173E-11	9.474E-10	4.62156E-11

Table 4.9. Late Risks Calculated with USEPA FGR-13 Risk Coefficients

Risk For Infant				Risk For Child		Risk For Teen		Risk For Adult	
Lat	Lon	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality
36	26.5	0	0	0	0	0	0	0	0
36	29	0	0	0	0	0	0	0	0
36	31.5	0	0	0	0	0	0	0	0
36	34	**0.00028**	**6.532E-05**	**0.00346**	**0.00221**	**0.004403**	**0.002772**	**0.00544**	**0.003356**
36	36.5	1.232E-05	4.851E-06	0.000436	0.000288	0.000543	0.000358	0.00066	0.000435
36	39	1.464E-06	1.744E-07	6.2E-06	1.83E-06	8.11E-06	2.32E-06	9.43E-06	2.77E-06
36	41.5	8.975E-07	9.913E-08	2.94E-06	5.14E-07	3.9E-06	6.61E-07	4.51E-06	7.91E-07
36	44	3.799E-07	4.134E-08	1.12E-06	1.34E-07	1.5E-06	1.77E-07	1.72E-06	2.04E-07
38.5	26.5	0	0	0	0	0	0	0	0
38.5	29	0	0	0	0	0	0	0	0
38.5	31.5	2.160E-19	3.067E-20	1.08E-18	2.84E-19	1.39E-18	3.54E-19	1.4E-18	3.24E-19
38.5	34	1.032E-14	3.867E-15	5.44E-13	3.59E-13	6.64E-13	4.37E-13	8.82E-13	5.85E-13
38.5	36.5	3.848E-10	2.532E-10	1.72E-08	1.16E-08	2.13E-08	1.44E-08	2.49E-08	1.69E-08
38.5	39	4.672E-08	5.106E-09	1.49E-07	2.35E-08	1.97E-07	3.05E-08	2.28E-07	3.63E-08
38.5	41.5	7.950E-08	8.507E-09	2.33E-07	2.62E-08	3.12E-07	3.48E-08	3.56E-07	3.98E-08
38.5	44	4.724E-08	5.029E-09	1.38E-07	1.51E-08	1.85E-07	2.01E-08	2.11E-07	2.31E-08
41	26.5	0	0	0	0	0	0	0	0
41	29	0	0	0	0	0	0	0	0
41	31.5	1.222E-23	6.987E-24	1.22E-21	6.94E-22	1.48E-21	8.42E-22	1.22E-21	6.97E-22
41	34	1.266E-14	4.456E-15	5.81E-13	3.77E-13	7.08E-13	4.59E-13	9.1E-13	5.96E-13
41	36.5	2.136E-13	1.005E-13	1.4E-11	9.4E-12	1.7E-11	1.14E-11	2.28E-11	1.53E-11
41	39	5.304E-13	3.329E-13	3.18E-11	2.14E-11	3.87E-11	2.61E-11	5.13E-11	3.47E-11
41	41.5	5.490E-11	1.081E-11	6.36E-10	3.52E-10	7.92E-10	4.31E-10	1E-09	5.59E-10
41	44	1.899E-10	1.155E-10	8.18E-09	5.58E-09	1.04E-08	7.1E-09	1.14E-08	7.75E-09

Table 4.10. Collective Dose and Risk for Akkuyu NPP Accident Case Study

City	Total Population	Collective Dose (man-Sv)	Collective Mortality Risk	Collective Morbidity Risk
Ankara	5 045 083	2.241E-06	8.898E-07	1.360E-06
Konya	2 079 225	9.174E-07	3.601E-07	5.460E-07
İstanbul	14 160 467	6.289E-06	2.497E-06	3.817E-06
Kocaeli	1 676 202	0	0	0
Balıkesir	1 162 761	0	0	0
İzmir	4 061 074	0	0	0
Manisa	1 359 463	0	0	0
Samsun	1 261 810	0	0	0
Erzurum	766 729	1.631E-05	6.954E-06	1.036E-05
Van	1 070 113	0.605	0.01480	0.132
Gaziantep	1 844 438	10.354	0.029	0.2679
Adana	2 149 260	503.080	146.753	225.392
Antalya	2 158 265	0	0	0
Mersin	1 705 774	14 016.004	3 583.301	5 790.914

The collective dose and health risk, due to the hypothetical accident at Akkuyu NPP, have been calculated for each of the 13 cities and results are presented in Table 4.10, together with the number of population living at these cities. Thirteen cities selected over Turkey include İstanbul, Balıkesir, İzmir, Manisa, Samsun, Kocaeli, Ankara, Konya, Gaziantep, Van, Erzurum, Adana and Antalya. Doses computed for all four age groups were averaged to give a good representation for the overall population at the selected receptor grids and then have been converted to the collective doses using population data of the cities based on the census results for 2013 provided from State Statistical Institute. Since age groups for which population data are given by TUIK are different from the age groups in DoseCAL, city's total population was used for the collective dose calculation. Total population of these 13 cities is 38 794 890 which make up 50.1 % of Turkish population. The highest collective impact of a potential accident the Akkuyu NPP is expected to be seen in Mersin, due to very large population of the city and high radiological consequences as seen from Table 4.10. In Mersin, the infants will experience the cancer risks of 0.000369, and hereditary risk of 6.713E-06. The adults will experience the cancer risks of 0.0004 and hereditary risks of 1.955E-05. These numbers mean that in every 10 000 adults 4 are expected to suffer from cancer, and in every 100 000 adults 2 are expected to pass on hereditary effects to their offsprings related to radiation exposure. Average cancer incidence data for man and woman in Turkey for 2009 is 221.5 people/100 000 people (Sağlık Bakanlığı, 2014). This means that increased cancer riks considering radiation related cancers will be 261.5 incidence in every 100 000 people.

Mortality risk for the infants will be 6.532E-05 morbidity risk for the infants will be 0.00028 in the case of a severe nuclear accident at Akkuyu NPP. These numbers mean that in every 10 000 infants 7 might die from radiation and 30 infants might suffer from cancer disease related to radiation.

After Mersin, the highest collective doses and risks are observed in Adana, Gaziantep and Van respectively. Whereas, Antalya, Koceali, Samsun, Balıkesir, Manisa and İzmir are the cities that have not affected from the accident at all. The collective dose in Mersin in the case of a severe nuclear accident at Akkuyu NPP will be 14016.004 man-Sv.

4.2.2. Case Study on Sinop NPP Accident Scenario

4.2.2.1 Release Time Determination for Sinop Accident Case Study

HYSPLIT and DoseCAL were run for four different release times for Sinop NPP accident case study, i.e. on 31th of April, 30th of July, 31st of January and 31st of October in 2005. As presented in Chapter 3.4.2, since 31st of October is the most rainy day of 2005 for Sinop, DoseCAL was initially run for the release time starting on 31st of October in 2005. Furthermore, to demonstrate the affects of vegetation cycle of the plants on ingestion doses, DoseCAL was also run for the release starting on other times than 31st of October in 2005. DoseCAL results have been presented in Figure 4.25, 4.26 and 4.27. As seen from these figures, the rain affects can clearly be seen on the external ground doses, which are the maximum for the release starting on 31st of October; however, the ingestion dose is the maximum for the release starting on 1st of August when the total doses are the maximum, as well. For the accidental release started on 1st of August, doses incurred from the ingestion of cow milk, potatoes and root vegetables are higher than the release starting on 31st of October. The comparison of the dose exposure by ingestion of the different foodstuffs for the releases starting at four different times is given in Table 4.11.

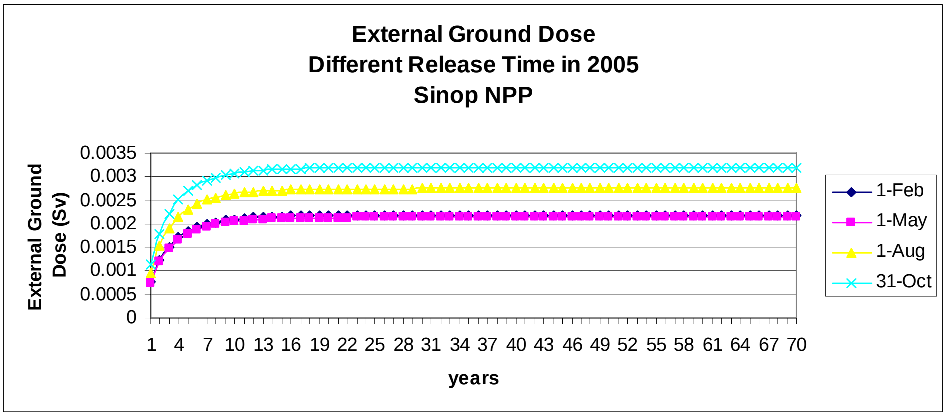

Figure 4.25. External Ground Doses for the Releases Starting on Different Times in 2005 for the Hypothetical Accident at Sinop NPP

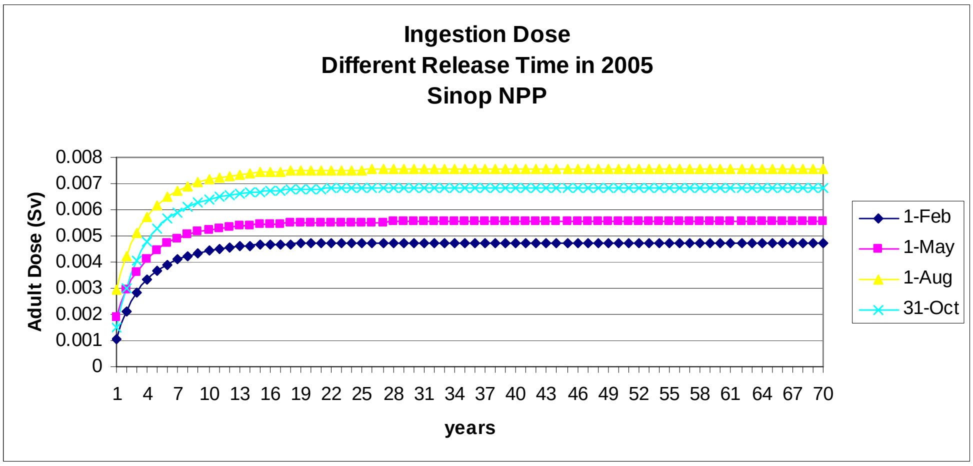

Figure 4.26. Ingestion Doses for Releases Starting on Different Times in 2005 for the Hypothetical Accident at Sinop NPP

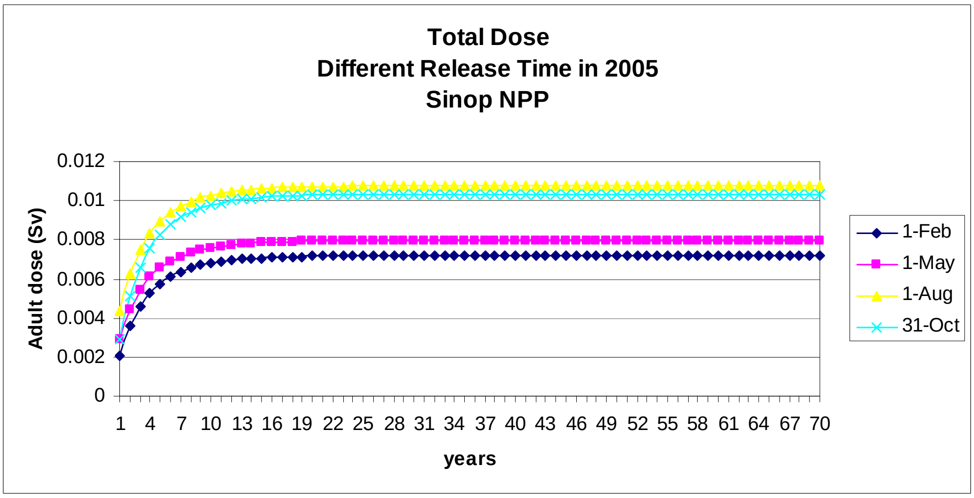

Figure 4.27. Total Dose Incurred for the Releases Starting on Different Times in 2005 for the Hypothetical Accident at Sinop NPP

For the accidental release starting on 1st of August 2005 leading to maximum doses, HYSPLIT and detailed DoseCAL results have been presented in this Chapter. The results for the release starting on 31st of October 2005, are given in Appendix B.

Table 4.11. Adult Doses (Sv) Incurred from Ingestion of the Foodstuffs For the Releases Starting at Different Times in 2005

Foodstuffs	1-Feb	1-May	1-Aug	31-Oct
Cereals	1.061E-03	1.041E-03	1.332E-04	1.546E-04
Beet	7.81E-07	7.65E-07	9.8E-07	1.14E-06
Potatoes	1.26E-04	1.23E-04	5.54E-04	1.83E-04
Berry	2.26E-05	2.21E-05	2.83E-05	3.29E-05
Fruits	6.14E-04	6.02E-04	9.61E-04	1.117E-03
Root Vegetables	6.43E-05	6.3E-05	2.49E-04	9.38E-05
Fruit Vegetables	3.67E-04	3.6E-04	4.61E-04	5.35E-04
Leafy Vegetables	1.1E-04	1.08E-04	1.38E-04	1.6E-04
Cow Milk	7.2E-04	1.478E-03	1.662E-03	8.02E-04
Lamb	4.04E-04	4.45E-04	5.39E-04	5.58E-04
Beef	5.12E-04	5.67E-04	6.9E-04	7.32E-04
Chicken	7.34E-04	7.2E-04	9.21E-04	1.07E-03
Egg	3.91E-06	3.83E-06	4.9E-06	5.69E-06

4.2.2.2. HYSPLIT Results for Sinop Accident Case Study

The graphical display results of HYSPLIT simulation for modeling the 9 isotopes accidentally released on 1st of August, 2005 at Sinop NPP are given in Figure 4.28. As seen from this Figure; the radioactive cloud passed from Sinop site to the southwestern direction in the first few days after the accident. Until 10th of August, almost whole country except for the eastern parts was affected from the accident. The area with the highest deposition remained as Sinop NPP site during the 15-day-simulation. The deposited activity on the source grid remained in the order of 10^7 Bq/m^2 for several days after the accident. The highest total deposited activity reached to 1.31×10^7 Bq/m^2. After 11th of August, the cloud moved away from Turkey to the southern direction.

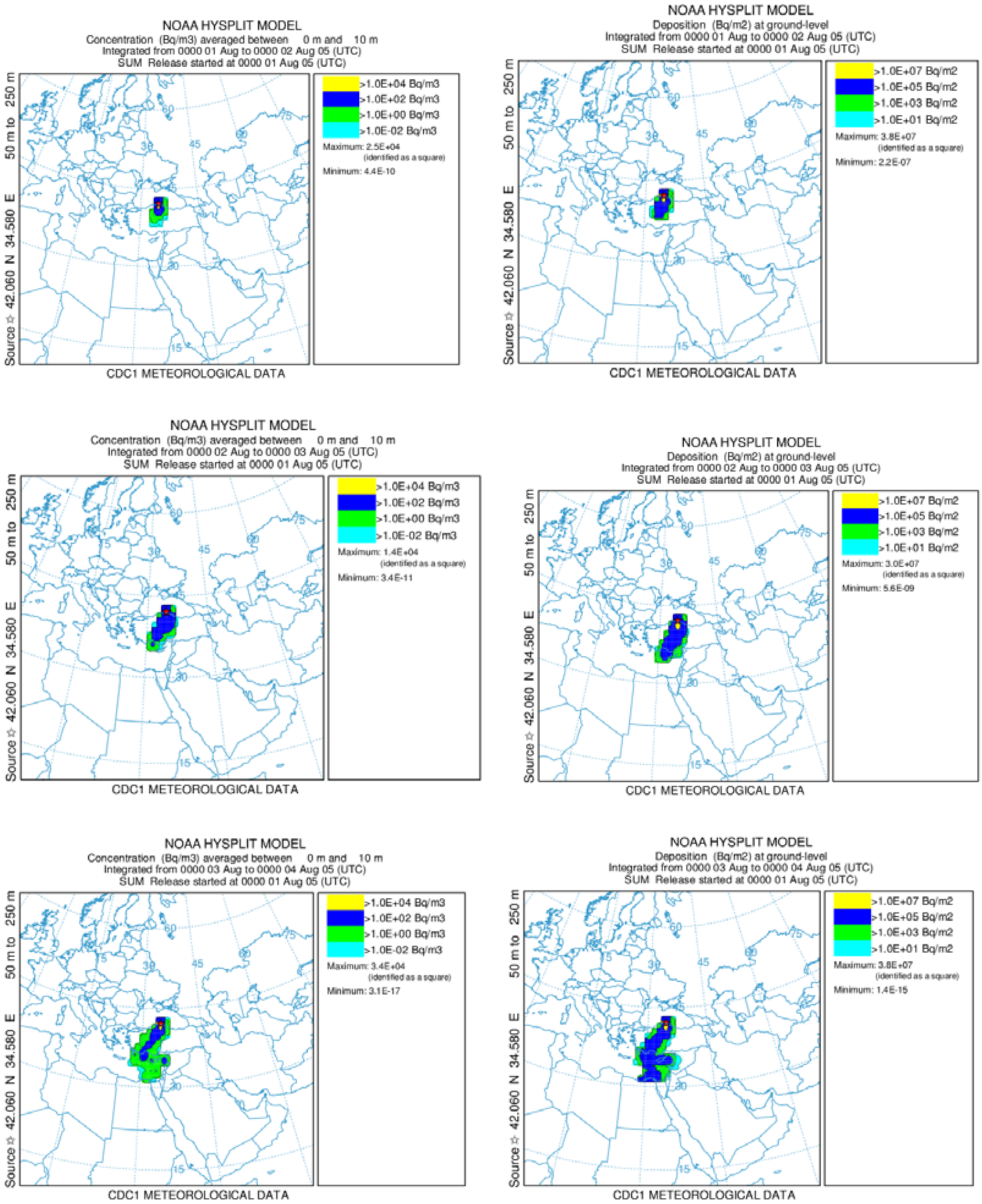

Figure 4.28. Atmospheric Dispersion Graphs of HYSPLIT for Hypothetical Accident at Sinop NPP (release started on 1st of August 2005)

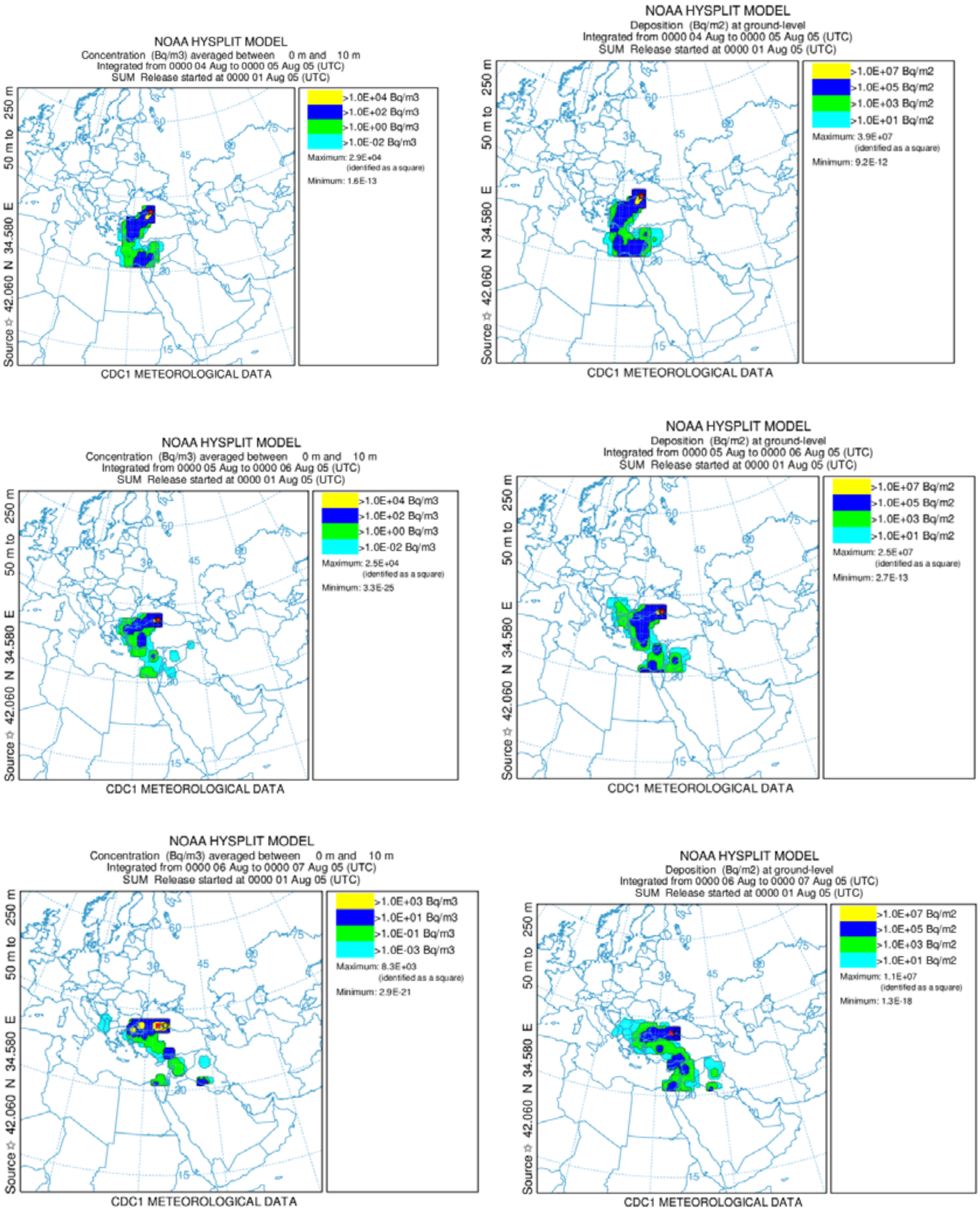

Figure 4.28. (continued)

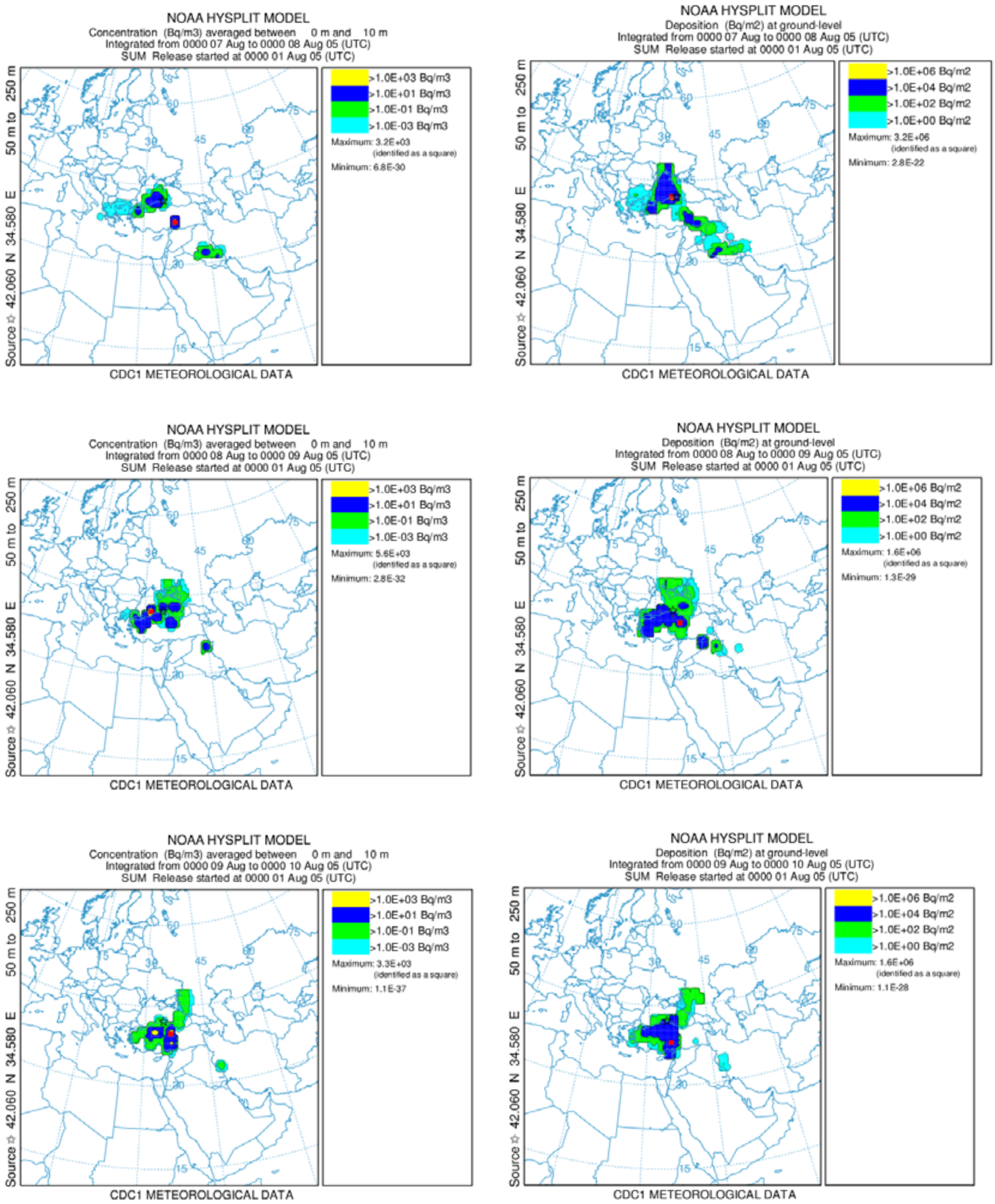

Figure 4.28. (continued)

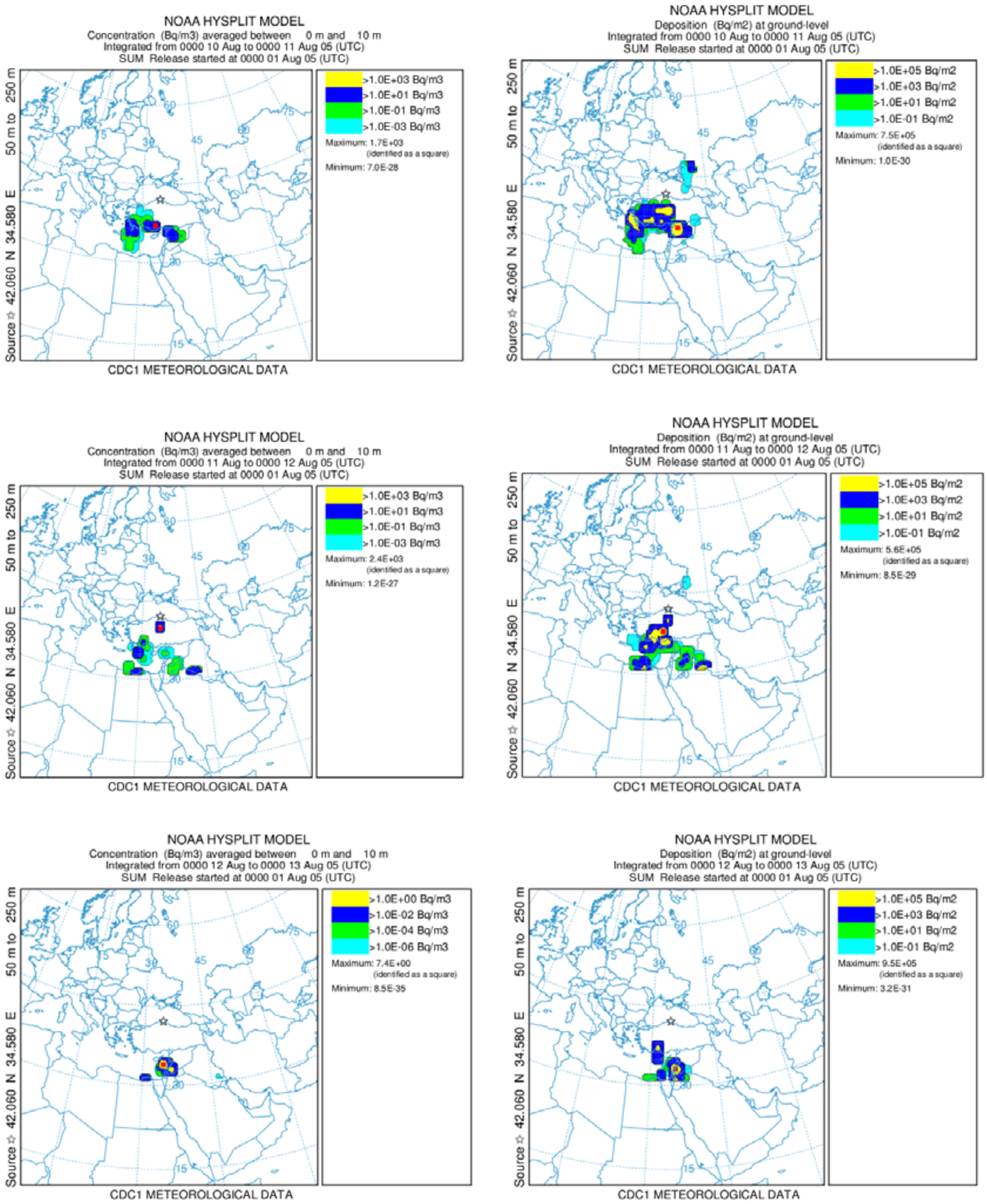

Figure 4.28. (continued)

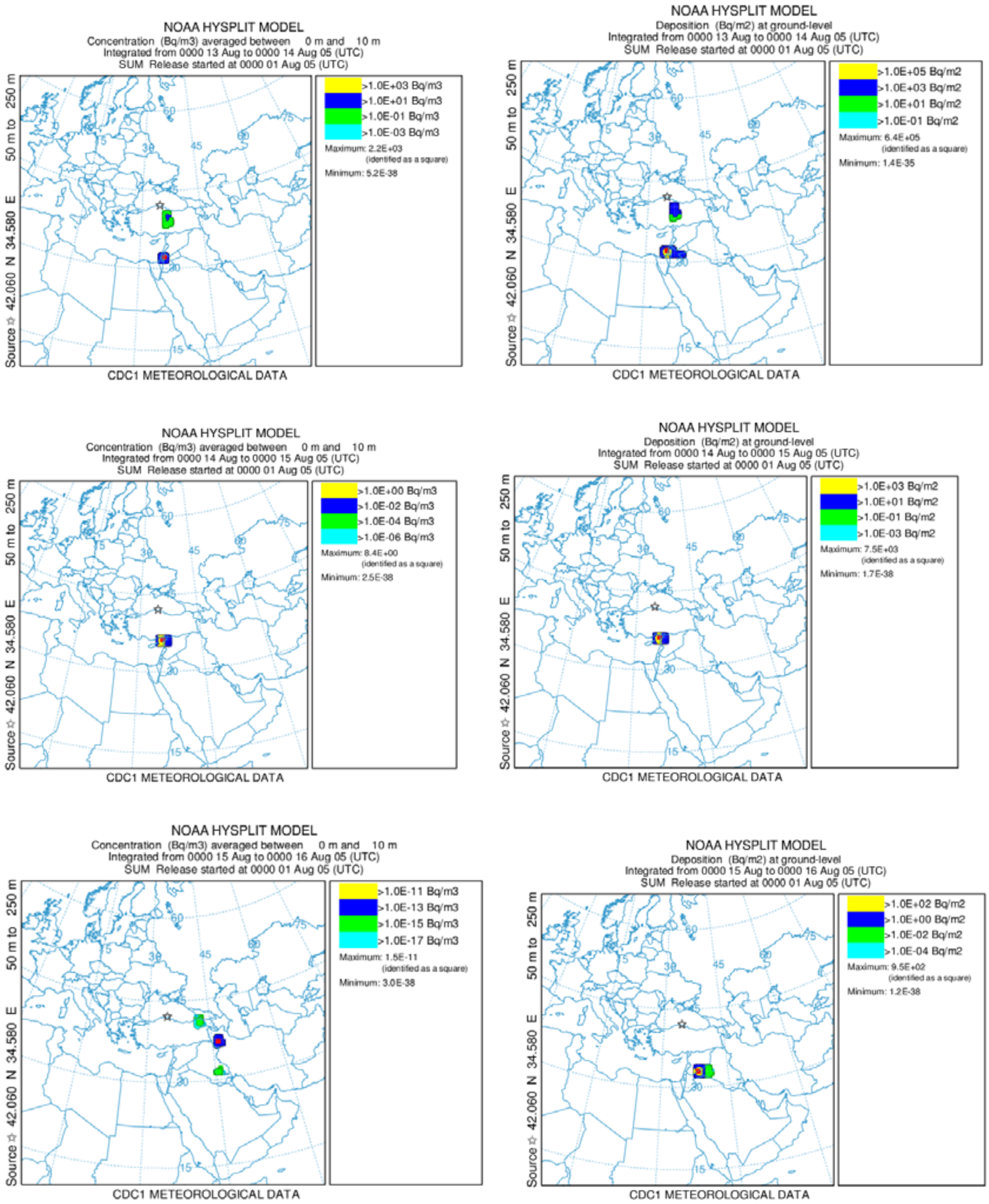

Figure 4.28. (continued)

4.2.2.3. DoseCAL Results for Sinop Accident Case Study

Individual doses and risks incurred 70 years after the accident, and collective dose and risks were calculated taking into account the most important 9 isotopes mentioned in Chapter 3.4.1 and are given in Table 4.12, 4.14, 4.15, 4.16 and 4.17

respectively. Activity concentration results in the grass and food products are given in Figure 4.29- 4.38.

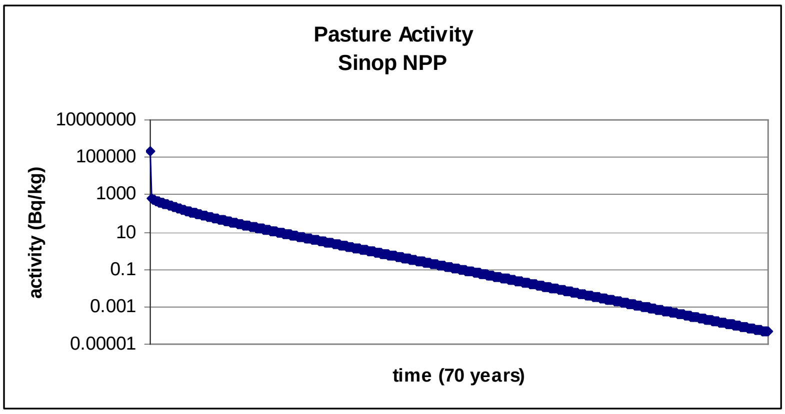

Figure 4.29. Activity in Pasture Grass for Hypothetical Accident at Sinop NPP

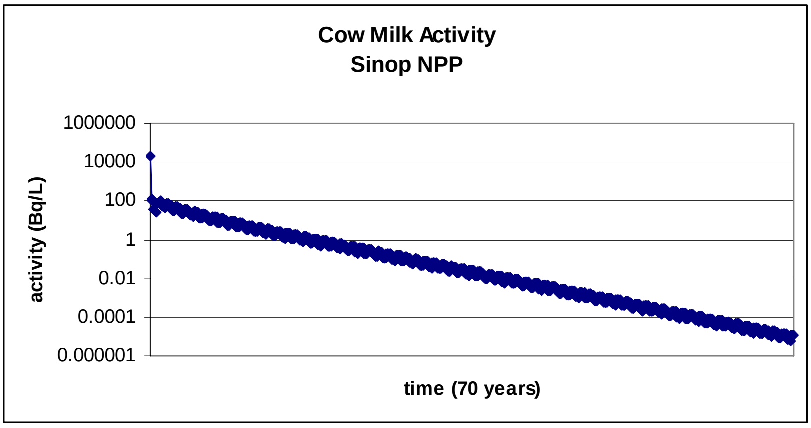

Figure 4.30.a. Annual Activity in Cow Milk for the Hypothetical Accident at Sinop NPP

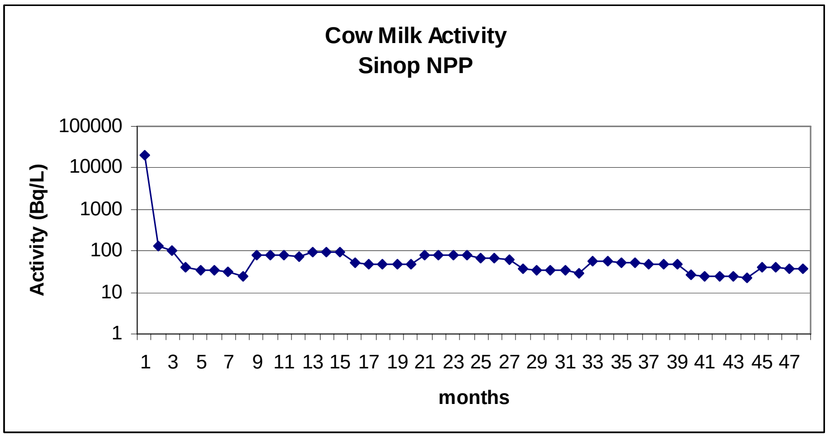

Figure 4.30.b. Monthly Activity in CowMilk for the Hypothetical Accident at Sinop NPP

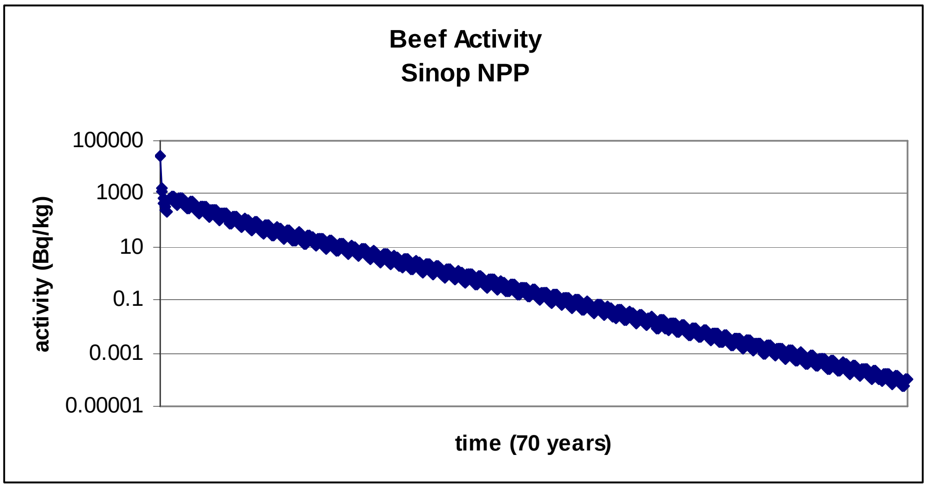

Figure 4.31.a. Annual Activity in Beef for the Hypothetical Accident at Sinop NPP

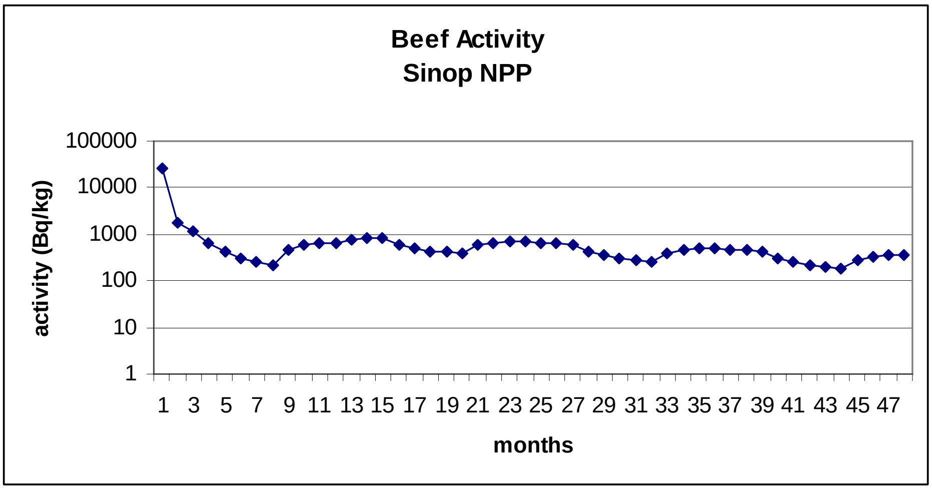

Figure 4.31.b. Monthly Activity in Beef for the Hypothetical Accident at Sinop NPP

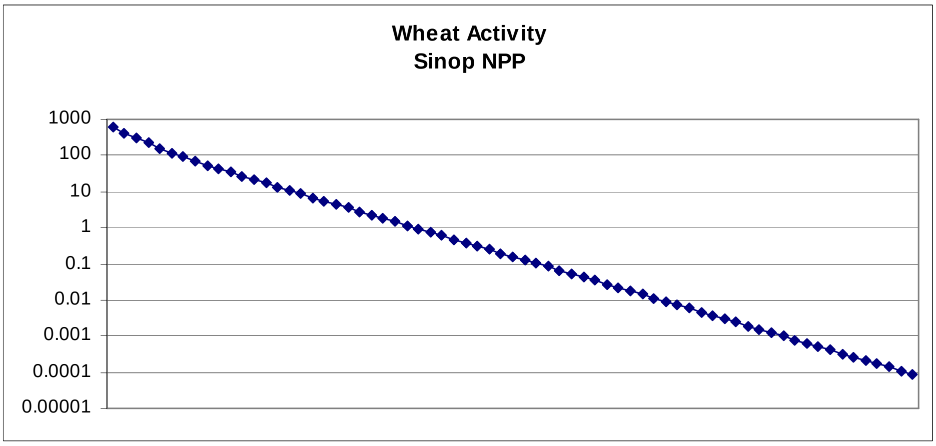

Figure 4.32. Activity in Wheat for the Hypothetical Accident at Sinop NPP

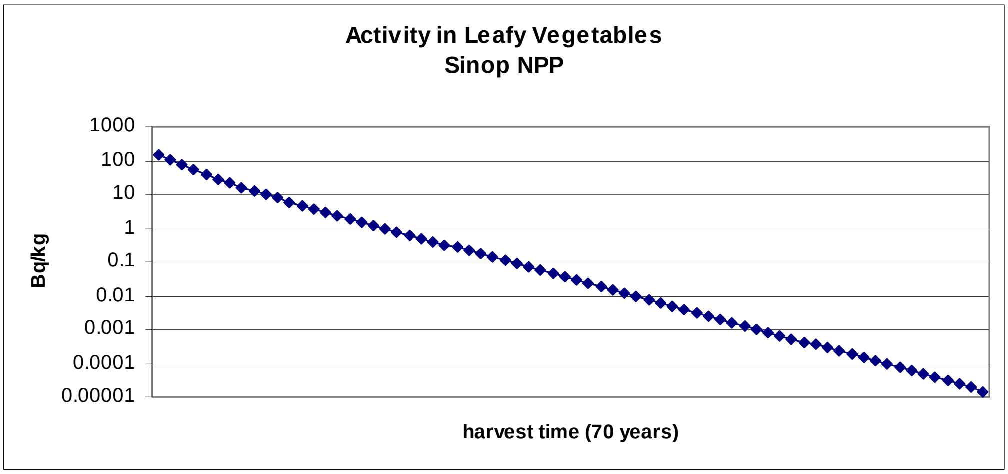

Figure 4.33. Activity in Leafy Vegetables for the Hypothetical Accident at Sinop NPP

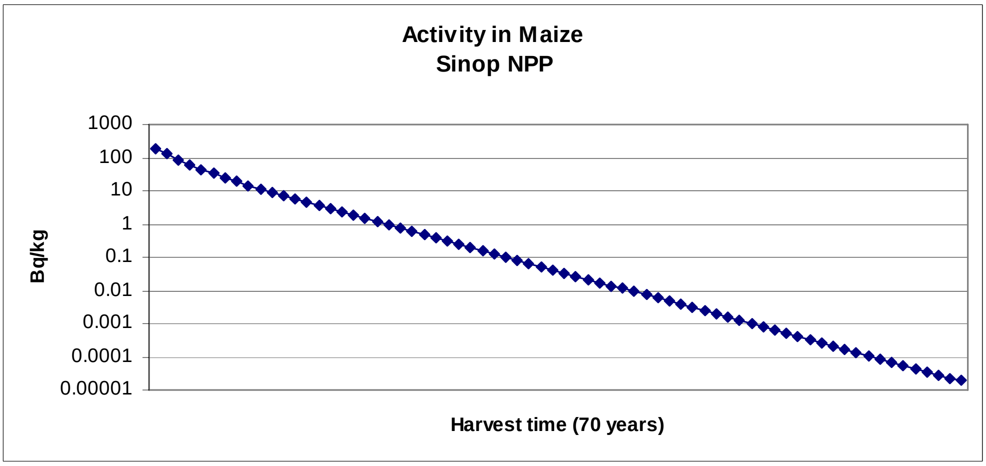

Figure 4.34. Activity in Maize for the Hypothetical Accident at Sinop NPP

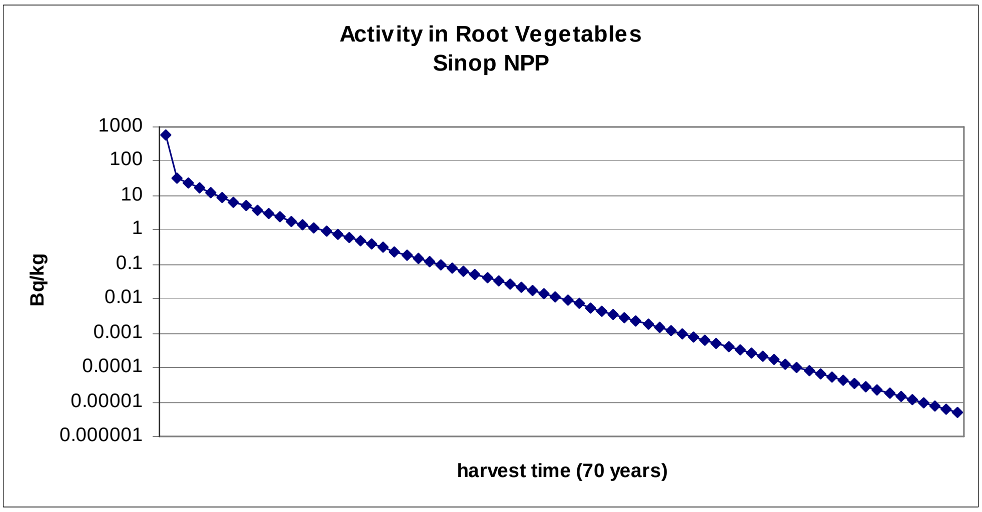

Figure 4.35. Activity in Root Vegetables for the Hypothetical Accident at Sinop NPP

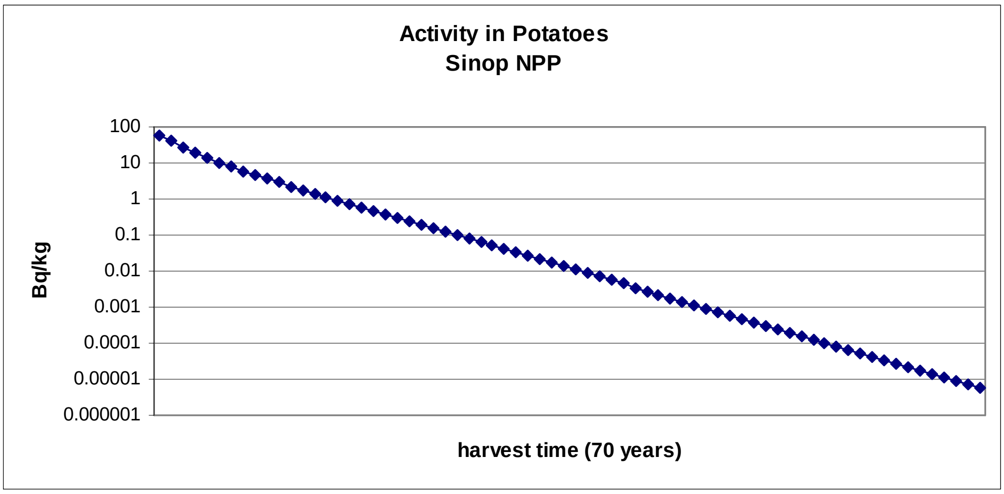

Figure 4.36. Activity in Potatoes for Hypothetical Accident at Sinop NPP

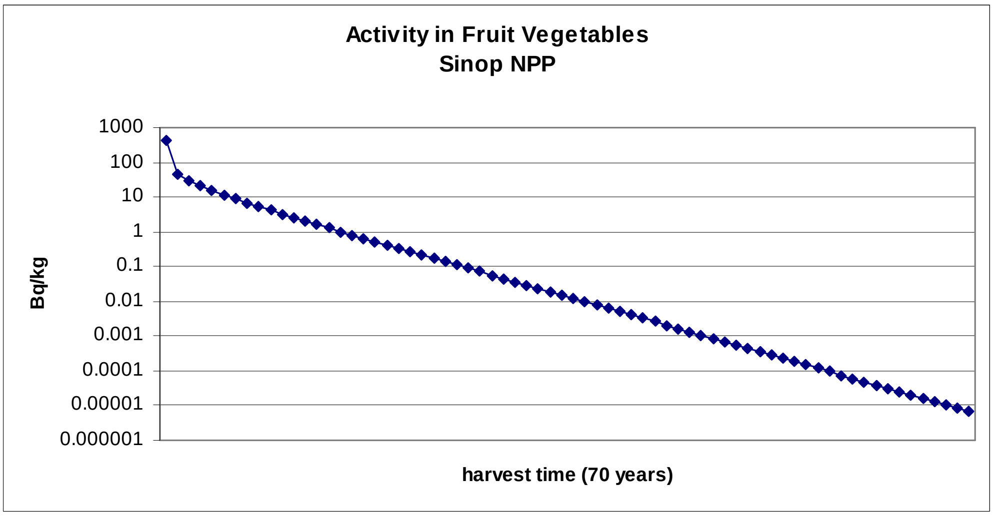

Figure 4.37. Activity in Fruit Vegetables for Hypothetical Accident at Sinop NPP

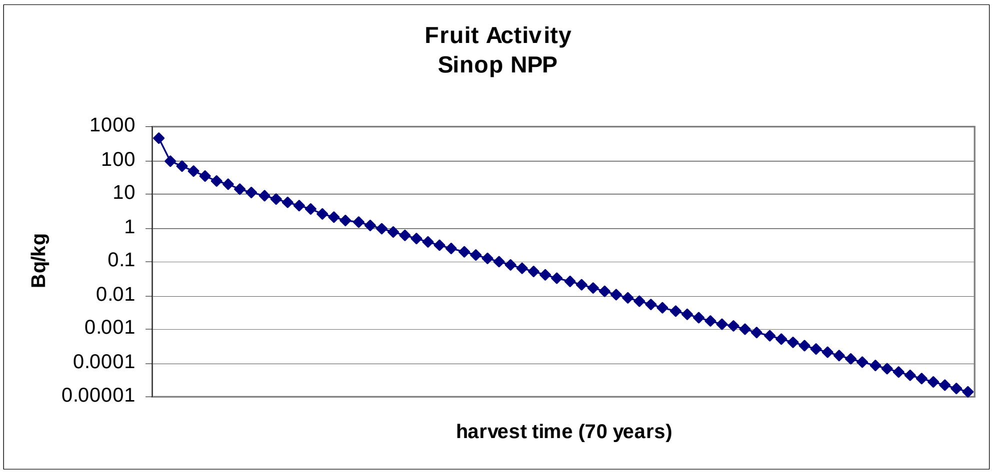

Figure 4.38. Activity in Fruits for Hypothetical Accident at Sinop NPP

As seen from the Figure 4.29, 4.30 and 4.31, the activity concentrations in beef, cow milk and pasture are very similar in value and pattern to those predicted due to a severe accident at Akkuyu NPP. Activity concentration values in all of the plants are higher in the case of hypothetical accident at Sinop NPP than Akkuyu NPP. Besides, beet, fruits, fruit vegetables and root vegetabes receive foliar uptake, though only beet and maize are contaminated by foliar uptake in the case of Akkuyu NPP accident. Pasture is contaminated by direct deposition in both cases.

Table 4.12. Dose Exposure for Different Pathways for 9 Isotopes Sinop NPP Accident (Release started on 1st of August, 2005)

<table>
<tr><th colspan="2">Dose (mSv)</th><th>External Cloud</th><th>External Ground</th><th>Inhalation</th><th>Ingestion</th><th>Total Dose</th></tr>
<tr><td rowspan="4">INFANT AVG.</td><td>After 1 year</td><td rowspan="4">0.0106</td><td>0.57</td><td rowspan="8">0.639</td><td>9.703</td><td>10.923</td></tr>
<tr><td>After 9 years</td><td>2.213</td><td>11.897</td><td>14.759</td></tr>
<tr><td>After 16 years</td><td>2.33</td><td>12.276</td><td>15.255</td></tr>
<tr><td>Lifetime</td><td>2.358</td><td>12.369</td><td>15.377</td></tr>
<tr><td rowspan="4">INFANT MAX.</td><td>After 1 year</td><td rowspan="4">0.0351</td><td>1.88</td><td>18.824</td><td>21.379</td></tr>
<tr><td>After 9 years</td><td>5.44</td><td>23.808</td><td>29.922</td></tr>
<tr><td>After 16 years</td><td>5.690</td><td>24.645</td><td>31.010</td></tr>
<tr><td>Lifetime</td><td>5.750</td><td>24.859</td><td>31.283</td></tr>
<tr><td rowspan="4">CHILD AVG.</td><td>After 1 year</td><td rowspan="4">0.0179</td><td>0.961</td><td rowspan="8">0.761</td><td>3.897</td><td>5.637</td></tr>
<tr><td>After 7 years</td><td>2.503</td><td>5.923</td><td>9.205</td></tr>
<tr><td>After 15 years</td><td>2.714</td><td>5.971</td><td>9.464</td></tr>
<tr><td>Lifetime</td><td>2.750</td><td>6.095</td><td>9.624</td></tr>
<tr><td rowspan="4">CHILD MAX.</td><td>After 1 year</td><td rowspan="4">0.0382</td><td>2.051</td><td>8.422</td><td>11.272</td></tr>
<tr><td>After 7 years</td><td>5.343</td><td>13.022</td><td>19.164</td></tr>
<tr><td>After 15 years</td><td>5.774</td><td>14.465</td><td>21.038</td></tr>
<tr><td>Lifetime</td><td>5.850</td><td>14.799</td><td>21.448</td></tr>
<tr><td rowspan="3">TEEN AVG.</td><td>After 1 year</td><td rowspan="3">0.0179</td><td>0.961</td><td rowspan="6">0.610</td><td>3.132</td><td>4.721</td></tr>
<tr><td>After 7 years</td><td>2.503</td><td>6.812</td><td>9.943</td></tr>
<tr><td>Lifetime</td><td>2.750</td><td>7.736</td><td>11.114</td></tr>
<tr><td rowspan="3">TEEN MAX.</td><td>After 1 year</td><td rowspan="3">0.0382</td><td>2.051</td><td>7.036</td><td>9.735</td></tr>
<tr><td>After 7 years</td><td>5.342</td><td>8.549</td><td>14.540</td></tr>
<tr><td>Lifetime</td><td>5.868</td><td>10.269</td><td>16.785</td></tr>
<tr><td rowspan="4">ADULT AVG.</td><td>After 1 year</td><td rowspan="4">0.0179</td><td>0.961</td><td rowspan="8">0.456</td><td>2.919</td><td>4.354</td></tr>
<tr><td>After 8 years</td><td>2.561</td><td>6.916</td><td>9.951</td></tr>
<tr><td>After 15 years</td><td>2.714</td><td>7.417</td><td>10.605</td></tr>
<tr><td>Lifetime</td><td>2.750</td><td>7.541</td><td>10.765</td></tr>
<tr><td rowspan="4">ADULT MAX.</td><td>After 1 year</td><td rowspan="4">0.0382</td><td>2.051</td><td>7.493</td><td>10.038</td></tr>
<tr><td>After 8 years</td><td>5.466</td><td>16.048</td><td>22.010</td></tr>
<tr><td>After 15 years</td><td>5.792</td><td>17.124</td><td>23.410</td></tr>
<tr><td>Lifetime</td><td>5.868</td><td>17.391</td><td>23.753</td></tr>
</table>

Major contributor to total effective dose is the ingestion dose as seen from Table 4.12. External ground pathway is the secondary dose-contributing pathway. Ingestion doses are the highest for the infant, child, teen and adult, respectively in the first year after the accident; since ingestion DCF for I-131, which is the most dominant isotope in the early phase after the accident, for the infants, is the highest. Infant ingestion doses remain the highest as years pass after the accident, since infants' growing up is taken into account and their food consumption rates increase when growing. Though ingestion doses of child are higher than teen and adult in the first year, adult and teen ingestion doses that are very close, become higher than children doses as years pass after the accident, since food consumption rates for the teen and adults are generally higher than childs (USNRC Reg. guide 1.109, 1977). Ingestion doses are highly dependant on the food consumption rates as seen from the differences between the doses of the average and maximum individuals.

Inhalation doses are the highest for the children, though the highest inhalation DCFs are of the infants, breathing rates for the children are higher than for the infants. Inhalation doses for the teens and the adults are lower than for the children, since DCF's for the radioiosopes considered in this case study for the children are higher than those for adults except cesium isotopes.

External doses are calculated for the infants and others (child, teen and adult). Although DCF's for the infants are 1.5 times higher than for the others, correction factor for the shielding is lower for the infants than for the others; hence external doses are lower for the infants. External ground doses are lower for the infants, too, in the first year and years after the accident.

Total doses are very close to each other for Sinop and Akkuyu NPP accident cases. However, ingestion doses in the case of Sinop NPP accident are approximately 1 mSv higher than those for Akkuyu NPP accident case, as seen from Table 4.13. The reason for this difference is the selection of the different release times that affects the meteorological pattern, feeding regime of the animals, plant vegetation and harvesting times. As explained in Chapter 4.2.1.2 and 4.2.2.2, results of Hysplit model demonstrate that the total deposited activity is higher and stayed longer on the ground in the case of Sinop NPP accident than that for Akkuyu NPP accident.

Table 4.13. Adult Doses incurred from Akkuyu NPP accident vs. Sinop NPP Accident for Average Individuals

	Dose (mSv)	Inhalation	External Ground	External Cloud	Ingestion	Total
Akkuyu NPP	After 1 year	0.0231	0.97	0.536	1.845	3.374
	After 8 years		2.577		5.845	8.982
	After 15 years		2.727		6.336	9.622
	Lifetime		2.762		6.457	9.777
Sinop NPP	After 1 year	0.0179	0.961	0.456	2.919	4.354
	After 8 years		2.561		6.916	9.951
	After 15 years		2.714		7.417	10.605
	Lifetime		2.750		7.541	10.765

As seen from Table 4.14, the most dose contributing isotopes are I-131, Cs-134 and Cs-137 in the first year after the accident. After the first year, the doses incurred by I-129, Xe-133 and Te-129 are zero, due to their short half-lives. The dose conseqeunces of Xe-133 is the least amongst others due to its short half-life, i.e. 5.25 days and its inert feature. In the long term, only Cs-134 and Cs-137 isotopes remain in the environment. According to the Figure 4.39, cow milk, cereals, fruits, chicken, beef, potatoes, lamb, fruit vegetables and root vegetables were the most ingestion dose contributing foods, respectively. Their ingestion leads totally to 7.541 mSv dose exposure for the adults. On the other hand, leafy vegetables, berries, egg and beet are of minor importance in terms of ingestion doses, namely their contribution to total ingestion dose is less than 2.3 %, 0.172 mSv.

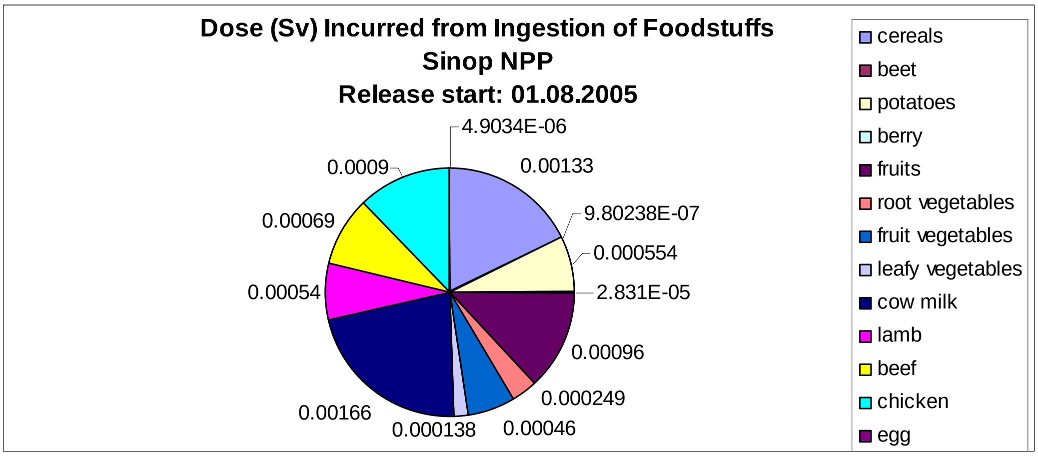

Figure 4.39. Dose Incurred by Ingestion of Foodstuffs for Sinop NPP Accident Case Study

Table 4.14. Dose Contribution of Different Isotopes for Hypothetical Accident at Sinop NPP (Sv)

(Release Started on 1st of August, 2005)

yr	Cs-137	Cs-134	Cs-136	I-131 gas	I-131 particulate	I-132 gas	I-132 particulate	Te-129	Te-129m	Te-132	Xe-133	SUM
1	0.000685	0.0017585	2.3E-05	0.001	0.0005	2.49E-06	4E-06	1E-06	7E-05	3E-04	8E-07	0.00435441
2	0.0006782	0.0011996	2.8E-12	3E-13	1.1E-13	0	0	0	5E-09	2E-20	0	0.00187781
3	0.0005514	0.0007183	3.6E-16	4E-20	1.8E-20	0	0	0	3E-11	4E-41	0	0.00126972
4	0.0004426	0.0004234	1.6E-24	1E-33	5.3E-34	0	0	0	3E-14	0	0	0.00086603
5	0.0003546	0.0002492	7.1E-33	0	0	0	0	0	2E-17	0	0	0.00060378
6	0.0002846	0.0001468	3.1E-41	0	0	0	0	0	2E-20	0	0	0.00043136
7	0.000228	8.641E-05	0	0	0	0	0	0	1E-23	0	0	0.00031443
8	0.000183	5.092E-05	0	0	0	0	0	0	7E-27	0	0	0.00023391
9	0.0001466	2.997E-05	0	0	0	0	0	0	4E-30	0	0	0.0001766
10	0.0001177	1.766E-05	0	0	0	0	0	0	3E-33	0	0	0.00013532
11	9.427E-05	1.039E-05	0	0	0	0	0	0	2E-36	0	0	0.00010466
12	7.567E-05	6.126E-06	0	0	0	0	0	0	1E-39	0	0	8.1794E-05
13	6.061E-05	3.604E-06	0	0	0	0	0	0	6E-43	0	0	6.4214E-05
14	4.863E-05	2.124E-06	0	0	0	0	0	0	0	0	0	5.0757E-05
15	3.897E-05	1.25E-06	0	0	0	0	0	0	0	0	0	4.0221E-05
16	3.127E-05	7.364E-07	0	0	0	0	0	0	0	0	0	3.2009E-05
17	2.505E-05	4.333E-07	0	0	0	0	0	0	0	0	0	2.5482E-05
18	2.011E-05	2.554E-07	0	0	0	0	0	0	0	0	0	2.0363E-05
19	1.611E-05	1.503E-07	0	0	0	0	0	0	0	0	0	1.626E-05
20	1.292E-05	8.854E-08	0	0	0	0	0	0	0	0	0	1.3013E-05
21	1.036E-05	5.211E-08	0	0	0	0	0	0	0	0	0	1.041E-05
22	8.312E-06	3.071E-08	0	0	0	0	0	0	0	0	0	8.343E-06
23	6.659E-06	1.807E-08	0	0	0	0	0	0	0	0	0	6.6769E-06
24	5.345E-06	1.065E-08	0	0	0	0	0	0	0	0	0	5.3553E-06
25	4.282E-06	6.268E-09	0	0	0	0	0	0	0	0	0	4.2884E-06
26	3.437E-06	3.694E-09	0	0	0	0	0	0	0	0	0	3.4407E-06
27	2.753E-06	2.174E-09	0	0	0	0	0	0	0	0	0	2.7555E-06

Table 4.14. Dose Contribution of Different Isotopes for Hypothetical Accident at Sinop NPP (Sv)

(Release Started on 1st of August, 2005) (continued)

28	2.21E-06	1.281E-09	0	0	0	0	0	0	0	0	0	2.2108E-06
29	1.771E-06	7.539E-10	0	0	0	0	0	0	0	0	0	1.7715E-06
30	1.421E-06	4.442E-10	0	0	0	0	0	0	0	0	0	1.4211E-06
31	1.138E-06	2.614E-10	0	0	0	0	0	0	0	0	0	1.1383E-06
32	9.135E-07	1.54E-10	0	0	0	0	0	0	0	0	0	9.1363E-07
33	7.318E-07	9.064E-11	0	0	0	0	0	0	0	0	0	7.319E-07
34	5.871E-07	5.34E-11	0	0	0	0	0	0	0	0	0	5.872E-07
35	4.705E-07	3.143E-11	0	0	0	0	0	0	0	0	0	4.7056E-07
36	3.776E-07	1.852E-11	0	0	0	0	0	0	0	0	0	3.7762E-07
37	3.024E-07	1.09E-11	0	0	0	0	0	0	0	0	0	3.0246E-07
38	2.428E-07	6.423E-12	0	0	0	0	0	0	0	0	0	2.4279E-07
39	1.945E-07	3.78E-12	0	0	0	0	0	0	0	0	0	1.9452E-07
40	1.561E-07	2.227E-12	0	0	0	0	0	0	0	0	0	1.5608E-07
41	1.251E-07	1.311E-12	0	0	0	0	0	0	0	0	0	1.2507E-07
42	1.004E-07	7.725E-13	0	0	0	0	0	0	0	0	0	1.0037E-07
43	8.043E-08	4.547E-13	0	0	0	0	0	0	0	0	0	8.0431E-08
44	6.454E-08	2.679E-13	0	0	0	0	0	0	0	0	0	6.4537E-08
45	5.171E-08	1.577E-13	0	0	0	0	0	0	0	0	0	5.1706E-08
46	4.151E-08	9.293E-14	0	0	0	0	0	0	0	0	0	4.1506E-08
47	3.325E-08	5.467E-14	0	0	0	0	0	0	0	0	0	3.3246E-08
48	2.668E-08	3.222E-14	0	0	0	0	0	0	0	0	0	2.6676E-08
49	2.138E-08	1.896E-14	0	0	0	0	0	0	0	0	0	2.1376E-08
50	1.715E-08	1.117E-14	0	0	0	0	0	0	0	0	0	1.7153E-08
51	1.374E-08	6.573E-15	0	0	0	0	0	0	0	0	0	1.374E-08
52	1.103E-08	3.874E-15	0	0	0	0	0	0	0	0	0	1.1029E-08
53	8.836E-09	2.28E-15	0	0	0	0	0	0	0	0	0	8.8363E-09
54	7.088E-09	1.343E-15	0	0	0	0	0	0	0	0	0	7.0883E-09
55	5.683E-09	7.908E-16	0	0	0	0	0	0	0	0	0	5.683E-09
56	4.556E-09	4.656E-16	0	0	0	0	0	0	0	0	0	4.5556E-09

Table 4.14. Dose Contribution of Different Isotopes for Hypothetical Accident at Sinop NPP (Sv)

(Release Started on 1st of August, 2005) (continued)

57	3.655E-09	2.743E-16	0	0	0	0	0	0	0	0	0	3.6555E-09
58	2.929E-09	1.615E-16	0	0	0	0	0	0	0	0	0	2.9292E-09
59	2.351E-09	9.515E-17	0	0	0	0	0	0	0	0	0	2.3507E-09
60	1.884E-09	5.6E-17	0	0	0	0	0	0	0	0	0	1.8837E-09
61	1.511E-09	3.3E-17	0	0	0	0	0	0	0	0	0	1.5115E-09
62	1.211E-09	1.942E-17	0	0	0	0	0	0	0	0	0	1.211E-09
63	9.721E-10	1.145E-17	0	0	0	0	0	0	0	0	0	9.7208E-10
64	7.786E-10	6.734E-18	0	0	0	0	0	0	0	0	0	7.7863E-10
65	6.248E-10	3.968E-18	0	0	0	0	0	0	0	0	0	6.2477E-10
66	5.006E-10	2.335E-18	0	0	0	0	0	0	0	0	0	5.0064E-10
67	4.017E-10	1.376E-18	0	0	0	0	0	0	0	0	0	4.0174E-10
68	3.218E-10	8.096E-19	0	0	0	0	0	0	0	0	0	3.2179E-10
69	2.583E-10	4.772E-19	0	0	0	0	0	0	0	0	0	2.5831E-10
70	2.066E-10	2.805E-19	0	0	0	0	0	0	0	0	0	2.066E-10

Table 4.15. Late Risks Calculated with ICRP-103 Risk Coefficients

For Sinop NPP Accident Case Study

Coordinate		INFANT		CHILD		TEEN		ADULT	
LAT	LON	Cancer risk	Hereditary risk	Cancer risk	Hereditary risk	Cancer risk	Hereditary Risk	Cancer risk	Hereditary risk
36	26.5	4.459E-08	8.108E-10	1.293E-07	2.35E-09	5.66E-08	1.029E-09	2.52E-08	1.23E-09
36	29	1.352E-06	2.457E-08	4.142E-06	7.53E-08	3.91E-06	7.105E-08	2.9E-06	1.41E-07
36	31.5	7.222E-07	1.313E-08	1.738E-06	3.16E-08	1.27E-06	2.312E-08	8.19E-07	4E-08
36	34	2.003E-07	3.642E-09	4.886E-07	8.88E-09	2.31E-07	4.204E-09	1.06E-07	5.19E-09
36	36.5	1.365E-07	2.481E-09	3.939E-07	7.16E-09	1.75E-07	3.175E-09	7.88E-08	3.84E-09
36	39	2.395E-10	4.354E-12	8.974E-10	1.63E-11	7.25E-10	1.319E-11	4.77E-10	2.32E-11
36	41.5	7.082E-12	1.288E-13	1.853E-11	3.37E-13	9.43E-12	1.714E-13	4.84E-12	2.36E-13
36	44	3.552E-11	6.458E-13	1.028E-10	1.87E-12	4.52E-11	8.21358E-13	2.02E-11	9.85E-13
38.5	26.5	8.229E-08	1.496E-09	2.034E-07	3.7E-09	1.48E-07	2.700E-09	9.46E-08	4.61E-09
38.5	29	1.074E-06	1.953E-08	3.662E-06	6.66E-08	3.71E-06	6.744E-08	2.92E-06	1.42E-07
38.5	31.5	2.377E-06	4.322E-08	7.202E-06	1.31E-07	6.98E-06	1.270E-07	5.18E-06	2.53E-07
38.5	34	5.797E-06	1.054E-07	5.639E-06	1.03E-07	5.42E-06	9.858E-08	4.05E-06	1.98E-07
38.5	36.5	6.882E-08	1.251E-09	1.442E-07	2.62E-09	8.93E-08	1.623E-09	4.92E-08	2.4E-09
38.5	39	8.202E-13	1.491E-14	2.026E-12	3.68E-14	9.51E-13	1.728E-14	4.35E-13	2.12E-14
38.5	41.5	6.704E-14	1.219E-15	1.088E-13	1.98E-15	6.42E-14	1.167E-15	3.19E-14	1.56E-15
38.5	44	9.587E-16	1.743E-17	2.104E-15	3.83E-17	2.47E-15	4.497E-17	1.77E-15	8.64E-17
41	26.5	1.610E-06	2.927E-08	8.894E-06	1.62E-07	1.1E-05	2.008E-07	8.74E-06	4.27E-07
41	29	3.144E-06	5.716E-08	1.520E-05	2.76E-07	1.81E-05	3.291E-07	1.5E-05	7.31E-07
41	31.5	8.450E-06	1.536E-07	3.762E-05	6.84E-07	4.53E-05	8.239E-07	3.61E-05	1.76E-06
41	34	0.000601	1.092E-05	0.0005147	9.36E-06	0.000547	9.943E-06	0.000441	2.15E-05
41	36.5	1.250E-06	2.273E-08	2.912E-06	5.29E-08	2.58E-06	4.700E-08	1.88E-06	9.16E-08
41	39	8.667E-09	1.576E-10	4.726E-08	8.59E-10	5.73E-08	1.042E-09	4.24E-08	2.07E-09
41	41.5	5.166E-16	9.393E-18	3.597E-15	6.54E-17	5.02E-15	9.122E-17	3.82E-15	1.86E-16
41	44	1.275E-16	2.319E-18	1.198E-15	2.18E-17	1.28E-15	2.331E-17	9.43E-16	4.6E-17

Table 4.16. Late Risks Calculated with USEPA FGR-13 Risk Coefficients for Sinop NPP Accident Case Study

Coordinate		INFANT		CHILD		TEEN		ADULT	
		Morbidity Risk	Mortality Risk	Morbidity Risk	Mortality Risk	Morbidity Risk	Mortality Risk	Morbidity Risk	Mortality Risk
36	26.5	3.07E-08	3.29E-09	4.37E-07	4.63E-08	5.37E-07	5.69E-08	4.68E-07	4.96E-08
36	29	5E-07	1.76E-07	2.71E-05	1.62E-05	3.35E-05	1.99E-05	3.73E-05	2.3E-05
36	31.5	2.35E-07	5.14E-08	7.36E-06	3.48E-06	9.08E-06	4.29E-06	9.55E-06	4.86E-06
36	34	9.73E-08	1.07E-08	1.38E-06	1.5E-07	1.7E-06	1.84E-07	1.48E-06	1.61E-07
36	36.5	9.43E-08	1.11E-08	1.34E-06	1.53E-07	1.64E-06	1.87E-07	1.44E-06	1.66E-07
36	39	1.74E-10	4.44E-11	5.37E-09	2.62E-09	6.71E-09	3.29E-09	6.51E-09	3.32E-09
36	41.5	3.88E-12	4.72E-13	6.17E-11	1.1E-11	7.59E-11	1.37E-11	6.83E-11	1.34E-11
36	44	7.96E-11	3.96E-11	4.88E-10	1.31E-10	5.67E-10	1.4E-10	5.13E-10	1.34E-10
38.5	26.5	2.78E-08	5.44E-09	9.47E-07	4.35E-07	1.16E-06	5.35E-07	1.16E-06	5.66E-07
38.5	29	4.39E-07	1.58E-07	2.78E-05	1.69E-05	3.41E-05	2.08E-05	3.97E-05	2.49E-05
38.5	31.5	8.18E-07	2.99E-07	4.78E-05	2.88E-05	5.9E-05	3.57E-05	6.56E-05	4.08E-05
38.5	34	3.85E-06	6.46E-07	3.67E-05	2.13E-05	4.69E-05	2.67E-05	5.4E-05	2.99E-05
38.5	36.5	2.01E-08	3.47E-09	4.04E-07	1.3E-07	5E-07	1.62E-07	4.65E-07	1.62E-07
38.5	39	2.56E-12	1.49E-12	1.13E-11	4.27E-12	1.26E-11	4.41E-12	1.17E-11	4.31E-12
38.5	41.5	7.78E-15	9.4E-16	1.19E-13	1.87E-14	1.46E-13	2.28E-14	1.31E-13	2.23E-14
38.5	44	1.46E-16	9.96E-17	1.28E-14	8.77E-15	1.61E-14	1.1E-14	1.67E-14	1.14E-14
41	26.5	1.08E-06	6.06E-07	8.55E-05	5.65E-05	0.000106	7.02E-05	0.000116	7.75E-05
41	29	1.64E-06	8.72E-07	0.000146	9.58E-05	0.000179	0.000118	0.00021	0.000139
41	31.5	4.17E-06	2.3E-06	0.000342	0.000226	0.000423	0.00028	0.000477	0.000318
41	34	0.000445	7.87E-05	0.004185	0.002541	0.005336	0.00317	0.006414	0.003689
41	36.5	6.61E-07	1.73E-07	1.8E-05	1.02E-05	2.24E-05	1.26E-05	2.49E-05	1.45E-05
41	39	6.92E-09	3.53E-09	4.15E-07	2.68E-07	5.22E-07	3.38E-07	5.27E-07	3.44E-07
41	41.5	4.52E-16	3.11E-16	3.63E-14	2.5E-14	4.57E-14	3.15E-14	4.66E-14	3.21E-14
41	44	1.02E-16	6.91E-17	1.19E-14	7.74E-15	1.48E-14	9.62E-15	1.42E-14	9.38E-15

Table 4.17. Collective Dose and Risk
Sinop NPP Case Study

CITY	Collective Dose (man-Sv)	Collective Mortality Risk	Collective Morbidity Risk
Ankara	13 989.037	3 306.854	5 656.959
Konya	216.447	47.866	81.770
İstanbul	39 264.230	9 281.632	15 877.872
Kocaeli	430.788	148.232	224.931
Balıkesir	298.833	102.827	156.032
İzmir	427.412	141.459	217.300
Manisa	3.467	0.524	1.119
Samsun	70.895	19.785	32.185
Erzurum	32.285	7.166	12.632
Van	7.226E-07	2.055E-08	7.119E-08
Gaziantep	6.634E-08	1.445E-08	2.108E-08
Adana	2.885	0.132	0.795
Antalya	88.863	19.403	33.628
Mersin	8.242	0.215	1.989
Sinop	1 052.439	243.306	420.522

Late risks were calculated with ICRP-103 and USEPA FGR-13 risk coefficients and given in Table 4.15 and 4.16. For Sinop, morbidity risk for the infants is 0.000445, mortality risk for them is 7.87E-05, that means in every 10 000 infants 5 infants will experience fatal risk and in every 10 000 infants 8 infants will suffer from radiation related sickness. In Sinop, the adults will experience the cancer risks of 0.0006, and hereditary risk of 1.092E-05. These numbers mean that in every 10 000 adults four are expected to suffer from cancer, and in every 100 000 adults 2 people are expected to pass on hereditary effects to their offsprings. Adding this number to the averege background cancer risks for Turkish people, incresed cancer risk will be 261.5 / 100 000 people.

As given in Table 4.17, İstanbul is the city where the people are exposed to maximum collective doses and risks due to its large population. A severe accident at Sinop NPP leads to 39 264.230 man-Sv collective lifetime doses in İstanbul. After İstanbul, the highest risk values were predicted in Ankara and Sinop. Compared to hypothetical accident at Akkuyu NPP, Sinop accident has more wide scale radiological influence overall Turkey. Since Antalya, Kocaeli, Samsun, Balıkesir, Manisa, İzmir and

Bursa are the cities that have not affected from the hypothetical accident at Akkuyu NPP, at all.

4.3. Results of Uncertainty and Sensitivity Analyses

4.3.1. Uncertainty Analysis Results

Uncertainty analysis was performed such that 100 DoseCAL trials were performed with all of the uncertain parameters changing simultaneously. The extent of the uncertainty is presented using the ratio of the 95th to the 5th percentiles of the uncertainty distribution; the term "uncertainty factor" is used in this study to represent this factor (EUR-18825, 2001 and Müller H., Pröhl G., Friedlandt W., Gardner R.H., 1993).

Figure 4.40 and 4.41 show the resulting cumulative frequency distribution for the total effective dose and for the grass activity 1 year after the accident. It indicates that 50 % of the dose results are less than 1.8 mSv, 50 % of the results on grass activity is less than 10.000 Bq/kg 1 year after the accident. The uncertainty analysis shows that the lifetime doses are in the range of 4.8 - 32 mSv and dose incurred 1 year after the accident is in the range of 1.1-2.8 mSv. There is an uncertainty factor of around 2.1-4.8 for doses 1 year after the accident and for the lifetime exposure. The range of uncertainty of individual foodstuff's contamination is larger than for the ingestion dose. As seen from Table 4.18, there is an uncertainty factor of 1.4-12.5 for ingestion doses incurred 1 year after the accident and lifetime exposure; however, this factor can reach to almost 11.4 and 22 in the case of beef and cow milk. This is because several foodstuffs contribute independently to the ingestion dose. The uncertainty in the external cloud and external ground doses are the same, since only one parameter, i.e. the reduction factor, contributes to the uncertainty in both cloudshine and groundshine doses.

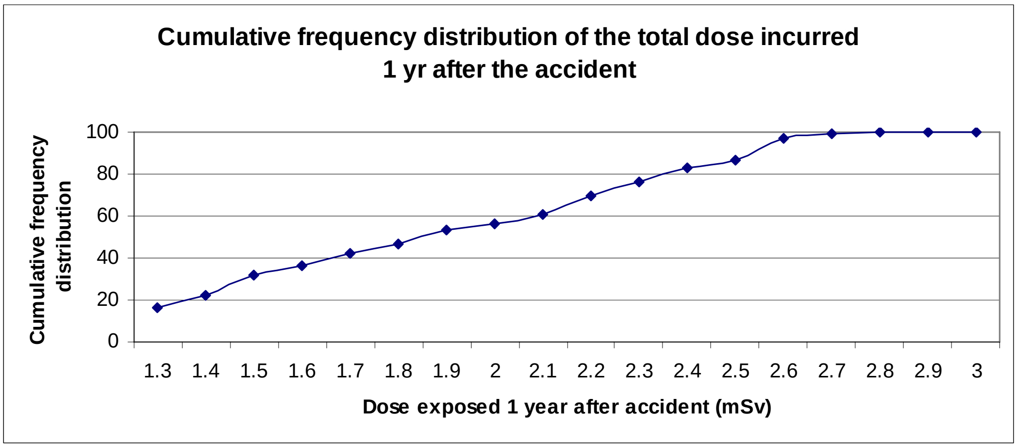

Figure 4.40. Cumulative Frequency Distribution of the Total Dose Incurred 1 year After Hypothetical Accident at Akkuyu NPP

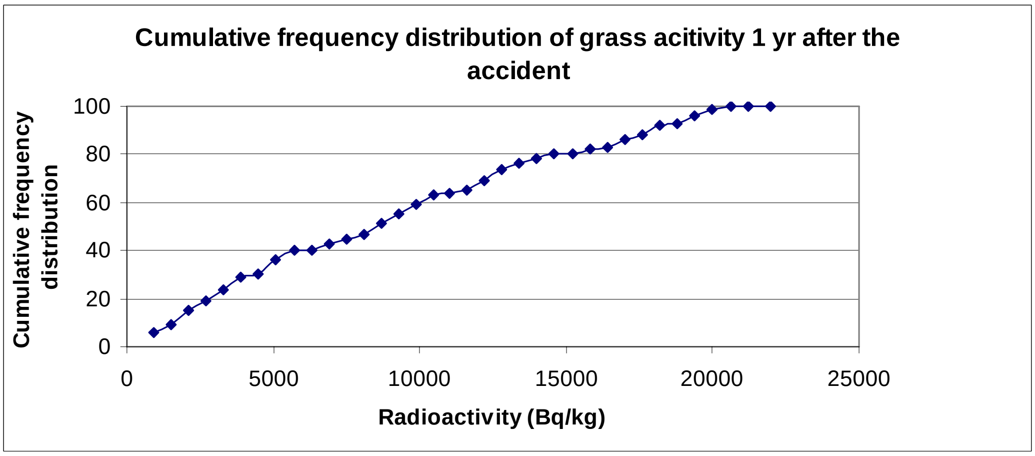

Figure 4.41. Cumulative Frequency Distribution of Grass Activity 1 year After Hypothetical Accident at Akkuyu NPP

Though almost all of the sources of uncertainty are taken into account, other sources of uncertainty may be the impact of food distribution, which is not considered in probabilistic assessment or in deterministic DoseCAL model.

Table 4.18. Resulting Uncertainty of the Model Results

Type of Result	Min.	Max.	Ratio Max/Min	5% Percentile	50 % Percentile	95 % Percentile	Ratio 95/5 %
1st yr dose (mSv)	1.106	2.824	2.552	0.00127	0.00196	0.0027	2.089
70th yr dose (mSv)	4.783	31.931	6.676	0.0057	0.0130	0.0273	4.795
1st yr ingestion dose (mSv)	7.85E-02	0.12	1.534	8.080E-05	9.31E-05	0.0001	1.377
70th yr ingestion dose (mSv)	1.064	26.968	25.351	0.0018	0.0089	0.0229	12.520
Inhalation dose (mSv)	0.371	0.703	1.894	0.0004	0.00054	0.00069	1.775
Extcloud dose (mSv)	1.45E-05	4.86E-05	3.349	1.585E-05	3E-05	4.76E-05	3.0054
1st yr extground dose (mSv)	0.611	2.045	3.349	0.00067	0.00126	0.0020	3.0054
70th yr extground dose (mSv)	1.738	5.819	3.349	0.0019	0.0036	0.0057	3.0054
1st month activity in grass (Bq/kg)	108 503.8	227 081.3	2.093	117 762.795	154 616.3	210 418.4	1.787
1st year activity in grass (Bq/kg)	872.570	20 606.14	23.615	1 450.988	9 042.937	19 783.18	13.634
2nd yr activity in wheat (Bq/kg)	270.729	4 795.691	17.714	577.232	2 866.906	4 732.469	8.199
1st yr activity in fruit (Bq/kg)	28.799	1 478.449	51.337	99.290	881.397	1 414.035	14.241
2nd yr activity in fruit (Bq/kg)	19.309	998.054	51.689	66.900	594.943	954.557	14.268
1st yr activity in fruit vegetables (Bq/kg)	6.541	212.589	32.502	17.851	95.801	196.6691	11.017
2nd yr activity in fruit vegetables (Bq/kg)	4.426	143.992	32.537	12.086	64.886	133.209	11.021
1st month activity in cow milk (Bq/L)	1549.52	24 317.57	15.694	2 287.359	6 595.58	17 155.36	7.500
1st yr activity in cow milk (Bq/L)	161.3625	9 583.256	59.390	356.987	2 111.963	8 093.933	22.673
1 st month activity in lamb (Bq/kg)	9 537.683	134 090.3	14.059	16 155.386	39 785.53	101 250.7	6.267
1st yr activity in lamb (Bq/kg)	555.731	67 874.02	122.135	1 380.538	12 693.08	57 048.73	41.324
1st month activity in beef (Bq/kg)	2 279.493	36 979.77	16.223	4 857.324	9 799.264	23 975.57	4.936
1st yr activity in beef (Bq/kg)	142.013	11 764.6	82.842	551.703	2 031.385	6 292.585	11.406
1st month activity in chicken (Bq/kg)	1.424	32.491	22.809	3.295	16.050	31.026	9.417
1st yr activity in chicken (Bq/kg)	1.436	32.502	22.628	3.307	16.062	31.038	9.387

Table 4.19. Uncertainty in the Activity Concentrations After the Accident

Time	Min.	Max.	Max/ Min	5% Percentile	50% Percentile	95% Percentile	Ratio 95/5 %
Fruits (Bq/kg)							
1st year	28.800	1478.449	51.337	99.2907	881.397	1414.035	14.241
2nd year	19.309	998.054	51.690	66.900	594.943	954.557	14.268
3rd year	13.351	690.086	51.690	46.257	411.363	660.011	14.268
4th year	9.450	488.449	51.690	32.741	291.166	467.162	14.268
5th year	6.838	353.446	51.690	23.692	210.691	338.042	14.268
Cow Milk (Bq/L)							
1st month	1549.52	24317.57	15.694	2287.359	6595.58	17155.36	7.500
1st year	161.3625	9583.256	59.390	356.987	2111.963	8093.933	22.673
2nd year	124.261	7585.122	61.041	298.441	1855.55	5925.732	19.856
3rd year	84.304	5252.039	62.299	202.931	1279.58	4116.095	20.283
4th year	59.046	3724.005	63.069	143.307	904.902	2927.994	20.432
Grass (Bq/kg)							
1st month	108503.8	227081.3	2.093	117762.79	154616.3	210394.9	1.787
1st year	872.570	20606.14	23.615	1450.988	9042.937	19595.63	13.505
2nd year	595.732	14068.98	23.616	990.651	6174.112	13379.04	13.505
3rd year	416.496	9836.074	23.616	692.596	4316.52	9353.717	13.505
4th year	297.932	7036.044	23.616	495.435	3087.738	6690.999	13.505

As seen from Table 4.18, the uncertainty increases with time for most of the parameters, particularly for ingestion doses, cow milk, beef and lamb. As understood from Table 4.19 the timely increase was especially observed in the 1st year after the accident. As seen from Table 4.19, uncertainty in the grass and cow milk activity does not change much 1 year after the accident; however, during the first year it increases remarkably. The uncertainty in the activity in fruits remains constant after the accident.

4.3.2. Sensitivity Analysis Results

DoseCAL model was run totally 9 600 times performing the 100 calculations for each of the 96 model parameters chosen for the sensitivity analysis. When each of the sensitive parameters changes within their minumum and maximum values, the other inputs were kept at their default values to see the affect of each parameter. The results were ranked to understand the effect of the aformentioned parameters on the doses. The end points of the model are the lifetime doses and doses incurred 1 year after the accident.

Spearman ρ coefficients between the parameters that are associated with the most important foodstuffs and radionuclides in terms of dose contribution, and doses have been calculated. If a perfect Spearman correlation of +1 or −1 occurs each of the variables is a perfect monotone function of the other.

4.3.2.1. **Sensitivity Analysis for Lifetime Doses**

Spearman ρ coefficients between the parameters and lifetime doses are given in Table 4.20.

Table 4.20. Spearman Coefficients between Parameters and the Lifetime Doses

Parameter	**Spearman** ρ	**Parameter**	**Spearman** ρ
Reduction factor for adult	1	Transfer factor for beef for Cs ($d.kg^{-1}$)	1
Inhalation rate for adult (m^3/hr)	1	Transfer factor for chicken for Cs ($d.kg^{-1}$)	1
Interception fraction for grass	1	Transfer factor for cow milk for I ($d.L^{-1}$)	1
Interception fraction for maize	1	Transfer factor for lamb for I ($d.kg^{-1}$)	1
Interception factor for other plants	0	Transfer factor for beef for I ($d.kg^{-1}$)	1
Grain consumption (kg/day)	1	Transfer factor for chicken for I ($d.kg^{-1}$)	0.994
Fruit (non-berry) consumption (kg/day)	1	Translocation factor for maize	1
Fruit vegetables consumption (kg/day)	1	Translocation factor for hay	0
Cow milk consumption (kg/day)	1	Translocation factor for fruits	0
Lamb consumption (kg/day)	1	Translocation factor for fruit vegetables	0
Beef consumption (kg/day)	1	Distribution coefficient for Cs (cm^3/gr)	0.993
Chicken consumption (kg/day)	1	Distribution coefficient for I (cm^3/gr)	0.800
Transfer factor of Cs for grass	1	Soil density in plant rooting zone (kg/m^3)	0.984
Transfer factor for maize for Cs	1	Hay feeding rate of cow in summer (kg/d)	1
Transfer factor for hay for Cs	1	Grass feeding rate of cow in summer (kg/d)	1
Transfer factor for cereals for Cs	1	Silage feeding rate of cow in summer (kg/d)	1
Transfer factor for fruits for Cs	1	Concentrates feeding rate of cow (kg/d)	1
Transfer factor for fruit vegetables for Cs	1	Hay feeding rate of cow in winter (kg/d)	1
Transfer factor for cow milk for Cs ($d.L^{-1}$)	1	Grass feeding rate of cow in winter (kg/d)	1

Table 4.20. Spearman Coefficients between Parameters and the Lifetime Doses (continued)

Parameter	Spearman ρ	Parameter	Spearman ρ
Transfer factor for lamb for Cs ($d.kg^{-1}$)	1	Silage feeding rate of cow in winter (kg/d)	1
Transfer factor for grass for I	1	Concentrates feeding rate of cow (kg/d)	1
Transfer factor for hay for I	0	Grass feeding rate of sheep in summer (kg/d)	1
Transfer factor for maize silage for I	0.520	Concentrates feeding rate of sheep (kg/d)	1
Transfer factor for cereals for I	0	Grass feeding rate of sheep in winter (kg/d)	1
Transfer factor for fruits for I	0	Hay feeding rate of cattle in summer (kg/d)	1
Transfer factor for fruit vegetables for I	0.999	Grass feeding rate of cattle in summer (kg/d)	1
Fraction of activity translocated to rootzone	-1	Maize feeding rate of cattle in summer (kg/d)	1
Fixation of Cs in soil (d^{-1})	-1	Concentrates feeding rate of cattle (kg/d)	1
Yield of grass	-1	Hay feeding rate of cattle in winter (kg/d)	1
Yield of maize	-1	Grass feeding rates of cattle in winter (kg/d)	1
Yield of wheat	0	Silage feeding rate of cattle in winter (kg/d)	1
Yield of fruits	0	Concentrates feeding rate of cattle (kg/d)	1
Yield of fruit vegetables	0	Storage time for lamb (d)	-1
Yield of cereals	0	Storage time for beef (d)	-1
Fraction of short biological half life of Cs in milk	-1	Storage time for cereals (d)	-1
Biological half life of Cs in beef (d)	-1	Storage time for fruits (d)	-1
Biological half life of Cs in lamb (d)	-1	Storage time for fruit vegetables (d)	-1
Biological half life of Cs in chicken (d)	-1	Storage time for cow milk (d)	-1
Short biological half life (d) of Cs in milk	-0.172	Storage time for chicken (d)	-1
Long biological half life (d) of Cs in milk	-1	Processing factor for fruits	1
Biological half life of I in cow milk (d)	0	Processing factor for fruit vegetables	1
Biological half life of I in beef (d)	-1	Processing factor for cereals	1
Biological half life of I in lamb (d)	-1	Processing factor for cow milk	1

Table 4.20. Spearman Coefficients between Parameters and the Lifetime Doses (continued)

Parameter	Spearman ρ	Parameter	Spearman ρ
Biological half life of I in chicken (d)	0	Processing factor for lamb	1
Weathering half life in the grass (d)	-1	Processing factor for beef	1
Growth dilution rate for grass in may (d^{-1})	-1	Processing factor for chicken	1
Water percolation velocity (m/yr)	-1		

As seen from Table 4.20, inhalation rate, reduction factor, interception fraction and translocation factors for maize and grass, soil-plant transfer factors of Cs, feed-animal transfer factors of Cs and I, food consumption rates, feeding rates, transfer factor of I for grass, food-processing factors have very strong positive correlation with the lifetime doses and their Spearman rho coefficient is +1.

- Inhalation rates are also direct multiplier in the inhalation dose. Hence, the more one inhales the air the more he incurres to inhalation dose.
- Reduction factors are the direct multipliers in the calculation of external doses. So the higher the reduction factors are the more the external doses.
- Interception fraction and translocation factors of the maize and grass are the direct multipliers in the calculation of activity from foliar uptake of maize and grass.
- Soil-plant transfer factors are also the direct multipliers in the calculation of activity from the root uptake. The correlation of Cs turns out to be important.
- The correlation of transfer factor of I for the grass is also strong.
- Feed-animal transfer factors are also the direct multipliers in the calculation of activity in the animal food products. The correlation of both Cs and I is strong.
- Food consumption rate and feeding rates are direct multipliers in the ingestion dose calculation since the activity in the foods and feeds directly affect the doses.
- Food processing factors are also direct multipliers in ingestion doses.

On the other hand, fraction of activity translocated to root zone, yield of grass and maize, food storage times, fixation of Cs in soil, growth dilution rate of grass, and water percolation velocity, fraction of short biological half life of Cs in milk, biological half life of Cs in meat, long biological half life of Cs in milk, biological half life of I in beef and lamb, and weathering half-life in the grass have very strong negative correlation with the output doses.

- Since storage time of foodstuffs is negative exponential multiplier in the calculation of activity concentration of the food products ready for consumption, the longer the storage time of foodproducts the less the dose exposure.
- Growth dilution rate of the grass and weathering half-life in the grass are the negative exponential multipliers in the calculation of activity concentration in the grass due to foliar uptake.
- Yield of grass and maize are the denominators and fraction of activity translocated to root zone is the negative multiplier in the calculation of activity concentration in the plant due to foliar uptake. Since grass and maize are the only plants posed to foliar uptake during the deposition, yields of the other plants and weathering half-life in other plants do not affect the results.
- Fixation of Cs in the soil is a negative exponential multiplier in the activity concentration in the root zone of soil.
- Biological half-life of Cs in meat, long biological half-life of Cs in milk and biological half-life of I in beef and lamb are both direct multiplier and negative exponential multiplier, and fraction of short biological half-life of Cs in milk is negative direct multiplier in the calculation of activity concentration of animal food products.
- Water percolation velocity is a negative exponential multiplier in the calculation of activity concentration in the root zone of the soil.

Poorly correlated parameters are soil-plant transfer factor of I for maize silage, short biological half life of Cs in cow milk, distribution coefficient for Cs and I. The change in their values does not change the lifetime doses in a proportional way, i.e. these parameters and lifetime doses are not perfect monotone function of each other. Spearman ρ coefficients for soil density in plant rooting zone, soil-plant transfer factor of I for fruit vegetables and feed-animal transfer factor of I for chicken are very close to 1.

- Distribution coefficient of Cs and I are the denominators used in the calculation of migration of radionuclides in the soil that is negative exponential multiplier in the calculation of activity in root zone of soil. Spearman rho coefficients between distribution coefficients and lifetime doses are close to one, i.e. it is 0.993 for Cs, 0.800 for I.

- Short biological half-life of Cs in milk is -0.172, so its effect on the results is almost zero.
- Spearman ρ coefficient between soil density in plant rooting zone and lifetime dose is 0.984, so as seen from Figure 4.42 the graph shows a fairly well monotonic relationship in the soil density and doses.
- Spearman ρ coefficient between feed-animal transfer factor of I for chicken and lifetime doses is 0.999; almost very strong positive correlation exist since feed-animal transfer factors are the direct multipliers in the calculation of activity in the animal food products.
- Spearman ρ coefficient between soil-plant transfer factor of I for fruit vegetables and lifetime dose is very close to 1, i.e. it is 0.999.

Sensitivity analysis depends on the season of the start of the release. For the plants having no foliar uptake during the fallout, the parameters related with foliar uptake do not affect the results and their spearman coefficients are zero. Weathering rate, translocation rate, yield and interception fraction are the parameters used in the calculation of concentration in the plant due to foliar uptake. Only grass and maize receive foliar uptake at the time of the release, so change in the aformentioned parameters only for maize and grass affects the doses. It should be stated that the most influencing plants may change if starting time of the release differs. If the effect of foliar uptake was observed more, the sensivite plants would change but the associated parameter types would remain the same.

Spearman rho for soil-plant transfer factors of I for the cereals, hay, fruits and biological half-life of I in cowmilk and chicken are also zero, which means these parameters do not affect the results at all. Since the storage time for cereals (and hay) and fruits are 180 and 90 days respectively, allowing radioactive decay of short-lived iodine. Biological half-life of I in cow milk is very short, i.e. 0.7 days, hence, its change does not affect the results at all.

How lifetime doses change with the less sensitive some input parameters whose Spearman rho coefficients are less than ±1, are presented in Figure 4.42. The influence of poorly correlated parameters with the resultant doses is very small as seen from Figure 4.42. How lifetime doses change with the most sensitive parameters whose absolute value of Spearman rho coefficients is one are given in Figure 4.43.

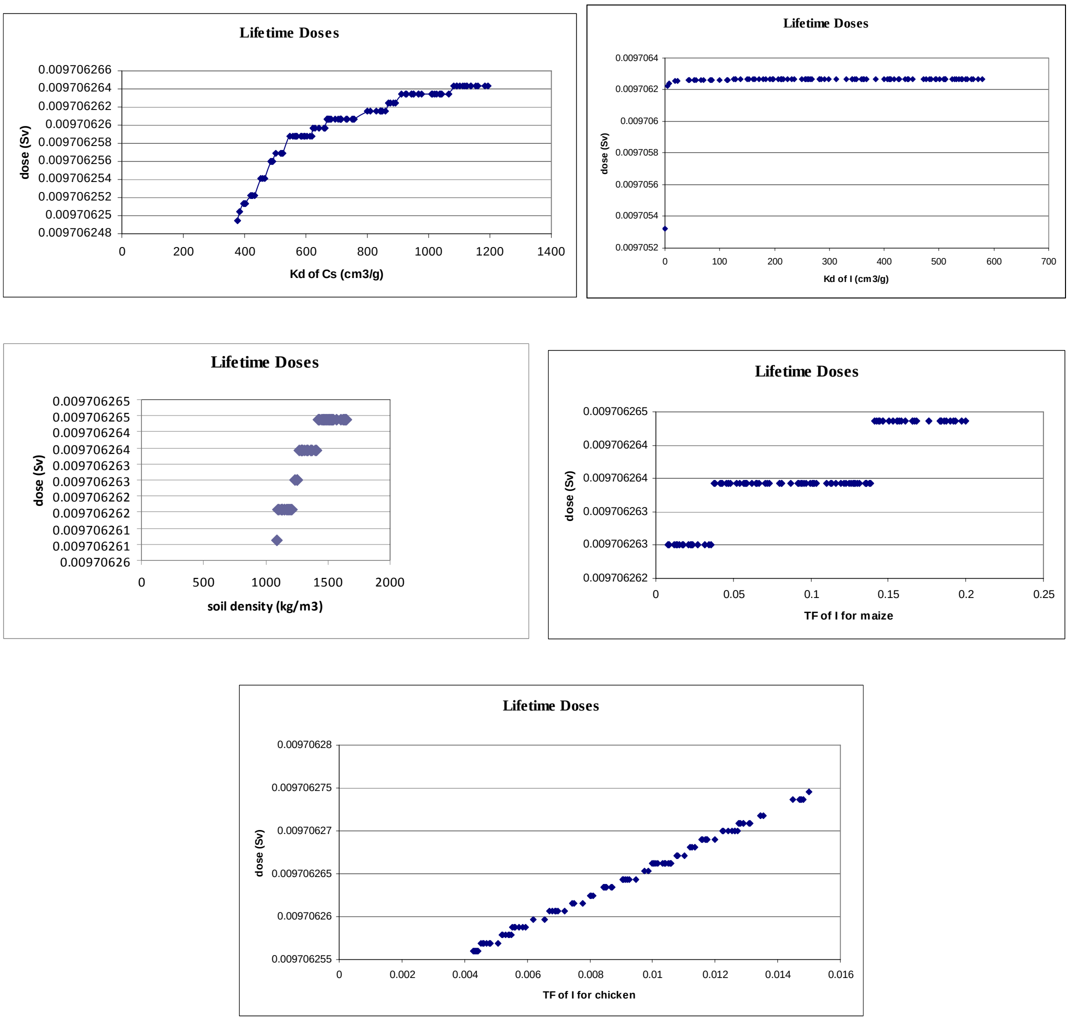

Figure 4.42. Lifetime Doses vs. Parameters with Poor Correlation

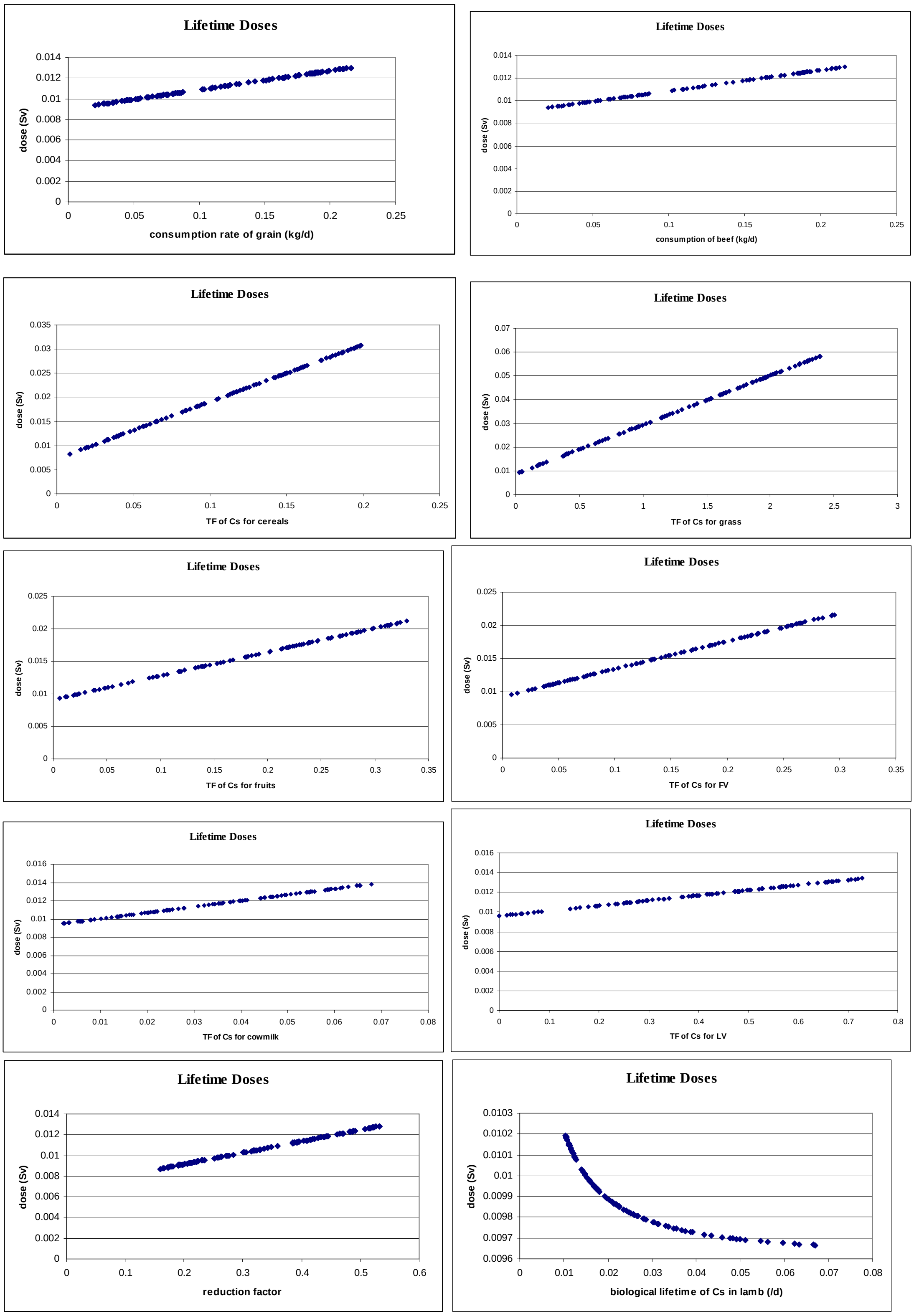

Figure 4.43. Lifetime Doses vs. Parameters with Good Correlation

The Figure 4.43 and Table 4.21 show the lifetime doses versus the most influencing sensitive parameters, which have the perfect correlation with the lifetime doses. It can be concluded that soil-plant transfer factors for Cs have a big influence on the lifetime dose results, feed-animal transfer factor for Cs for cow milk and reduction factors for external radiation, beef and grain consumption amounts have also the high effect on lifetime doses.

Since the sensitivity analysis proves that plant-soil transfer factos for Cs, feed-animal transfer factor of Cs for cow milk and, beef and grain consumption, and reduction factor have more influence on the lifetime doses, the uncertainty in these parameters are better to be decreased. It is well known that there is considerable variation in the soil to plant transfer of radiocaesium. This is due to differences in pH, potassium status, clay and organic matter content (Absalom, JP., Young, SD., Crout, NMJ., 1995).

Table 4.21. Lifetime Doses vs. the Most Sensitive Parameters

Parameter	Lifetime Doses
TF of Cs for grass	9.290-58.281 mSv
TF of Cs for cereals	8.30-30.77 mSv
TF of Cs for FV	9.567-21.591 mSv
TF of Cs for fruits	9.35-21.18 mSv
TF of Cs for cow milk	9.50-13.85 mSv
TF of Cs for LV	9.599-13.408 mSv
Beef consumption	9.38-13 mSv
Reduction factor	8.71-12.83 mSv
Grain consumption	9.37-12.155 mSv

Table 4.22 shows the lifetime doses versus some sensitive parameters that do not influence the results much but still have the perfect correlation.

Table 4.22. Lifetime Doses vs. Less Sensitive Parameters

Parameter	Lifetime Doses
TF of Cs for chicken	8.97-9.87 mSv
ST for cereals	9.895-9.721 mSv
ST for cowmilk	9.98-9.76 mSv
Weathering rate in the grass	9.684-9.733 mSv
Hay feeding rate of cattle in summer	9.704-9.728 mSv
TF of I for beef	9.700-9.751 mSv

4.3.2.2. Sensitivity Analysis for Short-term Doses

Table 4.23 shows the short-term doses, i.e. doses incurred 1 year after the accident, versus the most influencing sensitive parameters, which have the perfect correlation with the short-term doses. Spearman rho coefficients between parameters and short-term doses are almost the same with those with lifetime doses given in Table 4.20. However, different from the lifetime doses, iodine influence on the short-term doses is seen. For example, TF of iodine for cow milk has an important parameter on the short-term doses. The reason for TF for cereals not to be influential, at the first harvest after the accident, cereals have not been much contaminated, yet. Interception factor for the grass turns out to be an influencing factor as well, since grass activity is remarkably high due to the foliar uptake in the first year. On the other hand, influence of food consumption rates is not considerable on short-term doses.

Table 4.23. Short-Term Doses vs. the Most Sensitive Parameters

Parameter	Lifetime Doses
TF of Cs for grass	3.66-18.21 mSv
TF of Cs for FV	3.37-7.08 mSv
TF of Cs for fruits	3.23-6.79 mSv
TF of Cs for cow milk	3.29-4.48 mSv
Reduction factor	2.956-4.42 mSv
Interception factor for grass	2.89-4.42 mSv
TF of I for cow milk	2.76-4.20 mSv

Short-term doses vs. parameters with good correlation are given in Figure 4.44. For the short-term doses, again, transfer factors are influential, and cowmilk transfer factor for iodine and interception factor for the grass affect the short-term doses remarkably, as well. The soil-plant transfer factors are highly dependant on soil types; hence, DoseCAL may be upgraded to model the soil-plant TFs on gridded basis to take into account variety of soil types of Turkey. Besides, instead of equilibrium TF approach, dyamic transfer rate approach can be used to increase dynamic nature of the accident especially in the early phase after the accident.

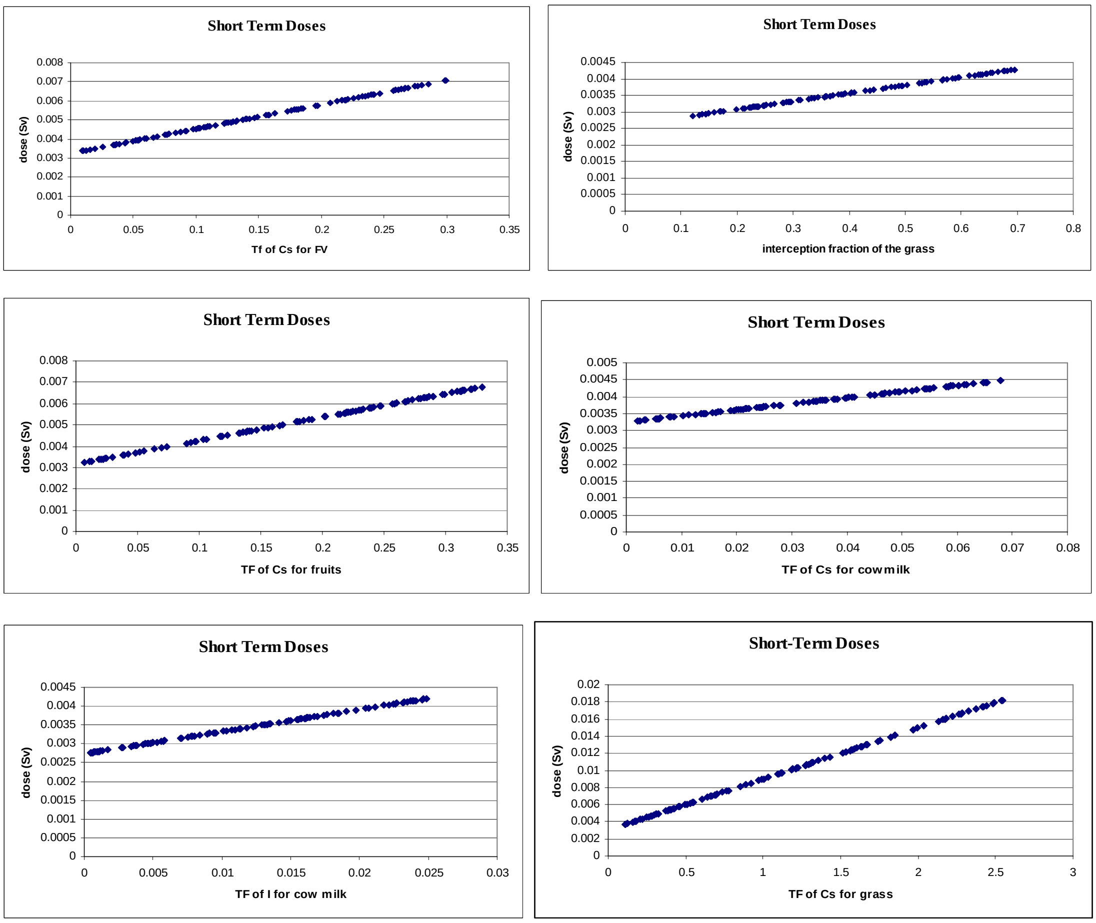

Figure 4.44. Short-Term Doses vs. Parameters with Good Correlation

Interception for the grass may be modeled in DoseCAL in such a way that plant canopy, leaf-area indices and rainfall are all taken into account; hence reliability of the interception for the grass can be increased. Beef and grain consumption of the people may also be modeled on gridded basis as well, and relevant food distribution regime may increase the realism of the model. Reduction factor, i.e. type of house and time spent indoor and outdoor, is also highly location dependant parameter and may be modeled on gridded basis to increase the reliability of the modeling study. As stated in Chapter 3.5 correlation between input parameters have not been considered in the sensitivity analysis.

CHAPTER 5

CONCLUSION

In this study, development of main framework of the new dynamic dose and risk calculation model has been introduced. DoseCAL model is successfully applied to calculate the radiological consequences of the atmospheric releases in the case of nuclear accidents. The number of radionuclides, feed and foodstuff types, and the number of age groups exposed to radiation, grid size, grid numbers, and period of calculation are flexible in the current software; their numbers may increase taking into account runtime and computer memory limitations.

The validation part of this model proves that DoseCAL has fairly good estimations in comparison to the observations in Finland after Chernobyl accident and the results of the other radioecological models participated in VAMP Exercise. It can be used to assist in emergencies resulted from the accidents at nuclear facilities in Turkey.

The DoseCAL model was successfully applied to the modeling of the radiological consequences of the hypothetical accidents at the planned Akkuyu and Sinop NPP's in Turkey. In the dose calculation, both meteorological pattern and plant's vegetation cycle turn out to be significant. The results showed that the dose incurred due to the atmospheric releases from the hypothetical accident at Sinop NPP is higher than at Akkuyu NPP. This can be explained by due to the different meteorological conditions and feeding regimes of the animals and harvesting regimes of the plants, though the source term is the same. Collective doses and risks are not only dependant on individual doses but also the number of population exposed to radiation. Hence, most of the big cities are affected seriously from the hypothetical accidents at Akkuyu and Sinop NPP. The hypothetical accident at Sinop NPP will have wider scale impact than that at Akkuyu NPP.

The last part of this study is uncertainty and sensitivity analysis, which were performed only for Akkuyu NPP accident case study. The lifetime doses are in the range of 4.8 - 32 mSv as a result of 100 trials performed for all of the uncertain parameters changing simultaneously. The parameters, which are of the upmost importance in dose contribution, have been identified by the sensitivity analysis. The results of sensitivity analysis were strongly dependent on radionuclide, foodstuff, deposition time and contamination period. The results of this study may serve as useful information for improving the reliability of predictive results and saving a major effort in the collection of relevant data by identifying the main contributor of input parameters to the model results.

This newly developed dose and risk calculation model can be used to be coupled with Hysplit model easily, and can be a part of radiation emergency system. To be a part of national system, the collection of Turkish specific data especially on ingestion pathway, is of great importance.

Since model development study is an iterative and dynamic process, which is open to continual improvement, some future work can be identified as follows;

- Wet interception may also modeled taking into account rainfall.
- Translocation may be modeled on a timely basis, namely plant vegetation stage may be taken into considered.
- Foodstuff types may also be increased in the model, for instance mushroom pathway may be included.
- The realism and reliability of the most sensitive parameters should be increased leading to increase the reliability of the modeling. Hence, adaptation of the DoseCAL model to different local conditions in Turkey may be a future study to take into account geographical differences as to data on crops and soil types, which are rather location dependant in Turkey.
    - Since TFs are of great importance as understood from the sensitivity analysis, the use of TFs may be improved in the model in such a way that; apart from their dependency on soil type, which is better to be considered on gridded basis, transfer of radionuclides into different soil layes may also be modeled, and instead of equilibrium TF approach used in current software, dynamic rate approach might be adopted into the model.

- Food consumption amount of the people may be modeled on gridded basis as well, and relevant food distribution regime may increase the realism of the model.
- Reduction factor, namely, type of house and time spent indoor and outdoor, is also highly location dependant parameter and may be modeled on gridded basis to increase the reliability of the modeling study.

- Though almost all of the sources of uncertainty are taken into account, other sources of uncertainty may be impact of food distribution, which is not considered in probabilistic or in deterministic DoseCAL model. This feature may be added into DoseCAL model easily.
- Heath risk module of DoseCAL may also be improved, in such a way that deterministic risks can be modeled as well.

REFERENCES

Abbott, M.L., Rood, A.S., COMIDA, A Radionuclide Food Chain Model for Acute Fallout Deposition, 1993.

Abbott, M.L., Rood A.S., Comida: A radionuclide food chain model for acute fallout 6825 PNNL-14321 deposition, Health Phys 66: 17–29, 1994.

Absalom JP, Young SD, Crout NMJ, Radiocaesium fixation dynamics: Measurement in six Cumbrian soils. European Journal of Soil Science 46:461-469,1995.

ANL/EAD-4, User's Manual for RESRAD Version 6, 2001.

Anspaugh, L.R., Shinn, J.H., Phelps, P.L., Kennedy, N.C., Resuspension and redistribution of plutonium in soils, Health Phys. 29 (1975) 571–582.

Apsimon, H.M.; Goddard, A.J.H.; Wrigley, J., Long-range atmospheric dispersion of radioisotopes. The MESOS model. Atmospheric Environment (1967) vol. 19 issue 1 1985. p. 99-111.

ARGOS home page, http://www.pdc-argos.com/ [last accessed on 1st of August, 2014]

Baklanov A., Sorensen J.H., "Parameterization of Radionuclide Deposition in Atmospheric Long Range Transport Modeling", 2000.

Bauer, L.R., and Hamby, D.M.: 1991, 'Relative Sensitivities of Existing and Novel Model Parameters in Atmospheric Tritium Dose Estimates', Rad. Prot. Dosimetry. 37, 253-260.

Bellman, R., and Astrom, K.J.: 1970, 'On Structural Identifiability', *Math. Biosci.* 7, 329-339.

Bergstroem, U., Nordlinder, S., Studsvik Eco and Safety AB, Nykoeping, Sweden, 1981.

Box, G.E.P., Hunter, W.G., and Hunter, J.S.: 1978, Statistics for Experimenters: an Introduction to Design, Data Analysis, and Model Building. John Wiley & Sons. New York.

Breshears, D.D.: 1987, Uncertainty and sensitivity analyses of simulated concentrations of radionuclides in milk. Fort Collins, CO: Colorado State University, MS Thesis, pp. 1-69.

Brown, J. and Simmonds, J., R., FARMLAND: A Dynamic Model for the Transfer of Radionuclides through Terrestrial Foodchains, 1995.

Ciffroy, P., Siclet, F., Damois, C., Luck, M., Duboudin, C., A dynamic model for assessing radiological consequences of routine releases in the Loire river: Parameterisation and uncertainty/sensitivity analysis, Journal of Environmental Radioactivity 83 (2005) 9-48.

Christoudias, T. and Lelieveld, J., Modelling the global atmospheric transport and deposition of radionuclides from the Fukushima Daiichi nuclear accident, Atmos. Chem. Phys., 13, 1425–1438, 2013.

Conover, W.J.: 1980, Practical Nonparametric Statistics. 2nd edn. John Wiley & Sons, New York.

Cox, N.D.: 1977, 'Comparison of Two Uncertainty Analysis Methods', Nuc. Sci. and Eng. 64, 258-265.

Crick, M.J., Hill, M.D. and Charles, D.: 1987, 'The Role of Sensitivity Analysis in Assessing Uncertainty. In: Proceedings of an NEA Workshop on Uncertainty Analysis for Performance Assessments of Radioactive Waste Disposal Systems, Paris, OECD, pp. 1-258.

Cunningham, M.E., Hann, C.R., and Olsen, A.R.: 1980, 'Uncertainty Analysis and Thermal Stored Energy Calculations in Nuclear Fuel Rods', Nuc. Technol. 47, 457-467.

Cukier, R.I., Fortuin, C.M., Shuler, K.E., Petschek, A.G. and Schaibly, J.H.: 1973, 'Study of the Sensitivity of Coupled Reaction Systems to Uncertainties in Rate Coefficients. I. Theory Z Chem. Phys. 59, 3873-3878.

Demiralp, M., and Rabitz, H.: 1981, 'Chemical Kinetic Functional Sensitivity Analysis: Elementary Sensitivities', J. Chem. Phys. 74, 3362-3375.

Downing, D.J., Gardner, R.H., and Hoffman, EO.: 1985, 'An Examination of Response-Surface Methodologies for Uncertainty Analysis in Assessment Models', Technometrics. 27, 151-163.

Draxler, R.R., and G.D. Hess, 1997: Description of the HYSPLIT_4 modeling system. NOAA Tech. Memo. ERL ARL-224, NOAA Air Resources Laboratory, Silver Spring, MD, 24 pp.

Draxler, R.R., Stunder, B., Rolph, G., and Stein, A., Taylor, A., Hysplit4 Users Guide, 2012.

Eckerman, K., F., Ryman, J., C., Federal Guidance Report No. 12 “External Exposure to Radionuclides in Air, Water and Soil”, 1993.

Environmental Modelling for Radiation Safety (EMRAS) Programme, "The Chernobyl I-131 Release: Model Validation and Assessment of the Countermeasure Effectiveness: Report of the Chernobyl 131I Release Working Group of EMRAS Theme 1".

EUR-18825, FZKA-6311, ISBN 92-894-2085-5, European Communities 2001 Probabilistic Accident Consequence Uncertainty Assessment Using COSYMA: Uncertainty from the Dose Module.

EUR-18826, FZKA-6312, ISBN- 92-894-2088-X, European Communities 2001 Probabilistic Accident Consequence Uncertainty Assessment Using COSYMA: Overall Uncertainty Analysis.

Eyüpoğlu, F., Türkiye topraklarının verimlilik durumları, 1999.

Gardner, R.H.: Huff, D.D., O'Neill, R.V., Mankin, J.B., Carney, J. and Jones, J.: 1980, 'Application of Error Analysis to a Marsh Hydrology Model', Water Resources Res. 16, 659-664.

Gardner, R.H., O'Neill, R.V., Mankin, J.B. and Carney, J.H.: 1981, 'A Comparison of Sensitivity Analysis and Error Analysis Based on a Stream Ecosystem Model', Ecol. Modelling. 12, 173- 190.

Garger, E.K., Hoffman, F.O., Thiessen, K.M., Uncertainty of the long-term resuspension factor, Atmos. Environ. 31 (1997) 1647–1656.

Health Canada, Recommendations on Dose Coefficients for Assessing Doses from Accidental Radionuclide Releases to the Environment, 1999.

Health Protection Agency, Application of the 2007 Recommendations of the ICRP to the UK, 2009.

Helton, J.C., Garner, J.W., Marietta, M.G., Rechard, R.E, Rudeen, D.K. and Swift, EN.: 1993. 'Uncertainty and Sensitivity Analysis Results Obtained in a Preliminary Performance assessment for the Waste Isolation Pilot Plant, Nuc. Sci. and Eng. 114, 286-331.

Helton, J.C., Garner, J.W., McCurley, R.D. and Rudeen, D.K. Sensitivity analysis techniques and results for performance assessment at the waste isolation pilot plant. Albuquerque, NM: Sandia National Laboratory; Report No. SAND90-7103, 1991.

Helton, J.C., Iman, R.L, Sensitivity Analysis of a Model for the Environmental Movement of Radionuclides', Health Phys. 42, 565-584, 1982.

Helton, J.C., Iman, R.L., Johnson, J.D., and Leigh, C.D. Uncertainty and Sensitivity Analysis of a Model for Multicomponent Aerosol Dynamics, *Nuc.* Technol. 73, 320-342, 1986.

Helton, J.C., Risk Analysis 14, 483-511,1994.

Hinton, T.G., Sensitivity Analyses of ECOSYS-87: An Emphasis on the Ingestion Pathway as a Function of Radionuclide and a Type of Deposition, 1994.

Hobbie, K.,"Intermediate Physics for Medicine and Biology ", 3rd edition, 1997.

Hoevea, J. E. T. and Jacobson, M. Z., Worldwide health effects of the Fukushima Daiichi nuclear accident, Energy and Environmental Science, 2012.

Hoffman, EO. and Gardner, R.H. Evaluation of Uncertainties in Environmental Radiological Assessment Models, in: Till, J.E.; Meyer, H.R. (eds) Radiological Assessments: a Textbook on Environmental Dose Assessment. Washington, DC: U.S. Nuclear Regulatory Commission; Report No. NUREG/CR-3332, 1983.

Homann S., G., HotSpot Health Physics Codes Version 2.07.1 User's Guide, National Atmospheric Release Advisory Center Lawrence Livermore National Laboratory Livermore, CA 94550, 2010.

Hwang, W.T., Lee, G.C. Suh, K.S. E.H.Kim, Choi, Y.G. Han, M.H., Cho,G.S. Sensitivity Analysis of a Dynamic Food Chain Model DYNACON Considering Korean Agricultural Model, 1998.

IAEA, Safety Series No. 100, Evaluating the Reliability of Predictions Made Using Environmental Transfer Models, 1989.

IAEA, Technical Report Series 472, Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Terrestrial and Freshwater Environments, 2010.

IAEA, TECDOC-733, The Utilization of Real Time Models as a Decision Aid Following a Large Release of Radionuclides into the Atmosphere", 1994.

IAEA, Technical Report TEC-DOC 904, Validation for Models Using Chernobyl Fallout Data from Southern Finland, Scenario S, 1996.

IAEA TECDOC-955, Generic Assessment Procedures for Determining Protective Actions during a Reactor Accident, 1997.

ICRP 71: Age-dependent Doses to Members of the Public from Intake of Radionuclides - Part 4 Inhalation Dose Coefficients, 1995b.

ICRP Publication 72: Age-Dependent Doses to the Members of the Public From Intake of Radionuclides Part 5, Compilation of Ingestion And Inhalation Coefficients, 1996.

ICRP Publication 103: Annals of ICRP, the 2007 Recommendations of the International Commission on Radiological Protection, 2007.

ICRP Publication 119: Compedium of Dose Coefficients based on ICRP Publication 60, 2012.

Iman, R.L. A Matrix-Based Approach to Uncertainty and Sensitivity Analysis for Fault Trees', Risk Analysis. 7, 21-33, 1978.

Iman, R.L. and Conover, W.J.: The Use of the Rank Transform in Regression, Technometrics, 21, 499-509, 1979.

Iman, R.L. and Conover, W.J. Small Sample Sensitivity Analysis Techniques for Computer Models, With an Application to Risk Assessment, Commun. Stats. Theor. and Meth. A9, 1749-1842, 1980.

Iman, R.L. and Conover, W.J. Sensitivity-analysis techniques: self-teaching curriculum. Albuquerque, NM: Sandia National Laboratories; Report No. NUREG/CR-2350, 1982.

Iman, R.L., Helton, J.C. and Campbell, J.E., An Approach to Sensitivity Analysis of Computer Models: Part I - Introduction, Input Variable Selection and Preliminary assessment', J. Qual. Technol., 13, 174-183, 1981a.

Iman, R.L. Helton, J.C. and Campbell, J.E., An Approach to sensitivity Analysis of Computer Models: Part II - Ranking of Input Variables, Response Surface Validation, Distribution Effect and Technique Synopsis, J. Qual. Technol. 13, 232-240, 1981b.

Iman R.L. and Helton J.C., A comparison of Uncertainty and Sensitivity Analysis Techniques for Computer Models. SAND84-1461, NUREG/CR-3904, 1985.

Iman, R.L. and Helton, J.C. 1988, 'An Investigation of Uncertainty and Sensitivity Analysis Techniques for Computer Models', Risk Analysis. 8, 71-90.

Iman, R.L. and Helton, J.C., 1991; 'The Repeatability of Uncertainty and Sensitivity Analyses for Complex Probabilistic Risk Assessments', Risk Analysis. 11, 591-606.

IRSN, Summary of the Fukushima accident's impact on the environment in Japan, one year after the accident, 2012.

Johnson R.H. and Mitchell N.G., The SPADE suite of codes: SPADE 3.0 PC Version; volume 1, User manual. WS Atkins Technical Note M1722-TN5, 1993.

Jow, H-N, Sprung, J. L, Rolistin, J. A. Ritchie, L. T. Chanin, D. I. MELCOR Accident Consequence Code System (MACCS) Model Description, Sandia National Laboratories, 1990.

Kanyar, B., Fulop N., TERNIRBU, 1996.

Kim, T.W., Chang, S.H. and Lee, B.H., Uncertainty and Sensitivity Analyses in Evaluating Risk of High Level Waste Repository, Rad. Waste Management and the Nuc. Fuel Cycle. 10, 321-356, 1988.

Kleijnen, J.EC., van Ham, G., and Rotmans, J., Techniques for Sensitivity Analysis of Simulation Modets: A Case Study of the CO_2 Greenhouse Effect, Simulation. 58, 410, 1992i

Kocar, C., Simulation of Operational Radiological Conseqeunces for NPPs, PhD Dissertation, 2003.

Kocar, C., Sökmen, N., "A Model for Radiological Consequences of Nuclear Power Plant Operational Atmospheric Releases", Journal of Environmental Radioactivity, Volume 100, Issue 1, Pages 89–93, January 2009.

Korhonen, R., Savolainen, I., Biospheric transfer model DETRA for assessment of radiation impacts. Technical Research Centre of Finland, Nuclear Engineering Laboratory, Research Reports 323, 1984 (in Finnish).

Krcgewski P.,CRLP Model, 1989.

Krieger, T.J., Durston, C., and Albright, D.C.: 1977 Statistical Determination of Effective Variables in Sensitivity Analysis', Trans. Am. Nuc. Soc. 28, 515-516.

Langham, W.H., "Plutonium distribution as a problem in environmental science", Environmental Plutonium (Proc. Symp. Los Alamos, 1971), (Fowler, E.B., Henderson R.W., Miligan, M.R., Eds.), Rep. LA-1756, Los Alamos National Laboratory, Los Alamos 3–11, 1971.

Margulies, T., Lancaster, L., and Kornasiewicz, R.A. Uncertainty and Sensitivity Analysis of Environmental Transport Models for Risk Assessment, In: Engineering Applications of Risk Analysis, Atlanta, GA: ASME, 11-19. 1991,

Mcguire, S. A., Ramsdell, Jr., J. V. and Athey, G. F., “RASCAL 3.0.5 Description of Models and Methods” NUREG-1887, 2007.

Meckbach, R., Jacobs, P., Paretzke, H.,G., Gamma exposures due to radionuclides deposited on urban environments. Part I: Kerma rates from urban contaminated surfaces. Radiation Protection Dosimetry 25, 167-180, 1988.

Minitab 17 Statistical Software, http://www.minitab.com/en-us/company/

Müller, H., Pröhl, G., ECOSYS-87: A Dynamic Model for Assessing Radiological Consequences of Nuclear Accidents, 1993.

Müller H., Pröhl G., Friedlandt W., Gardner R.H., Uncertainty in the Ingestion Dose, Radiation Protection Dosimetry, Vol.50, Nos 2-4, pp. 353-357, 1993.

Mülga Köy Hizmetleri Genel Müdürlüğü Toprak ve Gübre Araştırma Enstitüsü Müdürlüğü, Genel Yayın No: 220, Teknik Yayın No: T67 Ankara

Napier BA. GENII version 2 users’ guide. Prepared under contract DE-AC06-76RLO 1830 for the United States Department of Energy. Washington, DC; 2002.

NEA/OECD, Evaluations of ICRP Recommendaations 1997, 1990 and 2007, Chanegs in Underlying Science and Protection Policy and Their impact on European and UK Domestic Regulation, 2011.

Oblow, E.M.: 1978, 'Sensitivity Theory for General Nonlinear Algebraic Equations with Constraints', Nuc. Sci. and Eng. 65, 187-191.

Otis, M.D.: 1983, 'Sensitivity and Uncertainty Analysis of the PATHWAY Radionuclide Transport Model', Fort Collins, CO: Colorado State University, PhD Dissertation, pp. 1-86.

Pereira, A., Boraed, R., Methods for Uncertainty and Sensitivity Analysis. Review and recommendations for implementation in Ecolego, Sweden, 2006.

Poesen, J., An improved splash transport model, Z. Geomorphol. 29 (1985) 193–221.

Radiation Safety Standards, NRB-99/2009, Sanitary Regulations and Standards, SanPiN 2.6.1.2523-09.

Reed, K.L., Rose, K.A., and Whitmore, R.C. 1984, 'Latin Hypercube Analysis of Parameter Sensitivity in a Large Model of Outdoor Recreation Demand, Ecol. Modelling. 24, 159-169.

Rochedo, E. R. R., Conti, L. F. C., Paretzke, H. G. (1996): PARATI – a dynamic model for radiological assessments in urban areas. Part I.. Radiation Environmental Biophysics, 35:243–261.

RODOS home page, http://www.rodos.fzk.de/ [last accessed on 1st of August, 2014]

Rose, K.A.: 1983, 'A Simulation Comparison and Evaluation of Parameter Sensitivity Methods Applicable to Large Models, in: Analysis of Ecological Systems: State-of-the-art in Ecological Modelling (Lauenroth, G.V. Skogerboe, M. Flug eds.), Proceedings of a meeting at Colorado State University, May 24-28, 1982 Elsevier, New York.

Slaper, H., Blaauboer, R.O., Eggink,G., J., A Risk Assessment Method for Accidental Releases From Nuclear Power Plants in Europe, National Institute of Public Health and Environmental Protection Bilthoven, 1994.

Specter, H., Fukushima and Emergency Planning, 2013.

Steinhauser, G., Brandl, A. Thomas E. Johnson, "Comparison of the Chernobyl and Fukushima nuclear accidents: A review of the environmental impacts", Science of Total Environment 470–471 (2014) 800–817.

Stohl, A., Seibert, P., Wotawa, G., Arnold, D., Burkhart, J. F., Eckhardt, S., Tapia, C., Vargas, A., and Yasunari, T. J., "Xenon-133 and caesium-137 releases into the atmosphere from the Fukushima Dai-ichi nuclear power plant: determination of the source term, atmospheric dispersion, and deposition", Atmos. Chem. Phys., 12, 2313–2343, 2012.

Stubna M. and Kusovska Z., RTARC: A Computer Code for Radiological Severe Accident Consequence Assessment - Models and Code Description, 1993.

TAEK, Regulation on National Implementation in the case of Nuclear and Radiological Emergency, 2009.

TAEK, Çernobil Serisi-7, "20. Yılında Çernobil-Türkiye için Doz Değerlendirmeleri", 2006.

Wang, Y.Y., Biwer, B.M. and Yu, C. Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk, and Aquatic Food Pathways and the Suggested

Default Values for the RESRAD Code, ANL/EAIS/TM-103, Argonne National Laboratory, Argonne, 111, 1993.

U.S. Environmental Protection Agency, Federal Guidance Report-13, Cancer Risk Coefficients for Environmental Exposure to Radionuclides, 1999.

U.S. Environmental Protection Agency, Risk Assessment Guidance for Superfund; Volume-I Human Health Evaluation Manual Part A Baseline Risk Assessment. technical Report EPA/540/1-89/002, Washington, 1989

U.S. Environmental Protection Agency, Risk Assessment Guidance for Superfund; Volume-I Human Health Evaluation Manual Part B Development of Risk Based Preliminary Remediation Goals. Technical Report 9285.7-01B, Washington, 1991.

U.S. Environmental Protection Agency, Estimating Radiogenic Cancer Risks. Technical Report EPA/402-R-93-076, 1994.

U.S. Environmental Protection Agency, Health Effects Assessment Summary Tables. Technical Report EPA/540-R-97-036, 1997.

U.S. Environmental Protection Agency, K.F.Eckerman, R.W. Leggett, C.B. Nelson, J.S. Puskin, and A.C.B. Richardson Cancer Risk Coefficients for Envionmental Exposure to Radionuclides, Federal Guidance Report-11, Oakridge National Laboratory, Washington,1999.

U.S. NRC Regulatory Guide 1.109, “Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 51 Appendix I”, 1977.

U.S. NUREG 1150, Final Report, “Severe Accident Risk: An Assessment of U.S. Nuclear Plants”, December 1990.

U.S. NUREG, CR, “Plant and Animal Transfer factors Used in Performance Assessment Modeling”, 2003.

Sağlık Bakanlığı, Türkiye Halk Sağlığı Kurumu, TÜRKİYE KANSER İSTATİSTİKLERİ, 2014.

Suh, K.S., Jeong, H.J., Kim, E.H., Hwang, W.T., Han, M.H., 2006. Verification of the Lagrangian particle model using the ETEX experiment. Ann. Nucl. Energy 33, 1159–1163.

Suh, K.S., Han, M.H., Lee, S.H., Jung, C.W., 2008. Inter-comparison of the ENSEMBLE project. Nucl. Sci. Technol., 647–649 (Suppl. 5).

Suh, K.S., Han, M.H., Jung, S.H., Lee, C.W., 2009. Numerical simulation for a longrange dispersion of a pollutant using Chernobyl data. Math. Comput. Model. 49, 337–343.

Sørensen, J. H. Sensitivity of the DERMA Long-Range Gaussian Dispersion Model to Meteorological Input and Diffusion Parameters. Atmos. Environ. 32 (1998) 4195–4206.

Sørensen, J. H., A. Baklanov and S. Hoe. The Danish Emergency Response Model of the Atmosphere. J. Envir. Radioactivity 96 (2007) 122-129.

Ünver, Ö., Tuncel, G., A Modelling Study for the Health Risk Posed by Nuclear Power Plant in Bulgaria at Different Parts of Turkey, Fresenius Environmental Bulletin (Vol.13, No.9, 2004, pp.879-888).

Van Heerden, W.M., An analysis of soil transportation by raindrop splash, Trans. ASAE 10 (1967) 166–169.

Wilks, S.S., Determination of sample sizes for setting tolerance limits, Ann. Math. Stat. 12 (1941) 91–96.

Wilks, S.S., Statistical prediction with special reference to the problem of tolerance limits, Ann. Math. Stat. 13 (1942) 400–409.

Whicker, EW., Kirchner, T.B.: 1987, 'PATHWAY: A dynamic food-chain model to predict radionuclide ingestion after fallout deposition,' Health Phys. 52; 717-737.

Whicker, EW., Kirchner, T.B., Breshears, D.D., Otis, M.D. 1990, 'Estimation of radionuclide ingestion: the "Pathway" model', Health Phys. 59; 645-657.

Wright, A.C., A physically based model of the dispersion of splash droplets ejected from a water drop impact, Earth Surf. Process. Landf. 11 4 (1987) 351–367.

World Nuclear Association web page, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Appendices/RBMK-Reactors/, 2010 [last accessed on 1st of August, 2014]

Yu, C., Cheng, J-J., and Zielen, A-J.: 1991, 'Sensitivity Analysis of the RESRAD, a Dose Assessment Code,' Trans. Am. Nuc. Soc. 64; 73-74.

Zirnmerman, D.A., Hanson, R.T., and Davis, EA.: 1991, A comparison of parameter estimation and sensitivity analysis techniques and their impaet on the uneertainty in ground water flow model predictions. Albuquerque, NM: Sandia National Laboratory; Report No. NUREG/CR-5522.

APPENDIX A

DOSECAL SOURCE CODE

In this appendix, source code of newly developed model is given in CD. Example DoseCAL output file for inhalation dose of infants is also given in Table A.1.

Table A.1. DoseCAL Example Output File

INFANT INHALATION DOSE FROM CLOUD (Sv)													
LAT	LON	Cs-137	Cs-134	Cs-136	I-131(g)	I-131(p)	I-132(g)	I-132(p)	Te-129	Te-129m	Te-132	Xe-133	SUM
36	26.5	0	0	0	0	0	0	0	0	0	0	0	0
36	29	0	0	0	0	0	6.45E-10	0	0	0	0	0	6.45E-10
36	31.5	7.54E-12	3.02E-12	2.26E-09	1.61E-05	5.21E-11	1.38E-07	2.26E-11	1.12E-11	5.13E-12	8.18E-11	0	1.63E-05
36	34	2.52E-12	1.96E-12	3.35E-10	1.91E-06	6.57E-11	6.49E-09	4.69E-14	3.99E-13	1.08E-12	5.21E-12	0	1.92E-06
36	36.5	3.28E-12	4.13E-12	2.71E-12	3.74E-07	1.31E-10	1.47E-11	1.74E-12	2.43E-13	1E-11	1.77E-10	0	3.75E-07
36	39	1.92E-41	1.1E-40	1.4E-43	0	4.99E-37	0	1.51E-37	2.17E-37	3.23E-39	3.57E-35	0	3.66E-35
36	41.5	0	0	0	0	0	0	0	0	0	0	0	0
36	44	0	0	0	0	0	0	0	0	0	0	0	0
38.5	26.5	0	0	0	0	0	0	0	0	0	0	0	0
38.5	29	0	0	0	0	0	3.53E-09	0	0	0	0	0	3.53E-09
38.5	31.5	2.2E-09	3.42E-10	1.73E-10	4.43E-07	2.82E-08	3.52E-08	1.45E-09	7.8E-11	5.43E-10	1.48E-08	0	5.26E-07
38.5	34	1.12E-09	8.87E-10	1.41E-10	3.06E-06	9.51E-09	1.46E-07	6.95E-10	2.48E-10	5.64E-09	8.82E-09	0	3.23E-06
38.5	36.5	4.15E-10	9.92E-10	1.12E-10	2.04E-07	1.03E-08	2.93E-10	6.66E-10	2.29E-10	3.65E-09	4.94E-08	0	2.7E-07
38.5	39	0	0	1.4E-44	0	7.57E-34	0	4.41E-41	0	0	9.66E-40	0	7.57E-34
38.5	41.5	0	0	0	0	0	0	0	0	0	0	0	0
38.5	44	0	0	0	0	0	0	0	0	0	0	0	0
41	26.5	0	0	0	0	0	0	0	0	0	0	0	0
41	29	0	0	0	0	0	0	0	0	0	0	0	0
41	31.5	8.43E-10	1.53E-11	4.61E-12	2.72E-07	2.04E-11	5.56E-08	8.34E-13	5.92E-15	2.42E-14	1.74E-08	0	3.46E-07
41	34	1.8E-06	3.71E-06	9.84E-07	0.000146	8.53E-05	3.1E-06	2.07E-06	9.32E-07	1.62E-05	0.000178	0	0.000439
41	36.5	1.24E-07	2.56E-07	9.08E-08	5.89E-05	6.63E-06	1.3E-06	2.77E-07	3.3E-08	2.02E-06	1.49E-05	0	8.46E-05
41	39	7.82E-14	5.07E-14	1.52E-15	8.07E-06	7.22E-13	3.42E-07	1.21E-14	1.42E-13	1.16E-13	1.64E-12	0	8.41E-06
41	41.5	1.12E-29	3.21E-35	2.13E-32	0	2.22E-29	0	8.85E-28	3.03E-27	1.85E-32	1.75E-28	0	4.13E-27
41	44	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX B

CASE STUDIES WITH DIFFERENT RELEASE TIMES

In this appendix, modeling results for Akkuyu and Sinop accident case studies with different release times, are presented.

B.1. Akkuyu NPP Accident Case Study

For the release started on 29th of November 2000, the graphical display results of HYSPLIT simulation for 53 isotopes for the Akkuyu NPP case study are given in Figure B.1.

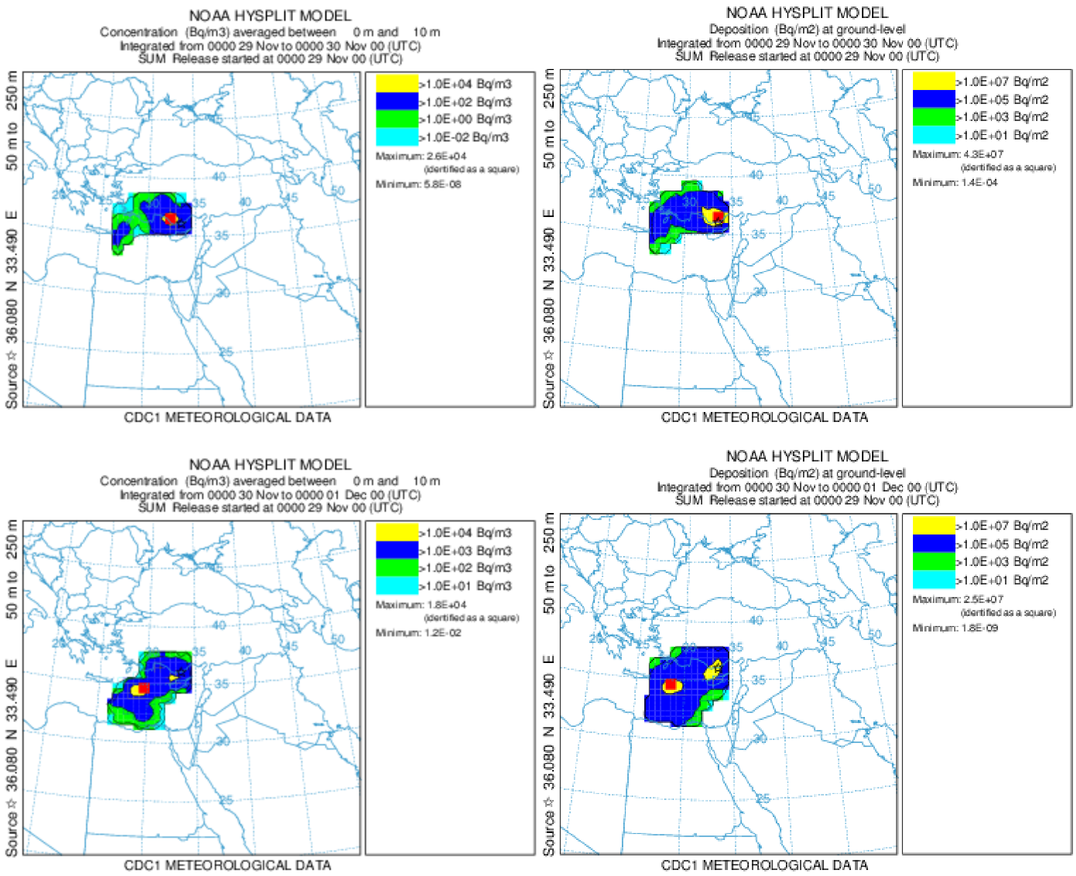

Figure B.1. Atmospheric Dispersion Graphs of HYSPLIT for Hypothetical Accident at Akkuyu NPP

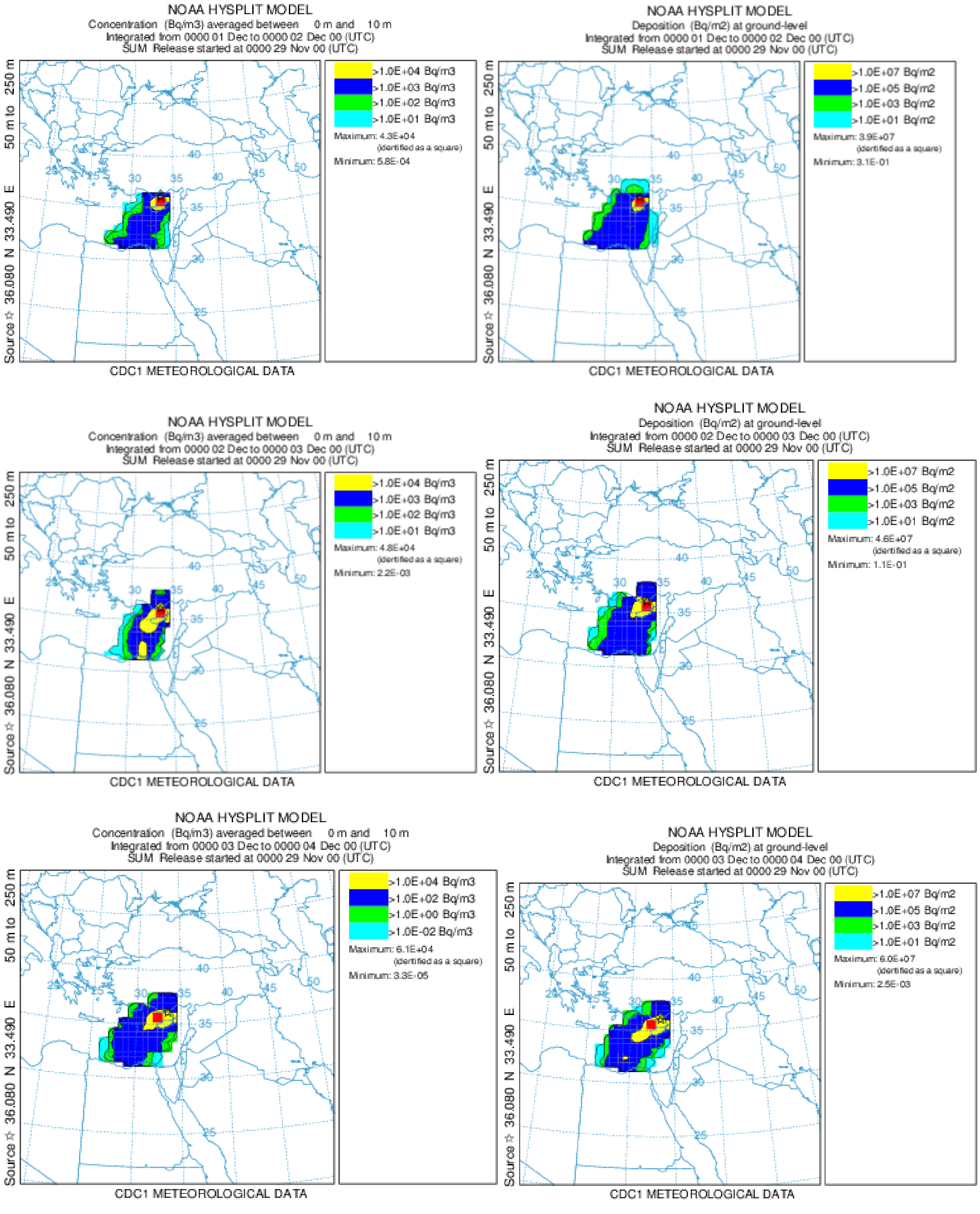

Figure B.1. (continued)

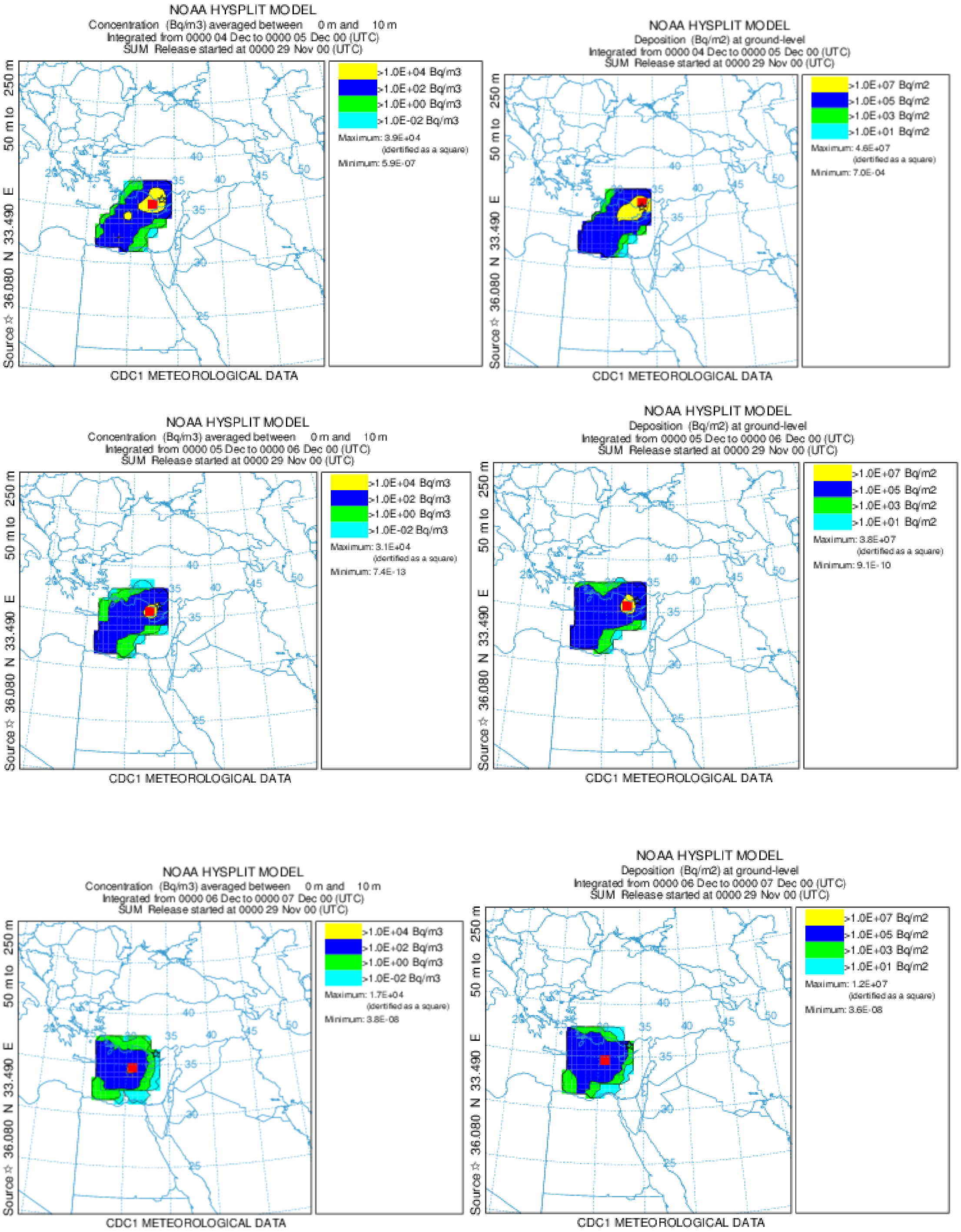

Figure B.1. (continued)

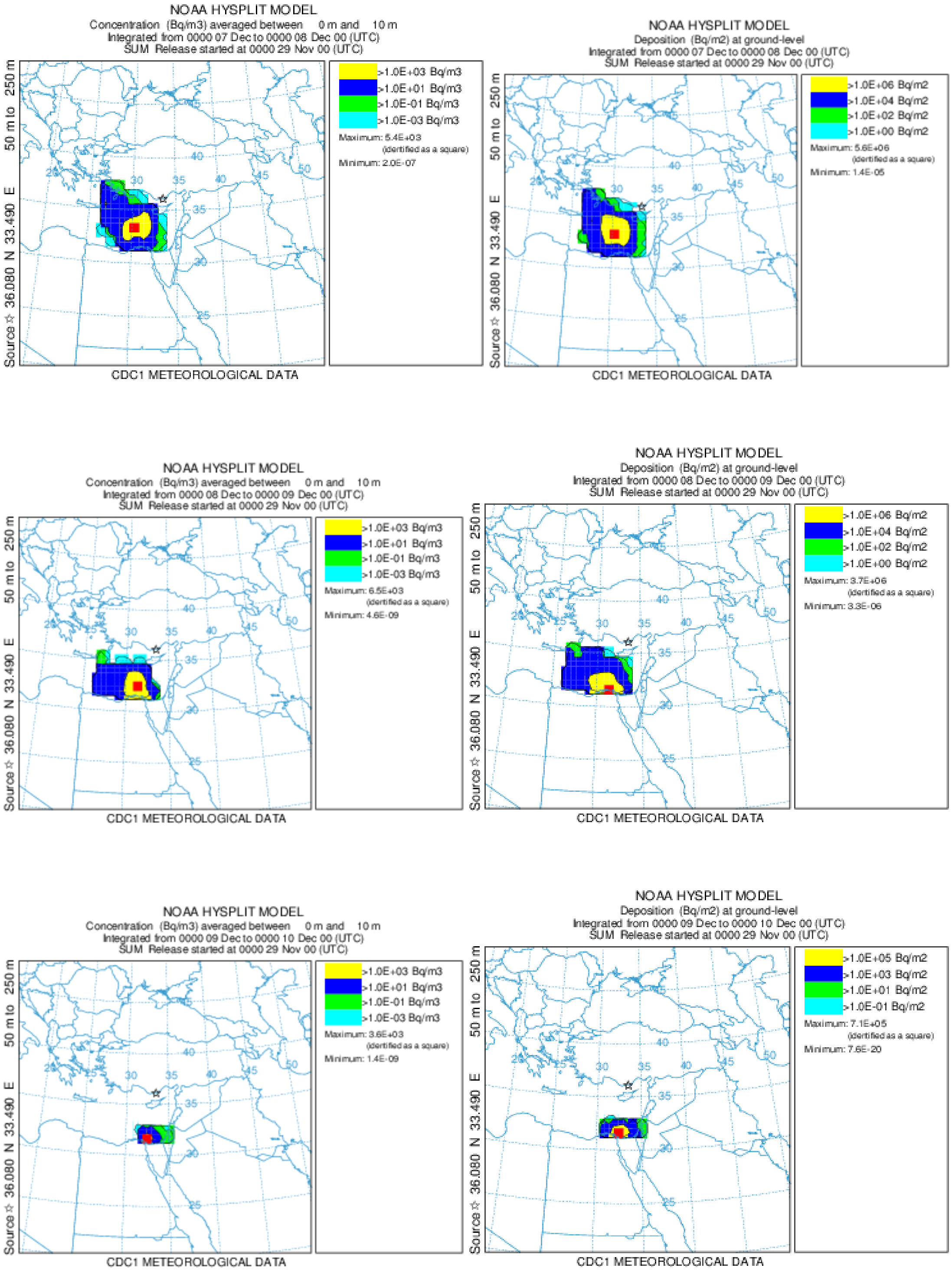

Figure B.1. (continued)

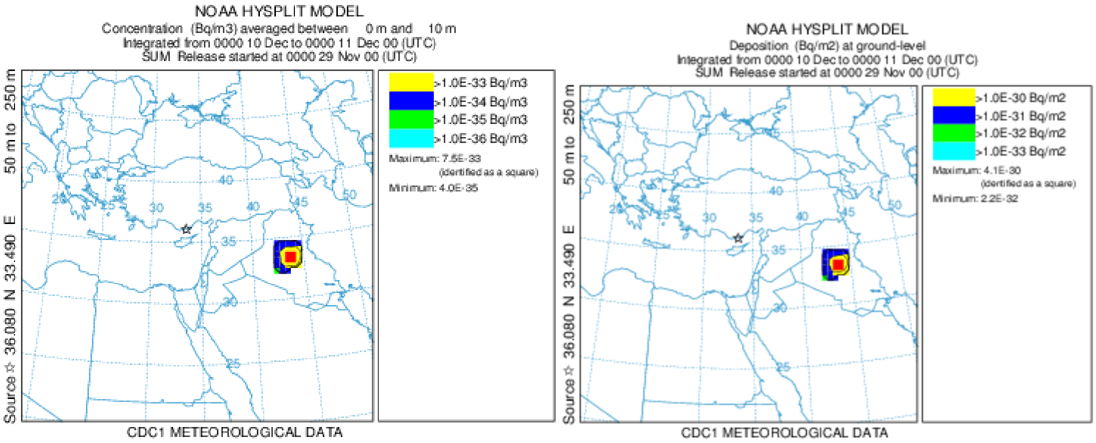

Figure B.1. (continued)

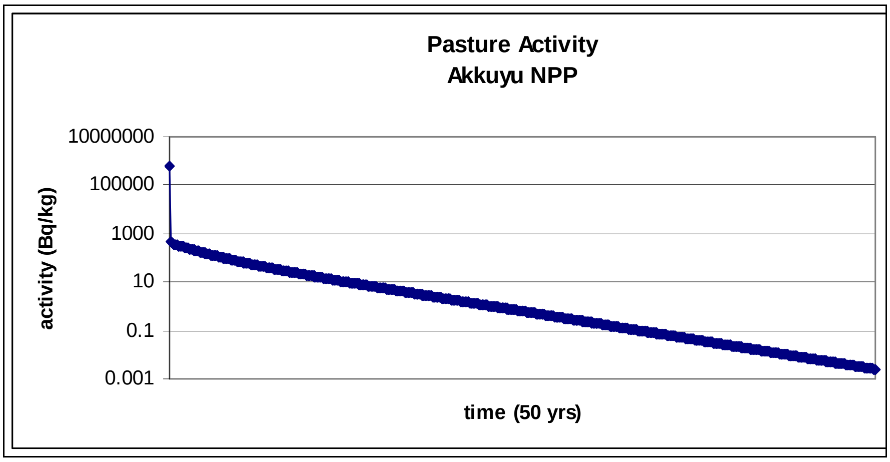

Figure B.2.a. Annual Activity in Pasture Grass for Hypothetical Accident at Akkuyu NPP

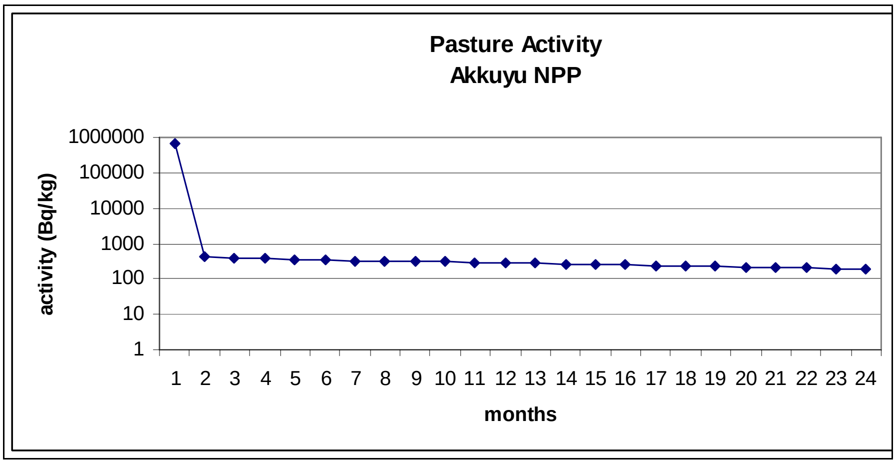

Figure B.2.b. Monthly Activity in Pasture Grass for Hypothetical Accident at Akkuyu NPP

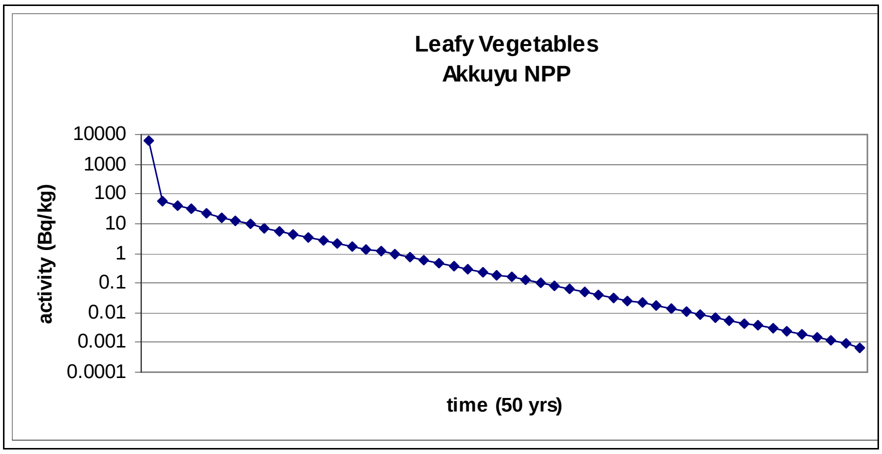

Figure B.3. Activity in Leafy Vegetables for Hypothetical Accident at Akkuyu NPP

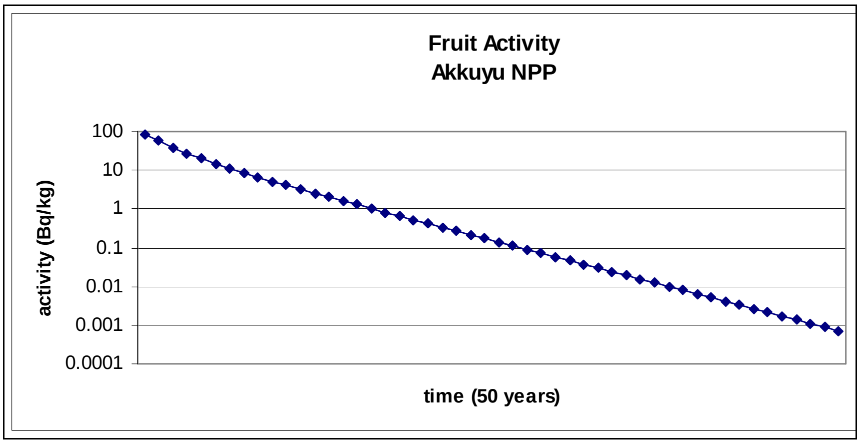

Figure B.4. Activity in Fruit for Hypothetical Accident at Akkuyu NPP

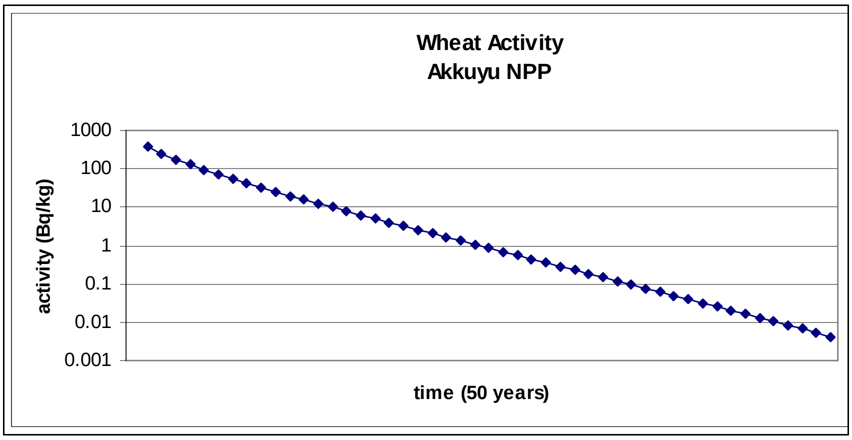

Figure B.5. Activity in Wheat for Hypothetical Accident at Akkuyu NPP

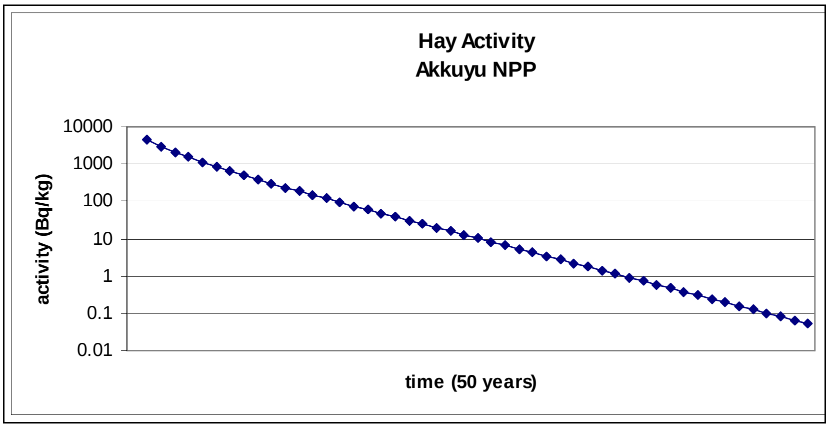

Figure B.6. Activity in Hay for Hypothetical Accident at Akkuyu NPP

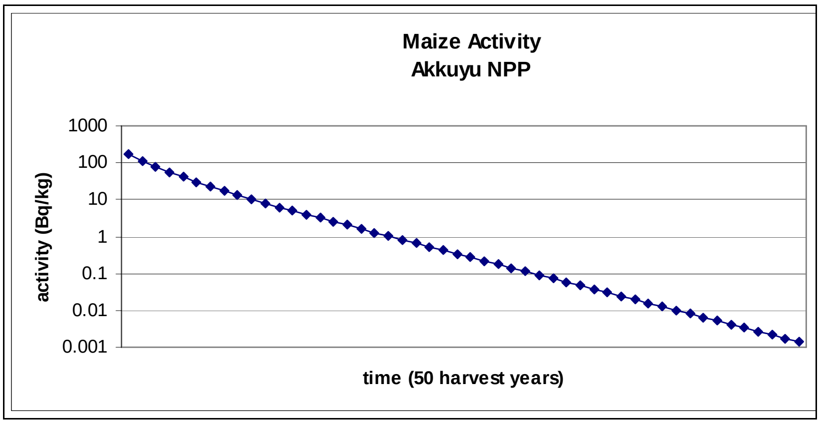

Figure B.7. Activity in Maize for for Hypothetical Accident at Akkuyu NPP

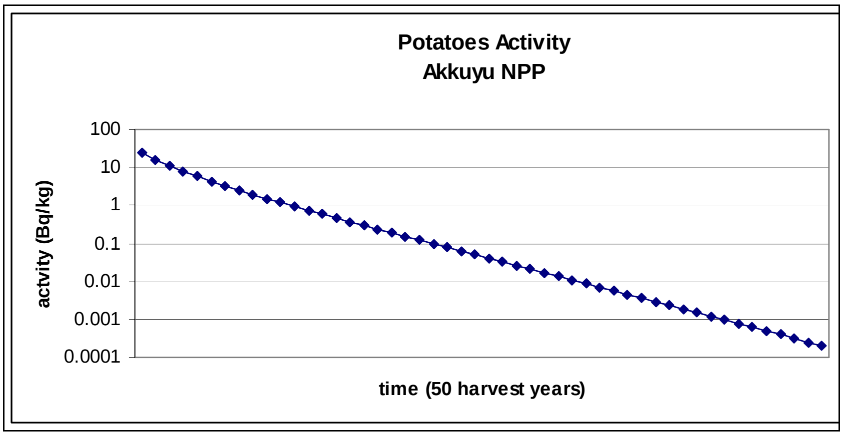

Figure B.8. Activity in Potatoes for Hypothetical Accident at Akkuyu NPP

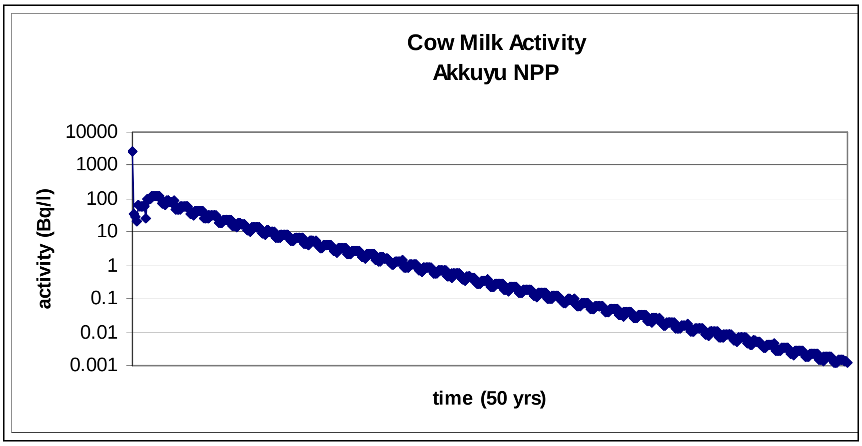

Figure B.9.a. Annual Activity in Cow Milk for Hypothetical Accident at Akkuyu NPP

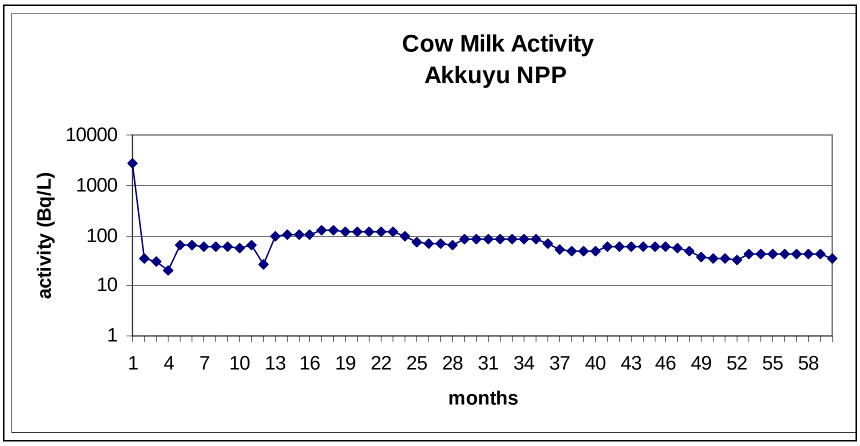

Figure B.9.b. Monthly Activity in Cow Milk for Hypothetical Accident at Akkuyu NPP

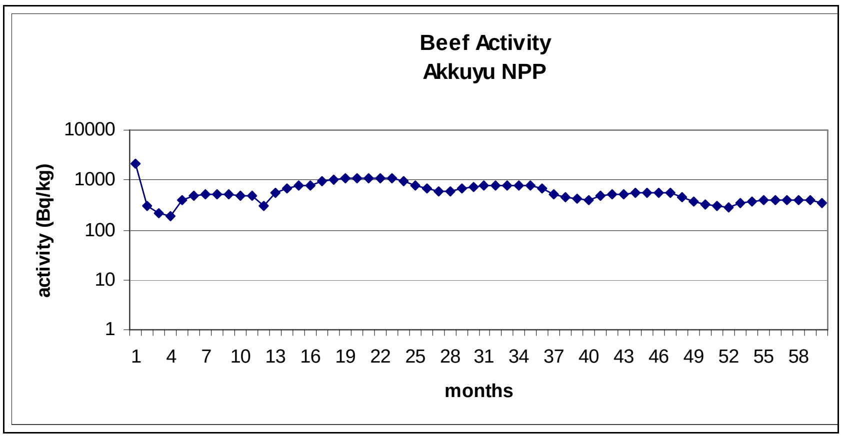

Figure B.10.a. Annual Beef Activity for Hypothetical Accident at Akkuyu NPP

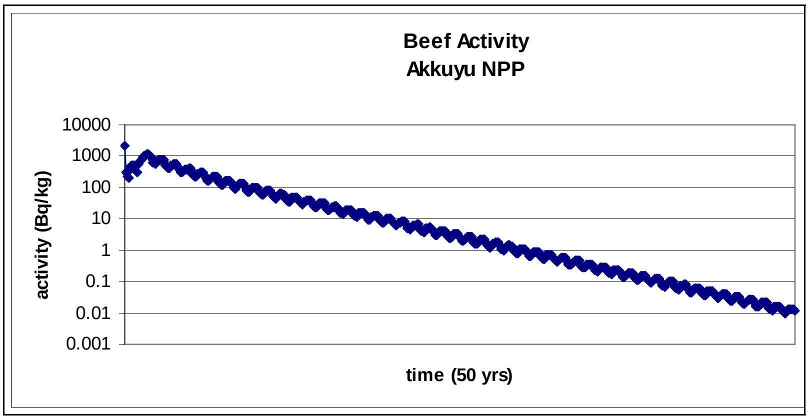

Figure B.10.b. Monthly Beef Activity for Hypothetical Accident at Akkuyu NPP

Leafy vegetables are the only plants, which exposed to radiation through foliar uptake during the fallout, so its activity is much higher than the other plants, which exposed to radiation via root uptake only in the long term. Since the new leaves formed by plant growth do not receive radioactive fallout; typically, leafy vegetables harvested 50 years after the accident is almost uncontaminated.

Table B.1. Adult Doses for Average Individuals Calculated with 9 vs. 53 Isotopes in the case of Hypothetical Accident at Akkuyu NPP

(Release started on 29th of November 2000)

Dose (mSv)		External Cloud	External Ground	Inhalation	Ingestion	Total Dose
9 isotopes	After 1 year	5.65E-03	0.65	0.168	2.594	3.417
	After 4 years		1.47		5.231	6.874
	After 10 years		1.80		6.537	8.511
	Lifetime		1.88		6.894	8.948
53 isotopes	After 1 year	7.54E-02	1.142	0.463	3.327	5.007
	After 4 years		2.465		7.119	10.122
	After 10 years		3.00		9.326	12.865
	Lifetime		3.123		10.007	13.669

Table B.2. Doses from Different Pathways for 9 Isotopes
Akkuyu NPP Accident

Dose (mSv)		External Cloud	External Ground	Inhalation	Ingestion	Total Dose
INFANT AVG.	After 1 year	4.85E-03	0.423	0.297	1.051	1.776
	After 9 years		1.645		2.67	4.617
	After 16 years		1.731		2.946	4.979
	Lifetime		1.752		3.018	5.072
INFANT MAX.	After 1 year	1.6E-02	1.395		2.039	3.747
	After 9 years		4.004		5.719	10.036
	After 16 years		4.187		6.329	10.829
	Lifetime		4.231		6.484	11.028
CHILD AVG.	After 1 year	8.17E-03	0.713	0.243	5.495	6.459
	After 7 years		1.861		6.990	9.102
	After 15 years		2.016		7.467	9.734
	Lifetime		2.042		7.557	9.850
CHILD MAX.	After 1 year	1.74E-02	1.522		14.004	15.786
	After 7 years		4.064		17.404	21.728
	After 15 years		4.303		18.458	23.021
	Lifetime		4.358		18.652	23.270
TEEN AVG.	After 1 year	8.17E-03	0.713	0.282	3.892	4.895
	After 7 years		1.861		6.579	8.730
	Lifetime		2.042		7.162	9.494
TEEN MAX.	After 1 year	1.74E-02	1.522		9.740	11.561
	After 7 years		4.064		15.722	20.085
	Lifetime		4.358		16.976	21.633
ADULT AVG.	After 1 year	8.17E-03	0.713	0.210	2.788	3.719
	After 8 years		1.861		5.733	6.812
	After 15 years		2.016		6.097	8.331
	Lifetime		2.042		6.187	8.447
ADULT MAX.	After 1 year	1.74E-02	1.522		7.331	9.080
	After 8 years		4.064		13.639	17.930
	After 15 years		4.303		14.423	18.953
	Lifetime		4.358		14.618	19.203

Table B.3. Dose Contribution of Different Isotopes for Hypothetical Accident at Akkuyu NPP (Sv) (Release Started on 29th of November, 2000)

yr	Cs137	Cs134	Cs136	I131gas	I131particulate	I132gas	I132particulate	Te129	Te129m	Te132	Xe133	SUM
1	0.000687	0.0017824	2.3E-05	5E-04	0.00042	1.46E-06	2E-06	5E-07	0.0001	1E-04	4E-07	0.00372015
2	0.0004935	0.0009003	3.9E-12	2E-13	1.4E-13	0	0	0	3E-09	2E-20	0	0.00139372
3	0.0004011	0.0005387	2.1E-16	2E-20	1.2E-20	0	0	0	2E-11	2E-41	0	0.00093974
4	0.0003216	0.0003172	9.4E-25	6E-34	3.7E-34	0	0	0	2E-14	0	0	0.00063875
5	0.0002578	0.0001868	4.1E-33	0	0	0	0	0	2E-17	0	0	0.00044463
6	0.0002068	0.00011	1.8E-41	0	0	0	0	0	1E-20	0	0	0.00031683
7	0.0001658	6.477E-05	0	0	0	0	0	0	8E-24	0	0	0.00023056
8	0.0001329	3.814E-05	0	0	0	0	0	0	5E-27	0	0	0.00017106
9	0.0001066	2.246E-05	0	0	0	0	0	0	3E-30	0	0	0.00012906
10	8.547E-05	1.323E-05	0	0	0	0	0	0	2E-33	0	0	9.8697E-05
11	6.852E-05	7.787E-06	0	0	0	0	0	0	1E-36	0	0	7.6304E-05
12	5.495E-05	4.587E-06	0	0	0	0	0	0	7E-40	0	0	5.9541E-05
13	4.406E-05	2.701E-06	0	0	0	0	0	0	4E-43	0	0	4.6765E-05
14	3.532E-05	1.59E-06	0	0	0	0	0	0	0	0	0	3.6914E-05
15	2.833E-05	9.366E-07	0	0	0	0	0	0	0	0	0	2.9268E-05
16	2.272E-05	5.516E-07	0	0	0	0	0	0	0	0	0	2.327E-05
17	1.821E-05	3.248E-07	0	0	0	0	0	0	0	0	0	1.8538E-05
18	1.461E-05	1.913E-07	0	0	0	0	0	0	0	0	0	1.4799E-05
19	1.171E-05	1.126E-07	0	0	0	0	0	0	0	0	0	1.1825E-05
20	9.394E-06	6.635E-08	0	0	0	0	0	0	0	0	0	9.4601E-06
21	7.531E-06	3.907E-08	0	0	0	0	0	0	0	0	0	7.5702E-06
22	6.039E-06	2.301E-08	0	0	0	0	0	0	0	0	0	6.0619E-06
23	4.843E-06	1.355E-08	0	0	0	0	0	0	0	0	0	4.857E-06
24	3.883E-06	7.978E-09	0	0	0	0	0	0	0	0	0	3.8908E-06
25	3.113E-06	4.698E-09	0	0	0	0	0	0	0	0	0	3.1177E-06
26	2.497E-06	2.767E-09	0	0	0	0	0	0	0	0	0	2.4994E-06
27	2.002E-06	1.629E-09	0	0	0	0	0	0	0	0	0	2.0033E-06
28	1.605E-06	9.592E-10	0	0	0	0	0	0	0	0	0	1.6057E-06
29	1.287E-06	5.649E-10	0	0	0	0	0	0	0	0	0	1.2876E-06

Table B.3. Dose Contribution of Different Isotopes for Hypothetical Accident at Akkuyu NPP (Sv) (Release Started on 29th of November, 2000) (continued)

yr	Cs137	Cs134	Cs136	I131gas	I131particulate	I132gas	I132particulate	Te129	Te129m	Te132	Xe133	SUM
30	1.032E-06	3.327E-10	0	0	0	0	0	0	0	0	0	1.0323E-06
31	8.273E-07	1.959E-10	0	0	0	0	0	0	0	0	0	8.2748E-07
32	6.635E-07	1.154E-10	0	0	0	0	0	0	0	0	0	6.6366E-07
33	5.321E-07	6.794E-11	0	0	0	0	0	0	0	0	0	5.3212E-07
34	4.266E-07	4E-11	0	0	0	0	0	0	0	0	0	4.2662E-07
35	3.421E-07	2.356E-11	0	0	0	0	0	0	0	0	0	3.4213E-07
36	2.743E-07	1.388E-11	0	0	0	0	0	0	0	0	0	2.7434E-07
37	2.2E-07	8.172E-12	0	0	0	0	0	0	0	0	0	2.2001E-07
38	1.764E-07	4.812E-12	0	0	0	0	0	0	0	0	0	1.7639E-07
39	1.414E-07	2.834E-12	0	0	0	0	0	0	0	0	0	1.4143E-07
40	1.134E-07	1.669E-12	0	0	0	0	0	0	0	0	0	1.1344E-07
41	9.094E-08	9.827E-13	0	0	0	0	0	0	0	0	0	9.0937E-08
42	7.291E-08	5.786E-13	0	0	0	0	0	0	0	0	0	7.2909E-08
43	5.847E-08	3.408E-13	0	0	0	0	0	0	0	0	0	5.8471E-08
44	4.688E-08	2.007E-13	0	0	0	0	0	0	0	0	0	4.6882E-08
45	3.758E-08	1.181E-13	0	0	0	0	0	0	0	0	0	3.7582E-08
46	3.014E-08	6.958E-14	0	0	0	0	0	0	0	0	0	3.0144E-08
47	2.417E-08	4.098E-14	0	0	0	0	0	0	0	0	0	2.417E-08
48	1.938E-08	2.412E-14	0	0	0	0	0	0	0	0	0	1.9376E-08
49	1.554E-08	1.421E-14	0	0	0	0	0	0	0	0	0	1.554E-08
50	1.246E-08	8.368E-15	0	0	0	0	0	0	0	0	0	1.2461E-08
51	9.99E-09	4.927E-15	0	0	0	0	0	0	0	0	0	9.9905E-09
52	8.012E-09	2.902E-15	0	0	0	0	0	0	0	0	0	8.0124E-09
53	6.425E-09	1.709E-15	0	0	0	0	0	0	0	0	0	6.4246E-09
54	5.152E-09	1.006E-15	0	0	0	0	0	0	0	0	0	5.1516E-09
55	4.13E-09	5.926E-16	0	0	0	0	0	0	0	0	0	4.1304E-09
56	3.312E-09	3.49E-16	0	0	0	0	0	0	0	0	0	3.3124E-09
57	2.657E-09	2.056E-16	0	0	0	0	0	0	0	0	0	2.6568E-09
58	2.13E-09	1.21E-16	0	0	0	0	0	0	0	0	0	2.1298E-09

Table B.3. Dose Contribution of Different Isotopes for Hypothetical Accident at Akkuyu NPP (Sv) (Release Started on 29th of November, 2000) (continued)

yr	Cs137	Cs134	Cs136	I131gas	I131particulate	I132gas	I132particulate	Te129	Te129m	Te132	Xe133	SUM
59	1.708E-09	7.127E-17	0	0	0	0	0	0	0	0	0	1.7075E-09
60	1.369E-09	4.197E-17	0	0	0	0	0	0	0	0	0	1.3694E-09
61	1.098E-09	2.471E-17	0	0	0	0	0	0	0	0	0	1.098E-09
62	8.802E-10	1.455E-17	0	0	0	0	0	0	0	0	0	8.8019E-10
63	7.06E-10	8.571E-18	0	0	0	0	0	0	0	0	0	7.0597E-10
64	5.661E-10	5.047E-18	0	0	0	0	0	0	0	0	0	5.6606E-10
65	4.538E-10	2.971E-18	0	0	0	0	0	0	0	0	0	4.5378E-10
66	3.64E-10	1.75E-18	0	0	0	0	0	0	0	0	0	3.6396E-10
67	2.918E-10	1.031E-18	0	0	0	0	0	0	0	0	0	2.9184E-10
68	2.34E-10	6.069E-19	0	0	0	0	0	0	0	0	0	2.3398E-10
69	1.877E-10	3.575E-19	0	0	0	0	0	0	0	0	0	1.8765E-10
70	1.502E-10	2.102E-19	0	0	0	0	0	0	0	0	0	1.5021E-10

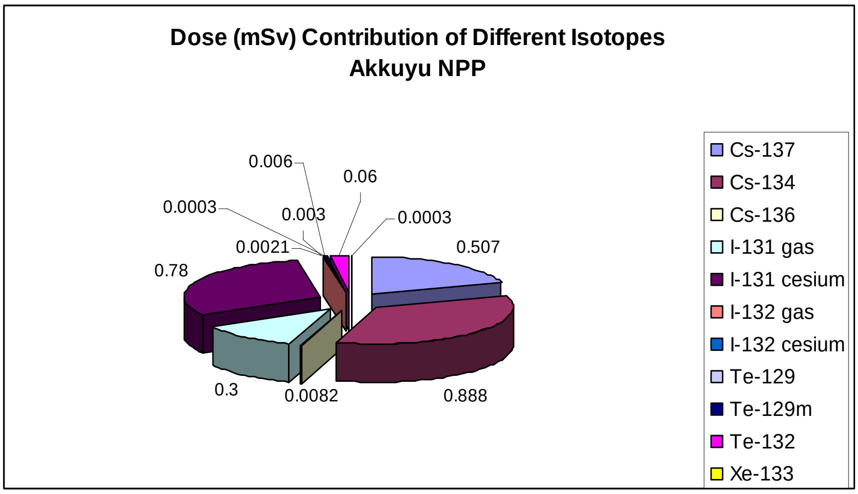

Figure B.11. Dose Contribution of the Different Isotopes for Akkuyu NPP Accident Case Study (Release started on 29th of November 2000)

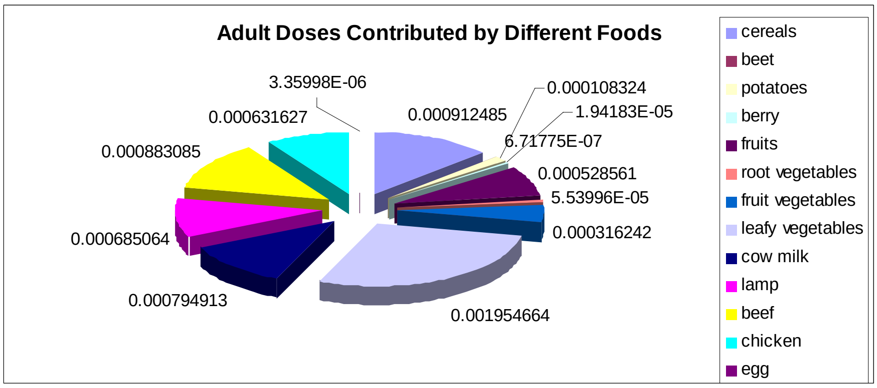

Figure B. 12. Adult Dose Contribution of the Different Foods for Akkuyu NPP Accident (Release started on 29th of November 2000)

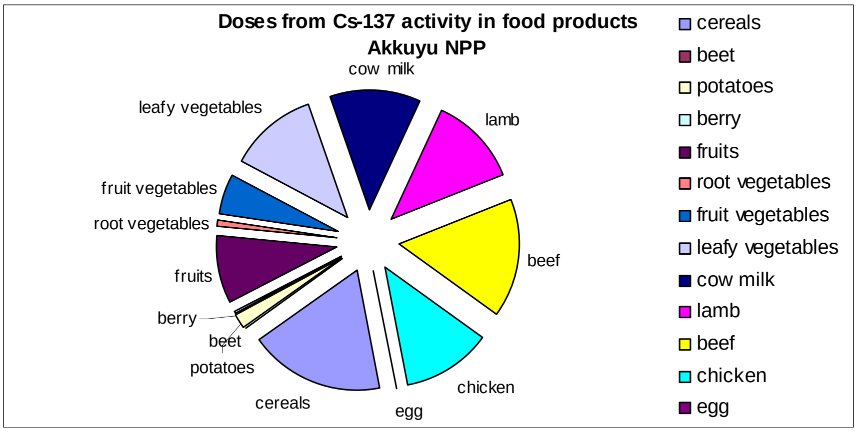

Figure B.13. Doses Incurred by Cs-137 in Food Products for Akkuyu NPP Accident Case Study (Release started on 29th of November 2000)

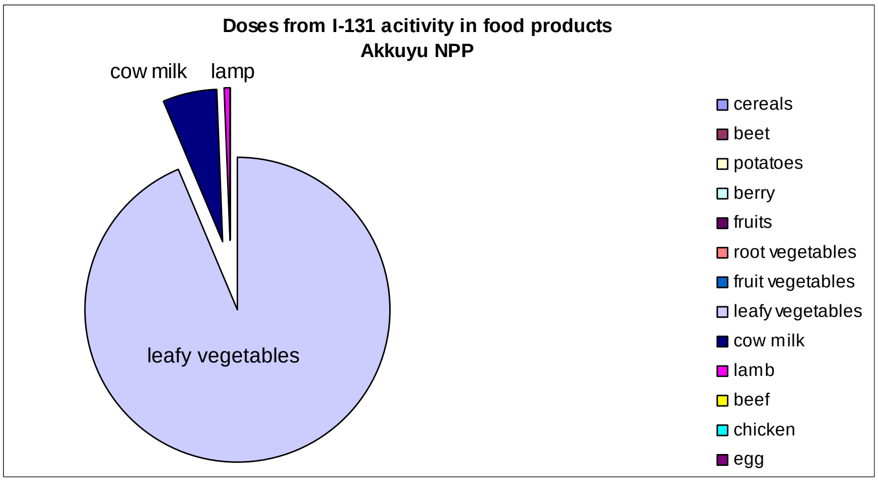

Figure B.14. Doses Incurred by I-131 in Food Products for Akkuyu NPP Accident Case Study (Release started on 29th of November 2000)

Table B.4. Late Risks Calculated with ICRP-103 Risk Coefficients

		Infant Late Risk		Child Late Risk		Teen Late Risk		Adult Late Risk	
Lat.	Lon.	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk
36	26.5	2.27196E-07	4.13083E-09	5.55835E-06	1.01061E-07	2.39992E-06	4.36348E-08	9.80422E-07	4.78255E-08
36	29	1.25173E-06	2.27587E-08	2.43375E-05	4.425E-07	1.14857E-05	2.08831E-07	5.23706E-06	2.55466E-07
36	31.5	2.0541E-05	3.73473E-07	0.00021933	3.98781E-06	0.000178673	3.24859E-06	0.000121079	5.90628E-06
36	34	9.76866E-05	1.77612E-06	0.000513019	9.32762E-06	0.000480193	8.73078E-06	0.000346365	1.68959E-05
36	36.5	0	0	0	0	0	0	0	0
36	39	0	0	0	0	0	0	0	0
36	41.5	0	0	0	0	0	0	0	0
36	44	0	0	0	0	0	0	0	0
38.5	26.5	7.77202E-09	1.41309E-10	3.51549E-07	6.3918E-09	1.79128E-07	3.25687E-09	8.78542E-08	4.28557E-09
38.5	29	4.90716E-08	8.92211E-10	1.62684E-06	2.9579E-08	8.55139E-07	1.5548E-08	4.36799E-07	2.13073E-08
38.5	31.5	5.43696E-06	9.88538E-08	1.03008E-05	1.87287E-07	8.24642E-06	1.49935E-07	5.71167E-06	2.78618E-07
38.5	34	1.1349E-05	2.06345E-07	9.33985E-06	1.69815E-07	5.65968E-06	1.02903E-07	3.58293E-06	1.74777E-07
38.5	36.5	0	0	0	0	0	0	0	0
38.5	39	0	0	0	0	0	0	0	0
38.5	41.5	0	0	0	0	0	0	0	0
38.5	44	0	0	0	0	0	0	0	0
41	26.5	1.46431E-12	2.66239E-14	2.49694E-11	4.53989E-13	2.61438E-11	4.75342E-13	2.20813E-11	1.07714E-12
41	29	1.80728E-10	3.28597E-12	2.30324E-09	4.18771E-11	3.0832E-09	5.60583E-11	2.69054E-09	1.31246E-10
41	31.5	2.92411E-06	5.31656E-08	2.07567E-06	3.77395E-08	9.67784E-07	1.75961E-08	5.24677E-07	2.5594E-08
41	34	9.51676E-07	1.73032E-08	6.57139E-07	1.1948E-08	2.98338E-07	5.42432E-09	1.61741E-07	7.88981E-09
41	36.5	0	0	0	0	0	0	0	0
41	39	0	0	0	0	0	0	0	0
41	41.5	0	0	0	0	0	0	0	0
41	44	0	0	0	0	0	0	0	0

Table B.5. Late Risks Calculated with USEPA FGR-13 Risk Coefficients

Risk For Infant				Risk For Child		Risk For Teen		Risk For Adult	
Lat	Lon	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality
36	26.5	4.254E-08	9.1021E-09	1.92E-05	2.5E-06	2.31E-05	3.02E-06	1.86E-05	2.56E-06
36	29	2.5959E-07	9.5378E-08	9.29E-05	1.94E-05	0.000112	2.36E-05	9.38E-05	2.21E-05
36	31.5	8.787E-06	5.5473E-06	0.001524	0.000802	0.001859	0.000983	0.001852	0.001037
36	34	7.0677E-05	2.4487E-05	0.004223	0.002436	0.005188	0.002995	0.005337	0.003176
36	36.5	0	0	0	0	0	0	0	0
36	39	0	0	0	0	0	0	0	0
36	41.5	0	0	0	0	0	0	0	0
36	44	0	0	0	0	0	0	0	0
38.5	26.5	5.3775E-09	2.4873E-09	1.52E-06	3.99E-07	1.84E-06	4.9E-07	1.57E-06	4.68E-07
38.5	29	2.6262E-08	1.2622E-08	7.26E-06	2.09E-06	8.79E-06	2.56E-06	7.69E-06	2.52E-06
38.5	31.5	4.1458E-06	7.3585E-07	7.15E-05	3.62E-05	8.9E-05	4.48E-05	9.29E-05	4.77E-05
38.5	34	8.2475E-06	1.0035E-06	4.47E-05	1.52E-05	5.78E-05	1.91E-05	6.37E-05	2.07E-05
38.5	36.5	0	0	0	0	0	0	0	0
38.5	39	0	0	0	0	0	0	0	0
38.5	41.5	0	0	0	0	0	0	0	0
38.5	44	0	0	0	0	0	0	0	0
41	26.5	1.2493E-12	8.4949E-13	2.95E-10	1.91E-10	3.56E-10	2.3E-10	3.94E-10	2.59E-10
41	29	2.1496E-10	1.3116E-10	2.99E-08	2.01E-08	3.64E-08	2.44E-08	4.27E-08	2.88E-08
41	31.5	2.0749E-06	2.2004E-07	6.94E-06	7.81E-07	9.23E-06	1.03E-06	1.03E-05	1.16E-06
41	34	6.9319E-07	7.3319E-08	2.29E-06	2.44E-07	3.05E-06	3.24E-07	3.42E-06	3.63E-07
41	36.5	0	0	0	0	0	0	0	0
41	39	0	0	0	0	0	0	0	0
41	41.5	0	0	0	0	0	0	0	0
41	44	0	0	0	0	0	0	0	0

Table B.6. Collective Dose and Risk for Akkuyu NPP Accident Scenario

City	Total Population	Collective Dose (man-Sv)	Collective Mortality Risk	Collective Morbidity Risk
Ankara	5045083	410.4666138	59.8044548	148.21637
Konya	2079225	296.7670593	48.20322037	112.279007
Istanbul	14160467	1152.091919	167.8582916	416.011597
Kocaeli	1676202	0.069916166	0.03079626	0.0458096
Balikesir	1162761	0.048499994	0.021362992	0.03177757
Izmir	4061074	23.27415466	2.919099569	9.74510384
Manisa	1359463	4.055537701	0.46193862	1.67571294
Samsun	1261810	17.87757874	2.269027233	7.49383116
Erzurum	766729	0	0	0
Van	1070113	0	0	0
Gaziantep	1844438	0	0	0
Adana	2149260	0	0	0
Antalya	2158265	3066.041992	780.1742554	1495.49463
Mersin	1 705 774	12060.86523	3680.619629	6319.31689

B.2. Sinop NPP Accident Case Study

For the release started on 31st of October 2005, the graphical display results of HYSPLIT simulation for 53 isotopes for the Sinop NPP case study are given in Figure B.15.

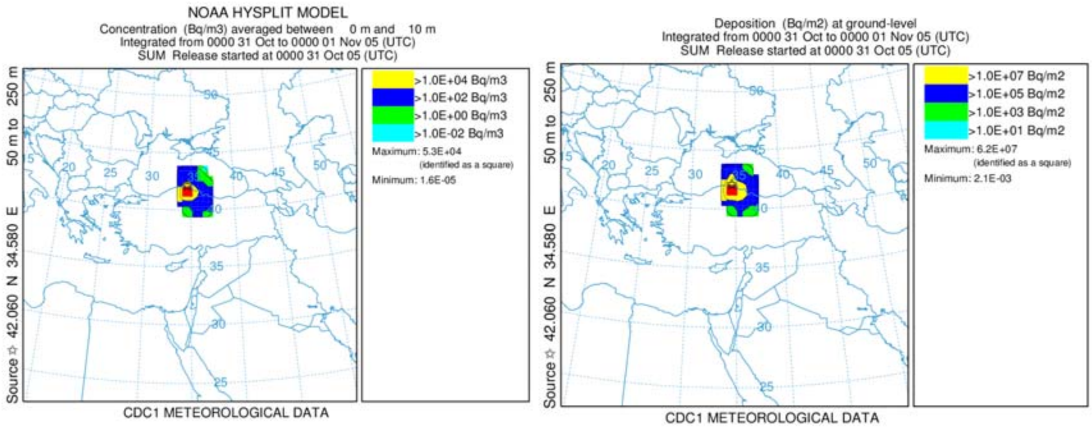

Figure B.15. Atmospheric Dispersion Graphs of HYSPLIT for Hypothetical Accident at Sinop NPP

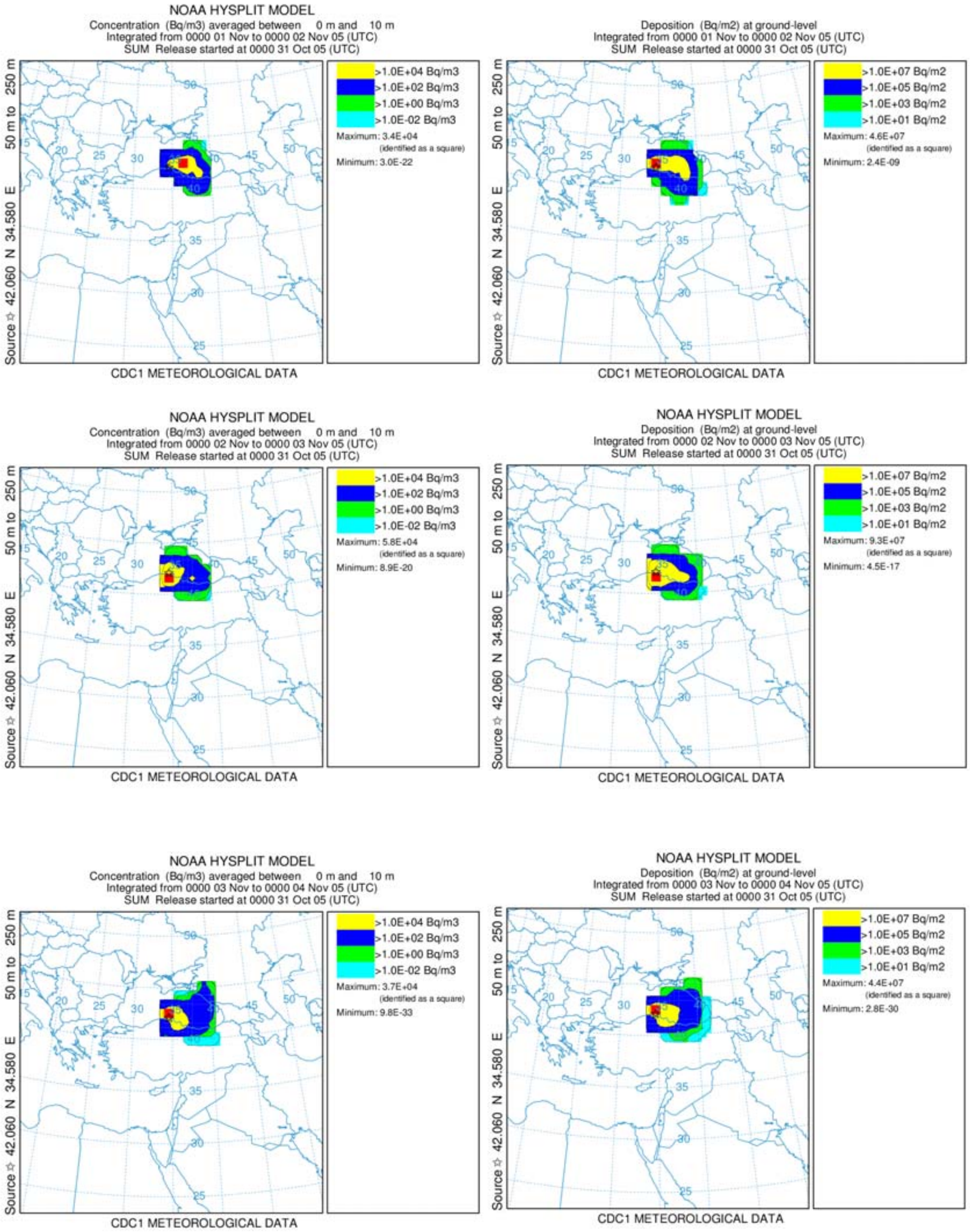

Figure B.15. (continued)

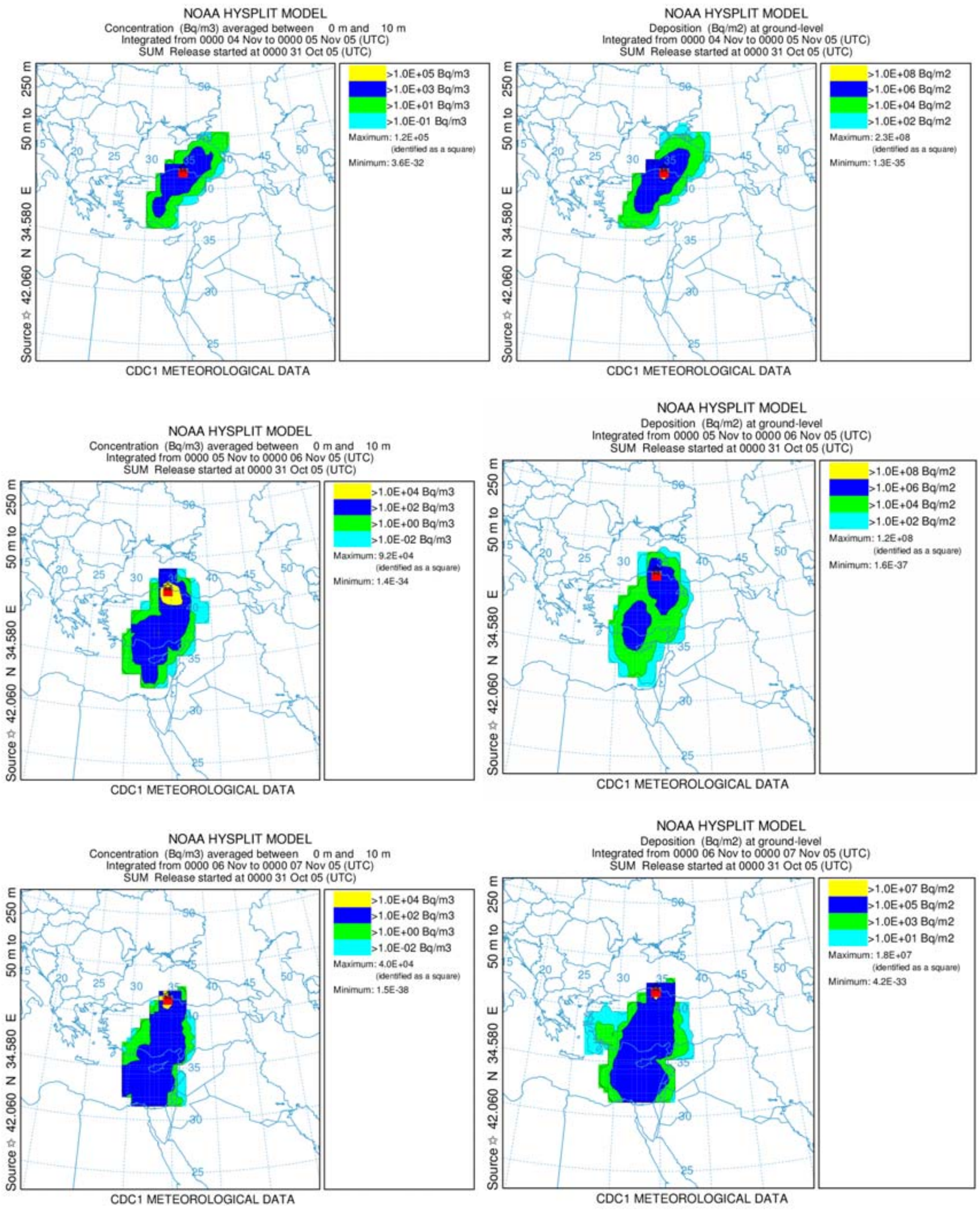

Figure B.15. (continued)

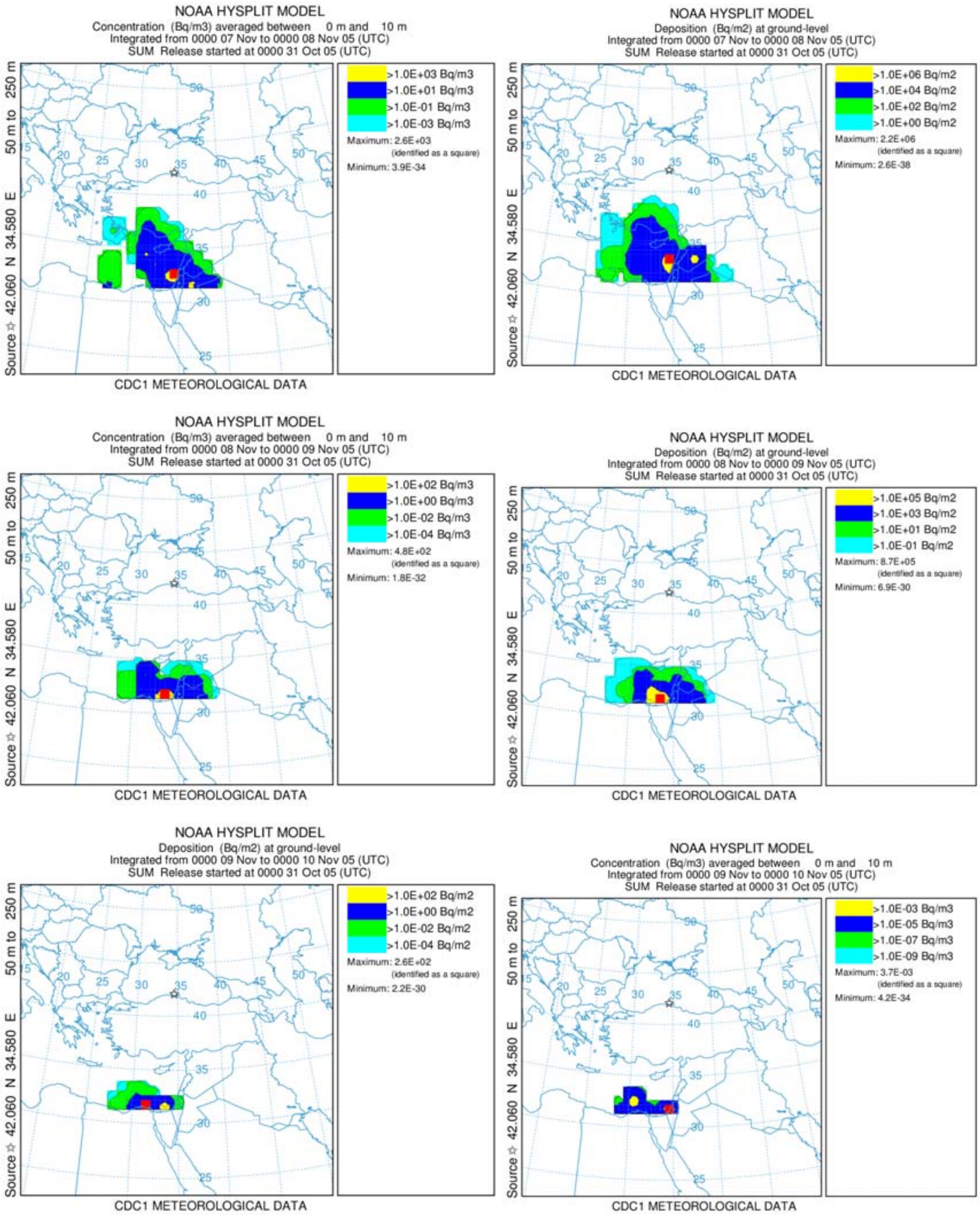

Figure B.15. (continued)

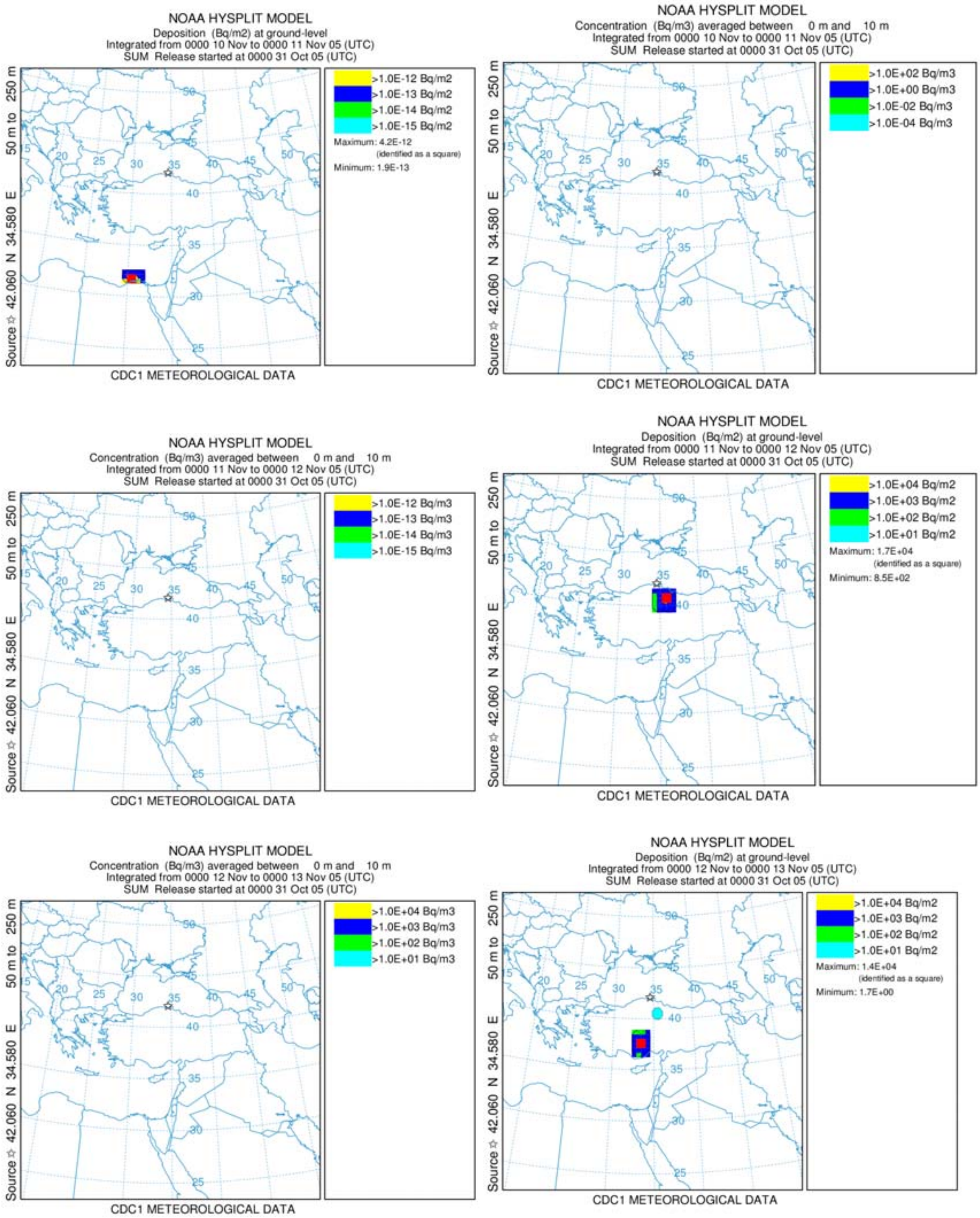

Figure B.15. (continued)

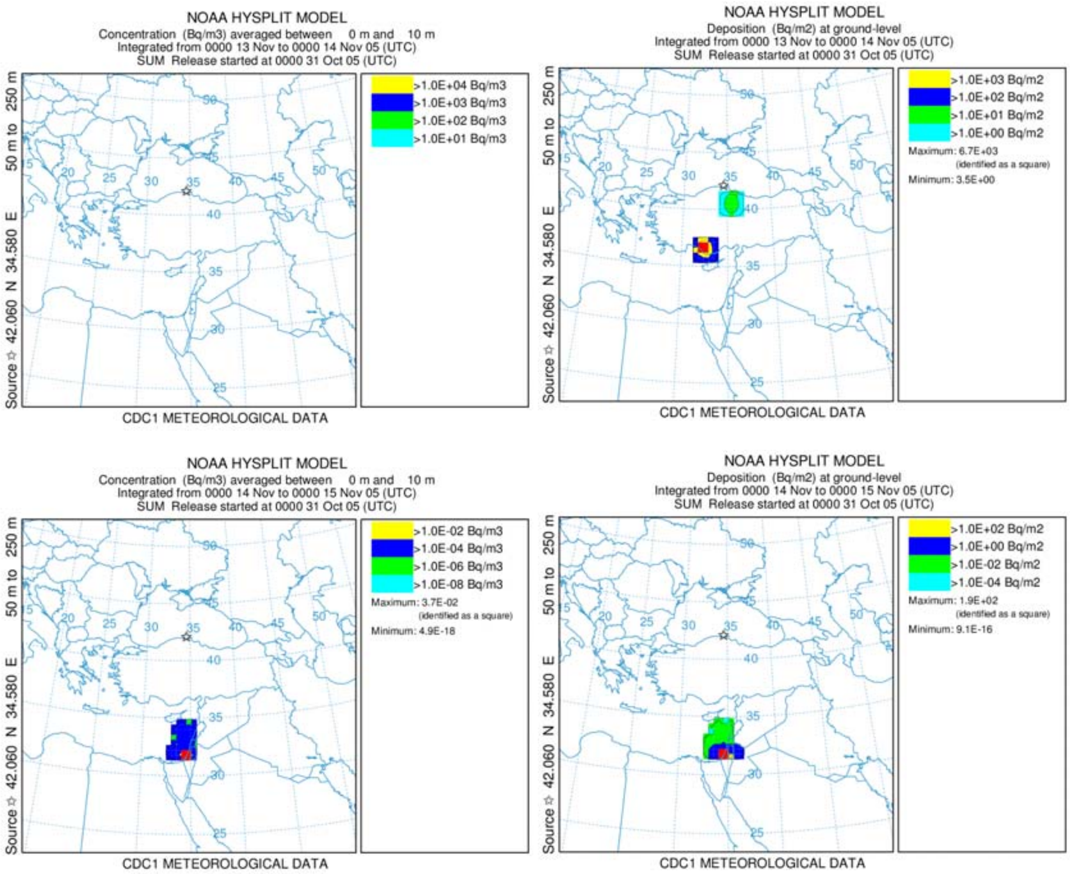

Figure B.15. (continued)

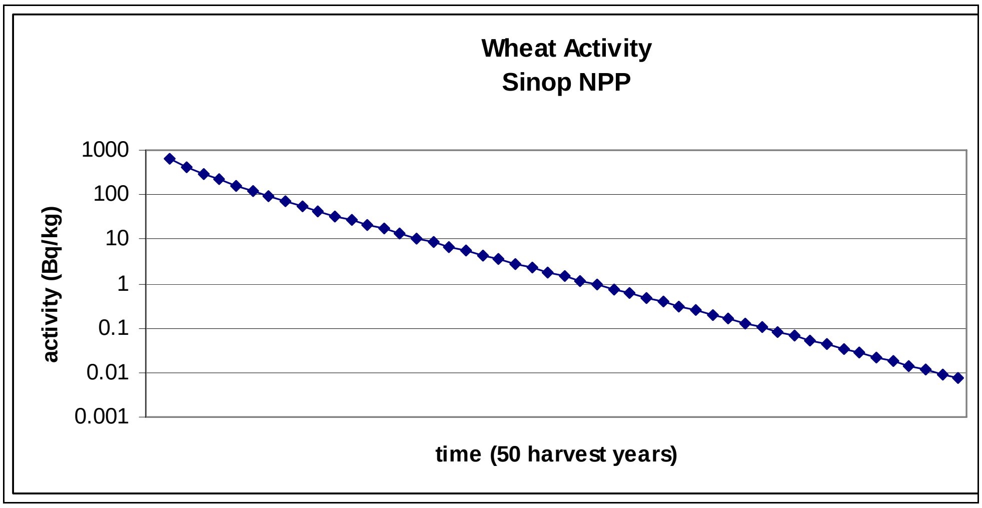

Figure B.16. Activity in Wheat for Hypothetical Accident at Sinop NPP

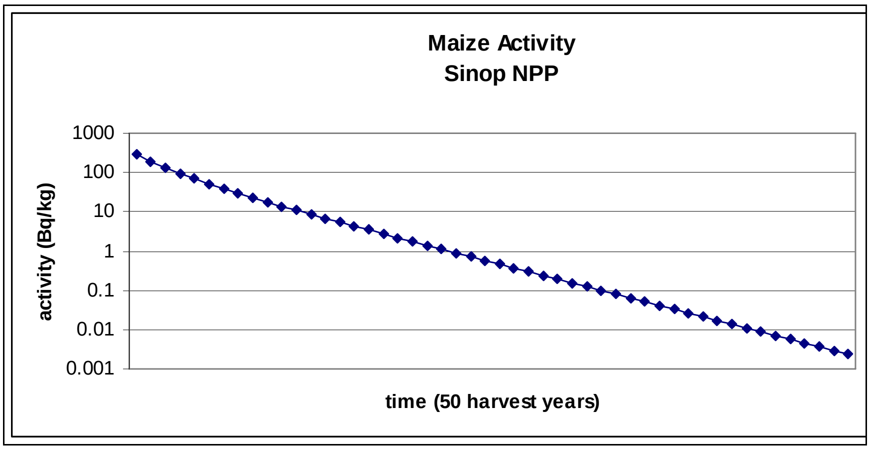

Figure B.17. Activity in Maize for Hypothetical Accident at Sinop NPP

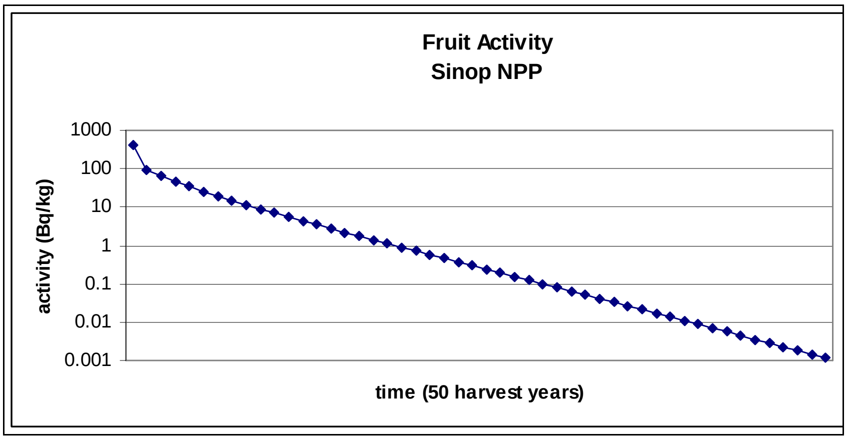

Figure B.18. Activity in Fruit for Hypothetical Accident at Sinop NPP

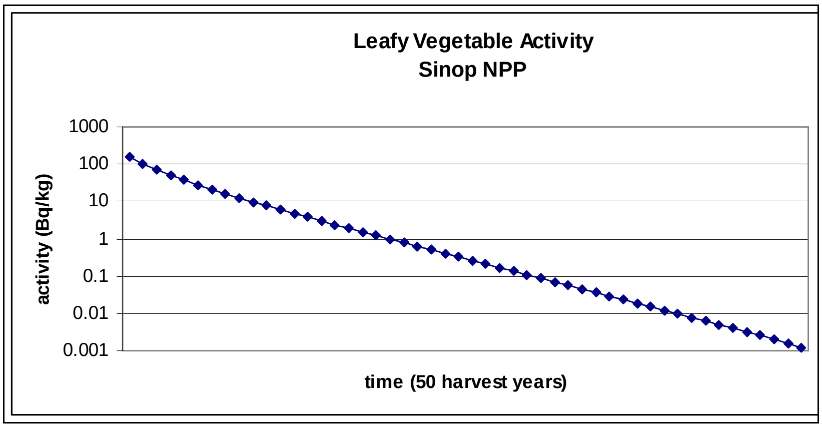

Figure B.19. Activity in Leafy Vegetables for Hypothetical Accident at Sinop NPP

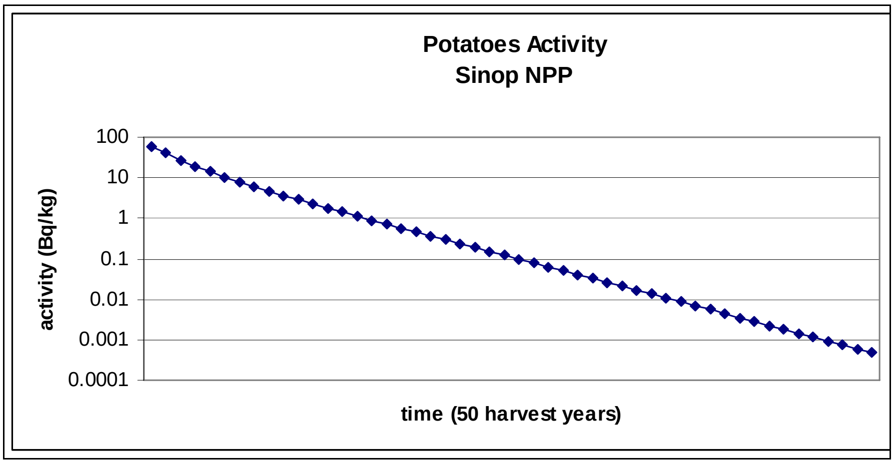

Figure B.20. Activity in Potatoes for Hypothetical Accident at Sinop NPP

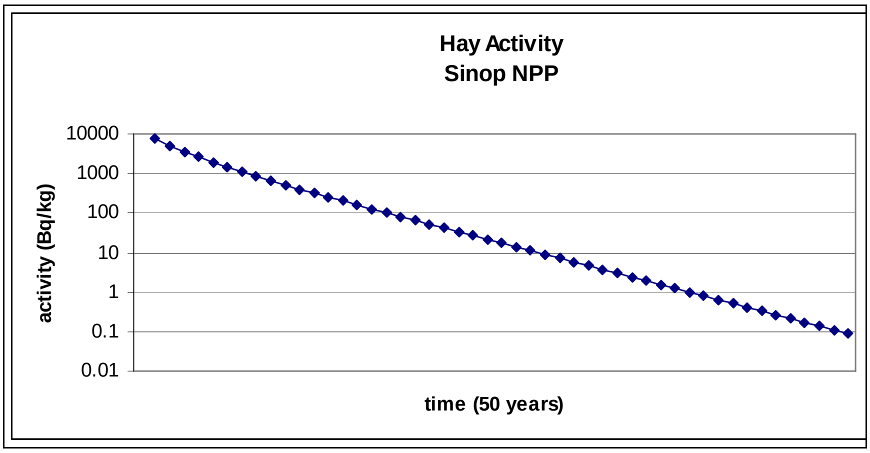

Figure B.21. Activity in Hay for Hypothetical Accident at Sinop NPP

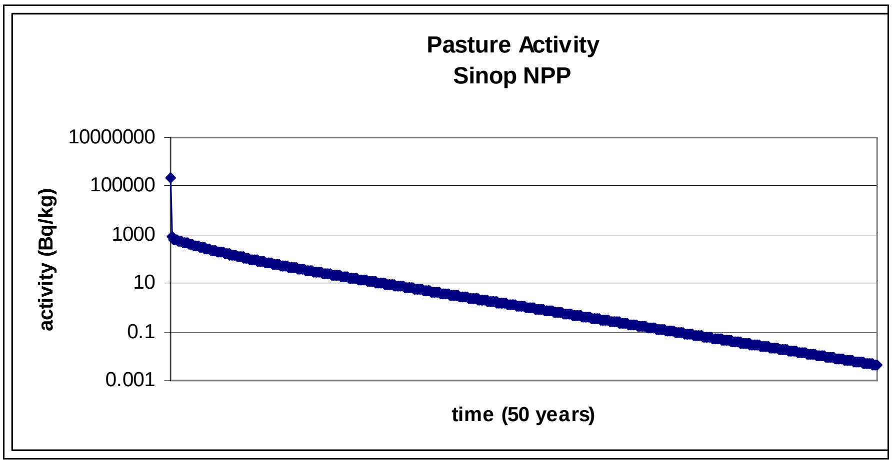

Figure B.22. Activity in Pasture Grass for Hypothetical Accident at Sinop NPP

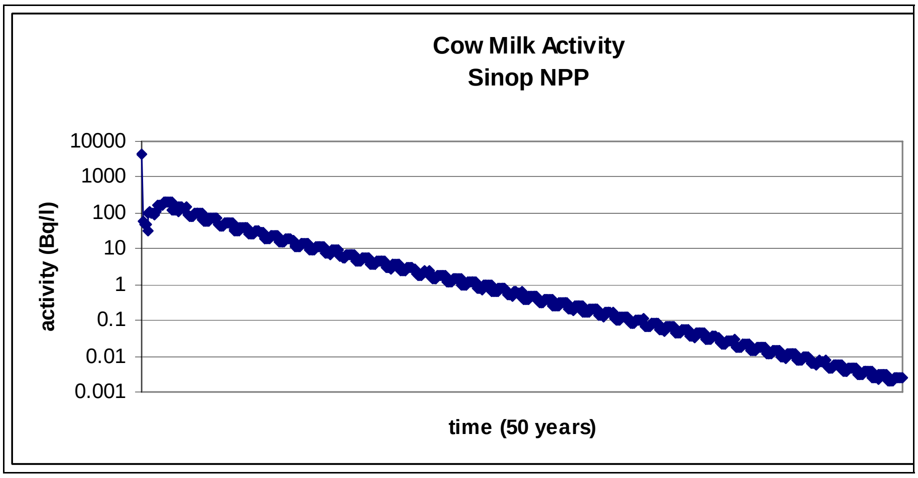

Figure B.23.a. Annual Activity in Cow Milk for Hypothetical Accident at Sinop NPP

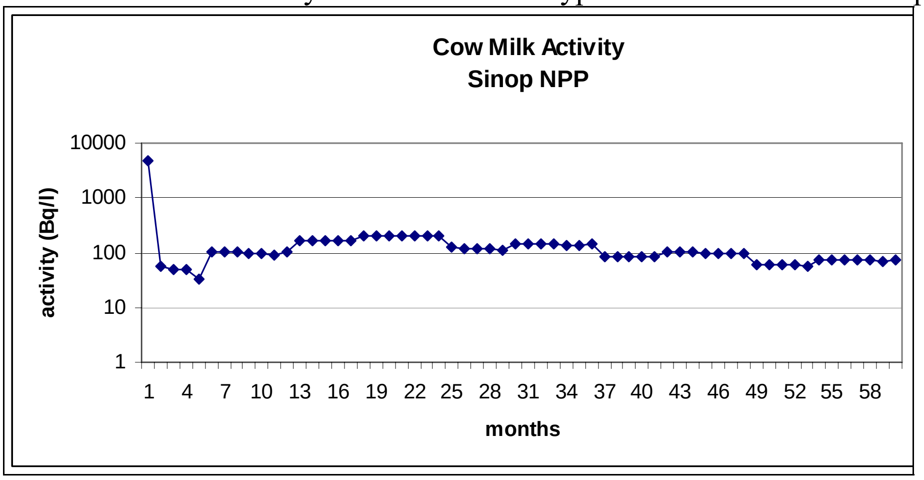

Figure B.23.b. Monthly Activity in Cow Milk for Hypothetical Accident at Sinop NPP

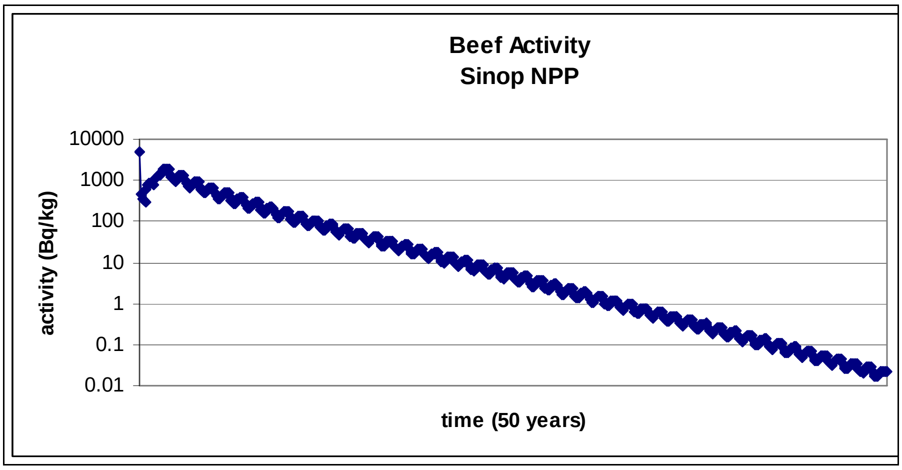

Figure B.24.a. Annual Activity in Beef for Hypothetical Accident at Sinop NPP

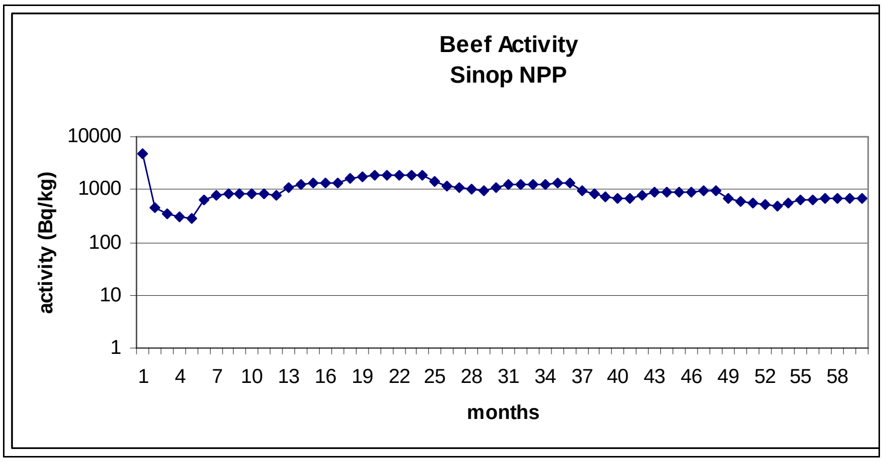

Figure B.24.b. Monthly Activity in Beef for Hypothetical Accident at Sinop NPP

Table B.7. Doses From Different Pathways for 9 Isotopes for Sinop NPP accident

Dose (mSv)		External Cloud	External Ground	Inhalation	Ingestion	Total Dose
INFANT AVG.	After 1 year	6.98E-03	0.667	0.439	2.067	3.180
	After 9 years		2.577		4.61	5.723
	After 16 years		2.713		5.048	8.207
	Lifetime		2.746		5.162	8.354
INFANT MAX.	After 1 year	2.3E-02	2.199		4.012	6.673
	After 9 years		6.276		9.793	16.531
	After 16 years		6.566		10.76	17.857
	Lifetime		6.635		11.007	18.104
CHILD AVG.	After 1 year	1.17E-02	1.124	0.533	1.197	2.866
	After 7 years		2.917		3.656	7.118
	After 15 years		3.162		4.412	8.119
	Lifetime		3.203		4.555	8.303
CHILD MAX.	After 1 year	2.51E-02	2.399		2.605	5.562
	After 7 years		6.227		8.193	15.499
	After 15 years		6.748		9.862	17.256
	Lifetime		6.836		10.170	17.564
TEEN AVG.	After 1 year	1.17E-02	1.124	0.411	1.526	3.073
	After 7 years		2.917		5.792	9.132
	Lifetime		3.203		6.716	10.342
TEEN MAX.	After 1 year	2.51E-02	2.399		3.466	6.301
	After 7 years		6.227		12.853	19.516
	Lifetime		6.836		14.84	21.112
ADULT AVG.	After 1 year	1.17E-02	1.124	0.302	1.489	2.927
	After 8 years		2.985		6.116	9.415
	After 15 years		3.162		6.693	10.169
	Lifetime		3.203		6.837	10.354
ADULT MAX.	After 1 year	2.51E-02	2.399		3.597	6.323
	After 8 years		6.370		13.509	20.206
	After 15 years		6.748		14.715	21.790
	Lifetime		6.836		15.060	22.223

Table B.8. Late Risks calculated with ICRP-103 Risk Coefficients for Sinop NPP Accident

		Infant Late Risk		Child Late Risk		Teen Late Risk		Adult Late Risk	
Lat.	Lon.	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk	Cancer Risk	Hereditary Risk
36	26.5	2.83346E-09	5.15174E-11	1.5823E-09	2.88E-11	1.3E-09	2.36035E-11	9.66E-10	4.71E-11
36	29	2.58339E-10	4.69707E-12	4.14174E-10	7.53E-12	4E-10	7.26946E-12	2.93E-10	1.43E-11
36	31.5	1.01878E-06	1.85233E-08	1.28673E-06	2.34E-08	8.43E-07	1.53307E-08	4.39E-07	2.14E-08
36	34	1.4071E-07	2.55836E-09	1.64423E-07	2.99E-09	1.1E-07	2.00143E-09	5.97E-08	2.91E-09
36	36.5	2.57177E-08	4.67594E-10	3.19272E-08	5.8E-10	2.19E-08	3.97795E-10	1.22E-08	5.96E-10
36	39	2.09497E-36	3.80903E-38	2.26407E-36	4.12E-38	2E-36	3.63081E-38	1.17E-36	5.7E-38
36	41.5	0	0	0	0	0	0	0	0
36	44	0	0	0	0	0	0	0	0
38.5	26.5	1.13782E-09	2.06877E-11	6.34168E-10	1.15E-11	5.21E-10	9.4663E-12	3.87E-10	1.89E-11
38.5	29	2.56636E-10	4.6661E-12	3.14904E-10	5.73E-12	2.36E-10	4.29762E-12	1.49E-10	7.28E-12
38.5	31.5	2.12133E-07	3.85696E-09	2.59601E-07	4.72E-09	2.77E-07	5.02936E-09	2.39E-07	1.17E-08
38.5	34	3.19848E-07	5.81541E-09	4.2551E-07	7.74E-09	3.7E-07	6.72194E-09	2.62E-07	1.28E-08
38.5	36.5	3.97017E-08	7.2185E-10	1.25809E-07	2.29E-09	1.55E-07	2.82499E-09	1.3E-07	6.36E-09
38.5	39	1.58141E-34	2.87529E-36	1.21404E-34	2.21E-36	8.96E-35	1.62998E-36	5.79E-35	2.82E-36
38.5	41.5	0	0	0	0	0	0	0	0
38.5	44	0	0	0	0	0	0	0	0
41	26.5	0	0	0	0	0	0	0	0
41	29	0	0	0	0	0	0	0	0
41	31.5	6.92447E-08	1.25899E-09	8.83275E-08	1.61E-09	8.85E-08	1.60833E-09	7.32E-08	3.57E-09
41	34	0.00017489	3.17983E-06	0.000395172	7.18E-06	0.000502	9.1317E-06	0.000424	2.07E-05
41	36.5	2.03095E-05	3.69264E-07	2.66142E-05	4.84E-07	2.97E-05	5.39759E-07	2.41E-05	1.18E-06
41	39	8.29262E-07	1.50775E-08	8.39308E-07	1.53E-08	5.81E-07	1.05715E-08	3.36E-07	1.64E-08
41	41.5	7.532E-12	1.36945E-13	1.2704E-11	2.31E-13	1.27E-11	2.30981E-13	9.47E-12	4.62E-13
41	44	0	0	0	0	0	0	0	0

Table B.9. Late Risks Calculated with USEPA FGR-13 Risk Coefficients for Sinop NPP Accident Scenario

Risk For Infant				Risk For Child		Risk For Teen		Risk For Adult	
Lat	Lon	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality	Morbidity	Mortality
36	26.5	1.681E-10	2.862E-11	2.377E-10	5.257E-11	3.400E-10	6.339E-11	4.954E-10	7.982E-11
36	29	2.104E-10	1.383E-10	5.330E-10	3.50E-10	5.512E-10	3.544E-10	5.512E-10	3.544E-10
36	31.5	3.204E-07	3.971E-08	8.364E-07	1.038E-07	1.780E-06	2.071E-07	1.786E-06	2.079E-07
36	34	4.007E-08	5.530E-09	1.033E-07	1.439E-08	2.158E-07	2.673E-08	2.177E-07	2.697E-08
36	36.5	7.691E-09	1.040E-09	2.126E-08	3.610E-09	4.371E-08	6.378E-09	4.424E-08	6.585E-09
36	39	5.769E-37	3.955E-37	1.524E-36	1.045E-36	3.273E-36	2.245E-36	3.274E-36	2.245E-36
36	41.5	0	0	0	0	0	0	0	0
36	44	0	0	0	0	0	0	0	0
38.5	26.5	6.751E-11	1.149E-11	9.505E-11	2.107E-11	1.359E-10	2.539E-11	1.979E-10	3.195E-11
38.5	29	9.326E-11	4.926E-11	2.394E-10	1.255E-10	3.389E-10	1.497E-10	3.389E-10	1.497E-10
38.5	31.5	3.803E-08	1.553E-08	2.511E-07	1.51E-07	3.519E-07	2.006E-07	3.909E-07	2.216E-07
38.5	34	8.537E-08	2.058E-08	3.391E-07	1.374E-07	5.7611E-07	1.9298E-07	6.0471E-07	2.085E-07
38.5	36.5	1.603E-08	8.2898E-09	1.448E-07	9.253E-08	2.017E-07	1.243E-07	2.202E-07	1.365E-07
38.5	39	1.248E-35	1.740E-36	2.442E-35	3.640E-36	4.561E-35	5.743E-36	5.196E-35	6.415E-36
38.5	41.5	0	0	0	0	0	0	0	0
38.5	44	0	0	0	0	0	0	0	0
41	26.5	0	0	0	0	0	0	0	0
41	29	0	0	0	0	0	0	0	0
41	31.5	1.614E-08	6.414E-09	8.559E-08	4.812E-08	1.248E-07	6.417E-08	1.365E-07	7.066E-08
41	34	5.075E-05	2.848E-05	0.0004675	0.00030989	0.00063595	0.00041641	0.0007109	0.0004629
41	36.5	4.267E-06	1.728E-06	2.763E-05	1.655E-05	4.002E-05	2.264E-05	4.435E-05	2.503E-05
41	39	1.905E-07	3.027E-08	4.751E-07	7.596E-08	9.654E-07	1.306E-07	9.849E-07	1.326E-07
41	41.5	7.692E-12	5.142E-12	1.946E-11	1.301E-11	1.946E-11	1.301E-11	1.946E-11	1.301E-11
41	44	0	0	0	0	0	0	0	0

Table B.10. Collective Dose and Risk for Sinop NPP Accident Scenario

City	Total Population	Collective Dose (man-Sv)	Collective Mortality Risk	Collective Morbidity Risk
Ankara	5 045 083	9428.724	3007.739	4543.570
Konya	2 079 225	11.985	2.004	3.2143538
Istanbul	14 160 467	26464.408	8442.080	12752.829
Kocaeli	1 676 202	0	0	0
Balikesir	1 162 761	0	0	0
Izmir	4 061 074	0.023506355	0.000184519	0.00162565
Manisa	1 359 463	0.017377583	0.000185306	0.00163258
Samsun	1 261 810	0.005781553	0	0
Erzurum	766 729	379.8347168	93.7773056	147.799
Van	1 070 113	0.000111009	9.34533E-07	1.397E-06
Gaziantep	1 844 438	0	0	0
Adana	2 149 260	1.445240378	0.385967374	0.57327324
Antalya	2 158 265	18.34008408	0.024362916	0.14884938
Sinop	204 568	3.839897156	0.012480112	0.06915757

CURRICULUM VITAE

PERSONEL INFORMATION

Surname, Name: Ünver, Özge
Nationality: Turkish (TC)
Date and Place of the Birth: 23.11.1975, Ankara
Marital status: Divorced with a son.
Phone: +90 312 2867114 (permanent home)
Cell phone: +90 532 6453244
E-mail: ozge.unver@taek.gov.tr

EDUCATION

Degree	Institution	Year of Graduation
1. Ph.D.	METU Environmental Engineering	2014

Thesis study: Development of a Radioecological Model for Accidental Radionuclide Release: Akkuyu and Sinop NPPs.

Degree	Institution	Year of Graduation
2. M.Sc.	METU Environmental Engineering	2003

Thesis study: A Modeling Study for the Health Risk Posed by Nuclear Power Plant in Bulgaria at Different Parts of Turkey.

Degree	Institution	Year of Graduation
3. B.Sc.	METU Environmental Engineering	1998

WORK EXPERIENCE

April 2012- : Environment and Waste Safety Division/ Nuclear Safety Department/ Turkish Atomic Energy Authority, Ankara, Turkey.
Division Head: This position deals with regulating environmental and radiological impacts of nuclear facilities including radioactive waste management and emergency preparedness. The position involves inspection, developing regulations and review-assesment of licensing documents. Developing emergency plans for nuclear powered warships visiting Turkish Ports and developing/improving of emergency planning regulations are also worked in this Division.
April 2001- September 2006 & May 2007-April 2012: Safety of Nuclear Installations Division / Nuclear Safety Department/ Turkish Atomic Energy Authority, Ankara, Turkey.
Environmental Engineer/ Inspector: Same as above.
September 2004- 2010: Technology Department/ Turkish Atomic Energy Authority, Ankara, Turkey.
Part-time Engineer: The position deals with coordinating the activites for radiological environmental impact assessment, background radioactivity monitoring, meteorological measurement program and other meteorological surveys for nuclear power plants proposed to be built in Turkey.

September 2006- May 2007: Environmental Monitoring and Radioactive Waste Safety Division/ Radiation Health and Safety Department/ Turkish Atomic Energy Authority, Ankara, Turkey.
Division Head: The position dealt with regulating and coordinating environmental radioactivity monitoring activities for food, drinking water, soil and building materials and management of radioactive wastes resulted from usage of radioactive materials.
April-July 2006: On the job training of IAEA in Korean Institute of Nuclear Safety, South Korea

Awards:

i) Fellowship award for on-the-job-training in KINS from IAEA within the Project of TUR 09/015 in April-July 2006.
ii) II. National Environmental Pollution Control Symposium, 2003, Ankara /The best poster award, “A Modelling Study For the Health Risk Posed by NPP in Bulgaria at Different Parts of Turkey”**.**
iii) Mediterranean Scientific Association MESAEP of Environmental Protection, 2003, Antalya/ The best poster award, “A Modelling Study For the Health Risk Posed by NPP in Bulgaria at Different Parts of Turkey”.

Publications:

i)“Development of a Numerical Model to Calculate Radiological Consequences of Nuclear Accidents”, full paper presented at and published in the proceedings of a refereed Conference regularly held by an International Organisation, Istanbul Technical University “Air Quality Management At Urban, Regional and Global Scales, 4th International Symposium and IUAPPA Regional Conference”, 10-13 September 2012, (APM.3.1.17)
ii)“A Modelling Study For the Health Risk Posed by NPP in Bulgaria at Different Parts of Turkey”, Fresenius Environmental Bulletin (Vol.13, No.9, 2004, pp.879-888).

Membership:
International Atomic Energy Authority- Radioactive waste safety committee corresponding membership (2011-2013 term, WASSC)

Computer Literacy:
Operating Systems: DOS (advanced), Windows (advanced), Unix (intermediate).
Programming Languages: Visual basic (advanced)
Package Programs: Microsoft Office (advanced)

Foreign Languages:
English (full fluency)

Interest and Hobbies:
Sports, movies.