UNDERGROUND TEST AREA SUBPROJECT
PHASE I DATA ANALYSIS TASK

VOLUME VIII

RISK ASSESSMENT
DOCUMENTATION PACKAGE

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DISCLAIMER

Preface

This document represents the documentation for the Phase I Data Analysis Task performed in support of the current Regional Flow Model, Transport Model, and Risk Assessment for the Nevada Test Site Underground Test Area Subproject. Because of the size and complexity of the model area, a considerable quantity of data were collected and analyzed in support of the modeling efforts. The data analysis task was broken into eight subtasks, and descriptions of the subtask activities are contained in the following eight volumes that comprise the Phase I Data Analysis Documentation.

- Volume I: Regional Geologic Model Documentation Package
- Volume II: Potentiometric Data Documentation Package
- Volume III: Groundwater Recharge and Discharge Data Documentation Package
- Volume IV: Hydrologic Parameter Data Documentation Package
- Volume V: Transport Parameter and Source Term Data Documentation Package
- Volume VI: Groundwater Flow Model Documentation Package
- Volume VII: Tritium Transport Model Documentation Package
- Volume VIII: Risk Assessment Documentation Package

Each of the volumes details the results of one or two related subtasks. A summary review of project data and results will be contained in the Phase I Report (in progress).

The Underground Test Area Subproject Phase I Data Analysis Task was led by IT Corporation; Tetra Tech, Inc.; GeoTrans, Inc.; and Daniel B. Stephens Corporation. The task could not have been completed without the cooperative efforts of many other participants involved in work at the Nevada Test Site. Their organizations are listed in alphabetical order:

- Bechtel Nevada
- Desert Research Institute
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- Raytheon Services Nevada
- U.S. Geological Survey - Geologic Division
- U.S. Geological Survey - Water Resources Division
- U.S. Geological Survey - Yucca Mountain Project

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List of Acronyms and Abbreviations

AIHC	American Industrial Health Council
ASTM	American Society of Testing Materials
BECAMP	Basic Environmental Compliance and Monitoring Program
BLM	U.S. Bureau of Land Management
Bq	Becquerel
°C	Degree(s) Celsius
CAS	Corrective Action Site(s)
CAU	Corrective Action Unit(s)
CDFG	California Department of Fish and Game
cells/g	Cells per gram
CFR	*Code of Federal Regulations*
Ci	Curie(s)
Ci/kg	Curie(s) per kilogram
Ci/L	Curie(s) per liter
cm	Centimeter(s)
CNHD	California Natural Heritage Division
COPC	Constituents of potential concern
CRAVE	Carcinogenic Risk Assessment Verification Endeavor
CSM	Conceptual Site Model
d	Day(s)
d/kg	Day(s) per kilogram
d/L	Day(s) per liter
d/wk	Day(s) per week
d/yr	Day(s) per year
DCF	Dose conversion factor
DDE_F	Data Documentation Evaluation Flags
DIF	Data Information Form
DNA	Deoxyribonucleic acid
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency

List of Acronyms and Abbreviations (Continued)

ER	Environmental Restoration
ERDBMS	Environmental Restoration Data Base Management System
ERP	Environmental Restoration Program
°F	Degree(s) Fahrenheit
FFACO	*Federal Facility Agreement and Consent Order*
ft	Foot (feet)
ft^3/s	Cubic foot (feet) per second
FWS	U.S. Fish and Wildlife Service
g	Gram(s)
g/cm^3	Gram(s) per cubic centimeter(s)
g/d	Gram(s) per day
g/L	Gram(s) per liter
g/m^2	Gram(s) per square meter
g/m^3	Gram(s) per cubic meter
Gy	Gray
HEAST	Health Effects Assessment Summary Tables
h/d	Hour(s) per day
HTO	Tritium oxide
h/yr	Hour(s) per year
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiation Protection
in.	Inch(es)
INEL	Idaho National Engineering Laboratory
IRIS	Integrated Risk Information System
IT	IT Corporation
J	Joule(s)
keV	Kiloelectron volts
kg	Kilogram(s)
kg/d	Kilogram(s) per day
km	Kilometer(s)
km^2	Square kilometer(s)
km/hr	Kilometer(s) per hour
L	Liter(s)

List of Acronyms and Abbreviations (Continued)

L/d	Liter(s) per day
L/s	Liter(s) per second
lb	Pound(s)
L/m^3	Liter(s) per cubic meter
LNT	Linear no-threshold
m	Meter(s)
m^3	Cubic meter(s)
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MeV	Megaelectron volt(s)
MeV/dis	Megaelectron volts/disintegration
m/s	Meter(s) per second
m^2	Square meter(s)
m^3/d	Cubic meter(s) per day
m^3/s	Cubic meter(s) per second
m^3/h	Cubic meter(s) per hour
m^3/kg	Cubic meter(s) per kilogram
m/yr	Meter(s) per year
mi	Mile(s)
mi^2	Square mile(s)
mi/hr	Mile(s) per hour
min	Minute(s)
min/yr	Minute(s) per year
mm	Millimeter(s)
mrem	Millirem(s)
mrem/yr	Millirem(s) per year
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection and Measurements
NDDB	Natural Diversity Data Base
NOAA	National Oceanic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NTS	Nevada Test Site
NTS EIS	Nevada Test Site Environmental Impact Statement

List of Acronyms and Abbreviations (Continued)

NWIS	National Water Information System
OBT	Organically bound tritium
pCi	PicoCurie(s)
pCi/cm^3	PicoCuri(s) per cubic centimeter
pCi/g	PicoCurie(s) per gram
pCi/L	PicoCurie(s) per liter
pCi/m^3	PicoCurie(s) per cubic meter(s)
pCi/min	PicoCurie(s) per minute
Q	Quality factor
QA	Quality Assurance
rad/d	Radiation per day
Rfc	Reference Concentration
Rfd	Reference Dose
RME	Reasonable Maximum Exposure
RWMS	Radioactive Waste Management Site
Sv	Sievert
TCI	Total cancer incidence
UGTA	Underground Test Area
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USGS	U.S. Geological Survey
w/yr	Week(s) per year
WWF	World Wilflife Fund
yr	Year(s)
μm	Micrometer(s)
$\mu Gy\text{-}h^{-1}$	Microgray per hour

1.0 Introduction

The Nevada Test Site (NTS), located in Nye County in southern Nevada, was the location of 908 nuclear detonations conducted in shafts and tunnels between 1951 and 1992. About one-third of these nuclear underground detonations were conducted near or below the water table (Duncan, 1993). As an unavoidable consequence of these testing activities, radionuclides have been introduced into the subsurface environment, impacting groundwater. The U.S. Department of Energy, Nevada Operations Office (DOE/NV) has been in the process of investigating the effects of these underground nuclear detonations as part of the Underground Test Area (UGTA) Subproject. Descriptions of the project, the data analysis task, and the Risk Assessment Subtask are briefly discussed.

1.1 Subproject Description

This subsection includes descriptions of the purpose, scope, objectives, strategy, and organization of the UGTA Subproject. The documentation that supports this effort is outlined in Section 1.2.5 of this report.

1.1.1 Subproject Purpose and Scope

The purpose of the subproject is to collect data and perform technical evaluations to support decisions about the corrective actions necessary to ensure that the weapons testing areas do not pose a significant risk to human health and the environment.

The scope of the UGTA Subproject includes the following activities:

- New and existing data collection and evaluation
- Quantification of risk to human health and the environment
- Selection of the corrective actions to reduce risk from the sites
- Implementation of corrective actions and closure of the testing areas

1.1.2 Subproject Objectives

The UGTA Subproject objectives are prerequisites to generating the necessary end products to complete the subproject. The objectives provide the framework for subproject strategy. The subproject definition establishes the starting point, and the objectives focus on the end products.

The overall objective of the UGTA Subproject is to evaluate the effects of the weapons testing areas on groundwater and to identify and implement the appropriate corrective actions. This objective ensures that risks to human health and the environment from impacted groundwater are within protective levels.

Meeting the overall objective requires that several specific project objectives be achieved:

- Effectively plan and scope the UGTA Subproject so that the necessary data are properly collected and relevant evaluations are properly performed.
- Prepare UGTA Subproject plans as guidance and information tools for efficiently conducting the subproject.
- Develop credible predictions of contaminant fate and transport.
- Quantify the risk to human health and the environment, in the absence of any present or future remedial action, to an acceptable level of uncertainty.
- Evaluate an appropriate range of remedial technologies applicable to the various contaminants and impacted media.
- Select appropriate corrective action alternatives.
- Implement selected corrective actions.
- Close the underground test areas.

1.1.3 Subproject Strategy

The Nevada Division of Environmental Protection regulates U.S. Department of Energy' s (DOE) Nevada corrective actions through the *Federal Facility Agreement and Consent Order* (FFACO, 1996). Appendix VI of this agreement, "The Corrective Action Strategy," describes the processes that will be used to complete the corrective actions, including those in the UGTA Subproject. The individual sites covered by the agreement are known as Corrective Action Sites (CASs), and they are grouped into Corrective Action Units (CAUs). The UGTA Subproject comprises six CAUs, generally reflecting the geographic locations and geologic and hydrologic environments of the weapons testing areas.

1.1.4 Subproject Organization

Because of the complexity of the problem at hand, the UGTA scope was separated into two major phases. Phase I project activities have focused on a regional investigation. During Phase II, several localized investigations focusing on the CAUs will be conducted.

Phase I has consisted of existing data assessment, groundwater flow and solute transport modeling, and a preliminary risk assessment which has been a key portion of the data assessment activities. The risk assessment has been designed to determine if there is an imminent risk to human health and the environment and to provide input to a value-of-information analysis that will identify and prioritize potential data needs. The results of Phase I will be directly used in

developing the work scope for the weapons testing areas and in implementing Phase II. Further information on the Phase I data analysis task is provided in the following subsection.

1.2 Phase I Data Analysis Task Description

This subsection includes a more detailed description of the purpose and scope, objectives, approach, and data requirements and organization of the UGTA Data Analysis Task.

1.2.1 Task Purpose and Scope

The primary purpose of the Data Analysis Task is to compile and analyze existing, as well as new, data. During Phase I, the focus of this analysis task has been a regional investigation. The Phase I Data Analysis Task scope of work includes the evaluation of regional groundwater flow conditions, the transport of tritium from the weapons testing areas, and the determination of the presence or absence of imminent risk to human health and the environment.

1.2.2 Task Objectives

The following were the objectives of the Phase I Data Analysis Task:

- Evaluate the regional groundwater flow conditions using a groundwater flow model.
- Evaluate the transport of tritium in groundwater using a groundwater transport model.
- Develop a preliminary assessment of risk to human health and the environment from the weapons testing areas.

1.2.3 Task Approach

The approach for the Phase I Data Analysis Task has included the following steps:

- Selection of a regional groundwater flow system large enough to encompass the NTS
- Selection of an area of investigation large enough to include the selected regional groundwater flow system
- Collection and analysis of data
- Simulation of regional groundwater flow with a three-dimensional numerical code
- Definition of the major flow paths from the weapons testing areas using a particle-tracking code

- Simulation of the transport of tritium using a numerical, one-dimensional transport code
- Calculations of risk to humans and the environment from exposure to tritiated groundwater

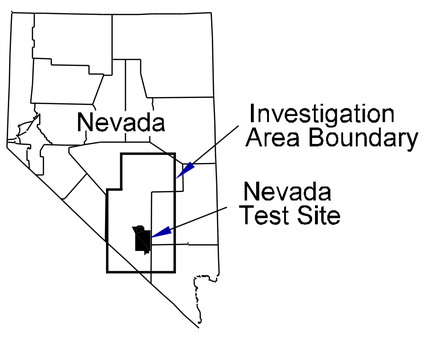
The NTS regional groundwater flow system (Figure 1-1), which fully encompasses the groundwater flow system underlying the NTS, was selected for this investigation; however, the boundary of this groundwater flow system has not been well defined in some areas. The flow system boundary defined by Waddell et al. (1984) was evaluated at the start of this investigation and is shown on Figure 1-1. The selected area of investigation had to be large enough to allow for a reevaluation and potential expansion of the groundwater flow system boundary. This area covers a large part of Southern Nevada and part of Inyo County in eastern California. The area extends from Death Valley, north to Antelope Valley, and from the Palmetto Mountains east to the Sheep Range, extending over an area of 80,650 square kilometers (31,140 square miles).

Data collection and analysis activities are dictated by the type of data needed. Data types and their methods of analysis are, in turn, dictated by the modeling approach and will not be discussed in this section; however, the documentation of necessary data types and the methods of analysis are discussed in the preceding volumes of this documentation.

The computer code selected to simulate groundwater flow is MODFLOW (McDonald and Harbaugh, 1988). This code was developed by the U.S. Geological Survey (USGS) for the numerical simulation of fully three-dimensional saturated groundwater flow in porous media; and it was also designed to simulate flow under both steady-state and transient conditions. The code will also be used to simulate flow in fractured media by invoking an equivalent porous media assumption. This assumption implies that, at the scale of the model, the hydraulic behavior of fractured geologic units is analogous to that of porous media.

The code selected to simulate pathlines is MODPATH (Pollock, 1989). This code was developed by the USGS to compute and display three-dimensional pathlines based on results from steady-state simulations from MODFLOW (McDonald and Harbaugh, 1988).

The program uses information on layer geometry, boundary conditions, and flux rates to calculate the velocities and positions of particles at different times. MODPATH was used to compute and display pathlines originating from individual underground nuclear testing locations located throughout the weapons testing areas. MODPATH also provides Darcy velocity distributions along the pathlines, which are required by the transport code.



SCALE

0 5 10 15 20 30 40 KILOMETERS

0 5 10 20 30 MILES

0 50,000 100,000 150,000 FEET

NOTE;
Metric coordinate system is Universal Transverse Mercator (UTM), Zone 11.
100,000-foot grid represents Nevada State Planar Coordinate System,
Central Zone, 1927 North American Datum.
North Latitude and West Longitude are displayed in decimal degrees.

LEGEND

PLAYAS
MOUNTAIN RANGES
TOWNS AND CITIES
HIGHWAYS
COUNTY BOUNDARIES
NEVADA-CALIFORNIA STATE LINE
NTS REGION GROUNDWATER - FLOW SYSTEM BOUNDARY

FIGURE 1-1
INVESTIGATION AREA LOCATION MAP

The code used to simulate contaminant transport is MC-TRANS (IT, 1995), and it was developed specifically for this subproject. This finite-element, one-dimensional, radionuclide transport model is capable of simulating advection in a dual-porosity, fractured system with dispersion, sorption, and first-order decay. The code was used to simulate the concentrations of tritium downgradient from selected nuclear test sites under the "no-action alternative." The code was used in the stochastic mode to evaluate the uncertainties associated with the predicted tritium concentrations.

The code used to estimate human health risk from exposure to tritium-contaminated groundwater is GW-RISK (this package), also developed specifically for this subproject. The code calculates impacts from radiological exposures including intake, dose, and risk; it uses factors derived from U.S. Department of Energy (DOE, 1993), International Commission on Radiation Protection (ICRP, 1991), and U.S. Environmental Protection Agency (EPA) guidance (EPA, 1989a, EPA 1989b; and EPA, 1991). The code uses tritium concentrations simulated by MC-TRANS (IT, 1995) as input for three of the most conservative predicted pathlines. The ecological risk assessment determines tritium concentrations below which no adverse effects to ecological receptors should be expected. These concentrations were compared with measured and modeled tritium concentrations in surface water and groundwater. Although no formal guidance exists on how to assess ecological risks associated with exposure to radionuclides, the general format suggested in the EPA *Framework* document (EPA, 1992) was used in conjunction with published radiation dose models (Baker and Soldat, 1992; Blaylock et al., 1993). Both human and ecological risk assessments included examination of data, exposure assessment, toxicity assessment, risk evaluation, and evaluation of uncertainties.

1.2.4 Task Data Requirements and Organization

Task data requirements and organization are briefly described in this section. Data required to achieve the objectives of the Phase I data analysis are as follows:

- Geologic data for regional groundwater flow and transport modeling
- Hydrologic data for regional groundwater flow modeling
- Transport parameter and tritium source data for Tritium transport modeling
- Risk-related data for assessment of risk to human health and the environment

MODFLOW (McDonald and Harbaugh, 1988) data requirements include hydrogeologic framework data, potentiometric data, hydraulic conductivity/transmissivity data, and groundwater recharge and discharge data. Data needs also include estimates of the uncertainties that are used to define the input variable bounds and the output variable target ranges for use in the model calibration process. MODPATH data requirements are MODFLOW data and porosity data. In addition to the Darcy velocities calculated by MODPATH, the transport model

(MC-TRANS) requires transport parameter data including bulk and fracture porosity, dispersion, and tritium matrix diffusion data. Data for the tritium source needed for the transport model include the tritium source initial spatial extent and concentration. Data needed for the risk assessment include the peak tritium concentration generated by the transport model from the flowpath at each receptor location. In addition, exposure scenario, tritium dosimetry, and tritium detriment and risk data are required.

The data analysis task was organized into several subtasks based on the approach and the major types of data needs. Data needs of the flow model were fulfilled under four subtasks: Geologic Model, Potentiometric Data, Groundwater Recharge and Discharge Data, and Hydrologic Parameter Data. Porosity data are needed by both MODPATH and MC-TRANS and were collected, together with data on dispersion and matrix diffusion, under the Transport Parameter Subtask. Data needed to define the source term were collected and analyzed under the Source Term Subtask. Data needed for risk assessment were collected and analyzed under the Risk Assessment Subtask.

1.2.5 Task Documentation

Work performed under the data analysis task is documented in the following eight volumes:

- Volume I - *Geologic Model Documentation Package* (IT, 1996a)
- Volume II - *Potentiometric Data Documentation Package* (IT, 1996b)
- Volume III - *Groundwater Recharge and Discharge Data Documentation Package* (IT, 1996c)
- Volume IV - *Hydrologic Parameter Data Documentation Package* (IT, 1996d)
- Volume V - *Transport Parameter and Source Term Data Documentation Package* (IT, 1996e)
- Volume VI - *Groundwater Flow Model Documentation Package* (IT, 1996f)
- Volume VII - *Tritium Transport Model Documentation Package* (IT, 1996g)
- Volume VIII - *Risk Assessment Documentation Package* (this package)

A separate documentation package was not prepared for the Source Term Subtask; however, results of this subtask are reported in Volume V of the task documentation.

The documentation packages are meant to fulfill several subproject needs. The first five packages serve as a repository of available and pertinent data collected for possible inclusion into the modeling process. There is little relationship between these five packages; instead, they are directly related to Volumes VI (Groundwater Flow) and VII (Tritium Transport), the packages which document the flow and transport modeling process and results. Volume VIII, Risk Assessment, is most directly related to Volume VII (Tritium Transport). Concentrations of tritium at specific locations and times required by the risk assessment are provided by the transport model. Figure 1-2 illustrates how information from each of the packages was used and how the packages related to each other.

A second subproject need was to centralize the required information in order to have it readily available for a highly technical review of the modeling process. The intended audience of these eight documents is the technical reviewer. A summary report of the entire project is contained in the *Regional Groundwater Flow and Tritium Transport Modeling and Risk Assessment of the Underground Test Area, Nevada Test Site, Nevada* (DOE, in press). It contains information related to the regulatory and risk management issues. This document is intended to serve as the primary subproject summary that reaches a broader audience.

1.3 Risk Assessment Subtask Description

The Risk Assessment Subtask assessed the dose risks to human health and the dose to ecological receptors that would result from exposure to groundwater contaminated with tritium as a result of the DOE' s underground nuclear testing program. This study was limited to the evaluation of tritium as a contaminant in the groundwater. The analyses were intended to be conservative and bounding for tritium in groundwater, but any effects from other contaminants were not included, and other sources of contamination or risk were not evaluated. Risks due to other contaminants will be considered at the CAU level and are out of the scope of this assessment. The objective of this assessment is to confine the boundaries around designated CAUs that delineate areas containing groundwater that may be unsafe for domestic or municipal use.

1.3.1 Human Health Risk Assessment

The human health portion of the risk assessment examined six human exposure scenarios and two receptors (Table 1-1). For each scenario, the tritium exposure mechanisms, intake, resultant doses, and risk to adults and children were evaluated. The likelihood of a specific land use or combination of land uses was not considered in this assessment (i.e., all land uses were assumed to occur with equal probability).

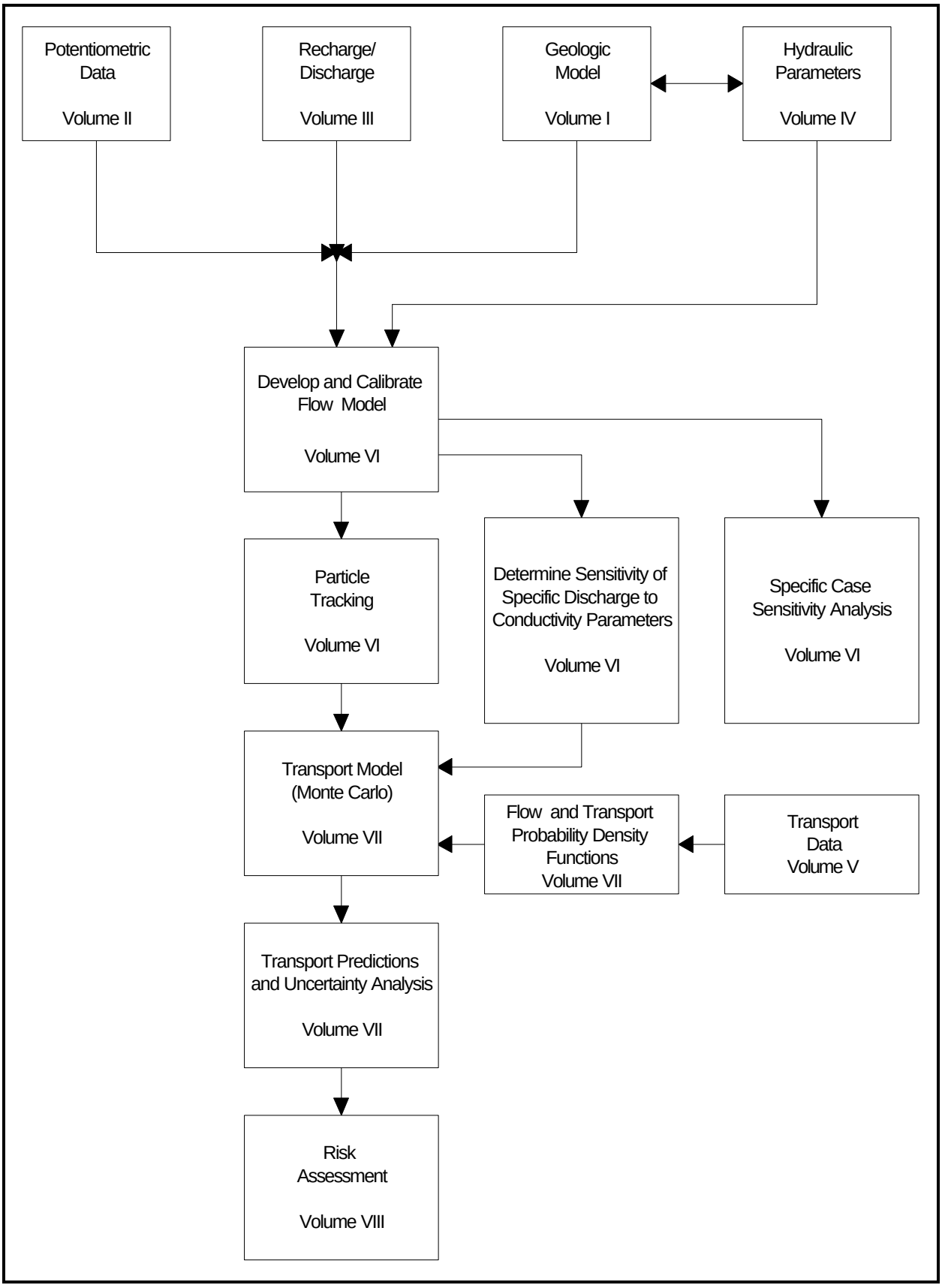


Figure 1-2
Data Utilization in Phase I Modeling

Table 1-1
Scenarios and Receptors Considered in the
UGTA Human Health Risk Assessment

Scenario Type	Receptor
Agricultural	Adults/Children
Industrial	Adults
Mining	Adults
Recreational	Adults/Children
Residential	Adults/Children
Tourism	Adults/Children

The human health risk assessment followed the general format of the Risk Assessment Guidance for Superfund (EPA, 1989a,b,c) combined with a rigorous uncertainty analysis. The human health risk assessment also employed site-specific parameters for exposure wherever possible and presented the model output as dose and risk. Dose output may be used to compare to DOE Order 5400.5, *Radiation Protection of the Public and the Environment* (DOE, 1993) or proposed EPA dose-based clean-up criteria. Risk output may be compared to the EPA target risk range of 10^{-6} to 10^{-4} as specified in the National Contingency Plan (NCP).

The EPA, National Council on Radiation Protection and Measurements (NCRP), ICRP, and literature values or ranges were used where site-specific information was not available. The exposure scenarios were intended to cover the range, from a dose and risk perspective, of hypothetical future land use activities without regard to any current or future planning efforts underway for the area. These results may be viewed as one of many tools available to decisionmakers in the CAU process. The tritium concentration ranges used in the exposure models represent the results of the regional modeling effort (the culmination of the UGTA Phase I, as documented in Volumes I through VII of the Data Documentation Packages). The human health risk analysis may also be used to help refine the focus of future data gathering efforts for the investigation phase of the UGTA once the project moves into the CAU-specific work scope.

1.3.2 Ecological Risk Assessment

The ecological risk assessment followed the general guidance of the *Framework for Ecological Risk Assessment* (EPA, 1992). Ecologically related resources and features within the region were discussed in an area description in Section 3.0. The problem formulation phase of the assessment

involved the review of available information in order to provide an understanding of the current extent of potential problems at the site. Information presented includes the identification of the constituent of concern, the conceptual site model, exposure pathways, and ecological endpoints.

The ecological exposure characterization identified contaminant transport and flow phenomena and specific ecological receptors and quantified exposure point concentration from both primary and secondary exposure pathways. The ecological effects characterization section discusses quantitative links between contaminant concentrations and effects on receptors. Literature reviews are the primary source of such dose-response information.

Finally, the risk characterization portion of the assessment describes potential dose to ecological receptors and populations of interest. Uncertainties associated with the estimation of dose and risk are also included in this section.

1.4 Report Organization

- Section 1.0 gives an overview of the project, Phase I data analysis task and risk assessment.

- Section 2.0 details the quality control for the data documentation, evaluation of the data quality, checking procedures, software quality assurance and standard methodologies. It describes the technical and peer review process and the corroboration of the data through the models.

- Section 3.0 describes the risk assessment concepts and methodology. It discusses the radiological effects of tritium and the exposure pathways for tritium. The analytical methods, dose, and risk methodologies are included in this section. It also presents the results and conclusions of human health risk assessment.

- Section 4.0 describes the physiography, climate, groundwater hydrology and surface hydrology for the NTS and off-site areas considered for an ecological risk assessment. The conceptual site model, selection of the constituents of potential concern, and exposure pathways are identified in this section.

2.0 Quality Control

A Quality Assurance (QA) program has been developed for all activities performed under the Environmental Restoration (ER) Project, including the UGTA Subproject. QA measures taken to control quality during the process of generating the products under the different data analysis subtasks include data documentation evaluation, data quality evaluation, checking procedures, software quality assurance, standard methodologies use, technical and peer reviews, and corroboration through the models.

2.1 Data Documentation Evaluation

During the documentation evaluation process of data, flags are assigned. The five levels of Data Documentation Evaluation Flags (DDE_F) are briefly presented below:

Level 1: Data are collected in accordance with Nevada Environmental Restoration Project (ERP) subproject quality assurance plans, approved Nevada procedures, and/or participant-specific procedures. This ranking indicates that all supporting documentation for the data is on file and is available for review by data users.

Level 2: Data are collected in accordance with approved plans and procedures as required for Level 1, with the exception that one or more documentation requirements may be deficient in some way. Examples of data documentation deficiencies may include lost or destroyed field-data collection forms or data acquired using interim or draft procedures.

Level 3: Data are collected using accepted scientific methodology (e.g., American Society of Testing Materials [ASTM], EPA methods, USGS procedures) and accompanied by supporting and corroborative documentation such as testing apparatus diagrams, field or laboratory notes, and procedures. Documents referenced to qualify submitted data under the Level 3 category are noted and described in Part II of the Data Information Form (DIF).

Level 4: Data are either collected by a participating Nevada ERP organization or another organization not associated with the Nevada ERP prior to the issuance and implementation of project-approved standard policies, procedures, or practices governing data acquisition and qualification. The methods of data collection are documented and traceable; however, the validity and prudency of data use or compliance with referenced procedures is indeterminate. Supporting documentation may or may not exist. Documentation provided to qualify submitted data under Level 4 shall be noted and described in Part II of the DIF.

Level 5: Data are obtained under unknown, undesirable, or uncertain conditions. When data documentation is unknown, any available supporting or helpful descriptions of the intended use and conditions of data capture should be described and listed in Part II of the DIF.

2.2 Data Quality Evaluation

The criteria used to evaluate the different types of required data were dependent on the type of data and the intended use of the data. Thus, various criteria were used to evaluate data quality. The general procedure assigned one or more flags to each record compiled in the database, indicating the data quality or suitability of the individual data record for the intended usage. Subtask-specific data quality evaluation procedures are described in detail in the corresponding subtask documentation package.

2.3 Checking Procedures

Various checking procedures were designed for quality control purposes. Checking procedures applicable to the UGTA data analysis subtasks include those developed for transcription of data, generation of figures, tables and logs, and performance of calculations. Data compiled by project personnel were subjected to the checking procedures before being added to the ER database. However, the bulk of the ER database is comprised of external digital databases developed by agencies external to the UGTA Subproject, mainly the National Water Information System (NWIS) data from the USGS. Internal procedures do not govern other ER database participants; therefore, their data were not subjected to the checking procedures described here.

2.4 Software Quality Assurance

Various computer codes were developed in-house to aid in the data analysis subtasks. Codes developed specifically for the UGTA Subproject were subjected to software quality assurance requirements such as validation/verification, preparation of operating manuals, and documentation of the theoretical basis for the calculations. Codes developed to load data and perform unit conversion codes used on the Environmental Restoration Database Management System (ERDBMS) were also checked.

2.5 Standard Methodologies

Only standard and widely accepted methodologies were used in the development of the interpretive products. The various methodologies used are too numerous to list here; however, they are described and referenced, where appropriate, in the sections discussing their use in the data analysis process.

2.6 Technical and Peer Reviews

The review process constitutes an important measure of product quality and was used throughout the performance of the data analysis activities. The review process consists of both technical and peer reviews. The technical review process is internal and is performed by qualified personnel.

The peer review process is intended to complement the technical review process and is usually performed by individuals who are independent of the project.

Products generated for the risk assessment were subjected to technical and peer reviews during their generation. The peer reviews were conducted during periodic meetings involving the IT Corporation (IT) risk assessors and internal and external peer review groups. Comments were recorded, evaluated, and addressed during the process of preparing this report. The comment resolutions were reviewed and approved by DOE.

2.7 Corroboration of Data through the Models

This step was completed as the groundwater flow model was calibrated. During the calibration process, interpretations were tested and modified as required. This step particularly applied to the geologic model where extensive interpretation was necessary. The geologic model was modified during the calibration of the flow model because the initial interpretations in some areas did not allow for the duplication of the observed hydraulic heads within the existing levels of uncertainties.

3.0 Human Health Risk Assessment

3.1 Overview

The human health risk assessment described in this section focuses on the radiological dose and resulting risk due to tritium contamination in the groundwater resulting from underground nuclear testing activities at three underground test sites on the NTS.

Human-health risk assessment is the quantitative process of estimating the hazards and risks associated with exposure to contaminants in the environment. Risk assessment is a multidisciplinary endeavor that requires the identification of the sequences of events (pathways) that have the potential for producing adverse health effects in one or more segments of the human population and estimates the probability that such effects will occur, based on an initial set of conditions (a scenario). The purpose of a risk assessment is to evaluate the relationship between the type and quantity of a contaminant in the environment and the effects it is expected to have on human health. The elements of a risk assessment are concerned with the identification and prediction of the following:

- Constituents of potential concern (COPCs)
- Exposure, which includes the characterization of the exposure setting, identification of potential receptors and exposure pathways, and the quantification of exposure
- Toxicity of the COPC
- Doses and risks associated with exposure to the COPC

This risk assessment addresses the requirements for radiation protection of the public and the environment in DOE Order 5400.5 (DOE, 1993b), which establishes the dose limits for members of the public from all DOE activities. The dose limits are expressed as "committed effective dose equivalents." The DOE limit is 100 mrem/yr and includes the sum of the effective dose equivalent from exposures to radiation sources external to the body and the committed effective dose equivalent from radionuclides taken into the body during the year. In addition, DOE Order 5400.5 (DOE, 1993b) establishes the policy to provide a level of protection for persons consuming water from a public drinking water supply operated by the DOE, either directly or by a DOE contractor. This level of protection should be equivalent to that provided to the public by the public community drinking water standards of 40 *Code of Federal Regulations* (CFR) Part 141, *National Interim Primary Drinking Water Regulations* (Safe Drinking Water Act) (40 CFR 141). The Safe Drinking Water Act requires that public drinking water systems shall not cause persons consuming the water to receive an effective dose equivalent greater than 4 mrem in

a year. In addition, the Safe Drinking Water Act establishes Maximum Contaminant Level Goals (MCLGs) for specific radionuclides. The MCLG established for tritium is 20,000 picoCuries per liter (pCi/L) (40 CFR 141).

The human health risk assessment, using tritium concentration distributions computed using the regional groundwater flow model, evaluates the mechanisms that enable tritium to be transported to a human receptor under various future land-use scenarios. These evaluations are performed using the GW.RISK code for exposure locations along the groundwater pathlines from their points of origin on the NTS to areas near potential off-site discharge points. The transport mechanisms involve several environmental media, including air, water, soil, and food. Once the tritium-to-human transport mechanisms are determined, the doses and the resulting risks to human health are calculated.

Because the prediction of risk is dependent upon many factors that are either not well quantified or vary unpredictably over space and time, a degree of uncertainty is associated with each step of the assessment. In this risk assessment, elements of uncertainty are described for each major phase, and uncertainty is considered in the final evaluation of risk. In addition, because a large amount of uncertainty is associated with the modeling of groundwater flow and the quantification of exposure, Monte Carlo analysis techniques have been used to quantitatively assess the effect of uncertainty in the modeling parameters on the modeling results.

3.1.1 Purpose

The purpose of this risk assessment is to provide a bounding estimate of the dose and resultant risk to human health for future land uses resulting from the release of tritium to groundwater from three underground test events at the NTS, which can be used as conservative estimates of dose and risk at other test events.

The results of the risk assessment will aid in determining the degree of action necessary to ensure short-term protection of human health and the environment at the NTS. Subsequent analysis will be performed to investigate the risk to human health for specific UGTA CAUs. This analysis will determine if the tritium concentration or dose to individuals exceeds the limits established in DOE Order 5400.5 (DOE, 1993b). In addition, this analysis computes the risk associated with each land-use scenario at every dose receptor location. Current DOE orders and current and proposed federal regulations regarding radiological contamination, largely for consistency with past radiation regulations and standard health physics practices, express radiological contamination limits in terms of annual dose or concentration rather than risk (DOE, 1993b; EPA, 1991; EPA, 1993a; EPA, 1994a). Comparisons are made between the calculated tritium concentrations and

dose and the current DOE orders and EPA regulations. This risk assessment also addresses the lifetime fatal cancer risk, lifetime cancer incidence risk, and lifetime radiation detriment; the lifetime fatal cancer and radiation detriment are compared to values based upon recommendations for protection to members of the public promulgated by the ICRP in their Publication 60 (ICRP, 1991). In addition, the lifetime risk of cancer incidence is compared to EPA cancer incidence risk requirements for feasibility studies for cleanup of Superfund hazardous waste sites.

3.1.2 Site Background

Tritium and other radionuclides were released directly to the ground by the underground detonation of nuclear devices at the NTS. The DOE/NV has initiated an UGTA groundwater corrective action investigation for the purpose of providing information to ensure the protection of human health and the environment. The NTS is currently used for a variety of government programs including defense and nondefense research and development, environmental restoration, and waste management. In the future, however, areas of the NTS may be withdrawn from DOE/NV and relinquished to the U.S. Bureau of Land Management (BLM). Under these circumstances, other land uses could be initiated, and members of the public who move onto or otherwise use former NTS lands could potentially be exposed to radiological contaminants present in the groundwater.

3.1.3 Scope

This risk assessment calculates the dose and resultant risk to potential future land users from the use of tritiated groundwater originating from three pathlines: TYBO, HOUSTON, and BOURBON. Tritium is the only radionuclide addressed because of its mobility and the mission of this study, which is to determine if there is an imminent risk to human health that needs to be addressed prior to the FFACO CAU-specific studies (which will deal with other radionuclides and metals in addition to tritium). In addition, this risk assessment performs the following tasks:

- Describes the human health risk assessment methodology
- Identifies tritium exposure scenarios associated with potential future land users
- Calculates tritium intake, dose, and risk for each scenario at each dose location.

This assessment is based on six proposed land-use scenarios that could occur as a result of lands being withdrawn from the NTS and given over for public use. The specific land uses considered were developed from input from stakeholder groups such as the Community Advisory Board. The Community Advisory Board requested that each land use be considered independently so as not to assign a subjective probability of each land use that could bias the results. Each of these scenarios was evaluated for its impacts on human health, and for each scenario, the tritium exposure mechanisms, intake, resultant dose, and risk to human health were evaluated. The

future land uses evaluated in this assessment are discussed in greater detail in the exposure assessment in Section 3.3.

Some future NTS land uses are more probable than others, and the decision to designate a specific land use in one area may exclude or significantly limit the extent of other land uses in that area. For example, an industrial or mining land use could require such enormous quantities of groundwater that their implementation would exclude agricultural uses of the land in that area. In addition, some land uses would be excluded from areas of the NTS due to the topography and/or climate. For example, it is highly unlikely that agricultural land uses would occur on the mesas in Areas 19 or 20 of the NTS. In this assessment, however, the probability of occurrence or location of a land use was considered to be equal for all land uses, and the likelihood for a specific land use or combination of land uses was not considered in the evaluation of risk.

3.1.4 Limitations of the Study

The primary limitations of this study lie in the uncertainties associated with the transport model over a great distance. The subsurface features of the land area addressed are not well understood, and this influences the transport model profoundly. The following conditions represent the major limitations of this study:

- Sampling data are lacking for the majority of the land area
- Model uncertainty in the fate and transport model is not quantified
- Land-use assumptions are likely to be overly conservative during the timeframe evaluated

3.1.5 Organization of the Human Health Risk Assessment

The human health risk assessment is divided into four main sections. Section 3.2 describes the identification of the chemicals of potential concern. Section 3.3 describes the exposure assessment. Section 3.4 provides the toxicity assessment for the COPC. Section 3.5 presents the characterization of risk for each of the land-use scenarios and the analysis of uncertainty associated with the risk characterization. Section 3.6 presents the conclusions of the human health risk assessment.

3.2 Identification of the Constituents of Potential Concern

The underground detonation of nuclear devices at the NTS has resulted in the release of a wide variety of radionuclides to the ground, including tritium. Essentially all of the tritium released from this testing has formed water, either by oxidation or exchange (Stead, 1963). In this form, tritium moves and behaves, both chemically and physically, as water in the groundwater system. Historically, investigators have encountered tritium in deep wells located in the vicinity of underground detonations. The concentration of tritium in the groundwater presently exceeds that

of fission and activation product radionuclides by five orders of magnitude or more and that of transuranic radionuclides by seven to eight orders of magnitude (Borg et al., 1976; Buddemeier, 1988; and Erikson, 1991). In addition, nearly all of the fission and activation products and all of the transuranics are significantly less mobile in the underground environment than tritium (Smith, 1993, and Smith et al., 1995). The dose and concomitant risk from an intake of tritium is approximately three orders of magnitude less than an equal intake of long-lived fission or activation products and five orders of magnitude less than that of transuranics (Eckerman et al., 1988). The present state of knowledge on the UGTA hydrological source terms suggests that, for the near term, tritium represents the radionuclide presenting the most significant risk (Smith et al., 1995). For this reason, tritium is the sole COPC evaluated in this risk assessment. The Nevada Department of Conservation and Natural Resources Division of Environmental Protection has established a groundwater Maximum Contaminant Level (MCL) of 20,000 pCi/L for public drinking water supplies. The state MCL is identical to the dose-based federal MCL specified in the Safe Drinking Water Act (40 CFR 141). The DOE has also adopted the requirements of the Safe Drinking Water Act by reference in DOE Order 5400.5 (DOE, 1993b).

3.3 Exposure Assessment

This section characterizes the exposure setting and identifies potentially exposed human populations on site and off site. It also identifies exposure pathways, describes the Monte Carlo analysis used to derive exposure point concentrations, and quantifies exposure to tritium. The overall purpose of this exposure assessment is to estimate the magnitude of the dose to human receptors due to exposure to tritium associated with past underground testing activities.

3.3.1 Characterization of Exposure Setting

General physical characteristics of the NTS UGTA and associated environs are briefly described in this section.

3.3.1.1 Surface Features

The NTS environment is characterized by desert valley and Great Basin mountain terrain and topography, climate, flora, and fauna typical of the Great Basin deserts of the southwest. Restricted access and extended wind transport times are notable features of the remote location of the NTS and adjacent U.S. Air Force lands. Also characteristic of this region are the great depths to slow-moving groundwater and the fact that there is little to no surface water present on site. The location of the NTS is shown in Figure 1-1.

The topography of the NTS is typical of much of the Basin and Range physiographic province of Nevada, Arizona, and Utah. North-south-trending mountain ranges are separated by broad, flat-floored, gently sloping valleys. Elevations range from about 910 meters (m) (3,000 feet [ft]) above mean sea level in the south and east to 2,100 m (6,900 ft) in the areas to the north and west. The slopes on the upland surfaces are steep and dissected, whereas the slopes on the lower surfaces are gentle and alleviated with rock debris from the adjacent highlands (DOE, 1992a).

The principal effect on the terrain from nuclear testing has been the creation of numerous dish-shaped surface subsidence craters, particularly in Yucca Flat. Most underground nuclear tests conducted in vertical shafts produced surface subsidence craters when the overburden above a nuclear event cavity collapsed and formed a rubble chimney to the surface. A few craters have been formed as a result of the tests conducted on or near the surface during atmospheric testing or by shallow depth-of-burial cratering experiments (DOE, 1992a).

3.3.1.2 Climate

Precipitation on the NTS is low; runoff is intermittent, and the majority of the active testing areas on the NTS drain into closed basins. Annual precipitation in southern Nevada is very light and depends largely upon elevation. For example, the mesas in the northwest portion of the NTS receive an average annual precipitation of 23 centimeters (cm) (5.9 inches [in.]), which includes winter snow accumulations (DOE, 1992a). The lower elevations receive approximately 15 cm (3.8 in.) of precipitation annually, with occasional snow accumulations lasting only a matter of days (DOE, 1992a).

Precipitation usually falls in isolated showers and in varying amounts. Summer precipitation occurs mainly in July and August, when intense heating of the ground below moist air masses (transported northward from the tropical Pacific Ocean through the Gulf of California and into the desert southwest) triggers thunderstorm development. Occasionally, tropical storms will move northeastward from the west coast of Mexico, bringing widespread heavy precipitation to southern Nevada during September and/or October (DOE, 1992a). The average daily maximum/minimum temperatures at an elevation of 2,000 m (6,600 ft) above mean sea level in Area 20 on Pahute Mesa are 4.4 to -2.2 degrees Celcius (°C) (40 to 28 degrees Fahrenheit [°F]) in January and 26.7 to 16.7 ºC (80 to 62°F) in July. In Area 6 (Yucca Flat, 1,200 m [3,900 ft] above mean sea level), the average daily maximum/minimum temperatures are 10.6 to 6.1 °C (51 to 43°F) in January and 35.6 to 13.9 °C (96 to 57°F) in July (DOE, 1992a).

The average windspeed at the NTS is 3.4 meters per second (m/s) and was derived from hourly meteorological measurements of windspeed and direction obtained from stations located on West Pahute Mesa, Yucca Flat, and Frenchman Flat (Soule, 1995 and 1996).

3.3.1.3 Biotic Environments

Locations on and off the NTS are arid environments. Detailed descriptions of the biotic environment (including vegetation, mammals, birds, reptiles, and microorganisms; with emphasis on aquatic and semi-aquatic species of special concern) are found in Chapter 4.0.

3.3.1.4 Groundwater Hydrology

The area treated in the geologic model subtask encompasses the NTS regional groundwater flow system which incorporates a large portion of southern Nevada and some of Inyo County, California. As described in Section 2.0 of Volume I (IT, 1996a), the model area centers around the NTS and ranges from Death Valley to the Pahranagat Valley and from the Sheep Range to Scotty's Junction. The area of investigation is approximately 28,000 square kilometers (km^2) (11,500 square miles [mi^2]).

On a regional scale, groundwater flows from northern recharge areas south and southwest across the area. Discharge occurs along a spring lineament in Ash Meadows. Three subbasins are located within the NTS regional groundwater flow system. The subbasins, from east to west, are the Ash Meadows, Alkali Flat/Furnace Creek Ranch, and Oasis Valley subbasins. Each subbasin has unique major recharge and discharge areas. These areas, with the distribution of rock types, aquifer properties, and structural features, control the direction and rate of groundwater migration. The subbasin boundaries are well defined in some areas and questionable in others.

Groundwater in the Ash Meadows subbasin moves from northern recharge areas in the Timpahute Range vicinity through eastern NTS to Ash Meadows. Groundwater in the Alkali Flats and Furnace Creek Ranch subbasins flows from northern recharge areas in the vicinity of Gold Flat and Kawich Valley through western NTS to the Amargosa Desert. Some intersubbasin transfer between the Alkali Flat, Furnace Creek Ranch, and Ash Meadows subbasins may occur across the Eleana Formation. Groundwater in the Oasis Valley subbasin flows from northern recharge areas in the vicinity of Kawich Valley and Eastern Pahute Mesa to Oasis Valley. Both the Oasis Valley and Ash Meadows subbasins are tributary to the Alkali Flat/Furnace Creek Ranch subbasin; the terminus for all intersubbasin flow is at Death Valley, California.

Recharge for all subbasins occurs by precipitation at higher elevations and infiltration along stream courses and the playas. Regional groundwater flow is from upland recharge areas to the north and east of the NTS and southwest toward discharge areas at Ash Meadows and Death

Valley. Discharge occurs naturally as evapotranspiration, spring discharge, and underflow. Artificial discharge occurs as groundwater pumpage from drinking water supply (public and domestic), agricultural, and industrial wells. Drinking and industrial water supply wells for the NTS produce water from the carbonate, volcanic, and valley-fill aquifers. South of the NTS, private and public water supply wells are completed in the valley-fill aquifer (DOE, 1992a).

The Yucca Flat and Frenchman Flat test areas are located within the Ash Meadows groundwater subbasin. Groundwater in these areas occurs within the alluvial, volcanic, and carbonate aquifers and within the volcanic and clastic confining unit. In Yucca Flat, the depth-to-water generally ranges from 160 m (530 ft) to about 580 m (1,900 ft) below the ground surface. The tuff confining unit forms the principal volcanic aquifer and confining units beneath the water table in the eastern two-thirds of the valley. Unconfined conditions and a downward hydraulic gradient are prevalent throughout the extent of the tuff confining unit (aquitard). Groundwater within the tuff confining unit is semiperched; and as a rule, the unit acts as a confining boundary for the upper carbonate aquifer (Winograd and Thordarson, 1975).

Regional groundwater flow in Frenchman Flat occurs within the major Cenozoic and Paleozoic hydrostratigraphic units at depths ranging from 157 to 360 m (515 to 1,200 ft) below the ground surface. Shallow-perched water is found within the tuff and lava flow aquitards in the southwestern part of the valley. The water table beneath Frenchman Flat is considerably shallower and stratigraphically higher than in Yucca Flat (Winograd and Thordarson, 1975).

Pahute Mesa is thought to be part of both the Oasis Valley and Alkali Flat/Furnace Creek Ranch subbasins. The location of the interbasin boundary is uncertain. Groundwater in this area occurs in volcanic aquifers and confining units, and it is thought to move south and southwest, through Oasis Valley, Crater Flat, and Western Jackass Flats (Blankennagel and Weir, 1973). Points of discharge are thought to include the springs in Oasis Valley, Alkali Flat, and Furnace Creek. The amount of recharge to Pahute Mesa and the amount of flow to the discharge points are not accurately known. Vertical gradients within Pahute Mesa suggest that flow may be downward in the eastern portion of the mesa, but upward in the western part (IT, 1996b).

The Rainier Mesa test area, located between Yucca Flat and Pahute Mesa, is part of either the Ash Meadows or the Alkali Flat/Furnace Creek Ranch subbasin, depending upon the exact location of the subbasin boundary. Groundwater in this area occurs in the welded tuff and bedded tuff aquifer, zeolitized tuff confining unit, lower carbonate aquifer, and tuffaceous and lower clastic confining units. The volcanic aquifer and confining units support a semiperched groundwater lens. Nuclear testing at Rainier Mesa has been conducted within the tuff confining unit. Studies conducted by Thordarson (1965) indicate that the perched groundwater is moving

downward into the lower carbonate aquifer. Regional groundwater flow patterns beneath Rainier Mesa are uncertain, but may be directed either toward Yucca Flat or toward the Alkali Flat discharge area to the south (DOE, 1992a).

Depths to groundwater beneath the NTS and surrounding region vary greatly. Groundwater depths in the southern NTS range from about 10 m (33 ft) beneath upper Fortymile Wash to 157 m (515 ft) beneath Frenchman Lake (Winograd and Thordarson, 1975) (compared to more than 610 m [2,000 ft] beneath Pahute Mesa in northern NTS). In the eastern portions of the NTS, the water table generally occurs in the alluvium and volcanic rocks above the lower carbonate aquifer.

The regional groundwater system does not naturally discharge to the surface on site, but flows from springs at Ash Meadows, Oasis Valley, Alkali Flat, and Furnace Creek and discharges to municipal and private wells off site (Blankennagel and Weir, 1973; Winograd and Thordarson, 1975). Perched groundwater is found locally throughout the NTS. Nine minor springs in the eastern and northern NTS emerge from perched groundwater lenses with low discharge rates that range from approximately 0.014 to 2.2 liters per second (L/s) (4.9×10^{-4} to 7.7×10^{-2} cubic feet per second [ft^3/s]). Although the water is known to be used by wildlife, these are localized, perched groundwater springs that do not appear to be connected with the regional groundwater system. Access to the regional groundwater on the NTS is only through open boreholes, water supply wells, and pumped groundwater at surface impoundments.

A complete description and discussion of the geologic and hydrogeologic features influencing groundwater movement at NTS can be found in Volumes I through VII of the Data Documentation Packages (IT, 1996a, b, c, d, e, f, g).

3.3.1.5 Surface Water Hydrology

Topography controls the direction and flow of surface water both on and from the NTS. Five major drainages that terminate within the NTS discharge to the Amargosa River and to the Amargosa Desert, west and south of the NTS; the other six major drainages terminate in valley-bottom playas (DOE, 1992c).

Infrequent flash floods occasionally discharge from the NTS boundary, particularly from Fortymile Canyon. Few flood studies have been conducted on the NTS; there are no surface water-gauging structures. As a consequence, there are few data for flood flow estimates. A flood analysis is currently in progress for drainages from Rainier Mesa in Area 12, and one has been completed for the Radioactive Waste Material Site (RWMS) in Area 5. The RWMS study indicated potential 100-year flood flows from five Frenchman Flat watersheds ranging from

approximately 18 to 260 cubic meters per second (m^3/s) (640 to 9,180 cubic feet per second [ft^3/s]) for watershed areas, ranging from approximately 1 to 235 km^2 (0.4 to 91 mi^2). For Fortymile Canyon, there have reportedly been substantial flood flows, but no quantitative estimates have been calculated (DOE, 1992c).

Springs from perched groundwater discharge at a low rate and either infiltrate or evaporate shortly downgradient of their outflow points (DOE, 1992c).

3.3.2 Potential Receptor Identification

The intent of this section is to identify populations at or near the area of concern that may potentially be exposed to tritium. Both current and future populations are considered. No populations or individuals are currently believed to be exposed to tritium from underground test activities. There are no residential or occupational populations that have contact with groundwater (or related pathways) from any on-site wells because these wells are not currently used as a source of potable water. In addition, the long travel time of tritium from the point of detonation to groundwater to an off-site residential well in the groundwater pathline makes it unlikely that tritium has reached any of the off-site wells. This is supported by monitoring data which indicate that tritium concentrations are below MCLs. It is, however, possible that future populations could be exposed to the tritium.

Future land uses were determined from public input. Land uses were suggested by the local citizen advisory boards and through public forums. In addition, the *Final Environmental Impact Statement for the Nevada Test Site and Off-Site Locations in the State of Nevada* (DOE/NV, 1996) lists potential uses of relinquished land under Alternative 4 (alternative use of withdrawn land). The NTS Development Corporation was also consulted. Suggested land uses were consolidated under the categories listed in Table 3-1.

Table 3-1
Scenarios and Receptors Considered in the UGTA Human Health Risk Assessment

Scenario	Receptor
Agriculture	Adult/Child
Industrial	Adult
Mining	Adult
Recreation	Adult/Child
Residential	Adult/Child
Tourism	Adult/Child

The agriculture land use included cattle ranching, dairy farming, and crop farming. It is considered a low probability activity for the NTS due to the harsh climate and topography and the high cost of drilling groundwater production wells. It was evaluated in this risk assessment because agriculture activities are practiced on lands in the vicinity of the NTS and ranching was performed in the past prior to the establishment of the NTS. Individuals were assumed to be exposed to tritium during their work and non-work hours. A scenario for exposure to children for the agriculture scenario was included for comparison purposes.

The industrial land-use scenario considered such applications as laboratory and solar energy research, manufacturing, processing, and fabrication. This land use is also of low probability due to the increased cost for workers, raw materials, transportation, and lack of infrastructure support. Workers were assumed to obtain their drinking water from the site. A child receptor was not considered for this scenario because children do not participate in industrial activities.

Mining was considered to take place underground. This would result in the exposure of miners to tritiated water vapor in the air in the mines. Drinking water and 20 percent of their food were assumed to be obtained locally. A child receptor was not considered for this scenario because federal laws preclude children from mining.

The recreation scenario considered such activities as hunting, hiking, prospecting, horseback riding, off-road motorcycle, and all-wheel drive vehicle activities. All activities were assumed to occur outdoors, all drinking and cooking water was assumed to originate from the site, and 20 percent of their food was obtained locally. A scenario for exposure to children for the recreation scenario was included for comparison purposes.

Residents were assumed to be on site for all but a few weeks per year and were assumed to be engaged in vigorous, outdoor working activities for most of each day. All household water was assumed to be obtained from local wells, and 20 percent of their food would be raised using local groundwater for irrigation. A scenario for exposure to children for the residential scenario was included for comparison purposes.

Tourists were assumed to be temporary residents who use the area a few weeks a year for recreational purposes. All water and 20 percent of their food would be obtained locally. A scenario for exposure to children for the tourism scenario was included for comparison purposes.

3.3.3 Conceptual Site Model

The intent of this section is to describe the exposure pathway elements of the tritiated groundwater, the fate and transport of tritium, the method of computing the tritium concentration in groundwater at dose receptor locations, and the identification of the exposure pathways to tritium for the dose receptors. The conceptual site model describes the course the tritium takes from the source to the exposed individual. In addition, the conceptual site model is designed to link the source, locations, and types of environmental releases with population locations and activity patterns to determine the significant pathways of human exposure (EPA, 1989a).

3.3.3.1 Exposure Pathway Elements

For exposure from tritiated groundwater and the associated dose and risk to occur, complete exposure pathways must exist. Such a pathway requires the following elements (EPA, 1989a):

- A source and mechanism for release of the tritiated groundwater
- A transport or retention medium
- A point of potential human contact (exposure point)
- An exposure route at the exposure point

If any of these elements is missing, the pathway is not considered complete. The primary complete pathways to humans associated with tritium releases at UGTA are illustrated in Figure 3-1. The following paragraphs briefly discuss the exposure pathway elements.

Sources of contamination in this risk assessment are the underground nuclear tests that were conducted at the NTS. The medium of primary contamination is the tritium-contaminated groundwater. Tritium is a constituent of the nuclear devices exploded underground, and it is also created during the detonation process. At least 99.9 percent of all tritium remaining after detonation is incorporated into water molecules in the form of tritium oxide (HTO). The HTO is physically and chemically like water and will migrate with the groundwater.

Exposure points are locations of human contact with the tritiated groundwater. Such points consider human activity patterns and the location of potentially exposed individuals relative to the pathline of the tritiated groundwater. In this analysis, contact with groundwater potentially contaminated with tritium is assumed to occur as a result of occupational and residential activities in the future. Contact points for groundwater include the use of on-site and off-site wells for the agriculture, industrial, mining, recreation, residential, and tourism scenarios. In order to maintain a conservative risk methodology, all exposures to water were assumed to have the same

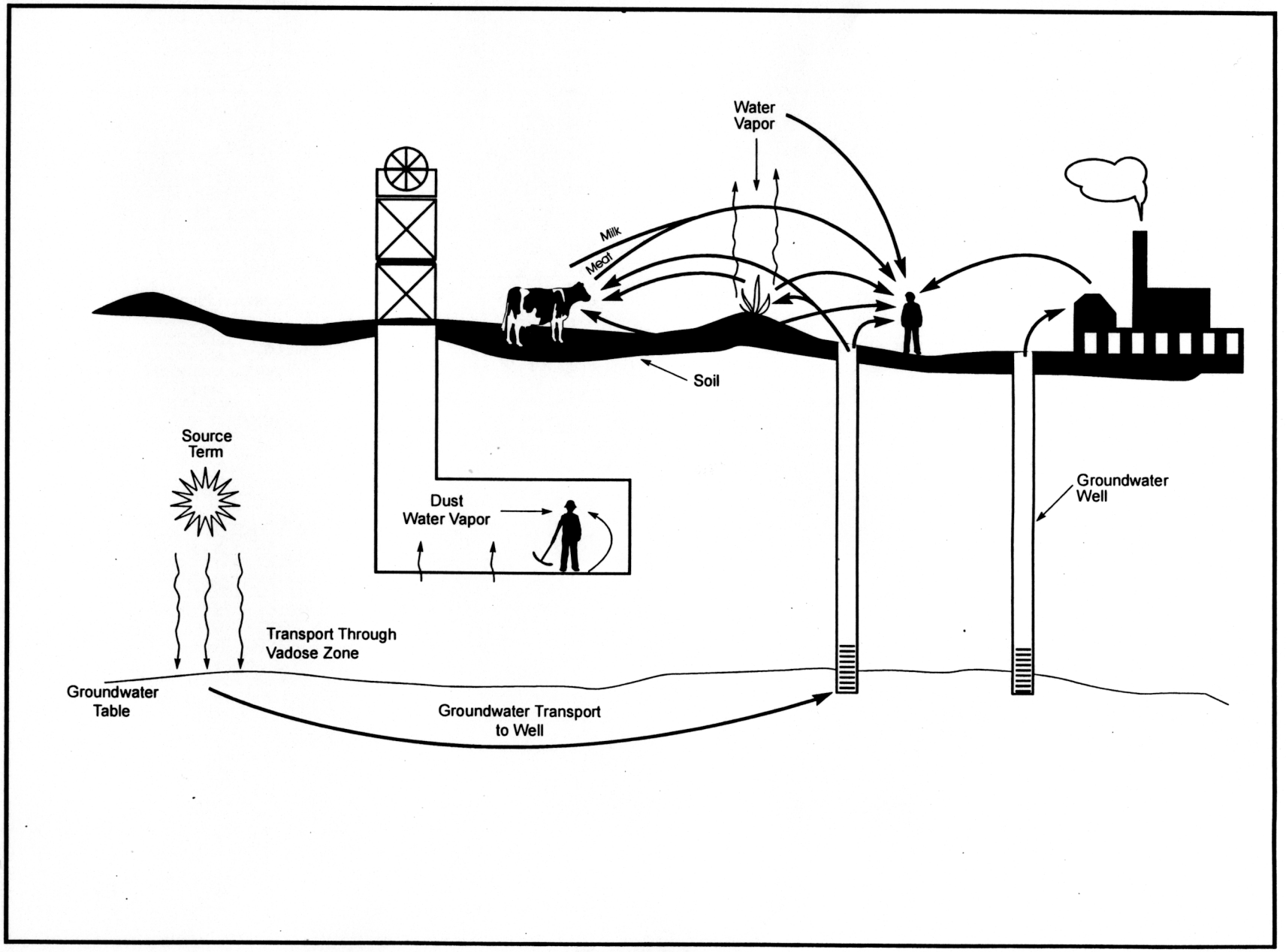


Figure 3-1
Human Health Exposure Pathways

concentration of tritium in groundwater at the location of interest. This risk assessment also considered pathways that could arise as a result of groundwater usage, such as the contamination of surface soil and air with tritium as a result of crop irrigation practices.

An exposure route is a way in which a constituent enters or comes into contact with the human body. The following are the possible exposure routes associated with the NTS UGTA:

- Inhalation
- Ingestion
- Dermal contact

Inhalation is a possible route of exposure to tritium. The assumed land use scenarios will result in tritium-contaminated groundwater evaporating into the air. The lungs have a large surface area through which tritium, just as normal water vapor, can be absorbed with little relative resistance to permeation.

Ingestion is also an effective route of absorption of tritium into the body and occurs primarily through eating and drinking. Ingestion of home-grown or cultivated vegetables, dairy products, and livestock are also potential exposure routes. Those secondary pathways are addressed below.

Dermal contact with tritium can also be a significant exposure pathway. Tritium, either as water vapor or as liquid, is capable of being absorbed through the skin. Clothing provides no protection against skin absorption (Osborne, 1966).

External exposure to radiation associated with tritium may also occur. However, because the beta particles emitted by tritium are of very low energy, they are not capable of penetrating the skin.

3.3.3.2 Fate and Transport

Analysis of the fate and transport of tritium from the BOURBON, HOUSTON, and TYBO events to on-site and off-site receptor locations was conducted using the NTS regional groundwater flow model developed specifically for this project. The geologic, groundwater flow, and tritium transport models used are described in detail in Volumes I and VI of the Data Documentation Package (IT, 1996a, b, c, d, e, f) and data specific to the models are presented in Volumes II through V (IT, 1996b, c, d, e). The tritium activity in groundwater was determined by simulating tritium transport along pathlines identified from a three-dimensional groundwater flow model. Along the one-dimensional pathlines of this model, tritium transport includes the processes of advection, dispersion, matrix diffusion, and radioactive decay. Because the values of several of

the model parameters are uncertain, a Monte Carlo approach using Latin hypercube sampling was used to define the uncertainty associated with the transport model.

Monte Carlo is a technique for modeling a real world situation in which one or more of the input parameters are either uncertain or vary in a mathematically describable way. It employs random sampling from probability distributions to assign values to the uncertain parameters in the model. The Latin hypercube technique allows various parameters to be rank correlated. The Monte Carlo technique is typically used in cases where too many parameters are uncertain or the mathematics are too complex to be solved analytically. In this case, the model that describes the transport of tritium in the environment includes dozens of parameter values that are best described by probability distributions rather than single values. The probability distributions include the normal, lognormal, exponential, or one of a number of other mathematical expressions that meet the requirements of a probability distribution function. The Monte Carlo simulation randomly selects the parameter values from the corresponding probability distributions to obtain a single model result (or realization) that is specific to that set of parameter values. This process is then repeated over a large number of trials until the probability distribution of the model result can be described.

Three underground event locations representing Yucca Flat (BOURBON), Central Pahute Mesa (HOUSTON), and Western Pahute Mesa (TYBO) were selected for transport simulations (Figure 3-2). The groundwater flow velocity along the paths originating from these three locations is greater than the velocity along paths originating from most of the surrounding test locations; therefore, the calculated tritium concentrations are significantly more conservative than average. Thus, the selected paths will portray downgradient migration of tritium to distances greater than would be expected from the majority of other test locations.

The course that the tritiated groundwater travels downgradient from a nuclear test event is defined as its pathline. Some events on the NTS were detonated above the water table; some near or below the water table. For this risk assessment, 415 pathlines from 254 events were examined. Pathlines were plotted for each event that could possibly impact the water table. If an event was determined to potentially impact the water table, a computation was performed that described up to three pathlines of the tritiated groundwater from that particular event. Pathlines were chosen for additional analysis if they resulted in tritium contamination at significantly greater than the average downgradient distance. The resulting paths chosen for the human health and ecological risk assessments were from the BOURBON, HOUSTON, and TYBO events.

DRAWING NUMBER

CHECKED BY:

APPROVED BY:

ER-20-6-1
U-20 WW
PEPATO
KASH
UE-19h
ER-20-2-1S
ER-19-1-1
UE-10j
UE-19c WW
1.0 km
5.0 km
PM-3
TYBO
HOUSTON
SARCOBATUS FLAT
(ET AREA)
10.0 km
1.0 km
ER-12-1
UE-15d WW
15.0 km
5.0 km
KANKAKEE
20.0 km
WW-8
WW-2
1.0 km
ER-20-5-1
25.0 km
10.0 km
5.0 km
ER-20-1
UE-4t
BOURBON
30.0 km
15.0 km
10.0 km
UE-16d WW
UE-1q
MICKEY/TORRIDO
35.0 km
20.0 km
ER-30-1-1
15.0 km
WW-A
ER-3-1-1
ER-3-2-1
25.0 km
20.0 km
40.0 km
WW-3
UE-6e
ER-6-1
45.0 km
30.0 km
OASIS VALLEY
(ET AREA)
35.0 km
ER-6-2
25.0 km
WW-C
50.0 km
WW-C-1
30.0 km
WW-4
WW-4A
35.0 km
40.0 km
UE-5c WW
J-13 WW
45.0 km
WW-5B
WW-5C
J-12 WW
50.0 km
WW-5A
55.0 km
60.0 km
ASH-B-1
65.0 km
70.0 km
75.0 km
80.0 km
Army 1 WW
LWS-A-1
90.0 km
MSH-C-1
95.0 km
AMARGOSA FLAT
(PETER PLAYA)
DEATH VALLEY
(ET AREA)
ASH MEADOWS (ET AREAS)
AND FRANKLIN LAKE PLAYA
(ALKALI FLAT)
FRANKLIN
LAKE PLAYA

SCALE
0 20 40 Miles
20 0 20 Kilometers

LEGEND

- Nevada Test Site
- Area Boundary
- Nellis Air Force Range
- Area of Regional Evapotranspiration
- Regional Pathline
- Wells

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Figure 3-2
Regional Flow Paths

In addition to these three events, the pathlines from events upgradient or along the pathlines of BOURBON, HOUSTON, and TYBO were evaluated. If the pathline of any other event came close to intercepting the pathlines from BOURBON, HOUSTON, or TYBO, their tritium source term was added. For example, the PEPATO and KASH events were upgradient of the TYBO event. These pathlines approach the TYBO pathline, and therefore, there is a possibility that the tritiated groundwater from them could add to the tritiated groundwater from the TYBO event. Therefore, to ensure that the calculated radiological source term is conservative and bounding, the tritium source terms from PEPATO and KASH events were added to the tritium source term of the TYBO event. For the same reasons, the tritium source terms from the KANKAKEE, MICKEY, and TORRIDO events were added to the BOURBON pathline.

The tritium concentration at selected distances downgradient from the event was calculated using the MC-TRANS contaminant-transport model computer code. At selected downgradient distances from the source, the change in concentration of tritium in groundwater with time was calculated. These calculations result in what are known as "breakthrough curves," which show the tritium concentration at a specific location as a function of time. At each location, a breakthrough curve was calculated corresponding to different sets of input parameters for each of the Latin hypercube trials. Each Latin hypercube trial results in a "realization," or a breakthrough curve, for each downgradient location. Two hundred realizations were performed for each pathline. The breakthrough curve data from all of the Monte Carlo trials are summarized in two ways for use in this risk assessment.

In the first method, the tritium concentration at each fixed location and time was recorded for each realization. These concentrations were then sorted from smallest to largest and summarized in the form of contour plots at selected percentage levels. The levels range from 0 to 100 percent and describe the percentage of realizations for which the tritium concentration was less than the corresponding concentration value. For example, if the 50 percent frequency value is at 100 pCi/L, it means that 50 percent of the Latin hypercube trials for that location and time resulted in breakthrough curves with a tritium concentration of less than 100 pCi/L. Contour plots were prepared which show the tritium concentration as a function of distance and time for selected percentage levels. The 95th percentile tritium concentration distributions for each dose receptor location were used in the risk assessment. The contour plots for the 95th percentile values for BOURBON, HOUSTON, and TYBO pathlines are shown in Figures 6-4d, 6-10d, and 6-16d, Volume VII of the Data Documentation Package, respectively (IT, 1996f). These contour plots, however, do not represent the potential range of outcomes that are important to the risk assessment.

The exposure time of the hypothetical future land user was assumed to be 30 years. To support the human health risk assessment, the tritium activity from all trials was summarized in a noncontinuous histogram for the 30-year period centered on the year when the maximum tritium concentration occurred in the contour plot at the 95 percent frequency level. However, the interval chosen was not -15 years to +15 years around the year of the maximum tritium concentration, it was -5 years to +25 years around the year of the maximum concentration. This interval was chosen because the distribution of the tritium concentration is not symmetrical, but skewed. A skewed distribution of contaminants in groundwater is typical in matrix diffusion-dominated flow systems. Choosing -5 to +25 years around the year of the maximum tritium concentration in groundwater ensured that the calculated dose and risk to a potential dose receptor would be conservative and bounding. The concentration values from each realization over the 30-year period were used to create a noncontinuous histogram of tritium concentrations for each dose location along the pathline.

The histograms are a presentation of the relative frequency of occurrence of tritium concentration in groundwater over the 30-year period surrounding the maximum tritium concentration. The histogram approximates the distribution of tritium activity at each location, resulting from inclusion of parameter uncertainty in the groundwater transport model. The histogram lists the fraction of realizations within a specific tritium concentration range. Each tritium concentration range is known as a bin, with 25 bins used in the risk assessment. The bins range from < 100 pCi/L, the bin with the minimum tritium concentration distribution, to 4.60×10^{9} to 1.00×10^{10} pCi/L, the bin with the maximum tritium concentration distribution. For instance, at a distance of 0.1 kilometers (km) (0.6 miles [mi]) from TYBO/PEPATO/KASH pathline, all of the lowest concentration bins had 0 percent of the realizations; the first bin with a positive realization was the bin representing tritium concentrations from 4.60×10^{3} to 1.00×10^{4} pCi/L, with 0.21 percent of the realizations. At this distance, the bin with the highest percent of realizations, 17.71 percent, was for 2.20×10^{6} to 4.60×10^{6} pCi/L. Each bin represents a range of tritium concentrations, whereas calculations of intake, dose, and risk require a specific tritium concentration. Therefore, the concentration with each bin was sampled by the GW.RISK code using Monte Carlo techniques. The histograms for the BOURBON/KANKAKEE/MICKEY/ TORRIDO, HOUSTON, and TYBO/PEPATO/KASH pathlines are tabulated in Table 6-1, 6-2, and 6-3 respectively in Volume VII of the Data Documentation Package (IT, 1996f). The tritium concentration data are also plotted as a function of downgradient distance for BOURBON/ KANKAKEE/MICKEY/TORRIDO, HOUSTON, and TYBO/PEPATO/KASH in Figures 6-5, 6-11, and 6-17 respectively in Volume VII of the Data Documentation Package (IT, 1996f).

Tritium groundwater distributions were defined for specific points along three groundwater pathlines (Table 3-2). These concentrations were then used as inputs to the human health model. The points in the pathlines were chosen based upon the proximity of groundwater production wells (where the currently existing land development could make the location attractive to future land users), the proximity to the NTS site boundary, or near off-site springs and seeps. The human health exposure model uses the 95th percentile of the tritium concentration at a given location to estimate dose; however, dose is reported at the 5th, 50th, and 95th percentiles of the resultant dose distribution. Tables 3-3 through 3-5 present the results of the tritium concentration modeling at the various distances from the TYBO/PEPATO/KASH, HOUSTON, and BOURBON/KANKAKEE/MICKEY/TORRIDO events, respectively. The tritium concentrations listed in the tables represent the peak concentration at the 95th percentile at each dose receptor location.

3.3.3.3 Identification of Exposure Pathways

By definition, the UGTA has only one transport medium: groundwater. Selected locations along the pathlines have been defined where hypothetical future human dose receptors may be exposed to the tritiated groundwater. This section discusses whether there is a source and transport mechanism and whether there may be an exposure route at the exposure points.

As previously discussed, tritium was assumed to be taken into the body through the following routes:

- Inhalation of tritiated water vapor
- Ingestion of tritiated water
- Ingestion of food exposed to tritiated water
- Ingestion of tritiated soil
- Ingestion of food exposed to tritiated soil
- Dermal absorption of tritiated water and water vapor

These routes of exposure were tied to land uses that are related to agriculture, industrial, mining, recreation, residential or tourism activities. The conceptual site model for these scenarios is presented in Figure 3-3. Because the receptor in each scenario is expected to be exposed through all of the same pathways as the receptors in the other scenarios (the scenarios differing only in the magnitude of exposure by each pathway), only one conceptual site model is presented. Table 3-6 summarizes the pathway selection process for this conceptual model.

For the agriculture scenario, an individual was assumed to consume drinking water from a domestic well and use this water source for all cooking and bathing activities. Water from this well was also assumed to be used as irrigation water and drinking water for livestock. Because surface soil could be contaminated with tritium as a result of irrigation with groundwater, it was

Table 3-2
Downgradient Distances for Dose Receptors

BOURBON		HOUSTON		TYBO	
kilometers	miles	kilometers	miles	kilometers	miles
0.1	0.06	0.1	0.06	0.1	0.06
1	0.6	1	0.6	1	0.6
2	1.2	2	1.2	2	1.2
3	1.9	3	1.9	2.9	1.8
4	2.5	4	2.5	3.9	2.4
5	3.1	5	3.1	4.9	3.0
7.5	4.7	6	3.7	7.3	4.5
10	6.2	7	4.3	9.8	6.1
12.5	7.8	8	5.0	12.2	7.6
15	9.3	9	5.6	14.7	9.1
17.5	10.9	10	6.2	17.1	10.6
20	12.4	15	9.3	19.6	12.2
25	15.5	20	12.4	24.5	15.2
30	18.6	25	15.5	29.4	18.3
35	21.7	30	18.6	31.8	19.8
40	24.9	35	21.7	34.3	21.3
45	28.0	40	24.9	37.1	23.1
50	31.1	45	28.0		
55	34.2				
60	37.3				
65	40.4				
70	43.5				
75	46.6				
80	49.7				
90	55.9				

Table 3-3
95th Percentile Tritium Concentration for the BOURBON Pathline

Distance from KANKAKEE		Peak Tritium Activity pCi/L
kilometers	miles	
0.1	0.06	1.53E+9
1	0.6	1.48E+8
2	1.2	5.84E+7
3	1.9	3.47E+7
4	2.5	2.01E+7
5	3.1	1.41E+7
7.5	4.7	7.43E+6
10	6.2	1.79E+8[a]
12.5	7.8	1.28E+9
15	9.3	2.69E+7
17.5	10.9	6.56E+6
20	12.4	2.39E+6
25	15.5	7.51E+5
30	18.6	1.68E+5
35	21.7	2.55E+4
40	24.9	6.62E+3
45	28.0	3.08E+3
50	31.1	7.48E+2
55	34.2	3.50E+2
60	37.3	1.86E+2
65	40.4	9.90E+1
70	43.5	4.44E+1
75	46.6	5.95E+0
80	49.7	6.08E-1
90	55.9	8.62E-1

[a]The tritium concentration increases where the MICKEY and TORRIDO event source terms contribute to the concentration in the pathline.

Table 3-4
95th Percentile Tritium Concentration Predicted for the HOUSTON Pathline

Distance from HOUSTON		**Peak Tritium Activity** pCi/L
kilometers	miles	
0.1	0.06	1.14E+9
1	0.6	1.39E+8
2	1.2	5.84E+7
3	1.9	4.01E+7
4	2.5	3.44E+7
5	3.1	2.60E+7
6	3.7	1.93E+7
7	4.3	1.44E+7
8	5.0	1.08E+7
9	5.6	7.59E+6
10	6.2	6.80E+6
15	9.3	3.51E+6
20	12.4	1.52E+6
25	15.5	5.92E+5
30	18.6	2.11E+5
35	21.7	8.89E+4
40	24.9	3.19E+4
45	28.0	7.43E-1

Table 3-5
95th Percentile Tritium Concentration Predicted for the TYBO Pathline

Distance from PEPATO		Peak Tritium Activity pCi/L
kilometers	miles	
0.1	0.06	2.27E+8
1	0.6	1.52E+9[a]
2	1.2	2.76E+8
2.9	1.8	1.41E+8
3.9	2.4	1.11E+8
4.9	3.0	8.40E+7
7.3	4.5	9.85E+7[b]
9.8	6.1	1.23E+8
12.2	7.6	5.64E+7
14.7	9.1	3.62E+7
17.1	10.6	2.46E+7
19.6	12.2	1.84E+7
24.5	15.2	1.29E+7
29.4	18.3	8.49E+6
31.8	19.8	7.34E+6
34.3	21.3	6.74E+6
37.1	23.1	6.15E+6

[a] The tritium concentration increases where the KASH event source term contributes to the concentration in the pathline.
[b] The tiritum concentration increases where the TYBO event source term contributes to the concentration in the pathline.

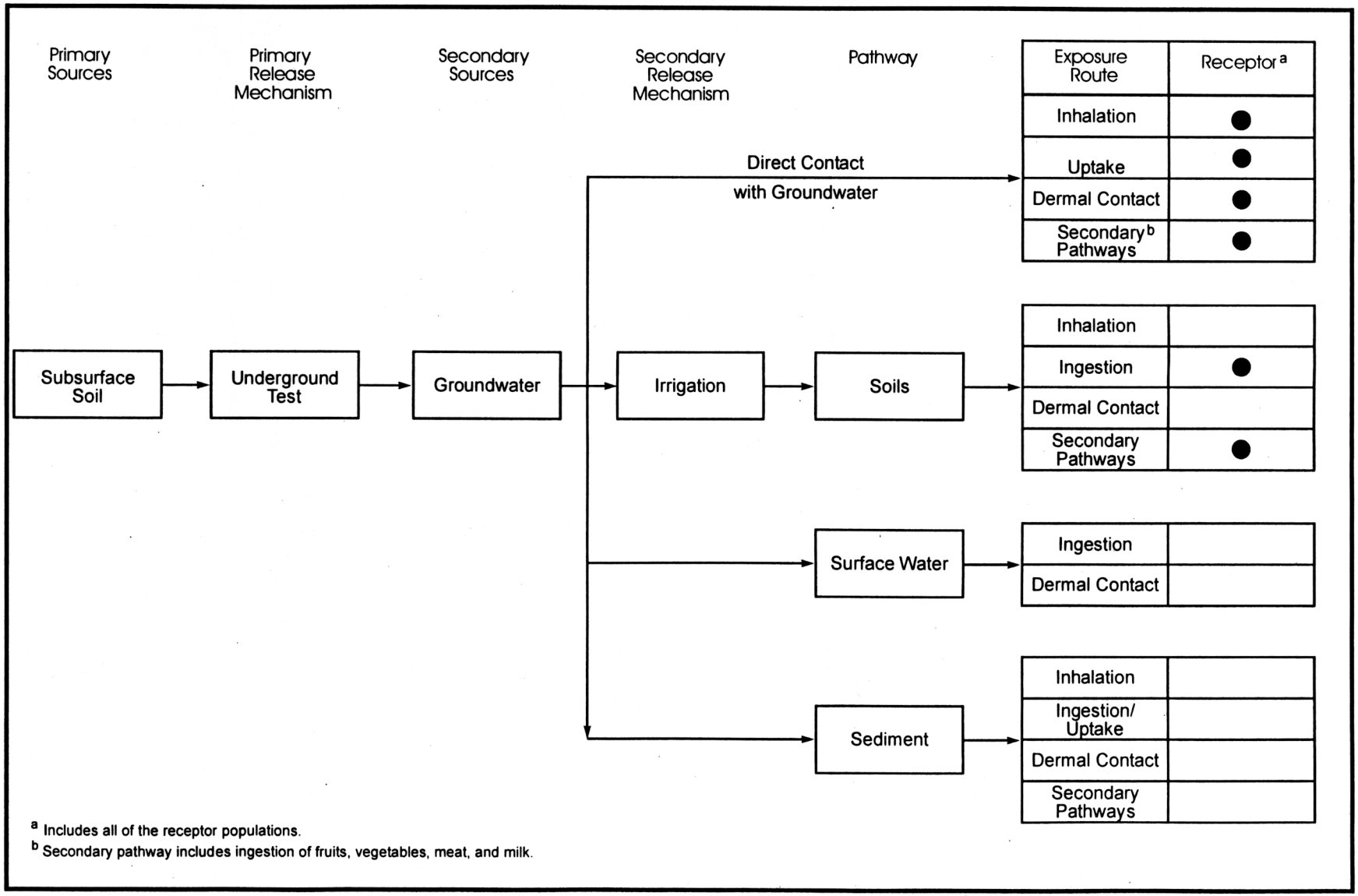

Figure 3-3
Site Conceptual Model for Future Land Use

Table 3-6
Summary of Pathways Used to Estimate Exposure

Potentially Exposed Population	Exposure Route, Medium, and Exposure Point	Pathway Selected for Evaluation?	Reasons for Selection or Exclusion
Future Land Use			
Residents[a] Industrial workers[b]	Ingestion of groundwater from local wells downgradient of the event	Yes	Residents use groundwater from local wells as drinking water.
Residents Industrial workers	Inhalation of tritium from evaporation of groundwater during home/work use	Yes	Tritium will evaporate with the groundwater, and groundwater is used by local residents.
Industrial workers	Ingestion of tritium-contaminated soil on the site	Yes	Contaminated soil is in an area potentially used by all workers.
Residents	Ingestion of tritium-contaminated soil on the site	Yes	Area could be developed in the future as a residential area. Resident is assumed to work in a dirty and dusty environment.
Residents	Ingestion of tritium that has accumulated in fish located in on-site ponds	No	Raising fish in on-site ponds is not expected in an arid environment.
Residents Industrial workers	Ingestion of tritium-contaminated food, including plants, meat, and milk	Yes	Residents and industrial workers obtain food from local farms and ranches irrigating with tritium-contaminated water.
Residents Industrial workers	Dermal absorption of tritium-contaminated water	Yes	All household and industrial water is assumed to be tritium-contaminated groundwater.

[a] Residents include the agriculture, residential, recreation, and tourism land-use exposure scenarios.
[b] Industrial workers include both mining and industrial worker land-use exposure scenarios.

assumed that the individual would also be exposed to tritium in soil via incidental ingestion. As previously mentioned, the land was assumed to be used for cattle ranching, dairy farming, and raising crops for food and animal fodder. Crops and livestock from the site would be used as food sources; therefore, a secondary route of exposure to the individual was modeled. The individual was also assumed to inhale tritium in indoor and outdoor air.

As part of the industrial scenario, groundwater usage for the industrial facility was assumed to equal 10 percent of the present groundwater production rate for the NTS. One percent of this water was assumed to be released into the building air. In addition to the inhalation of tritium, workers were assumed to obtain drinking water at the site and to use on-site shower facilities. Industrial workers were assumed to consume 20 percent of their food from local farms and dairy operations. Incidental ingestion of soil was also considered.

The mining scenario was considered to occur where workers may be exposed to tritiated water vapor. Miners were also assumed to be exposed to tritium in drinking and shower water. As in the industrial scenario, miners were also assumed to consume 20 percent of their food from local farms and dairy operations. Incidental ingestion of soil and inhalation of tritium in air were also considered viable pathways of exposure.

Individuals participating in recreational activities at the site were assumed to spend every weekend, 50 weeks per year, performing vigorous outdoor activities. A fraction of their food (20 percent) was assumed to be locally raised. In addition, drinking water and water used for cooking and bathing were assumed to be from on-site groundwater wells. This scenario also included the incidental ingestion of soil and inhalation of tritium in air.

Residents were assumed to be on site for all but a few weeks per year. They were assumed to be engaged in vigorous, outdoor working activities for most of every day. The residential exposure pathway emphasizes both primary and secondary exposure pathways. Twenty percent of the food consumed by the resident was assumed to be raised from crops grown using tritium-contaminated groundwater for irrigation, and livestock that feed on irrigated plants were assumed to be consumed by the resident. All water used for drinking, cooking, and bathing was also assumed to originate from domestic wells. Vigorous activities outdoors were assumed to occur 17 hours each day. Inhalation of tritium-contaminated air and the incidental ingestion of soil was also assumed.

Tourists were evaluated as temporary residents who would be performing residential activities 14 continuous days on site. During this period, 20 percent of all food and all water were assumed to be obtained locally. Tritiated groundwater was assumed to be the sole source of drinking, cooking, and bathing water. The scenario also included assumptions of exposure to tritium via inhalation of air and the incidental ingestion of contaminated soil.

3.3.4 Quantification of Exposure

This section defines the exposure concentrations, exposure models, input parameters, and doses to humans exposed to tritium. Risk models were designed in this assessment by coupling scenario-specific tritium intake mechanisms, tritium dose models, and cancer and genetic risk estimates. Parameters used in the models are summarized in Tables 3-7 and 3-8. Table 3-7 lists the impact parameters used to quantify tritium intake and dose. Table 3-8 lists the parameters that had distributions sampled for Monte Carlo analysis; it includes the range and type of distribution for each data set.

Table 3-7
Input Parameter Definitions and Values Used in Scenario Calculations
(Page 1 of 7)

Symbol	Definition	Units	Agriculture	Industrial	Mining	Recreational	Residential	Tourism
General Exposure Assumptions								
	Exposure duration	h/d	24	8	8	24	24	24
	Exposure duration	d/wk	7	5	5	NA	7	7
	Exposure duration	wk/yr	50	50	50	NA	50	2
	Exposure duration	d/yr	350	250	250	100	350	14
	Exposure duration	h/yr	8,400	2,000	2,000	2,400	8,400	336
	Exposure duration lifetime (adult)	yr	30	30	30	30	30	30
	Exposure duration lifetime (child)	yr	9	NA	NA	9	9	9
Inhalation Intake								
Outside Air								
HTO Concentration in Air								
C_{gw}	HTO concentration in groundwater	pCi/L	a	a	a	a	a	a
U_{wi}	Total groundwater use	L/s	78	78	78	78	78	78
F_i	Fraction of groundwater released to the atmosphere	dimensionless	1	1	1	1	1	1
$F_{a,gw}$	Land area of NTS	m^2	3.5E9	3.5E9	3.5E9	3.5E9	3.5E9	3.5E9
π	Pi	dimensionless	3.1416	3.1416	3.1416	3.1416	3.1416	3.1416
S	Windspeed	m/s	a	a	a	a	a	a
H	Mixing height	m	2	2	2	2	2	2

Note: See footnotes at end of table

Table 3-7
Input Parameter Definitions and Values Used in Scenario Calculations
(Page 2 of 7)

Symbol	Definition	Units	Agriculture	Industrial	Mining	Recreational	Residential	Tourism
Intake from Breathing Outside Air for Industrial and Mining								
BR	Breathing rate	m^3/d	[a]	[a]	[a]	[a]	[a]	[a]
T	Exposure duration	h/yr	NA	500	500	NA	NA	NA
Mine Air								
HTO Concentration in Mine Air								
TEMP	Air temperature in mine	°C	NA	NA	26	NA	NA	NA
$H_{a,m}$	Relative humidity in mine	dimensionless	NA	NA	50%	NA	NA	NA
$H_{a,m}$	Absolute humidity in mine at TEMP and $H_{ra,m}$	g/m^3	NA	NA	24.38	NA	NA	NA
C_{wv}	Concentration of HTO in water vapor in mine	pCi/L	NA	NA	[a]	NA	NA	NA
Intake from Breathing Mine Air								
BR_m	Breathing rate in mine	m^3/h	NA	NA	[a]	NA	NA	NA
T	Exposure duration	h/yr	NA	NA	2,000	NA	NA	NA
Building Air (Industrial)								
HTO Concentration in Building Air								
$B_{b,a}$	Area of building	m^2	NA	1,000	NA	NA	NA	NA
$B_{b,h}$	Height of building	m	NA	6	NA	NA	NA	NA
$R_{b,w}$	Rate of water use in building	L/s	NA	7.8	NA	NA	NA	NA
$C_{b,w}$	HTO concentration in building water	pCi/L	NA	[a]	NA	NA	NA	NA
$F_{b,w}$	Fraction of water released to building air	dimensionless	NA	0.01	NA	NA	NA	NA

Note: See footnotes at end of table

Table 3-7
Input Parameter Definitions and Values Used in Scenario Calculations
(Page 3 of 7)

Symbol	Definition	Units	Agriculture	Industrial	Mining	Recreational	Residential	Tourism
$R_{b,v}$	Ventilation rate of building	m^3/s	NA	0.00111	NA	NA	NA	NA
λ_s	Decay constant of tritium	per second	NA	1.79E-9	NA	NA	NA	NA
$B_{b,v}$	Interior volume of building	m^3	NA	6,000	NA	NA	NA	NA
Intake from Breathing Building Air								
BR_b	Breathing rate in building	m^3/h	NA	[a]	NA	NA	NA	NA
T_b	Exposure duration	h/yr	NA	2,000	NA	NA	NA	NA
Ingestion of Tritiated Water								
C_{dw}	HTO concentration in drinking water	pCi/L	[a]	[a]	[a]	[a]	[a]	[a]
R_{dw}	Drinking water ingestion rate	L/d	[a]	[a]	[a]	[a]	[a]	[a]
T	Exposure duration	d/yr	350	250	250	100	350	14
Ingestion of Tritiated Food								
HTO Concentration in Food Crops from Irrigation								
C_{iw}	HTO concentration in irrigation water	pCi/L	[a]	[a]	[a]	[a]	[a]	[a]
HTO Concentration in Food Crops from HTO in the Atmosphere								
CA	HTO concentration in air	pCi/m^3	[b]	[b]	[b]	[b]	[b]	[b]
F_w	Water fraction of crops	dimensionless	[a]	[a]	[a]	[a]	[a]	[a]
R_{fc}	Ratio of HTO in crops to HTO in air	dimensionless	[a]	[a]	[a]	[a]	[a]	[a]
H_a	Absolute humidity	g/m^3	[a]	[a]	[a]	[a]	[a]	[a]

Note: See footnotes at end of table

Table 3-7
Input Parameter Definitions and Values Used in Scenario Calculations
(Page 4 of 7)

Symbol	Definition	Units	Agriculture	Industrial	Mining	Recreational	Residential	Tourism
Concentration of Tritium in Beef								
Tritium Concentration in Beef from Feed								
F_b	Transfer coefficient: feed to cattle	d/kg	a	a	a	a	a	a
CA	HTO concentration in air	pCi/m^3	b	b	b	b	b	b
F_w	Water fraction of crops	dimensionless	a	a	a	a	a	a
$R_{fc,a}$	Ratio of HTO in crops to HTO in air	dimensionless	a	a	a	a	a	a
H_a	Absolute humidity	g/m^3	a	a	a	a	a	a
$IR_{b,}$	Beef cattle feed ingestion rate	kg/d	a	a	a	a	a	a
λ_d	Decay constant of tritium	per day	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4
T_b	Time from slaughter to consumption	d	a	a	a	a	a	a
Tritium Concentration in Beef from Drinking Water								
DW_b	Transfer coefficient: water to cattle	d/kg	a	a	a	a	a	a
C_{dw}	HTO concentration in drinking water	pCi/L	a	a	a	a	a	a
$IR_{b,dw}$	Beef cattle water ingestion rate	L/d	a	a	a	a	a	a
Tritium Concentration in Beef from Soil Ingestion								
$IR_{b,s}$	Soil ingestion rate by cattle	kg/d	a	a	a	a	a	a
$C_{s,iw}$	HTO concentration in soil	pCi/g	b	b	b	b	b	b
$F_{b,s}$	Transfer coefficient: soil to cattle	d/kg	a	a	a	a	a	a

Note: See footnotes at end of table

Table 3-7
Input Parameter Definitions and Values Used in Scenario Calculations
(Page 5 of 7)

Symbol	Definition	Units	Agriculture	Industrial	Mining	Recreational	Residential	Tourism
P_s	Bulk density of soil	g/cm^3	1.5	1.5	1.5	1.5	1.5	1.5
C_{gw}	HTO concentration in groundwater	pCi/g	a	a	a	a	a	a
θ	Volumetric water content	dimensionless	b	b	b	b	b	b
R_d	Retardation function for HTO	dimensionless	1	1	1	1	1	1
Concentration of Tritium in Milk								
Concentration of Tritium in Milk from Feed								
F_m	Transfer coefficient: feed to milk	d/kg	a	a	a	a	a	a
$IR_{m,fc}$	Dairy cattle feed ingestion rate	kg/d	a	a	a	a	a	a
C_{fc}	HTO concentration in crops	pCi/g	b	b	b	b	b	b
λ_d	Decay constant of tritium	per day	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4
T_m	Milk to market transport time	d	a	a	a	a	a	a
Concentration of Tritium in Milk from Drinking Water								
DW_m	Transfer coefficient: water to milk	d/L	a	a	a	a	a	a
C_{dw}	HTO concentration in drinking water	pCi/L	a	a	a	a	a	a
$IR_{m,dw}$	Dairy cattle water ingestion rate	L/d	a	a	a	a	a	a
λ_d	Decay constant of tritium	per day	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4
T_m	Milk to market transport time	d	a	a	a	a	a	a
$F_{m,dw}$	Milk production to water intake ratio	dimensionless	0.34	0.34	0.34	0.34	0.34	0.34
Concentration of Tritium in Milk from Soil Ingestion								
$IR_{m,s}$	Ingestion rate of soil by cattle	kg/d	a	a	a	a	a	a

Note: See footnotes at end of table

Table 3-7
Input Parameter Definitions and Values Used in Scenario Calculations
(Page 6 of 7)

Symbol	Definition	Units	Agriculture	Industrial	Mining	Recreational	Residential	Tourism
$C_{s,iw}$	HTO concentration in soil	pCi/g	[b]	[b]	[b]	[b]	[b]	[b]
$F_{m,s}$	Transfer coefficient: soil to milk	d/kg	[a]	[a]	[a]	[a]	[a]	[a]
λ_d	Decay constant of tritium	per day	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4	1.55E-4
T_m	Milk to market transport time	d	[a]	[a]	[a]	[a]	[a]	[a]
Ingestion of Tritium-Contaminated Soils								
IR_s	Ingestion rate of soil (adults)	g/d	0.48	0.48	0.48	0.15	0.15	0.15
IR_s	Ingestion rate of soil (child)	g/d	0.024	NA	NA	0.024	0.024	0.024
T	Exposure duration	d/yr	350	250	250	100	350	14
$C_{s,iw}$	HTO concentration in soil	pCi/g	[b]	[b]	[b]	[b]	[b]	[b]
Tritium Intake from Skin Absorption from the Atmosphere and Wet Skin								
Tritium Intake from the Air								
CA	HTO concentration in air	pCi/m^3	[b]	[b]	[b]	[b]	[b]	[b]
T	Exposure duration	min/yr	5.04E5	1.2E5	1.2E5	144000	5.04E5	2.02E4
Tritium Intake from Wetted Skin								
I_{sb}	Intake rate of skin-blotter effect	g/m^2	1	1	1	1	1	1
W	Wetted area of skin (adult)	m^2	1.8	1.8	1.8	1.8	1.8	1.8
W	Wetted area of skin (child)	m^2	1.16	NA	NA	1.16	1.16	1.16
N	HTO concentration in water	pCi/g	[a]	[a]	[a]	[a]	[a]	[a]
I	Intake rate for skin	$(pCi/min\ m^2)$/ pCi/L	5.1	5.1	5.1	5.1	5.1	5.1
P	Humidity of air at skin temperature	g/L	0.04	0.04	0.04	0.04	0.04	0.04

Note: See footnotes at end of table

Table 3-7
Input Parameter Definitions and Values Used in Scenario Calculations
(Page 7 of 7)

Symbol	Definition	Units	Agriculture	Industrial	Mining	Recreational	Residential	Tourism
T	Exposure duration	min	3,500	2,500	840	1,000	3,500	840
Intake from Tritiated Food Stuffs								
IR_b	Ingestion rate of beef by humans	g/d	[a]	[a]	[a]	[a]	[a]	[a]
$C_{b,t}$	HTO concentration in beef	pCi/g	[b]	[b]	[b]	[b]	[b]	[b]
IR_m	Ingestion rate of milk by humans	L/d	[a]	[a]	[a]	[a]	[a]	[a]
$C_{m,t}$	HTO concentration in milk	pCi/L	[b]	[b]	[b]	[b]	[b]	[b]
IR_{fc}	Ingestion rate of food crops by humans	kg/d	[a]	[a]	[a]	[a]	[a]	[a]
$C_{fc,t}$	HTO concentration in food crops	pCi/g	[b]	[b]	[b]	[b]	[b]	[b]
T_{ing}	Time ingesting food crops	d/yr	350	250	250	100	350	14
F_{ing}	Fraction of food grown on site	dimensionless	1	0.2	0.2	0.2	0.2	0.2
Dose								
Q	Quality factor	dimensionless	1	1	1	1	1	1
E	Energy emitted by tritium	MeV/dis	5.69E-3	5.69E-3	5.69E-3	5.69E-3	5.69E-3	5.69E-3
F	Fraction of tritium E deposited in soft tissue	dimensionless	1	1	1	1	1	1
T_e	Effective half-life of tritium in body	d	[a]	[a]	[a]	[a]	[a]	[a]
M	Mass of soft tissue	g	[a]	[a]	[a]	[a]	[a]	[a]

[a] Value derived from Monte Carlo runs. See Table 3-8.
[b] Value calculated in GW.RISK

NA - Not applicable
h/d - Hours(s) per day
d/wk - Day(s) per week
wk/yr - Week(s) per year
d/yr - Day(s) per year
h/yr - Hour(s) per year
L/s - Liter(s) per second
kg/d - Kilogram(s) per day
d/kg - Day(s) per kilogram
m^2 - Square meter(s)
m - Meter(s)
yr - Year(s)
m^3/d - Cubic meter(s) per day
C - Celcius
g/m^3 - Gram(s) per cubic meter
pCi/g - PicoCuries per gram
d - Day(s)
pCi/L - PicoCuries per liter
m^3/h - Cubic meters per hour
m^3/s - Cubic meters per second
m^3 - Cubic meter(s)
L/d - Liters per day
pCi/m^3 - PicoCuries per cubic meter(s)
g/cm^3 - Gram(s) per cubic centimeter
d/L - Day(s) per liter
g/d - Gram(s) per day
min/yr - Minute(s) per year
g/m^2 - Gram(s) per square meter
MeV/dis - Megaelectron volts/disintegration
min - Minute(s)
g - Gram(s)
pCi/min - PicoCuries per minute
g/L - Grams per liter

Table 3-8
Summary of Values Used to Estimate Exposure
(Page 1 of 4)

Variable	Range	Distribution	Reference
HTO Concentration in Groundwater (pCi/L)	5.7E-13 to 2.3E+8	Skewed	NTS regional groundwater flow model
Total groundwater use (L/s)	78	Constant	10 percent of NTS rate (DOE/NV, 1996)
Fraction of groundwater released to the atmosphere (unitless)	1	Constant	Conservative assumption
Land area of NTS (m^2)	3.5E+9	Constant	(DOE/NV, 1996)
Windspeed (m/s)	0.4 to 6.4	Normal	(Soule, 1995 and 1996)
Mixing height (m)	2	$\chi = 3.4$, $\sigma = 1.0$ Constant	(Yu et al., 1993b)
Breathing rate (m^3/d)	0.98 to 2.12	Uniform	(Layton, 1993)
Air temperature in mine °C	26°	Constant	Engineering judgment
Relative humidity in mine (unitless)	50 percent	Constant	Average in mesa tunnels
Absolute humidity in mine (g/m^3)	24.38	Constant	Handbook of Physics and Chemistry
Breathing rate in mine (m^3/h)	1.14 to 1.31	Uniform	(Layton, 1993)
Exposure duration in mine (h/yr)	2,000	Constant	(EPA, 1993a)
Industrial site, area of building (m^2)	1,000	Constant	Engineering judgment
Height of building (m)	6	Constant	Engineering judgment
Rate of water use in building (L/s)	7.8	Constant	0.1 percent of NTS production
Fraction of water released to building (unitless)	0.01	Constant	Engineering judgment
Ventilation rate of building (m^3/s)	0.00111	Constant	Engineering judgment
Decay constant of tritium (per second)	1.79E-9	Constant	(Shleien, 1992)
Interior volume of building (m^3)	6,000	Constant	Engineering judgment

Note: See footnote at end of table.

Table 3-8
Summary of Values Used to Estimate Exposure
(Page 2 of 4)

Variable	Range	Distribution	Reference
Breathing rate of industrial worker in building (m^3/h)	1.15 to 1.32	Uniform	(Yu et al., 1993b) (Layton, 1993)
Exposure duration in building for industrial worker (h/yr)	2,000	Constant	(EPA,1993a)
HTO concentration in drinking water (pCi/L)	5.7E-3 to 2.3E+8	Skewed	Same as groundwater based on NTS regional groundwater flow model
Drinking water ingestion rate (L/d)	0.66 to 1.86	Normal χ = 1.26, σ = 0.20	(Pennington, 1983)
Exposure duration on contaminated site (d/yr)	14 to 350	Constant for each exposure constant	(EPA, 1993) and engineering judgment
HTO concentration in irrigation water (pCi/L)	5.7E-13 to 2.3E-8	Skewed	Same as groundwater based on NTS regional groundwater flow model
Water fraction of crops (unitless)	0.12 to 0.95	Triangular likeliest = 0.80	(Hamby, 1993)
Ratio of HTO in crops to HTO in air (unitless)	0.40 to 1.20	Triangular likeliest = 0.80	(Hamby, 1993)
Absolute humidity (g/m^3)	2.38 TO 4.12	Normal X = 3.25 σ = 0.29	(Soule, 1995 and 1996)
Transfer coefficient feed to cattle (d/kg)	0.0024 to 0.02	Normal χ = 0.012	(Ng et al., 1977)
Beef cattle feed ingestion rate (kg/d)	30 to 85	Normal χ = 52 σ = 11	(Hamby, 1993)
Time from slaughter of beef to consumption (d)	2.2 to 16.5	Lognormal χ = 6.40 σ = 2.2	(Hamby, 1993)
Transfer coefficient water to beef (d/kg)	0.0024 to 0.02	Normal χ =0-01 σ = 0.001	(Ng et al., 1977)
Beef cattle water ingestion rate (L/d)	26 to 74	Normal χ = 50 σ = 8	(Hamby, 1993)
Soil ingestion rate by cattle (kg/d)	0.26 to 0.74	Normal χ = 0.5 σ = 0.08	(Rope and Adams, 1983)

Note: See footnote at end of table.

Table 3-8
Summary of Values Used to Estimate Exposure
(Page 3 of 4)

Variable	Range	Distribution	Reference
Transfer coefficient soil to cattle (d/kg)	0.007 to 0.013	Normal χ = 0.01 σ = 0.001	(Hamby, 1993)
Bulk density of soil (g/cm^3)	1.5	Constant	(Yu et al., 1993b)
Retardation function for HTO	1	Constant	Engineering judgment
Transfer coefficient feed to milk (d/kg)	0.0024 to 0.02	Normal χ = 0.012 σ = 0.0027	(Ng et al., 1977)
Dairy cow feed ingestion rate (kg/d)	20 to 60	Normal χ = 36 σ = 7.8	(Hamby, 1993)
Milk to market transport time (d)	0.8 to 10	Lognormal χ = 3.1 Standard deviation = 1.38	(Hamby, 1993)
Transfer coefficient water to milk (d/L)	0.0024 to 0.02	Normal χ = 0.01 σ = 0.001	(Ng et al., 1977)
Dairy cattle water ingestion rate (L/d)	50 to 160	Normal χ = 105 σ = 18.3	(Yu et al., 1993b)
Milk to market transport time (d)	0.8 to 10	Lognormal χ = 3.1 σ = 1.38	(Hamby, 1993)
Milk production to water intake ratio (unitless)	0.34	Constant	(Yu et al., 1993)
Transfer coefficient soil to milk (d/kg)	0.0024 to 0.02	Normal χ = 0.012 σ = 0.0027	(Ng et al., 1977)
Ingestion rate of soil (Adult) (g/d)	0.15 to 0.48	Constant, exposure specific	(Yu et al., 1993b)
Ingestion rate of soil (Child) (g/d)	0.024	Constant	(Calabrese et al., 1989)

Note: See footnote at end of table.

Table 3-8
Summary of Values Used to Estimate Exposure
(Page 4 of 4)

Variable	Range	Distribution	Reference
HTO intake from wetted skin			
Wetted skin area (m^2)			
Adult	1	Constant	(Osborne, 1968)
Child	1.8	Constant	(EPA, 1989a)
Intake rate for skin (pCi/min)/(pCi/L)	1.16 5.1	Constant Constant	(EPA, 1989a) (Osborne, 1968)
Humidity of air at skin temperature (g/L)	0.04	Constant	(Osborne, 1968)
Skin exposure duration (min/yr)	840 to 3,500	Constant	(EPA, 1993a)
Ingestion rate of beef (g/d)	190 to 336	Normal $\chi = 258$ $\sigma = 25.8$	(Whicker et al., 1990)
Ingestion rate of milk (L/d)	0.44 to 0.82	Normal $\chi = 0.63$ $\sigma = 0.063$	(Whicker et al., 1990)
Ingestion rate of food crops (kg/d)	0.263 to 0.489	Normal $\chi = 0.376$ $\sigma = 0.0376$	(Whicker et al., 1990)
Fraction of food grown on site (unitless)	0.2 to 1	Constant, exposure specific	(Whicker et al., 1990)
Tritium quality factor (unitless)	1	Constant	(DOE, 1993b; DOE, 1995a)
Tritium beta average energy (MeV/dis)	5.69E-3	Constant	(Kocher, 1981)
Fraction of tritium energy deposited in soft tissue (unitless)	1	Constant	(ICRP, 1979g)
Effective half-life of tritium in body (d)	7.88 to 9.5	Lognormal $\chi = 8.69$ $\sigma = 0.27$	(Hamby, 1993)
Mass of soft tissue (g) (Adult)	4.58E+4 to 1.06E+5	Lognormal $\chi = 7.02E+4$ $\sigma = 9.83 E+3$	(Lioy et al., 1992)
Mass of soft tissue (g) (Child)	3.00E+04	Constant	(Lioy et al., 1992)

The primary mechanism used to transport tritium to humans is the pumping of groundwater for use as drinking water, irrigation water, and process water for industrial purposes. Subsequent transport mechanisms are through air, food, and soil. Environmental transport modeling was used to estimate the amount of tritium present in a given transport mechanism and to estimate the amount of tritium that is available for intake by an individual.

Groundwater concentrations were obtained through the regional groundwater modeling effort and the Monte Carlo-based fate and transport modeling described in Section 3.3.3.2. Tritium cannot be filtered from the groundwater; therefore, all water in the environmental transport models, including that used for drinking, cooking, bathing, and irrigation, was assumed to have the same tritium concentration as the groundwater.

The analytical expressions used to calculate the tritium concentration in environmental media for each land-use scenario are essentially the same. Subsequently, the annual intake of tritium by an individual from ingestion of water, food, and soil and from inhalation of tritium-contaminated air were calculated by multiplying the intake rates and exposure duration by the calculated concentration in the environmental medium. With reference to dermal exposure, absorption of tritium through the skin was assumed to be directly proportional to the tritium concentration in the air and exposure time, and to its concentration in water and bathing/showering exposure time (Osborne, 1968; ICRP, 1979). Parameters specific to each land-use scenario were applied for exposure times and intake rates. The parameter values that describe the intake rates and exposure times were varied in accordance with assigned probability distributions covering the probable range of their values. The values of 23 parameters were randomly selected from their respective probability distributions using the Monte Carlo approach. Burmaster and Anderson (1994) recommended a set of good practices in performing and reviewing probabilistic risk assessments using Monte Carlo analysis in the context of the federal and state statutes concerning assessment of hazardous waste sites. Although the UGTA is not a hazardous waste site, the good practices recommended by Burmaster and Anderson were followed in applying Monte Carlo methodology in this risk assessment.

The tritium intake rates from all environmental pathways were summed to determine the total tritium intake. A dose conversion factor (DCF) was then multiplied by the intake value to determine the dose as a function of groundwater concentration for each land-use scenario. The DCF is calculated using a standard dose model. All of the energy from the tritium beta emissions was assumed to be absorbed in the soft tissue of the body from which it is eliminated with an average half-life of 8.69 days. The analytical expression for calculating the DCF is:

$$DCF = \frac{(5.12 \times 10^{-5} \times Q \times E \times f \times T_e)}{\ln(2) \times S} \quad \textbf{(1)}$$

where:

DCF	=	Dose conversion factor from pCi intake to rem;
Q	=	Quality factor for tritium beta emissions;
E	=	Average energy of tritium betas per disintegration (5.685E-3 MeV);
f	=	Fraction of energy absorbed in soft tissue (1.0);
T_e	=	Biological half-life in the body (random variable in days);
ln	=	Natural logarithm;
S	=	Soft tissue mass of the body (random variable in g); and
5.12×10^{-5}	=	Unit conversion factor ([rem × g]/[pCi × MeV]).

The biological half-life, T_e, was modeled as a lognormal distribution with a geometric mean of 8.69 days and a geometric standard deviation of 0.27 (Hamby, 1993). The mass of the soft tissue, S, was modeled as a lognormal distribution with a geometric mean of 70,200 grams (g) and a geometric standard deviation of 0.14 (Hamby, 1993). For the child dose receptor T_e was modeled as a normal distribution with a mean of 9.95 days and a standard deviation of 0.35 (Hill and Johnson, 1993) while S was modeled as a constant 30,000 g (Lioy et al., 1992).

The dose conversion factor varies over the weight of an adult and the retention time of tritium in the body. The estimated doses for each land-use scenario considered the variability about a given parameter in determining such things as the likelihood of doses exceeding a given level.

The calculation of tritium intake, dose, and risk was performed using a series of linked spreadsheets written in Crystal Ball, Version 4.0 (Decisioneering, 1996). Crystal Ball is a Monte Carlo forecasting code that has been used extensively in performing tritium dose and risk assessments (Straume and Carsten, 1993).

Details on the computational models for quantifying tritium intake are described in the following section.

3.3.4.1 Intake Models

The following sections describe the models used to calculate the intake of tritium by each of the three exposure pathways: inhalation, ingestion, and dermal absorption. These models include equations for the calculation of the annual intake of tritium, in picoCuries (pCi), by a human receptor exposed to tritiated groundwater through the inhalation and skin absorption of tritiated water vapor in the air, the ingestion of groundwater-derived drinking water, the ingestion of soil contaminated by tritiated groundwater, and the absorption of tritiated water by washing or bathing. Models are also presented for the calculation of the concentration of tritium in food (crops, beef, and milk) that has been grown using tritiated groundwater for irrigation and as drinking water. The equations used in calculating tritium intakes are found in Appendix A.

3.3.4.1.1 Inhalation Pathway

Inhalation intake is a function of breathing rate, exposure time, and the concentration of tritium in the air. Receptor-specific intakes were calculated by using breathing rates published in the open peer-reviewed scientific literature for use in dose assessment. These breathing rates are related to the energy needs of the modeled activities and the time over which the activity takes place. These breathing rates were coupled to food-energy intakes needed to sustain the assumed activity levels of the individual receptor (Layton, 1993). The mix of physical activities used in this analysis was for an individual performing outdoor activities as recommended in the RESRAD code manual (Yu et al., 1993a). RESRAD was established by DOE and prescribed in DOE Order 5400.5 (DOE, 1993b) for calculating soil clean-up concentrations. The equation used to calculate the intake of tritium by inhalation is:

$$INH = BR \times t \times C_a \qquad \textbf{(2)}$$

where:

INH = Tritium intake from inhalation (picoCuries per year [pCi/yr]);
BR = Breathing rate (cubic meters per hour [m^3/hr]);
t = Time breathing (hr/yr); and
C_a = Atmospheric concentration of tritium as HTO (picoCuries per cubic meter [pCi/m^3]).

The atmospheric concentration of tritium (C_a) was calculated based on the concentration of tritium in groundwater using the following equation:

$$C_a = \frac{(U_{wi} \times C_{gw} \times F_i)}{2\sqrt{\frac{F_{a,gw}}{\pi}} \times S \times H} \quad \textbf{(3)}$$

where:

C_a = Concentration of tritium in the atmosphere (pCi/m^3);
U_{wi} = Total groundwater production on the NTS (78 liters per second [L/s]);
C_{gw} = Concentration of HTO in groundwater (picoCuries per liter [pCi/L]);
F_i = Fraction of groundwater that is released to the atmosphere (unitless);
$F_{a,gw}$ = Land area of the NTS (3.5×10^9 square meters [m^2]);
S = Average wind speed at the NTS (3.4 meters per second [m/s]); and
H = Mixing height (2 m).

3.3.4.1.2 Ingestion Pathway

The ingestion pathway includes the ingestion of drinking water, food (crops, beef, and milk), and the inadvertent ingestion of soil. The intakes from tritium-contaminated crops (fruit, vegetables, and grain), beef and milk were calculated from the concentrations modeled by the methods described in this section using southern Nevada-specific consumption rates (Whicker et al., 1990). In order to provide a thorough description of the potential HTO intake, the concentration of HTO in pork, eggs, and poultry was assumed to be the same as beef. All by-products of beef and milk were assumed to have the same concentrations as the original product. For all land-use scenarios except agriculture, individuals were assumed to receive 20 percent of their food from farms and ranches using tritiated water for irrigation and drinking water. The individuals participating in the agricultural land-use scenario were assumed to get all of their food from their farm and dairy operations.

Drinking Water

The method for calculating the ingestion of tritiated water is analogous to the method for calculating the inhalation of HTO in the air (Equation 1). The drinking water intake is:

$$IWING = R_{dw} \times C_{dw} \times t \quad \textbf{(4)}$$

where:

IWING = Ingestion intake of tritiated groundwater (pCi/yr);
R_{dw} = Rate of drinking water ingestion (L/d);
C_{dw} = HTO concentration in drinking water (pCi/L); and
t = Time tritiated water being ingested (d/yr).

The HTO concentration in drinking water (C_{dw}) is assumed to equal the HTO concentration in groundwater (C_{gw}), while the rate of drinking water ingestion is from a study by the U.S. Food and Drug Administration's total diet study (Pennington, 1983).

Food Crops

The calculation of the ingestion of tritiated crops assumes that the crops were irrigated with tritiated groundwater and that the fraction of food grown on site is representative of rural areas in the United States. The types and amounts of food ingested are representative of average southern Nevada residents (Whicker et al., 1990). The HTO concentrations in food crops would be influenced by both the HTO concentration in irrigation water and the HTO concentration in the atmosphere.

The HTO concentration in crops due to irrigation water is calculated according to the equation:

$$C_{fc,iw} = 0.9 \times 0.001 \times C_{iw} \quad \textbf{(5)}$$

where:

$C_{fc,iw}$ = Concentration of HTO in crops due to HTO in irrigation water (pCi/g);
0.9 = Mass fraction of hydrogen in crops divided by the mass fraction of hydrogen in water;
0.001 = pCi/L to pCi/g conversion; and
C_{iw} = Concentration of HTO in irrigation water (same as C_{gw}) pCi/L.

The mass fraction of hydrogen in crops, 0.9, is from Yu et al. (1993a). This hydrogen fraction is conservative because it is largely dependent upon the water content of the crop, which is significantly less in many crops than the distribution assumed for C_{iw}.

The concentration of HTO in crops due to HTO in the atmosphere is adapted from the methodology developed by Hamby (1993). The equation used is:

$$C_{fc,a} = \frac{(C_a \times F_W \times R_{fc,a})}{H_a} \quad \textbf{(6)}$$

where:

$C_{fc,a}$ = HTO concentration in food crops due to HTO in the atmosphere (pCi/g);
C_a = Concentration of HTO in the atmosphere (pCi/m^3);
F_W = Fraction of food crop mass that is water (0.8);
$R_{fc,a}$ = Ratio of plant tritium concentration to atmospheric HTO (0.8); and
H_a = Annual average absolute humidity (3.25 grams per cubic meter [g/m^3]).

The fraction of crops that is water (F_W) is from Yu et al. (1993b). The ratio of plant tritium concentration to atmospheric HTO is modeled as a triangular distribution with a mode of 0.8 and a range of 0.4 to 1.2 (Hamby, 1993). The annual average absolute humidity was derived from temperature and relative humidity data provided for Pahute Mesa, Yucca Flat, and Mercury by the Las Vegas office of the National Oceanic and Atmospheric Administration (NOAA) (Soule, 1995 and 1996).

Beef

The concentration of HTO in beef includes contributions from HTO in feed, drinking water, and ingested soil. Much of the modeling of HTO in beef is based upon the research performed by Hamby (1993).

The concentration of HTO in beef due to HTO in feed is calculated by the following equation:

$$C_{b,fc} = F_b \times C_{fc,t} \times IR_{b,fc} \times e^{(-\lambda T_s)} \quad \textbf{(7)}$$

where:

$C_{b,fc}$ = HTO concentration in beef due to HTO in feed (pCi/g);
F_b = Equilibrium ratio of HTO in beef to the cattle's daily feed ingestion rate (d/kg);
$C_{fc,t}$ = HTO concentration in cattle feed (pCi/g);
$IR_{b,fc}$ = Feed ingestion rate of cattle (52 kg/d);
λ = Radiological decay constant for tritium (1.55×10^{-4}/d); and
T_s = Time from slaughter to consumption (6.4 d).

The parameter values F_b, $IR_{b,fc}$, and T_s were modeled as lognormal distributions. F_b has a geometric mean of 0.01 d/kg and a geometric standard deviation of 0.001 d/kg, while $IR_{b,fc}$ has a geometric mean of 52 kg/d and a geometric standard deviation of 11 kg/d (Ng, 1979; Little, 1979). T_s has a median of 6 days, while the 99.9 percent confidence level was chosen to cover an order of magnitude (Hamby, 1992 and 1993).

The concentration of HTO in beef due to the cattle's ingestion of drinking water is calculated in the following manner:

$$C_{b,dw} = DW_b \times C_{dw} \times IR_{b,dw} \times CF \times e^{(-\lambda T_s)} \quad \textbf{(8)}$$

where:

$C_{b,dw}$ = Concentration of HTO in beef due to HTO in drinking water (pCi/g);
DW_b = Transfer coefficient from water to beef (d/kg);
C_{dw} = HTO concentration in drinking water (pCi/L);
$IR_{b,dw}$ = Beef cattle water ingestion rate (L/d);
λ = Radiological decay constant for tritium (1.55×10^{-4}/d);
T_s = Time from slaughter to consumption (6.4 d); and
CF = Conversion factor kilograms/1,000 grams.

The HTO transfer coefficient from drinking water to beef (DW_b) was modeled as a normal distribution with a mean of 0.01 d/kg and a selected range from 0 to 0.02 d/kg. The ingestion rate of drinking water for beef cattle ($IR_{b,dw}$) was modeled as a normal distribution with a mean of 50 L/d and a selected range from 26 to 74 L/d (Yu et al., 1993b).

The concentration of HTO in beef due to cattle ingestion of soil is a function of the HTO concentration in soil, the cattle soil ingestion rate, and the HTO transfer rate from soil to beef. The relationship is described by the following equation:

$$C_{b,s} = IR_{b,s} \times C_{s,iw} \times F_{b,s} \times e^{(-\lambda T_s)} \quad \textbf{(9)}$$

where:

$C_{b,s}$ = Concentration of HTO in beef due to ingestion of HTO-contaminated soil (pCi/g);
$IR_{b,s}$ = Ingestion rate of soil by cattle (kg/d);
$C_{s,iw}$ = Concentration of HTO in soil due to HTO in irrigation water (pCi/g);
$F_{b,s}$ = HTO transfer coefficient from soil to beef (d/kg);
λ = Radiological decay constant for tritium (1.55×10^{-4}/d; and
T_s = Time from slaughter to consumption (6.4 d).

The ingestion rate of soil by beef and dairy cattle ($IR_{b,s}$) is from a review performed at the Idaho National Engineering Laboratory (INEL) and was modeled as a normal distribution with a mean of 0.5 kg/d and a standard deviation of 0.08 kg/d (Rope and Adams, 1983). The HTO transfer coefficient from soil to beef ($F_{b,s}$) was assumed to be a normal distribution with a mean of 0.01 d/kg and a standard deviation of 0.001 d/kg.

The concentration of HTO in soil from tritiated irrigation water (C_s) was calculated by the following equation:

$$C_{s,iw} = \frac{(C_{gw} \times \theta \times R_d)}{P_s} \times CF \quad \textbf{(10)}$$

where:

$C_{s,iw}$ = Concentration of HTO in soil due to HTO in irrigation water (pCi/g);
C_{gw} = HTO concentration in groundwater and irrigation water (picoCuries per cubic centimeter [pCi/cm^3]);
R_d = Retardation function for HTO in soil (1.0);

P_s = Bulk density of soil (grams per cubic centimeter [g/cm^3]);
CF = Conversion factor L/1,000 cm^3.

θ is defined by

$$\theta = \frac{R_s}{\theta_{sat}} \quad \textbf{(11)}$$

where:

θ_{sat} = Saturated water content (0.39), and:

$$R_s = \left[\frac{INF}{K_{sat}}\right]^{\left(\frac{1}{2b+3}\right)} \quad \textbf{(12)}$$

where:

K_{sat} = Hydraulic conductivity of the soil (5,550 meters per year [m/yr]);
b = Soil-specific exponential parameter (4.05), and:

$$INF = (1 - C_e) \times \left[(1 - C_r) \times P_r + Irr\right] \quad \textbf{(13)}$$

where:

C_e = Evapotranspiration coefficient (0.67);
C_r = Runoff coefficient (0.3);
P_r = Precipitation rate for NTS (0.127 m/yr); and
Irr = Irrigation rate (1.2 m/yr).

C_e is a function of the evapotranspiration rate, and is bounded by a value of one. The model for calculating HTO concentration in soil was originally designed by Argonne National Laboratory to determine the flux of contaminated surface water to the saturated zone (Yu et al., 1993b); however, the model does provide the appropriate relationship between the HTO concentration in soil water (C_{gw}) and the HTO concentration in the soil (C_s).

Several parameters used to calculate C_s are probabilistic in nature and were assigned pertinent distributions. The average evapotranspiration rate was calculated using Yu et al. (1993b) (Figure 12-1), giving a normal distribution with a mean of 1.07 and a standard deviation of 0.15. The precipitation rate is based upon NTS data and was fitted to a normal distribution with a mean of 0.127 m/yr and a standard deviation of 0.06 m/yr. The irrigation rate is based upon engineering judgment of the quantity needed to support agricultural activities. A normal distribution was assigned with a mean of 1.2 m/yr, a standard deviation of 0.12 m/yr, and a selected range of 1.00 to 1.80 m/yr. The range and distribution were selected based upon NTS rainfall, temperature patterns, and how they could affect the need for irrigation.

The total concentration of HTO in beef is the sum of the contributions from feed, drinking water, and soil. The concentration of HTO in beef is typically on the order of 0.1 percent of the concentration of HTO groundwater.

Milk

The concentration of tritium in milk was calculated in a manner analogous to the method used to calculate HTO concentration in beef. Dairy cows ingest HTO from feed, drinking water, and soil. The concentration in milk due to the ingestion of feed is:

$$C_{m,fc} = 1{,}000 \times F_m \times C_{fc,t} \times IR_{m,fc} \times e^{(-\lambda T_m)} \qquad \textbf{(14)}$$

where:

$C_{m,fc}$ = Concentration of HTO in milk due to the ingestion of feed (pCi/L);
1,000 = A unit conversion factor that translates grams to kilograms;
F_m = Equilibrium ratio in milk to the cow's daily ingestion rate of feed (d/L);
$C_{fc,t}$ = HTO concentration in feed (pCi/g);
$IR_{m,fc}$ = Dairy cow feed ingestion rate (kg/d);
λ = Radiological decay constant for tritium (1.55×10^{-4}/d); and
T_m = Milking to market transport time (3.1 d).

The parameter values F_m, $IR_{m,fc}$, and T_m were modeled as lognormal distributions. F_m has a geometric mean of 0.01 d/L and a geometric standard deviation of 0.001 d/L. $IR_{m,fc}$ is the cow's daily feed ingestion rate and has a geometric mean of 36 kg/d and a geometric standard deviation of 7.8 kg/d (Ng, 1979; Little, 1979). T_m is the time from milking to consumption and was

modeled as a lognormal distribution with a geometric mean of 3.1 days and a geometric standard deviation of 1.38 d (Hamby, 1992 and 1993).

The HTO concentration of tritium in milk due to HTO in drinking water is quantified using the following equation:

$$C_{m,dw} = F_{m,dw} \times DW_m \times C_{dw} \times IR_{m,dw} \times e^{(-\lambda T_m)} \quad \textbf{(15)}$$

where:

$C_{m,dw}$ = Concentration of HTO in milk due to the ingestion of drinking water (pCi/L);
$F_{m,dw}$ = Ratio of milk production to water intake;
DW_m = HTO transfer coefficient from drinking water to milk (d/L);
C_{dw} = HTO concentration in water (pCi/L);
$IR_{m,dw}$ = Dairy cow water ingestion rate (L/d);
λ = Radiological decay constant for tritium (1.55×10^{-4}/d); and
T_m = Milking to market transport time (3.1 d).

The HTO transfer coefficient from drinking water to milk (DW_m) was modeled as a normal distribution with a mean of 0.01 and a standard deviation of 0.001. The ingestion rate of drinking water for dairy cows ($IR_{m,dw}$) was modeled as a normal distribution with a mean of 105 L/d, a standard deviation of 18.3 L/d, and a selected range from 50 to 160 L/d (Yu et al., 1993b).

The concentration of HTO in milk due to the cow's ingestion of soil is a function of the HTO concentration in soil, the cow's soil ingestion rate, and the HTO transfer rate from soil to milk. The relationship is described in the equation:

$$C_{m,s} = 1{,}000 \times IR_{m,s} \times C_{s,iw} \times F_{m,s} \times e^{(-\lambda T_m)} \quad \textbf{(16)}$$

where:

$C_{m,s}$ = Concentration of HTO in milk due to the HTO in soil (pCi/L);
1,000 = A unit conversion factor that translates grams to liters for water;
$IR_{m,s}$ = Ingestion rate of soil by cattle (kg/d);
$C_{s,iw}$ = Concentration of HTO in soil from irrigation water (pCi/g) (see Equation 9);

F_m = HTO transfer coefficient from soil to milk (d/kg);
λ = Decay constant for tritium (1.55×10^{-4}/d); and
T_m = Milking to market transport time (3.1 d).

Soil

Individuals are assumed to inadvertently ingest soil. The HTO intake from soil ingestion for human receptors was modeled like that for beef and dairy cattle, where intake is the product of soil concentration (C_s), ingestion rate, and exposure time. The average ingestion rate is 0.1 gram per day (g/d), except for individuals in the agriculture, industrial, and mining land-use scenarios. For these cases, individuals were assumed to ingest 0.48 g/d. These ingestion rates are slightly higher than the guidance given by EPA (1991), but are justified due to the particularly dusty conditions in the desert. The soil ingestion rate for children is based upon a study by Calabrese et al. (1989) and is recommended by the American Industrial Health Council (AIHC, 1994).

3.3.4.1.3 Dermal Absorption

The model used to calculate the intake of HTO due to dermal (skin) absorption is presented in ICRP Publication 30 (ICRP, 1978), which is based upon the investigations of Osborne (1966 and 1968). Individuals are assumed to absorb HTO water vapor through their clothing and skin at all times while on site (Osborne, 1966). Measurements have demonstrated that tritiated water will rapidly penetrate clothing and skin (Osborne, 1966). In order to prevent significant absorption of tritium through the skin, an individual would have to wear air-supplied plastic suits that completely enclose the body (Osborne, 1966 and EG&G, 1992). None of the dose receptors would be expected to wear such equipment. Therefore, tritium absorption through the skin was assumed to occur for all dose recipients. The analytical expression for absorption from the atmosphere is shown below:

$$I_{s,a} = 0.01 \times C_a \times t \qquad \textbf{(17)}$$

where:

$I_{s,a}$ = Skin intake of tritium from the atmosphere per year (pCi);
0.01 = pCi/min of HTO absorbed through the skin, if air concentration is expressed in pCi/m^3;
C_a = HTO concentration in air (pCi/m^3) (see Equation 2); and
t = Exposure time (minutes).

Individuals were assumed to shower and/or bathe with water having a tritium concentration equal to groundwater. The expression that quantifies their skin intake is that of Osborne (1968):

$$I_{s,w} = (M \times W \times N) + (W \times I \times P \times N \times t) \quad \textbf{(18)}$$

where:

$I_{s,w}$ = Skin intake from wet skin (pCi);
W = Wetted area, assumed to be the entire skin area (1.8 m^2);
I = Intake rate for skin (5.1 pCi/min-m^2 per pCi/L);
P = Humidity of air at skin temperature (0.04 g/L);
N = Specific activity of HTO in air (pCi/g);
t = Exposure time (min); and
M = Intake due to blotter effect (g/m^2).

The total skin intake of tritium is the sum of $I_{s,a}$ (Equation 17) and $I_{s,w}$.

3.3.5 Uncertainty Associated with the Exposure Assessment

Several factors contribute to the uncertainty associated with the exposure assessment. Factors related to the hydrogeological transport model include the radiological source term concentrations used in the model and model related assumptions (Volumes I and IV of the Data Documentation Package [IT, 1996a, b, c, d]). In order to reduce some of the uncertainty associated with the predicted groundwater concentrations, Monte Carlo simulations were used to project a distribution of tritium concentrations as they relate to time and distance from a given event. Uncertainty is also associated with the selected exposure scenarios used in the assessment. This is a conservative assessment in that scenarios such as uptake of tritium from air by plants and ingestion of irrigated soil and dust by an industrial worker were considered. A Reasonable Maximum Exposure (RME) person (EPA, 1989a) was used as a receptor in all cases. With reference to the exposure parameters used in the models, the values of 23 parameters were randomly selected from their respective probability distributions using the Monte Carlo approach. This was done to decrease the uncertainty associated with parameter values.

3.4 Toxicity Assessment

Tritium is a beta-radiation emitting radionuclide, which means that it emits an electron from the nucleus of an unstable atom when a neutron is spontaneously converted to a proton and an electron during beta decay. Beta particles are ejected from the nucleus with sufficient energy to

ionize other molecules. In biological tissues, such ionizations can lead to health effects such as cancer and genetic damage.

The following section describes the physical characteristics of tritium and its behavior in biochemical systems. The known health effects of tritium are summarized, and dose-to-risk conversion factors for both cancer and genetic effects are presented.

3.4.1 Physical and Biochemical Characteristics of Tritium

Tritium is an isotope of the element hydrogen and is both naturally occurring and man-made. Between 30 and 50 degrees latitude in the northern hemisphere, natural background concentrations of tritium in surface water vary between 30 and 300 pCi/L (NCRP, 1979). The half-life for tritium is 12.26 years (Unterweger et al., 1980), decaying to helium while emitting a beta particle.

Beta particles are of very low energy, averaging 5.7 kiloelectron volts (keV), with a maximum of 18.6 keV; however, this is enough energy to ionize and excite molecules in their path. The penetration range of beta particles released in tissue during tritium decay averages less than 1 micrometer (µm), with a maximum range of only 6 µm (ICRP, 1983). Because of their small penetration range in tissue, tritium betas cannot penetrate the outer layer of dead skin cells. Therefore, tritium poses no direct external hazard to humans.

Tritium can be taken into the body through inhalation of air containing tritiated water vapor; ingestion of food, water, and soil containing tritium; and direct absorption through the skin. Once in the body, tritium is incorporated into tissues and organs, thereby resulting in internal irradiation of body organs. Because of its low beta energy, dilution throughout all of the soft tissues, and elimination with an average biological half-life of about nine days in adults (ICRP, 1979-1983), tritium as HTO has a relatively low radiological toxicity when compared to other pure beta emitters, such as ^{32}P or ^{90}Sr, or to common beta-gamma emitters such as ^{131}I or ^{137}Cs.

Although tritium is not considered a particularly toxic radionuclide, it presents a concern because it can become part of the biological hydrogen pool. In the environment, tritium poses a potential internal radiation hazard because compounds containing tritium undergo various chemical transformations, resulting in forms that can enter the body. In groundwater the chemical form that tritium takes is HTO. HTO is very mobile in the environment and can enter the body through inhalation, ingestion, and skin absorption (Osborne, 1968). Once inside the body, the HTO diffuses freely and rapidly across cellular membranes, equilibrating throughout the total body

water pool within a few hours (ICRP, 1979). The uniform concentration of HTO results in the radiation dose being uniformly distributed throughout the soft tissues of the body.

Tritium from HTO may exchange with other hydrogen atoms and, thereby, may become incorporated into organic molecules. HTO is the primary chemical precursor for other chemical forms of tritium (Hill and Johnson, 1993). Essentially any organic molecule can incorporate tritium in this manner. This process may result in a heterogeneous distribution of tritium within individual organs or even individual cells. In most organic compounds, whether inhaled, ingested with food, or synthesized *in situ*, the tritium bound to oxygen, nitrogen, phosphorus, or sulfur can readily exchange with hydrogen found in the body water pool; thus, it will have the same metabolism and distribution as HTO. This is known as the exchangeable bound tritium fraction. Tritium may also exchange with hydrogen in carbon-hydrogen bonds. Once bonded to carbon, tritium becomes less mobile and is known as nonexchangeable or organically bound tritium (OBT). OBT is normally released only as a result of enzymatic breakdown of the molecule containing the carbon-tritium bond (ICRP, 1989).

When tritiated organic compounds are ingested, a considerable fraction is broken down in the gastrointestinal tract, producing HTO (ICRP, 1979). Organic compounds of tritium may also catabolize to HTO after they have crossed the gastrointestinal tract (Lambert and Clifton, 1968; Feinendegen and Cronkite, 1977). Organic compounds of tritium are not very volatile under normal circumstances, and, therefore, the probability of their being inhaled as vapors is small. Tritiated organic compounds, which are metabolic precursors, are usually distributed throughout the soft tissues and are only rarely concentrated in particular cells or parts of cells (ICRP, 1979).

The one exception is thymidine, which, if not catabolized, is taken up only by the nuclei of cells synthesizing deoxyribonucleic acid (DNA).

The rate of tritium incorporation into the organic pool of the body depends on the duration of exposure and on the chemical nature of the compound in which the tritium is bound. Although chronic exposure to tritiated water results in higher tritium incorporation into the OBT compartment, the increase in dose due to OBT is only a few percent because almost all of the tritium in the cell is present as HTO (Diabate and Strack, 1993). The ICRP, in their Publication 30 (ICRP, 1978), and several authors (Snyder et al., 1968; Sanders and Reinig, 1968; Lambert and Clifton, 1967; and Moghissi et al., 1972) suggest that the contribution from OBT accounts for less than 10 percent of the dose. The biological rate of elimination constant is unknown for OBT; however, if HTO is ingested, only a small fraction becomes OBT.

When tritiated food is ingested, the OBT compartment becomes relatively more significant because more tritium is taken in as OBT. When crops have been chronically irrigated with tritiated water, the additional contribution to dose due to the ingestion of the plant OBT can be significant with respect to the dose calculated with only plant tritium as HTO considered. Based upon stoichiometric calculations reported on the estimated, nonexchangeable hydrogen content of the main components of organic material, approximately 70 percent of the hydrogen content in the edible parts of plants could be OBT (Diabate and Strack, 1993). For this analysis, the contribution to dose from ingestion of fruits, vegetables, and grains was evaluated by performing a sensitivity analysis. Food ingestion already contributes significantly to dose for the agriculture land-use scenario. If, as stated in the literature, tritium as OBT could comprise up to 70 percent of the hydrogen content of the edible parts of plants, then it could increase the food ingestion component of the dose by a factor of two (Diabate and Strack, 1993).

3.4.2 Toxicological Effects of Tritium

The toxicity of a hazardous material may be classified in several different ways. Radioactive materials are classified according to the dose they could present to radiological workers and members of the public. Radioactive materials and the practices involving their commercial use are regulated by the Nuclear Regulatory Commission (NRC), DOE, U.S. Department of Transportation (DOT), EPA, and the states. Regulatory controls of radioactive material are based upon exposure rates, dose rates, activity, and concentration in environmental media. The controls for release of radioactive material to the environment during DOE operations are defined in DOE Order 5400.5 (DOE, 1993b) and are based on the concentration of the radioactive material in the environment and dose to members of the public.

It is known that a fraction of the tritium released during underground testing will escape into and be transported with the groundwater, thereby becoming potentially available to future NTS land users. As previously discussed, the energy associated with the beta particles emitted upon decay of tritium is too low to present an external hazard; therefore, the fundamental issue in the environmental and biological dosimetry of tritium is its uptake and distribution within biological organisms.

When living cells are exposed to ionizing radiation, they may absorb some or all of the energy carried by the ionizing radiation. Damage to living cells occurs only when energy is transferred from the radiation to the cell. The amount of energy actually absorbed from radiation per unit mass of living cells that have absorbed the energy is called the absorbed dose. Internal radiation dose is a function of the type and energy of the emitted radiation and the amount and distribution of the radionuclide in the body. The typical distance traveled by a tritium beta particle is small

with respect to the dimension of a cell (Myers and Johnson, 1991). The beta particles do not leave the organ in which they originated; therefore, virtually all energy from tritium beta particles released in an organ is deposited in that organ.

In the study of chemical and biological effects of radiation, the gray (Gy) is used as the unit of measure of energy absorption, where 1 Gy represents one joule (J) of energy deposited per kilogram of material. The absorbed dose is defined in a volume of the material representing a very small mass. This dose is commonly taken to be the average dose over a tissue or an organ (ICRP, 1991), which is used as an indicator for the probability of stochastic effects occurring after irradiation.

Dose cannot be measured directly; it must be calculated based upon a combination of measurements and dosimetry models. Dose is a function of the intake rate of the following:

- The radionuclide
- The physicochemical aspects of the radionuclide
- How the radionuclide is distributed and cleared from the body
- The type and energy of the radioactive emissions
- The physical half-life of the radionuclide
- The mass of the various organs and tissues of the dose receptor

The model used to calculate dose in this risk assessment is that recommended by the ICRP Publication 30 (ICRP, 1979) and established by the EPA in their Federal Guidance Report No. 11 (Eckerman et al., 1988). Monte Carlo techniques were used to sample the distribution of parameter values required to calculate the dose. The calculated doses from all intakes are compared to the 100 millirems per year (mrem/yr) limit established in DOE Order 5400.5 (DOE, 1993b) for members of the public.

The biological effects of radiation are brought about through chemical changes in the cells caused by ionization, excitations, dissociations, and atom displacements. When determining radiation effects on living organisms, it is necessary to consider not only the total dosages of ionization produced within the organism, but also such factors as the density of the ionization, the dose rate, the localization effect, and the rates of both uptake and elimination of radioactive material. The uptake, deposition, and elimination of a radionuclide will vary with its chemical form, solubility, and the presence of a carrier. As an isotope of hydrogen, tritium can become part of essentially every organic molecule within the body.

Hazardous materials are classified by the EPA by their carcinogenic or noncarcinogenic effects on human health. Carcinogenicity risk is defined by the EPA as the probability that an individual will develop cancer sometime during his or her lifetime from a chronic exposure to the carcinogen in

question. The EPA classifies those agents that are known to cause cancer in humans as Group A carcinogens. All radionuclides are classified by the EPA as Group A human carcinogens because of their ionizing radiation emissions.

Risk associated with radiation dose is typically expressed as lifetime probabilities of a latent cancer fatality, total cancer incidence, and severe hereditary or genetic detriment. The last two risks, hereditary and genetic, are combined in this analysis and defined as the radiological detriment.

The lifetime risk coefficient for latent fatal cancer assumed in the human health risk assessment is that recommended by the ICRP (ICRP, 1991) for the whole population, 5.0×10^{-7} per millirem (mrem). This risk coefficient for latent fatal cancer is not specific to tritium, but is calculated based upon studies using all types of radiation. Risk coefficients specific to tritium have been published and compare favorably to those published by the ICRP and other scientific bodies (Straume, 1993).

The risk coefficient for total cancer incidence is from the EPA Health Effects Assessment Summary Tables (HEAST) (EPA, 1995). The total cancer incidence risk is the sum of the lifetime risk for fatal and nonfatal cancers. This is the risk characterization recommended by the EPA when quantifying risk from radionuclide contamination of Superfund sites (EPA, 1989). The HEAST is a comprehensive listing that consists of provisional risk assessment information relative to oral and inhalation routes for chemicals of interest to Superfund, the Resource Conservation and Recovery Act, and the EPA in general. Entries in the HEAST are limited to chemicals that have undergone review and have the concurrence of individual Agency Program Offices, and each is supported by an Agency reference. This risk assessment information has not, however, had sufficient review to be recognized as high quality, Agency-wide consensus information. The Integrated Risk Information System (IRIS) is the Agency' s official repository of Agency-wide consensus chronic human health risk information. IRIS evaluations are conducted by the Agency' s Work Group Review process, i.e., they have been examined by either the Reference Dose/Reference Concentration (RfD/RfC) Work Group or the Carcinogen Risk Assessment Verification Endeavor (CRAVE) Work Group. These Agency Work Groups conduct a process that leads to internal Agency scientific consensus regarding risk assessment information on a chemical. This information is recorded in IRIS, is considered to be "Work Group Verified," and does not appear in the HEAST. Thus, provisional risk assessment information in the HEAST is subject to possible review and revision by these Agency Work Groups. IRIS does not list a total cancer risk coefficient for tritium; therefore, the listing in HEAST was used in this risk assessment, 7.15×10^{-14} risk/pCi of intake. The HEAST also lists a risk coefficient for inhalation, 9.59×10^{-14}. The difference in value for the risk coefficient for inhalation is because the inhalation

risk coefficient assumes a standard rate of skin absorption that is a linear function of inhalation rate. In this risk assessment, skin absorption intake is calculated separately from inhalation intake, so the ingestion risk factor is used for all tritium. This assumption should be made because the tritium dose model used by the EPA assumes that tritium is instantaneously and uniformly distributed throughout all fluids and soft tissue in the body, regardless of the mode of intake.

In addition to its carcinogenic attributes, radioactivity is known to produce damage in germ cells; this damage, such as a mutations or chromosomal aberrations of the genetic material in the nucleus, may be transmitted and may manifest itself as hereditary disorders in the descendants of the exposed individual. Radiation has not been identified as a cause of such effects in humans, but experimental studies on plants and animals suggest that such effects will occur and that the consequences may range from the undetectably trivial, through gross malformations or loss of function, to premature death (ICRP, 1991). It is conservatively presumed that any nonlethal damage in human germ cells may be further transmitted to subsequent generations. This type of stochastic effect is called "hereditary." The hereditary and genetic risk are summed and defined as radiation detriment for this risk assessment. In this analysis, the coefficients for lifetime radiation detriment risk are those recommended by the ICRP. They are expressed as 1.3×10^{-7} per mrem and represent the risk to the whole population, including males, females, adults, and children (ICRP, 1991).

Comparisons between the relative toxicities or potentials for cell damage of different radiations are made on the basis of assuming equal energy absorption. Generally, the higher the energy transfer, the more effective it is in producing damage. The ratio of the absorbed dose of a specific energy (usually 250-keV x-rays) to the absorbed dose of any other ionizing radiation required to produce the same biological effect is called the quality factor. The quality factor is independent of the organ or tissue under consideration and of the biological endpoint. Because the uncertainties involved in estimating dose equivalent are large relative to the variation in stopping power for a particular radiation, a Quality Factor (Q) is usually assigned a constant value for each particular type of radiation. The recommended Q value by DOE and the EPA for tritium is one and is the value for Q assumed in this risk assessment.

3.4.2.1 Lifetime Cancer Risk

As previously stated, no cancer-risk information is available for human exposure to tritium. Estimates of tritium risk factors are obtained by adding the human-cancer data that are available for photons with dose-rate information from experimental animal studies. In the context of this risk assessment, a risk factor is a value which is used to relate dose to risk. The risk factors used in this assessment are point estimates based on the linear no-threshold (LNT) hypothesis. A risk factor is essentially a toxicity value for radiation that converts dose to the risk of a latent cancer

fatality, cancer incidence, or radiation detriment. In this risk analysis, the lifetime fatal and lifetime radiation detriment are those recommended by the ICRP (ICRP, 1991). The cancer incident risk factor includes the risk for both fatal and nonfatal cancer. The risk factor for total cancer incidence is from the HEAST.

3.4.2.2 Risk of Genetic Effects

If the damage caused by radiation occurs in the germ cells, this damage (e.g., mutations and chromosomal aberrations) may be transmitted to successive cells and manifest itself as hereditary disorders in the descendants of the exposed individual. Radiation has not been identified as a cause of such effects in man, but experimental studies on plants and animals suggest that such effects will occur and that the consequences may range from the undetectably trivial, through gross malformations or loss of function, to premature death. It may be presumed that any nonlethal damage in human germ cells may be further transmitted to subsequent generations, making this type of effect hereditary.

Hereditary effects occur predominantly in the progeny of the first two generations. Some hereditary effects are seriously harmful to the affected individual and are life threatening. Chromosomal aberrations may also result in congenital abnormalities in children. In addition, there are multifactorial disorders, whereby the expression of the genetic damage requires interaction with environmental factors. No reliable estimate is available for the probability coefficient for the multifactorial conditions, but, weighted for severity, the ICRP proposes a probability of 1.3×10^{-7} per mrem (ICRP, 1991). This value is used in the risk assessment.

3.4.3 Uncertainties Relating to Toxicity Information

The major uncertainty associated with tritium toxicity is the use of the LNT dose response model that has been used in radiation protection for many years. The LNT theory states that all doses, no matter how trivial, carry some risk, and the increase in risk is linear with dose. This model was postulated during the early days of the atomic age to predict risk to members of the public from fallout caused by aboveground testing of nuclear weapons. During the last several decades, the epidemiological evidence on both human and laboratory animal data demonstrates that there is a high-threshold dose prior to any biological effects being noted (on the order of 30,000 mrem) and an even higher threshold for the induction of cancer (80,000 mrem) (Raabe et al., 1980; Raabe, 1984; Evans, 1974). At this time, the LNT is the dosimetry model recommended by the DOE, NRC, and EPA and is the model used in this risk assessment. The uncertainty related to the LNT is called model uncertainty and is beyond the scope of this study to address in detail.

3.5 Risk Characterization

Risks to human health have been estimated for six specific land uses for three pathlines from nuclear events. A dose assessment has been performed in order to compare the committed

effective dose equivalent (CEDE) with the requirements in DOE Order 5400.5 (DOE, 1993b). In addition to the dose assessment, radiocarcinogenic and hereditary risk were estimated. The lifetime risk estimated include the total cancer incidence, fatal cancer, and radiation detriment from severe hereditary effects. There are no risk limits in DOE Order 5400.5. The estimated risks are included for information purposes.

The following land uses of the UGTA were selected as a result of community involvement from the community advisory board and other public interest groups:

- Agriculture
- Industrial
- Mining
- Recreation
- Residential
- Tourism

The radiation doses to individuals due to chronic exposure to HTO while engaged in six potential NTS land-use scenarios have been calculated. The land-use scenarios were postulated to be very conservative to ensure that the calculated doses would bound any realistic dose received by individuals.

The predominant risk from radiation exposure is cancer incidence. Lifetime total cancer incidence was calculated by multiplying the EPA slope factor for tritium by the tritium intake. This gives an estimate of the lifetime probability for getting cancer. Radiation-induced cancers may have a latency period, that is a delayed onset of 20 years or longer. Therefore, fatal cancer risk is referred to as latent cancer fatality. Radiation exposure can also result in other detrimental health effects, such as genetic and hereditary effects. In this risk assessment, the genetic effects to the first two generations are combined with the risk for hereditary effect, and the sum is defined as the radiation detriment. Neither the DOE nor the EPA recommend lifetime risk limits from exposure to radiation due to DOE operations. For information purposes it may be useful to compare the risk from the radiation dose to limits established by the EPA for remediating hazardous chemical contamination at Superfunds sites. The EPA recommends a lifetime total cancer incidence (TCI) limit of 10^{-4} for proposing remediation. If the TCI risk is less than 10^{-6}, the EPA requires no remediation. In addition to the TCI, lifetime latent fatal cancer risk (LFC) and radiation detriment were estimated as a function of the dose.

For all three pathlines and at all dose locations, the limiting land-use exposure scenarios are the agriculture and the residential. The tritium intake, dose, and resultant risk from the other land-use scenarios (industrial, mining, recreation, and tourism) are significantly lower.

3.5.1 Analysis of the TYBO Pathline

As discussed in Section 3.3.3.2, Fate and Transport, the tritium concentration from the TYBO/PEPATO/KASH event includes contributions from the PEPATO and KASH events, which are located upgradient. Of the three groundwater pathlines evaluated, the TYBO/PEPTO/KASH pathline had the highest tritium concentration for all specified distances downgradient. For this groundwater pathline, the tritium concentration exceeds the limit of 20,000 pCi/L referenced in DOE Order 5400.5 (DOE, 1993b) and the EPA *Safe Drinking Water Act* (40 CFR 141) at all dose-receptor locations, from 0.1 km to 37.1 km (0.06 to 23.1 mi). The peak concentration from the TYBO/PEPATO/KASH events is computed to reach the NTS border in two years, at the northeastern edge of Oasis Valley in nine years, the Nellis Air Force Range in 10 years, and the downgradient dose-receptor location at 37.1 km (23.1 mi) in 14 years.

The results of the dose and risk calculations for potential future land-use scenarios due to groundwater flow from West Pahute Mesa, the contribution from the TYBO/PEPATO/KASH events, are listed in Table 3-9. The results show, at the 50th percentile, the dose from the limiting land-use exposure scenario, agriculture, did not exceed the 100 mrem/yr limit at dose receptor locations at or beyond 12.2 km (7.6 mi) downgradient from the PEPATO event. This distance is off the NTS, but it is on the Nellis Air Force Range.

At the 95th percentile, the dose from the agriculture and residential land-use scenarios exceeded the 100 mrem/yr dose limit in DOE Order 5400.5 (DOE, 1993b) at locations beyond the NTS and Nellis Air Force Range boundary. At the 50th and 95th percentile for all other land-use exposure scenarios, the dose did not exceed the 100 mrem/yr limit at locations beyond the Nellis Air Force Range boundary.

At the 50th percentile, the risk calculations demonstrated the following for the TYBO pathline:

- Lifetime fatal cancer risk does not exceed 10^{-4} beyond the Nellis Air Force Range boundary. For all land-use scenarios except agriculture and residential, the lifetime fatal cancer risk does not exceed 10^{-6} beyond the Nellis Air Force Range.

- The TCI does not exceed 10^{-4} for any land-use scenario at locations beyond the Nellis Air Force Range.

- The TCI exceeds 1×10^{-6} at all dose receptor locations for the agricultural, residential, mining, and industrial land-use exposure scenarios.

Table 3-9A
TYBO Agriculture Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	7.65E+00	1.31E+02	1.73E+03	1.15E-04	1.97E-03	2.59E-02	3.14E-04	5.41E-03	7.07E-02	5.28E-05	9.06E-04	1.19E-02
1	0.6	3.94E+01	5.02E+02	7.84E+03	5.91E-04	7.53E-03	1.18E-01	1.63E-03	2.04E-02	3.19E-01	2.72E-04	3.46E-03	5.41E-02
2	1.2	3.24E+01	4.72E+02	4.79E+03	4.85E-04	7.07E-03	7.18E-02	1.35E-03	1.91E-02	1.86E-01	2.23E-04	3.25E-03	3.30E-02
2.9	1.8	2.09E+01	3.44E+02	3.08E+03	3.14E-04	5.16E-03	4.63E-02	8.59E-04	1.40E-02	1.28E-01	1.44E-04	2.38E-03	2.13E-02
3.9	2.4	1.62E+01	2.64E+02	2.19E+03	2.43E-04	3.96E-03	3.29E-02	6.56E-04	1.09E-02	8.43E-02	1.12E-04	1.82E-03	1.51E-02
4.9	3.0	7.00E+00	2.00E+02	1.73E+03	1.05E-04	3.01E-03	2.60E-02	2.77E-04	8.13E-03	6.99E-02	4.83E-05	1.38E-03	1.19E-02
7.3	4.5	1.88E+01	3.12E+02	2.32E+03	2.82E-04	4.68E-03	3.49E-02	7.73E-04	1.28E-02	9.15E-02	1.30E-04	2.15E-03	1.60E-02
9.8	6.1	1.74E+01	3.66E+02	2.56E+03	2.60E-04	5.50E-03	3.84E-02	7.21E-04	1.50E-02	1.06E-01	1.20E-04	2.53E-03	1.77E-02
12.2	7.6	3.71E-03	1.29E+02	1.17E+03	5.57E-08	1.93E-03	1.76E-02	1.52E-07	5.28E-03	4.75E-02	2.56E-08	8.90E-04	8.09E-03
14.7	9.1	2.05E-03	5.64E+01	8.05E+02	3.07E-08	8.45E-04	1.21E-02	8.50E-08	2.33E-03	3.31E-02	1.41E-08	3.89E-04	5.56E-03
17.1	10.6	2.02E-03	2.81E+01	5.66E+02	3.02E-08	4.22E-04	8.49E-03	8.30E-08	1.15E-03	2.37E-02	1.39E-08	1.94E-04	3.90E-03
19.6	12.2	1.09E-03	1.18E+01	4.71E+02	1.64E-08	1.78E-04	7.07E-03	4.60E-08	4.95E-04	1.87E-02	7.53E-09	8.17E-05	3.25E-03
24.5	15.2	5.78E-04	4.59E-01	3.07E+02	8.68E-09	6.89E-06	4.60E-03	2.40E-08	1.86E-05	1.23E-02	3.99E-09	3.17E-06	2.12E-03
29.4	18.3	5.37E-04	1.33E-01	2.05E+02	8.05E-09	2.00E-06	3.07E-03	2.17E-08	5.48E-06	8.18E-03	3.70E-09	9.20E-07	1.41E-03
31.8	19.8	5.66E-04	1.32E-01	1.82E+02	8.49E-09	1.98E-06	2.73E-03	2.30E-08	5.37E-06	7.36E-03	3.90E-09	9.11E-07	1.25E-03
34.3	21.3	6.15E-04	2.49E-01	1.71E+02	9.23E-09	3.74E-06	2.57E-03	2.52E-08	1.03E-05	6.96E-03	4.25E-09	1.72E-06	1.18E-03
37.1	23.1	5.67E-04	1.24E-01	1.43E+02	8.50E-09	1.86E-06	2.14E-03	2.34E-08	5.14E-06	5.83E-03	3.91E-09	8.55E-07	9.83E-04

Table 3-9B
TYBO Agriculture Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	7.14E+00	1.26E+02	1.65E+03	3.21E-05	5.66E-04	7.41E-03	6.71E-05	1.18E-03	1.54E-02	1.48E-05	2.61E-04	3.41E-03
1	0.6	3.83E+01	4.77E+02	7.37E+03	1.73E-04	2.15E-03	3.32E-02	3.55E-04	4.42E-03	6.91E-02	7.94E-05	9.88E-04	1.53E-02
2	1.2	3.11E+01	4.47E+02	4.42E+03	1.40E-04	2.01E-03	1.99E-02	2.89E-04	4.18E-03	4.07E-02	6.43E-05	9.25E-04	9.14E-03
2.9	1.8	2.03E+01	3.27E+02	2.95E+03	9.13E-05	1.47E-03	1.33E-02	1.87E-04	3.05E-03	2.80E-02	4.20E-05	6.76E-04	6.10E-03
3.9	2.4	1.55E+01	2.51E+02	1.98E+03	6.95E-05	1.13E-03	8.89E-03	1.44E-04	2.34E-03	1.81E-02	3.20E-05	5.20E-04	4.09E-03
4.9	3.0	6.20E+00	1.90E+02	1.61E+03	2.79E-05	8.56E-04	7.27E-03	5.86E-05	1.77E-03	1.51E-02	1.28E-05	3.94E-04	3.34E-03
7.3	4.5	1.80E+01	2.98E+02	2.16E+03	8.12E-05	1.34E-03	9.74E-03	1.70E-04	2.78E-03	2.00E-02	3.73E-05	6.18E-04	4.48E-03
9.8	6.1	1.65E+01	3.47E+02	2.49E+03	7.40E-05	1.56E-03	1.12E-02	1.54E-04	3.25E-03	2.33E-02	3.41E-05	7.19E-04	5.15E-03
12.2	7.6	3.51E-03	1.22E+02	1.13E+03	1.58E-08	5.49E-04	5.10E-03	3.27E-08	1.14E-03	1.04E-02	7.27E-09	2.53E-04	2.34E-03
14.7	9.1	1.97E-03	5.36E+01	7.68E+02	8.86E-09	2.41E-04	3.46E-03	1.85E-08	5.01E-04	7.16E-03	4.07E-09	1.11E-04	1.59E-03
17.1	10.6	1.92E-03	2.66E+01	5.48E+02	8.66E-09	1.20E-04	2.47E-03	1.81E-08	2.48E-04	5.09E-03	3.98E-09	5.52E-05	1.13E-03
19.6	12.2	1.05E-03	1.16E+01	4.38E+02	4.71E-09	5.23E-05	1.97E-03	9.93E-09	1.09E-04	4.03E-03	2.17E-09	2.41E-05	9.06E-04
24.5	15.2	5.34E-04	4.38E-01	2.82E+02	2.40E-09	1.97E-06	1.27E-03	5.12E-09	4.05E-06	2.66E-03	1.11E-09	9.07E-07	5.84E-04
29.4	18.3	5.11E-04	1.29E-01	1.90E+02	2.30E-09	5.82E-07	8.55E-04	4.73E-09	1.21E-06	1.78E-03	1.06E-09	2.68E-07	3.93E-04
31.8	19.8	5.21E-04	1.24E-01	1.73E+02	2.34E-09	5.60E-07	7.80E-04	4.90E-09	1.15E-06	1.61E-03	1.08E-09	2.57E-07	3.59E-04
34.3	21.3	5.98E-04	2.43E-01	1.61E+02	2.69E-09	1.09E-06	7.24E-04	5.63E-09	2.21E-06	1.52E-03	1.24E-09	5.02E-07	3.33E-04
37.1	23.1	5.46E-04	1.16E-01	1.36E+02	2.46E-09	5.23E-07	6.13E-04	5.09E-09	1.09E-06	1.27E-03	1.13E-09	2.40E-07	2.82E-04

Table 3-9C
TYBO Industrial Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	3.99E+00	6.11E+01	8.19E+02	5.99E-05	9.16E-04	1.23E-02	1.62E-04	2.51E-03	3.33E-02	2.76E-05	4.21E-04	5.65E-03
1	0.6	1.88E+01	2.40E+02	3.69E+03	2.82E-04	3.60E-03	5.53E-02	8.01E-04	9.68E-03	1.48E-01	1.30E-04	1.65E-03	2.55E-02
2	1.2	1.43E+01	2.37E+02	2.35E+03	2.15E-04	3.55E-03	3.52E-02	5.86E-04	9.64E-03	9.20E-02	9.87E-05	1.63E-03	1.62E-02
2.9	1.8	1.04E+01	1.69E+02	1.49E+03	1.57E-04	2.54E-03	2.23E-02	4.41E-04	6.91E-03	6.17E-02	7.21E-05	1.17E-03	1.03E-02
3.9	2.4	8.66E+00	1.31E+02	1.04E+03	1.30E-04	1.96E-03	1.56E-02	3.60E-04	5.32E-03	3.97E-02	5.98E-05	9.01E-04	7.16E-03
4.9	3.0	3.56E+00	1.02E+02	8.68E+02	5.34E-05	1.53E-03	1.30E-02	1.52E-04	4.11E-03	3.47E-02	2.46E-05	7.04E-04	5.99E-03
7.3	4.5	8.90E+00	1.56E+02	1.16E+03	1.34E-04	2.34E-03	1.74E-02	3.66E-04	6.44E-03	4.60E-02	6.14E-05	1.08E-03	7.99E-03
9.8	6.1	7.58E+00	1.85E+02	1.32E+03	1.14E-04	2.77E-03	1.97E-02	3.10E-04	7.50E-03	5.38E-02	5.23E-05	1.27E-03	9.08E-03
12.2	7.6	1.87E-03	6.35E+01	5.79E+02	2.80E-08	9.52E-04	8.69E-03	7.65E-08	2.61E-03	2.34E-02	1.29E-08	4.38E-04	4.00E-03
14.7	9.1	1.07E-03	2.74E+01	3.96E+02	1.60E-08	4.12E-04	5.95E-03	4.41E-08	1.12E-03	1.61E-02	7.37E-09	1.89E-04	2.74E-03
17.1	10.6	1.03E-03	1.46E+01	2.91E+02	1.54E-08	2.19E-04	4.37E-03	4.29E-08	6.05E-04	1.20E-02	7.10E-09	1.01E-04	2.01E-03
19.6	12.2	5.02E-04	4.80E+00	2.13E+02	7.53E-09	7.20E-05	3.19E-03	2.07E-08	1.94E-04	8.35E-03	3.47E-09	3.31E-05	1.47E-03
24.5	15.2	2.71E-04	2.16E-01	1.46E+02	4.07E-09	3.25E-06	2.19E-03	1.11E-08	8.87E-06	5.98E-03	1.87E-09	1.49E-06	1.01E-03
29.4	18.3	2.48E-04	7.21E-02	1.10E+02	3.73E-09	1.08E-06	1.65E-03	1.03E-08	2.98E-06	4.32E-03	1.71E-09	4.97E-07	7.57E-04
31.8	19.8	2.72E-04	5.05E-02	1.01E+02	4.08E-09	7.57E-07	1.52E-03	1.11E-08	2.06E-06	4.01E-03	1.88E-09	3.48E-07	6.99E-04
34.3	21.3	2.81E-04	1.04E-01	7.52E+01	4.21E-09	1.56E-06	1.13E-03	1.15E-08	4.25E-06	3.09E-03	1.94E-09	7.18E-07	5.19E-04
37.1	23.1	2.65E-04	5.84E-02	6.95E+01	3.98E-09	8.76E-07	1.04E-03	1.11E-08	2.41E-06	2.91E-03	1.83E-09	4.03E-07	4.79E-04

Figure 3-9D
TYBO Mining Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	3.72E+00	5.70E+01	7.79E+02	5.59E-05	8.56E-04	1.17E-02	1.52E-04	2.33E-03	3.15E-02	2.57E-05	3.94E-04	5.38E-03
1	0.6	1.77E+01	2.26E+02	3.46E+03	2.65E-04	3.38E-03	5.19E-02	7.43E-04	9.09E-03	1.42E-01	1.22E-04	1.56E-03	2.39E-02
2	1.2	1.32E+01	2.24E+02	2.24E+03	1.97E-04	3.35E-03	3.35E-02	5.38E-04	8.98E-03	8.83E-02	9.08E-05	1.54E-03	1.54E-02
2.9	1.8	9.49E+00	1.60E+02	1.42E+03	1.42E-04	2.40E-03	2.12E-02	4.11E-04	6.51E-03	5.77E-02	6.55E-05	1.10E-03	9.77E-03
3.9	2.4	7.70E+00	1.23E+02	9.50E+02	1.15E-04	1.84E-03	1.42E-02	3.20E-04	5.02E-03	3.75E-02	5.31E-05	8.48E-04	6.55E-03
4.9	3.0	3.38E+00	9.70E+01	7.96E+02	5.07E-05	1.45E-03	1.19E-02	1.36E-04	3.92E-03	3.20E-02	2.33E-05	6.69E-04	5.49E-03
7.3	4.5	8.53E+00	1.49E+02	1.12E+03	1.28E-04	2.23E-03	1.67E-02	3.52E-04	6.05E-03	4.37E-02	5.89E-05	1.03E-03	7.70E-03
9.8	6.1	6.98E+00	1.76E+02	1.24E+03	1.05E-04	2.63E-03	1.86E-02	2.79E-04	7.10E-03	5.12E-02	4.82E-05	1.21E-03	8.54E-03
12.2	7.6	1.83E-03	6.04E+01	5.56E+02	2.74E-08	9.06E-04	8.35E-03	7.20E-08	2.47E-03	2.25E-02	1.26E-08	4.17E-04	3.84E-03
14.7	9.1	1.03E-03	2.56E+01	3.78E+02	1.55E-08	3.84E-04	5.67E-03	4.18E-08	1.07E-03	1.53E-02	7.11E-09	1.77E-04	2.61E-03
17.1	10.6	9.83E-04	1.40E+01	2.75E+02	1.47E-08	2.10E-04	4.12E-03	3.99E-08	5.69E-04	1.13E-02	6.78E-09	9.65E-05	1.89E-03
19.6	12.2	4.84E-04	4.55E+00	2.02E+02	7.26E-09	6.83E-05	3.03E-03	1.98E-08	1.85E-04	7.96E-03	3.34E-09	3.14E-05	1.39E-03
24.5	15.2	2.52E-04	2.06E-01	1.33E+02	3.78E-09	3.10E-06	1.99E-03	1.05E-08	8.36E-06	5.52E-03	1.74E-09	1.42E-06	9.17E-04
29.4	18.3	2.36E-04	6.96E-02	1.03E+02	3.55E-09	1.04E-06	1.54E-03	9.67E-09	2.81E-06	4.00E-03	1.63E-09	4.80E-07	7.09E-04
31.8	19.8	2.56E-04	4.66E-02	9.36E+01	3.84E-09	6.99E-07	1.40E-03	1.05E-08	1.89E-06	3.77E-03	1.77E-09	3.21E-07	6.46E-04
34.3	21.3	2.57E-04	9.78E-02	6.96E+01	3.85E-09	1.47E-06	1.04E-03	1.08E-08	4.00E-06	2.82E-03	1.77E-09	6.75E-07	4.80E-04
37.1	23.1	2.54E-04	5.49E-02	6.77E+01	3.81E-09	8.24E-07	1.02E-03	1.02E-08	2.23E-06	2.74E-03	1.75E-09	3.79E-07	4.67E-04

Figure 3-9E
TYBO Recreation Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	1.51E+00	2.32E+01	3.22E+02	2.26E-05	3.48E-04	4.83E-03	6.13E-05	9.49E-04	1.30E-02	1.04E-05	1.60E-04	2.22E-03
1	0.6	6.91E+00	8.56E+01	1.48E+03	1.04E-04	1.28E-03	2.22E-02	2.85E-04	3.44E-03	6.02E-02	4.77E-05	5.90E-04	1.02E-02
2	1.2	5.06E+00	8.45E+01	8.77E+02	7.60E-05	1.27E-03	1.32E-02	2.10E-04	3.39E-03	3.43E-02	3.49E-05	5.83E-04	6.05E-03
2.9	1.8	3.49E+00	6.41E+01	5.39E+02	5.24E-05	9.61E-04	8.08E-03	1.48E-04	2.60E-03	2.24E-02	2.41E-05	4.42E-04	3.72E-03
3.9	2.4	3.08E+00	4.85E+01	3.86E+02	4.62E-05	7.27E-04	5.79E-03	1.26E-04	1.99E-03	1.49E-02	2.12E-05	3.34E-04	2.66E-03
4.9	3.0	9.72E-01	3.61E+01	3.14E+02	1.46E-05	5.41E-04	4.70E-03	4.24E-05	1.46E-03	1.25E-02	6.71E-06	2.49E-04	2.16E-03
7.3	4.5	3.08E+00	5.54E+01	4.37E+02	4.62E-05	8.32E-04	6.56E-03	1.25E-04	2.28E-03	1.72E-02	2.13E-05	3.83E-04	3.02E-03
9.8	6.1	3.30E+00	6.97E+01	4.81E+02	4.95E-05	1.05E-03	7.21E-03	1.40E-04	2.82E-03	1.94E-02	2.28E-05	4.81E-04	3.32E-03
12.2	7.6	7.07E-04	2.36E+01	2.24E+02	1.06E-08	3.53E-04	3.36E-03	2.93E-08	9.73E-04	9.09E-03	4.88E-09	1.63E-04	1.55E-03
14.7	9.1	3.81E-04	9.95E+00	1.53E+02	5.72E-09	1.49E-04	2.29E-03	1.54E-08	4.07E-04	6.07E-03	2.63E-09	6.86E-05	1.05E-03
17.1	10.6	3.55E-04	5.58E+00	1.14E+02	5.33E-09	8.37E-05	1.70E-03	1.45E-08	2.29E-04	4.63E-03	2.45E-09	3.85E-05	7.83E-04
19.6	12.2	1.78E-04	2.05E+00	8.06E+01	2.66E-09	3.07E-05	1.21E-03	7.51E-09	8.27E-05	3.22E-03	1.23E-09	1.41E-05	5.56E-04
24.5	15.2	1.06E-04	7.25E-02	4.74E+01	1.60E-09	1.09E-06	7.11E-04	4.38E-09	2.97E-06	1.93E-03	7.34E-10	5.00E-07	3.27E-04
29.4	18.3	9.59E-05	2.16E-02	3.82E+01	1.44E-09	3.23E-07	5.73E-04	3.95E-09	8.57E-07	1.52E-03	6.62E-10	1.49E-07	2.64E-04
31.8	19.8	9.75E-05	1.72E-02	3.43E+01	1.46E-09	2.58E-07	5.14E-04	4.03E-09	6.88E-07	1.38E-03	6.73E-10	1.18E-07	2.37E-04
34.3	21.3	1.02E-04	4.43E-02	2.95E+01	1.52E-09	6.65E-07	4.42E-04	4.20E-09	1.76E-06	1.20E-03	7.01E-10	3.06E-07	2.04E-04
37.1	23.1	9.94E-05	2.39E-02	2.68E+01	1.49E-09	3.58E-07	4.01E-04	4.03E-09	1.01E-06	1.08E-03	6.86E-10	1.65E-07	1.85E-04

Table 3-9F
TYBO Recreation Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	8.19E-01	1.25E+01	1.72E+02	3.69E-06	5.63E-05	7.75E-04	7.56E-06	1.17E-04	1.61E-03	1.70E-06	2.59E-05	3.56E-04
1	0.6	3.76E+00	4.54E+01	8.19E+02	1.69E-05	2.04E-04	3.68E-03	3.51E-05	4.25E-04	7.54E-03	7.78E-06	9.39E-05	1.69E-03
2	1.2	2.84E+00	4.42E+01	4.55E+02	1.28E-05	1.99E-04	2.05E-03	2.63E-05	4.11E-04	4.14E-03	5.87E-06	9.15E-05	9.43E-04
2.9	1.8	1.90E+00	3.43E+01	3.02E+02	8.57E-06	1.55E-04	1.36E-03	1.84E-05	3.21E-04	2.84E-03	3.94E-06	7.11E-05	6.26E-04
3.9	2.4	1.69E+00	2.64E+01	1.97E+02	7.62E-06	1.19E-04	8.88E-04	1.61E-05	2.47E-04	1.80E-03	3.51E-06	5.46E-05	4.08E-04
4.9	3.0	5.38E-01	1.93E+01	1.63E+02	2.42E-06	8.69E-05	7.35E-04	5.02E-06	1.81E-04	1.55E-03	1.11E-06	4.00E-05	3.38E-04
7.3	4.5	1.63E+00	3.02E+01	2.22E+02	7.32E-06	1.36E-04	1.00E-03	1.54E-05	2.84E-04	2.06E-03	3.37E-06	6.25E-05	4.60E-04
9.8	6.1	1.93E+00	3.74E+01	2.61E+02	8.68E-06	1.68E-04	1.17E-03	1.78E-05	3.49E-04	2.48E-03	3.99E-06	7.74E-05	5.40E-04
12.2	7.6	3.84E-04	1.29E+01	1.18E+02	1.73E-09	5.80E-05	5.32E-04	3.57E-09	1.20E-04	1.10E-03	7.96E-10	2.67E-05	2.45E-04
14.7	9.1	2.06E-04	5.51E+00	7.99E+01	9.26E-10	2.48E-05	3.59E-04	1.92E-09	5.14E-05	7.53E-04	4.26E-10	1.14E-05	1.65E-04
17.1	10.6	1.91E-04	3.03E+00	6.11E+01	8.61E-10	1.36E-05	2.75E-04	1.77E-09	2.84E-05	5.76E-04	3.96E-10	6.26E-06	1.26E-04
19.6	12.2	1.01E-04	1.11E+00	4.19E+01	4.52E-10	4.99E-06	1.89E-04	9.43E-10	1.03E-05	3.86E-04	2.08E-10	2.30E-06	8.68E-05
24.5	15.2	5.77E-05	3.87E-02	2.62E+01	2.60E-10	1.74E-07	1.18E-04	5.43E-10	3.59E-07	2.44E-04	1.19E-10	8.01E-08	5.42E-05
29.4	18.3	5.17E-05	1.13E-02	2.05E+01	2.33E-10	5.10E-08	9.23E-05	4.79E-10	1.07E-07	1.90E-04	1.07E-10	2.35E-08	4.25E-05
31.8	19.8	5.41E-05	8.98E-03	1.83E+01	2.43E-10	4.04E-08	8.22E-05	5.03E-10	8.30E-08	1.69E-04	1.12E-10	1.86E-08	3.78E-05
34.3	21.3	5.68E-05	2.40E-02	1.56E+01	2.56E-10	1.08E-07	7.04E-05	5.28E-10	2.22E-07	1.48E-04	1.18E-10	4.97E-08	3.24E-05
37.1	23.1	5.27E-05	1.34E-02	1.46E+01	2.37E-10	6.03E-08	6.57E-05	4.95E-10	1.27E-07	1.36E-04	1.09E-10	2.77E-08	3.02E-05

Table 3-9G
TYBO Residential Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	5.27E+00	8.12E+01	1.13E+03	7.91E-05	1.22E-03	1.69E-02	2.15E-04	3.32E-03	4.55E-02	3.64E-05	5.60E-04	7.78E-03
1	0.6	2.42E+01	2.99E+02	5.19E+03	3.63E-04	4.49E-03	7.78E-02	9.96E-04	1.20E-02	2.10E-01	1.67E-04	2.07E-03	3.58E-02
2	1.2	1.77E+01	2.96E+02	3.07E+03	2.66E-04	4.43E-03	4.60E-02	7.36E-04	1.19E-02	1.20E-01	1.22E-04	2.04E-03	2.12E-02
2.9	1.8	1.22E+01	2.24E+02	1.89E+03	1.83E-04	3.36E-03	2.83E-02	5.19E-04	9.11E-03	7.84E-02	8.43E-05	1.55E-03	1.30E-02
3.9	2.4	1.08E+01	1.70E+02	1.35E+03	1.62E-04	2.54E-03	2.03E-02	4.41E-04	6.96E-03	5.21E-02	7.43E-05	1.17E-03	9.32E-03
4.9	3.0	3.40E+00	1.26E+02	1.10E+03	5.10E-05	1.89E-03	1.65E-02	1.48E-04	5.11E-03	4.38E-02	2.35E-05	8.71E-04	7.57E-03
7.3	4.5	1.08E+01	1.94E+02	1.53E+03	1.62E-04	2.91E-03	2.30E-02	4.39E-04	7.99E-03	6.02E-02	7.44E-05	1.34E-03	1.06E-02
9.8	6.1	1.15E+01	2.44E+02	1.68E+03	1.73E-04	3.66E-03	2.52E-02	4.88E-04	9.87E-03	6.78E-02	7.96E-05	1.68E-03	1.16E-02
12.2	7.6	2.47E-03	8.25E+01	7.84E+02	3.71E-08	1.24E-03	1.18E-02	1.03E-07	3.41E-03	3.18E-02	1.71E-08	5.69E-04	5.41E-03
14.7	9.1	1.33E-03	3.48E+01	5.34E+02	2.00E-08	5.22E-04	8.01E-03	5.38E-08	1.42E-03	2.12E-02	9.20E-09	2.40E-04	3.69E-03
17.1	10.6	1.24E-03	1.95E+01	3.97E+02	1.87E-08	2.93E-04	5.96E-03	5.07E-08	8.01E-04	1.62E-02	8.58E-09	1.35E-04	2.74E-03
19.6	12.2	6.22E-04	7.17E+00	2.82E+02	9.33E-09	1.08E-04	4.23E-03	2.63E-08	2.89E-04	1.13E-02	4.29E-09	4.95E-05	1.95E-03
24.5	15.2	3.72E-04	2.54E-01	1.66E+02	5.59E-09	3.81E-06	2.49E-03	1.53E-08	1.04E-05	6.74E-03	2.57E-09	1.75E-06	1.14E-03
29.4	18.3	3.36E-04	7.55E-02	1.34E+02	5.04E-09	1.13E-06	2.00E-03	1.38E-08	3.00E-06	5.33E-03	2.32E-09	5.21E-07	9.22E-04
31.8	19.8	3.41E-04	6.01E-02	1.20E+02	5.12E-09	9.01E-07	1.80E-03	1.41E-08	2.41E-06	4.83E-03	2.36E-09	4.15E-07	8.28E-04
34.3	21.3	3.55E-04	1.55E-01	1.03E+02	5.33E-09	2.33E-06	1.55E-03	1.47E-08	6.17E-06	4.19E-03	2.45E-09	1.07E-06	7.12E-04
37.1	23.1	3.48E-04	8.35E-02	9.37E+01	5.22E-09	1.25E-06	1.40E-03	1.41E-08	3.55E-06	3.79E-03	2.40E-09	5.76E-07	6.46E-04

Table 3-9H
TYBO Residential Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	2.87E+00	4.38E+01	6.03E+02	1.29E-05	1.97E-04	2.71E-03	2.65E-05	4.11E-04	5.63E-03	5.94E-06	9.06E-05	1.25E-03
1	0.6	1.32E+01	1.59E+02	2.87E+03	5.92E-05	7.14E-04	1.29E-02	1.23E-04	1.49E-03	2.64E-02	2.72E-05	3.29E-04	5.93E-03
2	1.2	9.93E+00	1.55E+02	1.59E+03	4.47E-05	6.97E-04	7.17E-03	9.21E-05	1.44E-03	1.45E-02	2.06E-05	3.20E-04	3.30E-03
2.9	1.8	6.67E+00	1.20E+02	1.06E+03	3.00E-05	5.41E-04	4.76E-03	6.44E-05	1.12E-03	9.93E-03	1.38E-05	2.49E-04	2.19E-03
3.9	2.4	5.93E+00	9.23E+01	6.91E+02	2.67E-05	4.15E-04	3.11E-03	5.62E-05	8.66E-04	6.29E-03	1.23E-05	1.91E-04	1.43E-03
4.9	3.0	1.88E+00	6.76E+01	5.72E+02	8.47E-06	3.04E-04	2.57E-03	1.76E-05	6.32E-04	5.41E-03	3.90E-06	1.40E-04	1.18E-03
7.3	4.5	5.69E+00	1.06E+02	7.78E+02	2.56E-05	4.76E-04	3.50E-03	5.40E-05	9.94E-04	7.21E-03	1.18E-05	2.19E-04	1.61E-03
9.8	6.1	6.75E+00	1.31E+02	9.13E+02	3.04E-05	5.89E-04	4.11E-03	6.24E-05	1.22E-03	8.69E-03	1.40E-05	2.71E-04	1.89E-03
12.2	7.6	1.35E-03	4.51E+01	4.14E+02	6.06E-09	2.03E-04	1.86E-03	1.25E-08	4.22E-04	3.87E-03	2.79E-09	9.34E-05	8.56E-04
14.7	9.1	7.20E-04	1.93E+01	2.80E+02	3.24E-09	8.68E-05	1.26E-03	6.72E-09	1.80E-04	2.64E-03	1.49E-09	3.99E-05	5.79E-04
17.1	10.6	6.69E-04	1.06E+01	2.14E+02	3.01E-09	4.77E-05	9.62E-04	6.20E-09	9.96E-05	2.02E-03	1.39E-09	2.19E-05	4.42E-04
19.6	12.2	3.52E-04	3.88E+00	1.47E+02	1.58E-09	1.75E-05	6.60E-04	3.30E-09	3.62E-05	1.35E-03	7.28E-10	8.04E-06	3.04E-04
24.5	15.2	2.02E-04	1.35E-01	9.16E+01	9.09E-10	6.10E-07	4.12E-04	1.90E-09	1.26E-06	8.53E-04	4.18E-10	2.80E-07	1.90E-04
29.4	18.3	1.81E-04	3.97E-02	7.18E+01	8.15E-10	1.79E-07	3.23E-04	1.68E-09	3.76E-07	6.65E-04	3.75E-10	8.22E-08	1.49E-04
31.8	19.8	1.89E-04	3.14E-02	6.39E+01	8.52E-10	1.41E-07	2.88E-04	1.76E-09	2.91E-07	5.91E-04	3.92E-10	6.51E-08	1.32E-04
34.3	21.3	1.99E-04	8.40E-02	5.47E+01	8.95E-10	3.78E-07	2.46E-04	1.85E-09	7.78E-07	5.17E-04	4.12E-10	1.74E-07	1.13E-04
37.1	23.1	1.85E-04	4.69E-02	5.11E+01	8.31E-10	2.11E-07	2.30E-04	1.73E-09	4.44E-07	4.76E-04	3.82E-10	9.70E-08	1.06E-04

Table 3-9I
TYBO Tourism Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	2.09E-01	3.23E+00	4.51E+01	3.14E-06	4.84E-05	6.76E-04	8.57E-06	1.34E-04	1.87E-03	1.44E-06	2.23E-05	3.11E-04
1	0.6	9.47E-01	1.21E+01	1.77E+02	1.42E-05	1.81E-04	2.66E-03	3.91E-05	4.92E-04	7.33E-03	6.53E-06	8.33E-05	1.22E-03
2	1.2	7.17E-01	1.20E+01	1.28E+02	1.08E-05	1.81E-04	1.92E-03	2.86E-05	4.92E-04	5.05E-03	4.95E-06	8.30E-05	8.82E-04
2.9	1.8	5.75E-01	8.90E+00	7.83E+01	8.62E-06	1.33E-04	1.18E-03	2.36E-05	3.64E-04	3.19E-03	3.97E-06	6.14E-05	5.41E-04
3.9	2.4	4.00E-01	6.78E+00	5.54E+01	6.00E-06	1.02E-04	8.30E-04	1.63E-05	2.78E-04	2.21E-03	2.76E-06	4.68E-05	3.82E-04
4.9	3.0	1.66E-01	5.33E+00	4.45E+01	2.49E-06	7.99E-05	6.67E-04	7.07E-06	2.18E-04	1.81E-03	1.14E-06	3.68E-05	3.07E-04
7.3	4.5	4.29E-01	8.09E+00	6.04E+01	6.43E-06	1.21E-04	9.06E-04	1.79E-05	3.35E-04	2.43E-03	2.96E-06	5.58E-05	4.17E-04
9.8	6.1	3.59E-01	9.75E+00	6.83E+01	5.39E-06	1.46E-04	1.02E-03	1.59E-05	3.98E-04	2.76E-03	2.48E-06	6.73E-05	4.71E-04
12.2	7.6	1.09E-04	3.30E+00	3.24E+01	1.63E-09	4.95E-05	4.87E-04	4.28E-09	1.34E-04	1.31E-03	7.50E-10	2.28E-05	2.24E-04
14.7	9.1	5.53E-05	1.38E+00	2.06E+01	8.30E-10	2.07E-05	3.09E-04	2.31E-09	5.66E-05	8.33E-04	3.82E-10	9.50E-06	1.42E-04
17.1	10.6	5.57E-05	7.47E-01	1.58E+01	8.36E-10	1.12E-05	2.38E-04	2.30E-09	3.06E-05	6.50E-04	3.85E-10	5.15E-06	1.09E-04
19.6	12.2	2.71E-05	2.75E-01	1.21E+01	4.06E-10	4.12E-06	1.81E-04	1.10E-09	1.14E-05	4.80E-04	1.87E-10	1.90E-06	8.34E-05
24.5	15.2	1.42E-05	1.19E-02	7.18E+00	2.13E-10	1.79E-07	1.08E-04	5.94E-10	4.81E-07	2.90E-04	9.81E-11	8.22E-08	4.96E-05
29.4	18.3	1.36E-05	4.20E-03	5.61E+00	2.05E-10	6.30E-08	8.42E-05	5.63E-10	1.71E-07	2.28E-04	9.41E-11	2.90E-08	3.87E-05
31.8	19.8	1.32E-05	3.19E-03	5.04E+00	1.97E-10	4.78E-08	7.57E-05	5.32E-10	1.31E-07	2.07E-04	9.07E-11	2.20E-08	3.48E-05
34.3	21.3	1.43E-05	5.15E-03	3.83E+00	2.14E-10	7.72E-08	5.75E-05	5.79E-10	2.10E-07	1.59E-04	9.86E-11	3.55E-08	2.65E-05
37.1	23.1	1.40E-05	2.37E-03	3.73E+00	2.11E-10	3.55E-08	5.59E-05	5.92E-10	9.41E-08	1.54E-04	9.69E-11	1.63E-08	2.57E-05

Table 3-9J
TYBO Tourism Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	1.11E-01	1.74E+00	2.41E+01	5.01E-07	7.84E-06	1.08E-04	1.04E-06	1.62E-05	2.23E-04	2.30E-07	3.61E-06	4.98E-05
1	0.6	5.12E-01	6.41E+00	9.45E+01	2.30E-06	2.88E-05	4.25E-04	4.74E-06	5.98E-05	8.85E-04	1.06E-06	1.33E-05	1.96E-04
2	1.2	3.77E-01	6.28E+00	6.50E+01	1.70E-06	2.83E-05	2.93E-04	3.52E-06	5.90E-05	5.95E-04	7.80E-07	1.30E-05	1.35E-04
2.9	1.8	3.11E-01	4.77E+00	4.14E+01	1.40E-06	2.14E-05	1.86E-04	2.91E-06	4.42E-05	3.88E-04	6.44E-07	9.86E-06	8.57E-05
3.9	2.4	2.19E-01	3.66E+00	2.88E+01	9.83E-07	1.65E-05	1.29E-04	2.04E-06	3.42E-05	2.65E-04	4.52E-07	7.58E-06	5.95E-05
4.9	3.0	9.08E-02	2.79E+00	2.34E+01	4.09E-07	1.26E-05	1.06E-04	8.25E-07	2.60E-05	2.17E-04	1.88E-07	5.78E-06	4.85E-05
7.3	4.5	2.24E-01	4.34E+00	3.10E+01	1.01E-06	1.95E-05	1.40E-04	2.16E-06	4.04E-05	2.85E-04	4.64E-07	8.99E-06	6.43E-05
9.8	6.1	1.98E-01	5.20E+00	3.61E+01	8.90E-07	2.34E-05	1.62E-04	1.89E-06	4.83E-05	3.37E-04	4.09E-07	1.08E-05	7.47E-05
12.2	7.6	5.53E-05	1.78E+00	1.69E+01	2.49E-10	8.02E-06	7.61E-05	5.02E-10	1.66E-05	1.58E-04	1.15E-10	3.69E-06	3.50E-05
14.7	9.1	3.07E-05	7.37E-01	1.07E+01	1.38E-10	3.32E-06	4.81E-05	2.88E-10	6.90E-06	1.00E-04	6.35E-11	1.53E-06	2.21E-05
17.1	10.6	3.01E-05	3.94E-01	8.32E+00	1.35E-10	1.77E-06	3.74E-05	2.83E-10	3.71E-06	7.81E-05	6.23E-11	8.15E-07	1.72E-05
19.6	12.2	1.44E-05	1.52E-01	6.32E+00	6.47E-11	6.85E-07	2.85E-05	1.37E-10	1.41E-06	5.76E-05	2.98E-11	3.15E-07	1.31E-05
24.5	15.2	7.73E-06	6.44E-03	3.79E+00	3.48E-11	2.90E-08	1.71E-05	7.30E-11	6.00E-08	3.51E-05	1.60E-11	1.33E-08	7.85E-06
29.4	18.3	7.24E-06	2.19E-03	2.95E+00	3.26E-11	9.87E-09	1.33E-05	6.82E-11	2.05E-08	2.72E-05	1.50E-11	4.54E-09	6.11E-06
31.8	19.8	7.11E-06	1.67E-03	2.66E+00	3.20E-11	7.52E-09	1.20E-05	6.48E-11	1.56E-08	2.47E-05	1.47E-11	3.46E-09	5.51E-06
34.3	21.3	7.74E-06	2.72E-03	2.02E+00	3.48E-11	1.22E-08	9.10E-06	7.23E-11	2.56E-08	1.89E-05	1.60E-11	5.63E-09	4.18E-06
37.1	23.1	7.63E-06	1.23E-03	2.02E+00	3.43E-11	5.55E-09	9.10E-06	7.10E-11	1.16E-08	1.89E-05	1.58E-11	2.55E-09	4.19E-06

At the 95th percentile, the latent cancer fatality, radiation detriment, and total cancer incidence risk exceeded 10^{-4} for all dose-receptor locations for the agriculture, residential, industrial, mining, and recreation land-use exposure scenarios.

3.5.2 Analysis of the BOURBON Pathline

As discussed in Section 3.3.2.2, the tritium concentration in the groundwater flow from Central Pahute Mesa toward Oasis Valley includes contributions from the BOURBON, KANKAKEE, MICKEY, and TORRIDO events. The tritium concentration in this pathline exceeds the limit of 20,000 pCi/L until it reaches 35 km (21.7 mi) downgradient. No off-NTS location exceeds the limit of 20,00 pCi/L. The peak tritium concentration does not reach the site boundary at 70 km (43.5 mi) for 61 years. At that time, the peak tritium concentration in groundwater, at the 95th percentile, is only 44.4 pCi/L, which is not significantly different than the background concentrations of tritium in surface waters.

Analysis of the BOURBON pathline demonstrates the following:

- At the 50th percentile, the dose to the most limiting dose receptor does not exceed 100 mrem/yr at distances beyond 12.5 km (7.8 mi). The latent cancer fatality, total cancer incidence, and radiation detriment risks are less than 10^{-6} for all land-use exposure scenarios at downgradient locations greater than 20 km (12.4 mi).

- At the 95th percentile, the dose was less than 100 mrem/yr at greater than 20 km (12.4 mi) downgradient from the KANKAKEE event for all land-use exposure scenarios.

- At the 95th percentile, the latent cancer fatality, total cancer incidence, and radiation detriment did exceed 10^{-6} at any off-NTS location.

The results of dose and risk calculations for potential future land-use scenarios for the BOURBON pathline are listed in Table 3-10.

3.5.3 Analysis of the HOUSTON Pathline

For the HOUSTON pathline from Yucca Flat toward Ash Meadows, the tritium concentration exceeded 20,000 pCi/L at dose-receptor locations off the NTS and the Nellis Air Force Range. The peak concentration in the HOUSTON pathline is predicted to reach the NTS border in 16 years and the western border of the Nellis Air Force Range in 22 years.

These results of the dose and risk calculations for potential land-use exposure scenarios on the HOUSTON pathline are listed in Table 3-11. At no location off the Nellis Air Force Range does the calculated dose exceed 4 mrem/yr, even at the 95th percentile.

At both the 50th and 95th percentile, the dose from the most limiting land-use exposure scenarios, agricultural and residential, did not exceed the 100 mrem/yr dose rate limit at any off-site location.

At the 50th percentile, the lifetime fatal cancer risk, total cancer incidence, and radiation detriment risk did not exceed 10^{-6} at any location beyond the NT boundary for any land-use exposure scenario.

At the 95th percentile, the calculated risks demonstrate the following:

- For all land-use exposure scenarios, the lifetime fatal cancer risk did not exceed 10^{-4} at any location beyond the NTS boundary. The lifetime fatal cancer risk does not exceed 10^{-6} at locations beyond the Nellis Air Force Range for any land-use scenario.

- The TCI does not exceed 10^{-4} at any location beyond the Nellis Air Force Range and does not exceed 10^{-4} beyond the NTS boundary, except for the agriculture land-use scenario. The TCI does not exceed 10^{-6} beyond the Nellis Air Force Range for any land-use scenarios except agriculture.

- The radiation detriment risk does not exceed the suggested risk value of 10^{-4} at any off-site location. The radiation detriment does not exceed 10^{-6} at locations beyond the Nellis Air Force Range boundary.

3.5.4 Uncertainties

The results of any risk assessment contain uncertainties due to the following general sources:

- Parameter uncertainties
- Completeness uncertainties
- Model uncertainties

Table 3-10A
BOURBON Agriculture Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	3.17E+01	7.08E+02	1.34E+04	4.76E-04	1.06E-02	2.01E-01	1.33E-03	2.93E-02	5.47E-01	2.19E-04	4.89E-03	9.23E-02
1	0.6	1.06E+01	4.43E+02	4.32E+03	1.59E-04	6.65E-03	6.48E-02	4.54E-04	1.78E-02	1.69E-01	7.33E-05	3.06E-03	2.98E-02
2	1.2	3.94E-01	1.91E+02	1.80E+03	5.92E-06	2.86E-03	2.70E-02	1.61E-05	7.74E-03	7.19E-02	2.72E-06	1.32E-03	1.24E-02
3	1.9	3.56E-03	8.49E+01	9.06E+02	5.35E-08	1.27E-03	1.36E-02	1.41E-07	3.45E-03	3.65E-02	2.46E-08	5.86E-04	6.25E-03
4	2.5	1.84E-03	3.26E+01	5.23E+02	2.77E-08	4.88E-04	7.85E-03	7.53E-08	1.34E-03	2.05E-02	1.27E-08	2.25E-04	3.61E-03
5	3.1	1.17E-03	1.15E+01	3.59E+02	1.75E-08	1.73E-04	5.38E-03	4.88E-08	4.71E-04	1.47E-02	8.05E-09	7.96E-05	2.47E-03
7.5	4.7	2.06E-03	9.57E+00	2.05E+02	3.09E-08	1.44E-04	3.08E-03	8.58E-08	3.88E-04	8.10E-03	1.42E-08	6.61E-05	1.42E-03
10	6.2	2.13E+01	4.09E+02	3.97E+03	3.20E-04	6.13E-03	5.95E-02	8.96E-04	1.65E-02	1.59E-01	1.47E-04	2.82E-03	2.74E-02
12.5	7.8	9.79E+01	8.13E+02	1.13E+04	1.47E-03	1.22E-02	1.69E-01	4.09E-03	3.30E-02	4.35E-01	6.76E-04	5.61E-03	7.77E-02
15	9.3	2.47E-03	5.31E+01	8.73E+02	3.70E-08	7.97E-04	1.31E-02	1.00E-07	2.16E-03	3.56E-02	1.70E-08	3.66E-04	6.02E-03
17.5	10.9	9.38E-04	1.74E+00	2.37E+02	1.41E-08	2.61E-05	3.55E-03	3.83E-08	7.17E-05	9.59E-03	6.47E-09	1.20E-05	1.63E-03
20	12.4	4.64E-04	6.37E-03	8.38E+01	6.96E-09	9.56E-08	1.26E-03	1.91E-08	2.55E-07	3.41E-03	3.20E-09	4.40E-08	5.78E-04
25	15.5	3.34E-04	3.07E-03	1.92E+01	5.01E-09	4.61E-08	2.88E-04	1.33E-08	1.25E-07	7.73E-04	2.30E-09	2.12E-08	1.33E-04
30	18.6	2.89E-04	2.54E-03	6.91E+00	4.33E-09	3.81E-08	1.04E-04	1.20E-08	1.05E-07	2.81E-04	1.99E-09	1.75E-08	4.77E-05
35	21.7	3.03E-04	2.42E-03	1.17E+00	4.55E-09	3.64E-08	1.75E-05	1.24E-08	9.93E-08	5.08E-05	2.09E-09	1.67E-08	8.07E-06
40	24.9	2.52E-04	2.31E-03	3.71E-01	3.78E-09	3.47E-08	5.56E-06	1.04E-08	9.51E-08	1.51E-05	1.74E-09	1.60E-08	2.56E-06
45	28.0	2.83E-04	2.32E-03	2.05E-01	4.25E-09	3.48E-08	3.07E-06	1.19E-08	9.48E-08	7.74E-06	1.96E-09	1.60E-08	1.41E-06
50	31.1	2.75E-04	2.28E-03	5.22E-02	4.12E-09	3.42E-08	7.83E-07	1.11E-08	9.35E-08	2.01E-06	1.90E-09	1.57E-08	3.60E-07
55	34.2	2.57E-04	2.26E-03	1.52E-02	3.86E-09	3.38E-08	2.28E-07	1.05E-08	9.30E-08	6.28E-07	1.77E-09	1.56E-08	1.05E-07
60	37.3	2.56E-04	2.26E-03	7.33E-03	3.85E-09	3.38E-08	1.10E-07	1.08E-08	9.30E-08	2.88E-07	1.77E-09	1.56E-08	5.06E-08
65	40.4	2.46E-04	2.23E-03	5.58E-03	3.69E-09	3.34E-08	8.36E-08	1.02E-08	9.21E-08	1.97E-07	1.70E-09	1.54E-08	3.85E-08
70	43.5	2.42E-04	2.21E-03	5.45E-03	3.63E-09	3.31E-08	8.17E-08	1.02E-08	9.14E-08	1.97E-07	1.67E-09	1.52E-08	3.76E-08
75	46.6	2.69E-04	2.19E-03	4.84E-03	4.04E-09	3.29E-08	7.26E-08	1.10E-08	9.09E-08	1.82E-07	1.86E-09	1.51E-08	3.34E-08
80	49.7	2.52E-04	2.15E-03	4.58E-03	3.78E-09	3.22E-08	6.87E-08	1.02E-08	8.84E-08	1.74E-07	1.74E-09	1.48E-08	3.16E-08
90	55.9	2.39E-04	2.11E-03	4.38E-03	3.58E-09	3.16E-08	6.56E-08	9.78E-09	8.72E-08	1.69E-07	1.65E-09	1.46E-08	3.02E-08

Table 3-10B
BOURBON Agriculture Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	3.10E+01	6.79E+02	1.26E+04	1.39E-04	3.05E-03	5.66E-02	2.94E-04	6.38E-03	1.17E-01	6.41E-05	1.40E-03	2.61E-02
1	0.6	1.01E+01	4.19E+02	3.90E+03	4.55E-05	1.88E-03	1.75E-02	9.47E-05	3.86E-03	3.63E-02	2.10E-05	8.67E-04	8.07E-03
2	1.2	3.64E-01	1.82E+02	1.68E+03	1.64E-06	8.18E-04	7.56E-03	3.45E-06	1.68E-03	1.56E-02	7.53E-07	3.76E-04	3.48E-03
3	1.9	3.39E-03	8.15E+01	8.45E+02	1.53E-08	3.67E-04	3.80E-03	3.09E-08	7.58E-04	7.85E-03	7.02E-09	1.69E-04	1.75E-03
4	2.5	1.75E-03	3.07E+01	4.89E+02	7.87E-09	1.38E-04	2.20E-03	1.65E-08	2.85E-04	4.50E-03	3.62E-09	6.35E-05	1.01E-03
5	3.1	1.12E-03	1.09E+01	3.49E+02	5.04E-09	4.92E-05	1.57E-03	1.05E-08	1.01E-04	3.25E-03	2.32E-09	2.26E-05	7.23E-04
7.5	4.7	2.03E-03	9.05E+00	1.90E+02	9.16E-09	4.07E-05	8.55E-04	1.87E-08	8.41E-05	1.76E-03	4.21E-09	1.87E-05	3.93E-04
10	6.2	2.02E+01	3.87E+02	3.74E+03	9.07E-05	1.74E-03	1.68E-02	1.96E-04	3.56E-03	3.46E-02	4.17E-05	8.01E-04	7.74E-03
12.5	7.8	9.74E+01	7.71E+02	1.01E+04	4.38E-04	3.47E-03	4.53E-02	8.97E-04	7.15E-03	9.40E-02	2.02E-04	1.60E-03	2.09E-02
15	9.3	2.30E-03	5.09E+01	8.22E+02	1.04E-08	2.29E-04	3.70E-03	2.18E-08	4.77E-04	7.68E-03	4.76E-09	1.05E-04	1.70E-03
17.5	10.9	8.53E-04	1.66E+00	2.25E+02	3.84E-09	7.47E-06	1.01E-03	8.18E-09	1.54E-05	2.06E-03	1.76E-09	3.44E-06	4.65E-04
20	12.4	4.39E-04	5.88E-03	7.89E+01	1.97E-09	2.65E-08	3.55E-04	4.10E-09	5.45E-08	7.32E-04	9.08E-10	1.22E-08	1.63E-04
25	15.5	3.13E-04	2.92E-03	1.81E+01	1.41E-09	1.32E-08	8.13E-05	2.89E-09	2.73E-08	1.66E-04	6.49E-10	6.05E-09	3.74E-05
30	18.6	2.76E-04	2.45E-03	6.36E+00	1.24E-09	1.10E-08	2.86E-05	2.61E-09	2.29E-08	6.06E-05	5.71E-10	5.08E-09	1.32E-05
35	21.7	2.82E-04	2.31E-03	1.15E+00	1.27E-09	1.04E-08	5.16E-06	2.69E-09	2.17E-08	1.07E-05	5.84E-10	4.79E-09	2.37E-06
40	24.9	2.47E-04	2.20E-03	3.53E-01	1.11E-09	9.90E-09	1.59E-06	2.30E-09	2.06E-08	3.29E-06	5.12E-10	4.55E-09	7.30E-07
45	28.0	2.77E-04	2.21E-03	1.86E-01	1.24E-09	9.93E-09	8.37E-07	2.57E-09	2.07E-08	1.69E-06	5.73E-10	4.57E-09	3.85E-07
50	31.1	2.62E-04	2.17E-03	4.62E-02	1.18E-09	9.77E-09	2.08E-07	2.46E-09	2.02E-08	4.28E-07	5.43E-10	4.49E-09	9.56E-08
55	34.2	2.45E-04	2.18E-03	1.55E-02	1.10E-09	9.80E-09	6.98E-08	2.28E-09	2.02E-08	1.43E-07	5.07E-10	4.51E-09	3.21E-08
60	37.3	2.48E-04	2.17E-03	6.76E-03	1.12E-09	9.75E-09	3.04E-08	2.32E-09	2.02E-08	6.26E-08	5.14E-10	4.48E-09	1.40E-08
65	40.4	2.36E-04	2.13E-03	4.78E-03	1.06E-09	9.60E-09	2.15E-08	2.23E-09	1.99E-08	4.34E-08	4.88E-10	4.42E-09	9.90E-09
70	43.5	2.36E-04	2.12E-03	4.72E-03	1.06E-09	9.52E-09	2.12E-08	2.22E-09	1.97E-08	4.33E-08	4.89E-10	4.38E-09	9.77E-09
75	46.6	2.53E-04	2.11E-03	4.34E-03	1.14E-09	9.48E-09	1.95E-08	2.34E-09	1.98E-08	3.94E-08	5.23E-10	4.36E-09	8.99E-09
80	49.7	2.44E-04	2.05E-03	4.11E-03	1.10E-09	9.23E-09	1.85E-08	2.27E-09	1.92E-08	3.76E-08	5.05E-10	4.25E-09	8.51E-09
90	55.9	2.32E-04	2.02E-03	3.99E-03	1.04E-09	9.09E-09	1.79E-08	2.14E-09	1.88E-08	3.68E-08	4.80E-10	4.18E-09	8.26E-09

Table 3-10C
BOURBON Industrial Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	1.64E+01	3.37E+02	5.94E+03	2.45E-04	5.06E-03	8.91E-02	6.81E-04	1.37E-02	2.46E-01	1.13E-04	2.33E-03	4.10E-02
1	0.6	5.53E+00	2.19E+02	2.05E+03	8.30E-05	3.28E-03	3.07E-02	2.37E-04	8.88E-03	8.27E-02	3.82E-05	1.51E-03	1.41E-02
2	1.2	2.80E-01	9.41E+01	8.43E+02	4.20E-06	1.41E-03	1.26E-02	1.09E-05	3.83E-03	3.41E-02	1.93E-06	6.49E-04	5.81E-03
3	1.9	1.62E-03	3.97E+01	4.68E+02	2.44E-08	5.95E-04	7.03E-03	6.62E-08	1.64E-03	1.83E-02	1.12E-08	2.74E-04	3.23E-03
4	2.5	9.03E-04	1.58E+01	2.43E+02	1.35E-08	2.36E-04	3.65E-03	3.75E-08	6.49E-04	9.45E-03	6.23E-09	1.09E-04	1.68E-03
5	3.1	5.40E-04	5.16E+00	1.61E+02	8.10E-09	7.74E-05	2.41E-03	2.27E-08	2.12E-04	6.57E-03	3.73E-09	3.56E-05	1.11E-03
7.5	4.7	9.64E-04	4.48E+00	1.02E+02	1.45E-08	6.72E-05	1.53E-03	3.99E-08	1.81E-04	3.97E-03	6.65E-09	3.09E-05	7.02E-04
10	6.2	9.37E+00	2.02E+02	1.96E+03	1.41E-04	3.03E-03	2.95E-02	3.83E-04	8.09E-03	7.97E-02	6.47E-05	1.39E-03	1.36E-02
12.5	7.8	5.06E+01	4.07E+02	5.26E+03	7.60E-04	6.10E-03	7.89E-02	2.09E-03	1.67E-02	2.06E-01	3.49E-04	2.81E-03	3.63E-02
15	9.3	1.20E-03	2.50E+01	4.61E+02	1.80E-08	3.75E-04	6.92E-03	4.91E-08	1.02E-03	1.84E-02	8.26E-09	1.72E-04	3.18E-03
17.5	10.9	4.30E-04	9.55E-01	1.19E+02	6.44E-09	1.43E-05	1.78E-03	1.72E-08	3.84E-05	4.88E-03	2.96E-09	6.59E-06	8.18E-04
20	12.4	2.22E-04	3.90E-03	4.34E+01	3.33E-09	5.84E-08	6.51E-04	9.18E-09	1.55E-07	1.77E-03	1.53E-09	2.69E-08	2.99E-04
25	15.5	1.68E-04	1.49E-03	1.01E+01	2.51E-09	2.24E-08	1.52E-04	6.91E-09	6.12E-08	4.02E-04	1.16E-09	1.03E-08	6.98E-05
30	18.6	1.45E-04	1.24E-03	2.86E+00	2.17E-09	1.86E-08	4.29E-05	5.91E-09	5.12E-08	1.16E-04	1.00E-09	8.57E-09	1.97E-05
35	21.7	1.36E-04	1.17E-03	5.88E-01	2.04E-09	1.75E-08	8.82E-06	5.57E-09	4.77E-08	2.39E-05	9.39E-10	8.06E-09	4.06E-06
40	24.9	1.33E-04	1.11E-03	2.05E-01	2.00E-09	1.67E-08	3.08E-06	5.46E-09	4.61E-08	8.30E-06	9.19E-10	7.66E-09	1.41E-06
45	28.0	1.28E-04	1.11E-03	7.10E-02	1.92E-09	1.67E-08	1.07E-06	5.25E-09	4.58E-08	3.08E-06	8.82E-10	7.68E-09	4.90E-07
50	31.1	1.23E-04	1.11E-03	1.50E-02	1.85E-09	1.66E-08	2.24E-07	5.09E-09	4.56E-08	5.97E-07	8.51E-10	7.63E-09	1.03E-07
55	34.2	1.34E-04	1.10E-03	7.29E-03	2.01E-09	1.64E-08	1.09E-07	5.46E-09	4.52E-08	2.90E-07	9.26E-10	7.56E-09	5.03E-08
60	37.3	1.21E-04	1.09E-03	4.52E-03	1.81E-09	1.64E-08	6.78E-08	4.93E-09	4.49E-08	1.76E-07	8.34E-10	7.53E-09	3.12E-08
65	40.4	1.30E-04	1.09E-03	6.34E-03	1.95E-09	1.63E-08	9.51E-08	5.37E-09	4.51E-08	2.76E-07	8.98E-10	7.51E-09	4.37E-08
70	43.5	1.26E-04	1.07E-03	2.64E-03	1.89E-09	1.61E-08	3.97E-08	5.20E-09	4.39E-08	9.75E-08	8.67E-10	7.40E-09	1.82E-08
75	46.6	1.28E-04	1.04E-03	2.39E-03	1.92E-09	1.57E-08	3.59E-08	5.36E-09	4.26E-08	9.07E-08	8.85E-10	7.20E-09	1.65E-08
80	49.7	1.19E-04	1.03E-03	2.27E-03	1.79E-09	1.55E-08	3.40E-08	4.90E-09	4.26E-08	8.65E-08	8.24E-10	7.14E-09	1.56E-08
90	55.9	1.22E-04	1.03E-03	2.17E-03	1.82E-09	1.54E-08	3.25E-08	4.97E-09	4.22E-08	8.45E-08	8.39E-10	7.11E-09	1.50E-08

Table 3-10D
BOURBON Mining Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	1.51E+01	3.15E+02	5.73E+03	2.26E-04	4.72E-03	8.59E-02	6.27E-04	1.30E-02	2.36E-01	1.04E-04	2.17E-03	3.95E-02
1	0.6	5.20E+00	2.06E+02	1.93E+03	7.81E-05	3.10E-03	2.90E-02	2.25E-04	8.53E-03	7.71E-02	3.59E-05	1.42E-03	1.33E-02
2	1.2	2.53E-01	8.86E+01	7.97E+02	3.79E-06	1.33E-03	1.20E-02	1.00E-05	3.62E-03	3.18E-02	1.74E-06	6.11E-04	5.50E-03
3	1.9	1.51E-03	3.73E+01	4.42E+02	2.26E-08	5.60E-04	6.62E-03	6.18E-08	1.54E-03	1.75E-02	1.04E-08	2.58E-04	3.05E-03
4	2.5	8.33E-04	1.49E+01	2.30E+02	1.25E-08	2.23E-04	3.45E-03	3.53E-08	6.05E-04	8.92E-03	5.74E-09	1.03E-04	1.59E-03
5	3.1	5.04E-04	4.75E+00	1.55E+02	7.55E-09	7.13E-05	2.32E-03	2.13E-08	1.96E-04	6.29E-03	3.48E-09	3.28E-05	1.07E-03
7.5	4.7	9.10E-04	4.22E+00	9.68E+01	1.37E-08	6.33E-05	1.45E-03	3.71E-08	1.70E-04	3.72E-03	6.28E-09	2.91E-05	6.68E-04
10	6.2	8.61E+00	1.89E+02	1.91E+03	1.29E-04	2.84E-03	2.86E-02	3.59E-04	7.63E-03	7.58E-02	5.94E-05	1.31E-03	1.32E-02
12.5	7.8	4.73E+01	3.87E+02	4.93E+03	7.10E-04	5.80E-03	7.40E-02	1.97E-03	1.57E-02	1.95E-01	3.27E-04	2.67E-03	3.40E-02
15	9.3	1.14E-03	2.32E+01	4.33E+02	1.71E-08	3.48E-04	6.50E-03	4.76E-08	9.50E-04	1.73E-02	7.87E-09	1.60E-04	2.99E-03
17.5	10.9	3.93E-04	9.04E-01	1.14E+02	5.89E-09	1.36E-05	1.71E-03	1.60E-08	3.66E-05	4.54E-03	2.71E-09	6.24E-06	7.89E-04
20	12.4	2.02E-04	3.63E-03	4.14E+01	3.03E-09	5.44E-08	6.21E-04	8.47E-09	1.49E-07	1.65E-03	1.39E-09	2.50E-08	2.86E-04
25	15.5	1.59E-04	1.40E-03	9.20E+00	2.39E-09	2.10E-08	1.38E-04	6.60E-09	5.76E-08	3.71E-04	1.10E-09	9.64E-09	6.35E-05
30	18.6	1.35E-04	1.18E-03	2.67E+00	2.02E-09	1.77E-08	4.01E-05	5.63E-09	4.85E-08	1.11E-04	9.31E-10	8.13E-09	1.84E-05
35	21.7	1.26E-04	1.09E-03	5.72E-01	1.89E-09	1.63E-08	8.57E-06	5.20E-09	4.50E-08	2.26E-05	8.70E-10	7.51E-09	3.94E-06
40	24.9	1.27E-04	1.06E-03	2.00E-01	1.90E-09	1.59E-08	3.00E-06	5.11E-09	4.38E-08	7.65E-06	8.74E-10	7.30E-09	1.38E-06
45	28.0	1.24E-04	1.05E-03	6.98E-02	1.86E-09	1.57E-08	1.05E-06	5.07E-09	4.31E-08	2.87E-06	8.54E-10	7.23E-09	4.81E-07
50	31.1	1.17E-04	1.04E-03	1.48E-02	1.75E-09	1.56E-08	2.21E-07	4.79E-09	4.30E-08	5.85E-07	8.07E-10	7.16E-09	1.02E-07
55	34.2	1.25E-04	1.04E-03	6.96E-03	1.87E-09	1.56E-08	1.04E-07	5.23E-09	4.28E-08	2.70E-07	8.61E-10	7.16E-09	4.80E-08
60	37.3	1.12E-04	1.02E-03	4.52E-03	1.68E-09	1.53E-08	6.78E-08	4.65E-09	4.21E-08	1.69E-07	7.72E-10	7.05E-09	3.12E-08
65	40.4	1.21E-04	1.03E-03	6.11E-03	1.82E-09	1.55E-08	9.16E-08	5.10E-09	4.27E-08	2.49E-07	8.37E-10	7.12E-09	4.21E-08
70	43.5	1.17E-04	1.01E-03	2.55E-03	1.75E-09	1.51E-08	3.82E-08	4.82E-09	4.15E-08	9.28E-08	8.05E-10	6.97E-09	1.76E-08
75	46.6	1.25E-04	9.84E-04	2.26E-03	1.87E-09	1.48E-08	3.39E-08	5.12E-09	4.04E-08	8.54E-08	8.61E-10	6.79E-09	1.56E-08
80	49.7	1.07E-04	9.80E-04	2.12E-03	1.60E-09	1.47E-08	3.19E-08	4.48E-09	4.02E-08	8.21E-08	7.38E-10	6.76E-09	1.47E-08
90	55.9	1.16E-04	9.58E-04	2.07E-03	1.74E-09	1.44E-08	3.10E-08	4.75E-09	3.97E-08	8.01E-08	8.02E-10	6.61E-09	1.43E-08

Table 3-10E
BOURBON Recreation Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	5.90E+00	1.29E+02	2.32E+03	8.85E-05	1.94E-03	3.48E-02	2.46E-04	5.27E-03	9.48E-02	4.07E-05	8.92E-04	1.60E-02
1	0.6	1.80E+00	8.23E+01	7.82E+02	2.70E-05	1.23E-03	1.17E-02	7.17E-05	3.30E-03	3.07E-02	1.24E-05	5.68E-04	5.39E-03
2	1.2	1.37E-01	3.66E+01	3.39E+02	2.06E-06	5.50E-04	5.08E-03	6.09E-06	1.48E-03	1.37E-02	9.48E-07	2.53E-04	2.34E-03
3	1.9	5.89E-04	1.51E+01	1.66E+02	8.83E-09	2.26E-04	2.49E-03	2.39E-08	6.22E-04	6.53E-03	4.06E-09	1.04E-04	1.15E-03
4	2.5	3.39E-04	5.98E+00	8.76E+01	5.09E-09	8.96E-05	1.31E-03	1.44E-08	2.42E-04	3.38E-03	2.34E-09	4.12E-05	6.04E-04
5	3.1	2.12E-04	2.06E+00	5.97E+01	3.17E-09	3.09E-05	8.95E-04	8.54E-09	8.42E-05	2.49E-03	1.46E-09	1.42E-05	4.12E-04
7.5	4.7	3.49E-04	1.61E+00	3.88E+01	5.24E-09	2.41E-05	5.81E-04	1.46E-08	6.61E-05	1.54E-03	2.41E-09	1.11E-05	2.67E-04
10	6.2	3.53E+00	7.31E+01	7.73E+02	5.29E-05	1.10E-03	1.16E-02	1.50E-04	2.97E-03	3.04E-02	2.43E-05	5.04E-04	5.34E-03
12.5	7.8	1.79E+01	1.46E+02	1.91E+03	2.69E-04	2.19E-03	2.87E-02	7.39E-04	5.90E-03	7.64E-02	1.24E-04	1.01E-03	1.32E-02
15	9.3	4.62E-04	1.02E+01	1.61E+02	6.93E-09	1.53E-04	2.42E-03	1.87E-08	4.16E-04	6.51E-03	3.19E-09	7.05E-05	1.11E-03
17.5	10.9	1.61E-04	3.49E-01	4.38E+01	2.42E-09	5.23E-06	6.58E-04	6.72E-09	1.45E-05	1.81E-03	1.11E-09	2.41E-06	3.02E-04
20	12.4	8.65E-05	1.41E-03	1.61E+01	1.30E-09	2.11E-08	2.41E-04	3.52E-09	5.64E-08	6.54E-04	5.97E-10	9.72E-09	1.11E-04
25	15.5	6.79E-05	5.64E-04	3.79E+00	1.02E-09	8.45E-09	5.69E-05	2.77E-09	2.30E-08	1.53E-04	4.69E-10	3.89E-09	2.62E-05
30	18.6	5.46E-05	4.73E-04	1.29E+00	8.19E-10	7.10E-09	1.93E-05	2.25E-09	1.94E-08	5.16E-05	3.77E-10	3.27E-09	8.87E-06
35	21.7	4.88E-05	4.38E-04	2.44E-01	7.32E-10	6.58E-09	3.66E-06	1.99E-09	1.80E-08	9.51E-06	3.37E-10	3.03E-09	1.68E-06
40	24.9	5.17E-05	4.15E-04	5.65E-02	7.76E-10	6.23E-09	8.47E-07	2.15E-09	1.70E-08	2.29E-06	3.57E-10	2.87E-09	3.90E-07
45	28.0	4.74E-05	4.13E-04	2.80E-02	7.11E-10	6.20E-09	4.20E-07	1.90E-09	1.70E-08	1.19E-06	3.27E-10	2.85E-09	1.93E-07
50	31.1	4.53E-05	4.13E-04	1.12E-02	6.80E-10	6.19E-09	1.68E-07	1.83E-09	1.70E-08	4.65E-07	3.13E-10	2.85E-09	7.72E-08
55	34.2	5.00E-05	4.11E-04	2.86E-03	7.50E-10	6.16E-09	4.28E-08	2.08E-09	1.69E-08	1.23E-07	3.45E-10	2.84E-09	1.97E-08
60	37.3	4.82E-05	4.11E-04	3.10E-03	7.23E-10	6.17E-09	4.65E-08	1.97E-09	1.69E-08	1.33E-07	3.33E-10	2.84E-09	2.14E-08
65	40.4	4.52E-05	4.02E-04	1.97E-03	6.78E-10	6.03E-09	2.95E-08	1.87E-09	1.65E-08	8.25E-08	3.12E-10	2.77E-09	1.36E-08
70	43.5	4.49E-05	4.00E-04	1.05E-03	6.73E-10	5.99E-09	1.57E-08	1.81E-09	1.62E-08	3.79E-08	3.10E-10	2.76E-09	7.24E-09
75	46.6	4.91E-05	3.88E-04	8.96E-04	7.36E-10	5.82E-09	1.34E-08	1.99E-09	1.61E-08	3.36E-08	3.38E-10	2.68E-09	6.18E-09
80	49.7	4.42E-05	3.80E-04	8.38E-04	6.63E-10	5.70E-09	1.26E-08	1.79E-09	1.57E-08	3.23E-08	3.05E-10	2.62E-09	5.78E-09
90	55.9	4.47E-05	3.75E-04	8.09E-04	6.70E-10	5.63E-09	1.21E-08	1.86E-09	1.55E-08	3.13E-08	3.08E-10	2.59E-09	5.58E-09

Table 10-3F
BOURBON Recreation Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	3.43E+00	6.92E+01	1.25E+03	1.55E-05	3.12E-04	5.61E-03	3.20E-05	6.51E-04	1.19E-02	7.02E-06	1.43E-04	2.58E-03
1	0.6	9.74E-01	4.34E+01	4.15E+02	4.38E-06	1.95E-04	1.87E-03	8.89E-06	4.01E-04	3.82E-03	2.01E-06	8.99E-05	8.60E-04
2	1.2	8.58E-02	1.97E+01	1.76E+02	3.86E-07	8.87E-05	7.90E-04	7.72E-07	1.82E-04	1.63E-03	1.76E-07	4.08E-05	3.64E-04
3	1.9	3.18E-04	8.27E+00	8.69E+01	1.43E-09	3.72E-05	3.91E-04	2.93E-09	7.70E-05	8.05E-04	6.57E-10	1.71E-05	1.80E-04
4	2.5	1.90E-04	3.22E+00	4.40E+01	8.55E-10	1.45E-05	1.98E-04	1.77E-09	3.00E-05	4.03E-04	3.92E-10	6.68E-06	9.10E-05
5	3.1	1.15E-04	1.15E+00	3.26E+01	5.18E-10	5.16E-06	1.47E-04	1.08E-09	1.06E-05	3.02E-04	2.38E-10	2.38E-06	6.75E-05
7.5	4.7	1.93E-04	8.62E-01	1.97E+01	8.70E-10	3.88E-06	8.85E-05	1.80E-09	8.04E-06	1.83E-04	4.00E-10	1.78E-06	4.06E-05
10	6.2	1.93E+00	3.90E+01	3.95E+02	8.70E-06	1.75E-04	1.78E-03	1.84E-05	3.64E-04	3.64E-03	4.00E-06	8.07E-05	8.18E-04
12.5	7.8	1.00E+01	7.86E+01	1.02E+03	4.50E-05	3.54E-04	4.59E-03	9.41E-05	7.27E-04	9.34E-03	2.07E-05	1.63E-04	2.11E-03
15	9.3	2.46E-04	5.54E+00	8.60E+01	1.11E-09	2.49E-05	3.87E-04	2.30E-09	5.23E-05	8.04E-04	5.09E-10	1.15E-05	1.78E-04
17.5	10.9	8.92E-05	1.97E-01	2.43E+01	4.02E-10	8.84E-07	1.09E-04	8.46E-10	1.82E-06	2.26E-04	1.85E-10	4.07E-07	5.03E-05
20	12.4	4.81E-05	7.38E-04	8.44E+00	2.16E-10	3.32E-09	3.80E-05	4.47E-10	6.78E-09	7.89E-05	9.91E-11	1.53E-09	1.75E-05
25	15.5	3.77E-05	3.05E-04	1.91E+00	1.69E-10	1.37E-09	8.62E-06	3.47E-10	2.85E-09	1.78E-05	7.79E-11	6.32E-10	3.96E-06
30	18.6	2.98E-05	2.58E-04	6.93E-01	1.34E-10	1.16E-09	3.12E-06	2.80E-10	2.41E-09	6.40E-06	6.16E-11	5.35E-10	1.43E-06
35	21.7	2.66E-05	2.38E-04	1.26E-01	1.19E-10	1.07E-09	5.66E-07	2.50E-10	2.22E-09	1.15E-06	5.48E-11	4.93E-10	2.61E-07
40	24.9	2.79E-05	2.26E-04	3.03E-02	1.26E-10	1.02E-09	1.36E-07	2.66E-10	2.10E-09	2.89E-07	5.78E-11	4.68E-10	6.28E-08
45	28.0	2.55E-05	2.27E-04	1.62E-02	1.15E-10	1.02E-09	7.29E-08	2.39E-10	2.11E-09	1.52E-07	5.27E-11	4.69E-10	3.35E-08
50	31.1	2.43E-05	2.25E-04	5.97E-03	1.09E-10	1.01E-09	2.69E-08	2.29E-10	2.09E-09	5.59E-08	5.04E-11	4.67E-10	1.24E-08
55	34.2	2.75E-05	2.24E-04	1.58E-03	1.24E-10	1.01E-09	7.09E-09	2.56E-10	2.09E-09	1.42E-08	5.68E-11	4.64E-10	3.26E-09
60	37.3	2.59E-05	2.25E-04	1.81E-03	1.16E-10	1.01E-09	8.16E-09	2.45E-10	2.10E-09	1.71E-08	5.35E-11	4.65E-10	3.76E-09
65	40.4	2.48E-05	2.20E-04	1.16E-03	1.12E-10	9.90E-10	5.22E-09	2.31E-10	2.06E-09	1.04E-08	5.11E-11	4.55E-10	2.33E-09
70	43.5	2.45E-05	2.17E-04	5.05E-04	1.10E-10	9.75E-10	2.27E-09	2.27E-10	2.03E-09	4.55E-09	5.06E-11	4.48E-10	1.05E-09
75	46.6	2.59E-05	2.13E-04	4.48E-04	1.17E-10	9.60E-10	2.02E-09	2.40E-10	1.99E-09	4.09E-09	5.37E-11	4.42E-10	9.27E-10
80	49.7	2.32E-05	2.08E-04	4.25E-04	1.05E-10	9.36E-10	1.91E-09	2.20E-10	1.94E-09	3.89E-09	4.81E-11	4.31E-10	8.80E-10
90	55.9	2.42E-05	2.06E-04	4.11E-04	1.09E-10	9.29E-10	1.85E-09	2.23E-10	1.92E-09	3.79E-09	5.00E-11	4.27E-10	8.51E-10

Table 3-10G
BOURBON Residential Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	2.12E+01	4.52E+02	8.15E+03	3.18E-04	6.79E-03	1.22E-01	8.75E-04	1.84E-02	3.32E-01	1.46E-04	3.12E-03	5.62E-02
1	0.6	6.45E+00	2.87E+02	2.71E+03	9.67E-05	4.31E-03	4.07E-02	2.55E-04	1.15E-02	1.07E-01	4.45E-05	1.98E-03	1.87E-02
2	1.2	5.02E-01	1.28E+02	1.18E+03	7.53E-06	1.93E-03	1.77E-02	2.13E-05	5.21E-03	4.79E-02	3.47E-06	8.86E-04	8.12E-03
3	1.9	2.03E-03	5.24E+01	5.79E+02	3.04E-08	7.86E-04	8.69E-03	8.29E-08	2.17E-03	2.29E-02	1.40E-08	3.62E-04	4.00E-03
4	2.5	1.19E-03	2.08E+01	3.07E+02	1.78E-08	3.12E-04	4.61E-03	5.01E-08	8.43E-04	1.19E-02	8.19E-09	1.44E-04	2.12E-03
5	3.1	7.41E-04	7.11E+00	2.07E+02	1.11E-08	1.07E-04	3.10E-03	3.01E-08	2.92E-04	8.50E-03	5.11E-09	4.91E-05	1.43E-03
7.5	4.7	1.21E-03	5.71E+00	1.34E+02	1.81E-08	8.56E-05	2.02E-03	5.03E-08	2.33E-04	5.28E-03	8.33E-09	3.94E-05	9.28E-04
10	6.2	1.22E+01	2.54E+02	2.70E+03	1.83E-04	3.81E-03	4.05E-02	5.20E-04	1.03E-02	1.06E-01	8.41E-05	1.75E-03	1.86E-02
12.5	7.8	6.29E+01	5.15E+02	6.72E+03	9.43E-04	7.73E-03	1.01E-01	2.58E-03	2.08E-02	2.68E-01	4.34E-04	3.56E-03	4.64E-02
15	9.3	1.63E-03	3.57E+01	5.69E+02	2.44E-08	5.35E-04	8.54E-03	6.59E-08	1.44E-03	2.30E-02	1.12E-08	2.46E-04	3.93E-03
17.5	10.9	5.69E-04	1.22E+00	1.57E+02	8.54E-09	1.84E-05	2.35E-03	2.36E-08	5.12E-05	6.37E-03	3.93E-09	8.45E-06	1.08E-03
20	12.4	3.03E-04	4.96E-03	5.55E+01	4.54E-09	7.45E-08	8.33E-04	1.25E-08	1.99E-07	2.25E-03	2.09E-09	3.42E-08	3.83E-04
25	15.5	2.34E-04	1.96E-03	1.36E+01	3.51E-09	2.94E-08	2.03E-04	9.56E-09	8.01E-08	5.47E-04	1.62E-09	1.35E-08	9.36E-05
30	18.6	1.95E-04	1.66E-03	4.61E+00	2.93E-09	2.49E-08	6.92E-05	7.98E-09	6.82E-08	1.86E-04	1.35E-09	1.14E-08	3.18E-05
35	21.7	1.72E-04	1.53E-03	8.14E-01	2.58E-09	2.30E-08	1.22E-05	7.06E-09	6.31E-08	3.21E-05	1.19E-09	1.06E-08	5.62E-06
40	24.9	1.79E-04	1.45E-03	1.98E-01	2.69E-09	2.18E-08	2.96E-06	7.46E-09	5.93E-08	8.01E-06	1.24E-09	1.00E-08	1.36E-06
45	28.0	1.66E-04	1.45E-03	1.01E-01	2.49E-09	2.17E-08	1.51E-06	6.68E-09	5.95E-08	4.23E-06	1.15E-09	1.00E-08	6.94E-07
50	31.1	1.59E-04	1.44E-03	3.37E-02	2.38E-09	2.16E-08	5.06E-07	6.42E-09	5.95E-08	1.29E-06	1.09E-09	9.94E-09	2.33E-07
55	34.2	1.74E-04	1.44E-03	9.90E-03	2.61E-09	2.15E-08	1.49E-07	7.20E-09	5.92E-08	4.25E-07	1.20E-09	9.91E-09	6.83E-08
60	37.3	1.68E-04	1.44E-03	1.04E-02	2.52E-09	2.16E-08	1.57E-07	6.86E-09	5.91E-08	4.65E-07	1.16E-09	9.92E-09	7.21E-08
65	40.4	1.58E-04	1.41E-03	6.88E-03	2.37E-09	2.11E-08	1.03E-07	6.53E-09	5.79E-08	2.83E-07	1.09E-09	9.72E-09	4.75E-08
70	43.5	1.58E-04	1.40E-03	3.68E-03	2.37E-09	2.09E-08	5.52E-08	6.40E-09	5.66E-08	1.33E-07	1.09E-09	9.63E-09	2.54E-08
75	46.6	1.69E-04	1.36E-03	3.14E-03	2.54E-09	2.04E-08	4.71E-08	6.91E-09	5.63E-08	1.18E-07	1.17E-09	9.39E-09	2.17E-08
80	49.7	1.55E-04	1.33E-03	2.93E-03	2.32E-09	1.99E-08	4.39E-08	6.27E-09	5.48E-08	1.13E-07	1.07E-09	9.17E-09	2.02E-08
90	55.9	1.58E-04	1.33E-03	2.84E-03	2.38E-09	1.99E-08	4.25E-08	6.59E-09	5.47E-08	1.10E-07	1.09E-09	9.15E-09	1.96E-08

Table 3-10H
BOURBON Residential Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	1.22E+01	2.43E+02	4.37E+03	5.49E-05	1.09E-03	1.96E-02	1.12E-04	2.28E-03	4.16E-02	2.52E-05	5.03E-04	9.04E-03
1	0.6	3.48E+00	1.52E+02	1.45E+03	1.57E-05	6.83E-04	6.51E-03	3.18E-05	1.40E-03	1.33E-02	7.21E-06	3.14E-04	2.99E-03
2	1.2	2.98E-01	6.92E+01	6.13E+02	1.34E-06	3.11E-04	2.76E-03	2.70E-06	6.40E-04	5.69E-03	6.17E-07	1.43E-04	1.27E-03
3	1.9	1.10E-03	2.87E+01	3.04E+02	4.96E-09	1.29E-04	1.37E-03	1.02E-08	2.67E-04	2.82E-03	2.28E-09	5.93E-05	6.28E-04
4	2.5	6.63E-04	1.12E+01	1.54E+02	2.99E-09	5.03E-05	6.94E-04	6.21E-09	1.04E-04	1.41E-03	1.37E-09	2.32E-05	3.19E-04
5	3.1	4.01E-04	3.96E+00	1.13E+02	1.80E-09	1.78E-05	5.09E-04	3.75E-09	3.69E-05	1.05E-03	8.30E-10	8.19E-06	2.34E-04
7.5	4.7	6.65E-04	3.04E+00	6.83E+01	2.99E-09	1.37E-05	3.08E-04	6.24E-09	2.83E-05	6.36E-04	1.38E-09	6.29E-06	1.41E-04
10	6.2	6.58E+00	1.36E+02	1.37E+03	2.96E-05	6.11E-04	6.18E-03	6.39E-05	1.27E-03	1.27E-02	1.36E-05	2.81E-04	2.85E-03
12.5	7.8	3.51E+01	2.77E+02	3.58E+03	1.58E-04	1.25E-03	1.61E-02	3.30E-04	2.56E-03	3.29E-02	7.27E-05	5.74E-04	7.42E-03
15	9.3	8.64E-04	1.93E+01	3.02E+02	3.89E-09	8.65E-05	1.36E-03	8.08E-09	1.81E-04	2.82E-03	1.79E-09	3.98E-05	6.24E-04
17.5	10.9	3.14E-04	6.95E-01	8.59E+01	1.41E-09	3.13E-06	3.88E-04	2.97E-09	6.47E-06	7.97E-04	6.49E-10	1.44E-06	1.78E-04
20	12.4	1.68E-04	2.59E-03	2.95E+01	7.57E-10	1.17E-08	1.33E-04	1.57E-09	2.41E-08	2.74E-04	3.48E-10	5.40E-09	6.10E-05
25	15.5	1.30E-04	1.06E-03	6.83E+00	5.86E-10	4.79E-09	3.07E-05	1.20E-09	9.92E-09	6.31E-05	2.70E-10	2.20E-09	1.41E-05
30	18.6	1.05E-04	9.05E-04	2.48E+00	4.75E-10	4.07E-09	1.12E-05	9.94E-10	8.44E-09	2.29E-05	2.18E-10	1.87E-09	5.14E-06
35	21.7	9.38E-05	8.34E-04	4.30E-01	4.22E-10	3.75E-09	1.94E-06	8.76E-10	7.79E-09	3.93E-06	1.94E-10	1.73E-09	8.91E-07
40	24.9	9.73E-05	7.88E-04	1.02E-01	4.38E-10	3.54E-09	4.57E-07	9.20E-10	7.34E-09	1.00E-06	2.01E-10	1.63E-09	2.10E-07
45	28.0	8.92E-05	7.93E-04	5.78E-02	4.01E-10	3.57E-09	2.60E-07	8.37E-10	7.41E-09	5.43E-07	1.85E-10	1.64E-09	1.20E-07
50	31.1	8.51E-05	7.88E-04	1.58E-02	3.83E-10	3.54E-09	7.10E-08	7.96E-10	7.31E-09	1.44E-07	1.76E-10	1.63E-09	3.26E-08
55	34.2	9.59E-05	7.85E-04	5.45E-03	4.31E-10	3.53E-09	2.45E-08	8.94E-10	7.32E-09	4.95E-08	1.98E-10	1.62E-09	1.13E-08
60	37.3	8.97E-05	7.86E-04	6.08E-03	4.04E-10	3.54E-09	2.74E-08	8.52E-10	7.35E-09	5.84E-08	1.86E-10	1.63E-09	1.26E-08
65	40.4	8.71E-05	7.70E-04	3.65E-03	3.92E-10	3.46E-09	1.64E-08	8.07E-10	7.22E-09	3.58E-08	1.80E-10	1.59E-09	7.56E-09
70	43.5	8.56E-05	7.58E-04	1.77E-03	3.85E-10	3.41E-09	7.95E-09	7.95E-10	7.09E-09	1.59E-08	1.77E-10	1.57E-09	3.66E-09
75	46.6	9.07E-05	7.47E-04	1.58E-03	4.08E-10	3.36E-09	7.10E-09	8.37E-10	6.97E-09	1.44E-08	1.88E-10	1.55E-09	3.26E-09
80	49.7	8.12E-05	7.27E-04	1.49E-03	3.65E-10	3.27E-09	6.70E-09	7.70E-10	6.79E-09	1.36E-08	1.68E-10	1.51E-09	3.08E-09
`90	55.9	8.50E-05	7.25E-04	1.44E-03	3.83E-10	3.26E-09	6.48E-09	7.96E-10	6.77E-09	1.32E-08	1.76E-10	1.50E-09	2.98E-09

Table 3-10I
BOURBON Tourism Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	8.58E-01	1.83E+01	3.30E+02	1.29E-05	2.74E-04	4.95E-03	3.53E-05	7.46E-04	1.34E-02	5.92E-06	1.26E-04	2.28E-03
1	0.6	2.60E-01	1.16E+01	1.10E+02	3.91E-06	1.74E-04	1.65E-03	1.03E-05	4.67E-04	4.33E-03	1.80E-06	8.01E-05	7.58E-04
2	1.2	2.03E-02	5.19E+00	4.77E+01	3.05E-07	7.79E-05	7.15E-04	8.63E-07	2.10E-04	1.93E-03	1.40E-07	3.58E-05	3.29E-04
3	1.9	8.19E-05	2.12E+00	2.34E+01	1.23E-09	3.18E-05	3.51E-04	3.36E-09	8.77E-05	9.25E-04	5.65E-10	1.46E-05	1.61E-04
4	2.5	4.80E-05	8.40E-01	1.24E+01	7.20E-10	1.26E-05	1.86E-04	2.03E-09	3.41E-05	4.80E-04	3.31E-10	5.80E-06	8.56E-05
5	3.1	3.00E-05	2.87E-01	8.35E+00	4.50E-10	4.31E-06	1.25E-04	1.22E-09	1.18E-05	3.44E-04	2.07E-10	1.98E-06	5.76E-05
7.5	4.7	4.88E-05	2.31E-01	5.44E+00	7.31E-10	3.46E-06	8.16E-05	2.03E-09	9.40E-06	2.14E-04	3.36E-10	1.59E-06	3.75E-05
10	6.2	4.92E-01	1.03E+01	1.09E+02	7.38E-06	1.54E-04	1.64E-03	2.11E-05	4.18E-04	4.29E-03	3.40E-06	7.09E-05	7.53E-04
12.5	7.8	2.54E+00	2.09E+01	2.71E+02	3.82E-05	3.13E-04	4.07E-03	1.05E-04	8.41E-04	1.08E-02	1.76E-05	1.44E-04	1.87E-03
15	9.3	6.59E-05	1.44E+00	2.30E+01	9.88E-10	2.16E-05	3.46E-04	2.67E-09	5.84E-05	9.30E-04	4.54E-10	9.95E-06	1.59E-04
17.5	10.9	2.30E-05	4.96E-02	6.33E+00	3.45E-10	7.43E-07	9.50E-05	9.57E-10	2.07E-06	2.58E-04	1.59E-10	3.42E-07	4.37E-05
20	12.4	1.23E-05	2.01E-04	2.24E+00	1.84E-10	3.01E-09	3.37E-05	5.06E-10	8.05E-09	9.11E-05	8.46E-11	1.39E-09	1.55E-05
25	15.5	9.47E-06	7.93E-05	5.47E-01	1.42E-10	1.19E-09	8.21E-06	3.86E-10	3.24E-09	2.20E-05	6.54E-11	5.48E-10	3.77E-06
30	18.6	7.91E-06	6.72E-05	1.87E-01	1.19E-10	1.01E-09	2.81E-06	3.23E-10	2.76E-09	7.53E-06	5.46E-11	4.64E-10	1.29E-06
35	21.7	6.94E-06	6.20E-05	3.30E-02	1.04E-10	9.30E-10	4.94E-07	2.85E-10	2.55E-09	1.30E-06	4.79E-11	4.28E-10	2.27E-07
40	24.9	7.24E-06	5.87E-05	7.98E-03	1.09E-10	8.81E-10	1.20E-07	3.01E-10	2.40E-09	3.24E-07	5.00E-11	4.05E-10	5.51E-08
45	28.0	6.72E-06	5.86E-05	4.07E-03	1.01E-10	8.79E-10	6.10E-08	2.70E-10	2.41E-09	1.71E-07	4.64E-11	4.04E-10	2.81E-08
50	31.1	6.41E-06	5.83E-05	1.36E-03	9.61E-11	8.75E-10	2.04E-08	2.59E-10	2.41E-09	5.22E-08	4.42E-11	4.02E-10	9.38E-09
55	34.2	7.04E-06	5.81E-05	4.00E-04	1.06E-10	8.71E-10	6.01E-09	2.91E-10	2.40E-09	1.72E-08	4.85E-11	4.01E-10	2.76E-09
60	37.3	6.80E-06	5.81E-05	4.22E-04	1.02E-10	8.72E-10	6.34E-09	2.77E-10	2.39E-09	1.89E-08	4.69E-11	4.01E-10	2.91E-09
65	40.4	6.41E-06	5.70E-05	2.79E-04	9.62E-11	8.54E-10	4.18E-09	2.64E-10	2.34E-09	1.14E-08	4.42E-11	3.93E-10	1.92E-09
70	43.5	6.37E-06	5.64E-05	1.49E-04	9.55E-11	8.46E-10	2.23E-09	2.59E-10	2.29E-09	5.38E-09	4.39E-11	3.89E-10	1.03E-09
75	46.6	6.84E-06	5.50E-05	1.27E-04	1.03E-10	8.26E-10	1.90E-09	2.79E-10	2.28E-09	4.77E-09	4.72E-11	3.80E-10	8.76E-10
80	49.7	6.26E-06	5.37E-05	1.18E-04	9.39E-11	8.06E-10	1.78E-09	2.53E-10	2.22E-09	4.57E-09	4.32E-11	3.71E-10	8.17E-10
90	55.9	6.41E-06	5.36E-05	1.15E-04	9.62E-11	8.04E-10	1.72E-09	2.66E-10	2.21E-09	4.44E-09	4.42E-11	3.70E-10	7.90E-10

Table 3-10J
BOURBON Tourism Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	4.88E-01	9.72E+00	1.75E+02	2.19E-06	4.37E-05	7.86E-04	4.50E-06	9.11E-05	1.66E-03	1.01E-06	2.01E-05	3.61E-04
1	0.6	1.39E-01	6.07E+00	5.78E+01	6.27E-07	2.73E-05	2.60E-04	1.27E-06	5.60E-05	5.31E-04	2.89E-07	1.26E-05	1.20E-04
2	1.2	1.19E-02	2.77E+00	2.45E+01	5.36E-08	1.24E-05	1.10E-04	1.08E-07	2.56E-05	2.28E-04	2.47E-08	5.73E-06	5.07E-05
3	1.9	4.41E-05	1.15E+00	1.21E+01	1.98E-10	5.16E-06	5.47E-05	4.08E-10	1.07E-05	1.13E-04	9.12E-11	2.37E-06	2.51E-05
4	2.5	2.65E-05	4.47E-01	6.17E+00	1.19E-10	2.01E-06	2.78E-05	2.48E-10	4.16E-06	5.64E-05	5.49E-11	9.25E-07	1.28E-05
5	3.1	1.60E-05	1.58E-01	4.53E+00	7.22E-11	7.12E-07	2.04E-05	1.50E-10	1.48E-06	4.21E-05	3.32E-11	3.28E-07	9.37E-06
7.5	4.7	2.66E-05	1.22E-01	2.73E+00	1.20E-10	5.47E-07	1.23E-05	2.50E-10	1.13E-06	2.54E-05	5.51E-11	2.52E-07	5.66E-06
10	6.2	2.63E-01	5.43E+00	5.50E+01	1.18E-06	2.45E-05	2.47E-04	2.55E-06	5.07E-05	5.09E-04	5.45E-07	1.12E-05	1.14E-04
12.5	7.8	1.40E+00	1.11E+01	1.43E+02	6.32E-06	4.99E-05	6.45E-04	1.32E-05	1.03E-04	1.32E-03	2.91E-06	2.29E-05	2.97E-04
15	9.3	3.46E-05	7.70E-01	1.21E+01	1.56E-10	3.47E-06	5.43E-05	3.23E-10	7.23E-06	1.13E-04	7.16E-11	1.59E-06	2.50E-05
17.5	10.9	1.25E-05	2.78E-02	3.44E+00	5.64E-11	1.25E-07	1.55E-05	1.19E-10	2.59E-07	3.18E-05	2.60E-11	5.76E-08	7.11E-06
20	12.4	6.73E-06	1.04E-04	1.18E+00	3.03E-11	4.67E-10	5.30E-06	6.26E-11	9.60E-10	1.10E-05	1.39E-11	2.15E-10	2.44E-06
25	15.5	5.21E-06	4.25E-05	2.73E-01	2.35E-11	1.91E-10	1.23E-06	4.82E-11	3.97E-10	2.52E-06	1.08E-11	8.81E-11	5.66E-07
30	18.6	4.22E-06	3.62E-05	9.94E-02	1.90E-11	1.63E-10	4.47E-07	3.98E-11	3.38E-10	9.16E-07	8.73E-12	7.49E-11	2.06E-07
35	21.7	3.75E-06	3.33E-05	1.72E-02	1.69E-11	1.50E-10	7.75E-08	3.50E-11	3.11E-10	1.57E-07	7.76E-12	6.90E-11	3.56E-08
40	24.9	3.89E-06	3.15E-05	4.06E-03	1.75E-11	1.42E-10	1.83E-08	3.68E-11	2.94E-10	4.01E-08	8.05E-12	6.52E-11	8.41E-09
45	28.0	3.57E-06	3.17E-05	2.31E-03	1.61E-11	1.43E-10	1.04E-08	3.35E-11	2.96E-10	2.17E-08	7.39E-12	6.57E-11	4.79E-09
50	31.1	3.41E-06	3.15E-05	6.31E-04	1.53E-11	1.42E-10	2.84E-09	3.19E-11	2.93E-10	5.75E-09	7.05E-12	6.52E-11	1.31E-09
55	34.2	3.83E-06	3.14E-05	2.18E-04	1.72E-11	1.41E-10	9.81E-10	3.57E-11	2.93E-10	1.98E-09	7.93E-12	6.49E-11	4.51E-10
60	37.3	3.59E-06	3.14E-05	2.43E-04	1.61E-11	1.41E-10	1.09E-09	3.41E-11	2.94E-10	2.34E-09	7.43E-12	6.51E-11	5.04E-10
65	40.4	3.49E-06	3.08E-05	1.46E-04	1.57E-11	1.39E-10	6.58E-10	3.23E-11	2.89E-10	1.43E-09	7.21E-12	6.37E-11	3.02E-10
70	43.5	3.42E-06	3.03E-05	7.07E-05	1.54E-11	1.36E-10	3.18E-10	3.18E-11	2.84E-10	6.37E-10	7.09E-12	6.28E-11	1.46E-10
75	46.6	3.63E-06	2.99E-05	6.31E-05	1.63E-11	1.34E-10	2.84E-10	3.35E-11	2.79E-10	5.74E-10	7.51E-12	6.19E-11	1.31E-10
80	49.7	3.25E-06	2.91E-05	5.95E-05	1.46E-11	1.31E-10	2.68E-10	3.08E-11	2.72E-10	5.45E-10	6.72E-12	6.02E-11	1.23E-10
90	55.9	3.40E-06	2.90E-05	5.76E-05	1.53E-11	1.31E-10	2.59E-10	3.18E-11	2.71E-10	5.30E-10	7.04E-12	6.00E-11	1.19E-10

Table 3-11A
HOUSTON Agriculture Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	9.20E+01	1.07E+03	1.24E+04	1.38E-03	1.61E-02	1.86E-01	3.85E-03	4.36E-02	4.96E-01	6.35E-04	7.39E-03	8.56E-02
1	0.6	2.29E+01	3.82E+02	3.06E+03	3.44E-04	5.73E-03	4.58E-02	9.39E-04	1.54E-02	1.24E-01	1.58E-04	2.63E-03	2.11E-02
2	1.2	9.86E-02	1.18E+02	1.28E+03	1.48E-06	1.77E-03	1.91E-02	4.10E-06	4.83E-03	5.12E-02	6.80E-07	8.16E-04	8.80E-03
3	1.9	4.14E-03	6.56E+01	8.88E+02	6.21E-08	9.84E-04	1.33E-02	1.67E-07	2.73E-03	3.55E-02	2.85E-08	4.53E-04	6.12E-03
4	2.5	2.95E-03	3.99E+01	6.85E+02	4.43E-08	5.98E-04	1.03E-02	1.23E-07	1.62E-03	2.79E-02	2.04E-08	2.75E-04	4.73E-03
5	3.1	1.97E-03	2.26E+01	5.12E+02	2.96E-08	3.39E-04	7.69E-03	8.03E-08	9.23E-04	2.03E-02	1.36E-08	1.56E-04	3.54E-03
6	3.7	1.68E-03	1.37E+01	4.10E+02	2.52E-08	2.06E-04	6.15E-03	6.97E-08	5.58E-04	1.65E-02	1.16E-08	9.45E-05	2.83E-03
7	4.3	1.38E-03	8.90E+00	3.52E+02	2.07E-08	1.33E-04	5.28E-03	5.69E-08	3.68E-04	1.47E-02	9.54E-09	6.14E-05	2.43E-03
8	5.0	1.20E-03	5.01E+00	2.77E+02	1.79E-08	7.52E-05	4.15E-03	4.93E-08	2.03E-04	1.13E-02	8.26E-09	3.46E-05	1.91E-03
9	5.6	1.08E-03	2.66E+00	2.04E+02	1.62E-08	4.00E-05	3.06E-03	4.47E-08	1.09E-04	8.23E-03	7.45E-09	1.84E-05	1.41E-03
10	6.2	1.14E-03	1.79E+00	1.98E+02	1.72E-08	2.69E-05	2.98E-03	4.67E-08	7.26E-05	7.93E-03	7.90E-09	1.24E-05	1.37E-03
15	9.3	6.79E-04	1.27E-01	1.04E+02	1.02E-08	1.90E-06	1.55E-03	2.78E-08	5.16E-06	4.13E-03	4.68E-09	8.74E-07	7.15E-04
20	12.4	5.40E-04	1.46E-02	4.06E+01	8.10E-09	2.20E-07	6.10E-04	2.25E-08	5.89E-07	1.58E-03	3.73E-09	1.01E-07	2.80E-04
25	15.5	4.09E-04	3.70E-03	1.81E+01	6.14E-09	5.55E-08	2.71E-04	1.66E-08	1.50E-07	7.11E-04	2.82E-09	2.55E-08	1.25E-04
30	18.6	3.70E-04	3.25E-03	6.74E+00	5.55E-09	4.88E-08	1.01E-04	1.50E-08	1.33E-07	2.74E-04	2.56E-09	2.24E-08	4.65E-05
35	21.7	3.43E-04	3.01E-03	3.19E+00	5.15E-09	4.51E-08	4.79E-05	1.43E-08	1.23E-07	1.32E-04	2.37E-09	2.08E-08	2.20E-05
40	24.9	3.07E-04	2.66E-03	9.05E-01	4.61E-09	3.99E-08	1.36E-05	1.27E-08	1.10E-07	3.86E-05	2.12E-09	1.84E-08	6.24E-06
45	28.0	2.42E-04	2.12E-03	4.42E-03	3.63E-09	3.17E-08	6.62E-08	1.03E-08	8.75E-08	1.69E-07	1.67E-09	1.46E-08	3.05E-08

Table 3-11B
HOUSTON Agriculture Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	9.03E+01	1.01E+03	1.15E+04	4.06E-04	4.56E-03	5.18E-02	8.44E-04	9.41E-03	1.08E-01	1.87E-04	2.10E-03	2.38E-02
1	0.6	2.15E+01	3.63E+02	2.87E+03	9.69E-05	1.63E-03	1.29E-02	2.01E-04	3.38E-03	2.68E-02	4.46E-05	7.51E-04	5.95E-03
2	1.2	9.55E-02	1.10E+02	1.21E+03	4.30E-07	4.96E-04	5.46E-03	8.94E-07	1.04E-03	1.13E-02	1.98E-07	2.28E-04	2.51E-03
3	1.9	3.89E-03	6.42E+01	8.17E+02	1.75E-08	2.89E-04	3.68E-03	3.57E-08	5.97E-04	7.58E-03	8.05E-09	1.33E-04	1.69E-03
4	2.5	2.85E-03	3.75E+01	6.62E+02	1.28E-08	1.69E-04	2.98E-03	2.64E-08	3.51E-04	6.14E-03	5.90E-09	7.76E-05	1.37E-03
5	3.1	1.91E-03	2.16E+01	4.83E+02	8.59E-09	9.73E-05	2.17E-03	1.77E-08	2.03E-04	4.47E-03	3.95E-09	4.48E-05	1.00E-03
6	3.7	1.62E-03	1.30E+01	3.83E+02	7.29E-09	5.85E-05	1.72E-03	1.51E-08	1.22E-04	3.56E-03	3.35E-09	2.69E-05	7.92E-04
7	4.3	1.34E-03	8.40E+00	3.41E+02	6.03E-09	3.78E-05	1.53E-03	1.25E-08	7.92E-05	3.18E-03	2.77E-09	1.74E-05	7.05E-04
8	5.0	1.14E-03	4.71E+00	2.67E+02	5.14E-09	2.12E-05	1.20E-03	1.06E-08	4.37E-05	2.52E-03	2.36E-09	9.76E-06	5.53E-04
9	5.6	1.04E-03	2.62E+00	1.93E+02	4.70E-09	1.18E-05	8.68E-04	9.73E-09	2.43E-05	1.77E-03	2.16E-09	5.41E-06	3.99E-04
10	6.2	1.10E-03	1.65E+00	1.84E+02	4.95E-09	7.44E-06	8.27E-04	1.01E-08	1.55E-05	1.71E-03	2.28E-09	3.42E-06	3.80E-04
15	9.3	6.50E-04	1.19E-01	9.71E+01	2.93E-09	5.35E-07	4.37E-04	5.97E-09	1.11E-06	8.94E-04	1.35E-09	2.46E-07	2.01E-04
20	12.4	5.12E-04	1.35E-02	3.77E+01	2.30E-09	6.07E-08	1.70E-04	4.85E-09	1.28E-07	3.50E-04	1.06E-09	2.79E-08	7.80E-05
25	15.5	3.75E-04	3.52E-03	1.69E+01	1.69E-09	1.58E-08	7.59E-05	3.49E-09	3.26E-08	1.60E-04	7.77E-10	7.28E-09	3.49E-05
30	18.6	3.50E-04	3.11E-03	6.31E+00	1.58E-09	1.40E-08	2.84E-05	3.27E-09	2.89E-08	5.92E-05	7.25E-10	6.44E-09	1.31E-05
35	21.7	3.33E-04	2.87E-03	3.02E+00	1.50E-09	1.29E-08	1.36E-05	3.06E-09	2.68E-08	2.80E-05	6.90E-10	5.93E-09	6.24E-06
40	24.9	2.89E-04	2.52E-03	8.99E-01	1.30E-09	1.13E-08	4.04E-06	2.70E-09	2.37E-08	8.35E-06	5.99E-10	5.22E-09	1.86E-06
45	28.0	2.39E-04	2.05E-03	4.04E-03	1.08E-09	9.21E-09	1.82E-08	2.22E-09	1.91E-08	3.70E-08	4.95E-10	4.23E-09	8.36E-09

Table 3-11C
HOUSTON Industrial Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	4.28E+01	4.84E+02	5.64E+03	6.42E-04	7.26E-03	8.46E-02	1.74E-03	1.97E-02	2.28E-01	2.95E-04	3.34E-03	3.89E-02
1	0.6	1.07E+01	1.88E+02	1.42E+03	1.60E-04	2.81E-03	2.13E-02	4.35E-04	7.65E-03	5.79E-02	7.35E-05	1.29E-03	9.81E-03
2	1.2	4.30E-02	5.77E+01	6.20E+02	6.45E-07	8.65E-04	9.30E-03	1.74E-06	2.38E-03	2.56E-02	2.97E-07	3.98E-04	4.28E-03
3	1.9	1.93E-03	3.17E+01	4.24E+02	2.89E-08	4.76E-04	6.35E-03	7.73E-08	1.31E-03	1.70E-02	1.33E-08	2.19E-04	2.92E-03
4	2.5	1.42E-03	1.93E+01	3.30E+02	2.13E-08	2.89E-04	4.96E-03	5.89E-08	8.00E-04	1.35E-02	9.79E-09	1.33E-04	2.28E-03
5	3.1	9.50E-04	1.08E+01	2.46E+02	1.43E-08	1.63E-04	3.69E-03	4.02E-08	4.40E-04	1.00E-02	6.56E-09	7.48E-05	1.70E-03
6	3.7	8.30E-04	6.48E+00	2.01E+02	1.24E-08	9.72E-05	3.01E-03	3.34E-08	2.68E-04	8.08E-03	5.73E-09	4.47E-05	1.39E-03
7	4.3	6.58E-04	4.33E+00	1.60E+02	9.86E-09	6.49E-05	2.40E-03	2.78E-08	1.77E-04	6.65E-03	4.54E-09	2.99E-05	1.10E-03
8	5.0	5.97E-04	2.71E+00	1.37E+02	8.96E-09	4.07E-05	2.06E-03	2.46E-08	1.13E-04	5.77E-03	4.12E-09	1.87E-05	9.46E-04
9	5.6	5.49E-04	1.18E+00	1.11E+02	8.24E-09	1.76E-05	1.67E-03	2.25E-08	4.88E-05	4.58E-03	3.79E-09	8.12E-06	7.67E-04
10	6.2	5.70E-04	9.62E-01	9.60E+01	8.55E-09	1.44E-05	1.44E-03	2.29E-08	3.84E-05	3.79E-03	3.93E-09	6.63E-06	6.63E-04
15	9.3	3.23E-04	5.96E-02	4.91E+01	4.85E-09	8.95E-07	7.37E-04	1.41E-08	2.53E-06	2.00E-03	2.23E-09	4.12E-07	3.39E-04
20	12.4	2.56E-04	6.27E-03	2.08E+01	3.84E-09	9.40E-08	3.12E-04	1.06E-08	2.61E-07	8.20E-04	1.77E-09	4.33E-08	1.44E-04
25	15.5	1.84E-04	1.82E-03	8.62E+00	2.76E-09	2.73E-08	1.29E-04	7.72E-09	7.33E-08	3.49E-04	1.27E-09	1.26E-08	5.95E-05
30	18.6	1.77E-04	1.62E-03	3.54E+00	2.66E-09	2.43E-08	5.32E-05	7.34E-09	6.59E-08	1.45E-04	1.22E-09	1.12E-08	2.45E-05
35	21.7	1.64E-04	1.41E-03	1.49E+00	2.46E-09	2.11E-08	2.23E-05	6.89E-09	5.82E-08	6.12E-05	1.13E-09	9.71E-09	1.02E-05
40	24.9	1.44E-04	1.28E-03	4.39E-01	2.16E-09	1.92E-08	6.59E-06	5.83E-09	5.30E-08	1.87E-05	9.92E-10	8.84E-09	3.03E-06
45	28.0	1.26E-04	1.03E-03	2.17E-03	1.89E-09	1.55E-08	3.26E-08	5.26E-09	4.27E-08	8.43E-08	8.68E-10	7.13E-09	1.50E-08

Table 3-11D
HOUSTON Mining Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	4.00E+01	4.55E+02	5.37E+03	6.00E-04	6.83E-03	8.05E-02	1.62E-03	1.84E-02	2.21E-01	2.76E-04	3.14E-03	3.70E-02
1	0.6	1.01E+01	1.78E+02	1.36E+03	1.51E-04	2.67E-03	2.04E-02	4.18E-04	7.22E-03	5.50E-02	6.95E-05	1.23E-03	9.40E-03
2	1.2	3.89E-02	5.42E+01	5.93E+02	5.84E-07	8.13E-04	8.90E-03	1.51E-06	2.24E-03	2.38E-02	2.68E-07	3.74E-04	4.09E-03
3	1.9	1.80E-03	2.94E+01	4.11E+02	2.70E-08	4.41E-04	6.17E-03	7.40E-08	1.22E-03	1.65E-02	1.24E-08	2.03E-04	2.84E-03
4	2.5	1.36E-03	1.84E+01	3.05E+02	2.05E-08	2.77E-04	4.58E-03	5.53E-08	7.58E-04	1.26E-02	9.42E-09	1.27E-04	2.11E-03
5	3.1	9.23E-04	1.02E+01	2.34E+02	1.38E-08	1.52E-04	3.52E-03	3.77E-08	4.10E-04	9.39E-03	6.37E-09	7.01E-05	1.62E-03
6	3.7	7.80E-04	6.11E+00	1.91E+02	1.17E-08	9.16E-05	2.87E-03	3.15E-08	2.53E-04	7.79E-03	5.38E-09	4.21E-05	1.32E-03
7	4.3	6.36E-04	4.08E+00	1.54E+02	9.54E-09	6.12E-05	2.30E-03	2.59E-08	1.69E-04	6.23E-03	4.39E-09	2.82E-05	1.06E-03
8	5.0	5.75E-04	2.66E+00	1.33E+02	8.62E-09	3.99E-05	2.00E-03	2.38E-08	1.08E-04	5.37E-03	3.97E-09	1.83E-05	9.19E-04
9	5.6	5.11E-04	1.14E+00	1.07E+02	7.66E-09	1.71E-05	1.60E-03	2.13E-08	4.69E-05	4.33E-03	3.52E-09	7.87E-06	7.38E-04
10	6.2	5.43E-04	8.97E-01	9.02E+01	8.14E-09	1.35E-05	1.35E-03	2.25E-08	3.61E-05	3.58E-03	3.74E-09	6.19E-06	6.22E-04
15	9.3	3.18E-04	5.65E-02	4.77E+01	4.77E-09	8.48E-07	7.15E-04	1.33E-08	2.35E-06	1.90E-03	2.19E-09	3.90E-07	3.29E-04
20	12.4	2.44E-04	5.98E-03	1.96E+01	3.66E-09	8.98E-08	2.94E-04	1.00E-08	2.45E-07	7.82E-04	1.68E-09	4.13E-08	1.35E-04
25	15.5	1.80E-04	1.72E-03	8.05E+00	2.69E-09	2.59E-08	1.21E-04	7.36E-09	6.91E-08	3.28E-04	1.24E-09	1.19E-08	5.55E-05
30	18.6	1.73E-04	1.53E-03	3.38E+00	2.60E-09	2.30E-08	5.07E-05	7.05E-09	6.26E-08	1.39E-04	1.19E-09	1.06E-08	2.33E-05
35	21.7	1.58E-04	1.33E-03	1.41E+00	2.38E-09	2.00E-08	2.11E-05	6.37E-09	5.50E-08	5.67E-05	1.09E-09	9.19E-09	9.70E-06
40	24.9	1.37E-04	1.21E-03	4.36E-01	2.05E-09	1.82E-08	6.54E-06	5.66E-09	4.97E-08	1.73E-05	9.44E-10	8.36E-09	3.01E-06
45	28.0	1.23E-04	9.75E-04	2.07E-03	1.84E-09	1.46E-08	3.11E-08	4.96E-09	4.05E-08	8.05E-08	8.47E-10	6.73E-09	1.43E-08

Figure 3-11E
HOUSTON Recreation Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	1.67E+01	1.94E+02	2.25E+03	2.50E-04	2.91E-03	3.37E-02	6.89E-04	7.92E-03	9.14E-02	1.15E-04	1.34E-03	1.55E-02
1	0.6	4.09E+00	6.92E+01	5.52E+02	6.14E-05	1.04E-03	8.28E-03	1.67E-04	2.81E-03	2.23E-02	2.82E-05	4.78E-04	3.81E-03
2	1.2	1.81E-02	2.13E+01	2.32E+02	2.72E-07	3.20E-04	3.48E-03	7.57E-07	8.75E-04	9.28E-03	1.25E-07	1.47E-04	1.60E-03
3	1.9	7.88E-04	1.19E+01	1.60E+02	1.18E-08	1.79E-04	2.41E-03	3.06E-08	4.89E-04	6.41E-03	5.43E-09	8.22E-05	1.11E-03
4	2.5	5.37E-04	7.22E+00	1.23E+02	8.05E-09	1.08E-04	1.84E-03	2.21E-08	2.93E-04	5.02E-03	3.70E-09	4.98E-05	8.48E-04
5	3.1	3.54E-04	4.08E+00	9.26E+01	5.31E-09	6.12E-05	1.39E-03	1.43E-08	1.66E-04	3.64E-03	2.44E-09	2.81E-05	6.39E-04
6	3.7	2.98E-04	2.48E+00	7.50E+01	4.47E-09	3.72E-05	1.13E-03	1.25E-08	1.00E-04	2.98E-03	2.06E-09	1.71E-05	5.18E-04
7	4.3	2.49E-04	1.61E+00	6.45E+01	3.74E-09	2.42E-05	9.68E-04	1.00E-08	6.67E-05	2.65E-03	1.72E-09	1.11E-05	4.45E-04
8	5.0	2.17E-04	8.88E-01	4.99E+01	3.26E-09	1.33E-05	7.49E-04	8.81E-09	3.70E-05	1.99E-03	1.50E-09	6.13E-06	3.44E-04
9	5.6	1.96E-04	4.77E-01	3.70E+01	2.94E-09	7.15E-06	5.55E-04	8.14E-09	1.98E-05	1.51E-03	1.35E-09	3.29E-06	2.55E-04
10	6.2	2.06E-04	3.28E-01	3.59E+01	3.08E-09	4.92E-06	5.38E-04	8.44E-09	1.32E-05	1.45E-03	1.42E-09	2.26E-06	2.47E-04
15	9.3	1.21E-04	2.25E-02	1.86E+01	1.82E-09	3.38E-07	2.80E-04	5.00E-09	9.11E-07	7.57E-04	8.38E-10	1.55E-07	1.29E-04
20	12.4	9.68E-05	2.61E-03	7.36E+00	1.45E-09	3.91E-08	1.10E-04	4.02E-09	1.05E-07	2.92E-04	6.68E-10	1.80E-08	5.08E-05
25	15.5	7.42E-05	6.77E-04	3.28E+00	1.11E-09	1.02E-08	4.92E-05	3.02E-09	2.73E-08	1.28E-04	5.12E-10	4.67E-09	2.27E-05
30	18.6	6.55E-05	5.87E-04	1.22E+00	9.83E-10	8.81E-09	1.83E-05	2.69E-09	2.40E-08	4.80E-05	4.52E-10	4.05E-09	8.42E-06
35	21.7	6.17E-05	5.45E-04	5.83E-01	9.25E-10	8.17E-09	8.75E-06	2.56E-09	2.22E-08	2.37E-05	4.25E-10	3.76E-09	4.02E-06
40	24.9	5.57E-05	4.79E-04	1.64E-01	8.36E-10	7.18E-09	2.47E-06	2.29E-09	1.97E-08	7.02E-06	3.84E-10	3.30E-09	1.13E-06
45	28.0	4.44E-05	3.80E-04	8.17E-04	6.66E-10	5.70E-09	1.23E-08	1.84E-09	1.57E-08	3.15E-08	3.07E-10	2.62E-09	5.64E-09

Table 3-11F
HOUSTON Recreation Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	9.28E+00	1.04E+02	1.17E+03	4.18E-05	4.69E-04	5.28E-03	8.61E-05	9.66E-04	1.10E-02	1.92E-05	2.16E-04	2.43E-03
1	0.6	2.23E+00	3.71E+01	2.98E+02	1.00E-05	1.67E-04	1.34E-03	2.10E-05	3.46E-04	2.78E-03	4.61E-06	7.69E-05	6.16E-04
2	1.2	1.02E-02	1.13E+01	1.23E+02	4.60E-08	5.10E-05	5.56E-04	9.23E-08	1.06E-04	1.16E-03	2.12E-08	2.35E-05	2.56E-04
3	1.9	3.95E-04	6.56E+00	8.47E+01	1.78E-09	2.95E-05	3.81E-04	3.68E-09	6.13E-05	7.89E-04	8.18E-10	1.36E-05	1.75E-04
4	2.5	2.96E-04	3.82E+00	6.75E+01	1.33E-09	1.72E-05	3.04E-04	2.78E-09	3.59E-05	6.28E-04	6.14E-10	7.92E-06	1.40E-04
5	3.1	1.94E-04	2.23E+00	4.99E+01	8.73E-10	1.00E-05	2.25E-04	1.81E-09	2.08E-05	4.63E-04	4.02E-10	4.61E-06	1.03E-04
6	3.7	1.66E-04	1.33E+00	3.95E+01	7.47E-10	6.00E-06	1.78E-04	1.57E-09	1.25E-05	3.69E-04	3.43E-10	2.76E-06	8.18E-05
7	4.3	1.36E-04	8.58E-01	3.48E+01	6.14E-10	3.86E-06	1.57E-04	1.27E-09	8.03E-06	3.25E-04	2.82E-10	1.78E-06	7.21E-05
8	5.0	1.16E-04	4.85E-01	2.71E+01	5.21E-10	2.18E-06	1.22E-04	1.08E-09	4.51E-06	2.55E-04	2.40E-10	1.00E-06	5.60E-05
9	5.6	1.06E-04	2.67E-01	1.97E+01	4.79E-10	1.20E-06	8.88E-05	9.85E-10	2.50E-06	1.82E-04	2.20E-10	5.52E-07	4.08E-05
10	6.2	1.13E-04	1.71E-01	1.90E+01	5.08E-10	7.70E-07	8.57E-05	1.05E-09	1.61E-06	1.75E-04	2.34E-10	3.54E-07	3.94E-05
15	9.3	6.81E-05	1.21E-02	9.93E+00	3.06E-10	5.45E-08	4.47E-05	6.20E-10	1.14E-07	9.16E-05	1.41E-10	2.51E-08	2.05E-05
20	12.4	5.24E-05	1.39E-03	3.91E+00	2.36E-10	6.27E-09	1.76E-05	4.97E-10	1.31E-08	3.67E-05	1.09E-10	2.88E-09	8.10E-06
25	15.5	3.88E-05	3.62E-04	1.73E+00	1.74E-10	1.63E-09	7.78E-06	3.57E-10	3.35E-09	1.61E-05	8.02E-11	7.50E-10	3.58E-06
30	18.6	3.60E-05	3.19E-04	6.45E-01	1.62E-10	1.44E-09	2.90E-06	3.37E-10	2.98E-09	6.10E-06	7.45E-11	6.61E-10	1.34E-06
35	21.7	3.41E-05	2.93E-04	3.11E-01	1.54E-10	1.32E-09	1.40E-06	3.15E-10	2.74E-09	2.94E-06	7.06E-11	6.07E-10	6.43E-07
40	24.9	2.90E-05	2.59E-04	9.13E-02	1.31E-10	1.17E-09	4.11E-07	2.76E-10	2.42E-09	8.55E-07	6.01E-11	5.36E-10	1.89E-07
45	28.0	2.45E-05	2.11E-04	4.16E-04	1.10E-10	9.47E-10	1.87E-09	2.29E-10	1.97E-09	3.80E-09	5.06E-11	4.36E-10	8.60E-10

Table 3-11G
HOUSTON Residential Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	5.83E+01	6.79E+02	7.86E+03	8.74E-04	1.02E-02	1.18E-01	2.41E-03	2.77E-02	3.20E-01	4.02E-04	4.69E-03	5.42E-02
1	0.6	1.43E+01	2.42E+02	1.93E+03	2.15E-04	3.63E-03	2.90E-02	5.85E-04	9.82E-03	7.80E-02	9.88E-05	1.67E-03	1.33E-02
2	1.2	6.33E-02	7.47E+01	8.13E+02	9.50E-07	1.12E-03	1.22E-02	2.65E-06	3.06E-03	3.25E-02	4.37E-07	5.15E-04	5.61E-03
3	1.9	2.76E-03	4.17E+01	5.61E+02	4.14E-08	6.25E-04	8.42E-03	1.07E-07	1.71E-03	2.24E-02	1.90E-08	2.88E-04	3.87E-03
4	2.5	1.88E-03	2.53E+01	4.30E+02	2.82E-08	3.79E-04	6.45E-03	7.75E-08	1.03E-03	1.76E-02	1.30E-08	1.74E-04	2.97E-03
5	3.1	1.24E-03	1.43E+01	3.24E+02	1.86E-08	2.14E-04	4.86E-03	4.99E-08	5.81E-04	1.27E-02	8.55E-09	9.84E-05	2.24E-03
6	3.7	1.04E-03	8.67E+00	2.63E+02	1.57E-08	1.30E-04	3.94E-03	4.37E-08	3.52E-04	1.04E-02	7.20E-09	5.98E-05	1.81E-03
7	4.3	8.72E-04	5.64E+00	2.26E+02	1.31E-08	8.46E-05	3.39E-03	3.50E-08	2.33E-04	9.26E-03	6.02E-09	3.89E-05	1.56E-03
8	5.0	7.60E-04	3.11E+00	1.75E+02	1.14E-08	4.66E-05	2.62E-03	3.08E-08	1.30E-04	6.98E-03	5.24E-09	2.14E-05	1.21E-03
9	5.6	6.87E-04	1.67E+00	1.30E+02	1.03E-08	2.50E-05	1.94E-03	2.85E-08	6.94E-05	5.27E-03	4.74E-09	1.15E-05	8.94E-04
10	6.2	7.19E-04	1.15E+00	1.26E+02	1.08E-08	1.72E-05	1.88E-03	2.95E-08	4.61E-05	5.07E-03	4.96E-09	7.92E-06	8.66E-04
15	9.3	4.25E-04	7.88E-02	6.53E+01	6.38E-09	1.18E-06	9.79E-04	1.75E-08	3.19E-06	2.65E-03	2.93E-09	5.44E-07	4.50E-04
20	12.4	3.39E-04	9.13E-03	2.58E+01	5.08E-09	1.37E-07	3.87E-04	1.41E-08	3.66E-07	1.02E-03	2.34E-09	6.30E-08	1.78E-04
25	15.5	2.60E-04	2.37E-03	1.15E+01	3.90E-09	3.55E-08	1.72E-04	1.06E-08	9.55E-08	4.48E-04	1.79E-09	1.64E-08	7.93E-05
30	18.6	2.29E-04	2.06E-03	4.27E+00	3.44E-09	3.08E-08	6.40E-05	9.42E-09	8.39E-08	1.68E-04	1.58E-09	1.42E-08	2.95E-05
35	21.7	2.16E-04	1.91E-03	2.04E+00	3.24E-09	2.86E-08	3.06E-05	8.96E-09	7.77E-08	8.29E-05	1.49E-09	1.32E-08	1.41E-05
40	24.9	1.95E-04	1.68E-03	5.75E-01	2.92E-09	2.51E-08	8.63E-06	8.02E-09	6.89E-08	2.46E-05	1.35E-09	1.16E-08	3.97E-06
45	28.0	1.55E-04	1.33E-03	2.86E-03	2.33E-09	2.00E-08	4.29E-08	6.45E-09	5.50E-08	1.10E-07	1.07E-09	9.18E-09	1.97E-08

Table 3-11H
HOUSTON Residential Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	3.25E+01	3.65E+02	4.10E+03	1.46E-04	1.64E-03	1.85E-02	3.01E-04	3.38E-03	3.86E-02	6.72E-05	7.56E-04	8.49E-03
1	0.6	7.80E+00	1.30E+02	1.04E+03	3.51E-05	5.85E-04	4.69E-03	7.37E-05	1.21E-03	9.72E-03	1.61E-05	2.69E-04	2.16E-03
2	1.2	3.58E-02	3.97E+01	4.32E+02	1.61E-07	1.79E-04	1.95E-03	3.23E-07	3.70E-04	4.04E-03	7.41E-08	8.22E-05	8.95E-04
3	1.9	1.38E-03	2.29E+01	2.97E+02	6.22E-09	1.03E-04	1.33E-03	1.29E-08	2.15E-04	2.76E-03	2.86E-09	4.75E-05	6.14E-04
4	2.5	1.04E-03	1.34E+01	2.36E+02	4.67E-09	6.02E-05	1.06E-03	9.72E-09	1.26E-04	2.20E-03	2.15E-09	2.77E-05	4.89E-04
5	3.1	6.79E-04	7.80E+00	1.75E+02	3.06E-09	3.51E-05	7.87E-04	6.32E-09	7.27E-05	1.62E-03	1.41E-09	1.61E-05	3.62E-04
6	3.7	5.81E-04	4.67E+00	1.38E+02	2.61E-09	2.10E-05	6.23E-04	5.50E-09	4.36E-05	1.29E-03	1.20E-09	9.67E-06	2.86E-04
7	4.3	4.77E-04	3.00E+00	1.22E+02	2.15E-09	1.35E-05	5.49E-04	4.46E-09	2.81E-05	1.14E-03	9.88E-10	6.22E-06	2.52E-04
8	5.0	4.05E-04	1.70E+00	9.47E+01	1.82E-09	7.63E-06	4.26E-04	3.78E-09	1.58E-05	8.92E-04	8.39E-10	3.51E-06	1.96E-04
9	5.6	3.73E-04	9.33E-01	6.91E+01	1.68E-09	4.20E-06	3.11E-04	3.45E-09	8.75E-06	6.37E-04	7.71E-10	1.93E-06	1.43E-04
10	6.2	3.95E-04	5.99E-01	6.66E+01	1.78E-09	2.70E-06	3.00E-04	3.69E-09	5.64E-06	6.13E-04	8.17E-10	1.24E-06	1.38E-04
15	9.3	2.38E-04	4.24E-02	3.47E+01	1.07E-09	1.91E-07	1.56E-04	2.17E-09	4.00E-07	3.21E-04	4.93E-10	8.78E-08	7.19E-05
20	12.4	1.83E-04	4.87E-03	1.37E+01	8.26E-10	2.19E-08	6.16E-05	1.74E-09	4.60E-08	1.29E-04	3.80E-10	1.01E-08	2.84E-05
25	15.5	1.36E-04	1.27E-03	6.05E+00	6.10E-10	5.71E-09	2.72E-05	1.25E-09	1.17E-08	5.64E-05	2.81E-10	2.62E-09	1.25E-05
30	18.6	1.26E-04	1.12E-03	2.26E+00	5.67E-10	5.03E-09	1.02E-05	1.18E-09	1.04E-08	2.13E-05	2.61E-10	2.31E-09	4.67E-06
35	21.7	1.19E-04	1.03E-03	1.09E+00	5.37E-10	4.62E-09	4.90E-06	1.10E-09	9.59E-09	1.03E-05	2.47E-10	2.12E-09	2.25E-06
40	24.9	1.02E-04	9.06E-04	3.20E-01	4.57E-10	4.08E-09	1.44E-06	9.67E-10	8.49E-09	2.99E-06	2.10E-10	1.88E-09	6.62E-07
45	28.0	8.56E-05	7.37E-04	1.45E-03	3.85E-10	3.32E-09	6.55E-09	8.01E-10	6.88E-09	1.33E-08	1.77E-10	1.53E-09	3.01E-09

Table 3-11I
HOUSTON Tourism Adult

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	2.36E+00	2.74E+01	3.17E+02	3.54E-05	4.12E-04	4.76E-03	9.74E-05	1.12E-03	1.29E-02	1.63E-05	1.89E-04	2.19E-03
1	0.6	5.79E-01	9.81E+00	7.81E+01	8.69E-06	1.47E-04	1.17E-03	2.37E-05	3.97E-04	3.15E-03	4.00E-06	6.77E-05	5.39E-04
2	1.2	2.56E-03	3.02E+00	3.29E+01	3.84E-08	4.53E-05	4.93E-04	1.07E-07	1.24E-04	1.31E-03	1.77E-08	2.08E-05	2.27E-04
3	1.9	1.11E-04	1.68E+00	2.26E+01	1.67E-09	2.53E-05	3.40E-04	4.32E-09	6.93E-05	9.07E-04	7.68E-10	1.16E-05	1.56E-04
4	2.5	7.60E-05	1.02E+00	1.74E+01	1.14E-09	1.53E-05	2.61E-04	3.13E-09	4.15E-05	7.11E-04	5.24E-10	7.04E-06	1.20E-04
5	3.1	5.00E-05	5.77E-01	1.31E+01	7.51E-10	8.66E-06	1.97E-04	2.02E-09	2.35E-05	5.15E-04	3.45E-10	3.98E-06	9.05E-05
6	3.7	4.22E-05	3.51E-01	1.06E+01	6.33E-10	5.26E-06	1.59E-04	1.77E-09	1.42E-05	4.23E-04	2.91E-10	2.42E-06	7.32E-05
7	4.3	3.53E-05	2.28E-01	9.12E+00	5.29E-10	3.42E-06	1.37E-04	1.42E-09	9.43E-06	3.75E-04	2.43E-10	1.58E-06	6.30E-05
8	5.0	3.07E-05	1.26E-01	7.06E+00	4.60E-10	1.88E-06	1.06E-04	1.25E-09	5.23E-06	2.82E-04	2.12E-10	8.66E-07	4.87E-05
9	5.6	2.78E-05	6.76E-02	5.24E+00	4.17E-10	1.01E-06	7.86E-05	1.15E-09	2.81E-06	2.13E-04	1.92E-10	4.66E-07	3.61E-05
10	6.2	2.90E-05	4.64E-02	5.08E+00	4.35E-10	6.97E-07	7.62E-05	1.19E-09	1.86E-06	2.05E-04	2.00E-10	3.20E-07	3.51E-05
15	9.3	1.72E-05	3.19E-03	2.64E+00	2.58E-10	4.78E-08	3.96E-05	7.09E-10	1.29E-07	1.07E-04	1.19E-10	2.20E-08	1.82E-05
20	12.4	1.37E-05	3.68E-04	1.04E+00	2.06E-10	5.52E-09	1.56E-05	5.70E-10	1.48E-08	4.12E-05	9.46E-11	2.54E-09	7.19E-06
25	15.5	1.05E-05	9.58E-05	4.65E-01	1.57E-10	1.44E-09	6.97E-06	4.28E-10	3.86E-09	1.82E-05	7.24E-11	6.61E-10	3.21E-06
30	18.6	9.27E-06	8.32E-05	1.72E-01	1.39E-10	1.25E-09	2.58E-06	3.80E-10	3.39E-09	6.79E-06	6.39E-11	5.74E-10	1.19E-06
35	21.7	8.72E-06	7.72E-05	8.29E-02	1.31E-10	1.16E-09	1.24E-06	3.63E-10	3.14E-09	3.35E-06	6.02E-11	5.32E-10	5.72E-07
40	24.9	7.90E-06	6.78E-05	2.33E-02	1.19E-10	1.02E-09	3.49E-07	3.24E-10	2.79E-09	9.93E-07	5.45E-11	4.68E-10	1.60E-07
45	28.0	6.28E-06	5.38E-05	1.16E-04	9.42E-11	8.08E-10	1.73E-09	2.60E-10	2.22E-09	4.45E-09	4.33E-11	3.72E-10	7.97E-10

Table 3-11J
HOUSTON Tourism Child

Distance		Annual Dose (percentile)			Lifetime Fatal Cancer Risk (percentile)			Lifetime Cancer Incidence (Slope Factor) (percentile)			Lifetime Radiation Detriment (percentile)		
Kilometers	Miles	5	50	95	5	50	95	5	50	95	5	50	95
0.1	0.06	1.30E+00	1.46E+01	1.64E+02	5.85E-06	6.57E-05	7.39E-04	1.21E-05	1.35E-04	1.54E-03	2.69E-06	3.02E-05	3.40E-04
1	0.6	3.12E-01	5.20E+00	4.17E+01	1.40E-06	2.34E-05	1.88E-04	2.95E-06	4.84E-05	3.89E-04	6.46E-07	1.08E-05	8.63E-05
2	1.2	1.43E-03	1.59E+00	1.73E+01	6.44E-09	7.15E-06	7.78E-05	1.29E-08	1.48E-05	1.62E-04	2.96E-09	3.29E-06	3.58E-05
3	1.9	5.53E-05	9.18E-01	1.19E+01	2.49E-10	4.13E-06	5.34E-05	5.15E-10	8.58E-06	1.10E-04	1.14E-10	1.90E-06	2.46E-05
4	2.5	4.15E-05	5.35E-01	9.44E+00	1.87E-10	2.41E-06	4.25E-05	3.89E-10	5.03E-06	8.79E-05	8.59E-11	1.11E-06	1.95E-05
5	3.1	2.72E-05	3.12E-01	6.99E+00	1.22E-10	1.40E-06	3.15E-05	2.53E-10	2.91E-06	6.48E-05	5.62E-11	6.46E-07	1.45E-05
6	3.7	2.32E-05	1.87E-01	5.54E+00	1.05E-10	8.40E-07	2.49E-05	2.20E-10	1.75E-06	5.16E-05	4.81E-11	3.87E-07	1.15E-05
7	4.3	1.91E-05	1.20E-01	4.88E+00	8.59E-11	5.41E-07	2.19E-05	1.78E-10	1.12E-06	4.55E-05	3.95E-11	2.49E-07	1.01E-05
8	5.0	1.62E-05	6.79E-02	3.79E+00	7.29E-11	3.05E-07	1.70E-05	1.51E-10	6.31E-07	3.57E-05	3.35E-11	1.40E-07	7.84E-06
9	5.6	1.49E-05	3.73E-02	2.76E+00	6.71E-11	1.68E-07	1.24E-05	1.38E-10	3.50E-07	2.55E-05	3.08E-11	7.72E-08	5.72E-06
10	6.2	1.58E-05	2.40E-02	2.67E+00	7.11E-11	1.08E-07	1.20E-05	1.48E-10	2.26E-07	2.45E-05	3.27E-11	4.96E-08	5.52E-06
15	9.3	9.53E-06	1.70E-03	1.39E+00	4.29E-11	7.63E-09	6.25E-06	8.69E-11	1.60E-08	1.28E-05	1.97E-11	3.51E-09	2.88E-06
20	12.4	7.34E-06	1.95E-04	5.48E-01	3.30E-11	8.77E-10	2.47E-06	6.96E-11	1.84E-09	5.14E-06	1.52E-11	4.04E-10	1.13E-06
25	15.5	5.43E-06	5.07E-05	2.42E-01	2.44E-11	2.28E-10	1.09E-06	5.00E-11	4.70E-10	2.26E-06	1.12E-11	1.05E-10	5.01E-07
30	18.6	5.04E-06	4.47E-05	9.03E-02	2.27E-11	2.01E-10	4.06E-07	4.72E-11	4.17E-10	8.54E-07	1.04E-11	9.25E-11	1.87E-07
35	21.7	4.78E-06	4.11E-05	4.35E-02	2.15E-11	1.85E-10	1.96E-07	4.41E-11	3.84E-10	4.11E-07	9.89E-12	8.50E-11	9.01E-08
40	24.9	4.07E-06	3.63E-05	1.28E-02	1.83E-11	1.63E-10	5.75E-08	3.87E-11	3.39E-10	1.20E-07	8.42E-12	7.50E-11	2.65E-08
45	28.0	3.42E-06	2.95E-05	5.82E-05	1.54E-11	1.33E-10	2.62E-10	3.20E-11	2.75E-10	5.32E-10	7.09E-12	6.10E-11	1.20E-10

The parameter uncertainties, such as exposure and toxicity factors, contain a combination of parameter uncertainty and model uncertainty. Parameter uncertainty is the dominant contributor to the total uncertainty of an exposure estimate.

Completeness uncertainty relates to whether all major pathways, contaminants, and release mechanisms have been included in the risk assessment. It is unlikely that a significant pathway has been excluded altogether; more likely, a pathway may have been assumed to be present when it actually is not. Completeness uncertainty is not anticipated to be a large contributor to the total uncertainty of a given risk estimate.

Model uncertainties are the most difficult to address due to the unknown nature of their sources. Examples of model uncertainties include the derivation of the latent cancer fatality, total cancer incidence, and radiation detriment risk responses in human health risk assessment and postulated mechanisms of action used to quantify toxicity for the ecological risk receptors. Additional sources of model uncertainty include dispersion estimates which are usually theoretical in nature, not analytical. Model uncertainties may also be a major contributor to the total uncertainty of a risk estimate; however, they are difficult to quantify within a regulatory framework.

The risk models include significant uncertainty when applied to the doses calculated in this risk assessment. The risk models are derived assuming a linear nonthreshold relationship between the effects found at high dose and high dose rate effects from low doses. In discussing the limitations of radiological risk for doses less than 1,000 mrem, the National Academy of Sciences, in the BEIR V report noted, "The possibility that there may be no risk from exposures comparable to external natural background cannot be ruled out. At such low doses and dose rates, it must be acknowledged that the lower limit of the range of uncertainty in the risk estimates extends to zero" (NAS, 1990). The official position statement of the Health Physics Society recommends that "Assessment of radiogenic health risks be limited to dose estimates near and above 10,000 mrem. Below this level, only dose is credible and statements of associated risks are more speculative than credible" (HPS, 1995).

The following two major types of uncertainties should be considered when reviewing the results of the exposure assessment: uncertainties associated with determining the tritium concentration at the receptor location (i.e., transport mechanism) and those associated with the assumptions used in the exposure models. Uncertainties associated with the data evaluation process relate to the first major type of uncertainty.

Uncertainties associated with the assumptions used in the exposure models that have potential for highly overestimating dose and risk include selecting the upper-bound tritium concentrations as input, assuming a probability of one for all land-use exposure scenarios at all dose-receptor locations, assuming that a receptor inhabits a single location for thirty years, and that the computed tritium concentration is accurately modeled over the 30-year exposure time.

The use of standard tritium transfer coefficients tend to moderately overestimate dose and risk. For exposure parameters such as exposure time, frequency, and duration, the potential to overestimate or underestimate risk is low. These qualitative ratings are based on quantitative analysis of uncertainty. The greatest contributor to uncertainty in the tritium intake by the dose receptor for each land use is associated with the uncertainty in the concentration of tritium in groundwater.

3.6 Conclusions

Tritium was selected as the primary contaminant of concern for the next 100 years due to its mobility in groundwater and its abundance in the hydrologic source term. Tritium in all three pathlines evaluated will decay to a concentration significantly below regulatory limits in about 100 years. However, in the near term, the risks from tritium are believed to be higher than from any other single contaminant. Tritium concentration in groundwater and the radiation doses received by individuals from chronic exposure to HTO while engaged in six potential land-use exposure scenarios have been calculated. The land-use scenarios were postulated to be very conservative and pessimistic to ensure that the calculated doses would bound any realistic dose that could be received by individuals.

The agriculture and residential land-use scenarios resulted in greater dose and risk estimates than the other four land-use scenarios. This is true at all dose locations for all three pathlines. The mining and industrial land use scenarios resulted in the next highest dose and risk, approximately 40 percent of the dose and risk from the agriculture land-use scenario. For all six land-use scenarios, the drinking water and food ingestion exposure pathways contributed most significantly to tritium intake, dose, and risk. For the agriculture land-use scenario, the drinking water and food ingestion exposure pathways contributed approximately 54 and 45 percent, respectively, of the tritium intake, dose, and risk. For the other five land-use scenarios, the drinking water exposure pathway contributed approximately 84 to 86 percent of the tritium intake, dose, and risk, while the food ingestion pathway contributed approximately 14 percent. The dermal exposure pathway, absorption of tritiated water vapor and liquid through the skin, is the only other exposure pathway that contributes more than one percent of the tritium intake, dose, and risk.

The regulatory limit on control of radioactive material released to the environment due to DOE operations is established in DOE Order 5400.5 (DOE, 1993). The dose limit is 100 mrem per year from all exposure pathways. In addition, DOE Order 5400.5 references the EPA *National Primary Drinking Water Regulations* (40 CFR 141) for control of dose to members of the public from ingestion of drinking water due to the release of radioactive material to the environment from DOE operations. The limit for tritium is 20,000 pCi/L and is comparable to an MCLG. DOE Order 5400.5 does not address risk limits to members of the public. Additional discussion on the tritium dose, concentration, and risk for each pathline is found in this section.

At the 50th percentile, doses for the agriculture land-use scenarios exceed the 100 mrem/yr dose limit listed in DOE Order 5400.5 (DOE, 1993b) at dose receptor locations on the TYBO pathline on and off of the NTS. None of these dose locations is located downgradient of the Nellis Air Force Range. The highest calculated dose rate at a location off the NTS (129 mrem/yr) was calculated for the agriculture land-use scenario on the TYBO groundwater pathline. This scenario, however, is unlikely at this location because of the hilly terrain and harsh climate. The highest calculated dose at a location off the Nellis Air Force Range (0.25 mrem/yr) was also on the TYBO pathline for the agriculture land-use exposure scenario.

The tritium concentration computed for the TYBO pathline exceeds the MCLG at all dose-receptor locations, both on site and off site.

For the TYBO/PEPATO/KASH pathline, the maximum estimated dose to adult and child receptors at the 50th percentile does not exceed the 100 mrem/yr limit at locations beyond 12.2 km (7.6 mi) from the PEPATO event. This includes locations off the NTS but not beyond the Nellis Air Force Range boundary. At the 95th percentile, the estimated dose to adult and child receptors exceeds 100 mrem/yr for the agriculture land-use scenarios at all locations on the pathline. The maximum estimated lifetime TCI risk, at the 50th percentile, does not exceed 10^{-4} at locations beyond 19.6 km (12.2 mi) for the adult and child receptors. These locations are off the NTS but are not beyond the Nellis Air Force Range boundary. The maximum estimated lifetime TCI risk, at both the 50th and 95th percentile, exceeds 10^{-6} at all dose receptor locations. The lifetime fatal cancer and radiation detriment are less than the TCI at all locations for all land-use scenarios.

For the HOUSTON pathline, the maximum estimated dose to adult and child receptors at the 50th percentile does not exceed 100 mrem/yr at locations beyond 2 km (1.2 mi) from the HOUSTON event. At the 95th percentile, the maximum estimated dose does not exceed 100 mrem/yr at locations beyond 15 km (9.3 mi). The locations where 100 mrem/yr is exceeded for both the 50th and 95th percentile are on the NTS. The maximum estimated TCI risk, at the 50th percentile,

does not exceed 10^{-6} at any location beyond the NTS boundary. At the 95th percentile the lifetime TCI risk exceeds 10^{-4} at locations beyond the NTS boundary but not the Nellis Air Force Range boundary. At the 95th percentile the lifetime TCI risk exceeds 10^{-6} at dose locations beyond the Nellis Air Force Range for every land-use scenario except recreation and tourism. The lifetime fatal cancer and radiation detriment are less than the TCI at all locations for all land-use scenarios.

For the BOURBON/KANKAKEE/MICKEY/TORRIDO pathline, the maximum estimated doses to adult and child receptors do not exceed 100 mrem/yr for both the 50th and 95th percentile at any location beyond the NTS boundary. The maximum estimated TCI risk, for both the 50th and 95th percentile, does not exceed 10^{-6} at any location beyond the NTS boundary. The lifetime fatal cancer and radiation detriment are less than the TCI at all locations for all land-use scenarios.

Tables 3-12, 3-13, 3-14 and 3-15 summarize the annual dose, lifetime fatal cancer risk, and lifetime total cancer incidence at both the 50th and 95th percentile for the agriculture adult, agriculture child, residential adult, and residential child land-use scenarios, respectively, at specific locations of interest. These locations are the event sites, NTS boundary, and, where applicable, the Nellis Air Force Range boundary.

The dose and risk calculations demonstrate the following:

- In the near term, the most imminent risk from long-term exposure of tritium in groundwater is obtained at receptor points along the TYBO pathway.
- In the near term, tritium migration from HOUSTON and BOURBON do not constitute human health hazards off the NTS.

Sensitivity tests were performed on the mathematical models used to calculate intake, dose, and risk. The sensitivity test measures the amount of uncertainty in a calculated intake, dose, or risk that is caused by both the uncertainty in the input parameter values and uncertainty in the model.

Table 3-12
Estimated Dose and Risk for Potential Agriculture Adult Scenario at the Nevada Test Site

Distance (kilometers)	**Location**	**Annual Dose** (percentile) (mrem/yr)		**Lifetime Fatal Cancer Risk** (percentile)		**Lifetime Cancer Incidence (Slope Factor)** (percentile)	
		50	**95**	**50**	**95**	**50**	**95**
TYBO Pathline							
0.1	PEPATO Event	1.3×10^{2}	1.7×10^{3}	2.0×10^{-3}	2.6×10^{-2}	5.4×10^{-3}	7.1×10^{-2}
9.8	TYBO Event & NTS Boundary	3.7×10^{2}	2.6×10^{3}	5.5×10^{-3}	3.8×10^{-2}	1.5×10^{-2}	1.1×10^{-1}
31.8	Nellis Air Force Range Boundary	1.3×10^{-1}	1.8×10^{2}	2.0×10^{-6}	2.7×10^{-3}	5.4×10^{-6}	7.4×10^{-3}
37.1	Oasis Valley Discharge Area	1.2×10^{-1}	1.4×10^{2}	1.9×10^{-6}	2.1×10^{-3}	5.1×10^{-6}	5.8×10^{-3}
HOUSTON Pathline							
0.1	HOUSTON Event	1.1×10^{3}	1.2×10^{4}	1.6×10^{-2}	1.9×10^{-1}	4.4×10^{-2}	5.0×10^{-1}
30	NTS Boundary	3.3×10^{-3}	6.7×10^{0}	4.9×10^{-8}	1.0×10^{-4}	1.3×10^{-7}	2.7×10^{-4}
40	Nellis Air Force Range Boundary	2.7×10^{-3}	9.1×10^{-1}	4.0×10^{-8}	1.4×10^{-5}	1.1×10^{-7}	3.9×10^{-5}
BOURBON Pathline							
0.1	KANKAKEE Event	7.1×10^{2}	1.3×10^{4}	1.1×10^{-2}	2.0×10^{-1}	2.9×10^{-2}	5.5×10^{-1}
10	BOURBON Event	4.1×10^{2}	4.0×10^{3}	6.1×10^{-3}	6.0×10^{-2}	1.7×10^{-2}	1.6×10^{-1}
70	NTS Boundary	2.2×10^{-3}	5.5×10^{-3}	$3.3 \text{ x} \times 10^{-8}$	8.2×10^{-8}	9.1×10^{-8}	2.0×10^{-7}

Table 3-13
Estimated Dose and Risk for Potential Agriculture Child Scenario at the Nevada Test Site

Distance (kilometers)	**Location**	**Annual Dose** (percentile) (mrem/yr)		**Lifetime Fatal Cancer Risk** (percentile)		**Lifetime Cancer Incidence (Slope Factor)** (percentile)	
		50	**95**	**50**	**95**	**50**	**95**
TYBO Pathline							
0.1	PEPATO Event	1.3×10^{2}	1.7×10^{3}	5.7×10^{-4}	7.4×10^{-3}	1.2×10^{-3}	1.5×10^{-2}
9.8	TYBO Event & NTS Boundary	3.5×10^{2}	2.5×10^{3}	1.6×10^{-3}	1.1×10^{-2}	3.3×10^{-3}	2.3×10^{-2}
31.8	Nellis Air Force Range Boundary	1.2×10^{-1}	1.7×10^{2}	5.6×10^{-7}	7.8×10^{-4}	1.2×10^{-6}	1.6×10^{-3}
37.1	Oasis Valley Discharge Area	1.2×10^{-1}	1.4×10^{2}	5.2×10^{-7}	6.1×10^{-4}	1.1×10^{-6}	1.3×10^{-3}
HOUSTON Pathline							
0.1	HOUSTON Event	1.0×10^{3}	1.2×10^{4}	4.6×10^{-3}	5.2×10^{-2}	9.4×10^{-3}	1.1×10^{-1}
30	NTS Boundary	3.1×10^{-3}	6.3×10^{0}	1.4×10^{-8}	2.8×10^{-5}	2.9×10^{-8}	5.9×10^{-5}
40	Nellis Air Force Range Boundary	2.5×10^{-3}	9.0×10^{-1}	1.1×10^{-8}	4.0×10^{-6}	2.4×10^{-8}	8.4×10^{-6}
BOURBON Pathline							
0.1	KANKAKEE Event	6.8×10^{2}	1.3×10^{4}	3.1×10^{-3}	5.7×10^{-2}	6.4×10^{-3}	1.2×10^{-1}
10	BOURBON Event	3.9×10^{2}	3.7×10^{3}	1.7×10^{-3}	1.7×10^{-2}	3.6×10^{-3}	3.5×10^{-2}
70	NTS Boundary	2.1×10^{-3}	4.7×10^{-3}	$9.5 \times \times 10^{-9}$	2.1×10^{-8}	2.0×10^{-8}	4.3×10^{-8}

Table 3-14
Estimated Dose and Risk for Potential Residential Adult Scenario at the Nevada Test Site

Distance (kilometers)	**Location**	**Annual Dose** (percentile) (mrem/yr)		**Lifetime Fatal Cancer Risk** (percentile)		**Lifetime Cancer Incidence (Slope Factor)** (percentile)	
		50	**95**	**50**	**95**	**50**	**95**
TYBO Pathline							
0.1	PEPATO Event	8.1×10^{1}	1.1×10^{3}	1.2×10^{-3}	1.7×10^{-2}	3.3×10^{-3}	4.6×10^{-2}
9.8	TYBO Event & NTS Boundary	2.4×10^{2}	1.7×10^{3}	3.7×10^{-3}	2.5×10^{-2}	9.9×10^{-3}	6.8×10^{-2}
31.8	Nellis Air Force Range Boundary	6.0×10^{-2}	1.2×10^{2}	9.0×10^{-7}	1.8×10^{-3}	2.4×10^{-6}	4.8×10^{-3}
37.1	Oasis Valley Discharge Area	8.4×10^{-2}	9.4×10^{1}	1.3×10^{-6}	1.4×10^{-3}	3.6×10^{-6}	3.8×10^{-3}
HOUSTON Pathline							
0.1	HOUSTON Event	6.8×10^{2}	7.9×10^{3}	1.0×10^{-2}	1.2×10^{-1}	2.8×10^{-2}	3.2×10^{-1}
30	NTS Boundary	2.1×10^{-3}	4.3×10^{0}	3.1×10^{-8}	6.4×10^{-5}	8.4×10^{-8}	1.7×10^{-4}
40	Nellis Air Force Range Boundary	1.7×10^{-3}	5.8×10^{-1}	2.5×10^{-8}	8.6×10^{-6}	6.9×10^{-8}	2.5×10^{-5}
BOURBON Pathline							
0.1	KANKAKEE Event	4.5×10^{2}	8.2×10^{3}	6.8×10^{-3}	1.2×10^{-1}	1.8×10^{-2}	3.3×10^{-1}
10	BOURBON Event	2.5×10^{2}	2.7×10^{3}	3.8×10^{-3}	4.1×10^{-2}	1.0×10^{-2}	1.1×10^{-1}
70	NTS Boundary	1.4×10^{-3}	3.7×10^{-3}	$2.1 \times \times 10^{-8}$	5.5×10^{-8}	5.7×10^{-8}	1.3×10^{-7}

Table 3-15
Estimated Dose and Risk for Potential Residential Child Scenario at the Nevada Test Site

Distance (kilometers)	**Location**	**Annual Dose** (percentile) (mrem/yr)		**Lifetime Fatal Cancer Risk** (percentile)		**Lifetime Cancer Incidence (Slope Factor)** (percentile)	
		50	**95**	**50**	**95**	**50**	**95**
TYBO Pathline							
0.1	PEPATO Event	4.4×10^{1}	6.0×10^{2}	2.0×10^{-4}	2.7×10^{-3}	4.1×10^{-4}	5.6×10^{-3}
9.8	TYBO Event & NTS Boundary	1.3×10^{2}	9.1×10^{2}	5.9×10^{-4}	4.1×10^{-3}	1.2×10^{-3}	8.7×10^{-3}
31.8	Nellis Air Force Range Boundary	3.1×10^{-2}	6.4×10^{1}	1.4×10^{-7}	2.9×10^{-4}	2.9×10^{-7}	5.9×10^{-4}
37.1	Oasis Valley Discharge Area	4.7×10^{-2}	5.1×10^{1}	2.1×10^{-7}	2.3×10^{-4}	4.4×10^{-7}	4.8×10^{-4}
HOUSTON Pathline							
0.1	HOUSTON Event	3.7×10^{2}	4.1×10^{3}	1.6×10^{-3}	1.9×10^{-2}	3.4×10^{-3}	3.9×10^{-2}
30	NTS Boundary	1.1×10^{-3}	2.3×10^{0}	5.0×10^{-9}	1.0×10^{-5}	1.0×10^{-8}	2.1×10^{-5}
40	Nellis Air Force Range Boundary	9.1×10^{-4}	3.2×10^{-1}	4.1×10^{-9}	1.4×10^{-6}	8.5×10^{-9}	3.0×10^{-6}
BOURBON Pathline							
0.1	KANKAKEE Event	2.4×10^{2}	4.4×10^{3}	1.1×10^{-3}	2.0×10^{-2}	2.3×10^{-3}	4.2×10^{-2}
10	BOURBON Event	1.4×10^{2}	1.4×10^{3}	6.1×10^{-4}	6.2×10^{-3}	1.3×10^{-3}	1.3×10^{-2}
70	NTS Boundary	7.6×10^{-4}	1.8×10^{-3}	3.4×10^{-9}	8.0×10^{-9}	7.1×10^{-9}	1.6×10^{-8}

Sensitivity is calculated by computing rank correlation coefficients between every assumption and all forecasts (e.g., intake, dose, and risk). Correlation coefficients provide a meaningful measure of the degree to which assumptions and forecasts change together. If an assumption and a forecast have a high correlation coefficient, it means that the assumption has a significant impact on the calculated intakes, dose, and risk. Correlation coefficients range from -1 to 1. Positive coefficients indicate that an increase in the assumption is associated with an increase in the intake, dose, and risk. Negative coefficients imply the reverse situation. The larger the absolute value of the correlation coefficient, the stronger the relationship.

The results of the sensitivity test demonstrate the following:

- The most significant positive correlation coefficient is the tritium concentration distribution, greater than 0.99.
- There were no significant negative correlation coefficients. The negative correlation coefficient varied from -0.16 to -0.01.
- Drinking water intake is ranked second among all other parameters. The numerical value of its rank correlation coefficient varies from scenario to scenario and for each different forecast. The range of the correlation coefficients for drinking water intake was 0.15 to 0.3.
- The most significant contribution to dose and risk for all land-use exposure scenarios is from drinking water and food ingestion.
- All other exposure pathways contribute less than 2 percent of the dose and risk.
- The sensitivity analysis demonstrates that the correlation coefficients vary widely with each land-use exposure scenario and forecast.
- Only tritium concentration distribution and drinking water intake exceeded a correlation coefficient of 0.23. For some forecast and land-use exposure scenarios combinations, (e.g., the agriculture child land-use scenario forecast for dose), the correlation coefficient for drinking water ingestion rate is the second highest, less only than that of tritium concentration distribution, but its value is only 0.4.
- The effects of fate and transport modeling assumptions, exposure parameter assumptions, and dose and risk coefficient assumptions on the estimated dose and risk were analyzed. The results are summarized in Table 3-16. The greatest uncertainty for overestimating dose and risk lies in the risk coefficients. None of the parameters selected should result in underestimating the dose and risk.

Table 3-16
Uncertainty Associated with the Human Health Risk Assessment

Assumption	Effect on Dose and Risk[a]		
	Potential Magnitude for Overestimation of Dose and Risk	Potential Magnitude for Underestimating Dose and Risk	Potential Magnitude for Over or Underestimating Dose and Risk
Fate and Transport Modeling			
Regional groundwater flow model concentration during 30-year exposure time	High		
Exposure Parameter Estimation			
Assumption that all land-use scenarios occur during times of peak concentration at all dose locations during 30-year exposure time	High		
Tritium Transfer Coefficient Factors			
Assumed in exposure pathway	Moderate		
Exposure times assumed for each intake mechanism for each exposure pathway			Low
Intake rates assumed for exposure pathways			Low
Tritium in food crops incorporated as organically bound tritium	Low		
Dose and Risk Estimation			
Dose coefficient factor methodology	Low		
Total cancer incident risk factor	Very High		
Lifetime fatal cancer risk factor	Very High		
Radiation detriment risk factor	Very High		

[a]Assumptions marked as "Low" could affect dose and risk by less than one order of magnitude, assumptions marked "Moderate" could affect estimates of dose and risk by between one and two orders of magnitude, assumptions marked "High" could affect dose and risk estimates between two and three orders of magnitude, and assumptions marked "Very High" affect dose and risk by greater than three orders of magnitude.

4.0 Ecological Risk Assessment

4.1 Ecological Features

Generally speaking, both the on- and off-site locations are arid environments. Each of these locations, however, has freshwater springs and associated wetland species. Species found within the on- and off-site discharge areas are listed in Tables 4-1, 4-2, 4-3, and 4-4.

4.1.1 NTS Species

The vegetation of the NTS is comprised of the desert shrub associations typical of both the Mojave and Great Basin Deserts or the transition desert between these two. Extensive floral collection has yielded 711 taxa of vascular plants within or near the boundaries of the NTS. Although shrubs are the dominant forms, herbaceous plants are well represented and play an important role in supporting animal life at the NTS (DOE, 1992c; DOE, 1992a).

The Mojave Desert is characterized by creosote bush (*Larrea tridentata*) in association with codominants such as burro-weed (*Ambrosia dumosa*), desert thorn (*Lycium andersonii*), hopsage (*Grayia spinosa*), shadscale (*Atriplex confertifolia*), and four-winged saltbush (*A. canescens*) (DOE, 1992c).

In the transitional areas between the lowlands of the Mojave and Great Basin Deserts, several unique plant associations are present. The bajadas above the Mojave Desert and the floors of the open drainage basins in intermediate elevations are typically occupied by homogeneous stands of blackbrush (*Coleogyne ramosissima*). The valley floors of the closed drainage basins at the middle and lower elevations are occupied by stands of hopsage and various species of Lycium, occasionally in association with creosote bush (DOE, 1992c). The Great Basin Desert is largely characterized by big sagebrush (*Artemisia tridentata*) and black sagebrush (*A. nova*) in the intermediate elevations and shadscale in association with winterfat (*Ceratoides lanata*), green molly (*Kochia americana*), or greasewood (*Sarcobatus vermiculatus*). Some of these species can be found near groundwater discharge areas (Table 4-1); however, most are upland species that use surface water and are adapted to arid conditions.

Table 4-1
Plants That May Be Associated with the
Nevada Test Site Springs and Off-Site Discharge Areas

VASCULAR PLANTS[a]			
Scientific Name	**Common Name**	**Status[b]**	**Location[c]**
Trees, Shrubs, and Woody Vines			
Pluchea sericea[d]	arrow weed	FACW	AM
Sarcobatus vermiculatus	greasewood	FACU	AM, OV
Suaeda torreyanna v. torreyanna	Torrey's sea-blite	FAC+	AM, OV
Suaeda occidentalis[d]	Western sea-blite	FACW	AM
Suaeda intermedia[d]	shrubby sea-blite	FAC	AM
Prosopis pubescens	screw bean	FAC	AM
Lythrum californicum	California loosestrife	OBL	AM
Fraxinus velutina v. coriacca	leather-leaf ash	FAC	AM
Populus fremontii	Fremont cottonwood	FACW	AM, AC
Salix exigua v. stenophylla	narrow-leaved willow	OBL	AM
Salix gooddinga	Gooding's willow	FACW	AM, OV
Vitis arizonica	wild grape	FACU	AM
Herbs			
Amaranthus blitoides	prostrate amaranth	FACU	AM, OV
Berula erecta	water parsnip	OBL	AM, OV
Hydrocotyle verticillata	marsh pennywort	OBL	AM
Apocynum cannabinum v. glaberrinium	Indian hemp	FAC	AM
Asclepias fascicularis	narrow-leaved milkweed	FAC-	AM
Asclepias speciosa	showy milkweed	FACW	AM
Aster exilis	aster	N	AM
Aster intricatus[d]	shrubby alkali aster	OBL	AM
Aster pauciflorus	marsh alkali aster	FACW	AM, OV
Baccharis emoryi[d]	Emory baccharis	FACW	AM
Conyza coulteri	Coulter's conyza	FAC	AM
Crepis runcinata ssp. hallii	meadow hawksbeard	FACW	AM

See footnotes at end of table.

Table 4-1
Plants That May Be Associated with the
Nevada Test Site Springs and Off-Site Discharge Areas

VASCULAR PLANTS[a]			
Scientific Name	**Common Name**	**Status[b]**	**Location[c]**
Grindelia fraxino-pratensis	Ash Meadows gum plant	FACW	AM
Helianthus nuttallii	annual sunflower	FACW	AM
Iva axillaris v. robustior	poverty weed	FACW	AM, OV
Pluchea purpurescens	salt marsh fleabane	OBL	AM
Solidago spectabilis	showy goldenrod	FACW	AM, OV
Xanthium strumarium v. canadense	common cocklebur	FAC	AM, OV
Heliotropium curassavicum	alkali heliotrope	OBL	AM, OV
Plagiobothrys stipitatus	popcornflower	FACW	AM
Hutchinsia procumbens	prostrate hutchinsia	N	AM
Nastertium officinale	watercress	OBL	AM
Cleomella brevipes	stinkweed	FACU	AM
Allenrolfia occidentalis[d]	iodine bush	FACW	AM
Atriplex lentiformis[d]	quailbrush	FAC+	AM
Atriplex parryi[d]	Parry's saltbush	FACW	AM
Atriplex phyllostegia	arrow saltbush	FACW	AM, OV
Kochia californica	red molly	FACW	AM
Nitrophila mohavensis	Amargosa niterwort	FACW	AM
Nitrophila occidentalis	nitrophila	FACW	AM, OV
Cressa truxillensis[d]	alkali weed	FACW	AM
Glycyrrhiza lepidota	wild licorice	FAC-	AM
Trifolium wormskioldia	clover	OBL	OV
Centaurium namophilum	spring-loving centaury	W[e]	AM
Malvella leprosa[d]	alkali mallow	FAC	AM
Gaura parviflora	velvetweed	W[e]	AM
Oenothera elata	Hooker's evening primrose	FACW	AM
Dodecatheon pulchellum	shooting star	FACW	AM

See footnotes at end of table.

Table 4-1
Plants That May Be Associated with the
Nevada Test Site Springs and Off-Site Discharge Areas
(Page 3 of 6)

VASCULAR PLANTS[a]			
Scientific Name	**Common Name**	**Status[b]**	**Location[c]**
Samolus parviflorus	water-pimpernel	OBL	AM
Ranunculus cymbalaria v. saximontanus	buttercup family	OBL	OV
Anemopsis californica	yerba mansa	OBL	AM, OV
Castilleja linariaefolia	Wyoming paintbrush	W[e]	AM
Cordylanthus tecopensis[d]	Tecopa bird's beak	W[e]	AM
Mimulus guttatus	monkey flower	OBL	AM, OV
Veronica americana	American brooklime	OBL	AM
Verbena bracteata	verbena	FACU	AM
Carex praegracilis	sedge	FACW	AM, OV
Cladium californicum	saw grass	OBL	AM, AC
Eleocharis parishii	spikerush	OBL	AM, OV
Eleocharis rostellata	spikerush	OBL	AM
Fimbristylis thermalis	hot springs fimbristylis	OBL	AM, OV
Schoenus nigricans	black sedge	OBL	AM
Scirpus americanus[d]	American bulrush	OBL	AM
Scirpus olneyi	bulrush	N	AM, OV, AC
Scirpus robustus	alkali bulrush	OBL	AM, OV
Sisyrinchium demissum	blue-eyed grass	OBL	AM
Juncus balticus	Baltic rush	OBL	AM, OV
Juncus cooperi	Cooper's rush	FACW+	AM
Juncus nodosus	knotted rush	OBL	AM, OV
Triglochin concinnum	arrow grass	OBL	AM, OV
Calochortus striatus[d]	alkali mariposa lily	FACW	AM
Najas marina	spiny naiad	OBL	AM
Spiranthes infernalis[d]	Ash Meadows lady's tresses	W[e]	AM
Spiranthes romanzoffiana	orchid family	FACW	AM

See footnotes at end of table.

Table 4-1
Plants That May Be Associated with the
Nevada Test Site Springs and Off-Site Discharge Areas

VASCULAR PLANTS[a]			
Scientific Name	**Common Name**	**Status[b]**	**Location[c]**
Andropogon glomeratus[d]	bushy bluestem	FACW	AM
Distichlis spicata	saltgrass	FAC+	AM, AC
Hordeum jubatum[d]	foxtail barley	FAC	AM
Leptochloa uninerva[d]	Mexican sprangletop	FACW	AM
Muhlenbergia asperfolia[d]	scratchgrass	FACW+	AM
Muhlenbergia utilis	Aperejo grass	FACW	AM
Panicum virgatum	switch grass	FAC	AM
Phragmites australis	common reed	FACW+	AM, OV
Spartina gracilis	alkali cord grass	FACW	AM
Sporobolus airoides[d]	alkali sacaton	FAC	AM
Potamogeton pectinatus[d]	sago pondweed	OBL	AM
Ruppia maritima	wigeon grass	OBL	AM
Ruppia cirrhosa[d]	ditch grass	OBL	AM
Typha domingensis	southern cattail	OBL	AM, OV

ALGAE[f]	
Genus	**Species**
Division: Chrysophyta (Golden-brown algae) **Order: Pennales**	
Achnanthes	*exigua, lanceolata, minutissima, saxonica*
Amphora	*submontana*
Asterionella	*formosa*
Denticula	*elegans*
Epithemia	*adnata v. proboscidea, sorex*
Fragilaria	*construens, sp.*[g]
Gomphonema	*parvulum*
Hantzschia	*sp.*
Meridian	*circulare*

See footnotes at end of table.

Table 4-1
Plants That May Be Associated with the
Nevada Test Site Springs and Off-Site Discharge Areas

ALGAE[f]	
Genus	**Species**
Navicula	*crytocephala, cuspidata v. ambigua, laevissima, minima, rhynchocephala v. amphiceras*
Nitzschia	*amphibia, gracilis, linearis, palea, tryblionella, sp.*
Pinnularia	*abaujensis v. subundulata, viridis v. minor, sp.*
Stauroneis	*anceps*
Surirella	*ovalis*
Order: Centrales	
Melosira	*granulata*
Stephanodiscus	*niagarae*
Order: Vaucheriales	
Vaucheria	*sp.*
Division: Chlorophyta (Green algae) **Order: Volvocales**	
Chlamydomonas	*sp.*
Haematococcus	*lacustris*
Order: Ulotricales	
Microthamnion	*kuetzingianum*
Protoderma	*viride*
Stigeoclonium	*sp.*
Order: Oedogoniales	
Oedogonium	*sp.*
Order: Chlorococcales	
Ankistrodesmus	*falcatus*
Chlorella	*vulgaris*
Oocystis	*borgei*
Scenedesmus	*acutus*
Order: Zygnematales	
Closterium	*turgidum*
Cosmarium	*sp.*

Table 4-1
Plants That May Be Associated with the
Nevada Test Site Springs and Off-Site Discharge Areas

ALGAE[f]	
Genus	**Species**
Spirogyra	*juergensii*
Ulothrix	*sp.*
Division: Cyanophyta (Blue-green algae) Order: Oscillatoriales	
Lyngbya	*sp.*
Oscillatoria	*sp.*
Phormidium	*tenue, sp.*
Order: Nostocales	
Calothrix	*sp.*

[a] All vascular plants listed here were listed by Beatley (1976) and represent native flora found in spring areas in the vicinity of Ash Meadows and Oasis Valley, southern Nevada.

[b] The Status column lists the wetland indicator status of vascular plants according to the U.S. Fish and Wildlife Service system (Reed, 1988) with status listings updated according to the U.S. Fish and Wildlife Service, April 1996 update (FWS, 1996a): OBL = Obligate Wetland--occur almost always in wetlands; FACW = Facultative Wetland -- usually occur in wetlands; FAC = Facultative -- equally likely to occur in wetlands or nonwetlands; FACU = Facultative Upland -- usually occur in nonwetlands, but occasionally found in wetlands; N = Not enough data to determine status. Position within each range may be further indicated by + or -, with + indicating a higher likelihood of occurring in a wetland.

[c] The Location column lists the location where the species has been observed: AM = Ash Meadows, AC = Amargosa Canyon (Williams et al., 1981), OV = Oasis Valley.

[d] Species reported for Ash Meadows only (USDI, 1995). Other species are present in these areas, but this receptor list is based on the observations of those found near springs, or having a wetland status of FAC, FACW, or OBL (see below). Complete data were not available for the Nevada Test Site (NTS) and other discharge areas.

[e] W = Wetland status not indicated by Reed (1988), but considered a wetland plant by Ash Meadows National Wildlife Refuge (USDI, 1995).

[f] Algae species were collected and identified from the NTS springs (Taylor and Giles, 1979). Algae also live in the springs at other discharge areas (algae are a known food source for pupfish and other organisms inhabiting springs), but no data were available characterizing species assemblages in those areas.

[g] The abbreviation sp. refers to a specie of the genus listed that was not identified.

There are at least 46 species of mammals, 190 species of birds, and 32 species of reptiles inhabiting the NTS either seasonally or year-round. Rodents, including kangaroo rats (*Dipodomys* spp.), various species of mice, gophers, and ground squirrels, comprise nearly half of all mammal species and are widely distributed across the NTS. The black-tailed jackrabbit (*Lepus californicus*) is also widespread on the NTS. Mule deer (*Odocoileus hemionus*) are the most numerous of the large mammals found on NTS, inhabiting the sagebrush and pinyon-juniper associations of the high mesas in all seasons except winter. Recent inventories estimated deer populations on Rainier and Pahute Mesa at 1,500 and 2,000 individuals, respectively (DOE, 1992c). Wild horses (*Equis caballus*) inhabit portions of the Pahute Mesa area, and the population has been censused since 1989. At that time there were 60 horses excluding foals, expanding to 65 in 1992 (Greger and Romney, 1993). Monitoring of on-site springs has yielded information on species that use these water sources (Table 4-2).

Most bird species (approximately 86 percent) found on the NTS are migrants or seasonal residents (Table 4-3). Full-time residents include seven species of raptors (hawks, owls, and eagles), two species of game birds (Gambel's quail and chukar, *Callipepla gambelii and Alectoris chukar*, respectively), two species of woodpeckers, and at least 14 species of passerines. In the winter, large flocks of finches, sparrows, larks, and other passerines descend on the NTS for use as winter feeding grounds (DOE, 1992c).

The reptiles of the NTS include one species of tortoise, 14 species of lizards, and 17 species of snakes. Of the lizards, the side-blotched lizard (*Uta stansburiana*), western whiptail (*Cnemidophorus tigris*), desert horned lizard (*Phrynosoma platyrhinos*), and desert spiny lizard (*Sceloporus occidentalis*) are the most abundant and widespread, while the most common snake species on the NTS appears to be the western shovel-nosed snake (*Chionactis occipitalis*) (DOE, 1992c). Species that are expected to use the on-site springs are listed in Table 4-4.

Microorganisms are known to be present in the aquifers and aquitards beneath the NTS. Work is in progress to identify these organisms, and there is a possibility that novel species may be present (Russell, 1996). This effort is, however, not expected to reach completion within the near future.

Table 4-2
Mammals That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name
MAMMALS	
Equus caballus	feral horse
Bos taurus	cattle
Odocoileus hemionus	mule deer
Antilocapra anericana	antelope
Felis concolor	mountain lion
Lynx rufus	bobcat
Canis latrans	coyote[b]
Vulpes macrotis	kit fox[b]
Sylvilagus audubonii	cottontail[c]
Lepus californicus	jackrabbit[b,c]
Equus asinus[d]	feral burro
Neotoma sp.[d]	woodrat

[a] Data were taken from observations made for the BECAMP studies through frequent monitoring of springs and well reservoirs over the period of 1988 through 1992 (Romney and Greger, 1992; Greger and Romney, 1992; Greger, 1994). Other species are present in these areas, but this receptor list is based on the observations of those utilizing water sources on the NTS. Complete information, including utilization data, was not available for the other discharge areas.

[b] Present in Death Valley (DOE, 1995)

[c] Present at the Ash Meadows National Wildlife Refuge (USDI, 1995)

[d] Unpublished observation (J. Downey, Downey & Gutentag LLC, personal communication, June 12, 1996)

Table 4-3
Birds That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]
Order Podicipediformes: Grebes		
Podiceps nigricollis	eared grebe	M
Podilymbus podiceps	pied-billed grebe	M
Order Pelecaniformes: Totipalmate Swimmers		
Pelecanus occidentalis	brown pelican[c]	M, R
Order Ciconiformes: Herons, Ibises, and Storks		
Ardea herodias	great blue heron	M
Botaurus lentiginosus	American bittern	M
Bubulcus ibis	cattle egret	M
Butorides striatus	green-backed heron	M
Casmerodius albus	great egret	M
Egretta thula	snowy egret	M
Nycticorax nycticorax	black-crowned night heron	M
Plegadis chihi	white-face ibis	M
Order Anseriformes: Waterfowl		
Aix sponsa	wood duck	M
Anas acuta	northern pintail	M
Anas americana	American wigeon	M
Anas clypeata	northern shoveler	M
Anas crecca	green-winged teal	M
Anas cyanoptera	cinnamon teal	M
Anas discors	blue-winged teal	M
Anas platyrhynchos	mallard	M
Anas stepera	gadwall	M
Aythya affinis	lesser scaup	M
Aythya americana	redhead	M
Aythya collaris	ring-necked duck	M

See footnotes at end of table.

Table 4-3
Birds That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]
Aythya valisneria	canvasback	M
Branta canadensis	Canada goose	M
Bucephala albeola	bufflehead	M
Bucephala clangula	common goldeneye	M
Mergus merganser	common merganser	M
Oxyura jamaicensis	ruddy duck	M
Order Falconiformes: Diurnal Birds of Prey		
Cathartes aura	turkey vulture	PR
Pandion haliaetus	osprey	M
Accipiter cooperii	Cooper's hawk	PR
Accipiter gentilis	northern goshawk[c]	M, R
Accipiter striatus	sharp-shinned hawk	PR
Aquila chrysaetos	golden eagle	PR, B
Buteo jamaicensis	red-tailed hawk	PR, B
Circus cyaneus	northern harrier	WR
Falco peregrinus	peregrine falcon	M, R
Falco sparverius	American kestrel	PR, B
Order Galliformes: Gallinaceous Birds		
Alectoris chukar	chukar	PR, B
Callipepla gambelii	Gambel's quail	PR, B
Order Gruiformes: Rails, Cranes, and Allies		
Fulica americana	American coot	PR, B
Gallinola chloropus	common moorhen	M
Order Charadriiformes: Shorebirds, Gulls, and Alcids		
Charadrius semipalmatus	semipalmated plover	M
Charadrius vociferus	killdeer	M, B
Himantopus mexicanus	black-necked stilt	M

See footnotes at end of table.

Table 4-3
Birds That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]
Recurvirostra americana	American avocet	M, B
Actitis macularia	spotted sandpiper	M
Calidris mauri	western sandpiper	M
Calidris minutilla	least sandpiper	M
Catroptophorus semipalmatus	willet	M
Gallinago gallinago	common snipe	M
Limnodromus scolopaceus	long-billed dowitcher	M
Limosa fedoa	marbled godwit	M
Numenius americanus	long-billed curlew	M
Tringa melanoleuca	greater yellowlegs	M
Tringa solitaria	solitary sandpiper	M
Phalaropus lobatus	red-necked phalarope	M
Phalaropus tricolor	Wilson's phalarope	M
Larus californicus	California gull	M
Larus delawarensis	ring-billed gull	M
Larus philadelphia	Bonaparte's gull	M
Order Columbiformes: Pigeons and Allies		
Zenaida macroura	mourning dove	SR, B
Order Cuculiformes: Cuckoos and Allies		
Geococcyx californianus	greater roadrunner	PR, B
Order Strigiformes: Owls		
Tyto alba	common barn-owl	PR, B
Asio otus	long-eared owl	PR, B
Bubo virginianus	great horned owl	PR
Order Caprimulgiformes: Goatsuckers and Allies		
Chordeiles acutipennis	lesser nighthawk	SR
Order Apodiformes: Swifts and Hummingbirds		
Aeronautes saxatalis	white-throated swift	SR

See footnotes at end of table.

Table 4-3
Birds That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]
Order Coraciiformes: Rollers, Kingfishers, and Allies		
Ceryle alcyon	belted kingfisher	M
Order Piciformes: Woodpeckers and Allies		
Colaptes auratus	northern flicker	PR
Sphyrapicus nuchalis	red-naped sapsucker	M
Order Passeriformes: Perching Birds		
Contopus sordidulus	western wood-pewee	SR
Sayornis nigricans	black phoebe	SR
Sayornis saya	Say's phoebe	SR, B
Myiarchus cinerascens	ash-throated flycatcher	SR
Tyrannus verticalis	western kingbird	SR, B
Tyrannus vociferans	Cassin's kingbird[c]	SR, B
Eremophila alpestris	horned lark	PR, B
Hirundo pyrrhonota	cliff swallow	M
Hirundo rustica	barn swallow	M
Riparia riparia	bank swallow	M
Stelgidopteryx serripennis	northern rough-winged swallow	PR
Tachycineta bicolor	tree swallow	M
Tachycineta thalassina	violet-green swallow	PR
Aphelocoma coerulescens	scrub jay	PR
Corvus corax	common raven	PR, B
Gymnorhinus cyanocephalus	pinyon jay	PR
Parus gambeli	mountain chickadee[c]	PR
Psaltriparus minimus	bushtit	PR, B
Cistothorus palustris	marsh wren	M
Salpinctes obsoletus	rock wren	PR, B
Polioptila caerulea	blue-gray gnatcatcher	SR

See footnotes at end of table.

Table 4-3
Birds That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]
Regulus calendula	ruby-crowned kinglet	M
Ixoreus naevius	varied thrush[c]	M
Sialia currucoides	mountain bluebird	PR
Sialia mexicana	western bluebird[c]	PR
Turdus migratorius	American robin	M
Mimus polyglottos	northern mockingbird	SR, B
Oreoscoptes montanus	sage thrasher	M
Toxostoma lecontei	Le Conte's thrasher	PR, B
Anthus rubescens	American pipit	M
Bombycilla cedrorum	cedar waxwing	M
Phainopepla nitens	phainopepla	R
Lanius ludovicianus	loggerhead shrike	PR, B
Sturnus vulgaris	European starling	PR
Dendroica coronata	yellow-rumped warbler	M, B
Dendroica petechia	yellow warbler	M
Geothylpis trichas	common yellowthroat	M
Wilsonia pusilla	Wilson's warbler	M
Piranga ludoviciana	western tanager	M
Passerina amoena	lazuli bunting	SR
Passerina cyanea	inidigo bunting[c]	M
Pheucticus melanocephalus	black-headed grossbeak	SR
Amphispiza belli	sage sparrow	PR, B
Amphispiza bilineata	black-throated sparrow	SR, B
Chondestes grammacus	lark sparrow	M
Junco hymenalis	dark-eyed junco	PR
Melospiza melodia	song sparrow	M
Passerculus sandwichensis	savannah sparrow	M

See footnotes at end of table.

Table 4-3
Birds That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]
Pipilo chlorurus	green-tailed towhee	M
Pooecetes gramineus	vesper sparrow[c]	M
Spizella breweri	Brewer's sparrow	SR, B
Spizella passerina	chipping sparrow	SR, B
Zonotrichia leucophrys	white-crowned sparrow	M
Agelaius phoeniceus	red-winged blackbird	M
Euphagus cyanocephalus	Brewer's blackbird	M
Icterus parisorum	Scott's oriole[c]	SR
Molothus ater	brown-headed cowbird	SR, B
Quiscalus mexicanus	great-tailed grackle	SR, B
Sturnella neglecta	western meadowlark	M
Xanthocephalus xanthocephalus	yellow-headed blackbird	M
Carduelis pinus	pine siskin	WR
Carduelis psaltria	lesser goldfinch	PR
Carduelis tristis	American goldfinch	WR
Carpodacus cassinii	Cassin's finch[c]	SR
Carpodacus mexicanus	house finch	PR, B

[a] Bird species listed are from observations made for the BECAMP studies through frequent monitoring of springs and well reservoirs on the NTS over the period of 1988 through 1992 (Romney and Greger, 1992; Greger and Romney, 1992; Greger, 1994). Other species are present in these areas, but this receptor list is based on the observations of those using water sources on the NTS. Utilization data were not available for the other discharge areas, but are assumed to be similar.

[b] Status refers to the amount of time the species spends on the NTS: SR = Summer resident; WR = Winter resident; PR = Permanent resident; M = Spring-fall migrant; R = Rare or unusual sighting; B = Breeds on the NTS (Greger and Romney, 1992)

[c] Not listed as present at the Ash Meadows National Wildlife Refuge (USDI, 1995)

Table 4-4
Reptiles and Amphibians That May Be Associated with the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name
AMPHIBIANS	
Toads	
Bufo boreas	western toad
Bufo woodhousei	woodhouse toad
Bufo punctatus	red-spotted toad
Frogs	
Hyla regilla	Pacific treefrog
Rana catesbeiana	bullfrog
REPTILES	
Lizards	
Coleonyx variegatus	western banded gecko
Sceloporus magister	desert spiny lizard
Uta stansburiana	side-blotched lizard
Urosaurus graciosus	long-tailed brush lizard
Xantusia vigilis	desert night lizard
Sceloporus occidentalis	western fence lizard
Snakes	
Masticophis flagellum	coachwhip
Pituophis melanoleucus	gopher snake
Lampropeltis getulus	common kingsnake
Crotalus sp.[b]	rattlesnake

[a]This is a partial list obtained from the BECAMP studies through frequent monitoring of springs and well reservoirs on the Nevada Test Site over the period of 1988 through 1992 (Romney and Greger, 1992; Greger and Romney, 1992; Greger, 1994).
[b]Unpublished observation (J. Downey, Downey & Gutentag LLC, personal communication, June 12, 1996)

4.1.2 Off-Site Springs

Information on the ecology of the off-site discharge points is limited primarily to that of Ash Meadows. It is assumed that species common to the Great Basin and Mojave deserts are also common to the off-site areas. Species known to use water sources in these areas are listed in Tables 4-1, 4-2, 4-3, and 4-4.

Ash Meadows

Ash Meadows provides a haven to a variety of common species of plants and animals typical of the desert southwest. Plants include creosote bush, salt grass (*Distichlis spicata*), shadscale, ash trees (*Fraxinus velutina* var. *coriacea*), mesquite (*Prosopis julifera* and *P. pubescens*), and burro-weed (Sada, 1990). Common animals include amphibians (toads and frogs), reptiles (lizards and snakes), several mammalian species (rodents, bats, coyote, bobcat, bighorn sheep, squirrels, gophers, badgers), and more than 200 species of birds. Many nonnative species are also present and compete with and/or prey upon endemics. These exotics include mosquitofish (*Gambusia affinis*), sailfin mollies (*Poecilia latipinna*), crayfish (*Procambarus clarkii*), bullfrogs (*Rana catesbeiana*), and largemouth bass (*Micropterus salmoides*), (U.S. Fish and Wildlife Service [FWS], 1991).

Oasis Valley

Limited information exists on the flora and fauna of Oasis Valley. Common plant species within the area include shadscale, cheeseweed (*Hymenoclea salsola*), rabbit brush (*Chrysothamnus*), desert thorn (*Lucium pallidium*), blackbrush (*Coleogyne ramosissma*), pinon pine (*Pinus monophylla*), Utah juniper (*Juniperus osteosperna*), and big sagebrush.

Furnace Creek

The Travertine Springs area of Furnace Creek is overgrown with vegetation which includes desert holly, mesquite, baccharis, saltgrass, and cattails. An endemic species, Golden carpet (*Gilmania luteola*), grows on rocky areas near, but not directly on, the spring. Nonnative trees, including palms and saltcedars, have invaded the area. Signs of sightings of wildlife near the springs include coyotes (*Canis latrans*), foxes, desert bighorn sheep (*Orvis canadensis*), and a variety of birds and small mammals. Texas Spring has experienced the invasion of pioneer species in areas where habitat has been disturbed by humans. Such species include buckwheat (*Eriogonum* sp.) and *Euphorbia* species. Fish have also been observed in the area (Douglas and Sanchez, 1974).

Amargosa River

Tecopa Hot Springs within the Amargosa Canyon supports riparian vegetation characterized by bulrush (*Scirpus olneyi*) and salt grass (*Distichlis spicata*). Numerous minor seeps and springs that feed the river support sawgrass (*Cladium californicum*). Around Willow Spring and Willow Creek Reservoir are stands of cottonwood (*Populus fremontii*) and thickets of mesquite, willow, and tamarisk. The spring and reservoir are reportedly overgrown with cattail (Williams et al., 1981). Approximately 240 bird species have been found by the Los Angeles Audubon Society to use the canyon area.

4.1.3 Species of Special Concern

Numerous species of special concern are found on the NTS and on the adjacent discharge areas. These species are discussed below and listed in Table 4-5.

4.1.3.1 NTS Species of Special Concern

There are no plants listed under the Endangered Species Act of 1973, as amended, that are threatened, endangered, or considered candidate species for protection on the NTS. The desert tortoise (*Gopherus agassizii*) and a few bird species are, however, listed (Table 4-5).

The Mojave population of the desert tortoise was formally listed as a threatened species by the FWS on April 2, 1990 (55 FR 12178) pursuant to the Endangered Species Act of 1973, as amended. Tortoise habitat is characterized by creosote bush, alkali sink, and tree yucca habitats in valleys; on alluvial fans; and in low rolling hills at elevations generally ranging from approximately 600 to 1,200 m (1,970 to 3,900 ft) above mean sea level (54 FR 32326). Desert tortoises are present on the NTS, but in low to very low abundance. Tortoise habitats are found in the southern third of the NTS outside the area of nuclear test activities in Yucca Flat, Rainier Mesa, and Pahute Mesa (DOE, 1992c; DOE, 1992a). The desert tortoise is threatened by loss and degradation of habitat due to construction activities (e.g., roads, pipelines, housing developments, and energy developments), mining activities, grazing, and off-road vehicle use. Other important threats include upper respiratory disease and predation of juvenile tortoises by ravens (DOE, 1992c).

There is one endangered, one threatened, and one candidate bird species that may be found in the vicinity of the NTS, as shown in Table 4-5; these species are the peregrine falcon (endangered, *Falco peregrinus*), Western snowy plover (threatened, *Charadrius alexandrinus*

Table 4-5
Sensitive Species That May Be Associated With the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]	Location[c]
PLANTS			
Nitrophila mohavensis	Amargosa niterwort	E, CA(E)	AM, DV
Astragalus phoenix	Ash Meadows milk-vetch	T	AM
Centaurium namophilum	Spring-loving centaury	T	AM, DV
Enceliopsis nudicaulis corrugata	Ash Meadows sunray	T	AM
Ivesia eremica	Ash Meadows ivesia	T	AM
Grindelia fraxino-pratensis	Ash Meadows gum plant	T	DV, AM
Mentzelia leucophylla	Ash Meadows blazing star	T	AM
Astragalus funerus	Black milk vetch	NV	OV, NTS
Lathyrus hitchcokianus	Bullfrog hills sweet pea	NV	OV
Sclerocactus polyancistrus	Mojave fishhook cactus	NV	OV
Arctomecon merriamii	White bear paw poppy	BLM, NPS	DV, AM, NTS
Cordylanthus tecopensis	Tecopa bird's beak	BLM, NPS	DV, AM
Petalonyx thurberi ssp. gilmanii	Death Valley sandpaper plant	BLM, NPS	DV
Salvia funerea	Death Valley sage	BLM	AV
Calochortus striatus	Alkali mariposa lily	BLM	AM
Spiranthes infernalis	Ash Meadows lady's tresses	BLM	AM
Astragalus beatleyae	Beatley milk-vetch	C	NTS
Camissonia megalantha	Cane Spring evening primrose	BLM	NTS
Frasera pahutensis	Green gentian	BLM	NTS
Gulium hilendiae kingstonense	Kingston bedstraw	BLM	NTS
Penstemon albomarginatus	White-margined beardtongue	BLM	AV
Penstemon fruticiformis ssp. Amargosae	Death Valley beardtongue	BLM	AV
Penstemon pahutensis	Beardtongue	BLM	NTS
Phacelia beatleyae	Beatley phacelis	BLM	NTS
Cympoterus ripleyi v. Saniculoides	Sanicle biscuitroot	BLM	NTS
INVERTEBRATES			
Ambrysus amargosus	Ash Meadows naucorid beetle	T	AM, AV

See footnotes at end of table.

Table 4-5
Sensitive Species That May Be Associated With the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]	Location[c]
Agabus rumppi	Death Valley Agabus diving beetle	NPS, BLM	DV
Ambrysus amargosus	Furnace Creek navcorid bug	BLM	AV
Assiminea infima	Badwater snail	BLM, NPS	DV
Microcylloepus formicoideus	Furnace Creek riffle beetle	BLM, NPS	DV
Microcylloepus smilis	Riffle beetle	BLM, NPS	DV
Pyrgulopsis erythropoma	Ash Meadows pebblesnail	BLM	AM
Pyrgulopsis cristalis	Crystal Spring snail	BLM	AM
Pyrgulopsis nanus	Distal-gland springsnail	BLM	AM
Pyrgulopsis pisteri	Median-gland springsnail	BLM	AM
Pyrgulopsis fairbankensis	Fairbanks springsnail	BLM	AM
Pyrgulopsis micrococcus	Oasis Valley springsnail	BLM	NTS, OV, AV
Pyrgulopsis isolatus	Elongate-gland springsnail	BLM	AM
Tryonia variegata	Amargosa tryonia snail	BLM	AM, AV
Tryonia ericae	Minute tyronia snail	BLM	AM
Tyronia elata	Point of Rocks tryonia snail	BLM	AM
Tyronia robusta	Robust tryonia	BLM, NPS	DV
Tryonia angulata	Sportinggoods tryonia snail	BLM	AM
Pelcocrus shoshone	Amargosa naucorid bug	BLM	AM
Stenelmis callida callida	Devils Hole riffle beetle	BLM	AM
FISH			
Cyprinodon diabolis	Devil's Hole pupfish	E	AM
Cyprinodon nevadensis mionectes	Ash Meadows Amargosa pupfish	E	AM
Cyprinodon nevadensis pectoralis	Warm Springs pupfish	E	AM
Rhinichthys osculus nevadensis	Ash Meadows speckled dace	E	AM, AV

See footnotes at end of table.

Table 4-5
Sensitive Species That May Be Associated With the Nevada Test Site Springs and Off-Site Discharge Areas[a]

Scientific Name	Common Name	Status[b]	Location[c]
Rhinichthys osculus	Oasis speckled dace	NV, BLM	OV
Cyprinodon nevadensis calidae	Tecopa pupfish	BLM	AV
AMPHIBIANS AND REPTILES			
Gopherus agassizii	Desert tortoise	T, CA(T)	NTS, DV
Bufo nelsoni	Amargoso toad	C, NV	AV
Heloderma suspectum cinctum	Banded gila monster	BLM, NV	AV
BIRDS			
Haliaeetus leucocephalus	Bald eagle	T	AM
Falco peregrinus	Peregrine falcon	E	NTS, AM
Charadrius montanus	Mountain plover	C	NTS
Charadrius alexandrinus nivosus	Western snowy plover	T	NTS, AM
Buteo regalis	Ferruginous hawk	BLM, NV	NTS, AM
Buteo swainsoni	Swainson's hawk	BLM, NV	NTS, AM
Plegadis chihi	White-faced glossy ibis	NV, BLM	AM
Numenius americanus	Long-billed curlew	BLM	NTS
Chlidonias nigra	Black tern	BLM, NPS	AM
Ixobrychus exilis hesperis	Western least bittern	BLM, NPS	AM
MAMMALS			
Microtus montanus nevadensis	Ash Meadows montane vole	BLM, NPS	AM
Plecotus townsendii	Townsend's big-eared bat	BLM, NPS	AM

[a] Sensitive species listed are all those reported for areas where information was available. These species may or may not utilize impacted water sources, and thereby become exposed to UGTA contamination. Some species known to inhabit spring areas and use discharged groundwater are listed in Tables 4-1 through 4-4.

[b] Status refers to the listing status used by the U.S. Fish and Wildlife Service: E = Endangered -- in danger of extinction in all or significant portions of their ranges; T = Threatened -- likely to be classified as Endangered in the foreseeable future if present trends continue; C - candidate for Federal endangered species list with substantial information available to support proposing to list the species as endangered or threatened. This information has been updated from references cited in "c" using the following documents: FWS, 1996a; FWS, 1996b; FWS, 1996c. BLM = protected by the Bureau of Land Management (BLM, 1988 and personal communication with McNatt, R., - BLM, 1996). NV = protected by the State of Nevada (Cooper, K., 1996).
CA = protected by the State of California (CNHD, 1996). NPS = National Park Service.

[c] Locations where the species have been observed: AM = Ash Meadows (USDI, 1995); AV = Amargosa Valley (Williams et al., 1981); NTS = Nevada Test Site (DOE, 1992a and c); OV = Oasis Valley (Metscher, V., Bureau of Land Management, personal communication with Patty Gallo, IT, Nov. 7, 1995); DV = Death Valley/Furnace Creek

nivosus), and the mountain plover (candidate *Charadrius montanus*). Although peregrine falcons have been sighted on the NTS in the past, the likelihood of this species occurring in the area is small. Plovers are shorebirds that may migrate through the area, but would be unlikely to stop at the NTS (DOE, 1992c).

Species listed as protected under the Federal Endangered Species Act of 1973 as amended, and formerly listed Category 2 candidate species are usually protected by the U.S. Bureau of Land Management (BLM, 1988) and the State of Nevada (Cooper, 1996). Most of the nonrodent mammals present at the NTS, including mule deer and wild horses, have been placed in the "protected" classification by the State of Nevada (DOE, 1992a). Former Candidate 2 species protected by the BLM and the state include the ferruginous hawk (*Buteo regalis*) and Swainson' s hawk (*B. swainsoni*). Ferruginous hawks may occur in small numbers onsite during migration, and Swainson' s hawks may occupy the NTS during summer months. Several species of plants and invertebrates, as shown in Table 4-5, are also offered protection under these statutes.

4.1.4 Off-Site Species of Special Concern

Ash Meadows and the Amargosa River are two off-site areas that contain several species of special concern. No federally protected species are associated with Oasis Valley or Furnace Creek; however, information in these areas is severely lacking. More information is currently being sought from the State of Nevada.

Ash Meadows

Ash Meadows contains a large number of indigenous species. The area is distinguished by the presence of water in the otherwise arid Mojave desert environment, which accounts for much of its ecological richness. Evolutionary time is another factor lending to the uniqueness of the ecosystem. The native species have evolved essentially in isolation, surviving in the wet "island" oases remaining after the glacial retreat and subsequent warming following the last ice age (William, 1984). This isolation has led to species diversification and specification.

Ash Meadows provides habitat for several protected species (Table 4-5) which include the federally endangered Devil' s Hole pupfish (*Cyprinodon diabolis*), a small fish found only in this region. Of the endangered and threatened species found in this riparian community, four are fish; one is an aquatic insect; three are birds; and six are plant species. The majority of the federally listed species in this area are also listed in the State of Nevada program (Table 4-5). Formerly federally listed Candidate 2 species that are protected at the state level include the ferruginous

hawk, Swainson' s hawk, white-faced glossy ibis (*Plegadis chihi*), the Ash Meadows montane vole (*Microtus montanus nevadensis*) Townsend' s big-eared bat (*Plecotus townsendii*), and several plants and invertebrates.

Amargosa River

A few species have been federally classified as sensitive species in association with the riparian habitats of Amargosa Canyon Valley. As listed in Table 4-5, these include a beetle (threatened) and a fish species (endangered). The Tecopa pupfish and three invertebrates which were formerly listed as Candidate 2 species are protected by the BLM (1988).

Oasis Valley

Information on the flora and fauna inhabiting the area is severely lacking. As of 1996 (FWS, 1996a; FWS, 1996b; FWS, 1996c), no federally listed protected species are associated with Oasis Valley. Formerly listed candidate species that remain protected by the State of Nevada include the Oasis Valley Spring snail (*Pyrgulopis micrococcus*), Oasis speckled dace (*Rhinichthys osculus*), the black milk vetch (plant) (*Astragalus funerus*), bullfrog hills sweet pea (*Lathyrus hitchcokianus*), and the Mojave fishhook cactus (*Sclerocactus polyancistrus*). These species are also protected by the BLM (BLM, 1988).

Furnace Creek

Information was sought from the California Department of Fish and Game (CDFG), California Natural Heritage Division (CNHD, 1966), for the discharge points in the Death Valley area of California. These included the Furnace Creek Ranch, Franklin Well, and Alkali Flat areas. Specific geographical areas searched were those identified as USGS 7.5-minute series quadrangles: Stewart Valley, Eagle Mountain, Badwater, Bole Spring, Death Valley Junction, Devil' s Golf Course, Franklin Well, East of Echo Canyon, Echo Canyon, Furnace Creek, Lees Camp, and Nevares Peak. The CNHD searched its Natural Diversity Data Base (NDDB) for rare, threatened, endangered, and sensitive plants and animals that have been observed in those areas. The CNHD notes that the absence of a special animal or plant from the database for the area in question does not necessarily mean that the specie is absent from that location, but only that it has not been observed there (CNHD, 1996).

A number of species kept on lists by CDFG (animals), Audubon (birds only), and California Native Plant Society (plants) were shown to occur in the areas searched. These species are ranked as to their rarity and threats and inventoried in the NDDB, but have no federal or state legal status. In order to meet regulatory requirements, and since no disruptive activities are planned for these sites, species listed in this document are limited to documented occurrences of

species with federal or state legal status. Federally endangered or threatened species include seven plants, one invertebrate, four fish, one reptile and three birds. This includes the former federal candidate C2 species, since these have been retained on an interim species list by the BLM, and the new federal list has not been finalized (McNatt, 1996) and the National Park Service (Threloff, 1996). As shown in Table 4-5, this includes three insects, two snails, and three plants.

4.2 Problem Formulation

Problem formulation is the first step of the ecological risk assessment process. Problem formulation can be defined as a systematic planning step that identifies the major factors to be considered in a particular assessment (EPA, 1992). In short, it establishes the goals, breadth, and focus of the assessment and is linked to the regulatory and policy context of the assessment. The problem formulation process begins with the initial stages of characterizing exposure and ecological effects expected and observed. Problem formulation describes the relationships among assessment and measurement endpoints, data required, and methodology that will be used to analyze the data.

The UGTA is defined as impacted groundwater created by underground nuclear testing. Therefore, any way in which the groundwater may contact an ecological receptor (i.e., all seeps, springs, and well reservoirs) will be evaluated for the potential to present a risk to the NTS and surrounding ecosystems. Points of contact were eliminated from further consideration where an element necessary to complete an exposure pathway is determined to be lacking.

4.2.1 Study Site Identification

Section 3.0 of this report described the physical and biological characteristics of the NTS. These characteristics (i.e., physiography, groundwater and surface hydrology, climate, operational history, and biota) provide the building blocks from which the conceptual model of the site was developed. There are numerous points at which groundwater flowing under the NTS discharges to surface water off site. These discharge points were considered as study sites where potential exists for the completion of a pathway from the contaminant source to an ecological receptor. Locations of these discharge points are shown in Figure 4-1 (off site). Groundwater both on site and off site was also considered a study site for groundwater microorganisms. Finally, points on site and off site where ditches may be created through the use of groundwater for irrigation purposes (a near-future scenario in the human health risk assessment) were also considered study sites.

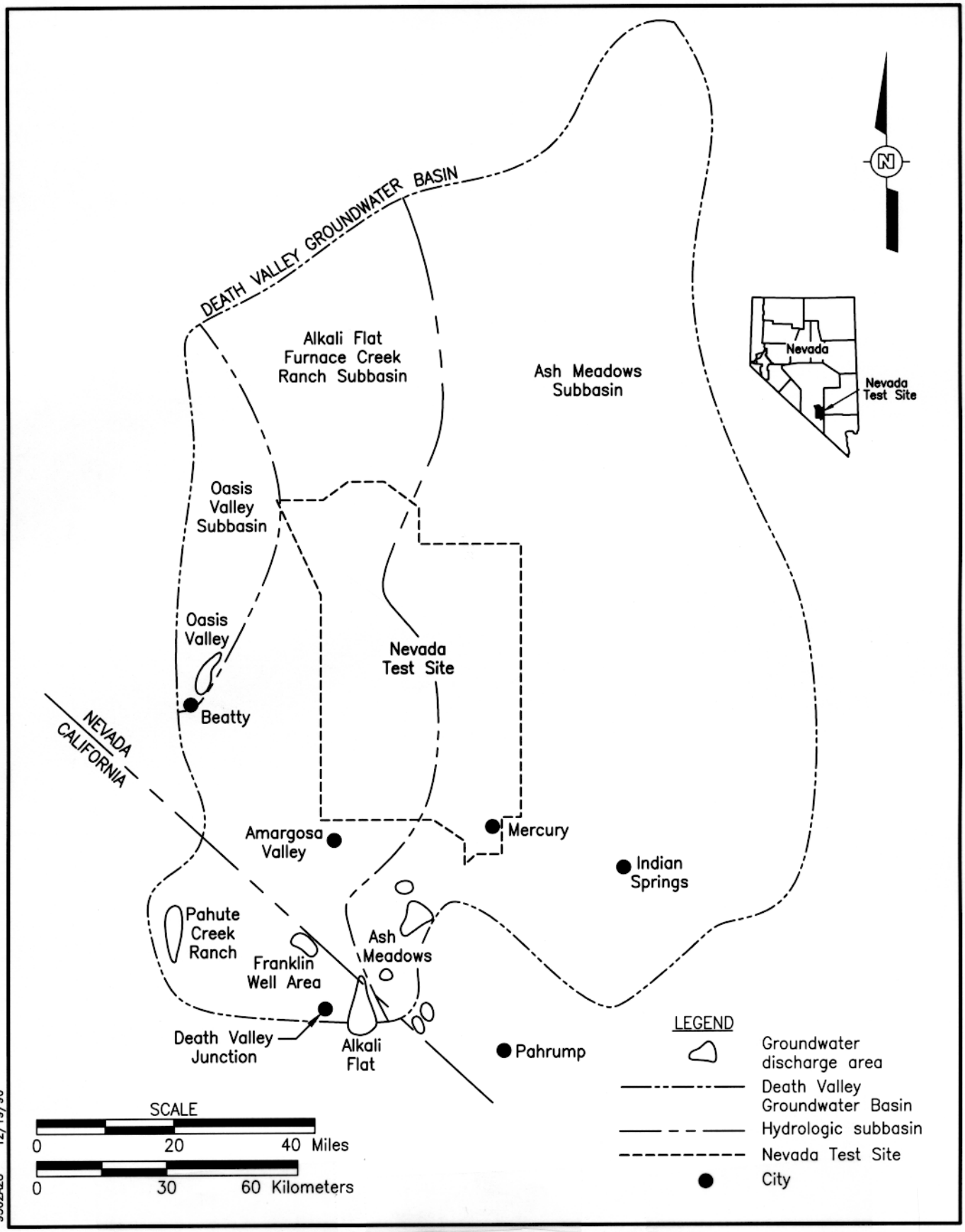

Figure 4-1
Generalized Groundwater Subbasins and Surface Discharge Points

4.2.1.1 Conceptual Site Model

A Conceptual Site Model (CSM) (Figure 4-2) was developed describing sources of constituents present, constituent release and transport mechanisms, potential routes of migration, and potential ecological receptors. Discharge points where groundwater and surface water meet were assessed as exposure points for aquatic and semiaquatic receptors, as were the irrigation ditches. Groundwater bacteria were selected as receptors for groundwater located both on site and off site.

4.2.1.2 Study Site Descriptions

All deep groundwater was considered as a medium of concern for groundwater microorganisms. Both on- and off-site locations may exist as potential discharge points. This effort focuses on those wells and springs on and around the NTS that may be in contact with aquatic and semiaquatic biota.

4.2.1.2.1 On-Site Springs

Although springs exist on the NTS, they are believed to originate from perched water zones and not from deep groundwater (Laczniak et al., 1994). Contamination associated with these springs is, therefore, likely to be associated with activities other than underground testing. Springs described by Giles (1976) in a report about how springs could be improved for wildlife use include Cane, Tippipah, Topopah, Green (also known as Reitmann), White Rock, Captain Jack, Oak, and Tub Springs. Further descriptions concerning freshwater algae growth were made by Taylor and Giles (1979). It is not known whether improvements for wildlife were made at these springs, although all of these springs were active as of the 1992 *Basic Environmental Compliance and Monitoring Program (BECAMP) Report* (Greger, 1994).

4.2.1.2.2 Off-site Springs

A large spring-fed area to the south, where the aquifers flowing under the NTS are known to discharge, is in the lowlands known as Ash Meadows. Approximately 25 springs exist in the northern and eastern parts of Ash Meadows. Many of the springs are in lime-encrusted pools. The Oasis Valley and headwaters of the Amargosa River are the second largest spring-fed areas in the region, and vegetation is similar between the two areas. Detailed descriptions of the springs at Ash Meadows, Oasis Valley, Furnace Creek, and Amargosa River are included below.

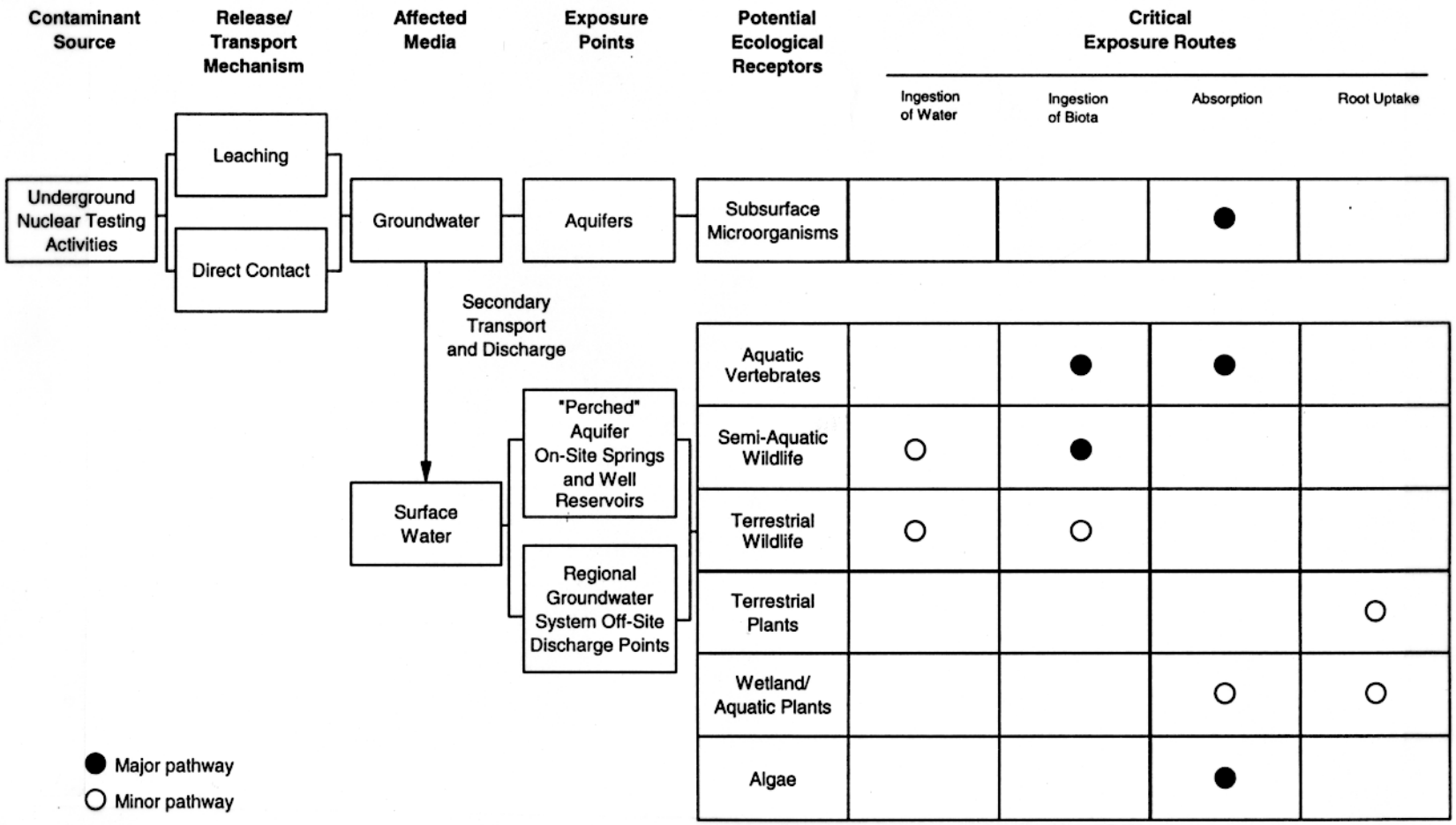

Figure 4-2
Conceptual Site Model
Ecological Risk Assessment

Ash Meadows, Nevada

Ash Meadows, located in southwestern Nye County, Nevada, and southeastern Inyo County, California, is a unique riparian ecosystem. It is approximately 150 km (90 mi) northwest of Las Vegas, Nevada, at 670 m (2,200 ft) above sea level. The Ash Meadows soils are silts and clays with slow internal drainage and high salt content, and the water table is near the surface in much of the area. There are numerous small streams, meadows with continuously moist soils, and groves of small ash trees (hence the name Ash Meadows). Ash Meadows is characterized by more than thirty seeps and springs which discharge in the range of 17 to 20 thousand acre-feet of water annually (Ash Meadows National Wildlife Refuge, 1989). This discharge may be described as "fossil" water, having taken over 10,000 years to reach its Ash Meadows destination (Baugh and Deacon, 1983). Aside from groundwater discharge, the only other source of water to this area is rain, averaging less than 6 cm (2 in.) per annum. As is typical of the desert environment, the annual evaporation rate is quite high, averaging 250 cm (98 in.) (Sada, 1990). This area supports a wide variety of biota, including numerous endemic species.

Ash Meadows was designated a National Wildlife Refuge in June 1984, after weathering decades of groundwater pumping and habitat destruction that is believed to have directly attributed to the extinction of two, and possibly more, species. While the refuge wholly encompasses much of the critical habitat for several of the sensitive species of the area, many of the plant species are more widespread and are not entirely protected within the confines of the refuge. In an uncommon arrangement, the refuge houses a small portion of the Death Valley National Monument (the Devil' s Hole area) which was incorporated into the monument in the late 1950s. The FWS manages the National Wildlife Refuge at Ash Meadows, and the U.S. Park Service has authority over the Devil' s Hole area.

Oasis Valley

Oasis Valley is located in southwestern Nevada, adjacent to the Nevada-California border. Both small and large springs are found in Oasis Valley. The larger springs include the Beatty Springs used as the municipal water supply for Beatty, an unnamed spring north of the Ranch Trueba headquarters, Goss Springs, an unnamed spring at the Fleur-de-lis Ranch, and an unnamed spring in the Amargosa Narrows just south of Beatty. Other springs include Indian Springs, Crystal Springs, Long Springs, and several hot springs. The average depth to water below the land surface in areas with phreatophyte vegetation (e.g., salt grass, Bermuda grass, greasewood, and salt brush) is 2 to 3 m (7 to 10 ft). The high rate of evaporation and poor drainage characteristics of the soil have resulted in soils of high salinity, evidenced by soils crusted by a salt efflorescence at the surface (Malmberg and Eakin, 1962).

Furnace Creek

Springs in the Furnace Creek area of Death Valley include Travertine Springs and Texas Spring. Travertine Springs consists of open soil ditches that collect the water and covey it to a concrete-lined ditch and of a sump intercepting water not collected by the ditch system. This water is piped for human usage. Some of the water from the springs recharges the fan at Furnace Creek Wash.

The entrance of the Texas Spring tunnel consists of approximately 15 m (49 ft) of parallel rock-retaining walls shored up by timber. As of 1974, plans existed to further alter this spring for human usage (Douglas and Sanchez, 1974).

Amargosa River

Amargosa Canyon along the Amargosa River may be an area that receives UGTA-impacted groundwater. It is one of the three segments of the 264-km (164 mi) Amargosa River which contains permanently flowing water. It lies approximately 65 km (40 mi) north of the town of Baker, California, in San Bernardino County. Just north of the Canyon is Tecopa Hot Springs. The flow entering the Canyon emanated from subterranean flows where numerous minor springs and seeps feed the river.

4.2.2 Constituent(s) of Potential Ecological Concern Selection

The constituent of potential ecological concern being considered in this assessment is tritium because it is the most mobile of the constituents associated with the underground nuclear testing and because its physical half-life (12.3 years) is long enough to ensure its presence in the environment after several years. It was assumed that, if the predicted risk associated with exposure to tritium is low, potential risks associated with other radionuclide contaminants are also likely to be low. For these reasons, this study focuses on tritium.

4.2.3 Exposure Pathway Identification

Complete exposure pathways must exist for exposures to occur. A complete exposure pathway requires the following:

- A source and mechanism for contaminant release
- A transport medium
- A point of environmental contact
- An exposure route at the exposure point (EPA, 1989a)

If any of these four components is absent, a pathway is generally considered to be incomplete. Complete exposure pathways are shown in Figure 4-3.

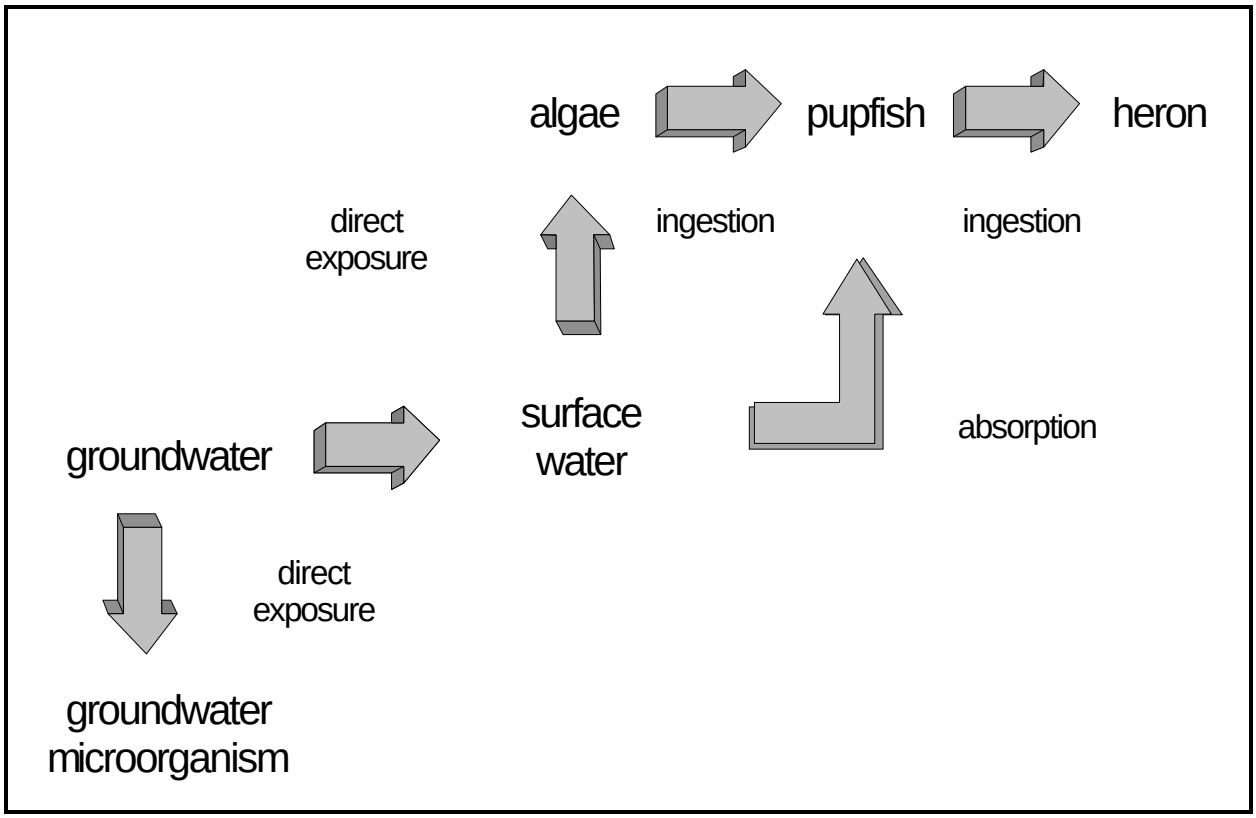

Figure 4-3
Simplified Ecological Exposure Pathway Model
for the Nevada Test Site Underground Test Area

By definition, the UGTA has only one transport medium: groundwater. Groundwater itself can serve as an exposure medium. The discharge sites discussed earlier create surface water and provide points of environmental contact for plant and animal receptors. The same is true for the irrigation ditches. In addition, there is potential for biota to be exposed to tritium in ditches created through the use of groundwater for irrigation purposes (a near-future scenario in the human risk assessment). Left to be determined is whether there is a source and mechanism (i.e., nuclear test-released nonsorptive, water-soluble contaminants into a particular groundwater discharge system) and whether there may be an exposure route at the exposure point (i.e., a receptor present to ingest, absorb, or inhale contaminants).

Ecological receptors may be exposed to water-borne contaminants via consumption of radionuclides in groundwater (or surface water) or through direct irradiation from external sources. A possible, but unlikely, scenario for terrestrial receptors is dermal exposure to contaminants in groundwater. Likewise, significant exposure via inhalation or direct radiation from groundwater is unlikely because such organisms using wells and springs are expected to spend little time near or in the water. Tritium is primarily a weak beta-emitter, and, as such, is not

expected to penetrate the outer skin or external membranes of animals or plants (Section 4.4). Root uptake is the only likely pathway for exposure of vascular emergent plants to tritium. Secondary exposure pathways involve contaminants that are transferred through the food chain via consumption of contaminated animal or plant tissues. Because aquatic and semiaquatic species are expected to receive greater exposure to tritium-contaminated groundwater and surface water than terrestrial species, this study focused on species more closely associated with the aquatic habitats. All exposure scenarios in this assessment address chronic exposures.

4.2.3.1 Animal Exposure Routes

Possible exposure routes by which fish and semiaquatic wildlife may be exposed to tritium within the UGTA include consumption of contaminated animal or plant tissues and consumption of contaminated abiotic media (groundwater). Direct absorption of tritium across the gills may also be significant for fish.

Consumption of Contaminated Tissues

Some contaminants may be bioaccumulated in plants or animal tissues and passed through food web interactions to higher trophic levels. The ability of contaminants to be passed from lower to higher trophic levels is dependent on their flow inside the plant or prey animal. If the contaminant is solely ingested and excreted by the prey, without absorption from the gastrointestinal tract and storage in its tissues, then the exposure of higher trophic levels is minimized. The dose received by the predator is dependent upon the contaminant concentration in the prey, its ingestion rate, and the amount of contaminated matter consumed. This route of exposure is believed to be the major exposure route for fish and semiaquatic receptors associated with the UGTA.

Direct Consumption of Contaminated Groundwater

Many species of mammals (i.e., cattle which are not considered an ecological receptor) are known to drink from well reservoirs and springs on the NTS. Similar species may use the off-site springs. Because desert species are often adapted to survive in water-limited environments, direct consumption of water was considered a pathway of secondary importance and was not evaluated.

4.2.3.2 Plant Exposure Routes

Algae have been studied at several of the natural springs, and these lower plants may directly absorb tritium, as water would be absorbed, across the cellular membrane. Submerged portions and the roots of vascular wetland plants may also be exposed to tritium either by absorption or through root uptake. Exposure of algae to tritium will be evaluated.

4.2.3.3 Microorganism Exposure Routes

Passive or active transport of contaminants across cellular membranes is the route by which deep subsurface microorganisms may be exposed to groundwater within aquifers. This pathway will also be addressed.

4.2.4 Ecological Receptor Identification

An ecosystem is a combination of the abiotic (nonliving) physicochemical environment and the assemblage of biotic (living) organisms that combine to form an interrelated and independent system. The environment at the NTS and off-site areas support numerous plants and animals. All possible receptors (i.e., all vertebrate and plant species that have been identified to use the NTS and adjacent areas of interest to the UGTA) are listed in tables discussed in the following sections. The list of receptors was narrowed in the characterization of exposure section to a few representative species with a reasonable potential of being exposed to the contaminants from the UGTA.

4.2.4.1 Vegetation

Aquatic and riparian species were collected, identified, and deposited in the BECAMP herbarium during the 1988 study (Romney and Greger, 1992), but the information resulting from this effort was not published. However, fifty-two species of freshwater algae were identified in samples collected from the eight known natural springs on site (Table 4-1), where filamentous green algae accounted for most of the algal biomass (Taylor and Giles, 1979).

Vegetation at spring and seepage areas off site, including the Ash Meadows and Oasis Valley and headwaters of the Amargosa River, were studied by Beatley (1976). Native species that may inhabit spring areas are listed in Tables 4-1 and 4-5.

4.2.4.2 Mammals

Large and small mammals have also been studied on the NTS under BECAMP since 1987. On-site springs and well reservoirs have been extensive and frequent monitoring sites of large mammal usage (Greger and Romney, 1992; Romney and Greger, 1992; Greger, 1994). Mammals observed using water sources from 1988 through 1992 include cattle, horses, mountain lions (*Felis concolor*), and mule deer. It is unlikely that these water sources have been used directly by small mammals, since these animals generally obtain water from their food sources; however, they may feed on vegetation near these sources. Currently, no information has been found on the use of off-site springs by mammals, although similar species are known to live in those discharge areas. Species that may be found in the on- and off-site discharge areas are listed in Tables 4-2 and 4-5.

4.2.4.3 Birds

Bird species that may be found using water resources on the NTS and in the off-site discharge areas are listed in Tables 4-3 and 4-5. Many of the species are migratory, and their use of the sources is limited.

4.2.4.4 Reptiles and Amphibians

A list of reptiles compiled for both the on- and off-site areas is presented in Table 4-4. Lizard studies were conducted in an attempt to discern radiological damage, but this was presumably due to aboveground testing. The only reptile noted as having been observed using water sources was the desert tortoise. Sensitive species that may be found in the on- and off-site discharge areas are listed in Table 4-5.

4.2.4.5 Fish

Several different species of pupfish are found in association with the off-site discharge points, and a list of these fish is found in Table 4-5.

4.2.4.6 Microbes

Samples obtained from a 21-m^3 (740-ft^3) section of rock, 390 m (1,300 ft) below the surface of Rainier Mesa, were subjected to microbiological analyses including direct counts and the abundance diversity, morphology, and metabolic traits of culturable organisms. The viable cell counts (1.44 to 4.45 cells per gram [cells/g] dry weight) were considerably lower than the total cell counts (5.84 to 7.68 cells/g dry weight), possibly due to the selective nature of the isolation medium used. However, no additional viability could be detected with further attempts to culture other additional microbial types using various media and techniques (Russell et al., 1994). Diversity measures in microbial communities and organisms identities were based on morphology and metabolic rates.

4.2.5 Potential Ecological Effects

For a given set of environmental conditions, species have characteristic attributes such as birth rates, age and sex distributions, migration patterns, and mortality rates. A species' habitat preferences, food preferences, and other behavioral characteristics (e.g., nesting, foraging, rearing young) may also determine population size and distribution in an area and may also significantly affect the potential for exposure.

A contaminant entering the environment will cause adverse affects if the following conditions exist:

- It exists in a form and concentration sufficient to cause harm.
- It comes into contact with organisms or environmental media with which it can interact.
- The interaction that takes place is detrimental to life functions.

Adverse effects may also occur if a contaminant interacts with other chemicals present in a synergistic manner that could raise the overall toxicity of the contaminated environment. The likelihood of ecological harm is, thus, a combined function of chemical, physical, and biological factors, depending on the nature of the contaminant and the nature of the environment into which it is released.

Contaminants may enter the environment or move among environmental compartments on several possible time scales. The type of release occurring at the NTS would be considered chronic in nature, representing continuous releases via groundwater discharge. The constituents and concentrations involved in these releases depend on the rate of movement from the contaminant sources to the points of discharge. Chronic toxicity due to contaminants in an ecosystem can greatly increase the mortality rate of component populations or can change the organisms' ability to survive and reproduce in the following less direct ways:

- Altering developmental rates, metabolic processes, physiologic function, or behavior patterns
- Increasing susceptibility to disease, parasitism, or predation
- Disrupting reproductive functions
- Causing mutations or otherwise reducing the viability of offspring

Ecological effects are most easily expressed as some impairment of a biological function or condition. There are two basic approaches to expressing ecological effects: (1) contaminant-related effects observed in site organisms, populations, or communities and an interpretation of associated ecological implications in relation to appropriate endpoints; or (2) comparison of on-site measured concentrations in abiotic media to established benchmarks (such as water quality standards or toxicity values). Where tritium is the stressor of concern, a modification of the second approach was used, with concentrations being modeled to discharge points and well locations, and was compared to a tritium benchmark concentration. In addition, available monitoring data were also compared to the benchmark values. As mentioned earlier, this ecological risk assessment focuses on chronic exposure.

4.2.6 Endpoints

This section contains a discussion of the assessment and measurement endpoints used. Some individual organisms may be more sensitive to tritium than others; therefore, protection of individuals would not be a practical goal. This is true except for those instances where a special status or protected species is involved. In this case, individual organisms must also be protected from environmental perturbations. The overall assessment endpoint for this risk assessment is the protection of aquatic and semiaquatic populations, groundwater microorganisms, and special status individuals from adverse effects that may be associated with exposure to tritium in the environment.

Adverse effects to biota were assessed or measured through the use of available groundwater and surface water monitoring data, flow and transport modeling results, and toxicity-based benchmark values. Current monitoring data were used to address present impacts, and data obtained through flow and transport modeling were used to evaluate potential future impacts to aquatic and semiaquatic biota. Radiological benchmarks have been established for terrestrial animal and plant populations by the International Atomic Energy Agency (IAEA, 1991 [as cited in Kahn, 1992]) and for aquatic populations by the National Council on Radiation Protection and Measurements (NCRP, 1991). In addition, radiation effects data were gleaned to obtain benchmarks specific to sensitive life stages of protected species. Monitoring data and modeling results were compared to the benchmark values. Adverse impacts were predicted to occur when benchmarks were exceeded.

4.3 Exposure Assessment

Tritium concentrations in both on- and off-site groundwater wells and areas where groundwater discharges to the surface serve as exposure point concentrations. The great blue heron, the pupfish and their eggs, an algae, and a generic groundwater microorganism were chosen as ecological receptors. Tritium exposure models were used to estimate the concentration of tritium that would produce a specified radiation dose to adult pupfish and eggs and the great blue heron.

4.3.1 Exposure Point Concentrations

Exposure point concentrations are tritium concentrations in both on- and off-site groundwater wells. Concentrations of tritium in surface waters that serve as discharge points for groundwater were also used as exposure point concentrations. In both cases, current concentrations were obtained from monitoring data (maximum concentrations), and future concentrations (the 95 percent value of each of the Monte Carlo realizations) were obtained through groundwater flow and transport modeling. This conservative approach was used to insure protection of the aquatic and semiaquatic populations.

4.3.2 Selected Ecological Receptors

Four specific receptors were selected to evaluate possible adverse effects on biota that are closely associated with the discharge points. These receptors are the great blue heron (*Ardea herodias*), a predatory bird assumed to feed exclusively on fish; a generic pupfish (adult and eggs) to represent the protected fish within the surface water systems; a generic algae that represents a plant maximally exposed to surface water; and a generic groundwater microorganism to represent the bacteria and protozoans in groundwater. A discussion of these receptors is presented below.

4.3.2.1 Semiaquatic

The great blue heron represents a top predator of the freshwater habitats associated with UGTA surface water discharge points. Surveys conducted in and around the vicinity of the NTS indicate the presence of the species. This species was selected as a representative predator because it is common to the areas of interest and because there is generally more data on this species than on other semiaquatic species that are likely to use the springs.

Great blue heron are large birds, weighing about 2.4 kg (5.3 pounds [lb]) (Dunning, 1993). For the purpose of this risk assessment, great blue herons are considered to be strict predators. They typically hunt along shorelines of rivers, streams, ponds, and lakes. The typical diet of these birds is a diverse mix of aquatic and terrestrial species including fish, crayfish, insects, mice, frogs, turtles, and snakes (Martin et al., 1951). For exposure modeling purposes, the heron is assumed to feed exclusively on fish.

Great blue herons are colonial in nesting habit. The adult birds will fly considerable distances from the heronry to foraging areas. Feeding territories have been reported to change seasonally from 6,000 to 84,000 m^2 (1.5 to 20.8 acres) (EPA, 1993). It must be recognized, however, that the size of the foraging area depends upon the distribution and quality of the feeding habitat. It is conservatively assumed herein that the heron will feed exclusively within a given contaminated spring.

4.3.2.2 Fish

Because several species of fish are found in the off-site springs that are of special status, a generic pupfish was selected as the fish receptor. The adult pupfish was assumed to have a total length of 6.35 cm (2.5 in.). A discussion of some of the protected fish within Ash Meadows is presented below.

Devil's Hole Pupfish (Cyprinodon diabolis)

The most studied and documented of the sensitive species found at Ash Meadows is the Devil' s Hole pupfish. This small fish typically measures from one to two inches in length and weighs only a few grams (McNulty, 1986); it has a lifespan of less than one year (Sigler, 1987). The pupfish population fluctuates throughout the year, reaching its peak in the summer months. The latest account (1972 to 1984) of population size noted a maximum of 553 fish in the summer months and a low of 127 fish in the winter (Sada, 1990). The habitat which sustains the only natural population of this small fish consists of a small surface pool of warm water surrounded by a rocky limestone shelf (upon which the fish feed and spawn). The water in this pool, known as Devil' s Hole, is connected to a large subterranean reservoir (Sigler, 1987; Soltz and Naiman, 1978). The pupfish diet is known to consist heavily of diatoms and algae and occasionally invertebrates such as beetles, amphipods, and snails (Sada, 1990). Algal growth in the pool is enhanced by owl excrement, which provides vital nutrients to the organisms. No information was found pertaining to natural predators of the pupfish; however, the greatest threat to this population historically has been decreasing water levels within the spring pool. In the past, groundwater pumping in and near the springs for human irrigation and consumptive purposes resulted in the exposure of the feeding and spawning shelf. Stability of the water level is currently assured through the enforcement of a 1976 Supreme court ruling, which mandates that a safe water level be maintained at Devil' s Hole, enabling the fish assess to the limestone shelf (McNulty, 1986).

Ash Meadows Amargosa Pupfish (Cyprinodon nevadensis mionectes)

The Ash Meadows Amargosa pupfish is found at elevations of 655 to 700 m (2,150 to 2,300 ft) in the larger, warmer springs of Ash Meadows. This small minnow rarely exceeds 7 cm (3 in.) in length and feeds on small aquatic invertebrates. It currently inhabits the following groundwater discharge areas: Fairbanks, Rogers, Longstreet, Jackrabbit, Big and Point-of-Rocks Springs, Crystal Pool, and two springs in the Bradford group (World Wildlife Fund [WWF], 1990). Spring pool sizes vary widely, from 15 to 4.5 m (49 to 15 ft) in diameter and 6 to 2 m (20 to 7 ft) in depth, respectively. The discharge rate from springs in the area ranges from 238.2 L/s (8.41 ft^3/s) to as slow as 0.087 L/s (0.003 ft^3/s) (Sada, 1990). Unlike other spring systems in the area, the waters from some of these springs may mix with other springs in close proximity, allowing for interaction between these pupfish populations. A population census taken in June 1982 and July 1983 revealed 568 and 1,189 individuals in Jackrabbit Spring, respectively, and 1,189 and 1,822 individuals in Big Spring, respectively. No other pupfish populations have been quantified, and minimal information on feeding and breeding habits is available. Because this pupfish is a subspecies in the *C. nevadensis* complex, it may be inferred that its lifestyle is similar to that of other subspecies more thoroughly studied (e.g., the Warm Springs pupfish) (Sada, 1990). The largest threat to this pupfish population has been, and continues to be, exotic

competition/predation and habitat alteration through groundwater pumping and/or water diversion.

Warm Springs Pupfish (Cyprinodon nevadensis pectoralis)

The Warm Springs pupfish is currently found throughout the following six warm springs in the Ash Meadows area: North and South Indian Springs, Marsh Spring, North and South Scruggs Springs, and School Spring. Each of these springs exists within an area less than 2.6 km (1.6 mi) square at an elevation of approximately 710 m (2,300 ft) (Soltz and Naiman, 1978). All of its existing natural habitat is quite small, with spring pools generally less than 2 m (7 ft) in diameter and 1.3 m (14.3 ft) in depth. Each of the springs that support the pupfish is entirely isolated from other water systems in the area in an arrangement that has effectively isolated these Warm Springs pupfish populations for centuries. This pupfish subspecies, branching from the Amargosa pupfish (*C. nevadensis*) species, is the physically smallest of the six recognized subspecies, with adults reaching a maximum length of 6.35 cm (2.5 in.) (Sigler, 1987). The populations of pupfish fluctuate dramatically throughout the year, presumably due to food availability, which is common in other pupfish species of the area. According to the U.S. Fish and Wildlife Service, almost half of the entire Warm Springs population at Ash Meadows, gauged at close to 500 fish, exists in School Spring (WWF, 1990). The five other populations of the Warm Spring pupfish can be expected to be quite small as well, due to habitat constraints. While the specific feeding habits of this pupfish have not been explored, it can be reasonably assumed that their mainstay includes algae and substrate organisms, as with the other pupfish found in Ash Meadows (Sada, 1990). Predation by introduced fish and bird species, particularly belted kingfishers, pose a significant threat to this pupfish. Other threats include water-level fluctuation, competition for resources by nonnative species, and habitat alteration/destruction (WWF, 1990).

Ash Meadows Speckled Dace (Rhinichthys osculus nevadensis)

Today, the Ash Meadows speckled dace is found in Bradford Springs, Big Spring, Tubb Springs, and Jackrabbit Spring, a fraction of what is believed to be this fish' s historical range (Williams and Sada, 1985 [as cited in Sada, 1990]). Population counts in 1983 indicated 11 fish in Jackrabbit Spring, 13 in Big Spring, and 35 individuals in Tubb Spring. No population census had been conducted at Bradford Springs. An estimate of 500 total speckled dace within the springs at Ash Meadows was noted in the "1990 Recovery Plan for the Endangered and Threatened Species of Ash Meadows, Nevada" (National Park Service, 1990). The Ash Meadows speckled dace reaches a maximum of 10 cm (4 in.) in length and may live for up to four years (John, 1964 [as cited in Sada, 1990]). This species prefers flowing streams to spring pools and generally feeds on drifting insects (Moyle, 1976). The major threats to this species

include nonnative competition, predation, and population vulnerability due to their relative small size (La Rivers, 1962; Williams and Sada, 1985 [as cited in Sada, 1990]).

4.3.2.3 Vegetation

Algal species that contribute to the bulk of algal biomass at these natural springs studied were filamentous green algae (*Chlorophyta*) and two diatoms (*Achnanthes lanceolata* and *Gomphonema parvulum*) (Taylor and Giles, 1979). The complete list of algal species present at each spring is presented in Table 4-1. Emergent wetland vegetation and other plant species are present at both off-site and some on-site springs. However, because algae were found at all of the springs on site and similar assemblages are likely at the off-site discharge areas, algae will serve as the receptor to be evaluated against benchmarks for risk posed by tritium to vegetation. Algae are also representatives of photosynthesizing organisms and are a recognized primary food source for pupfish.

4.3.2.4 Groundwater Microorganisms

The science of groundwater ecology is somewhat in its infancy of development and exploration (Gibert et al., 1994). Consequently, the ecology of groundwater systems beneath the NTS and adjacent locations have not been characterized as extensively as the flora and fauna that inhabit the terrestrial environments of these areas. The Deep Subsurface Microbiology Program funded by DOE has enabled investigators from the Desert Research Institute and the University of Nevada to characterize the microorganisms that reside in the deep subsurface and tunnel systems at Rainier Mesa, NTS (e.g., Russell et al., 1994; Amy et al., 1992). Because the taxonomy of groundwater microorganisms is poorly developed (Gounot, 1994), identification of these organisms was primarily based on specific chemical responses and biological properties of the bacteria. For this reason, groundwater receptors associated with the UGTA Risk Assessment will be designated as nonspecific groundwater microorganisms.

4.3.3 Tritium Exposure Models for Adult Fish and Heron

An aquatic dose model created by Pacific Northwest Laboratory was used to estimate the concentration of tritium in water necessary to produce a dose of 1 radiation per day (rad/d) to the pupfish and a dose of 0.1 rad/d to the heron (Baker and Soldat, 1992). The external doses from tritium to the pupfish and heron are not considered because the external dose rate factors for immersion and sediment are zero (Baker and Soldat, 1992). Consequently, tritium will not pose an external threat to an organism. Exposure to tritium will, however, result in an internal dose to the pupfish and heron due to the release of beta radiation from the radioactive decay of tritium

over time. Tritium is a unique radioactive threat because it is found as part of the water molecule itself. The tritium will, therefore, distribute itself uniformly and quickly throughout the body of an organism.

The dosimetry models used in estimating the internal dose to the adult pupfish, heron, and fish eggs are discussed in the following sections. Additional details on the internal dosimetry methodology with example calculations for the adult pupfish, heron, and fish eggs will be found in Appendix B.

4.3.3.1 Aquatic Internal Dose for the Adult Pupfish

The pupfish immersed in tritium-contaminated water will receive an internal radiation dose. It is assumed that the ingested tritium will become uniformly distributed in the body of the pupfish. The upper limit considered for the internal dose rate in an aquatic organism is 1.0 rad/d (Section 4.4).

The internal dose rate in rad/d is given by the following equation:

$$R_{fish} = \left(E_{tritium,\,fish}\right)\left(b_{tritium,\,fish}\right) \quad (1)$$

where:

R_{fish} = internal total-body dose rate received by the pupfish (assumed to be 1 rad/d); and

$b_{tritium,\,fish}$ = specific body burden of tritium in the pupfish (curies per kilogram [Ci/kg]) which is found using the following equation:

$$b_{tritium,\,fish} = \left(C_{tritium}\right)\left(BF_{tritium,\,fish}\right)\left(CF\right) \quad (2)$$

where:

$C_{tritium}$ = concentration of tritium in water to which the pupfish is exposed (Curies per liter [Ci/L]);

$Bf_{tritium,\,fish}$ = 0.001 cubic meters per kilogram (m^3/kg) and represents the bioaccumulation factor for tritium in the pupfish (Baker and Soldat, 1992);

CF = conversion factor (0.001 liters per cubic meter [$L/m^{3]}$); (needed only if the concentration of tritium in water is given in units of radioactivity per liter); and

$E_{tritium,\,fish}$ = effective energy absorbed for tritium per unit activity in the pupfish (kg-rad/Ci-day) and is defined by Equation 4-3:

$$E_{tritium,\,fish} = \varepsilon_{tritium,\,fish}\left(MeV/dis\right) \times 5.12 \times 10^4 \quad (3)$$

where:

$\varepsilon_{tritium,\ fish}$ is equal to 0.0058 megaelectron volts (MeV/dis) per disintegration and is the effective absorbed energy for a 1.163-cm (0.458-in.) radius pupfish exposed to tritium's radioactivity (Baker and Soldat, 1992).

4.3.3.2 Aquatic Internal Dose to the Heron

The heron will receive an internal dose from tritium via ingestion of the pupfish. The internal radiation exposure to the heron depends upon the uptake of tritium by consumption of pupfish as well as the heron's ability to remove the tritium from its body following exposure.

The internal dose rate received by the heron is given by the following equation:

$$R_{heron} = \left\{ \left(b_{tritium,fish}\right) \left(U_{fish}\right) \left(f_{tritium,heron}\right) \left(E_{tritium,heron}\right) \left(B_{tritium,heron}\right) \right\} / M_{heron} \quad (4)$$

where:

R_{heron} = internal total-body dose rate received by the heron (assumed to be 0.1 rad/d);
U_{fish} = intake rate of pupfish by the heron equal to 0.6 kg/d (Baker and Soldat, 1992);
M_{heron} = mass of heron equal to 2.39 kg (Dunning, 1993);
b_{fish} = body burden of pupfish (Ci/kg) defined previously in Equation 4-2;
$f_{tritium,heron}$ = fraction of radionuclide initially retained in total body of heron (unitless) equal to 1.0 (Baker and Soldat, 1992);
$E_{tritium,heron}$ = defined previously. The value for $\varepsilon_{tritium,heron}$ is equal to 0.0058 MeV/dis, for a heron with a 10 cm (4 in.) radius (Baker and Soldat, 1992); and
$B_{tritium,heron}$ = bioaccumulation factor of tritium in the heron (day) defined below:

$$B_{tritium,heron} = \left\{ 1 - \exp\left(\left(-\lambda_{tritium,heron}\right)\left(T_e\right)\right) \right\} / \lambda_{tritium,heron} \quad (5)$$

where Equation 4-6 defines the effective decay constant in the heron with units of inverse days:

$$\lambda_{tritium,heron} = \left\{ \left(\lambda_{biological}\right) + \left(\lambda_{radiological}\right) \right\} \quad (6)$$

The parameter $\lambda_{biological} = 1n(2)/T_{biological}$

where:

$\lambda_{biological}$ = biological decay constant of tritium and $T_{biological}$ is the biological half-life of the tritium which is equal to 10 days (Baker and Soldat, 1992).

$$\text{The parameter } \lambda_{radiological} = 1n(2)/T_{radiological} \quad (7)$$

where:

$\lambda_{radiological}$ = radiological decay constant of tritium and $T_{radiological}$ is the radiological half-life of tritium which is equal to 12.35 years (Baker and Soldat, 1992).

The variable T_e is defined as the exposure time or period of exposure which is assumed to be 365 days (Baker and Soldat, 1992).

4.3.3.3 Model Assumptions

Both internal dose models mentioned above contain assumptions that are critical to the estimation of exposure. These assumptions include the following:

- The external dose from tritium is considered insignificant.
- Because tritium exists as part of the water molecule, it is easily absorbed into the body.
- Dose rates reach an equilibrium with the water concentration of tritium.
- Concentration of tritium in water is averaged over one year (Baker and Soldat, 1992).
- Absorbed energy via radioactive beta decay is not dependent upon the pupfish's effective radius due to the small size of the fish (Baker and Soldat, 1992).
- Tritium is the only radionuclide present.
- A spherical geometry is assumed, and all activity is located at the center of the organism (Baker and Soldat, 1992).
- All radioactive material is assumed to be totally absorbed by the organism and treated as a "point source" at the center of the organism (Baker and Soldat, 1992).
- There is a one-year exposure period (Baker and Soldat, 1992).
- The heron only consumes pupfish exposed to tritium.
- The mass of the heron is 2.39 kg (5.27 lb).

4.3.4 Tritium Exposure Model for Fish Eggs

An aquatic dose model developed by Blaylock et al. (1993) was used to estimate the concentration in surface water that would result in a dose of 1.0 rad/d to fish eggs (Section 4.4). As with the previous models, exposure was assumed to be exclusively internal. Internal dose to a fish egg was estimated using the equation below:

$$D_\beta = \left(5.76 \times 10^{-4}\right)\left(E_\beta\right)\left(n_\beta\right)\left(C_o\right) \quad (8)$$

where:

D_β = internal dose to the egg (microGray per hour [$\mu Gy\text{-}h^{-1}$]);
E_β = the average energy of the β particle (MeV);
n_β = the proportion of transition producing a β-particle of energy E_β (MeV); and
C_o = the concentration of the radionuclide in the organism (Becquerel [Bq] kg^{-1}, wet weight).

The dose rate equation was modified to provide a dose in rad/d. All conversion factors are referenced from Turner (1986).

$$D_\beta = \left(\left(5.76 \times 10^{-4}\right)\left(E_\beta\right)\left(n_\beta\right)\left(c_o\right)\ \mu Gy/h\right)\left(24\ h/day\right)\left(10^{-6}\ Gy/\mu Gy\right)\left(1\ rad/0.01\ Gy\right)$$
$$= 1.3824 \times 10^{-6}\left(E_\beta\right)\left(n_\beta\right)\left(C_o\right) \quad (9)$$

This equation was slightly modified with the following relationship and solved for the concentration in the water. The biological concentration factor for tritium is assumed to be 1.0. This is defined as the ratio of the concentration of tritium in the egg to the concentration in water at steady-state conditions. With this in mind,

$$C_w = C_o \quad (10)$$

where:

C_o = concentration of tritium in the egg (Bq kg^{-1}, wet weight); and
C_w = concentration of the tritium in the water (Bq kg^{-1}, wet weight).

The dose equation was then modified to:

$$D_\beta = 1.3824 \times 10^{-6}\left(E_\beta\right)\left(n_\beta\right)\left(C_W\right) \quad (11)$$

Yielding a dose in rad/d.

Finally, the equation below was used to estimate the concentration of tritium in the water:

$$C_W = D_\beta / \left(\left(1.3824 \times 10^{-6}\right)\left(E_\beta\right)\left(n_\beta\right)\right) \quad (12)$$

Assumptions associated with the model are similar to those mentioned earlier for the Baker and Soldat (1992) dose model and include the following:

- The external dose from tritium is considered insignificant.
- Because tritium exists as part of the water molecule, it is easily absorbed into the egg and has a bioconcentration factor of 1.
- Dose rates reach an equilibrium with the water concentration of tritium.
- The approximate radii of the fish eggs are 1 to 2 millimeters (mm).
- The range of beta particle energy in water does not exceed the radius of the fish egg.
- Tritium is the only radionuclide present.
- Tritium is uniformly distributed throughout the interior of the egg.
- All beta radiation is assumed to be absorbed by the egg and treated as a "point source" at the center of the egg.

4.4 Effects Assessment

Because tritium is a radionuclide, adverse effects associated with exposure to tritium will be attributed to radiation. Tritium is not a chemically toxic compound; consequently, the discussion that follows will focus on the effects of radiation exposure.

Radioactive atoms, which represent unstable forms of an element, undergo spontaneous nuclear transformations. Charged particles and electromagnetic waves are given off in the form of radiation. Excess energy released in this way is termed ionizing radiation. Tritium is a beta radiation source. Beta particles are emitted from within the nuclei of atoms undergoing a radioactive decay process. The ability of beta particles to penetrate a material is dependent upon the energy of the particle. Radionuclides that emit beta particles can be hazardous external sources, and all beta emitters do pose some risk as an internal radiation hazard if inhaled or ingested. Tritium beta particles do not have enough energy to penetrate a single layer of dead skin cells (Myers and Johnson, 1991).

The dosage and biological effectiveness of radiation due to tritium incorporated in biological tissues has been studied primarily in laboratory animals and humans, although some data exists for aquatic organisms. A major concern for tritium is incorporation into Deoxyribonucleic Acid (DNA). The radioactive decay of tritium in a DNA molecule can result in breakdown or rearrangement of the molecule, resulting in genetic or somatic defects. However, the ionizing

radiation of decaying tritium in cells in general is probably more likely (NCRP, 1979). Radiotoxic effects of tritiated water exposure to embryos and fetuses are consistent with those expected from an equivalent, absorbed dose of external radiation (NCRP, 1979). These effects include tumors (NCRP, 1979) and chromosome aberrations (Straume and Carsten, 1993).

The radioactive hydrogen isotope tritium enters aquatic systems in the form of tritiated water, which consists of an atom of the nonradioactive hydrogen isotope protium, an oxygen, and a tritium atom, rather than the normal two protiums and one oxygen. Tritium can be exchanged just as protium between the tissue-water compartment and the tissue-bound compartment. Another pathway for entry of tritium into the nonexchangeable component for animals is the ingestion and incorporation of food molecules containing nonexchangeable tritium. In studies on a herbivorous fish, calculations showed that 60 percent of nonexchangeable hydrogen came from tissue-water hydrogen and 40 percent from food. However, food-chain transfer of exchangeable tritium hydrogens is unimportant because equilibrium conditions with ambient water exist in both consumer and food item, and turnover occurs more rapidly than food intake. In plants, photosynthesis and other reduction reactions incorporate tritium into the nonexchangeable component of plants (Vanderploeg et al., 1975).

Tritium bioaccumulation factors are approximately 1, reflecting equilibration between ambient water and tissue water. Tritium in emergent portions of rooted aquatic plants such as cattails may be lower due to mixture with less contaminated air moisture. Biological half times range from minutes for single-celled algae to days for the few fish studied. An 8-day half-time for tritium elimination from the tissue-bound compartment was reported for goldfish and mosquitofish, and 62 hours for 70 percent of the tissue-bound hydrogen in aquatic snails (Vanderploeg et al., 1975).

Information regarding the responses of groundwater organisms to toxicants is very limited (Notenboom et al., 1994). Such information is primarily focused on heavy metals and organic contaminants. Because specific data on potential adverse impacts of radiation on groundwater fauna could not be found in the open literature, impacts on UGTA groundwater receptors will be assessed qualitatively based on information on radiation effects on freshwater microorganisms. According to Whicker and Schultz (1982), ranges of acute lethal doses to bacteria and protozoans are approximately 6,000 to 90,000 rads, and 8,000 to 30,000 rads, respectively. The lethal dose for 50% of the population (LD_{50}) range for aquatic microorganisms under acute radiation exposure is 10,00 to 500,000 rads (NCRP, 1991).

A dose rate of 1 rad/d was used as the toxicological benchmark for the protection of aquatic life with emphasis on adult pupfish and their eggs (Table 4-6). This value has been recommended by

Table 4-6
Radiological Benchmark and Acute Toxicity Values for the Nevada Test Site Underground Test Area Ecological Receptors

Receptor	Benchmark Dose[a] rad/d	Benchmark Tritium Concentration[b] pCi/L	Range of Acute Lethal Doses[c] rad
Microorganisms	1	—[d]	6×10^3 - 9×10^5
Algae	1	—[d]	3×10^3 - 0.5×10^6
Pupfish (adult)	1	3.4×10^9	7×10^2 - 6×10^3
Pupfish (eggs)	1	3.4×10^9	7×10^2 - 6×10^3[e]
Heron	0.1	9.3×10^7	1×10^2 - 0.5×10^3

[a] Benchmark dose values obtained from NCRP, 1991 and IAEA, 1992 as cited in Kahn, 1992.
[b] Tritium concentrations are estimated in Section 4.3.
[c] Acute lethal doses are from Whicker and Schultz, 1982.
[d] Specific tritium benchmark values were not estimated for microorganisms and algae. Benchmark tritium concentrations of fish and herons were assumed to be protective of bacteria and algae based on comparisons of acute lethal doses.
[e] This is the range for fish in general.

the NCRP Scientific Committee on the Effects of Ionizing Radiation on Aquatic Organisms (NCRP, 1991) and is expected to provide protection to aquatic populations. Laboratory studies using various aquatic invertebrate species have revealed an apparent threshold for significant effects on sterility or on hatchability and abnormality production when embryos, larvae, or adults carrying embryos are exposed to beta-emitting radioisotope concentrations of 0.1×10^9 to 1.0×10^9 pCi/L (Blaylock and Trabalka, 1978). The lowest concentration of tritiated water to which developing fish eggs have been exposed and biological effects reported is 1.0×10^9 pCi/L (Strand et al., 1973). This value is associated with rainbow trout eggs exposed six hours after fertilization and a suppression of the immune response (antibody production) noted in fish fry. Interestingly, there exists an inverse correlation between the age of bony fish and radiation sensitivity (Polikarpov, 1966; NCRP, 1991).

Radiation effects have been investigated at several freshwater environments associated with DOE facilities. These areas include ponds and streams at the Hanford Site, White Oak Lake at Oak Ridge National Laboratory, and seepage basins and a reactor cooling reservoir at the Savannah River Plant. Each of these areas contains a mixture of radionuclides at above-background concentrations in surface water and sediment. As summarized by Talmage and Meyers-Schöne (1995), although effects have been reported in individual organisms within some of these aquatic systems, adverse effects were not observed at the population or community level. In addition, it appears that long-term exposure has resulted in the resilience of populations of freshwater biota to dose rates of less than 1 rad/d.

A direct comparison of field studies with tritium-specific laboratory studies is difficult because of confounding factors in the field. As an example, studies conducted at the nuclear waste ponds and streams of the Hanford Site revealed an assortment of radionuclides within both surface water and sediment with maximum water concentrations at the sites ranging from 10^{3} to 10^{7} pCi/L (Emery and McShane, 1980). Although tritium was not listed as a radionuclide of interest or concern for any of these sites, the range of concentrations is lower than that expected to induce adverse effects in aquatic invertebrates and fish. In addition to the dose received from both water and sediment sources, environmental factors relating to habitat conditions also contributed to the variability with these field studies. In this case, conclusive evidence of impacted biota was not indicated by field survey. According to laboratory studies, however, dose rates from sediments at one site may have been great enough to limit the colonization and growth of aquatic life. For these reasons, the benchmark of 1 rad/d reflects evidence primarily from laboratory investigations.

A comparison of acute lethal doses to primitive plants, higher plants, bacteria, fish, and birds as presented in Table 4-6, indicate algae and bacteria as considerably less sensitive to the adverse effects of radiation than either birds or fish (Whicker and Schultz, 1982). Based on this information, the value of 1 rad/d is expected to provide sufficient protection to each of the aquatic receptor species selected including fish eggs. Because the heron is a semiaquatic species, a more conservative benchmark value will be used that will provide sufficient protection to the bird. The IAEA Committee on the Effects of Ionizing Radiation on Plants and Animals recommends a dose of 0.1 rad/d for the protection of terrestrial populations (IAEA, 1992) (Table 4-6).

4.5 Risk Characterization

This section addresses the actual evaluation of risk and the uncertainties incorporation associated with the assessment.

4.5.1 Estimated Threshold Values

In order to provide sufficient protection to pupfish (all life stages), heron, and algae that may be exposed to tritium, tritium concentrations in surface water at the discharge points should not exceed 9.3×10^{7} pCi/L (Table 4-6). This concentration would result in a dose of 0.028 rad/d to adult pupfish, 0.027 rad/d to pupfish eggs, and 0.1 rad/d to the heron which ingests the fish. In contrast, a dose of 1 rad/d to the pupfish would require in a tritium concentration in water of 3.4×10^{9} pCi/L and a dose of 3.6 rad/d to the heron. A concentration of 3.4×10^{9} pCi/L was estimated as the concentration of tritium in water that would result in a dose of 1.0 rad/d to pupfish eggs. Because this concentration would not offer suitable protection to the heron, the more protective threshold concentration for the aquatic and semiaquatic receptors associated with the springs or surface water pools, or 9.3×10^{7} pCi/L, was used as the threshold value below

which adverse impacts to birds and fish would not be expected. Because algae and microorganisms are less sensitive to the effects of radiation than fish and birds, protection of the pupfish and the heron should allow for sufficient protection to algae, higher plants, and microorganisms exposed to tritium. The tritium concentration of 9.3×10^7 pCi/L should, therefore, be the threshold concentration for protection of the surface water and groundwater ecosystems (Table 4-6).

Although correct, the predicted tritium concentrations appear to be high. This is explained by the fact that a tritium concentration of 10^7 to 10^9 pCi/L in water would be extremely unlikely, even at the point of discharge. Tritium exists in the water molecule itself because it is a form of hydrogen. Thus, tritiated water will spread out quickly and become uniformly distributed throughout the body of water in which it is found. This fact reduces the probability that local areas of high concentrations can exist in which the pupfish or other aquatic species may be exposed to tritium.

4.5.2 Current Exposure

Current tritium concentrations in groundwater and surface water were obtained from published groundwater monitoring data. The current exposure scenarios evaluated were the following:

- Exposure of groundwater microorganisms to groundwater
- Exposure of aquatic and semiaquatic biota to surface water springs on site and off site.

Published data on tritium concentrations in groundwater indicate the highest concentration of tritium detected in NTS groundwater during 1993 was 4.8×10^7 pCi/L (DOE, 1994). This concentration was measured at U-4u, an emplacement/postshot hole. The maximum tritium concentration measured in any on-site groundwater monitoring well in 1994 was 6.18×10^7 pCi/L at U-20n (DOE, 1996). Although these values are high, these concentrations do not exceed the ecological protection value of 9.3×10^7 pCi/L. The maximum concentration of tritium detected in any of the Long-Term Hydrological Monitoring Program Wells on the NTS was 3.17×10^2 in Well UE-7ns in 1993 (DOE, 1994) and 2.60×10^4 pCi/L in Well UE-5N in 1994 (DOE, 1996). Groundwater microorganisms currently associated with on-site groundwater are, therefore, not expected to be adversely impacted by tritium in NTS groundwater.

With reference to the NTS springs, the annual average tritium concentration detected in the seven springs on site was 5.4 pCi/L (DOE, 1994). This concentration is seven orders of magnitude less than the tritium concentration expected to be hazardous to semiaquatic and aquatic biota. Tritium was not detected in on-site natural springs during the 1994 sampling period (DOE, 1996).

Data from the 1993 Long-Term Hydrological Monitoring Program for locations in the vicinity of the NTS (DOE, 1994) indicate that none of the springs within Ash Meadows contained tritium concentrations in excess of 2.0 pCi/L. The maximum concentration detected in a groundwater well within Ash Meadows in 1993 was 2.3 pCi/L. Tritium concentrations within Goss Springs in Oasis Valley were between 0.3 and 74 pCi/L. Specie Springs within the Amargosa Valley contained tritium concentrations that ranged from "not detected" to 20 pCi/L. Groundwater wells in the vicinity of Beatty, Nevada, contained tritium concentrations ranging from not detected to 2.10×10^2 pCi/L. These concentrations are, as expected, less than those detected on site and are not predicted to adversely impact groundwater or surface water biota associated with these waters.

4.5.3 Near-Future Exposure

Near-future tritium concentrations in groundwater, surface water, and irrigation water were estimated using the groundwater concentrations predicted through the flow and transport modeling process. As mentioned earlier, the near-future exposure scenarios considered were the following:

- Exposure of groundwater microorganisms to groundwater
- Exposure of aquatic and semiaquatic biota to surface water at the off-site discharge locations
- Exposure of riparian species to surface water in irrigation ditches

The flow and transport modeling results indicate that tritium concentrations in groundwater both on site and off site may exceed the toxicity-based benchmark set for bacteria at 9.3×10^7 pCi/L (Tables 3-3, 3-4, and 3-5). For groundwater movement west of Pahute Mesa to Oasis Valley/Beatty, potentially hazardous concentrations of tritium are expected to occur from the source out to about 4.9 km laterally from the source (Figure 4-4). In the case of flow movement from Central Pahute Mesa to Oasis Valley/Beatty, groundwater concentrations in excess of 9.3×10^7 pCi/L are expected to occur from the event to about 2 km downgradient from the event (Figure 4-4). Finally, groundwater flow from the Yucca Flat area to Amargosa Valley/Ash Meadows is expected to exceed the toxicological benchmark for groundwater microorganisms from the source to about 2 km downgradient from the event (Figure 4-4). It is, therefore, possible that concentrations of tritium that may reach groundwater in the near future may adversely impact groundwater organisms, at least those populations located within a few kilometers of UGTA. In addition to potential adverse impacts on groundwater microorganisms, any drainage ditches formed through the use of groundwater for irrigation purposes within this distance may also impact aquatic and semiaquatic receptors.

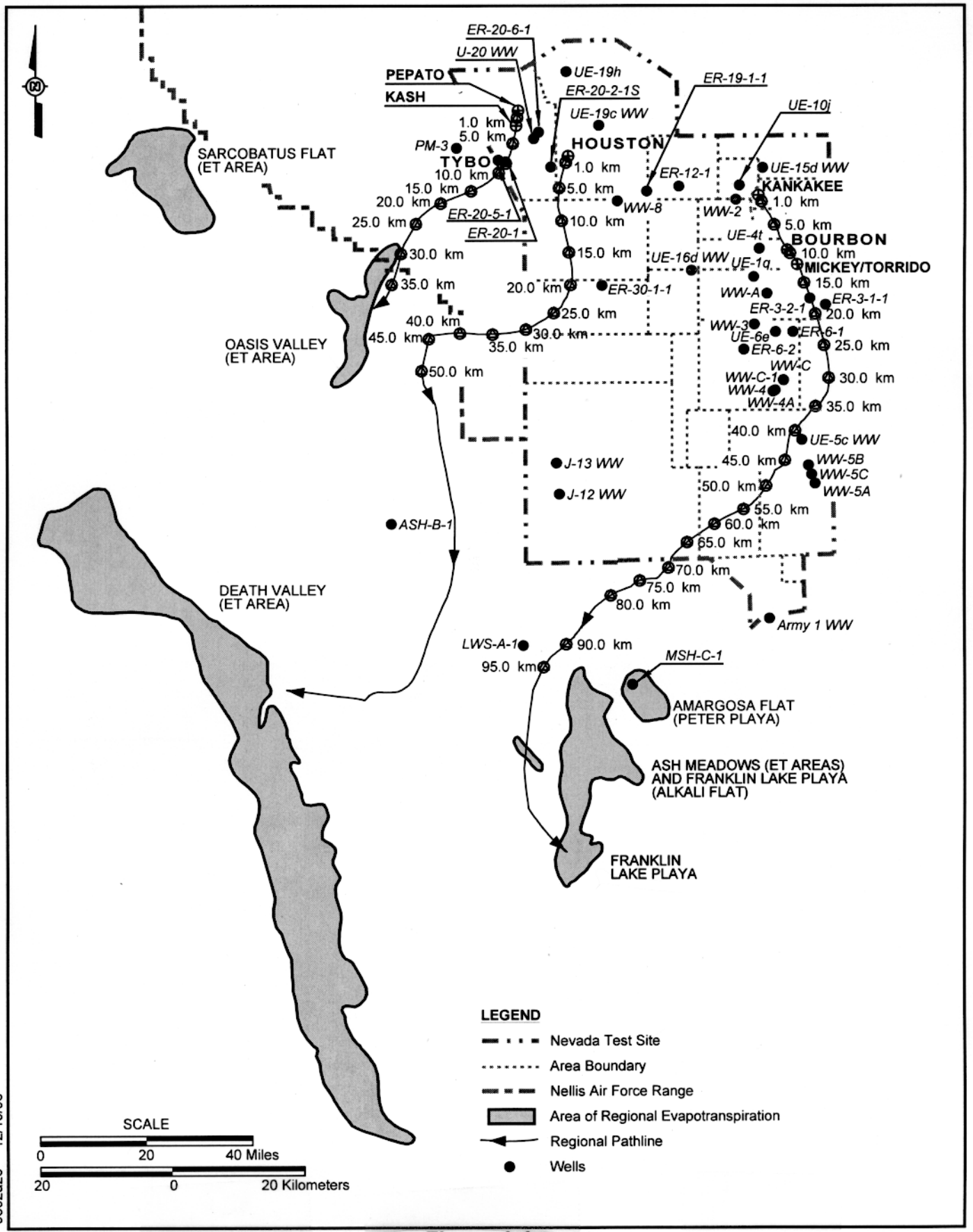

Figure 4-4
Pathlines for Transport - Modeled Underground Events

Groundwater modeling results indicate that tritium concentrations in excess of 9.3×10^{7} pCi/L are not expected to reach the off-site springs. As shown in Tables 4-7, 4-8 and 4-9, concentrations at the three discharge points modeled reveal tritium concentrations of less than 1.1×10^{7} pCi/L. Near-future concentrations of tritium at the surface water discharge points are, therefore, not expected to adversely impact fish, heron, algae, or groundwater microorganisms.

4.5.4 Overall Risk

Based on comparisons of the predicted concentrations of tritium in groundwater and surface water to the ecological benchmark values and examination of the groundwater and spring monitoring data, it is evident that aquatic and semiaquatic receptors associated with the off-site discharge points are not currently or predicted in the future to be exposed to concentrations of tritium detrimental to spring and groundwater ecosystems. Near-future ecological risks to these receptors as they relate to the No-Action Alternative are not anticipated due to the slow movement of tritium through the groundwater system and the high ecotoxicological thresholds associated with tritium exposure.

Table 4-7
Maximum Tritium Activity for Groundwater Flow from West Pahute Mesa Toward Oasis Valley

Distance from TYBO		Tritium Activity[a]
km	mi	pCi/L
2	1	1.9×10^{8}
4.5	2.8	7.9×10^{8}
7	4	5.4×10^{7}
9.5	5.9	4.4×10^{7}
12	7.5	3.0×10^{7}
17	11	2.2×10^{7}
22	14	1.3×10^{7}
24.5	15.2	1.2×10^{7}
27	17	1.1×10^{7}
30	19	1.1×10^{7}

[a]The value at which 95 percent of the Monte Carlo realizations had a smaller value, based on the cumulative density of maximum tritium activity for each realization.

Table 4-8
Maximum Tritium Activity for Groundwater Flow from Central Pahute Mesa Toward Oasis Valley

Distance from HOUSTON		Tritium Activity[a] pCi/L
km	mi	
1	0.6	2.3×10^{8}
3	2	5.2×10^{7}
5	3	3.3×10^{7}
7	4	1.9×10^{7}
10	6	1.0×10^{7}
15	9	4.5×10^{6}
20	12	1.9×10^{6}
25	16	6.5×10^{-5}
30	19	2.4×10^{-5}
35	22	1.2×10^{-5}
40	25	4.7×10^{-4}
45	28	7.5×10^{-4}
50	31	2.1×10^{-25}

[a]The value at which 95 percent of the Monte Carlo realizations had a smaller value, based on the cumulative density of maximum tritium activity for each realization.

Table 4-9
Maximum Tritium Activity Predicted for Groundwater Flow from Yucca Flat Toward Ash Meadows

Distance from BOURBON		Tritium Activity[a] pCi/L
km	mi	
0.8	0.5	2.2×10^{8}
3.3	2.1	1.4×10^{8}
5.8	3.6	4.5×10^{7}
8.3	5.2	1.2×10^{7}
10.8	6.71	4.9×10^{6}
15.8	9.82	9.0×10^{5}
20.8	12.9	2.3×10^{5}
25.8	16.0	4.0×10^{4}
30.8	19.1	1.5×10^{4}
35.8	22.3	7.7×10^{3}
40.8	25.4	2.5×10^{3}
45.8	28.5	1.2×10^{3}
50.8	31.6	7.0×10^{2}
60.8	37.8	1.2×10^{2}
70.8	44.0	7.0×10^{1}
80.8	50.2	8.8×10^{6}

[a]The value at which 95 percent of the Monte Carlo realizations had a smaller value, based on the cumulative density of maximum tritium activity for each realization.

Although groundwater organisms are not thought to be presently exposed to hazardous concentrations of tritium in groundwater on site or off site, flow and transport modeling results indicate that elevated concentrations of tritium may reach groundwater at concentrations toxic to bacteria in the future. Hazardous concentrations are, however, only predicted to occur within a few kilometers of the NTS underground test areas. In addition, because bacteria are several orders of magnitude less sensitive to radiation than vertebrates (Whicker and Schultz, 1982), it is unlikely that concentrations of 10^8 pCi/L would be detrimental to groundwater microbial populations.

A near-future scenario that may result in adverse risk to on-site aquatic and semiaquatic receptors is that related to the irrigation drainage ditches. These hypothetical ditches, which were assumed to contain tritium concentrations in surface water equivalent to those predicted in nearby groundwater, may provide habitat for plant and animal life. Concentrations located approximately 4 km from the three UGTA locations were predicted to exceed 9.3×10^7 pCi/L by less than an order of magnitude. Because concentrations did not exceed the benchmark concentration of 3.4×10^9 pCi/L for aquatic life, only semiaquatic species may actually be at risk. The likelihood to species such as the great blue heron is moderated, however, by the conservative assumptions of permanent water within a ditch, maximum tritium concentrations, and the exclusive use of food resources within the ditch.

Current and near-future ecological risk predictions were based on existing monitoring data and on the groundwater modeling results. Uncertainties associated with these data are, therefore, propagated throughout the ecological risk assessment. Because this assessment is conservative in nature, it is likely to over rather than underestimate potential ecological risks.

4.6 Uncertainty

Uncertainties that are associated with the assessment of ecological risks at UGTA are numerous and include those that are related to the determination of the radionuclide source concentrations, the groundwater model, the exposure model, and the benchmark values used to evaluate risk. Uncertainties associated with the groundwater model are numerous and include such things as groundwater flow velocity and flow path as discussed in the *Tritium Transport Model Documentation Package* (IT, 1996g). Variations of specific parameter values may serve to either over or underestimate tritium exposure concentrations. In addition, the groundwater model is a regional model that does not have the scale of a local model such as that currently being developed for Frenchman Flat. The exposure models and benchmark values are conservative in nature and may, therefore, actually be overprotective. Within the exposure models, it is assumed that the entire home range of the heron is restricted to a given contaminated spring and that its

entire diet consists of fish from that spring. Fish, algae, and groundwater microorganisms are also assumed to receive the maximum exposure from a given surface water or groundwater source. Specifically, maximum measured concentrations were used for the monitoring data, and 95 percent values of each of the Monte Carlo realizations were used for the groundwater modeling results. This ensures that the ecological risk assessment was conservative in nature and evaluates potential risks to maximally exposed receptors. Hypothetical near-future exposure scenarios are also assumed to exist, specifically the existence of irrigation drainage ditches that contain water throughout the year. This is unlikely to actually occur due to the arid environment and likelihood of intense farming within the area. With regard to risk, the threshold dose of 0.1 rad/d is used in the estimation of the final water concentration that will ensure protection of the entire spring ecosystem. This value is an order of magnitude more conservative than that recommended for the protection of aquatic populations and was used to insure the protection of semiaquatic species (e.g., heron). It should be added that use of the more conservative benchmark provides an additional amount of insurance that special status species, such as the desert pupfish, will be protected.

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Appendix A

Intake Models

Intake Models

This appendix describes the models used to calculate the intake of tritium by each of the three exposure pathways: inhalation, ingestion, and absorption by dermal contact. These models include equations for the calculation of the annual intake of tritium, in picoCuries (pCi), by a human receptor exposed to tritiated groundwater through the inhalation and skin absorption of tritiated water vapor in the air, the ingestion of groundwater-derived drinking water, the ingestion of soil contaminated by tritiated groundwater, and the absorption of tritiated water by washing or bathing. Models are also presented for the calculation of the concentration of tritium in food stuffs, including food crops, beef, and milk, that have been grown using tritiated groundwater for irrigation and as drinking water for livestock.

Inhalation Pathway

Inhalation intake is a function of breathing rate, exposure time, and the concentration of tritium in the air. Receptor-specific intakes were calculated using breathing rates related to the energy needs of the anticipated activities and the time over which the activity takes place. These breathing rates were coupled to food-energy intakes needed to sustain the assumed activity levels of the individual receptor (Layton, 1993). The mix of physical activities used in this analysis was for an individual performing outdoor activities as recommended in the RESRAD code manual (Yu et al., 1993a). The equation used to calculate the intake of tritium by inhalation is:

$$INH = BR \times t \times C_a \quad (1)$$

where:

INH = Tritium intake from inhalation (picoCuries per year [pCi/year]);
BR = Breathing rate (cubic meters per hour [m^3/hour]);
t = Time breathing (hours/year); and
C_a = Atmospheric concentration of tritium as HTO (picoCuries per cubic meter [pCi/m^3]).

The atmospheric concentration of tritium (C_a) was calculated based on the concentration of tritium in groundwater using the following equation:

$$C_a = \frac{(U_{wi} \; x \; C_{gw} \; x \; F_i)}{2 \sqrt{\frac{F_{a,gw}}{\pi}} \; x \; S \; x \; H} \qquad (2)$$

where:

C_a = Concentration of tritium in the atmosphere (pCi/m^3);
U_{wi} = Total groundwater production on the NTS (78 liters per second [L/s]);
C_{gw} = Concentration of HTO in groundwater (picoCuries per liter [pCi/L]);
F_i = Fraction of groundwater that is released to the atmosphere (unitless);
$F_{a,gw}$ = Land area of the NTS (3.5 x 10^9 square meters [m^2]);
S = Average wind speed at the NTS (3.4 meters per second [m/s]); and
H = Mixing height (2 meters [m]).

Ingestion Pathway

The ingestion pathway includes the ingestion of drinking water, food (food crops, beef, and milk), and the inadvertent ingestion of soil. The intakes from tritium-contaminated food crops (fruit and vegetables), beef, and milk were calculated from the concentrations modeled by the methods described in this section using southern Nevada-specific consumption rates (Whicker et al., 1990). In order to provide a thorough description of the potential HTO intake, the concentration of HTO in pork, eggs, and poultry were assumed to be the same as beef. All by-products of beef and milk were assumed to have the same concentrations as the original product. For all land-use scenarios except agriculture, individuals are assumed to receive 20 percent of their food from farms and ranches using tritiated water for irrigation and drinking water. The individuals participating in the agricultural land-use scenario were assumed to get all of their food from their farm and dairy operations.

Drinking Water. The ingestion of tritiated water is analogous to the method for calculating the inhalation of HTO in the air (Equation 1). The drinking water intake is:

$$IWING = R_{dw} \; x \; C_{dw} \; x \; t \qquad (3)$$

where:

IWING = Ingestion intake of tritiated groundwater (pCi/year);
R_{dw} = Rate of drinking water ingestion (1.2 L/day);
C_{dw} = HTO concentration in drinking water (pCi/L); and
t = Time tritiated water being ingested (days/year).

The HTO concentration in drinking water (C_{dw}) is assumed to equal the HTO concentration in groundwater (C_{gw}) while the rate of drinking water ingestion is from a study by the U.S. Food and Drug Administration's total diet study (Pennington, 1983).

Food Crops. The ingestion of tritiated food crops assumes that the crops were irrigated with tritiated groundwater and that the fraction of food grown on site is representative of rural areas in the United States. The types and amounts of food ingested are representative of average southern Nevada residents (Whicker et al., 1990). The HTO concentrations in food crops are influenced by both the HTO concentration in irrigation water and the HTO concentration in the atmosphere.

The HTO concentration in food crops due to irrigation water is calculated according to the equation:

$$C_{fc,iw} = 0.9 \; x \; 0.001 \; x \; C_{iw} \qquad (4)$$

where:

$C_{fc,iw}$ = Concentration of HTO in food crops due to HTO in irrigation water (picoCuries per gram [pCi/g]);
0.9 = Mass fraction of hydrogen in food crops;
0.001 = pCi/L to pCi/g conversion; and
C_{iw} = Concentration of HTO in irrigation water (same as groundwater [C_{gw}]) pCi/L.

The mass fraction of hydrogen in food crops is from Yu et al. (1993b). This hydrogen fraction is conservative because it is largely dependent upon the water content of the crop, which is significantly less than that used to estimate this mass fraction value in many crops.

The concentration of HTO in food crops due to HTO in the atmosphere is adapted from the methodology developed at the Savannah River Laboratory (SRL) (Hamby, 1993). The equation used is:

$$C_{fc,a} = \frac{(C_a \; x \; F_W \; x \; R_{fc,a})}{H_a} \qquad (5)$$

where:

$C_{fc,a}$ = HTO concentration in food crops due to HTO in the atmosphere (pCi/g);
C_a = Concentration of HTO in the atmosphere (pCi/m^3);
F_W = Fraction of food crop mass that is water (0.8);
$R_{fc,a}$ = Ratio of plant tritium concentration to atmospheric HTO (0.8); and
H_a = Annual average absolute humidity (3.25 grams per cubic meter [g/m^3]).

The fraction of food crops that is water (F_W) is from Yu et al. (1993b). The ratio of plant tritium concentration to atmospheric HTO is modeled as a triangular distribution with a mode of 0.8 and a range of 0.4 - 1.2 (Hamby, 1993). The annual average absolute humidity was derived from temperature and relative humidity data provided by the Las Vegas office of the National Oceanic and Atmospheric Administration (NOAA) for Pahute Mesa, Yucca Flats, and Mercury (Soule, 1995 and 1996).

Beef. The concentration of HTO in beef includes contributions from HTO in feed crops, drinking water, and ingested soil. Much of the modeling of HTO in beef is based upon the SRL research (Hamby, 1993). The concentration of HTO in beef due to HTO in feed crops is calculated by the equation:

$$C_{b,fc} = F_b \; x \; C_{fc,t} \; x \; IR_{b,fc} \; x \; e^{(-\lambda T_s)} \qquad (6)$$

where:

$C_{b,fc}$ = HTO concentration in beef due to HTO in feed crops (pCi/g);
F_b = Equilibrium ratio of HTO in beef to the cattle's daily feed ingestion rate (days/kg);
$C_{fc,t}$ = HTO concentration in cattle feed (pCi/g);

$IR_{b,fc}$ = Feed ingestion rate of cattle (52 kg/day);
λ = Radiological decay constant for tritium (1.55×10^{-4}/day); and
T_s = Time from slaughter to consumption (6.4 days).

The parameter values F_b, $IR_{b,fc}$, and T_s were modeled as lognormal distributions. F_b has a geometric mean of 0.01 days/ kg and a geometric standard deviation of 0.001 days/kg, while $IR_{b,fc}$ has a geometric mean of 52 kg/day and a geometric standard deviation of 11 kg/day (Ng, 1979; Little, 1979). T_s has a median of 6 days, while the 99.9 percent confidence level was chosen to cover an order of magnitude (Hamby, 1992, 1993).

The concentration of HTO in beef due to the cattle's ingestion of drinking water is calculated in the following manner:

$$C_{b,dw} = DW_b \times C_{dw} \times IR_{b,dw} \times CF \times e^{(-\lambda T_s)} \quad (7)$$

where:

$C_{b,dw}$ = Concentration of HTO in beef due to HTO in drinking water (pCi/g);
DW_b = Transfer coefficient from water to beef (days/kg);
C_{dw} = HTO concentration in drinking water (pCi/L);
$IR_{b,dw}$ = Beef cattle water ingestion rate (L/day);
λ = Radiological decay constant for tritium (1.55×10^{-4}/day);
T_s = Time from slaughter to consumption (6.4 days); and
CF = Conversion factor kg/1,000g.

The HTO transfer coefficient from drinking water to beef (DW_b) is modeled as a normal distribution with a mean of 0.01 days/kg and a selected range from 0 to 0.02 days/kg. The ingestion rate of drinking water for beef cattle ($IR_{b,dw}$) is modeled as a normal distribution with a mean of 50 L/day with a selected range from 26 to 74 L/day (Yu et al., 1993b).

The concentration of HTO in beef due to cattle ingestion of soil is a function of the HTO concentration in soil, the cattle soil ingestion rate, and the HTO transfer rate from soil to beef. The relationship is described by the equation:

$$C_{b,s} = IR_{b,s} \times C_{s,iw} \times F_{b,s} \times e^{(-\lambda T_s)} \quad (8)$$

where:

$C_{b,s}$ = Concentration of HTO in beef due to ingestion of HTO contaminated soil (pCi/g);
$IR_{b,s}$ = Ingestion rate of soil by cattle (kg/day);
$C_{s,iw}$ = Concentration of HTO in soil due to HTO in irrigation water (pCi/g);
$F_{b,s}$ = HTO transfer coefficient from soil to beef (days/kg);
λ = Radiological decay constant for tritium (1.55×10^{-4}/day; and
T_s = Time from slaughter to consumption (6.4 days).

The ingestion rate of soil by cattle and dairy cows ($IR_{b,s}$) is from a review performed at the Idaho National Engineering Laboratory (INEL) and is modeled as a normal distribution with a mean of 0.5 kg/day and a standard deviation of 0.08 kg/day (Rope and Adams, 1983). The HTO transfer coefficient from soil to beef ($F_{b,s}$) was assumed to be a normal distribution with a mean of 0.01 days/kg and a standard deviation of 0.001 days/kg.

The concentration of HTO in soil from tritiated irrigation water (C_s) was calculated by the equation:

$$C_{s,iw} = \frac{(C_{gw} \times \theta \times R_d)}{P_s} \times CF \quad (9)$$

where:

$C_{s,iw}$ = Concentration of HTO in soil due to HTO in irrigation water (pCi/g);
C_{gw} = HTO concentration in groundwater and irrigation water (picoCuries per cubic centimeter [pCi/L]);
R_d = Retardation function for HTO in soil (1.0);

P_s = Bulk density of soil (grams per cubic centimeter [g/cc]);
CF = Conversion factor (L/1,000cc).

θ is defined by:

$$\theta = \frac{R_s}{\theta_{sat}} \quad (10)$$

where:

θ_{sat} = Saturated water content (0.39); and:

$$R_s = \left[\frac{INF}{K_{sat}}\right]^{\left(\frac{1}{2b+3}\right)} \quad (11)$$

where:

K_{sat} = Hydraulic conductivity of the soil (5,550 m/year);
b = Soil-specific exponential parameter (4.05); and:

$$INF = (1 - C_e)\ x\ \left[(1 - C_r)\ x\ P_r + Irr\right] \quad (12)$$

where:

C_e = Evapotranspiration coefficient (0.9999);
C_r = Runoff coefficient (0.3);
P_r = Precipitation rate for NTS (0.127 m/year); and
Irr = Irrigation rate (1.2 m/year).

C_e is a function of the evapotranspiration rate, but in the NTS arid environment, C_e is bounded by a value of one. The model for calculating HTO concentration in soil was originally designed by

Argonne National Laboratory to determine the flux of contaminated surface water to the saturated zone (Yu et al., 1993b); however, the model does provide the appropriate relationship between the HTO concentration in soil water (C_{gw}) and the HTO concentration in the soil (C_s).

Several parameters used to calculate C_s are probabilistic in nature and were assigned pertinent distributions. The average evapotranspiration rate was calculated using Figures 12-1 of Yu et al. (1993b), giving a normal distribution with a mean of 1.07 and a standard deviation of 0.15. The precipitation rate is based upon NTS data and was fitted to a normal distribution with a mean of 0.127 m/year and a standard deviation of 0.06 m/year. The irrigation rate is based upon engineering judgement of the quantity needed to support agricultural activities. A normal distribution was assigned with a mean of 1.2 m/year, a standard deviation of 0.12 m/year, and a selected range of 1.00 to 1.80 m/year. The range and distribution were selected based upon the NTS rainfall and temperature patterns and how they could affect the need for irrigation.

The total concentration of HTO in beef is the sum of the contributions from feed, drinking water, and soil. The concentration of HTO in beef is typically on the order of 0.1 percent of the concentration of HTO groundwater.

Milk. The concentration of tritium in milk is calculated in a manner analogous to the method used to calculate HTO concentration in beef. Dairy cows ingest HTO from feed crops, drinking water, and soil. The concentration in milk due to the ingestion of feed crops is:

$$C_{m,fc} = 1{,}000 \; x \; F_m \; x \; C_{fc,t} \; x \; IR_{m,fc} \; x \; e^{(-\lambda T_m)} \qquad (13)$$

where:

$C_{m,fc}$ = Concentration of HTO in milk due to the ingestion of feed crops (pCi/L);
1,000 = A unit conversion factor that translates g to kg;
F_m = Equilibrium ratio in milk to the cow's daily ingestion rate of feed (days/L);
$C_{fc,t}$ = HTO concentration in feed crops (pCi/g);
$IR_{m,fc}$ = Dairy cow feed ingestion rate (kg/day);
λ = Radiological decay constant for tritium (1.55×10^{-4}/day); and
T_m = Milking to market transport time (3.1 days).

The parameter values F_m, $IR_{m,fc}$, and T_m were modeled as lognormal distributions. F_m has a geometric mean of 0.01 days/L and a geometric standard deviation of 0.001 days/L. $IR_{m,fc}$ is the cow's daily feed ingestion rate, and has a geometric mean of 36 kg/day and a geometric standard deviation of 7.8 kg/day (Ng, 1979; Little, 1979). T_m is the time from milking to consumption and was modeled as a lognormal distribution with a geometric mean of 3.1 days and a geometric standard deviation of 1.38 days (Hamby, 1992, 1993).

The HTO concentration of tritium in milk due to HTO in drinking water is quantified using the equation:

$$C_{m,dw} = F_{m,dw} \times DW_m \times C_{dw} \times IR_{m,dw} \times e^{(-\lambda T_m)} \quad (14)$$

where:

$C_{m,dw}$ = Concentration of HTO in milk due to the ingestion of drinking water (pCi/L);
$F_{m,dw}$ = Ratio of milk production to water intake;
DW_m = HTO transfer coefficient from drinking water to milk (days/L);
C_{dw} = HTO concentration in water (pCi/L);
$IR_{m,dw}$ = Dairy cow water ingestion rate (L/day);
λ = Radiological decay constant for tritium (1.55×10^{-4}/day); and
T_m = Milking to market transport time (3.1 days).

The HTO transfer coefficient from drinking water to milk (DW_m) is modeled as a normal distribution with a mean of 0.01 and a standard deviation of 0.001. The ingestion rate of drinking water for dairy cows ($IR_{m,dw}$) is modeled as a normal distribution with a mean of 105 L/day, a standard deviation of 18.3 L/day, and a selected range from 50 to 160 L/day (Yu et al., 1993b).

The concentration of HTO in milk due to the cow's ingestion of soil is a function of the HTO concentration in soil, the cow's soil ingestion rate, and the HTO transfer rate from soil to milk. The relationship is described in the equation:

$$C_{m,s} = 1{,}000 \; x \; IR_{m,s} \; x \; C_{s,iw} \; x \; F_{m,s} \; x \; e^{(-\lambda T_m)} \qquad (15)$$

where:

$C_{m,s}$ = Concentration of HTO in milk due to the HTO in soil (pCi/L);
1,000 = A unit conversion factor that translates g to L for water;
$IR_{m,s}$ = Ingestion rate of soil by cows (kg/day);
$C_{s,iw}$ = Concentration of HTO in soil from irrigation water (pCi/g) (see Equation 9);
F_m = HTO transfer coefficient from soil to milk (days/kg);
λ = Decay constant for tritium (1.55×10^{-4}/day); and
T_m = Milking to market transport time (3.1 days).

Soil. Individuals are assumed to inadvertently ingest soil. The HTO intake from soil ingestion for human receptors is modeled like that for cattle and dairy cows, where intake is the product of soil concentration (C_s), ingestion rate, and exposure time. The average ingestion rate is 0.1 gram per day, except for individuals in the agricultural, industrial, and mining land-use scenarios. For these cases, individuals were assumed to ingest 0.48 grams per day. These ingestion rates are slightly higher than the guidance given by EPA (1991), but are justified due to the particularly dusty conditions in the desert.

Dermal Absorption

The model used to calculate the intake of HTO due to dermal (skin) absorption is that presented in ICRP Publication 30, which is based upon the investigations of Osborne (1966 and 1968). Individuals are assumed to absorb HTO water vapor through their skin at all times while on site. The analytical expression for absorption from the atmosphere is shown below:

$$I_{s,a} = 0.01 \; x \; C_a \; x \; t \qquad (16)$$

where:

$I_{s,a}$ = Skin intake of tritium from the atmosphere per year (pCi);
0.01 = pCi/minute of HTO absorbed through the skin if air concentration is expressed in pCi/m^3;

C_a = HTO concentration in air (pCi/m^3)(see Equation 2); and
t = Exposure time (minutes).

Individuals are assumed to shower, bathe, and otherwise get their skin wet with water having a tritium concentration equal to groundwater. The expression that quantifies their skin intake is that of Osborne (1968):

$$I_{s,w} = (M \times W \times N) + (W \times I \times P \times N \times t) \quad (17)$$

where:
$I_{s,w}$ = Skin intake from wet skin (pCi);
W = Wetted area, assumed to be the entire skin area (1.9 m^2);
I = Intake rate for skin (5.1 pCi/minute-m^2 per pCi/L);
P = Humidity of air at skin temperature (0.04 g/L);
N = Specific activity of HTO in air (pCi/g);
t = Exposure time (minutes); and
M = intake due to blotter effect (g/m^2).

The total skin intake of tritium is the sum of $I_{s,a}$ and $I_{s,w}$.

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Appendix B
Ecological Dose Assessment Calculation Briefs

Purpose:

The purpose of the following is to estimate the contaminant (or radionuclide) concentration that would expose either the pup fish (primary organism) or the heron (secondary organism) to a 1.0 rad/day combined internal and external dose rate. The total for both internal and external exposure to a radionuclide must be below 1 rad/day. This was accomplished by using an existing spreadsheet model that utilized a method outlined in Baker & Soldat, 1992. Two outcomes can be calculated by using this spreadsheet: 1) internal/external dose rate of 1.0 rad/day for the fish (which exposes the heron to a greater than 1.0 rad/day dose rate via consumption of the fish), and 2) internal/external dose rate of 1.0 rad/day for the heron (which exposes the fish to lower than a 1.0 rad/day dose rate.)

The concentration of a radionuclide needed for a 1.0 rad/day dose rate in the fish or heron was calculated using an iterative technique with the existing spreadsheet model. This allowed the internal/external dose rate to be calculated in the spreadsheet as a function of radionuclide concentration only while holding all of the other parameters fixed. The concentration (with units of Ci/m^3) was manually changed in a systematic manner until a dose rate of 1.0 rad/day was calculated to the desired accuracy. A summary of the methodology used for this internal dose model is described below.

The same procedure was performed for another calculation to determine the concentration that would expose either the pup fish (primary organism) or the heron (secondary organism) to a 0.1 rad/day internal and external dose rate. The same spreadsheets are used for this calculation as well.

The concentration of tritium in water needed to expose the fish/heron to a 1.0 or 0.1 rad/day dose rate, respectively, are converted from Ci/m^3 to pCi/L. The conversion from Ci/m^3 to pCi/L was accomplished by using the following relationship:

$$1\ Ci/m^3 = (1\ Ci/m^3)(10^{12}\ pCi/Ci)(m^3/1000\ L) = 10^9\ pCi/L \quad (1)$$

The concentration of tritium in water (in pCi/L) is provided next to the dose rate result in the spreadsheet model for easy comparison.

References:

Baker, D.A., and Soldat, J.K., 1992, *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment*, DOE-AC06-76RLO, pp. 1-21.

U.S. Department of Energy, 1994, *Hanford Site Risk Assessment Methodology (HSRAM), "Ecological Dose and Exposure Calculations*," DOE/RL-91-45, Review Draft, pp. E12-E18.

Methodology:

Aquatic Internal Dose

The total daily doses to a primary organism are estimated as the sum of doses (based on a weighted gamma energy from radioactive decay for specific radionuclides) received from all internal and external exposure to all radioactive contaminants in the environment in which the organisms reside.

The total internal total-body dose rate (rad/day) to an organism exposed to N radionuclides is given by equation 2:

$$R_c = \sum_{i=1}^{N} b_{ic} \cdot E_{ic} \quad (2)$$

where: R_c = Internal total-body dose rate of organism c (rad/day),
$b_{i,c}$ = Specific body burden of nuclide i in organism c (Ci/kg),
$E_{i,c}$ = Effective energy absorbed for radionuclide i per unit activity in organism c (kg-rad/Ci-day) (See below:)

$$E_{i,c} = \varepsilon_{i,c} \text{ (MeV/dis) x } 5.12E04 \quad (3)$$

where $\varepsilon_{i,c}$= the effective radionuclide energy for diameter of aquatic organism for nuclide i in organism c. The proportionality constant, 5.14E4, is defined on page 3 of Baker & Soldat, 1992.

The specific body burden of nuclide i in organism c (Ci/kg) for the primary organism is given by:

$$b_{i,c} = C_{i,c} \text{ x } BF_{i,c} \text{ x } CF_{i,c} \quad (4)$$

where: R_c = Internal total-body dose rate of organism c (rad/day)
$b_{i,c}$ = specific body burden of nuclide i in organism c (Ci/kg)
$C_{i,c}$ = concentration of radionuclide i in water to which organism c is exposed (Ci/L)
$Bf_{i,}$ = bioaccumulation factor for nuclide i and organism c (m^3/kg)
CF = conversion factor (0.001 L/m^3).

The spreadsheet labeled "Internal Fish and Heron Example" has two parts. The first part is labeled "Internal Fish Dose as Primary Organism." This spreadsheet is clearly labeled with headers and performs the following calculation:

$$R_c = \sum_{i=1}^{N} E_{ic} \cdot C_{ic} \cdot BF_{ic} \cdot CF_{ic} \quad (5)$$

where everything is defined above. R_c is calculated in rad/day and rad/yr in the spreadsheet.

The heron, as the secondary organism, consumes the fish and thus receives an exposure internally due to the uptake of radionuclides in fish. The internal dose rate received by the heron is given by equation 6:

$$R_c = \frac{\sum_{i=1}^{N} b_i \cdot U_c \cdot f_{1_i} \cdot E_{ic} \cdot B_{ic}}{M_c} \quad (6)$$

where: R_c = Internal total-body dose rate of secondary organism c (rad/day)
U_c = intake rate of primary organism by secondary organism c (kg/d),
M_c = mass of secondary organism c (kg)
b_i = body burden of primary organism (Ci/kg),
$f_{i,c}$ = fraction of radionuclide initially retained in total body of secondary organism (unitless)
$E_{i,c}$ = defined previously
$B_{i,c}$ = effective decay constant of radionuclide i in the secondary organism (day) defined below as equation 7:

$$B_{ic} = \frac{(1 - \exp(-\lambda_{ic} \cdot T_e))}{\lambda_{ic}} \quad (7)$$

where equation 4 defines the effective decay content in the secondary organism:

$$\lambda_{ic} = (\lambda_b + \lambda_r) day^{-1} \quad (8)$$

The parameter $\lambda_b = \ln(2)/T_b$ where λ_b=biological decay constant of radionuclide and T_b is the biological half-life of the radionuclide in the organism, and $\lambda_r = \ln(2)/T_r$ where λ_r=radiological decay constant of radionuclide and T_r is the radiological half-life of the radionuclide in the organism. The variable T_e is defined as the exposure time or period of exposure which is assumed to be 365 days (Baker and Soldat, 1992).

The second section of the spreadsheet labeled "Internal Fish and Heron Example" calculates the internal dose rate to a heron due to consumption of a fish containing radioactive material. The headers for the spreadsheet are clearly labeled with the appropriate units as well.

Aquatic External Dose:

The primary organism resides in the water continuously. They can be exposed externally from immersion in water contaminated with radionuclides and from contaminated river bottom sediments. It can be assumed that primary organisms get 100% of their exposure from immersion in the water. Secondary organisms can be exposed externally from immersion in the water, and/or exposure to river bottom or shoreline sediments. Therefore, the external exposure to the secondary organism is weighted by the fraction of the time it is exposed to these pathways. Immersion and sediment dose rate factors are used to calculate external dose rates. The following equation was used to calculate the dose rate from immersion in water (equation 9):

$$R_c = \sum_{i=1}^{N} C_{ic} \cdot DF_{im} \cdot F_{\exp} \cdot CF \quad (9)$$

where: R_c = dose rate (rad/day) from immersion in the water,
$C_{i,c}$ = concentration of radionuclide i in water to which the organism c is exposed (Ci/L),
$Df_{im,i}$ = immersion dose rate factor for radionuclide i (rad-m^3/Ci-day),
F_{exp} = exposure fraction (unitless),
CF = conversion factor (0.001 in units of L/m^3).

If there is a surface swimming animal (secondary organism), its dose rate can be assumed to be half of that of the same animal completely immersed in water.

Example Calculations:

Please see the IT Calculation Brief, "NTS-UGTA Eco Risk Fish/Heron Dose Model, 12/1/95, Project #: 764027.02.03.00.00 for example calculations that verify example calculations in Baker & Soldat, 1992.

By Doug Bowen **Date** 8/16/96 **Subject** Fish Egg Dose Model: 9.32×10^7 pCi/L **Sheet No.** 1 **of** 3

Chkd. By SD **Date** 8/25/96 **Proj. No.** 764027.01.02.04.00

Purpose:

The purpose of the following is to estimate the dose rate in rad/day that fish eggs would be exposed to assuming a concentration of tritium in water of 9.32E+07 pCi/L. This was accomplished using a radiation dose rate model developed by Blaylock et al. (1993) that specifically defines dose rate equations for fish eggs/embryos for alpha, beta and gamma radiation residing in an aquatic environment. For this work, tritium is the only radionuclide evaluated. Tritium is a pure beta emitter so only those equations valid for beta radiation were considered. The beta particle emitted from tritium has an average energy of 5.68 keV and a maximum energy of 18.6 keV. Equations 11 and 12 in Blaylock et al. (1993) were found to be applicable for our calculation. However, equation 12 is only valid if the range of the beta particles in the water exceeds the radius of the fish eggs themselves. The range of an 18.6 keV beta particle emitted from tritium (which correspond to the maximum beta particle energy for tritium) into water is approximately given by Table 5.1 in Turner (1986) as 0.0077 mm. This range would typically be shorter than this because the beta energy from tritium decay is approximately 6 keV on the average which is much less than the maximum. The approximate radius of a fish egg is approximately 1-2 mm. Therefore, since the range of the beta particle emitted from tritium is very small compared to the radius of the fish egg, equation 12 in Blaylock et al. (1993) is not used.

The dose rate to either the large or small fish in the Blaylock model will be the same as that for the dose rate in fish eggs (also presented in the Blaylock model). It turns out that tritium is unique with respect to internal dose because of its extremely low energy beta particle emitted during radioactive decay and physical properties. Since tritium's beta particle has a range in water that is smaller than the radius of the fish egg itself, it is assumed to be 100% absorbed inside the egg. This is not true for the majority of other radionuclides. Blaylock's model has cases for internal dose rates to large or small fish, depending on how much of the beta particle energy gets absorbed. For tritium this does not matter. In each case, tritium's beta particle is 100% absorbed inside the organism and the same model applies for the small fish, large fish and the fish egg. The dose rate limit considered for this calculation for fish eggs/embryos was assumed to be 1.0 rad/day.

A spreadsheet was developed that allows the calculation of the dose rate in rad/day to be calculated by knowing properties of tritium and assuming a concentration of tritium in water of 9.32E+07 pCi/L. Equation 12 in Blaylock et al. (1993) requires a concentration of the radionuclide inside the fish egg/embryo itself. However, tritium has a unique property in that its Biological Concentration Factor is 1.0. This means that the concentration of the tritium inside the eggs is equal to the concentration of the water outside the eggs. This allows a direct calculation of the amount of tritium in the water itself. Equation 11 in Blaylock et al. (1993) also assumes that the beta energy considered is low. Tritium emits beta particle with an average energy of 5.85 keV with a maximum energy of 18.6 keV. The beta particle emitted from tritium is considered to be of extremely low energy.

For these calculations it is assumed that all of the beta radiation is internally absorbed within the egg and that the tritium is uniformly distributed throughout the egg's interior. The dose rate calculated is assumed to be only for the egg's exposure to tritium. No other radionuclides are assumed to be present.

References:

Baker, D.A., and Soldat, J.K. 1992. *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment*, DOE-AC06-76RLO, pp. 1-21.

Blaylock, B.G., Frank, M.L., O'Neal, B.R. 1993. *Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment*, ES/ER/TM-78, pp 7-9. Oak Ridge National Laboratory.

Polikarpov, G.G. 1966. Radioecology of Aquatic Organisms, pg. 194. New York, New York: Reinhold Book Division,.

Turner, James E. 1986. Atoms, Radiation, and Radiation Protection, pg. 90. New York, New York: Pergamon Press.

Methodology:

Aquatic Internal Dose to Fish Eggs

Equation 11 of Blaylock et al. (1993) provides the internal dose rate for fish eggs/embryos exposed to tritium. This equation is given below:

$$D_\beta = (5.76 \times 10^{-4})(E_\beta)(n_\beta)(C_o) \quad \mu Gy\text{-}h^{-1} \tag{1}$$

where:

E_β = the average energy of the β particle (MeV). For tritium this energy is 0.006 MeV.
n_β = the proportion of transition producing a β-particle of energy E_β (MeV)
C_o = the concentration of the radionuclide in the organism (Bq kg^{-1} wet weight) (Also the concentration of the radionuclide in the water).

The units are converted to provide a dose rate in rad/day and a concentration in water with units of pCi/L.

The following conversion will allow the concentration in water to be converted to pCi/L from Bq/Kg (this requires that the density of water, 1 g/cm^3 be introduced as well). All conversion factors referenced from Turner, 1986.

$$1 \text{ Bq/kg} = (1 \text{ Bq/kg})(\text{Ci}/3.7 \times 10^{10} \text{ Bq})(\text{pCi}/10^{-12} \text{ Ci})(\text{kg}/1000 \text{ g})(1 \text{ g/cm}^3)(\text{cm}^3/9.9997 \times 10^{-4} \text{ L}) = 27.028 \text{ pCi/L}. \tag{2}$$

The dose rate equation is modified, below, to provide the units desired. All conversion factors are referenced from Turner, 1986.

$$D_\beta = ((5.76 \times 10^{-4})(E_\beta)(n_\beta)(C_o) \ \mu Gy/h)(24 \text{ h/day})(10^{-6} \text{ Gy}/\mu Gy)(1 \text{ rad}/0.01 \text{ Gy}) = 1.3824 \times 10^{-6}(E_\beta)(n_\beta)(C_o) \text{ rad/day}. \tag{3}$$

This equation is then slightly modified with the following relationship then solved for the concentration in the water. Table A.1 provides the Biological Concentration Factor (BCF) for Tritium as 1.0. This is defined as the ratio of the concentration of the contaminant in freshwater fish to the concentration in water at steady-state conditions. Assume that steady-state conditions exist. We then get:

$$\text{BCF}=1.0=(\text{Concentration of Tritium in Freshwater Fish (Eggs)})/(\text{Concentration of Tritium in Water}) \tag{4}$$

Let:

C_o = Concentration of tritium in the organism (Bq kg^{-1} wet weight)
C_w = Concentration of the tritium in the water (Bq kg^{-1} wet weight)

Then,

$$C_w = C_o \tag{5}$$

Then equation 3, above, becomes:

$$D_\beta = 1.3824 \times 10^{-6}(E_\beta)(n_\beta)(C_w) \text{ rad/day} \tag{6}$$

The spreadsheet consists 6 or 7 columns of input. For the first table, Column A defines the radionuclide being considered. Column B defines the average beta energy from tritium per decay. Column C is the probability of decay by a particular decay mode. Column D is the concentration of tritium in water (pCi/L). Column E is the concentration of tritium in water (Bq/Kg). The value in Column E is converted from Column D. Column F represents the concentration of tritium in the organism (Bq/Kg- wet weight). Column G is the dose rate in rad/day.

The bottom table is a "check" for the dose rate calculated in the top table. Column A is the radionuclide considered. Column B is the dose rate calculated in table 1 in rad/day. Column C is the average beta energy per decay from tritium. Column D is the probability of decay by a particular decay mode. Column E is the concentration of tritium in the water (Bq/Kg) and Column F is the concentration of tritium in water (pCi/L).

Sample Calculation:

Tritium Specific Information

E_β = 5.68E-03 MeV (Table A.1, Blaylock et al., 1993)
BCF = 1.0 (Table A.1, Blaylock et al., 1993)
C_w = 9.32E+07 pCi/L. This corresponds to a previous study in which it was calculated that this would be the concentration necessary to expose a heron to a 0.1 rad/day dose rate by consuming pup fish contaminated with tritium.
n_β = 1 (pg. 309, Turner). The probability that tritium decays via a beta particle is 100%.

Now, substitute these values into equation (6) to get:

$$D_\beta = 1.3824x10^{-6}(5.68E\text{-}03\ MeV)(1.0)(9.32E+07\ pCi/L)/(27.028\ pCi/L\ per\ Bq/Kg)\ rad/day. \quad (7)$$

$$\mathbf{D_\beta = 2.708E\text{-}02\ rad/day}$$

This answer is in agreement with the spreadsheet results.

By Doug Bowen **Date** 8/16/96 **Subject** Fish Egg Dose Model: 1 rad/day **Sheet No.** 1 **of** 3

Chkd. By SD **Date** 8/25/96 **Proj. No.** 764027.01.02.04.00

Purpose:

The purpose of the following is to estimate the tritium concentration in water (pCi/L) that would expose fish eggs/embryos to a 1.0 rad/day internal dose rate. This was accomplished using a radiation dose rate model developed by Blaylock et al. (1993) that specifically defines dose rate equations for fish eggs/embryos for alpha, beta and gamma radiation residing in an aquatic environment. For this work, tritium is the only radionuclide evaluated. Tritium is a pure beta emitter so only those equations valid for beta radiation were considered. The beta particle emitted from tritium has an average energy of 5.68 keV and a maximum energy of 18.6 keV. Equations 11 and 12 in Blaylock et al. (1993) were found to be applicable for our calculation. However, equation 12 is only valid if the range of the beta particles in the water exceeds the radius of the fish eggs themselves. The range of an 18.6 keV beta particle emitted from tritium (which correspond to the maximum beta particle energy for tritium) into water is approximately given by Table 5.1 in Turner (1986) as 0.0077 mm. This range would typically be shorter than this because the beta energy from tritium decay is approximately 6 keV on the average which is much less than the maximum. The approximate radius of a fish egg is approximately 1-2 mm. Therefore, since the range of the beta particle emitted from tritium is very small compared to the radius of the fish egg, equation 12 in Blaylock et al. (1993) is not used.

The dose rate to either the large or small fish in the Blaylock model will be the same as that for the dose rate in fish eggs (also presented in the Blaylock model). It turns out that tritium is unique with respect to internal dose because of its extremely low energy beta particle emitted during radioactive decay and physical properties. Since tritium's beta particle has a range in water that is smaller than the radius of the fish egg itself, it is assumed to be 100% absorbed inside the egg. This is not true for the majority of other radionuclides. Blaylock's model has cases for internal dose rates to large or small fish, depending on how much of the beta particle energy gets absorbed. For tritium this does not matter. In each case, tritium's beta particle is 100% absorbed inside the organism and the same model applies for the small fish, large fish and the fish egg. The dose rate limit considered for this calculation for fish eggs/embryos was assumed to be 1.0 rad/day.

A spreadsheet was developed to calculate the concentration of tritium in water needed to expose the fish eggs to the 1.0 rad/day dose rate. Equation 11 in Blaylock et al. (1993) requires a concentration of the radionuclide inside the fish egg/embryo itself. However, tritium has a unique property in that its Biological Concentration Factor is 1.0. This means that the concentration of the tritium inside the eggs is equal to the concentration of the water outside the eggs. This allows a direct calculation of the amount of tritium in the water itself. Equation 11 in Blaylock et al. (1993) also assumes that the beta energy considered is low. Tritium emits beta particle with an average energy of 5.85 keV with a maximum energy of 18.6 keV. The beta particle emitted from tritium is considered to be of extremely low energy.

For these calculations it is assumed that all of the beta radiation is internally absorbed within the egg and that the tritium is uniformly distributed throughout the egg's interior. The dose rate calculated is assumed to be only for the egg's exposure to tritium. No other radionuclides are assumed to be present.

References:

Baker, D.A., and Soldat, J.K. 1992. *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment*, DOE-AC06-76RLO, pp. 1-21.

Blaylock, B.G., Frank, M.L., O'Neal, B.R. 1993. *Methodology for Estimating Radiation Dose Rates to Freshwater Biota Exposed to Radionuclides in the Environment*, ES/ER/TM-78, pp 7-9. Oak Ridge National Laboratory.

Polikarpov, G.G. 1966. Radioecology of Aquatic Organisms, pg. 194. New York, New York: Reinhold Book Division.

Turner, James E. 1986. Atoms, Radiation, and Radiation Protection, pg. 90. New York, New York: Pergamon Press.

Methodology:

Aquatic Internal Dose to Fish Eggs

Equation 11 of Blaylock et al. (1993) provides the internal dose rate for fish eggs/embryos exposed to tritium. This equation is given below:

$$D_\beta = (5.76x10^{-4})(E_\beta)(n_\beta)(C_o) \quad \mu Gy\text{-}h^{-1} \tag{1}$$

where:

E_β = the average energy of the β particle (MeV). For tritium this is 0.006 MeV.
n_β = the proportion of transition producing a β-particle of energy E_β (MeV)
C_o = the concentration of the radionuclide in the organism (Bq kg $^{-1}$ wet weight)

The units are converted to provide a dose rate in rad/day and a concentration in water with units of pCi/L. The dose rate equation is modified, below, to provide the units desired. All conversion factors are referenced from Turner, 1986.

$$D_\beta = ((5.76x10^{-4})(E_\beta)(n_\beta)(C_o)\ \mu Gy/h\ )(24\ h/day)(10^{-6}\ Gy/\mu Gy)(1\ rad/0.01\ Gy) = 1.3824x10^{-6}(E_\beta)(n_\beta)(C_o)\ rad/day. \tag{2}$$

This equation is then slightly modified with the following relationship then solved for the concentration in the water. Table A.1 of Blaylock et al., 1993, provides the Biological Concentration Factor (BCF) for Tritium as 1.0. This is defined as the ratio of the concentration of the contaminant in freshwater fish to the concentration in water at steady-state conditions. Assume that steady-state conditions exist. We then get:

$$BCF=1.0=(\text{Concentration of Tritium in Freshwater Fish (Eggs)})/(\text{Concentration of Tritium in Water}) \tag{3}$$

Let:

C_o = Concentration of tritium in the organism (Bq kg $^{-1}$ wet weight)
C_w = Concentration of the tritium in the water (Bq kg $^{-1}$ wet weight)

Then,

$$C_w = C_o$$

Then equation 2, above, becomes:

$$D_\beta = 1.3824x10^{-6}(E_\beta)(n_\beta)(C_w)\ rad/day. \tag{4}$$

Finally, solving for the concentration of tritium in the water:

$$C_w = D_\beta/((1.3824x10^{-6})(E_\beta)(n_\beta))\ Bq\ kg^{-1}\ wet\ weight \tag{5}$$

This equation is then used in the spreadsheet to calculate the concentration in water equivalent to a 1.0 rad/day dose rate limit. The following conversion will allow the concentration in water to be converted to pCi/L (this requires that the density of water, 1 g/cm ^{3} be introduced as well). All conversion factors referenced from Turner, 1986.

$$1 \text{ Bq/kg} = (1 \text{ Bq/kg})(\text{Ci}/3.7\text{x}10^{10} \text{ Bq})(\text{pCi}/10^{-12} \text{ Ci})(\text{kg}/1000 \text{ g})(1 \text{ g/cm}^3)(\text{cm}^3/9.9997\text{x}10^{-4} \text{ L}) = 27.028 \text{ pCi/L.} \quad (6)$$

This conversion was introduced into the spreadsheet as well.

The spreadsheet consists 5 columns of input. Column A defines the radionuclide being considered. Column B defines the dose rate limit desired (rad/day). Column C provides the spreadsheet with the radionuclide's average beta energy per decay (MeV). Column D is the probability of decay by a particular decay mode. 100% is equivalent to 1.0, in the case of tritium. Column E defines the concentration of the radionuclide in water (Bq/Kg). This column provides the result to the calculation. Column F converts the result in column E from units of Bq/Kg to pCi/L.

Sample Calculation:

Tritium Specific Information

E_β = 5.68E-03 MeV (Table A.1, Blaylock et al., 1993)
BCF = 1.0 (Table A.1, Blaylock et al., 1993)
D_β = 1.0 rad/day (Assumed and discussed earlier as the exposure limit for the fish eggs.)
n_β = 1 (pg. 309, Turner) The probability that tritium decays via a beta particle is 100%.

Now, substitute these values into equation (5):

$$C_W = (1.0)/((1.3824\text{x}10^{-6})(5.68\text{E-}03)(1.0)) \text{ (Bq kg}^{-1} \text{ wet weight)} = 1.2739\text{E+}08 \text{ Bq/Kg} \quad (7)$$

Lastly, using equation/conversion (6) to convert units to pCi/L:

$$C_w = (1.2739\text{E+}08 \text{ Bq/Kg})((27.028 \text{ pCi/L})/(1 \text{ Bq/kg})) = \mathbf{3.4432E+09 \text{ pCi/L}} \quad (8)$$

This answer is in agreement with the spreadsheet results.

Estimation of Tritium Dose Rate to a Fish and a Heron

Radiation doses to a pup fish and a heron exposed to tritium-contaminated water were estimated using an aquatic dose model created by Pacific Northwest Laboratory (Baker and Soldat, 1992). The external dose due to tritium in the pup fish and heron are not considered because the external dose rate factors for immersion and sediment are zero (table 2, Baker & Soldat, 1992). Consequently, tritium will not pose an external threat to an organism. Tritium will, however, expose the pup fish and heron to an internal dose due the release of beta radiation from the radioactive decay of tritium over time. Tritium is a unique radioactive threat since it is found as part of the water molecule itself. The tritium will therefore distribute itself uniformly quickly throughout the body of an organism.

Aquatic Internal Dose for the Pup Fish

The pup fish immersed in tritium-contaminated water will receive an internal radiation dose. It is assumed that the ingested tritium will become uniformly distributed in the body of the pup fish. The upper limit considered for the internal dose rate in an organism is 1.0 rad per day. The internal dose rate in rad per day is given by the following equation:

$$R_{fish} = (E_{tritium,fish})(b_{tritium,fish}) \quad (1)$$

where:

R_{fish} = Internal total-body dose rate received by the pup fish (rad/day),
$b_{tritium,fish}$ = Specific body burden of tritium in the pup fish (Ci/kg) and is found using the following equation:

$$b_{tritium,fish} = (C_{tritium})(BF_{tritium,fish})(CF) \quad (2)$$

where:

$C_{tritium}$ = concentration of tritium in water to which the pup fish is exposed (Ci/L).
$Bf_{tritium,fish}$ = 0.001 m^3/kg and represents the bioaccumulation factor for tritium in the pup fish (table 1, Baker & Soldat, 1992).
CF = conversion factor (0.001 L/m^3). This is needed only if the concentration of tritium in water is given in units of radioactivity per L.

$E_{tritium,fish}$ = Effective energy absorbed for tritium per unit activity in the pup fish (kg-rad/Ci-day) and is defined by equation 3:

$$E_{tritium,fish} = \varepsilon_{tritium,fish}\ (MeV/dis) \times 5.12E04 \quad (3)$$

where $\varepsilon_{tritium,fish}$ is equal to 0.0058 MeV per disintegration and is the effective absorbed energy for a 1.163 cm radius pup fish exposed to tritium's radioactivity (Table 2, Baker & Soldat, 1992).

Aquatic Internal Dose for the Heron

The heron will receive an internal dose from tritium via ingestion of the pup fish. The internal radiation exposure to the heron depends upon the uptake of tritium by consuming pup fish in its diet as well as the heron's ability to remove the tritium from its body after exposure. The internal dose rate received by the heron is given by the following equation:

$$R_{heron} = \{(b_{tritium,fish})(U_{fish})(f_{tritium,heron})(E_{tritium,heron})(B_{tritium,heron})\}/M_{heron} \quad (4)$$

where:

U_{fish} = intake rate of pup fish by the heron equal to 0.6 kilogram per day (table 3, Baker & Soldat, 1992).
M_{heron} = mass of heron equal to 2.39 kg,
b_{fish} = body burden of pup fish (Ci/kg) defined previously in equation 2,
$f_{tritium,heron}$ = fraction of radionuclide initially retained in total body of heron (unitless) equal to 1.0 (table 1, Baker & Soldat, 1992),
$E_{tritium,heron}$ = defined previously. The value for $\varepsilon_{tritium,heron}$ is equal to 0.0058 MeV/dis, for a heron with a 10 cm radius (Table 2, Baker & Soldat, 1992),
$B_{tritium,heron}$ = bioaccumulation factor of tritium in the heron (day) defined below:

$$B_{tritium,heron} = \{1-\exp((-\lambda_{tritium,heron})(T_e))\}/\lambda_{tritium,heron} \quad (5)$$

where equation 6 defines the effective decay constant in the heron with units of inverse days:

$$\lambda_{tritium,heron} = \{(\lambda_{biological}) + (\lambda_{radiological})\} \quad (6)$$

The parameter $\lambda_{biological} = \ln(2)/T_{biological}$ where $\lambda_{biological}$ = biological decay constant of tritium and $T_{biological}$ is the biological half-life of the tritium in equal to 10 days (Table 1, Baker & Soldat, 1992). The parameter $\lambda_{radiological} = \ln(2)/T_{radiological}$ where $\lambda_{radiological}$ = radiological decay constant of tritium and $T_{radiological}$ is the radiological half-life of tritium which is equal to 12.35 years (Table 2, Baker & Soldat, 1992). The variable T_e is defined as the exposure time or period of exposure which is assumed to be 365 days (Baker & Soldat, 1992).