PNNL-14955

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Assessment of Food Chain Pathway Parameters in Biosphere Models

Annual Progress Report for Fiscal Year 2004

B.A. Napier
K.M. Krupka
R.J. Fellows
D.A. Cataldo
M.M. Valenta
T.J. Gilmore

November 2004

Pacific Northwest National Laboratory

Proudly Operated by Battelle Since 1965

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

This document was printed on recycled paper.
(9/2003)

Technical Letter Report
PNNL-14955

Assessment of Food Chain Pathway Parameters in Biosphere Models

Annual Progress Report for Fiscal Year 2004

Prepared by:
B.A. Napier
K.M. Krupka
R.J. Fellows
D.A. Cataldo
M.M. Valenta
T.J. Gilmore

30 November 2004

Prepared by
Pacific Northwest National Laboratory
Richland, WA 99352

P. R. Reed, NRC Project Manager

Prepared for
Division of Systems Analysis and Regulatory Effectiveness
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001
NRC Job Code Y6469

Abstract

This Annual Progress Report describes the work performed and summarizes some of the key observations to date on the U.S. Nuclear Regulatory Commission's project *Assessment of Food Chain Pathway Parameters in Biosphere Models,* which was established to assess and evaluate a number of key parameters used in the food-chain models used in performance assessments of radioactive waste disposal facilities. Section 2 of this report describes activities undertaken to collect samples of soils from three regions of the United States, the Southeast, Northwest, and Southwest, and perform analyses to characterize their physical and chemical properties. Section 3 summarizes information gathered regarding agricultural practices and common and unusual crops grown in each of these three areas. Section 4 describes progress in studying radionuclide uptake in several representative crops from the three soil types in controlled laboratory conditions. Section 5 describes a range of international coordination activities undertaken by Project staff in order to support the underlying data needs of the Project. Section 6 provides a very brief summary of the status of the GENII Version 2 computer program, which is a "client" of the types of data being generated by the Project, and for which the Project will be providing training to the US NRC staff in the coming Fiscal Year. Several appendices provide additional supporting information.

Contents

Acknowledgements

The authors are particularly grateful for the technical guidance, review, and encouragement provided by Phillip R. Reed of the U.S. Nuclear Regulatory Commission. The authors would like to thank S.R. Baum, K.M. Geiszler, I.V. Kutnyakov, V.L. LeGore, M.J. Lindberg, H.T. Schaef, and T.S Vickerman (all of PNNL) for assisting with various aspects of the analyses and characterization of the groundwater and soil samples. We would also like to thank R.J. Serne, W.J. Deutsch, and their PNNL coworkers for providing written descriptions of the methods used for analysis and characterization of the groundwater and soil samples.

Acronyms

ASA	American Society of Agronomy
ASTM	American Society for Testing and Materials
CEC	cation exchange capacity
cpm	counts per minute
cps	counts per second
DDI	distilled deionized (water)
DOE	U.S. Department of Energy
DUP	duplicate sample
EPA	U.S. Environmental Protection Agency
ICP-MS	inductively coupled plasma-mass spectroscopy (spectrometer)
ICP-OES	inductively coupled plasma-optical emission spectroscopy (same as ICP-AES)
ICDD	International Center for Diffraction Data, Newtown Square, Pennsylvania
IRSE	Institute of Radiation Safety and Ecology, Kurchatov, Kazakhstan
ISTC	International Science and Technology Center
JCPDS	Joint Committee on Powder Diffraction Standards
MPA	Mayak Production Association, Ozersk, Russia
ND	not detected
PDF™	powder diffraction file
PNNL	Pacific Northwest National Laboratory
QA	quality assurance
STS	Semipalatinsk Test Site, Kazakhstan
USGS	U.S. Geological Survey
XRD	X-ray powder diffractometry analysis (commonly called X-ray diffraction)
XRF	X-ray fluorescence analysis

Units of Measure

Å	angstrom
g	gram
L	liter
M	molarity, mol/L
mg	milligram
mL	milliliter
N	Normality (of a solution), in number of gram equivalent weights of solute per liter of solution
I/I_o	relative intensity of an XRD peak to the most intense peak
wt%	weight percent
ºC	temperature in degrees Celsius [T(ºC) = T(K) – 273.15)
λ	wavelength
μ	micro (prefix, 10^{-6})
μeq	microequivalent
μg	microgram
μm	micrometer
θ	angle of incidence (Bragg angle)

1.0 Introduction

The U.S. Nuclear Regulatory Commission's project *Assessment of Food Chain Pathway Parameters in Biosphere Models* has been established to assess and evaluate a number of key parameters used in the food-chain models used in performance assessments of radioactive waste disposal facilities. The objectives of the research program are to:

- Provide data and information for the important features, events, and processes of the pathway models for use in biosphere computer codes. These codes calculate the total effective dose equivalent (TEDE) to the average member of the critical group and maximally exposed individual. This exposure is for the reference biosphere from radionuclides in the contaminated ground water release scenarios in NRC's performance assessments of waste disposal facilities and decommissioning sites,
- Reduce uncertainties in food-chain pathway analysis from the agriculture scenarios of biosphere models in performance assessment calculations,
- Provide better data and information for food-chain pathway analyses by:
    - Performing laboratory and field experiments, including integral and separate effect experiments, to evaluate the potential pathways and uptake mechanisms of plants and animals contaminated by long-lived radionuclides,
    - Presenting food-chain pathway data and information by regional and local geographical locations,
    - Quantifying uncertainties in the radioactive contamination of food crops and long-term build up of radionuclides in soils with contaminated ground water from water irrigation systems,
    - Determining data on factors affecting radionuclide uptake of food crops including irrigation water processes, soil physical and chemical properties, soil leaching and retention properties near crop roots, soil resuspension factors and other soil and plant characteristics,
    - Obtaining experimental data in both deterministic and as probabilistic distributions,
    - Determining food-chain pathway data and information for a prioritized list of radionuclides:
- Review and evaluate data and information published by the international scientific community on food-chain pathway issues.

The results of this research program will provide needed food-chain and animal product pathway data and information for important radionuclides that will be used by the NRC staff to assess dose to persons in the reference biosphere (e.g., persons who live and work in an area potentially affected by radionuclide releases) of waste disposal facilities and decommissioning sites. Data from this research program are expected to be used in biosphere models to calculate the dose from ground water release scenarios in performance assessment computer codes.

In Fiscal Year 2004, efforts were undertaken on most of these objectives. This Annual Progress Report describes the work performed and summarizes some of the key observations to date.

Section 2 of this report describes activities undertaken to collect samples of soils from three regions of the United States, the Southeast, Northwest, and Southwest, and perform analyses to characterize their physical and chemical properties. Section 3 summarizes information gathered regarding agricultural practices and common and unusual crops grown in each of these three areas. Section 4 describes progress in studying radionuclide uptake in several representative crops from the three soil types in controlled laboratory conditions. Section 5 describes a range of international coordination activities undertaken by Project staff in order to support the underlying data needs of the Project. Section 6 provides a very brief summary of the status of the GENII Version 2 computer program, which is a “client” of the types of data being generated by the Project, and for which the Project will be providing training to the US NRC staff in the coming Fiscal Year. Several appendices provide additional supporting information.

2.0 Sampling and Analysis of Groundwater and Soil Samples

Uncontaminated soil and groundwater samples were collected from 3 sites that are in the vicinity of waste disposal facilities of interest to NRC and unaffected by disposal activities at those sites. The soil and groundwater samples were collected for use in Task 4 for the plant radionuclide uptake studies. The areas for sampling include currently operating and proposed waste disposal facilities and decommissioning sites, including the commercial low-level radioactive waste (LLW) sites in the states of Washington and South Carolina.

2.1 Sampling Sites for Groundwater and Soil Samples

Three areas for soil and water samples were identified that met the objectives identified in the work plan for the "Assessment of Food Chain Pathway Parameters in Biosphere Models" project. These sites include the Hanford Site, Washington; Savannah River, South Carolina; and Nye County, Nevada. These sites are each located near a current or proposed nuclear waste disposal facility or decommissioning site, and together provide a range of soil characteristics for the radionuclide biouptake studies.

The experimental design of the uptake experiments requires approximately 300 liters of water and 0.2 cubic meters of soil from each site. The latitude and longitude position of each sampling location was recorded by using a global positioning system (GPS) unit to provide traceability and the opportunity to provide duplicate samples if required. In addition, at the one privately owned site in Nye County, Nevada, it was arranged through an agreement with the landowner that the site would be available for re-sampling should any additional material be needed.

2.1.1 Hanford Site, Washington

The sampling site for the Hanford soil and groundwater samples is located off Washington highway 240 near the area referred to as the "Yakima Barricade" at the western entrance to the U.S. Department of Energy Hanford Site in southeastern Washington State. Logistically, the sample site is easily assessable by road, and a pump is installed in the well used for groundwater sampling (Figure 2.1). The Hanford Site designation for the well is 699-49-100C, and the coordinates are North 46.577, West 119.726. The well has been used in the past for providing water to the guard shack at the Yakima Barricade (see structure in background at top of right photograph in Figure 2.1), and is still used to provide "up-gradient background" groundwater samples (i.e., water not affected by Hanford disposal activities) to the Hanford Site environmental programs. The water chemistry of the well has been well characterized, and the analyses are available through the Hanford Environmental Information System (HEIS) data base.

The Hanford soil[1] sample was collected within 100 m of the well used for the groundwater sample, and the coordinates for the location of the soil sample are North 46.5757, West 119.7259. The soil sample is a silty, very fine sand that is referred to as the McGee Ranch soil. The soil in this area has been extensively characterized, because there are plans to use this sediment as a soil covering for surface barriers on waste-disposal areas at the Hanford Site (Bechtel Hanford 2002) (Figure 2.1).

Groundwater Sampling | Soil Sampling

Figure 2.1. Locations of Groundwater and Soil Samples from the Hanford Site

2.1.2 Nye County, Nevada

The sampling site (Figure 2.2) in Nye County is located in a desert valley approximately 110 miles west of Las Vegas in the Amargosa Valley, Nevada. The soil and groundwater samples were collected from private land owned by Dave Rau. To get to the site, one must travel west from Las Vegas approximately 110 miles on Nevada highway 95. At the junction of highways 95 and 373, go south for 10 miles to Mecca Road, and then turn west and go 5.5 miles to Van Patton Drive. At this junction, one then turns south and goes to the third driveway on the west side which has the address 1658 Van Patton Drive.

---

[1] Because of its depositional history, the unconsolidated surface and near-surface geologic material at the Hanford Site is referred to as a "sediment" in Hanford Site literature.

The groundwater was collected from an irrigation well that is used to flood irrigated pastureland. The coordinates for the well used for the groundwater sample are North 36 29' 24.4", West 116 30' 51.5". The pasture was used to grow alfalfa for about 14 years up until about 1996, when it was allowed to turn to pasture. According to the land owner, the soil was originally conditioned using approximately 10 tons/acre of gypsum. No commercial fertilizer was used on the pasture.

The soil was approximately 2.5 feet thick at the sample site, and consists of a light brown silty sand. The coordinates for the site of the soil sample are North 36 29' 23.7", West 116 30' 52.0". Near the base, the occurrence of white streaks in the soil increased until the soil transitioned into broken-up calcrete.

Figure 2.2. Location in Nye County, Nevada Where Groundwater and Soil Samples were Collected

2.1.3 Savannah River Site, South Carolina

This site was selected because this soil provides a good representation of forest soil from the southeastern United States. PNNL staff also had contacts at the U.S. Department of Energy Savannah River Site who could cost-effectively provide uncontaminated groundwater and soil samples from this location. This site receives considerably more infiltration from rainfall and snowmelt, and has a soil that is expected to have a higher organic carbon content than the soil samples from Hanford and Nye County. The water samples are from well HSB-85A (Figure 2.3) at coordinates North 33 17' 6.548", West 81 39' 17.7448". The soil samples were collected near well MSB 21 TA (Figure 2.4) at coordinates North 33 19' 58.31", West 81 44' 39.2". The groundwater and soil samples were provided by J. Rossabi, who at that time worked at the Savannah River Technology Center in Aiken, South Carolina. The locations selected for the groundwater and soil samples represent “clean” groundwater and soil, which do not contain any radionuclide contamination at concentrations above natural background levels. Also, each sampling location has background data associated with it that was collected as part of the environmental monitoring program at the Savannah River Site.

Figure 2.3. Well Used for Groundwater Sample from Savannah River Site

Figure 2.4. Location Where Soil Sample Collected from Savannah River Site [Soil was sampled from surface (bottom photograph) near the feet of the person standing in the trees in the top photograph.]

2.2 Methods for Analysis and Characterization of Groundwater and Soil Samples

The following method descriptions were taken, with the permission of the lead authors, from reports published by the PNNL Applied Geology and Geochemistry Group, such as Deutsch et al. (2004) and Serne et al. (2004).

2.2.1 Analysis of Groundwater Samples

2.2.1.1 pH and Conductivity

The pH values of the groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using a solid-state pH electrode and a pH meter calibrated with buffers bracketing the expected range. This measurement is similar to *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods* SW-846 9040B (EPA 1995). Electrical conductivity was measured and compared to potassium chloride standards with a range of 0.001 M to 1.0 M. The pH and conductivity subsamples were filtered prior to analysis.

2.2.1.2 Alkalinity

The alkalinity of the groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using standard titration. A volume of standardized sulfuric acid (H_2SO_4) was added to the sample to an endpoint of pH 8.3 and then an endpoint of pH 4.5. The volume of H_2SO_4 needed to achieve each endpoint is used to calculate the phenolphthalein ($OH^- + CO_3^{2-}$) and total ($OH^- + HCO_3^- + CO_3^{2-}$) alkalinity as calcium carbonate ($CaCO_3$). The alkalinity procedure is similar to Standard Method 2320 B (Clesceri et al. 1998).

2.2.1.3 Anions

Analyses of dissolved anions in groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using an ion chromatograph. Bromide, carbonate, chloride, fluoride, nitrate, phosphate, and sulfate were separated on a Dionex AS17 column with a gradient elution technique from 1 mM to 35 mM KOH and measured using a conductivity detector. This methodology is similar to Method 9056 in *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods EPA SW-846* (EPA 1994b) with the exception of using gradient elution with NaOH.

2.2.1.4 Total Carbon

Total carbon contents of the groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using a Shimadzu Carbon analyzer Model TOC-V csn that is equipped with an autosampler. The method used of measuring the carbon content of the groundwater samples is described in PNNL Technical Procedure AGG-TOC-001 (PNNL 2004),[2] and is similar to EPA Method 9060 (Total Organic Carbon) in *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods EPA SW-846* (EPA 1986). The adequacy of the system performance was confirmed by analyzing for known quantities of a liquid carbon standard.

2.2.1.5 Cations and Trace Metals

Analyses of major cations, such as Al, Ca, Fe, K, Mg, Mn, Na, and Si, dissolved in the groundwater samples from the Hanford Site, Nye County, and Savannah were completed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) (EPA Method 6010B, EPA 1996). Trace metals analyses, including Ag, As, Cd, Cr, Mo, Pb, Ru, Se, and U, were completed by inductively coupled plasma-mass spectroscopy (ICP-MS) using a method that is similar to EPA Method 6020 (EPA 1994a). For both ICP-OES and ICP-MS, high-purity calibration standards were used to generate calibration curves and to verify continuing calibration during the analysis. Multiple dilutions of selected samples were made and analyzed to investigate and correct for matrix interferences. The ICP-MS results are reported as total element concentration in terms of the specific isotope measured. The instrument software converts the concentration of an isotope of an element to the total concentration of the element based on the distribution of isotopes in the natural environment. For example, the total Cr concentration is reported from the raw count rates for both ^{52}Cr and ^{53}Cr isotopes based on taking the raw counts and dividing by the fraction of ^{52}Cr and ^{53}Cr found in nature to yield estimates of total Cr in the sample.

2.2.2 Characterization and Analysis of Bulk Soil Samples

2.2.2.1 X-ray Diffraction

The primary crystalline minerals present in each bulk soil sample were identified using a Scintag X-ray powder diffraction (XRD) unit equipped with a Pelter thermoelectrically cooled detector and a copper X‑ray tube. The diffractometer was operated at 45 kV and 40 mA. Individual scans were obtained from 2 to 65° 2θ with a dwell time of 2 seconds. Scans were collected electronically and processed using the JADE® XRD pattern-processing software. Identification of the mineral phases in the background-subtracted patterns was based on a comparison of the XRD patterns measured for the sludge samples

---

[2] PNL. 2004. "PNNL Technical Procedure AGG-TOC-001 [Operating of Carbon Analyzer (TOC-V + SSM-5000A + ASI (Shimadzu))]." Procedure in review, Pacific Northwest National Laboratory, Richland, Washington.

with the mineral powder diffraction files (PDF™) published by the Joint Committee on Powder Diffraction Standards (JCPDS) International Center for Diffraction Data (ICDD).

2.2.2.2 Elemental Analysis by X-ray Fluorescence

At the time of this progress report, bulk elemental analysis by X-ray fluorescence (XRF) of the soil samples from the Hanford Site, Nye County, and Savannah River Site were in the sample queue for completion at the GeoAnalytical Laboratory in the Department of Geology at the Washington State University, Pullman, Washington. These analyses are being completed using an existing service contract that PNNL has established with Washington State University. The XRF analyses were originally going to be done on new, state-of-the-art XRF instrumentation purchased by the Applied Geology and Geochemistry Group at PNNL. However, delays in its installation, shakedown testing, and approval of its technical operation procedure required that the XRF analyses for these soil samples be completed elsewhere. The results of the XRF analyses will be included in the final project technical report along with the analysis and characterization results described in this progress report.

2.2.2.3 Particle Size Distribution

American Society for Testing and Materials (ASTM) procedures ASTM D1140-00 (ASTM 2000) (*Standard Test Methods for Amount of Material in Soils Finer Than the No. 200 [75 µm] Sieve*) and D422-63 (ASTM 2003a) (*Standard Test Method for Particle-Size Analysis of Soils*) were used for particle size analysis of the soil samples from the Hanford Site, Nye County, and Savannah River Site. In ASTM D422-63, a sedimentation process using a hydrometer is used to determine the distribution of particle sizes smaller than 75 µm, while sieving was used to measure the distribution of particle sizes larger than 53 µm (retained on a No. 270 sieve). A No. 10 sieve, which has sieve size openings of 2.00 mm, was first used to remove the fraction larger than "very coarse" prior to particle size analysis.

2.2.2.4 Moisture Content

Gravimetric water contents of the soil samples from the Hanford Site, Nye County, and Savannah River Site were determined using PNNL procedure PNL-MA-567-DO-1 (PNL 1990).[3] This procedure is based on the ASTM Method D2216-98 (*Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*) (ASTM 1998). One representative subsample of each soil sample was placed in tared containers, weighed, and dried in an oven at 105°C (221°C) until constant weight was achieved, which took at least 24 hours. The containers then were removed from the oven, sealed, cooled, and weighed. At least two weighings, each after a 24-hour heating, were

[3] PNL. 2000. "PNNL Technical Procedure SA-7. Water Content." Procedure approved in May 2000, in Procedures for Ground-Water Investigations, PNL-MA-567, Pacific Northwest National Laboratory, Richland, Washington.

performed to ensure that all moisture was removed. The gravimetric water content was computed as the percentage change in soil weight before and after oven drying.

2.2.2.5 Cation Exchange Capacity

The cation exchange capacity (CEC) of the soil samples from the Hanford Site, Nye County, and Savannah River Site were determined using the method described in ASA (1982). This method is particularly suited to arid land soils, including these containing carbonate, gypsum, and zeolites, This procedure involves two steps. The first step consists of saturation of the cation exchange sites with Na by reaction of the soil with pH 8.2, 60% ethanol solution of 0.4-*N* NaOAc–0.1 *N* NaCl. This is then followed by extraction of 0.5 *N* MgNO*3*. The concentrations of dissolved Na and Cl are then measured in the extracted solution so that the dissolved Na from the excess saturation solution, carried over from the saturation step to the extraction step, is deducted from the total Na. This provides amount of exchangeable Na, which is equivalent to the CEC.

2.2.2.6 Carbon Content

The total carbon and the inorganic carbon contents of the soil samples from the Hanford Site, Nye County, and Savannah River Site were measured using a Shimadzu Carbon Analyzer Model TOC-V csn. The method used to measure the carbon contents of the soil samples is described in PNNL Technical Procedure AGG-TOC-001 (PNNL 2004),[4] and is similar to ASTM Method E1915-01 (*Test Methods for Analysis of Metal Bearing Ores and Related Materials by Combustion Infrared Absorption Spectrometry*) (ASTM 2001). Known quantities of calcium carbonate standards were analyzed to verify that the instrumentation was operating properly. Inorganic carbon content was determined through calculations performed using the microgram per-sample output data and sample weights. The organic carbon content of the soil samples was calculated by subtracting the inorganic carbon contents from the respective total carbon contents for each sample.

2.2.2.7 1:1 Soil:Water Extracts

The water-soluble inorganic constituents in the soil samples from the Hanford Site, Nye County, and Savannah River Site were determined using a 1:1 soil:deionized-water extract method. The extracts were prepared by adding an exact weight of deionized water to approximately 60 to 80 g of soil subsample. The weight of deionized water needed was calculated based on the weight of the field-moist samples and their previously determined moisture contents. The sum of the existing moisture (porewater) and the deionized water was fixed at the mass of the dry soil. The appropriate amount of deionized water was added to screw cap jars containing the soil samples. The jars were sealed and briefly shaken by hand, then placed on a mechanical orbital shaker for one hour. The samples were allowed to settle until the supernatant liquid was fairly clear.

---

[4] PNL. 2004. "PNNL Technical Procedure AGG-TOC-001 [Operating of Carbon Analyzer (TOC-V + SSM-5000A + ASI (Shimadzu))]." Procedure in review, Pacific Northwest National Laboratory, Richland, Washington.

The supernatant was carefully decanted and separated into unfiltered aliquots for conductivity and pH determinations, and filtered aliquots (passed through 0.45 µm membranes) for anion, carbon, and cation analyses. More details can be found in Rhoades (1996) and within *Methods of Soils Analysis - Part 3* (ASA 1996). The methods used for the pH, conductivity, anion, carbon, and cation analyses are the same as those described above for the analysis of the groundwater samples. The results for the analyses of the 1:1 soil:water extracts for the three soil samples are reported in terms of both units per gram of soil and units per milliliter of pore water. This conversion is based on a soil-to-water ratio of 1.0.

2.3 Results of Analyses and Characterization of Groundwater and Soil Samples

Table 2.1 lists the tables and figures that contain the results of the analyses and characterization studies of the groundwater, soil, and 1:1 soil:water extract samples from the Hanford Site, Nye County, and Savannah River Site.

In the following tables, analyses are listed for primary and duplicate samples of one of the three groundwater, soil, and 1:1 soil:water extract samples. A duplicate sample is selected at random when a set of samples is submitted for analyses as part of the standard laboratory quality-assurance operating procedures used by the analytical laboratories in the PNNL Applied Geology and Geochemistry Group.

The background-subtracted XRD patterns for the Hanford Site, Nye County, and Savannah River Site soil samples are shown in Figure 2.5, Figure 2.6, and Figure 2., respectively. Each XRD pattern is shown as a function of degrees 2θ based on Cu K_{α} radiation (λ=1.5406 Å). The vertical axis in each pattern represents the intensity in counts per second (cps) of the XRD peaks. In order to conveniently scale the XRD patterns on the vertical axes and visualize the minor XRD peaks, it was necessary to cutoff the intensity of the most intense XRD peak in each pattern. These intensity cutoffs are labeled on each XRD pattern, and correspond to the largest XRD peak for feldspar for the Hanford Site soil sample, and for quartz for the Nye County and Savannah River Site soil samples.

At the bottom of each XRD pattern, one or more schematic database (PDF) patterns considered for phase identification are also shown for comparison purposes. The height of each line in the schematic PDF patterns represents the relative intensity of an XRD peak (i.e., the most intense [the highest] peak has a relative intensity [I/I_o] of 100%). As noted previously, a crystalline phase typically must be present at greater than 5 wt% of the total sample mass (greater than 1 wt% under optimum conditions) to be readily detected by XRD.

Table 2.1. Tables and Figures Containing the Results of the Analyses and Characterization Studies of the Groundwater, Soil, and 1:1 Soil:Water Extract Samples from the Hanford Site, Nye County, and Savannah River Site

Type of Sample	Table or Figure Numbers	Results Reported
Groundwater Samples	Table 2.2	pH and Conductivity
	Table 2.3	Alkalinity at pH 8.3 and 4.5 Endpoints
	Table 2.4	Dissolved Anions by IC
	Table 2.5	Total Dissolved Carbon
	Table 2.6	Dissolved Macro and Trace Elements by ICP-OES
	Table 2.7 and Table 2.8	Dissolved Trace Metals by ICP-MS
Soil Samples	Figure 2.5, Figure 2.6, and Figure 2.7	XRD for Hanford Site, Nye County, and Savannah River Site Samples, Respectively
	Table 2.9	Particle Size of Bulk Solid
	Table 2.10	Moisture Content
	Table 2.11	Cation Exchange Capacity (CEC)
	Table 2.12	Contents of Total, Inorganic, and Organic Carbon
1:1 Soil:Water Extracts	Table 2.13	pH and Conductivity
	Table 2.14	Alkalinity at pH 8.3 and 4.5 Endpoints
	Table 2.15	Dissolved Anions by IC
	Table 2.16 and Table 2.17	Dissolved Macro and Trace Elements by ICP-OES
	Table 2.18 and Table 2.19	Dissolved Trace Metals by ICP-MS

The following minerals were identified in the soil samples (see Figure 2.5, Figure 2.6, and Figure 2.):

- Hanford Site soil – quartz, plagioclase feldspar, microcline feldspar, amphibole, chlorite, and mica
- Nye County soil - quartz, plagioclase feldspar, microcline feldspar, amphibole, zeolite, and mica
- Savannah River Site soil - quartz

More detailed analyses would be required to refine the identities of the general mineral identifications (e.g., plagioclase, amphibole, zeolite, mica, etc.) to specific compositions. The soil sample from Nye County appears to contain a zeolite mineral. Although the pattern for this soil sample (Figure 2.) was a good match to the database pattern for clinoptilolite (PDF 47-1870), other compositions of zeolites may also match this pattern. Several reflections (i.e., 16.62, 25.50, and 33.44 °2θ) in the XRD pattern for soil from the Savannah River Site could not be identified. Additional XRD patterns measured at slower scanning rates would be needed to identify the minerals associated with these reflections.

Table 2.2. pH and Conductivity Values for the Groundwater Samples

Groundwater Samples	pH	Conductivity (mS/cm)
Hanford Site	8.43	0.544
Hanford Site (duplicate)	8.35	0.543
Nye County	8.42	0.197
Savannah River Site	8.75	1.052

Table 2.3. Alkalinity Values for the Groundwater Samples

Groundwater Samples	Alkalinity at pH 8.3 Endpoint	Total Alkalinity at pH 4.5 Endpoint
	(mg $CaCO_3$/L)	
Hanford Site	0.0*	168.36
Hanford Site (duplicate)	0.0	167.63
Nye County	15.372	290.60
Savannah River Site	0.0	81.984

* Alkalinity values of 0.0 mg $CaCO_3$/L at the pH 8.3 endpoint indicate that the starting pH values of the respective groundwater samples were near or less than pH 8.3.

Table 2.4. Concentrations of Dissolved Anions in the Groundwater Samples

Groundwater Samples	Br^-	CO_3^{2-}	Cl^-	F^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
	(µg/mL)						
Hanford Site	<0.48	222.7	20.07	0.42	13.76	<0.51	79.75
Hanford Site (duplicate)	<0.48	220.9	20.00	0.42	13.66	<0.51	79.49
Nye County	<0.48	389.1	44.96	5.91	2.47	<0.51	187.0
Savannah River Site	<0.48	59.38	2.60	0.09	<0.43	<0.51	5.29

Table 2.5. Concentrations of Total Dissolved Carbon in the Groundwater Samples

Groundwater Samples	Total Dissolved Carbon		
	#1	#2	Average
	(mg/L)		
Hanford Site	39.85	40.14	40.00
Nye County	68.40	68.33	68.37
Savannah River Site	17.83	17.74	17.79

Table 2.6. Concentrations of Dissolved Macro and Trace Metals in the Groundwater Samples as Determined by ICP-OES

Groundwater Samples	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr
	(µg/L)									
Hanford Site	ND	<1.3E+02	<1.3E+02	1.8E+02	<6.3E+01	ND	5.8E+04	ND	<2.5E+01	<6.3E+01
Hanford Site (duplicate)	ND	<1.3E+02	<1.3E+02	1.5E+02	<6.3E+01	ND	5.9E+04	ND	<2.5E+01	<6.3E+01
Nye County	ND	<1.3E+02	8.8E+02	8.1E+01	<6.3E+01	ND	1.9E+04	ND	<2.5E+01	<6.3E+01
Savannah River Site	ND	<1.3E+02	<1.3E+02	6.3E+01	<6.3E+01	ND	3.3E+04	ND	ND	<6.3E+01
	Cu	**Fe**	**K**	**Li**	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**P**
	(µg/L)									
Hanford Site	<2.5E+02	<2.5E+01	7.6E+03	<2.5E+03	2.2E+04	ND	<2.5E+01	2.4E+04	<2.5E+01	<3.1E+02
Hanford Site (duplicate)	<2.5E+02	<2.5E+01	7.7E+03	<2.5E+03	2.2E+04	ND	ND	2.4E+04	<2.5E+01	<3.1E+02
Nye County	<2.5E+02	<2.5E+01	1.4E+04	<2.5E+03	1.7E+04	ND	<2.5E+01	2.1E+05	<2.5E+01	<3.1E+02
Savannah River Site	<2.5E+02	<2.5E+01	<1.3E+03	<2.5E+03	8.2E+02	ND	<2.5E+01	1.7E+03	<2.5E+01	<3.1E+02
	Pb	**S**	**Se**	**Si**	**Sr**	**Ti**	**Tl**	**V**	**Zn**	**Zr**
	(µg/L)									
Hanford Site	ND	ND	<5.0E+02	2.9E+04	2.3E+02	ND	ND	<2.5E+02	3.7E+02	<2.5E+01
Hanford Site (duplicate)	ND	ND	<5.0E+02	2.9E+04	2.3E+02	ND	ND	<2.5E+02	3.5E+02	ND
Nye County	ND	ND	<5.0E+02	2.2E+04	5.3E+02	ND	ND	ND	<6.3E+01	ND
Savannah River Site	ND	ND	<5.0E+02	1.3E+04	8.5E+01	ND	ND	<2.5E+02	<6.3E+01	<2.5E+01

Table 2.7. Concentrations of Dissolved Trace Metals in the Groundwater Samples as Determined by ICP-MS

Groundwater Samples	Ag – total based on		As – total based on	Cd – total based on		Cr – total based on	
	^{107}Ag	^{109}Ag	^{75}As	^{111}Cd	^{114}Cd	^{52}Cr	^{53}Cr
	(µg/L)						
Hanford Site	<1.25E-01	<1.25E-01	2.51E+00	<5.00E-01	<5.00E-02	2.05E+00	2.24E+00
Hanford Site (duplicate)	<1.25E-01	<1.25E-01	2.85E+00	<5.00E-01	<5.00E-02	1.99E+00	2.55E+00
Nye County	<1.25E-01	<1.25E-01	4.02E+01	<5.00E-01	<5.00E-02	<1.25E+00	1.53E+00
Savannah River Site	<1.25E-01	<1.25E-01	<2.50E+00	<5.00E-01	<5.00E-02	<1.25E+00	1.28E+00

Table 2.8. Concentrations of Dissolved Trace Metals in the Groundwater Samples as Determined by ICP-MS (Continued)

Groundwater Samples	Mo – total based on		Pb – total based on		Ru – total based on		Se – total based on	U – total based on
	^{95}Mo	^{98}Mo	^{206}Pb	^{208}Pb	^{101}Ru	^{102}Ru	^{82}Se	^{238}U
	(µg/L)							
Hanford Site	<2.50E+00	1.26E+00	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<2.50E+01	2.32E+00
Hanford Site (duplicate)	<2.50E+00	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<2.50E+01	2.30E+00
Nye County	1.34E+01	1.24E+01	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<2.50E+01	3.78E+00
Savannah River Site	<2.50E+00	<1.25E+00	<1.25E+00	1.32E+00	<1.25E+00	<1.25E+00	<2.50E+01	<5.00E-02

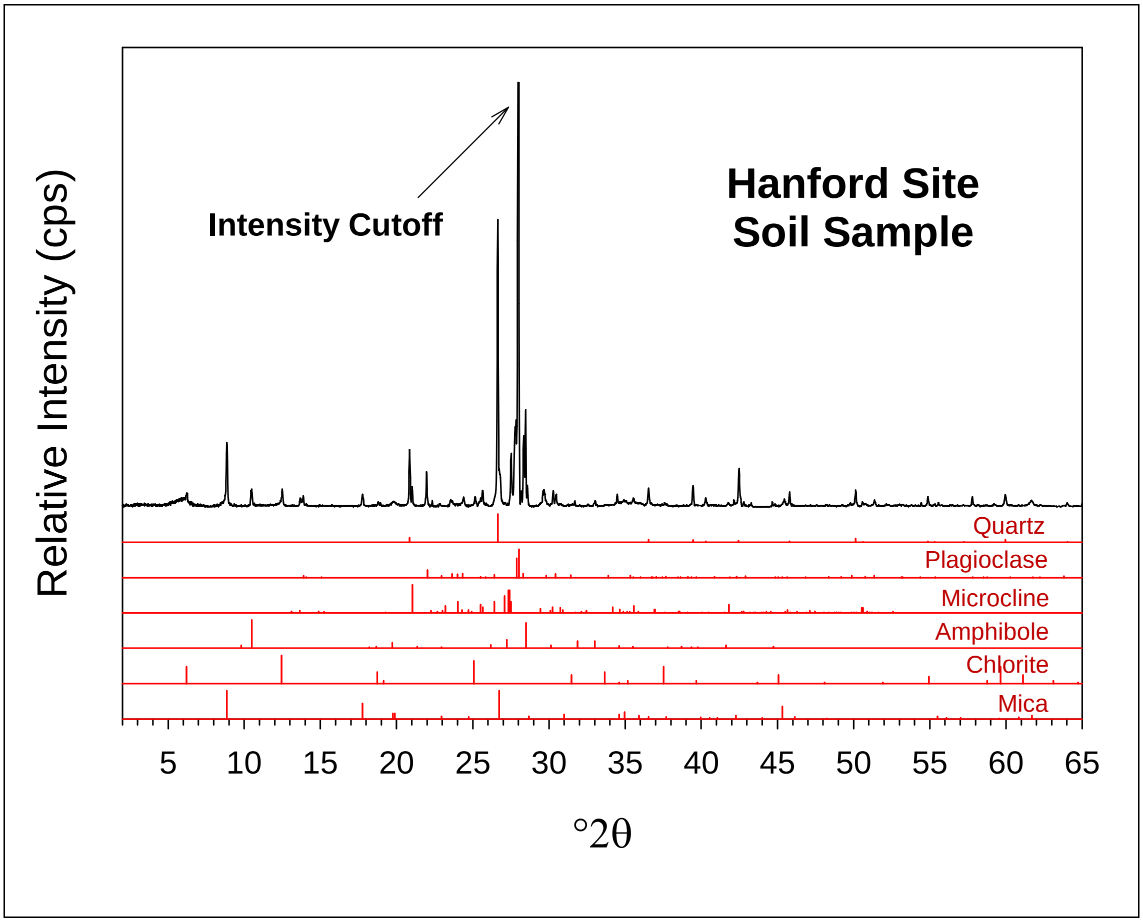


Figure 2.5. Background-Subtracted XRD Pattern for Hanford Site Soil Sample

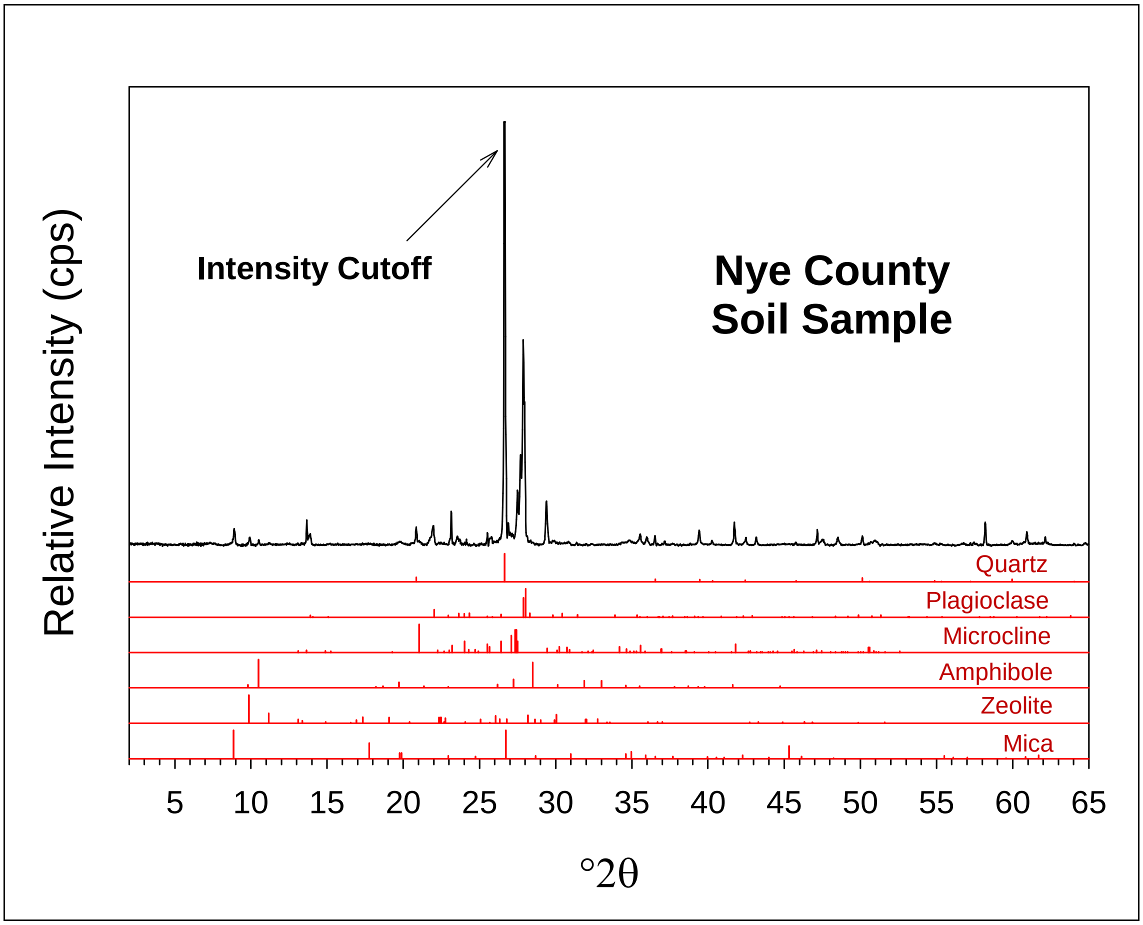


Figure 2.6. Background-Subtracted XRD Pattern for Nye County Soil Sample

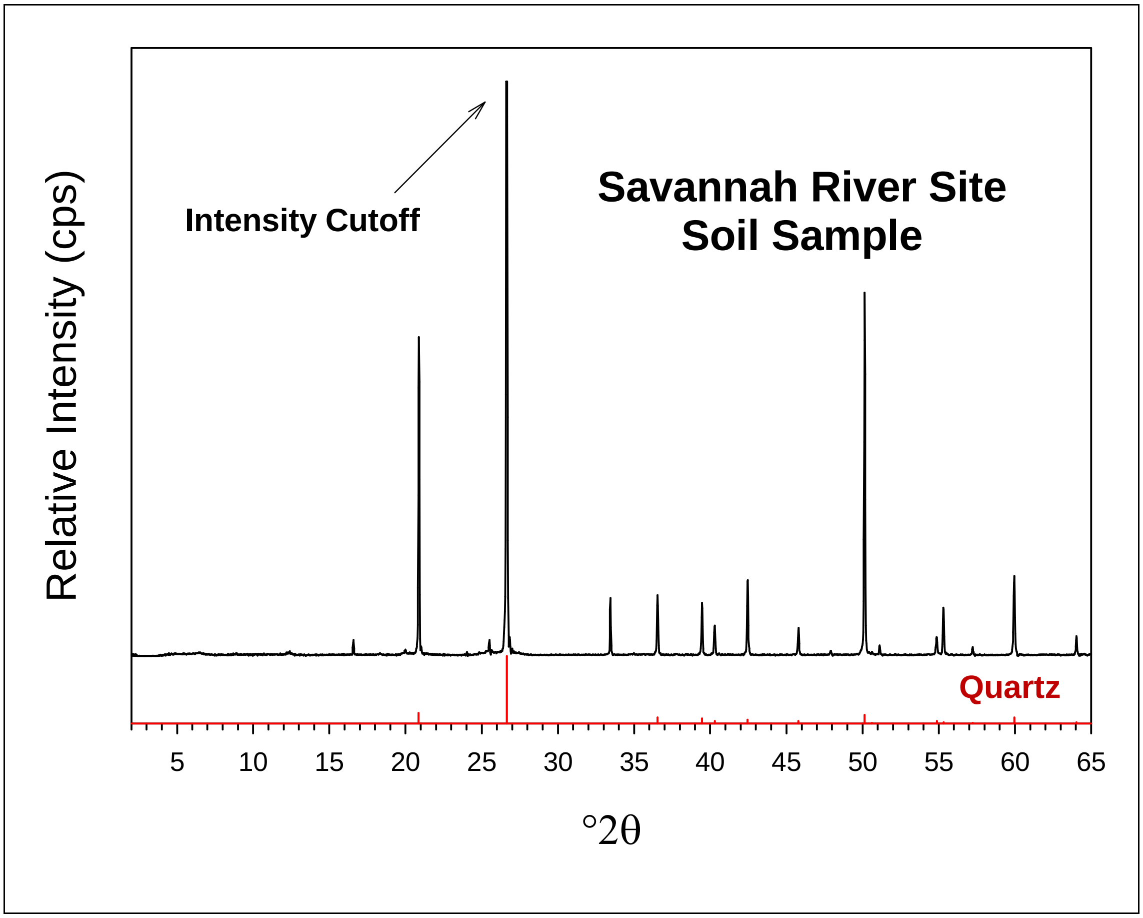


Figure 2.7. Background-Subtracted XRD Pattern for Savannah River Site Soil Sample

Table 2.9. Particle Size Analysis of the Bulk Soil Samples

Soil Samples	Gravel (x > 2 mm)	Sand (2 > x > 0.050 mm)	Silt/Clay (x < 0.050 mm)
	(wt%)		
Hanford Site	0.0	82.92	17.08
Nye County	0.0	98.99	1.01
Savannah River Site	0.0	97.01	2.99

Table 2.10. Moisture Contents of the Bulk Soil Samples

Soils	Moisture (wt%)	
	First Weighing	Second Weighing
Hanford Site	2.49	2.39
Nye County	2.51	2.30
Nye County (duplicate)	2.57	2.38
Savannah River Site	0.25	0.21

Table 2.11. Cation Exchange Capacity (CEC) Values for the Soil Samples

Soils	CEC (meq/100 g)			
	#1	#2	#3	Average
Hanford Site	38.2	35.1	ND*	36.7
Nye County	27.3	28.5	29.3	28.4
Savannah River Site	26.8	22.4	ND*	24.6

* ND – Third analysis of CEC not determined for these soil samples.

Table 2.12. Carbon Contents of the Soil Samples

Soil	Total Carbon			Total Inorganic Carbon			Total Inorganic Carbon As $CaCO_3$	Total Organic Carbon (by difference)
	#1	#2	Ave	#1	#2	Ave	Ave	Ave
	(wt%)							
Hanford Site	0.36	0.36	0.36	0.09	0.09	0.09	0.72	0.27
Nye County	1.10	1.08	1.09	0.97	0.98	0.97	8.11	0.12
Nye County (duplicate)	1.38	1.38	1.38	1.26	1.22	1.24	10.31	0.14
Savannah River Site	0.63	0.63	0.63	0.0	0.0	0.0	0.0	0.63

Table 2.13. pH and Conductivity Values for the 1:1 Soil:Water Extracts

1:1 Soil:Water Extracts	pH	Conductivity (mS/cm)	Conductivity (mS/cm) Dilution Corrected (in Pore Water)
Hanford Site	7.48	0.184	7.38
Nye County	8.07	0.400	15.94
Nye County (duplicate)	8.14	0.407	15.85
Savannah River Site	4.46	0.303	120.90

Table 2.14. Alkalinity Values for the 1:1 Soil:Water Extracts

1:1 Soil:Water Extracts	Akalinity at pH 8.3 Endpoint	Total Alkalinity at pH 4.5 Endpoint	Porewater Total Alkalinity at pH 4.5 Endpoint Dilution Corrected (in Pore Water)
	(mg $CaCO_3$/L)		
Hanford Site	0.0*	85.644	3436.0
Nye County	6.588	137.61	5485.7
Nye County (duplicate)	5.124	142.74	5557.3
Savannah River Site	0.0*	10.248	4088.9

* Alkalinity values of 0.0 mg $CaCO_3$/L at the pH 8.3 endpoint indicate that the starting pH values of the respective extract samples were near or less than pH 8.3.

Table 2.15. Concentrations of Dissolved Anions in 1:1 Soil:Water Extract

1:1 Soil:Water Extracts	**Br^-**	**CO_3^{2-}**	**Cl^-**	**F^-**	**NO_3^-**	**SO_4^{2-}**
	(µg/g soil)					
Hanford Site	<0.48	70.36	<0.236	0.16	2.50	1.36
Nye County	<0.48	161.8	6.86	7.03	5.57	30.81
Nye County (duplicate)	<0.48	162.0	6.92	7.07	5.20	30.69
Savannah River Site	<0.48	<50.00	2.85	5.53	2.22	29.22
	(µg/mL pore water)					
Hanford Site	<19.30	2,823	<9.452	6.62	100.3	54.63
Nye County	<19.17	6,446	273.5	280.4	222.0	1,228
Nye County (duplicate)	<18.73	6,307	269.5	275.2	202.3	1,195
Savannah River Site	<191.9	<19,950	1,136	2,205	886.8	11,660
See dilution factors in another table – 40.12, 39.86, 38.93, and 399.00 Dilution factor corrected - µg in water extract per mL Pore Water						

Table 2.16. Concentrations (µg/g soil) of Dissolved Macro and Trace Metals in the 1:1 Water Extracts as Determined by ICP-OES

1:1 Soil:Water Extracts	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr
	(µg/g soil)									
Hanford Site	ND	ND	<2.5E+02	<1.2E-01	<2.5E-01	<1.2E+00	2.10E+01	ND	<6.2E-01	<1.2E-01
Nye County	<5.0E-01	ND	<2.5E+02	<1.3E-01	<2.5E-01	<1.3E+00	5.40E+00	ND	<6.3E-01	<1.3E-01
Nye County (duplicate)	<5.0E-01	<5.0E+00	<2.5E+02	<1.3E-01	<2.5E-01	<1.3E+00	5.64E+00	ND	<6.3E-01	<1.3E-01
Savannah River Site	1.23E+01	ND	<2.5E+02	4.20E-01	<2.5E-01	<1.2E+00	1.98E+01	ND	<6.2E-01	<1.2E-01
	Cu	**Fe**	**K**	**Li**	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**P**
	(µg/g soil)									
Hanford Site	<2.5E+00	<5.0E-01	<6.2E+01	<1.2E+00	5.19E+00	ND	<2.5E-01	<2.5E+00	<1.2E+00	<6.2E+00
Nye County	<2.5E+00	<5.0E-01	<6.3E+01	<1.3E+00	2.44E+00	ND	ND	8.20E+01	<1.3E+00	<6.3E+00
Nye County (duplicate)	<2.5E+00	<5.0E-01	<6.3E+01	<1.3E+00	2.38E+00	ND	<2.5E-01	8.36E+01	<1.3E+00	<6.3E+00
Savannah River Site	<2.5E+00	1.70E+00	<6.2E+01	<1.2E+00	3.31E+00	2.71E+01	ND	<2.5E+00	<1.2E+00	<6.2E+00
	Pb	**S**	**Se**	**Si**	**Sr**	**Ti**	**V**	**Zn**	**Zr**	
	(µg/g soil)									
Hanford Site	ND	<1.0E+01	ND	<2.5E+01	7.89E-02	<2.5E-01	ND	<1.2E-01	ND	
Nye County	<1.3E+00	1.15E+01	ND	<2.5E+01	5.79E-02	<2.5E-01	<2.5E+00	1.65E-01	<2.5E-01	
Nye County (duplicate)	ND	1.11E+01	ND	<2.5E+01	5.99E-02	ND	<2.5E+00	<1.3E-01	ND	
Savannah River Site	<1.2E+00	1.26E+01	<5.0E+00	<2.5E+01	1.23E-01	<2.5E-01	<2.5E+00	2.68E-01	<2.5E-01	

Table 2.17. Concentrations (µg/L pore water) of Dissolved Macro and Trace Metals in the 1:1 Water Extracts as Determined by ICP-OES

1:1 Soil:Water Extracts	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr
	(µg/L pore water)									
Hanford Site	ND	ND	<1.0E+07	<5.0E+03	<1.0E+04	<5.0E+04	8.44E+05	ND	<2.5E+04	<5.0E+03
Nye County	<2.0E+04	ND	<1.0E+07	<5.0E+03	<1.0E+04	<5.0E+04	2.15E+05	ND	<2.5E+04	<5.0E+03
Nye County (duplicate)	<1.9E+04	<1.9E+05	<9.7E+06	<4.9E+03	<9.7E+03	<4.9E+04	2.20E+05	ND	<2.4E+04	<4.9E+03
Savannah River Site	4.92E+06	ND	<1.0E+08	1.68E+05	<1.0E+05	<5.0E+05	7.91E+06	ND	<2.5E+05	<5.0E+04

	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P
	(µg/L pore water)									
Hanford Site	<1.0E+05	<2.0E+04	<2.5E+06	<5.0E+04	2.08E+05	ND	<1.0E+04	<1.0E+05	<5.0E+04	<2.5E+05
Nye County	<1.0E+05	<2.0E+04	<2.5E+06	<5.0E+04	9.74E+04	ND	ND	3.27E+06	<5.0E+04	<2.5E+05
Nye County (duplicate)	<9.7E+04	<1.9E+04	<2.4E+06	<4.9E+04	9.25E+04	ND	<9.7E+03	3.26E+06	<4.9E+04	<2.4E+05
Savannah River Site	<1.0E+06	6.78E+05	<2.5E+07	<5.0E+05	1.32E+06	1.08E+07	ND	<1.0E+06	<5.0E+05	<2.5E+06

	Pb	S	Se	Si	Sr	Ti	V	Zn	Zr	
	(µg/L pore water)									
Hanford Site	ND	<4.0E+05	ND	<1.0E+06	3.17E+03	<1.0E+04	ND	<5.0E+03	ND	
Nye County	<5.0E+04	4.56E+05	ND	<1.0E+06	2.31E+03	<1.0E+04	<1.0E+05	6.57E+03	<1.0E+04	
Nye County (duplicate)	ND	4.34E+05	ND	<9.7E+05	2.33E+03	ND	<9.7E+04	<4.9E+03	ND	
Savannah River Site	<5.0E+05	5.03E+06	<2.0E+06	<1.0E+07	4.90E+04	<1.0E+05	<1.0E+06	1.07E+05	<1.0E+05	

Table 2.18. Concentrations of Dissolved Macro and Trace Metals in 1:1 Water:Extracts as Determined by ICP-MS

1:1 Soil:Water Extracts	**Ag – total based on**	**As – total based on**	**Cd – total based on**		**Cr – total based on**		**Mo – total based on**	
	^{109}Ag	**^{75}As**	**^{111}Cd**	**^{114}Cd**	**^{52}Cr**	**^{53}Cr**	**^{97}Mo**	**^{98}Mo**
	(µg/g soil)							
Hanford Site	2.09E-04	7.02E-03	<1.25E-04	<1.25E-04	<2.50E-03	<5.00E-03	2.35E-03	2.35E-03
Nye County	8.07E-05	3.94E-02	1.63E-04*	1.41E-04*	<2.50E-03	<5.00E-03	1.31E-02	1.33E-02
Nye County (duplicate)	6.12E-05	3.89E-02	<1.25E-04*	<1.25E-04*	<2.50E-03	<5.00E-03	1.37E-02	1.39E-02
Savannah River Site	<5.00E-05	1.21E-03	5.98E-04	5.41E-04	<2.50E-03	<5.00E-03	<5.00E-04	<5.00E-04
	(µg/L pore water)							
Hanford Site	8.40E+00	2.82E+02	<5.01E+00	<5.01E+00	<1.00E+02	<2.01E+02	9.42E+01	9.42E+01
Nye County	3.22E+00	1.57E+03	6.50E+00*	5.62E+00*	<9.97E+01	<1.99E+02	5.24E+02	5.31E+02
Nye County (duplicate)	2.38E+00	1.51E+03	<4.87E+00*	<4.87E+00*	<9.73E+01	<1.95E+02	5.34E+02	5.43E+02
Savannah River Site	<1.99E+01	4.84E+02	2.39E+02	2.16E+02	<9.97E+02	<1.99E+03	<1.99E+02	<1.99E+02

* Indicated values for each respective cadmium isotope are suspect because the values for the primary and duplicate extract samples are too dissimilar.

Table 2.19. Concentrations of Dissolved Trace Elements in 1:1 Water:Extracts as Determined by ICP-MS (Continued)

1:1 Soil:Water Extracts	Pb – total based on		Ru – total based on		Se – total based on	U – total based on
	^{206}Pb	^{208}Pb	^{101}Ru	^{102}Ru	^{82}Se	^{238}U
	(µg/g soil)					
Hanford Site	<1.25E-03	<2.50E-03	<5.00E-05	<5.00E-05	<5.00E-03	1.93E-04
Nye County	<1.25E-03	<2.50E-03	<5.00E-05	<5.00E-05	<5.00E-03	1.92E-03
Nye County (duplicate)	<1.25E-03	<2.50E-03	<5.00E-05	<5.00E-05	<5.00E-03	2.07E-03
Savannah River Site	5.66E-03	6.07E-03	<5.00E-05	<5.00E-05	<5.00E-03	4.27E-03
	(µg/L pore water)					
Hanford Site	<5.01E+01	<1.00E+02	<2.01E+00	<2.01E+00	<2.01E+02	7.73E+00
Nye County	<4.98E+01	<9.97E+01	<1.99E+00	<1.99E+00	<1.99E+02	7.65E+01
Nye County (duplicate)	<4.87E+01	<9.73E+01	<1.95E+00	<1.95E+00	<1.95E+02	8.05E+01
Savannah River Site	2.26E+03	2.42E+03	<1.99E+01	<1.99E+01	<1.99E+03	1.70E+03

2.4 References for Section 2

ASA (American Society of Agronomy). 1982. *Methods of Soil Analysis. Part 2, Chemical and Microbiological Properties*. SSSA Book Series 9 (Part 2), AL Page (eds.), Soil Science Society of America, Madison, Wisconsin.

ASA (American Society of Agronomy). 1996. *Methods of Soil Analysis. Part 3, Chemical Methods*. SSSA Book Series 5, DL Sparks (eds.), Soil Science Society of America, Madison, Wisconsin.

ASTM (American Society for Testing and Materials). 1998. *Method D2216-98. Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials). 2000. *Method D1140-00. Standard Test Methods for Amount of Material in Soils Finer Than the No. 200 (75 µm) Sieve*. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials). 2001. *Method E1915-01. Test Methods for Analysis of Metal Bearing Ores and Related Materials by Combustion Infrared Absorption Spectrometry*. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials). 2003a. *Method D422-63. Standard Test Method for Particle-Size Analysis of Soils (Revised 1998).* American Society for Testing and Materials, West Conshohocken, Pennsylvania.

ASTM (American Society for Testing and Materials). 2003b. *Method D4129-98. Standard Test Method for Total and Organic Carbon in Water by High Temperature Oxidation and by Coulometric Detection*. American Society for Testing and Materials, West Conshohocken, Pennsylvania.

Clesceri LS, AE Greenberg, and AD Eaton. 1998. *Standard Methods for the Examination of Water and Wastewater, 20th Edition*. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, DC.

Deutsch WJ, KM Krupka, MJ Lindberg, KJ Cantrell, CF Brown, and HT Schaef. 2004. *Hanford Tanks 241-C-203 and 241-C-204: Residual Waste Contaminant Release Model and Supporting Data*. PNNL-14903, Pacific Northwest National Laboratory, Richland, Washington.

EPA (U.S. Environmental Protection Agency). 1984. *Method 300.0A. Test Method for the Determination of Inorganic Anions in Water by Ion Chromatography*. EPA-600/4-84-017, U.S. Environmental Protection Agency, Washington, D.C.

EPA (U.S. Environmental Protection Agency). 1986. "Method 9060. Total Organic Carbon." *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods*, EPA SW-846, Third Ed., Vol. I, Section C, Chapter 5 (Miscellaneous Test Methods), pp. 9060-1 to 9060-5, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. Available at: http://www.epa.gov/epaoswer/hazwaste/test/pdfs/9060.pdf

EPA (U.S. Environmental Protection Agency). 1994a. "Method 6020. Inductively Coupled Plasma-Mass Spectrometry." *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods*, EPA SW-846, Third Ed., Vol. I, Section A, Chapter 3 (Inorganic Analytes), pp. 6020-1 to 6020-18, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. Available at: http://www.epa.gov/epaoswer/hazwaste/test/pdfs/6020.pdf

EPA (U.S. Environmental Protection Agency). 1994b. "Method 9056. Determination of Inorganic Anions by Ion Chromatography." *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods*, EPA SW-846, Third Ed., Vol. I, Section C, Chapter 5 (Miscellaneous Test Methods), pp. 9056-1 to 9056-16, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. Available at: http://www.epa.gov/epaoswer/hazwaste/test/pdfs/9056.pdf

EPA (U.S. Environmental Protection Agency). 1995. "Method 9040B. pH Electrometric Measurement." *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods*, EPA SW-846, Third Ed., Vol. I, Section C, Chapter 8 (Methods for Determining Characteristics), pp. 9040B-1 to 9040B-5, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. Available at: http://www.epa.gov/epaoswer/hazwaste/test/pdfs/9040b.pdf

EPA (U.S. Environmental Protection Agency). 1996. "Method 6010B. Inductively Coupled Plasma-Atomic Emission Spectrometry." *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods*, EPA SW-846, Third Ed., Vol. I, Section A, Chapter 3 (Inorganic Analytes), pp. 6010B-1 to 6010B-25, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC. Available at: http://www.epa.gov/epaoswer/hazwaste/test/pdfs/6010b.pdf

Rhoades JD. 1996. "Salinity: Electrical Conductivity and Total Dissolved Solids." *Methods of Soil Analysis*, Part 3, JM Bigham (ed.), pp. 417-435. American Society of Agronomy, Madison, Wisconsin.

Serne RJ, BN Bjornstad, DG Horton, DC Lanigan, CW Lindenmeier, MJ Lindberg, RE Clayton, VL LeGore, RD Orr, IV Kutnyakov, SR Baum, KN Geiszler, MM Valenta, and TS Vickerman. 2004. *Characterization of Vadose Zone Sediments Below the TX Tank Farm: Boreholes C3830, C3831, C3832 and RCRA Borehole 299 W10-27*. PNNL-14594, Pacific Northwest National Laboratory, Richland, Washington.

USGS (United States Geological Survey). 2001. "Alkalinity and Acid Neutralizing Capacity." *National Field Manual for the Collection of Water-Quality Data*, Second Ed., SA Rounds and FD Wilde (eds.), United States Geological Survey, Washington, DC. Available URL:
http://water.usgs.gov/owq/FieldManual/Chapter6/section6.6/html/section6.6.htm

3.0 Agricultural Practices at the 3 Sites

A review has been conducted of site-specific characteristics and information on agricultural and gardening practices in the area of each of the soil and groundwater sampling sites. This information has been summarized from information gleaned from literature surveys, environmental impact statements, recent census data, area agricultural extension agencies, and site visits.

3.1 Washington

Agricultural practice information is based on current conditions in the south central part of eastern Washington, encompassing the Columbia Basin and Yakima Valley. Most of the following information is derived from the 2002 Census of Agriculture data for Benton, Franklin, Grant, and Yakima Counties (NASS 2002b; 2002c; 2002d; 2002e), monitoring and analysis information from the Department of Energy's Hanford Site (Schreckhise et al. 1993; Rittmann 2004), and a Land Use Census prepared for the Washington Public Power Supply System (now called Energy Northwest) (McDonald 1989). The information was compiled by DOE contractors by combining historical information with available government statistics. No surveys of farming practices or individual consumption patterns have been performed by DOE contractors for this region in several decades.

This area is one of the most productive farming regions in the United States. The area ranks first in the nation in production of apples and hops, and is in the top 10 for production of potatoes, grapes, hay, fruits and berries, sweet corn, and pigeons. The climate is semi-arid; the overall population density is moderate. Non-dryland agriculture, commercial and private gardens, relies on irrigation from surface water (the Columbia River via the Columbia Basin Irrigation District, with withdrawals at Grand Coulee Dam) or various smaller irrigation districts formed from the Yakima River. Some areas not served by the irrigation districts use available groundwater. Large areas far from rivers also rely on rainfall; these areas tend to lay fallow on alternate years to collect moisture. This dryland farming is primarily cattle grazing or winter wheat.

The climate of eastern Washington is semi-arid, with approximately 15 cm of precipitation per year, primarily in the winter months of November through January. Summers are hot (July monthly temperatures can average up to 30° C, a typical July averages about 25° C); winters can be cold (the coldest January average is -11° C, a typical January average is -1° C) (Stone et al. 1983).

The wide variety of agricultural products produced in eastern Washington is illustrated in Table 3.1. This information is summarized from NASS (2004b; c; d; and e) and McDonald (1989). The agricultural balance in the region is quite dynamic, and the acreage of all crops changes from year to year, but the productive nature of the region is apparent in this Table. Although the largest area is occupied by unirrigated cattle grazing and a rotating cycle of fallow land and winter wheat, the irrigated portions of the area produce a highly profitable range of products. Alfalfa hay is exported from the area to dairies in the more populated regions of Washington and Oregon. Apples and other soft tree fruits such as cherries, plums, apricots, and peaches are grown. While apples are the primary cash crop, their influence is decreasing in recent years as Red Delicious apple orchards are replaced with other crops. The region is host to the second-largest production of wine grapes in the United States; nearly 300 wineries now produce many varieties of *vitis vinifera* wines (and Concord grape production for juices and jellies is also large). A number of unusual crops are also produced. The production of the spice hops, used in beer making, is the largest in the United States, and over one-quarter of the world's output is grown in the area (hops production is also decreasing slightly, as the participants in the hops marketing association voluntarily reduce production to raise prices). Another specialty crop is mint oil (spearmint and peppermint). A wide range of vegetables is commercially grown, including sweet corn, onions, peppers, squash, beans, asparagus, and lettuce. Until recently, the region was one of the largest producers of asparagus in the United States; however, competition from South American countries is resulting in elimination of many local asparagus fields (they are largely being replaced with potatoes). Some crops are grown also for seed, such as carrot, onion, turnip, corn, radish, clover, and peas, as well as grass seed. Sugar beets have been an important crop historically; however in recent years production has been greatly curtailed because of low sugar prices. The only major commercial poultry operation is in Yakima County. Beef cattle are grazed in dryland areas throughout the region, and a number of major feed lots are also present. The dairy industry is growing through development of large commercial feeding and milking companies. Because of the productive fruit tree farming, bee keeping is also a surprisingly large activity. Franklin County is the 7^{th} largest producer of pigeons in the United States.

The predominant method of irrigation is use of overhead sprinklers. Furrow or rill irrigation was the most common method of irrigating many Columbia Basin crops until about 1985 when sprinkler irrigation began to increase dramatically. Center-pivot

Table 3.1. Agricultural activities in Washington Counties of Benton, Franklin, Grant, and Yakima within 80 km of the Columbia Generating Station, Hanford, Washington.

Crop	*Acreage*	*Livestock*	*Head*
Dryland grazing	257122	Poultry	687500
Winter Wheat	214037	Cattle	459532
Annual Fallow	188253	Dairy Cows	49971
Alfalfa	130317	Bee Colonies	28113
Corn	68271	Sheep	17748
Vegetables	62531	Pigeons	10400
Potatoes	59242		
Apples	40296		
Irrigated Grazing	40124		
Grapes	34413		
Seed Production	28370		
Sweet Corn	26593		
Hops	20929		
Mint	19696		
Tree Fruit	12880		
Melons	749		

sprinkler systems allowed higher planting density, reduced the amount of irrigation labor needed, and allowed more economical production. It is estimated that about 60% of the onions grown in the Columbia Basin are now irrigated by center-pivot systems. More recently, drip irrigation has gained popularity, with about 20 percent of today's crops irrigated by this method. Irrigation water is available from most canal-supplied systems roughly from mid-April through October. In order to conserve pumping energy, most overhead systems are now designed to use minimal pressure on movable booms. However, for fixed systems, such as those in orchards, higher pressures are needed. In many areas, the irrigation systems as also used in early spring as a form of frost protection. In these systems, water is sprayed directly onto the flowers and buds of the fruit trees, to keep the temperature of the booms and fruits above a critical damage temperature (which may be slightly below freezing). As a result, the tree fruit irrigation systems are intentionally designed to wet the fruits when operating. According to the 1998 Washington Census of Agriculture, 6220 km^2 (1,554,813 acres) were irrigated, of which 81% was sprinkler, 16% was gravity feed (furrow or rill), and 3% was drip.

Although the winters are relatively cold, spring planting and orchard growth begins often in March or Aril, so the growing season is relatively long. Historically grown in the region commercially, lettuce or spinach give two crops per year. Up to four harvests per year may be obtained from alfalfa. Most crops require irrigation for essentially the entire growing season, the exception being dryland wheat, which as noted uses a two-year water cycle. Growing and irrigation seasons for the crops currently commercially grown, and a few that may be prevalent in private gardens, are presented in Table 3.2. The lengths of the growing season are derived from information of (Schreckhise et al. 1993) and McDonald (1989).

The irrigation requirements for essentially all crops are determined by the total evapotranspiration of the growing crop plus an overwatering term. Overwatering is required to avoid accumulation of salts in the surface soil. In arid regions, the overwatering rate usually is determined by calculating the amount of water required to flush accumulated salts out of the surface soil to maintain productivity. The value of this parameter is a function of the total water requirement of the crop, and is usually on the order of 100 mm/yr (BSC 2003). The average on-farm delivery is about 1130 mm to all crops in the Columbia Basin Project. Average annual crop irrigation requirements are estimated at 830 mm. This is a difference of about 300 mm in losses, but the percentage of this approximate value that is runoff compared to deep percolation (recharge) is not known since much of the surface runoff is captured and reused (http://www.sidney.ars.usda.gov/personnel/pdfs/Irrigation%20Technologies%20Comparisons.pdf). The acreage irrigated in the Columbia Basin Project has steadily increased since the first water deliveries in the early 1950's. In the period of 1969 to 1996, the irrigated acreage increased from 480,600 acres to 622,053 acres. In 1993, the issuance of additional water service contracts and groundwater licenses was suspended by the Bureau of Reclamation. That action was taken in response to the Northwest Power Planning Council and National Marine Fisheries Service requests to halt new irrigation diversions.

Table 3.2. Growing and Irrigation Seasons for Eastern Washington Crops

Crop (Planting – Harvest Dates)		*Days*
Lawn Grass (March-October)		240
Leafy Vegetables (April - September)		
	Mint (April -July/August)	90
	Spinach (2 crops)	90
	Asparagus (March - June)	60
	Hops (May-September)	150
Other Vegetables (March – October)		
	Potatoes (March/April-August/October)	120-140
	Corn (April/May –August/September)	120-180
	Onion (March -July/September)	150-200
	Carrot (April -September)	200
Fruits (April – October)		
	Apples (April -September)	200
	Pears (April -September)	180
	Soft tree fruit (April -June/August)	90-150
	Grapes (April – September/October)	180
Grains (October – July)		
	Winter Wheat (October-July)	270
Forage (March – October)		
	Alfalfa (4 harvests)	240

While this Bureau of Reclamation moratorium is in place, CBP's irrigated acreage will remain at present levels. The volume of water delivered on a project-wide basis to farms has decreased from about 4.1 to 3.7 acre-feet/acre in the period of 1969-1996. (For only the Columbia Basin Project, this is an annual total of 2.3 million acre-feet, or about 750 billion gallons. The Washington statewide total is around 1.1 trillion gallons.). The decrease in farm deliveries over time is primarily due to a change in irrigation practices by farmers. Farmers have converted from less efficient gravity or surface methods of applying water to more efficient pressurized methods such as center-pivot sprinklers. The conversion from gravity application of water to the use of center-pivot sprinklers and other pressurized irrigation systems has increased substantially since the early 1970's.

Irrigation requirements for the crops commercially raised in eastern Washington, plus some additional crops likely to be grown in private gardens, are presented in Table 3.3. The generic annual irrigation requirements in Table 3.3 are from Schreckhise et al. (1993), and the specific ones are developed from Washington State data taken from the 1998 Census of Agriculture (http://www.nas.usda.gov/census/census97/fris/fris.htm).

The productive yield of crops is a function of weather, water supply, soil type, and amounts of fertilizer added. The average yield of several commercial and garden crops for the eastern Washington region has been estimated based on production levels

Table 3.3. Annual Irrigation Requirements for Selected Crops in Eastern Washington

Crop		*Irrigation mm/year*
Lawn Grass		1000
Leafy Vegetables		900
	Mint	760-860
	Spinach (2 crops)	640
	Asparagus	880
	Hops	760
Other Vegetables		1000
	Potatoes	640
	Sweet Corn	640
	Onion	510-610
	Carrot	560
Fruits		900
	Apples	1070
	Pears	820
	Soft tree fruit	820
	Grapes	380
Grains		0
	Winter Wheat	0-490
	Corn	730
Forage		1200
	Alfalfa (4 harvests)	700

presented in McDonald (1989) or on values reported by Rittmann (2004). These values are presented in Table 3.4. Generic values are also presented; these are taken from Schreckhise et al. (1993).

3.2 Nevada

Agricultural practice information is based on current conditions in the southern portions of Nye County, Nevada, (primarily the general areas of Beatty, Amargosa Valley, and Pahrump), with additional general information from adjacent portions of California (YMP 1997; BSC 2003). Most of the following information is derived from the 1997 “Biosphere” survey conducted for the Department of Energy’s Yucca Mountain Project (DOE 1997) or ongoing DOE monitoring programs in the area (e.g., YMP 1997; 1999). The information is consistent with, but somewhat more specific than, the 2002 Census of Agriculture data for all of Nye County (NASS 2002a). The information was compiled by DOE contractors by combining historical information, color aerial photographs of the region, and the results of field trips to the area with verification with landowners and other people knowledgeable with conditions in the region (YMP 1997).

This area is mountainous and arid; the overall population density is low and commercial agricultural activities are limited. Essentially all agriculture, commercial and private gardens, relies on irrigation from groundwater. Because of the relatively small scale of agricultural activities, the distribution of crop types varies from year to year.

Table 3.4. Estimated Average Harvested Yield of Crops for Eastern Washington

Crop		*Yield kg/m²*
Leafy Vegetables		1.5
	Mint oil	0.01*
	Asparagus	0.4
	Hops	0.2
	Lettuce	2.4
Other Vegetables		4
	Potatoes	4.8
	Sweet Corn	1.8
	Onion	4.0
	Carrot	4.3
Fruits		2
	Apples	2.7
	Pears	2.8
	Soft tree fruit	1.4
	Grapes	2.4
Grains		0.8
	Winter Wheat	0.7
	Corn	1.1
Forage		2
	Alfalfa (4 harvests)	1.4

*Mint oil is pressed from the mint leaves, and is a small fraction of the harvested mass.

Overall agricultural production has been increasing over the past several years; however, the total productivity of the area is limited by the availability of groundwater.

The climate of southern Nevada is dry, with approximately 10 cm of precipitation per year, primarily in the winter months of December through March. Summers are very hot (July monthly temperatures can average up to 40° C); winters are mild (the coolest averages are still above 0° C) (BSC 2003).

Agriculture mainly involves growing feed (e.g., alfalfa) for farm animals; however, small-scale gardening and animal husbandry are common (YMP 1997). Commercial agriculture in the Amargosa Valley farming triangle includes a dairy (approximately 5,000 cows). A fish farm operated briefly in the area (approximately 15,000 catfish and bass; YMP 1999), but it has since ceased operations. There are approximately 2,200 acres planted in alfalfa, 300 acres in other hay, 80 acres in pistachios, 9 acres in fruit trees, 10 acres in grapes, and 5 acres each in onions and garlic. The dairy is the primary livestock operation, but numerous individuals keep other small animals, including recent additions such as ostriches. These and other characteristics of commercial production within an 84-km radius of Yucca Mountain are summarized in Table 3.5 (adapted from data presented in BSC 2003). Agriculture depends entirely on irrigation, and local wells

Table 3.5. Agricultural activities within a 22,000 km^2 region of southern Nevada and southeastern California (adapted from BSC 2003)

Crop	*Acreage*	*Livestock*	*Head*
Alfalfa hay	2248	Cattle	275
Other hay	229	Milk cows	6731
Barley	127	Pigs	52
Oats	32	Sheep	3
Pistachios	80	Goats	38
Other tree fruit	9	Ostriches	157
Grapes	10	Poultry	74
Onions	5	Catfish	15,000
Garlic	5		

provide water for household, agriculture, horticulture, and animal husbandry. There are no naturally occurring surface waters (i.e., perennial lakes and streams) in the area.

The proportions of various types of irrigation are presented in Table 3.6. In this region, alfalfa and other hays are the most common crops (YMP 1997, NASS 2002a), and dry hay used for livestock feed is produced locally and imported from outside the area (Horak and Carns 1997). Water is added to locally grown alfalfa hay and commercial feed before feeding it to animals (Horak and Carns 1997).

Irrigation methods differ among crop types. Drip irrigation often is used on orchard and gardens, and overhead sprinklers and surface irrigation often are used on fields, especially the larger commercial operations (BSC 2003). In the Amargosa Valley in 1997, about 85 percent of field crops were irrigated with overhead sprinklers and all of the fruit and nut crops were irrigated with drip systems that cause little foliar deposition (BSC 2003). This ratio differs from the Nevada statewide averages, for which about 26% is sprinklers, and 73% is rill or furrow. There is little information about the preferred methods of irrigating gardens in the Amargosa Valley, but it may be assumed that sprinkler irrigation is common.

Table 3.6. Types of irrigation in southern Nevada

Crop Type	*Sprinkler*	*Drip*	*Surface*	*No Data*	*Total*
Grains and Forage	56%		7%	1%	64%
Fruits and Nuts		1%	0.07%	3%	4%
Leafy and other Vegetables				0.01%	0.01%
To be planted	2%		3%		5%
Fallow	14%			7%	21%
Sod	4%			2%	6%
Total	76%	1%	10%	13%	100%

There is no evidence to suggest the widespread use of water treatment in this region and there is only a small quasi-municipal system where a water standard could be enforced (State of Nevada 1997).

Because of the hot summers and mild winters, the growing season is relatively long. Although not grown commercially, it would be possible to obtain 2 crops per year of vegetables such as lettuce or spinach. Up to six harvests per year may be obtained from alfalfa. All crops require irrigation for essentially the entire growing season. Growing and irrigation seasons for the crops currently commercially grown, and a few that may be prevalent in private gardens, are presented in Table 3.7. The lengths of the growing season are derived from data of (BSC 2003), with the addition of information about pistachio trees from the University of California extension service (http://cekern.ucdavis.edu/Custom_Program143/Adequate_Irrigation_in_August_Important_for_Shell_Splitting.htm).

Table 3.7. Growing and Irrigation Seasons for Southern Nevada Crops

Crop (Planting – Harvest Dates)		*Days*
Lawn Grass (All year)		365
Leafy Vegetables (February – November)		
	Lettuce (2 crops)	40-80
	Spinach (2 crops)	40-80
Other Vegetables (March – December)		
	Potatoes	100-120
	Carrots (2 crops)	70-80
	Onions (2 crops)	100-120
Fruits and Nuts (March – October)		
	Pistachios	220 (April-October)
	Other tree fruits (apples)	240
	Grapes	183
Grains (November – July)		
	Oats	160
	Barley	210-270
	Winter Wheat	210-270
Forage (January – December)		
	Alfalfa (6 harvests)	335
	Oat hay	75

The irrigation requirements for essentially all crops are determined by the total evapotranspiration of the growing crop plus an overwatering term. Overwatering is required to avoid accumulation of salts in the surface soil. In arid regions, the overwatering rate usually is determined by calculating the amount of water required to flush accumulated salts out of the surface soil to maintain productivity. The value of this parameter is a function of the total water requirement of the crop, and is usually on the order of 10 cm/yr (BSC 2003). Irrigation requirements for the crops commercially raised, plus some additional crops likely to be grown in private gardens, are presented in Table 3.8. The annual irrigation requirements in Table 4 are derived from data of (BSC 2003), with the addition of information about pistachio trees from the University of California extension service (http://cekern.ucdavis.edu/Custom_Program143/Adequate_Irrigation_in_August_Important_for_Shell_Splitting.htm). The total pistachio irrigation is approximated as the total evapotranspiration for pistachios plus the overwatering amount applied to apples by (BSC 2003).

The productive yield of crops is a function of weather, water supply, soil type, and amounts of fertilizer added. The average yield of several commercial and garden crops for the southern Nevada/southeastern California region has been estimated by BSC (2003). These values are presented in Table 3.9. The range for pistachio yield is based on generic pistachio harvests as reported at http://www.uga.edu/fruit/pistacio.htm.

Table 3.8. Annual Irrigation Requirements for Selected Crops in Southern Nevada

Crop		*Irrigation mm/year*
Lawn Grass		1610
Leafy Vegetables		
	Lettuce (per crop for 2 crops)	320-340
	Spinach (per crop for 2 crops)	240-270
Other Vegetables		
	Potatoes	840
	Carrots (per crop for 2 crops)	470-530
	Onions (per crop for 2 crops)	410-920
Fruits and Nuts		
	Pistachios	1100
	Other tree fruits (apples)	1820
	Grapes	980
Grains		
	Oats	570
	Barley	840
	Winter Wheat	940
Forage		
	Alfalfa (6 harvests)	1950
	Oat hay	460

Table 3.9. Estimated Average Harvested Yield of Crops for Southern Nevada (adapted from BSC 2003).

Crop		*Yield kg/m*^{2}
Leafy Vegetables		
	Lettuce (per crop for 2 crops)	3.25
	Spinach (per crop for 2 crops)	1.78
Other Vegetables		
	Potatoes	5.15
	Carrots (per crop for 2 crops)	3.64
	Onions (per crop for 2 crops)	4.92
Fruits and Nuts		
	Pistachios	0.17-0.28
	Other tree fruits (apples)	2.67
	Grapes	1.51
Grains		
	Oats	0.28
	Barley	0.44
	Winter Wheat	0.54
Forage		
	Alfalfa (per harvest for 6 harvests)	1.02
	Oat hay	1.87

3.3 South Carolina

Agricultural practice information is based on current conditions in the coastal plain (Low Country) areas of South Carolina as reported by the South Carolina Department of Agriculture and the Clemson University Extension Service. The information is consistent with, but somewhat more specific than, the 2002 Census of Agriculture data for Aiken and Barnwell Counties (NASS 2002f; 2002g). Local Department of Energy analyses (e.g., DOE 2000) generally use information from a land and water use survey by Hamby (1991); this information is summarized in Simpkins and Hamby (2002). Much of this information used by DOE is actually default values from NRC Regulatory Guide 1.109.

This area is relatively flat, with abundant forests. The number of farms in South Carolina is estimated at 24,000, and the average farm size in the state is 196 acres. Total cash receipts for crops and livestock in South Carolina average $1.5 billion a year. The top ten commodities in the state for cash receipts are broilers; greenhouse, nursery, and floriculture; turkeys; tobacco; cattle and calves; cotton lint and seed; eggs; milk; soybeans; and hogs. In the year 2003, the national ranks of some South Carolina crops were:

2nd in flue-cured tobacco production
3rd in peach production
6th in turkeys raised

7th in sweet potatoes production
7th in cantaloupes
8th in watermelon production

Production of peanuts is greatly increasing. South Carolina acreage increased nearly 12,000 acres in 2004. Most of the increase is coming in the newer areas of peanut production, specifically, Calhoun and Orangeburg counties. Peanut production is shifting from Virginia and North Carolina to South Carolina. Palmetto State farmers planted some 18,500 acres of peanuts in 2003, increasing to 30,000 in 2004 (Southeast Farm Press, 2004).

The growing season in all of South Carolina ranges from more than 290 days in the south to less than 190 days in the northwestern mountains. The climate of South Carolina is classified as humid subtropical except in the Blue Ridge Mountains, where it is humid continental. The state's annual average temperature varies from the mid-50's in the mountains to the low-60's along the coast. During the winter, average temperatures range from the mid-30's in the mountains to low-50's in the Lowcountry. During summer, average temperatures range from the upper 60's in the mountains to the mid-70's in the Lowcountry. South Carolina has four distinct seasons. The mountains tend to block many of the cold air masses arriving from the northwest, thus making the winters somewhat milder. Measurable snowfall may occur from 1 to 3 times in a winter in all areas except the Lowcountry, where snowfall occurs on average once every three years. Accumulations seldom remain very long on the ground except in the mountains. Tropical cyclones affect the South Carolina coast on an infrequent basis, but do provide significant influence annually through enhanced rainfall inland during the summer and fall months. Hurricanes are the most intense warm season coastal storms and are characterized by storm surge, winds, precipitation, and tornadoes. The average annual precipitation is approximately 48 inches, with an annual total in the mountains of 70 to 80 inches, an annual total in the Midlands of 42 to 47 inches and an annual total along the coast of 50 to 52 inches.

The climate is such that most agriculture does not require irrigation, except as a supplement to natural precipitation. Annual rainfall at various South Carolina cities is shown in Table 3.10.

As a result of the moister climate, irrigation is not as significant a use of water resources as it is in the western states. Irrigated land, and overall surface water and groundwater usage for irrigation in selected South Carolina counties is shown in Table 3.11. Water withdrawal for irrigation use from 203 reporting entities totaled 27,121,140,00 gallons, with 116 surface water systems accounting for 10,707,640,000 gallons and 128 groundwater systems accounting for 16,413,500,000 gallons (http://www.scdhec.net/eqc/water/pubs/wtruse2001.pdf). Compare this statewide total of 27 billion gallons with the Columbia Basin Project in Washington State, which annually uses about 750 billion gallons.

Table 3.10. Monthly Rainfall in Selected South Carolina Cities (from http://www.clemson.edu/irrig/Managmnt/Precip.htm)

Month	***Augusta***	***Columbus***	***Macon***	***Savannah***	***Charleston***	***Columbia***	***Greenville/ Spartanburg***
Jan	4.05	4.59	4.56	3.59	3.45	4.42	4.1
Feb	4.27	4.85	4.74	3.22	3.3	4.12	4.41
Mar	4.65	5.77	4.79	3.78	4.34	4.82	5.39
Apr	3.31	4.3	3.46	3.03	2.67	3.28	3.86
May	3.77	4.17	3.57	4.09	4.01	3.68	4.42
Jun	4.13	4.07	3.58	5.66	6.43	4.8	4.77
Jul	4.24	5.54	4.3	6.38	6.84	5.5	4.63
Aug	4.5	3.73	3.63	7.46	7.22	6.09	3.95
Sep	3.02	3.23	2.78	4.47	4.73	3.67	3.96
Oct	2.84	2.22	2.18	2.39	2.9	3.04	3.99
Nov	2.48	3.56	2.73	2.19	2.49	2.9	3.65
Dec	3.4	4.97	4.31	2.96	3.15	3.59	4.14
Annual	44.66	51	44.63	49.22	51.53	49.91	51.27

Many crops can be grown in the South Carolina environment. South Carolina has a "certified roadside market program" for truck farms. Crops commonly available include apples, beets, berries, cabbage, cantaloupe, cucumbers, eggplant, greens (including collard, turnip, and mustard), nectarines, okra, peaches, peanuts, pecans, peppers, plums, sweet potatoes, tomatoes, and watermelons (www.scda.state.sc.us/consumerinformation/scroadsidemarket/scroadsidemarket.htm).

Broiler chickens are the top animal product cash commodity in South Carolina. Poultry is raised in large commercial operations. Beef cattle and dairy cows are also common. South Carolina is the 8th largest producer of turkeys in the United States.

In South Carolina, cotton has the largest percentage of irrigated acreage followed by corn, land in vegetables, land in orchards, and soybeans. (Note that while 460,000 acres of soybeans are grown in the state, only 8650 of those are irrigated – less than 2%). Total land area of various irrigated crops in South Carolina are listed in Table 3.12. This is illustrated in Figure 3.1. Of the total irrigated acreage in South Carolina, 85% is sprinkler systems, 11% is drip or trickle systems, and 4% is flood or gravity systems. (South Carolina 2000 irrigation survey, http://www.clemson.edu/irrig/Survey/SURVEY00.PDF).

Most crops are only irrigated during periods of drought or during the hotter summer months. The average water application on irrigated areas is 200 mm/year. Average rates of irrigation for selected crops are given in Table 3.13. Specific values are derived from information from the 1998 Census of Agriculture (www.nass.usda.gov/census/census97/fris/fris.htm), and generic information is from Simpkins and Hamby (2002).

Table 3.11. Surface Water and Groundwater Use for Irrigation in South Carolina (DHEC 2003). Water use in millions of gallons.

County	*Surface Water*	*Groundwater*	*Total*	*Irrigated Acres*[1]
Acreage	-1			
Aiken	0	207	207	1340
Allendale	720	3,708.32	4,428.32	9350
Bamberg	543.7	526.85	1,070.55	11,585
Barnwell	87.2	53.87	141.07	5075
Beaufort	33.78	734.06	767.84	1950
Berkeley	1,300.00	21.86	1,321.86	
Calhoun	838.45	1,559.23	2,397.68	12,175
Charleston	57.3	0	57.3	950
Chester	1.85	0	1.85	335
Chesterfield	0	225.5	225.5	900
Clarendon	154	465.72	619.72	7,525
Colleton	841.5	1,930.89	2,772.39	759
Darlington	236.02	29	265.02	2,525
Dillon	0	34.9	34.9	304
Edgefield	423.95	43.3	467.25	6,735
Florence	20.74	78.56	99.3	5,100
Georgetown	648.74	0.01	648.75	985
Greenville	88.26	0	88.26	102
Greenwood	0	1.2	1.2	27
Hampton	89.66	1,408.97	1,498.63	4,715
Horry	54.99	75.52	130.51	5,040
Jasper	0	373.2	373.2	1,795
Lee	9	36	45	3,515
Lexington	212.76	692.72	905.48	11,835
Marion	0	24.94	24.94	10,599
Marlboro	210.84	256.59	467.43	1,510
Newberry	134.8	37.92	172.72	489
Oconee	317.7	0	317.7	2
Orangeburg	1,496.73	2,708.47	4,205.20	29,490
Pickens	10.8	0	10.8	250
Richland	23.5	0	23.5	1,010
Saluda	944.86	0	944.86	4,450
Spartanburg	318.77	0	318.77	3,030
Sumter	868.74	1,163.40	2,032.14	10,135
Williamsburg	3	0	3	200
York	16	15.5	31.5	285
Total	10,707.64	16,413.50	27,121.14	161,069

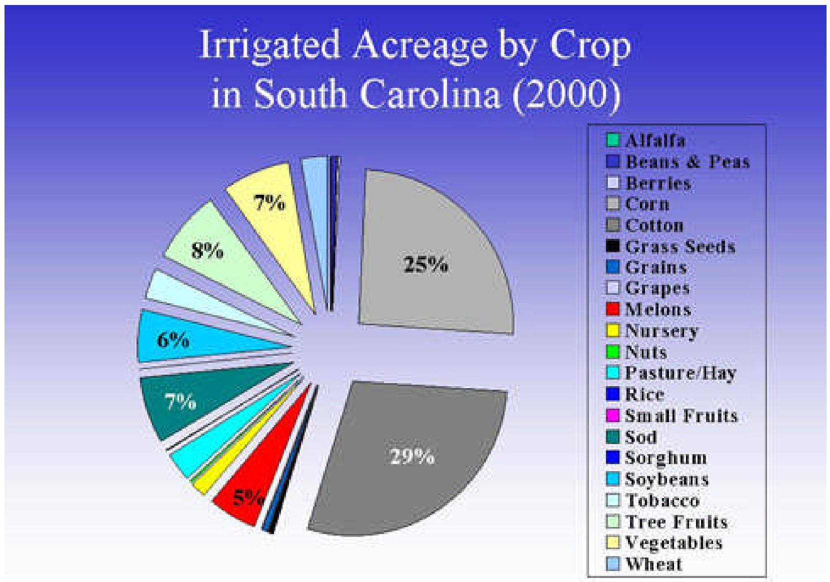
Table 3.12. Total Irrigated Crop Acreage in South Carolina in Year 2000.

Crop	*Irrigated Acres*
Alfalfa	80
Apples	64
Beans&peas	836
Berries	252.5
Corn	39245
Cotton	44400
Grass seeds	1000
Grains	800
Grapes	109.2
Lettuce	16
Melons	8298
Nursery	2676
Nuts	290
Pasture/Hay	4589
Potatoes	50
Rice	90
Small fruits	331
Sorghum	100
Soybeans	8650
Tobacco	5195
Tree fruits	12222
Vegetables	11141
Wheat	4300
Other	594

Table 3.13. Irrigation Requirements for Selected Crops in South Carolina

Crop		*Irrigation mm/year*
Leafy Vegetables		
		0.9
Other Vegetables		
	Potatoes	0.6
	Sweet Corn	0.2
	Tomatoes	0.8
Fruits and Nuts		
	Tree fruits	1.5
Grains		
	Corn	0.7
	Wheat	0.3
Forage		
	Alfalfa	0.0

Figure 3.1. Irrigated Acreage by Crop in South Carolina in Year 2000 (http://www.clemson.edu/irrig/Survey/Crop.htm).



Because South Carolina is subtropical, the growing season for most crops is quite long. The South Carolina growing season is illustrated in Figure 3.2. As is evident, some crops are grown year around. Others have distinct harvest seasons, but the plants themselves have much longer growth periods, many approaching year round.

Productivity of various crops is presented in Table 3.14. The normalized yield is presented in Table 3.15.

Figure 3.2. Crop availability in South Carolina by Month (http://www.scda.state.sc.us/consumerinformation/agfacts/agfacts.htm)

SOUTH CAROLINA PRODUCE AVAILABILITY CALENDAR

COMMODITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Apples									X	X	X	X
Butter Beans							X	X	X	X	X	
Cabbage				X	X	X						
Cantaloupes					X	X	X	X				
Cucumbers					X	X			X	X	X	
Green Onions			X	X	X	X	X	X	X	X	X	
Mixed Greens	X	X	X	X	X	X	X	X	X	X	X	X
Peaches					X	X	X	X	X			
Peanuts (Green)								X	X			
Peppers (Variety)						X	X	X	X	X	X	
Tomatoes						X	X		X	X	X	
Squash (Yellow)					X	X	X	X	X	X		
Sweet Corn					X	X	X	X				
Sweet Potatoes								X	X	X	X	X
Watermelons						X	X	X				

Table 3.14. Total production of various crops in South Carolina

	Cotton	*Soybeans*	*Oat hay*	*Oats*	*Tobacco*	*Corn*	*Wheat*
	(Bales)	(Bushels)	(Tons)	(Bushels)	(Lbx1000)	(Bushels)	(Bushels)
Abbeville	1/	7,500	17,400	1/	-	1/	22,300
Aiken	9,400	198,000	25,900	12,000	-	337,600	103,900
Allendale	6,400	379,700	2,000	27,900	-	1,178,300	550,200
Anderson	1,100	62,200	44,300	81,000	-	88,900	173,000
Bamberg	11,700	240,300	7,100	116,000	-	1,111,850	220,000
Barnwell	11,100	198,000	5,000	13,800	-	598,600	158,800
Beaufort	-	9,100	1,000	1/	-	96,200	1/
Berkeley	1,000	51,000	3,900	1/	598	380,100	29,000
Calhoun	40,500	199,200	4,400	66,700	-	990,600	311,700
Charleston	-	15,600	2,100	1/	-	122,900	1/
Cherokee	1/	19,500	13,100	1/	-	1/	20,000
Chester	3,000	1/	13,000	19,800	-	58,100	31,300
Chesterfield	800	226,600	16,800	1/	834	302,600	147,800
Clarendon	17,500	1,006,700	5,100	24,000	6,439	3,108,500	1,142,100
Colleton	2,400	215,600	11,100	69,600	698	1,330,000	129,500
Darlington	38,400	1,330,000	10,100	58,500	9,513	1,033,500	1,345,500
Dillon	25,100	1,018,800	1,800	26,000	10,362	582,600	1,101,600
Dorchester	9,000	230,100	5,300	77,600	1,260	993,300	94,500
Edgefield	4,500	42,000	8,000	1/	-	26,300	18,800
Fairfield	-	1/	7,100	1/	-	24,600	12,000
Florence	17,700	1,352,700	3,100	41,800	21,346	1,582,400	774,000
Georgetown	1,400	72,800	3,500	1/	3,126	263,100	27,600
Greenville	1/	9,900	18,800	1/	-	63,300	28,900
Greenwood	1/	1/	16,400	1/	-	21,100	1/
Hampton	22,500	244,100	4,000	24,700	-	1,097,900	369,700
Horry	1,900	1,044,500	4,800	130,000	31,195	1,800,300	632,700
Jasper	1/	12,500	3,000	1/	-	176,000	15,400
Kershaw	1,500	96,600	10,800	1/	-	118,800	57,600
Lancaster	1/	29,700	16,000	1/	-	46,900	9,500
Laurens	1/	13,000	24,400	21,600	-	49,200	38,400
Lee	40,700	893,100	4,200	1/	1,833	951,350	705,600
Lexington	4,100	227,700	24,700	59,400	-	523,600	112,500
McCormick	-	-	2,800	1/	-	1/	1/
Marion	5,600	577,100	3,300	38,000	10,244	480,400	388,000
Marlboro	48,400	687,700	5,900	42,300	1,634	248,300	493,500
Newberry	500	109,500	28,400	56,300	-	199,900	175,500
Oconee	-	35,000	26,600	1/	-	63,900	43,800
Orangeburg	54,800	732,600	19,900	257,000	-	4,293,000	988,700
Pickens	-	1/	19,500	1/	-	40,400	1/
Richland	600	276,000	7,900	1/	-	432,300	211,000
Saluda	2,100	63,600	27,400	25,600	-	74,200	114,600
Spartanburg	-	39,000	33,300	51,300	-	115,700	45,000
Sumter	14,100	1,098,700	6,300	47,600	2,795	3,063,900	973,400
Union	-	1/	9,000	1/	-	1/	1/
Williamsburg	50,600	374,800	4,400	52,300	15,487	1,873,700	244,300
York	4,700	36,400	27,100	32,600	-	33,500	41,600
Other	1,900	23,100	-	146,600	446	42,300	46,700
State Total	455,000	13,500,000	560,000	1,620,000	117,810	30,020,000	12,150,000

Table 3.15. Estimated Average Harvested Yield of Crops for South Carolina

Crop	*Yield kg/m²*
Corn	0.59
Sorghum	0.27
Wheat	0.32
Barley	0.31
Oats	0.20
Soybeans	0.15
Peas	0.14
Hay	0.46
Alfalfa	0.58
Potatoes	2.52
Sweet Potatoes	1.18
Peanuts	0.31
Cotton	0.07
Tobacco	0.26

3.4 References for Section 3

BSC (Bechtel SAIC Company) 2003. *Agricultural and Environmental Input Parameters for the Biosphere Model.* ANL-MGR-MD-000006 REV 01. Las Vegas, Nevada: Bechtel SAIC Company.

DHEC. 2002. *South Carolina Water Use Report, 2001 Summary*, South Carolina Department of Health and Environmental Control, Columbia, SC.

DOE. 2000. *High-Level Waste Tank Closure Draft Environmental Impact Statement,* DOE/EIS-0303D, Department of Energy, Savannah River Operations Office, Aiken, South Carolina.

DOE (U.S. Department of Energy) 1997. *The 1997 "Biosphere" Food Consumption Survey Summary Findings and Technical Documentation*. Las Vegas, Nevada: U.S. Department of Energy, Office of Civilian Radioactive Waste Management (available only by request).

Hamby, D.M. 1991. *Land and Water Use Characteristics in the Vicinity of the Savannah River Site*, WSCR-RP-91-17, Westinghouse Savannah River Company, Aiken, South Carolina.

Horak, C. and Carns, D. 1997. *Amargosa Focus Group Report.* Biosphere Study. Las Vegas, Nevada: University of Nevada, Las Vegas.

McDonald, J.E. 1989. *1988 50-Mile Land Use Census*, Washington Public Power Supply System, Richland, Washington.

NASS (National Agricultural Statistics Service) 2002. 2002 Census of Agriculture County Profile, Nye, Nevada.
http://www.nass.usda.gov/census/census02/profiles/nv/cp32023.PDF

NASS (National Agricultural Statistics Service) 2002. 2002 Census of Agriculture County Profile, Benton, Washington.
http://www.nass.usda.gov/census/census02/profiles/wa/cp53005.PDF

NASS (National Agricultural Statistics Service) 2002. 2002 Census of Agriculture County Profile, Franklin, Washington.
http://www.nass.usda.gov/census/census02/profiles/wa/cp53021.PDF

NASS (National Agricultural Statistics Service) 2002. 2002 Census of Agriculture County Profile, Grant, Washington.
http://www.nass.usda.gov/census/census02/profiles/wa/cp53025.PDF

NASS (National Agricultural Statistics Service) 2002. 2002 Census of Agriculture County Profile, Yakima Washington.
http://www.nass.usda.gov/census/census02/profiles/wa/cp53077.PDF

NASS (National Agricultural Statistics Service) 2002. 2002 Census of Agriculture County Profile, Aiken, South Carolina.
http://www.nass.usda.gov/census/census02/profiles/sc/cp45003.PDF

NASS (National Agricultural Statistics Service) 2002. 2002 Census of Agriculture County Profile, Barnwell, South Carolina.
http://www.nass.usda.gov/census/census02/profiles/sc/cp45011.PDF

Rittmann, P.D. 2004. *Exposure Scenarios and Unit Factors for the Hanford Tank Waste Performance Assessment*, HNF-SD-WM-TI-707 Rev. 4. Fluor Government Group, Richland, Washington.

Schreckhise, R.G., K. Rhoads, J.S. Davis, B.A. Napier, and J.V. Ramsdell. 1993. *Recommended Environmental Dose Calculation Methods and Hanford-Specific Parameters*, PNL-3777 Rev 2, Pacific Northwest Laboratory, Richland, Washington

Simpkins, A.A., and D.M. Hamby. 2002. “Uncertainty in Transport Factors Used to Calculate Historical Dose from ^{131}I Releases at the Savannah River Site,” *Health Physics*, 85 (2); 194-203.

Southeast Farm Press, *South Carolina peanut acres to expand*, April 14, 2004.

State of Nevada 1997. *Ground Water Pumpage Inventory Amargosa Valley, No. 230 1997.* Carson City, Nevada: State of Nevada, Department of Conservation and Natural Resources.

Stone, W.A., J.M. Thorp, O.P. Gifford, and D.J. Hoitink. Climatological Summary for the Hanford Area. PNL-4622, Pacific Northwest Laboratory, Richland, Washington.

YMP (Yucca Mountain Site Characterization Project) 1997. *Yucca Mountain Site Characterization Project: Summary of Socioeconomic Data Analyses Conducted in Support of the Radiological Monitoring Program, First Quarter 1996 to First Quarter 1997.* TRW Environmental Safety Systems, Inc. Las Vegas, Nevada.

YMP (Yucca Mountain Site Characterization Project) 1999. *Yucca Mountain Site Characterization Project: Summary of Socioeconomic Data Analyses Conducted in Support of the Radiological Monitoring Program, April 1998 to April 1999.* North Las Vegas, Nevada: Yucca Mountain Site Characterization Office.

4.0 Plant Studies

4.1 Introduction

The Nuclear Regulatory Commission (NRC), currently tasked with the determination of risk associated with long-term storage of nuclear waste and processing by-products at various locations within the United States, has decided that the available data for critical radioisotope uptake and transfer within crop type plants present in the current literature is inadequate for their needs. The isotopes of concern were selected based on conflicting data currently present in the literature on transfer factors. Specifically, under conditions like those to be encountered at present and future nuclear waste storage/processing facilities where material may enter the groundwater and subsequently be present in irrigation water to human crop plants.

The soil to plant pathway for transfer of radionuclides is dependent on a number of factors. These include:

a) the plant species itself;
b) the route of exposure (e.g. root versus foliar exposure)
c) the chemical nature and reactivity of the isotope as it may affect the availability of the isotope within the soil pore water or complexation with another available ligand;
d) the similarity of the isotope chemical structure to normally assimilated inorganic plant nutrients (analogues);
e) the chemical nature of the soil e.g. reducing or anaerobic conditions, soluble mineral ion content, pH, etc.; and
f) the plant's environment (i.e. stressed versus non-stressing environments).

The current effort will address the uptake and distribution of Technetium-99 (^{99}Tc) in three differing soil types. The label was surface applied to the soil as irrigation water and allowed to be flushed down into the soil profile to the plant roots.

4.2 Material and Methods

4.2.1 Soil Uptake Experiment

The effort for FY04 was to accurately determine realistic transfer factors of a selected isotope (^{99}Tc) from soils associated with nuclear waste storage/processing facilities (e.g. Hanford, Washington, Savannah River, Georgia, and Yucca Mt., Nevada) to crop plants (e.g. alfalfa, onions, corn, and potatoes). Isotope use involved ^{99}Tc, to be followed by ^{241}Am, ^{125}I, ^{63}Ni, and Pu, in this order.

4.2.1.1 Soils

Three soils were selected for the study:

- Hanford Sandy Loam Soil
- Nevada Nye County Sandy Clay Soil
- Savannah River Sands

Table 4.1 Summarized soil properties from Soil Analysis Section

Soil	pH	CEC	%OM	%Sand	%Silt/Clay
Hanford	7.48	37	0.27	83	17
Nevada	8.07	28	0.12	99	1
Savannah River	4.46	25	0.63	97	3

All soils were received from the various sites in sealed 5-gallon plastic buckets. The Washington State Hanford soil and the Nevada Nye County soil were: 1) air dried in the green house in soil bins for at least 7 days with frequent turnover; 2) sieved through 2 mm standard soil sieves (No. 10) and stored in sealed plastic lined cans at room temperature until used. We were made aware during this time that the soil from Savannah River now falls under the Post-9/11 Restricted Shipping Regulations of the United States Department of Agriculture Animal Plant Health Inspection Service (USDA-APHIS). The reason given for this restriction was the potential for fire-ant contamination. Following a lengthy approval period by APHIS the Savannah River soils were therefore processed as follows:

- The soil was considered contaminated until heat-treated and therefore handled using sterile technique. This meant that it was opened and handled only in an appropriate biosafety cabinet. These are within locked, negative air-pressure laboratories, with controlled access to authorized personnel only. At the minimum, safety apparel included a lab coat and two (2) pairs of disposable gloves that could be subsequently autoclaved.
- All soil residues were treated by either heating in a forced air oven at 110°-125°C for 16 h or autoclaving at temperatures ≥ 110°C and 15 pounds pressure for a minimum of 30 min.

Prior to use in the experiment all soils were tested for soil water holding capacity and per cent moisture remaining in air dried/sieved soil.

Table 4.2. Numbers of pots employed for each plant species for the different soil types.

Plant Species	Hanford	Nevada	Savannah River
Onion	5-Rad and 5-Control	5-Rad	5-Rad
Alfalfa	5-Rad and 5-Control	5-Rad	5-Rad
No. of Pots -1st Run	10-Rad and 10-Control	10-Rad	10-Rad
Potato	5-Rad and 5-Control	5-Rad	5-Rad
Corn	5-Rad and 5-Control	5-Rad	5-Rad
No. of Pots – 2nd Run	10-Rad and 10-Control	10-Rad	10-Rad

4.2.1.2 Plants

Four plant species have been chosen to represent a root, seed and grain crop:

Onion (*Alium cepa*) as starter plants var.
Alfalfa (*Medicago sativa*) var.
Potato (*Solanum tuberosum*) var.
Corn (*Zea mays*) var. Sugar Dot.

All seed are obtained locally (Columbia Basin Feed and Grain, Pasco, WA). The amount of dried plant material required for the animal studies meant that several plants were placed in each pot: Onion-5 (3 gal-pot); Alfalfa-2 (3 gal-pot); Potato-1 (3 gal-pot); Corn-3 (3 gal-pot). The plants were grown for a minimum of 45 to 60 days, or until maturity (flowering and seed set) for each species.

Plants were grown in two growth chambers of identical make and model. The control plants were grown in the chamber in PSL Rm. 609 and the exposed plants in the radiation zone chamber in RTL-520 Rm. 314 (Figure 4.1). Growth chamber conditions included a light intensity of ~400 µEinsteins/m^2/sec at soil level from a combination of fluorescent/incandescent lamps, a 12/12 h light/dark cycle with an 18°C night and 27°C day temperature, and 80% relative humidity. Note that the small size of the growth chamber makes it unsuitable for large plants, bushes, or trees.

Each pot contained 5 kg of soil. The soils in the pots were maintained at ~60% to 80% field capacity as measured by a soil moisture meter and sensors (Cole-Parmer Co., Vernon Hills, Illinois) placed 1/3 of the distance from the top to bottom of the soil column. The plants were watered with DI water as needed and once weekly with a 1/10th strength Hoagland's solution if nutrient stress became evident. The upper surface of the soil was covered (5mm-deep) with black polyethylene beads to minimize water transpiration from the soil surface and prevent splashing when watering and amending with label (Figure 4.2).

Fig. 4.1. The growth chamber for experimental plants in RTL-520 Room 314 (rectangular white structure with 2 doors in center of photgraph).

Fig. 4.2. Hanford soil pot with germinating alfalfa showing secondary containment and plastic lined pot with polyethylene beads on top of soil and water sensor wire going into soil.

4.2.1.3 Label Amendment

Technetium-99 (^{99}Tc) a group VII element, was the isotope used for the experiments conducted this FY. Technetium most closely resembles rhenium and, to a lesser extent, manganese. The pertechnetate ion, TcO_4^-, is a weaker oxidant than permanganate, but stronger than perrhenate (Wildung et al. 1979). In aqueous solutions the pertechnetate ion is highly stable over a broad pH range and at concentrations of 1.1 x 10^{-5} to 0.18 M. Given the conditions in most aerobic agricultural soils and natural waters of the world pertechnetate would be the predominant form of Tc present. This is also the case for the soluble species of Tc in the alkaline wastes from Hanford (Wildung et al. 1979).

The exposure scenario followed was an irrigation route. Therefore the isotope was applied in each pot to the surface of the soil in 100-mL aliquots (as small droplets) at four separate times: 1) immediately following planting; 2) 1-week post-emergence; 3) onset of flowering; and 4) initiation of seed development. Subsequent watering as described above was non-radioactive to promote movement of the isotope into the root zone. The rate of isotope application is given in Table 4.3 below.

Table 4.3. Chemical form, specific activity (mCi/g), and activity (µCi)/pot of soil for ^{99}Tc

Attributes	Technetium-99
Chemical Form	Ammonium Pertechnetate
Solvent	0.01N NH_4OH
Sp. Activity	17.049917 mCi/g
Final Activity/Pot	20 µCi
Activity/100 mL Aliquot	4 µCi
Aliquot Chemical Composition	0.001N NH_4OH,pH=~8.0

4.2.1.4 Sample Processing

When the plants were mature, water was withheld for three days to dry out the soil prior to harvest. The plants were then transferred to the hood and the soil loosened around the plant. The tissue samples (stem, leaves, fruit/seed, roots) were removed from the plants, rinsed in 0.001 N NH_4OH, blotted dry, placed in tared glass containers, and a fresh weight taken. All samples were then placed in an 80°C forced air oven for 24- to 48-h to dry. The containers were allowed to cool in a dessicator and a dry weight taken. The dried samples were then ground with a Wiley Mill (Sargent Welch, Inc. Philadelphia, PA) to a 20 mesh size. The samples were then stored at room temperature.

For isotope analysis three samples of each tissue (0.1-, 0.25-,or 0.5g depending on availability) were transferred to pre-weighed and labeled 15-mL scintillation vials. The vials were marked with sample name and date. The tissues were then wet digested according to the method of Cataldo et al. (1983). Briefly, the dried tissues were wetted with 10 mL of 3 N NH_4OH, covered and digested for 12- to 20-h on low heat (~60°C) in the hood. They were then brought to dryness in a forced air oven at 110°C. The vials were then placed in a muffle furnace at 200°C for 2-h, then at 450°C for 20-h. The ashed samples were then be cooled, wetted with 1-mL of 0.1 N NH_4OH, evaporated to dryness, and re-muffled at 450°C for 20-h. The samples were then cooled and suspended in 10-mL of 0.01 N NH_4OH and allowed to settle overnight. A 0.5 ml aliquot was then taken for liquid scintillation analysis using previously constructed quench curves. Soil samples (3 from each pot – composited and sub-sampled 3x for each pot) taken at the finish of the experiment were processed in a similar fashion.

Fig. 4.3. Harvested Alfalfa (A) and Onion (B) prior to drying.

Fig. 4.4. Harvested potato showing root, tubers, leaves, and stem samples.

4.2.2 Leaf Absorption and Translocation

4.2.2.1 Plant Material

The plant selected for this procedure was the common bean (*Phaseolus vulgaris*, cv. "Black Valentine"). The plants were seeded on potting soil in the greenhouse and grown for 28- to 35-days prior to use. The green house was held at 23°C day and night with a 12/12 h photoperiod supplemented with fluorescent and metal halide lamps.

4.2.2.2 Procedure – Leaf Abrasion

Plants were transferred from the greenhouse to a contamination zone in RTL-520 Rm. 314. A central leaflet of a true trifoliate leaf located approximately 2 or 3 nodes above the primary leaves and at the second node below the youngest leaf was selected. This leaf will be the primary source of phloem photosynthetic translocate to the youngest leaf (sink).

The leaf was suspended in a horizontal position. The leaf surface was then gently abraded with carborundum (200 mesh) to a slightly dull appearance (sufficient to score/penetrate the cuticle) and rinsed with distilled water. A ring of lanolin was placed around the abraded area and the abraded surface of the leaf flooded with a labeling solution consisting of Hanford groundwater containing 0.1 µCi /mL (220,000 dpm/mL) of ^{99}Tc as pertechnetate. The solution was allowed to remain on the surface for 1 h with occasional additions (100µL) of non-labeled groundwater to prevent desiccation.

At the end of this time the leaf surface was rinsed with distilled water and blotted dry. The plant was then separated into source leaf, leaves and stem above the source leaf, and leaves and stem below and placed into tared glass jars. A fresh weight was taken and the tissue processed for ^{99}Tc as described above.

4.3 Results and Discussion

The plant component was structured as a sequential exposure, harvest, analysis of the test plants through several isotopes. The following Experiment Tracking Table gives the dates that each portion was initiated and completed during FY-04 for ^{99}Tc.

Table 4.4. Dates of experiment initiation, plant harvesting, and completion of the isotope analysis for each of the plants and soils tested.

Soil	Plant	Start	Harvested	Analysis*
Hanford	Alfalfa	3/15/2004	7/7/2004	10/1/2004
	Onion	3/15/2004	7/8/2004	10/1/2004
	Corn	7/14/2004	11/2/2004	
	Potato	7/15/2004	11/2/2004	
Nevada	Alfalfa	3/15/2004	7/8/2004	11/1/2004
	Onion	3/15/2004	7/8/2004	11/1/2004
	Corn	7/14/2004	11/2/2004	
	Potato	7/15/2004	11/2/2004	
Savannah River**	Alfalfa	6/2/2004		
	Onion	6/2/2004		
	Corn			
	Potato			

*Completion of dry weight and isotope distribution analysis.
**Second time starting the soil. Initial plantings failed to grow.

The experiments were initiated upon receipt of all three soil types (see Table 4.4). However, shortly after the reception of the Savannah River Soil it was found that these soils were restricted by the USDA because of possible contamination with fire ants. Therefore the decision was made to start with the Hanford and Nevada soils which were not restricted while getting APHIS approval for the treatment and handling procedures for the Savannah River soil.

Following the heat treatment prescribed by the USDA the Savannah River soil pots were planted with alfalfa seed and onion bulbs. However, the alfalfa failed to germinate and while the onion bulbs germinated, all died within four weeks. These were the same seed as used previously for the other soils. Further, plants growing in the other soils in the growth chamber at the same time continued to grow normally. This led to the conclusion that there was something that might be in the soil that was inhibiting growth. It was then decided to cut the original soil by 25% with acid-washed quartz sand to attempt to dilute any potential inhibitor and replant once again with the alfalfa and a fresh set of onion bulbs (Table 4.4). The results shown below in Fig. 4.5 show that again the plants growing in this soil (both the onions and the alfalfa) continue to suffer phytotoxic symptomology after almost 100 days of growth. Based on these results we would like to discontinue the Savannah River soil plantings until a further assessment of the soil can be conducted.

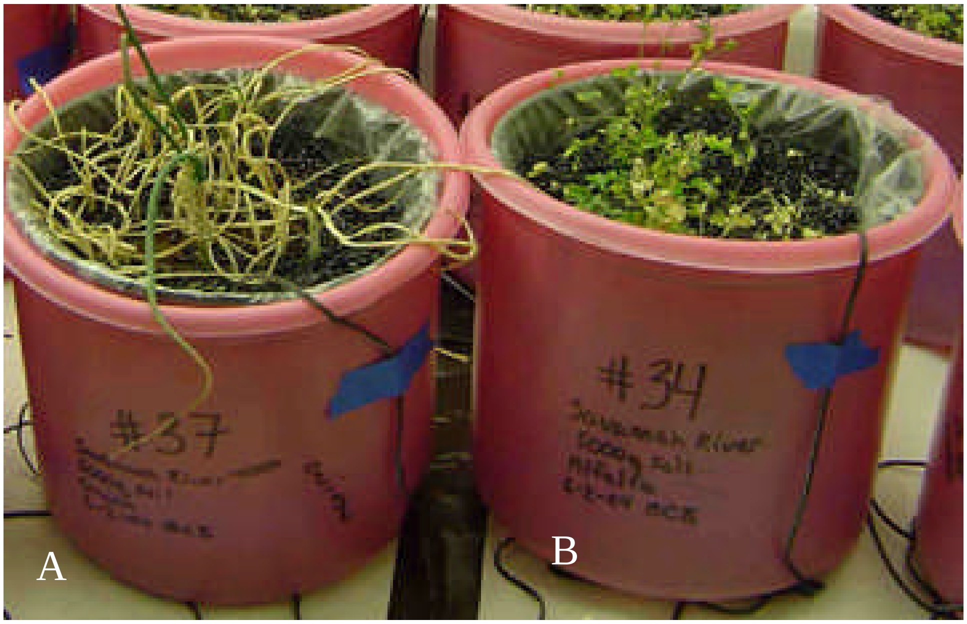


Figure 4.5. Onions (A) and alfalfa (B) grown for 100 days in Savannah River Soil amended with ^{99}Tc and showing necrosis and stunting.

4.3.1 Plant Growth in Differing Soil Types

There were significant differences in the growth of the same plant species in the Hanford and Nevada soils maintained under the same conditions and held to the same percent moistures. This is shown in Table 4.5 of the harvested plant dry wt. This is particularly evident for the alfalfa and corn plants. Both species are high nitrogen requiring plants and although nutrient solution was added to both soils at the same rates this somehow may not have been available to the Nevada plants. In the case of the alfalfa, a legume which may fix its own N, nodules were not found on the roots in either soil type. The Hanford soils are deficient in Mo, an essential element for nodule formation, and the Mo content of the Nevada soil is not known at this time.

There were no significant differences evident between the onions (Figs. 4.6 and 4.7) and potatoes in either soil type. The root structures of these plants are storage organs and are morphologically and functionally different from either the alfalfa or corn. There was also no toxicological effect on dry matter accumulation for either the onions or alfalfa from ^{99}Tc-amendment as evident in the control dry weights.

Table 4.5. Average plant dry weight (g) ± S.D. (N=5) for alfalfa, onions, Corn, and potatoes grown to maturity in either Hanford or Nevada soil.

Soil Type	Alfalfa	Onion	Corn	Potato
Hanford - Amended	32.96 ± 0.92	25.15 ± 7.53	12.06 ± 5.75	28.27 ± 9.20
Hanford - Control	34.33 ± 12.72	24.44 ± 1.44	DNA*	DNA
Nevada - Amended	4.93 ± 0.75	17.00 ± 3.19	5.48 ± 0.85	20.64 ± 6.8

*DNA = Data not available

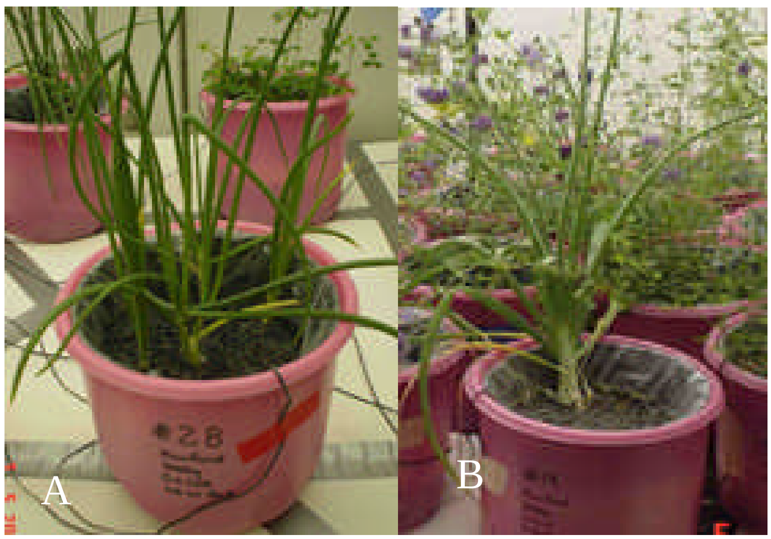


Fig 4.6 Hanford soil grown Control (A) and 99Tc amended (B) onion plants.

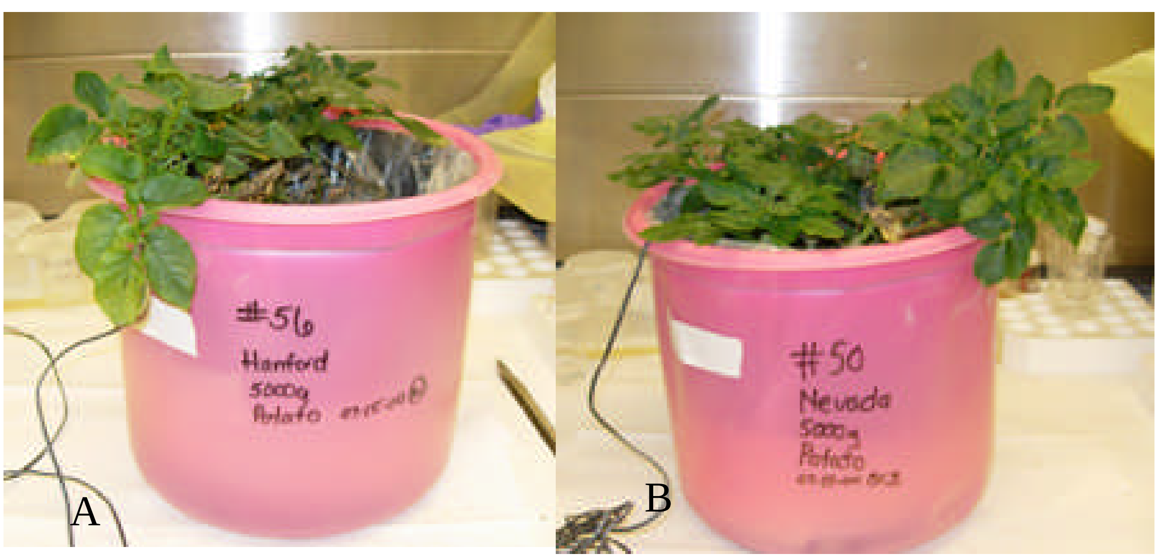


Fig. 4.7. Hanford (A) and Nevada (B) soil-grown potatoes. Both amended with ^{99}Tc.

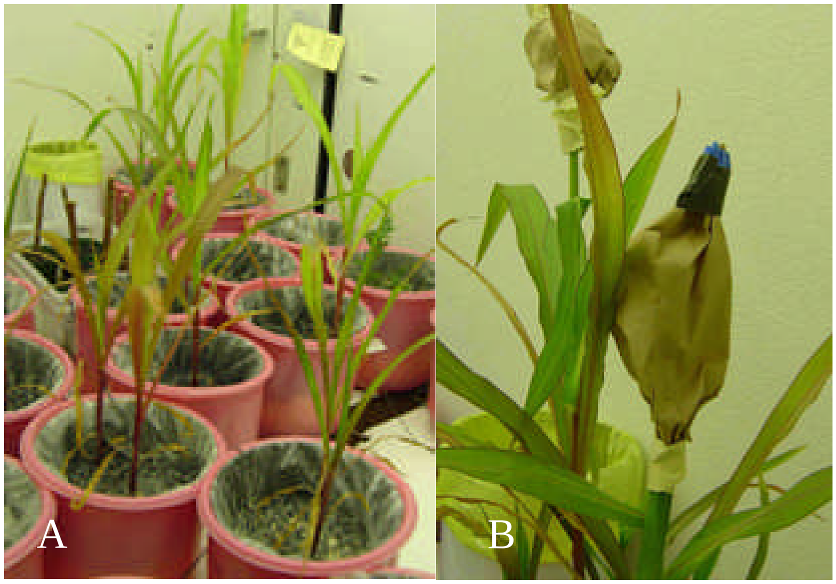


Fig. 4.8. Exposed corn plants (A) and the covers (B) that were placed over the tassels to prevent loss of potentially radioactive pollen.

Figures 4.6, 4.7, and 4.8, illustrate the similarities between plants grown in both soils. In Fig. 4.8A the younger corn plants in both soils appear identical but only in the Hanford soil did they continue to grow significantly beyond this stage although both tasseled and set seed. The isotope data is currently being processed.

4.3.2 Technetium Uptake and Distribution

The growth difficulties experienced with the plants described above indicated the there are significant differences in the soil types and how the plants react to them. As there are significant differences in the plant's growth/dry matter accumulation so too are there major differences in the relative accumulation of ^{99}Tc from the two soils assayed. This is very evident in the data presented in Table 4.6. Here the specific activity (^{99}Tc dpm/g dry wt. of tissue) of each plant and tissue is compared for the two soil types.

In all instances plant tissues grown in the Hanford soil accumulated 5- to 20-fold more ^{99}Tc than those of the same tissues from the Nevada soil. This was particularly true for the leaves of the Hanford onions that had a dry wt of only 1.47 times that of onions grown in the Nevada soil but an activity over 20 times greater. While the Hanford soil has a marginally higher CEC (See Table 4.1 and soil section) than the Nevada soil (37 vs. 28) and a higher silt/clay content (17% vs. 1%) both soils received the same supplemental fertilizer at the same rates and were grown side-by-side in the same chamber. This dramatically illustrates the effect a single soil type has over another in the uptake of ^{99}Tc and the need for careful consideration of these factors when considering the potential for contaminant transfer. It is also important to note that the primary consumable of the plant, the bulb, had very low specific activity as well as percent of the total activity in the plant (Table 4.6). This occurred because the outer layers of the bulb were removed to minimize soil contamination, a practice usually conducted when the bulb is used for human food.

Since it is nearly impossible to remove all adhering soil from the roots (particularly the fine roots) these were discarded for the alfalfa and only the above ground tissues were analyzed. Once again, for the alfalfa grown in the Hanford soil there was significantly more activity in the leaves than in those from the Nevada soil plants (Table 4.6, 45347 vs. 4637 dpm/g dry wt.). This demonstrates that the apparent soil availability/uptake differences are evident in more than the one plant species. In the alfalfa as in the onion most of the activity was found in the leaves of the plant. But in this case these are the principal source of forage for other herbivores in the food chain.

Table 4.6. Mature tissue specific activity of crop plants (N=5) grown in ^{99}Tc-ammended Hanford and Nevada soil.

Plant	Segment	Hanford Soil Avg. Specific Activity (DPM/g Dry Wt.) ± S.D.	Nevada Soil Avg. Specific Activity (DPM/g Dry Wt.) ± S.D.
Onion			
	Leaves	106072±54977	5134±1737
	Bulb[1]	324±133[1]	35±18[1]
	Flower[2]	133	-
Alfalfa	Leaves	45347±7566	4637±1496
	Stem	3031±599	692±281
	Flowers	4229±940	509±161

1. Bulb peeled of outer layer prior to processing.
2. Only a single plant flowered during growth period

When the data is expressed as percent distribution of the total activity recovered from the plants (Table 4.7) similar patterns are evident for both soil types in that for both plant species >%90 of the ^{99}Tc found in the plants was located in the leaves. While this is somewhat skewed for the alfalfa given that the roots were not analyzed it does indicate that significant amounts of the ^{99}Tc will be available for the forage. Also of interest are the differences in the amount of material transported into the floral reproductive structures. Much of the carbon and mineral translocated to the alfalfa flowers/seed comes from the storage and production in the leaves and stems while in the case of the onion the primary storage organ is the bulb. There was less ^{99}Tc found in the stems of the Hanford plants because these plants were more advanced in flower and seed formation than those plants in the Nevada soil. There is more mobilization of storage material in the stems during seed formation and this reduced amount was probably caused by this remobilization to the seed and roots at this stage of the plants life.

Table 4.7. Percent distribution of total label recovered in the two plant species grown in either Hanford or Nevada soil.

Plant	Segment	Hanford Soil Avg. Percent Total Label Recovered± S.D.	Nevada Soil Avg. Percent Total Label Recovered± S.D.
Onion			
	Leaves	99.38 ± 0.35	98.62 ± 0.49
	Bulb[1]	0.61 ± 0.37[1]	1.29 ± 0.43[1]
	Flower[2]	0.07	-
Alfalfa	Leaves	91.31 ± 5.12	85.01± 2.73
	Stem	6.47 ± 4.00	15.78 ± 2.93
	Flowers	2.23 ± 1.45	0.27[2]

1. Bulb peeled of outer layer prior to processing.
2. Only a single plant flowered during growth period

The soil data from each of the pots that the plants were grown in is now being analyzed. This information will allow an average concentration ratio to be derived for the plant species based on the soil types.

4.3.3 Leaf Abrasion Studies

The leaf studies conducted are also being analyzed at this time and the data is not available but will be placed in future monthly reports.

5.0 International Coordination and Collaboration

Task 7 of the Project involves two types of collaborations with scientists from other countries. One type is participation in working groups of the International Atomic Energy Agency (IAEA), and the other is establishment of contractual relationships with individual institutes.

5.1 International Atomic Energy Agency

The PNNL Project Manager Bruce Napier is a formal member of the IAEA's Environmental Modeling for RAdiation Safety (EMRAS) coordinated research program. This past year, he attended all EMRAS meetings for the working group associated with the revisions to IAEA's Technical Report Series No. 364 "Handbook of parameter values for the prediction of radionuclide transfer in temperate environments." This handbook contains a summary of information gathered in various international databases related to radionuclide behavior in soil, plant, farm animal, and freshwater aquatic systems. This working group first met in Vienna, Austria, in October 2003. In the 2003 meeting, it was generally decided that the revision to TRS-364 should include additional discussion and explanation of the processes of interest in the report text. The data tables should be introduced with necessary modeling assumptions, with a review of possible alternatives. Various existing headings in the document were reviewed and additions were suggested. In the discussions, about 13 separate contributions were defined, with about 20 contributors. It became apparent during this working group meeting that progress was minimal, and little material had been drafted, although a great deal of information has been collected and entered into a start of a computerized database. Most discussion centered on the depth of review intended for this handbook: it was decided that it was not necessary to exhaustively review all pertinent literature, and that existing synthesis reports could be trusted and used. Completion of the update to TRS-364 is not likely before 2007, given the amount of data to be collected and the limitations of the volunteer workforce. Some additional key people need to be contacted.

There were 14 participants in the TRS-364 revision group meeting; Bruce Napier was the only U.S. representative in this group. (One new Canadian participant, Tamara Yankovich from AECL, was the only other North American.) About half of the attendees had been at the original meeting in Vienna in 2003 and about half were new. Therefore, the working group leader proceeded to work through a "critical analysis" of the existing TRS-364 with the entire group, determining the interests and availability of people to work on portions. (The current version of the "critical analysis" is included as Appendix 2). As noted in the first meeting, the data tables should be introduced with necessary modeling assumptions, with a review of possible alternatives. Data presentation should include a discussion of "co-factors" – those associated parameters and circumstances (e.g., soil type, concentrations of chemical analog elements) as a means of reducing uncertainty in their use. Uncertainty ranges or probability density functions should also be included where possible.

About 85% of the references used in the original draft of TRS-364 have been gathered, in addition to a number of newer ones. Major sources of information available include:

- The International Union of Radioecologists (IUR) database. This is largely current through 1992 (the source of the original TRS-364 values) plus some information for tropical conditions (through 1997). This database was entirely the work of Martin Frissell, who has retired. It has no current “owner,” and is not being maintained.
- An update to the IUR database through 2001, including many co-factors.
- The RADFLUX database, assembled by the IUR; Ministry of Agriculture, Fisheries, and Food (MAFF – now called the Food Safety Authority); and IRSN (Institut de Radioprotction et de Surete Nucleaire). This contains about 18,000 individual entries, including both plants and animal products. This is largely the same as the IUR database. Note that while there are very many entries, over half of them relate to fallout ^{90}Sr, and most of the rest to fallout ^{137}Cs.
- A food processing database, with ratios of radionuclide concentrations before and after food processing. Like the RADFLUX database, nearly all of the entries concern either ^{90}Sr or ^{137}Cs.

It was suggested that sources and information be categorized on a scale of 1 – 4 (with 1 indicating an excellent analysis of a large amount of literature, and 4 being a bad translation of one paper). This sort of scale may be included in the final report as an indicator of the “quality” of the reported transfer factors.

The scope of the report was discussed. It was agreed that the focus was human health risks from radionuclides in the environment, rather than ecological effects (i.e., not timber).

The IUR is listed as a co-sponsor of the EMRAS Working Group. However, at this time the support of the IUR consists of allowing them to use their logo on the advertising. There is no formal interaction, other than that Pascal Santucci, the head of the IAEA Working Group, is also the chair of the IUR working group. However, there are no additional participants from the IUR, and there will be no additional meetings.

The proposed outline of the revised report was again revised, and lead authors tentatively assigned to chapters. A majority of the lead authors were not in attendance at this meeting (and may not agree to participate!); these are marked with question marks below. The outline includes:

- Interception processes (Gerhard Proehl?): including retention on vegetation/weathering;
- Translocation (Owen Hoffman?, George Shaw?); including fruit;
- Soil-to-plant concentration ratios (Ann Nisbet?, Christian van de Castille?): the group must work with the International Union of Radioecologists (IUR) to obtain the data used for the original TRS-364, plus any additional data that has been accumulated. These data were originally collected by Martin Frissell, who is no longer working on the database;

- Resuspension/soil adhesion (Tom Hinton?): this topic needs to be added to the report;
- Kd (Miguel Vidal): it was decided to expand the discussion and application of the Kd to several areas other than simply applying it to soil leaching;
- Losses from soil: in addition to the soil-leaching mechanism for long-term removal from the biosphere, it was decided to include washoff and erosion;
- Animal products (Brenda Howard?, Gerhard Kirchner?): There was interest in this topic to include the allometric approaches to animal concentrations developed for the US Department of Energy's Biota Dose Calculator, as implemented in the RESRAD-BIOTA computer code. Bruce Napier will contact Dr. Kathryn Higley at Oregon State University and Dr. Charles Brandt at Pacific Northwest National Laboratory about this topic;
- Freshwater aquatic systems (Luigi Monte and John Britton may have already started to prepare this section): it was decided to greatly expand this section and to subdivide it into rivers, lakes, estuaries, and coastal waters. Beyond just "fish", it was decided to include several components of aquatic food webs;
- Natural and forest ecosystems (Phillip Ciffray): the European experience includes radionuclide transport in managed forests and grazing lands. The members of the former Fruits and Forests working group will supply additional information about processes in other-than-plowed fields;
- Food processing (Aino Rantavaara? Tom Hinton?): the existing TRS-364 incorporated directly an IAEA VAMP report;
- Analogs (Elisabeth Leclerc-Cassac): Much of the data in the various tables are not actually measured; there is a great deal of "expert judgment" involved. It was decided that a section must be added describing the use of analogies and other applications of judgment to the selection of parameters;
- Speciation (Brit Seidl?):
- Special Radionuclides (Phil Davis? Dan Galeriu?): this will include tritium, ^{14}C, and perhaps isotopes of sulfur

The Working Group discussed ideas for using the IAEA's EMRAS website for communication and information gathering; however, the potential for use of the IAEA's website is limited because of IAEA rules about what may be posted.

The next meeting of the working group took place October 2004, in conjunction with the annual EMRAS plenary meeting in Vienna. However, because of the timing in relation to the US budgetary fiscal year, Bruce Napier was not able to attend. A "critical analysis" and status of work was prepared for this meeting; it is attached as Appendix B.

Bruce Napier met with Dr. Stuart Conney of the British Food Standards Agency (formerly known as MAFF). Dr. Conney is the program manager in charge of the various radioecological experiments that are of interest to the NRC. Many of the projects have summaries on the FSA website, and reports are available (mostly hard copy for a fee). The available information is listed at the FSA website http://www.foodstandards.gov.uk/science/research/researchinfo/radiologicalresearch/

5.2 Kazakhstan

Collaboration was investigated with the National Nuclear Center, Institute of Radiation Safety and Ecology (IRSE), in the city of Kurchatov, Kazakhstan. The project hosted a two-day visit to PNNL by the Institute Director, Ms. Larissa Ptitskaya. Ms. Ptitskaya is known to PNNL Project Manager Bruce Napier through collaborations with the International Science and Technology Center (ISTC). The Kazakhstan National Nuclear Center was formed in 1992 as a joint research center based at the Semipalatinsk Test Site (STS). The IRSE carries out research on radiation safety at the STS and radioecology of plants and animals.

The Semipalatinsk Test Site, known as the “polygon”, is a 19,000 km^2 zone located in the northeast of Kazakhstan, 800 km north of the capital Almaty (Figure 5.1). Between 1949 and 1989, the former USSR conducted about 456 nuclear explosions at STS. Until 1963, most of the explosions were carried out on the surface and in the atmosphere (including 126 atmospheric tests with 30 surface bursts). During the 40 years of testing, the total energy released in the testing was equivalent to 17.4 megatons of TNT. After the breakup of the Soviet Union, effective control over the area by local governments was lost. The region is a combination of arid plains and lightly forested mountains. Between 30,000 and 40,000 people live near the site, and a small number of people actually live on the site, primarily semi-nomadic herders and farmers.

The STS is very large, and large portions are relatively uncontaminated. However, the three main operating areas, known as “Ground Zero” (where many early atmospheric tests were conducted in the northwest quadrant of the site [Figure 5.2]), Technical Area G (also known as the Degelen Massif, where most tests took place in tunnels near the southwest quadrant of the site), and Balapan (where most tests occurred in vertical shafts in the eastern quadrant of the site) have locations that are highly contaminated. The various areas have soil contamination from tests and fallout, groundwater contamination, and contamination of plants and animals. In three areas, cratering experiments were conducted that resulted in creation of artificial lakes (Figure 5.3), one of which is quite large. Cattle and other animals now drink from these contaminated lakes.

Following the breakup of the Soviet Union, the Russian military moved out of the STS, and took nearly all records of activities and resulting contamination with them. It is the job of the IRSE to reconstruct the contamination patterns at STS and to determine the health and ecological impacts. Because site security is minimal, various individuals and groups have returned to the site. Some raise crops or herd animals, and others “prospect” for recyclable metals and other items. Animals herded on the site include sheep, cattle, and horses (Figure 5.4). The IRSE also samples mice and other rodents. Another Institute of Radiation Medicine in the National Nuclear Center also investigates human exposures and body burdens.

Figure 5.1. The location of the Semipalatinsk Test Site in Kazakhstan

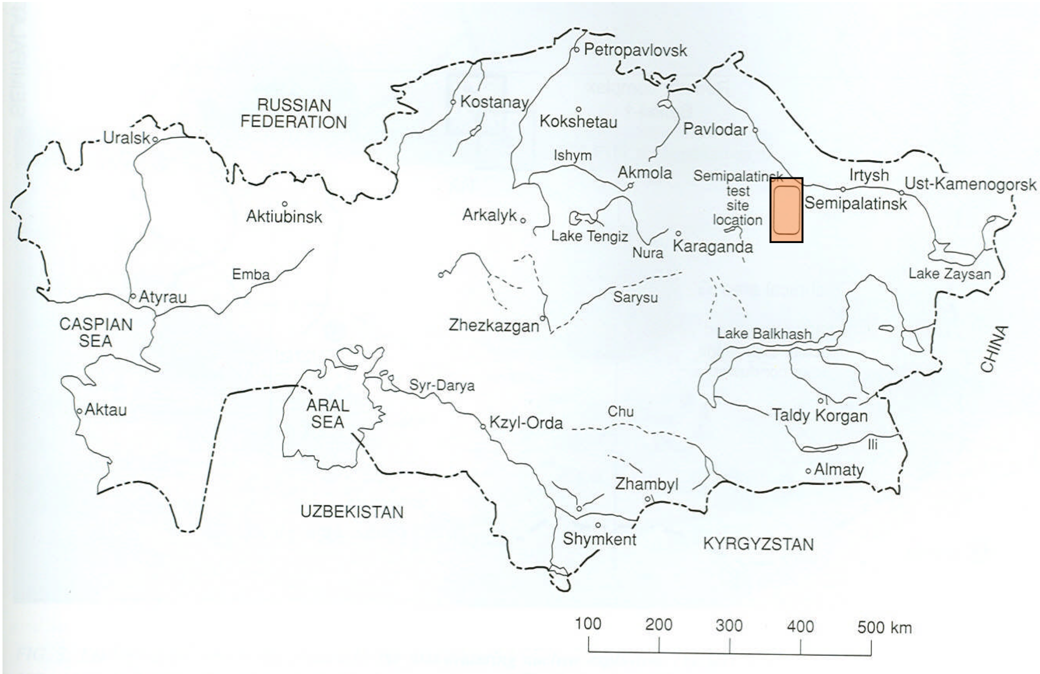


Figure 5.2. The STS around "Ground Zero"

Figure 5.3. “Lake Balapan” created at STS by a cratering test explosion

Ms. Ptitskaya provided several papers describing conditions and ongoing research. Most are in the Russian language, but some interesting ones are in English. These include

- J.G.D. Werner, R.P. Plisak, V.V. Polevik, T.M. Ponomareva, N.K. Aralbaev, P.P. Dubinchin, R.J. Magasheva, G.N. Jakunin, S.V. Plisak, IMPACT OF RADIONUCLIDE MIGRATION ON DEVELOPMENT OF ZONAL ECOSYSTEMS OF SEMIPALATINSK TEST SITES, which provides measurements of concentrations of the radionuclides ^{241}Am, ^{137}Cs, $^{152, 154}Eu$, and “alpha” in soil and ashed native plants *Artemisia sublessingiana* (sagebrush) and *Stipa sareptana* (bunchgrass),

- J.G.D. Werner, R.P. Plisak, R.J. Magasheva, V.V. Polevik, T.M. Ponomareva, N.K. Aralbaev, P.P. Dubinchin, G.N. Jakunin, S.V. Plisak, RADIONUCLIDE MIGRATION IMPACT ON DEVELOPMENT OF HALOPHYTE SYSTEMS OF SEMIPALATINSK TEST SITE, which provides measurements of ^{137}Cs and “alpha” in soil and the salt-tolerant species *Halimione verrucifera* (saltbush) and *Haolcnemum strobilaceum (*a weed), and

- J.G.D. Werner, R.P. Plisak, R.J. Magasheva, G.N. Jakunin, V.V. Polevik, T.M. Ponomareva, N.K. Aralbaev, P.P. Dubinchin, S.V. Plisak, PECULIARITIES OF RADIONUCLIDE MIGRATION IN INTRAZONAL ECOSYSTEMS OF

Figure 5.4. Nomadic residents herding cattle on the STS near "Ground Zero"

SEMIPALATINSK TEST SITES AND IMPACT ON DEVELOPMENT OF MEADOW VEGETATION, which provides measurements of ^{137}Ca and ^{238}U in soils and ashes of the local meadow plants *Calamagrostis epigeios*, S*anguisorba officinalis* (a flowering plant commonly called burnet), *Galatella biflora* (an aster-like flowering plant), *Elytrigia repens* (quackgrass), *Inula Britannica* (a weed pest commonly called British yellowhead), *Achnatherum splendens* (needle grass), and *Glycyrrhiza uralensis* (Chinese licorice).

There is insufficient information in these reports to derive soil-to-plant concentration factors (because the wet or dry weight of the plants prior to ashing is not provided), however, it may be possible to obtain this information from the authors or from IRSE.

Ms. Ptitskaya has promised to provide additional information regarding soil, plant, and animal concentrations measured at the STS. She indicates that information may be available for the radionuclides of tritium, cobalt, strontium, cesium, europium, plutonium, americium, and radon. This contact will be followed up in the coming year.

Contact information:

Ms. Larissa Ptitskaya
K-810 Project Manager
Director, Institute of Radiation Safety and Ecology
2 Krasnoarmeiskaya St.
490021 Kurchatov, Kazakhstan

Email irbe@nnc.kz
Facsimile +7 (32251) 234 13

5.3 Russia

The PNNL Project Manager Bruce Napier has a long-standing working relationship with staff at the Mayak Production Association in central Russia. The Mayak Production Association[5] (MPA) was the first Soviet complex for the production of plutonium for nuclear weapons. It is located in the northern part of Chelyabinsk Oblast about halfway between the major cities of Ekaterinburg and Chelyabinsk, and its operating areas are about 10 km from the town of Ozersk. Ozersk is the largest populated area nearby, but other nearby populated areas included Novogorny Village, Metlino Village (now evacuated due to discharges to the Techa River), New Metlino Village, and Kyshtym Town.

The MPA became operational in June 1948. The enterprise consisted of several facilities located at a distance of from 500 m to 5 km from the main site. These facilities include

- reactors (Group F Plants),
- radiochemical Plants (Group B Plants), including waste treatment and high-level waste storage (Complex C); and
- industrial complex for production of ^{239}Pu (Group V Plants).

The operation of the MPA began during the cold war period and caused multiple environmental and public health problems. The startup of the enterprise and productivity increases in the first decade of operation were performed under a sense of urgency and without appropriate scientific knowledge and technological experience in the field of ecology. This resulted in an anthropogenic pressure on the ecosystem: Practically all objects in the environment became radioactively contaminated, and the residents in the enterprise-impact zone were exposed to effective doses that are estimated to have been as high as 400 mSv. The current radiation situation around the MPA site is affected by the following radiation incidents and practices:

- discharge of liquid radioactive waste into the Techa River (1949-1956);

[5] MPA is a facility of the Federal Agency for Atomic Energy of the Russian Federation

- discharge of liquid radioactive waste into the natural surface-water reservoir (Lake Karachai);
- accidental discharge of radioactive materials into the atmosphere (1957) as a result of a thermal explosion in a liquid radioactive waste-storage tank;
- wind transport of radionuclides from the dried out banks of Lake Karachai (1967); and
- routine discharges of radionuclides into the atmosphere during the early years of the enterprise operation.

The current radiation situation on the MPA site is characterized by the presence of long-lived ^{90}Sr and ^{137}Cs in the environment; lesser amounts of plutonium also contribute to prolonged population exposure. The doses currently being accumulated are small compared to those experienced in the late 1940s and early 1950s. The short-lived radionuclides, which were the major source of early high exposure, have decayed and are no longer significant sources of exposure.

After the 1957 tank explosion, a special research institute was established in the town of New Metlino to evaluate the results of environmental contamination of farm fields and forests. This was known by the acronym ONIS. The staff at ONIS published (in Russian) many reports that were later used to help the USSR respond to the accident at Chernobyl. Because of funding constraints in recent years, the institute at ONIS has been dissolved, and the staff mostly re-absorbed by the Mayak Central Laboratory. The Central Laboratory staff were also actively involved in some of the researches, and also have access to the original research reports.

The head of the Mayak Central Laboratory, Dr. Sergey Rovny, has been involved for several years with projects funding by the United States through the Joint Coordinating Committee on Radiation Effects Research. PNNL Project Manager Bruce Napier has worked with him and his staff since 1995. Because of the Central Laboratory’s familiarity with the ONIS research, the availability of large areas of existing outdoor contamination, and their admitted willingness to work with US researchers, they are a logical partner for additional NRC-funded studies. Bruce Napier has a verbal agreement with Dr. Rovny to participate in studies of radionuclide uptake.

During the past year, the Russian government under Mr. Vladimir Putin has drastically reorganized. The former Russian Ministry of Atomic Energy (known by its Russian abbreviation MINATOM) has been replaced by the Federal Agency for Atomic Energy (ROSATOM), and lines of authority and responsibility have only recently been designated. The Mayak PA has lost some “status” and is now a facility of ROSATOM. These changes have made it difficult to acquire a visa to visit Mayak. PNNL Project Manager Bruce Napier has only recently been able to obtain a visa, and is scheduled to meet with Dr. Rovny and the Mayak Central Laboratory staff in early December 2004. The intent of the meeting is to discuss the potential interest for joint studies funded in Russia by the NRC through the auspices of the JCCRER, evaluate the Mayak capabilities, and potentially prepare a proposal for plant and/or animal uptake studies.

In January 1994, the US and Russian governments signed an agreement on cooperation in research on radiation effects. This agreement established a Joint Coordinating Committee on Radiation Effects Research, which met initially in October 1994 and established a set of research guidelines and an initial group of draft proposals for work. The draft proposals were directed in three main directions: dose reconstruction and epidemiology for the public, dose reconstruction and epidemiology for radiation workers, and environmental effects. The agreement lasts for 5 years; it was last renewed in 1999. Because of deteriorating relations between the US and Russia following the most recent Iraq war, the JCCRER agreement has not yet been renewed for the second time. If the agreement is not renewed, then an alternative mechanism for the projects would have to be established.

Contact Information:

Sergey Rovny
Head, Mayak Central Laboratory
Central Laboratory
Mayak Production Association
31 Lenin St.
456784 Ozersk, Russia

Telephone: +7 (35171)-28945
Fax: +7 (35171)-26945
E-mail: rovny@cpl.po-mayak.ru; rel@envc.chel-65.chel.ru

6.0 Status of the GENII Version 2 Computer Code

One task of the Project is to provide training on the GENII Version 2 computer code package. The GENII computer code was developed at Pacific Northwest National Laboratory (PNNL) to provide a state-of-the-art, technically peer-reviewed, documented set of programs for calculating radiation dose and risk from radionuclides released to the environment incorporating internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) and the radiological risk estimating procedures of Federal Guidance Report 13. The codes were designed with the flexibility to accommodate input parameters for a wide variety of generic sites. GENII Version 1 was released in 1988 (Napier et al. 1988). A new version of the codes, GENII Version 2, has been developed incorporating improved transport models, exposure options, dose and risk estimation, and user interfaces (Napier et al. 2004; Napier 2004). The new version is specifically designed to function within the Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES), a framework that allows GENII to execute with, and provide inputs to, other related programs. This new version has only recently become available, as it is being developed without programmatic funding.

GENII is intended to be used as a general-purpose package for estimating the consequences of radionuclides released into the environment. Available release scenarios include chronic and acute releases to water or to air (ground level or elevated sources), and initial contamination of soil or surfaces. Radionuclide transport via air, water, or biological activity may be considered. Air transport options include both puff and plume models, each allow use of an effective stack height or calculation of plume rise from buoyant or momentum effects (or both). Building wake effects can be included in acute atmospheric release scenarios. GENII implements models developed for the U.S. Nuclear Regulatory Commission for surface water transport. GENII does not explicitly include modules for performing groundwater transport calculations, however the FRAMES system, in which GENII functions, allows addition of other computer modules to the GENII system. Exposure pathways include direct exposure via water (swimming, boating, and fishing), soil (surface and buried sources), air (semi-infinite cloud and finite cloud geometries), inhalation, and ingestion pathways. Special models are included for tritium and carbon-14; the tritium model includes exposure via skin absorption. An additional capability for releases of radon isotopes is planned.

The code provides radiation dose and/or risk estimates for health effects to individuals or populations; radiation dose may be reported as either effective dose equivalent or organ dose, and health risk may be reported as cancer incidence or fatalities. GENII Version 1 implemented dosimetry models recommended by the ICRP in Publications 26, 30, and 48, and approved for use by DOE Order 5400.5. GENII Version 2 implements these models plus those of ICRP Publications 56 through 72, and the related risk factors published in Federal Guidance Report 13. At the discretion of the user, different dose and risk approaches may be compared and contrasted. These dosimetry and risk models are considered to be 'state of the art' by the international radiation protection community and have been adopted by most national and international organizations as their standard dosimetry methodology.

The GENII Version 2 system consists of four independent atmospheric models, one surface water model, three independent environmental accumulation models, one exposure module, and one dose/risk module, each with a specific user interface code. The computer programs are of several types: user interfaces (i.e., interactive, window- driven programs to assist the user with scenario generation and data input), internal and external dose factor libraries, the environmental dosimetry programs, and FRAMES-supplied file-viewing routines. For maximum flexibility, the code has been divided into several interrelated, but separate, exposure and dose calculations. The components of the system communicate with each other through a series of intermediate data files. Each of the intermediate files is accessible to the user through the FRAMES data-visualization utilities. Each module is also connected to the sensitivity/uncertainty driver SUM^3, which allows assignment of distributions to all input parameters and which will run the entire system in a Monte Carlo fashion.

Data entry is accomplished via interactive, window-driven user interfaces. Default exposure and consumption parameters are provided for both the average (population) and maximum individual, however, these may be modified by the user. Source term information may be entered as radionuclide release quantities for transport scenarios, or as initial radionuclide concentrations in environmental media (air, water, soil). For input of released or initial concentrations, decay of parent radionuclides and ingrowth of radioactive decay products may be considered prior to the start of and during the exposure scenario. A single code run can accommodate unlimited numbers of radionuclides including the source term and any radionuclides that accumulate from decay of the parent, because the system works sequentially on individual decay chains.

The source input module is provided by FRAMES. The four atmospheric dispersion models are available for use depending on the nature of the problem to be solved and the quality of available data. The acute and chronic gaussian-plume models can be run on either hourly or compiled joint-frequency data on wind speed, direction, and stability. The acute and chronic lagrangian-puff models require more-detailed hourly inputs, but provide more detailed transport modeling options. Dry and wet deposition, for gases and various types of particles, is estimated in each case. Utility programs are included to translate several types of available meteorological data into GENII input files. The single surface–water transport model incorporates simple and complex submodels for rivers, lakes, and coastal regions, and may be used for simulating either accidents or routine releases. As noted, GENII does not include a groundwater transport module, but others that function within FRAMES may be used if desired. The three terrestrial transport models are tailored for chronic accumulation, accidental releases, and defined initial contaminant distributions in surface or deep soils. The human intake module allows customization of the exposure of individuals to the environmental contamination, up to 15 categories of pathways (with as many as 4 pathways per category) for up to 6 age groups are available. The dose and risk module includes the older ICRP models (for comparison with DOE and NRC regulations), the newer ICRP models, and risk estimation using EPA slope factors, dose-to-risk conversion factors, or the latest Federal

Guidance Report 13 methods. The various impacts modules are provided by FRAMES to manipulate, summarize, and organize output as desired.

The code package also provides interfaces, through FRAMES, for external calculations of atmospheric dispersion, geohydrology, biotic transport, and surface water transport. Target populations are identified by direction and distance (radial or cartesian grids for Version 2) for individuals, populations, and for intruders into contained sources.

A stochastic edition of GENII Version 1, named GENII-S, was developed for the Waste Isolation Pilot Plant assessments by Sandia National Laboratory (Leigh et al. 1992). GENII Version 2 is completely stochastic, using the FRAMES Sensitivity and Uncertainty in Multimedia Models (SUM^3) driver.

A set of CDs with the complete installation package for GENII Version 2 in FRAMES was provided to the NRC Project Manager in November 2004. This version is believed to be complete and fully functional. The code was the subject of a major review by the US Department of Energy in 2004 (DOE 2003; 2004). However, because the code is new and has not undergone independent review and testing, some problems may remain.

6.1 GENII-related References:

Napier, B. A., R. A. Peloquin, D. L. Strenge, and J. V. Ramsdell. 1988. *GENII - The Hanford Environmental Radiation Dosimetry Software System*. PNL-6584, Vols. 1-3. Pacific Northwest Laboratory, Richland, Washington.

Napier BA, DL Strenge, JV Ramsdell, Jr, PW Eslinger, and CJ Fosmire. 2004. *GENII Version 2 Software Design Document* . PNNL-14584, Pacific Northwest National Laboratory, Richland, WA.

Napier BA. 2004. *GENII Version 2 Users' Guide* . PNNL-14583, Pacific Northwest National Laboratory, Richland, WA.

Leigh, C. D., B. M. Thompson, J. E. Campbell, D. E. Longsine, R. A. Kennedy, and B. A. Napier. 1992. *User's Guide for GENII-S: A Code for Statistical and Deterministic Simulations of Radiation Doses to Humans from Radionuclides in the Environment*, SAND91-0561A, Sandia National Laboratories, Albuquerque, New Mexico

U.S. Department of Energy. *GENII Computer Code Application Guidance for Documented Safety Analysis. Interim Report*, DOE-EH-4.2.1.4-Interim-GENII Rev. 1, September 2003.

U.S. Department of Energy. *Software Quality Assurance Improvement Plan: GENII Gap Analysis, Final Report*, DOE-EH-4.2.1.3-GENII-Gap Analysis, May 2004.

Appendix A
Nevada Plant Studies

APPENDIX A – Nevada Plant Studies

A.1 Introduction

We previously embarked on a potentially viable means to exploit the transfer factors for natural elements ranging from nutrient elements to natural rare earth elements in the Amargosa Valley, NV. We met with the owner of T&T Ranches some 20 miles south of the pending repository. One of the farms that is owned has been used for exploratory cultivation of a wide variety of tree species and other food crops. At present they have standing crops including: pistachio, almond, fig, carob, alfalfa, grapes, apples, pomegranate, pecan, field oats, apricots, and nectarines. All are irrigated from the underlying aquifer, using surface irrigation (not overhead sprinklers), and are registered as organic farm products (no pesticides or refined fertilizers). We placed a contract with the rancher to allow sampling of all available crops over the next three years. This will include leaves and fruit at maturity, soil core samples down to 15 feet, and groundwater. A sampling trip was taken in July to collect soil cores, and up to six replicates of leaves, stems, and fruits of alfalfa, almond, apple, apricot, carob, fig, grape, nectarine, oats, pecan, pistachio, and pomegranate.

The location of the Nelle Ranch where the samples were taken is given in Fig. A-1 below.

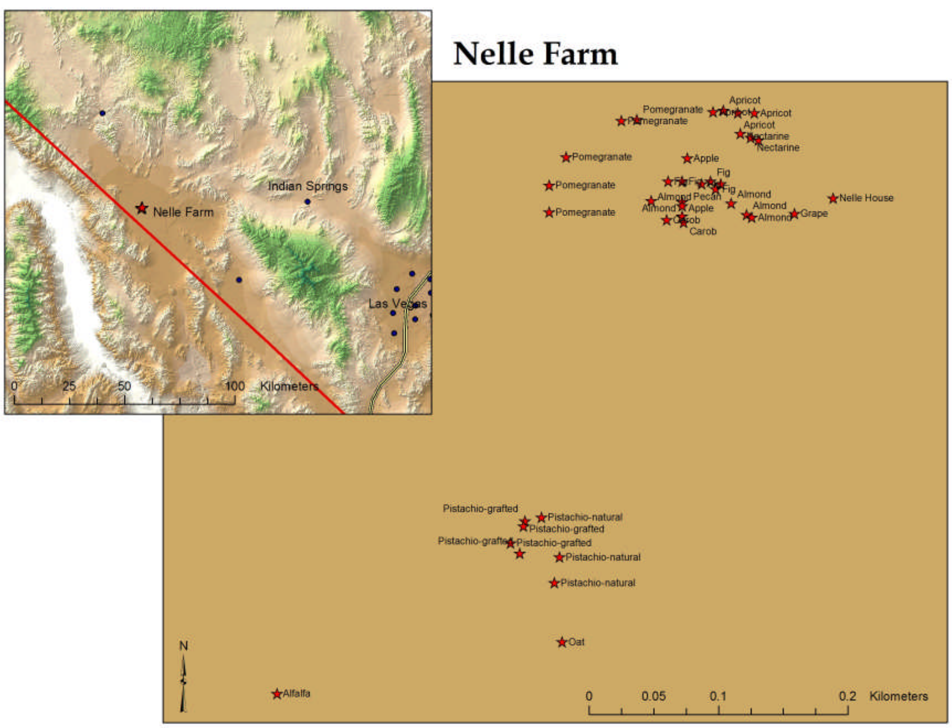


Figure A-1. Location of the Nelle Ranch in southern Nevada and distribution of the vegetation sampled

A.2 Materials and Methods

The samples were collected July of 2004 at the Nelle farm, placed in paper bags, and shipped overnight to the Pacific Northwest National Laboratory. They were then unpacked, a fresh weight taken, the samples transferred to tared glass jars, and dried at 80°C for 72- to 96-h. Dry weights were then taken and the samples stored at room temperature in the closed jars.

The dried samples were then ground with a Wiley Mill (Sargent Welch, Inc. Philadelphia, PA) to a 20 mesh size. The samples were again stored at room temperature. Selected samples (10-g aliquots) have been sent to Huffman Labs, Inc. (Golden, Colorado) for wet digestion and ICP analysis. These are given in Table A-1.

Table A-1. Ten grams of each of the following dried and ground (20 mesh) plant tissue sent to Huffman Laboratories. Golden, CO, for analysis.

GPS	Crop	Variety	TreeID	Sample ID	Segment	Code
74	Alfalfa			4	Stem&Leaf	AFL-AFS
58	Almond		3	3	Leaf	ALL
58	Almond		3	3	Fruit	ALF
55	Apple	Golden delicious	1	1	Leaf	AP1L
55	Apple	Golden delicious	1	1	Fruit	AP1F
38	Apricot		2,3,4,5	3	Fruit	ARF
44	Apricot			4	Leaf	ARL
64	Carob		1	2	Leaf	CRL
64	Carob		1	2	Fruit	CRF
53	Fig		4	5	Leaf	FIL
53	Fig		4	5	Fruit	FIF
75	Grape		1	1	Leaf	GR1L
75	Grape		1	1	Fruit	GR1F
73	Oat	Feed		2	All	FOL-FOS
67	Pistachio-grafted	Grafted	2	3	Leaf	GPL
67	Pistachio-grafted	Grafted	2	3	Fruit	GPF
71	Pistachio-natural	Natural	2	3	Leaf	NPL
71	Pistachio-natural	Natural	2	3	Fruit	NPF
39	Pomegranate		1	1	Leaf	POL
39	Pomegranate		1	1	Fruit	POF

Arrangements are being made with the Radiation Center at Oregon State University to have the bulk of these samples analyzed for a range of constituents using neutron activation analysis (NAA). With the NAA technique, very small samples (less than 1 gram each) of the plant tissues are irradiated, and the constituents made radioactive. Neutron activation analysis is a non-destructive, highly precise and accurate analytical technique capable of determining up to 48 elements in almost all types of sample matrices. The NAA procedure involves irradiating the samples and appropriate standard reference materials with neutrons in the Oregon State reactor to produce unstable radioactive nuclides. Many of these radionuclides emit gamma-rays with characteristic energies that can be measured utilizing high-resolution semiconductor detectors. The rate that the gamma-rays are emitted from an element in the sample is directly proportional to its concentration. Samples as small as 1mg can be quantitatively measured by NAA. Detection limits are in the parts per million to parts per billion range depending on the element and sample matrix. A new professor at Oregon State has recently installed an automated system for performing the sample counting. This should allow analysis for a suite of constituents within the next half year.

A.2 Results

The following plants were sampled as shown in Figures A-2 to A-4 and Table A-2.

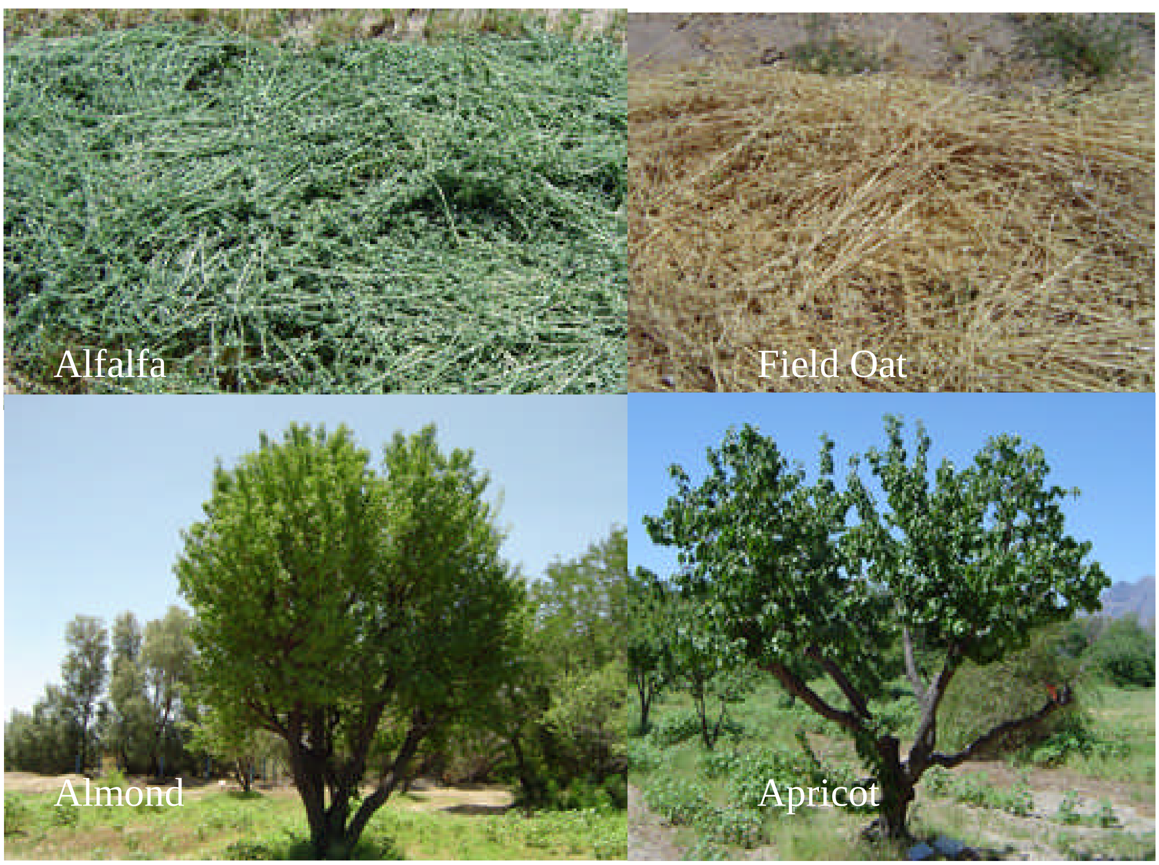


Fig. A-2. Plants sampled.

Fig A-3. Sampled Plants

Fig. A-4. Plants sampled.

Table A-2. Summary of samples and final dry weights.

GPS	Crop	Variety	TreeID	Sample ID	Segment	Code	Jar Wt. (g)	Dry Wt. (g)	Total Sample Wt (g)
74	Alfalfa	Feed		1	Stem&Leaf	AFL-AFS	232.70	287.69	54.99
74	Alfalfa			2	Stem&Leaf	AFL-AFS	232.10	281.23	49.13
74	Alfalfa			3	Stem&Leaf	AFL-AFS	232.85	287.38	54.53
74	Alfalfa			4	Stem&Leaf	AFL-AFS	231.85	298.89	67.04
74	Alfalfa			5	Stem&Leaf	AFL-AFS	232.46	292.46	60.00
74	Alfalfa			6	Stem&Leaf	AFL-AFS	232.25	287.66	55.41
74	Alfalfa			7	Stem&Leaf	AFL-AFS	192.34	241.11	48.77
74	Alfalfa			8	Stem&Leaf	AFL-AFS	232.00	277.25	45.25
57	Almond		2	2	Leaf	ALL	120.49	132.48	11.99
57	Almond		2	2	Stem	ALS	120.47	150.53	30.06
57	Almond		2	2	Fruit	ALF	231.64	267.61	35.97
58	Almond		3	3	Leaf	ALL	120.40	134.74	14.34
58	Almond		3	3	Stem	ALS	121.53	138.20	16.67
58	Almond		3	3	Fruit	ALF	233.08	246.40	13.32
59	Almond		4	4	Leaf	ALL	170.63	178.67	8.04
59	Almond		4	4	Stem	ALS	121.05	142.26	21.21
59	Almond		4	4	Fruit	ALF	141.55	171.52	29.97
60	Almond		5	5	Leaf	ALL	166.06	185.60	19.54
60	Almond		5	5	Stem	ALS	121.16	158.30	37.14
60	Almond		5	5	Fruit	ALF	232.79	255.49	22.70
61	Almond		6	6	Leaf	ALL	172.31	184.30	11.99
61	Almond		6	6	Stem	ALS	120.45	144.82	24.37
61	Almond		6	6	Fruit	ALF	233.16	260.78	27.62
62	Almond		1	1	Leaf	ALL	172.00	183.27	11.27
62	Almond		1	1	Stem	ALS	121.62	149.19	27.57
62	Almond		1	1	Fruit	ALF	231.81	255.70	23.89
55	Apple	Golden delicious	1	1	Leaf	AP1L	165.88	179.38	13.50
55	Apple	Golden delicious	1	1	Stem	AP1S	141.16	174.34	33.18
55	Apple	Golden delicious	1	1	Fruit	AP1F	191.33	245.67	54.34
55	Apple	Golden delicious	1	2	Leaf	AP1L	165.56	187.58	22.02
55	Apple	Golden delicious	1	2	Stem	AP1S	141.16	154.34	13.18
55	Apple	Golden delicious	1	2	Fruit	AP1F	192.21	263.83	71.62
63	Apple		2	1	Leaf	AP2L	172.17	179.10	6.93
63	Apple		2	1	Stem	AP2S	142.12	160.34	18.22
63	Apple		2	1	Fruit	AP2F	142.07	149.68	7.61
63	Apple		2	2	Leaf	AP2L	121.22	127.65	6.43
63	Apple		2	2	Stem	AP2S	121.59	139.14	17.55
63	Apple		2	2	Fruit	AP2F	232.80	265.30	32.50

38	Apricot		5	1	Leaf	ARL	172.45	187.27	14.82
38	Apricot		5	1	Stem	ARS	232.76	240.79	8.03
38	Apricot		5	2	Leaf	ARL	171.65	179.08	7.43
38	Apricot		5	2	Stem	ARS	142.27	151.15	8.88
38	Apricot		5	3	Leaf	ARL	172.78	181.90	9.12
38	Apricot		5	3	Stem	ARS	141.78	147.44	5.66
38	Apricot		2,3,4,5	3	Fruit	ARF	192.51	250.89	58.38
44	Apricot			4	Leaf	ARL	172.99	188.92	15.93
44	Apricot			4	Stem	ARS	233.03	261.63	28.60
44	Apricot			4	Fruit	ARF	Totaled w/ 2,3, 4,5		
45	Apricot			5	Leaf	ARL	173.10	194.47	21.37
45	Apricot			5	Stem	ARS	232.96	253.85	20.89
45	Apricot			5	Fruit	ARF	Totaled w/ 2,3, 4,5		
46	Apricot			6	Leaf	ARL	172.95	197.57	24.62
46	Apricot			6	Stem	ARS	141.39	159.59	18.20
46	Apricot			6	Fruit	ARF	Totaled w/ 2,3, 4,5		
64	Carob		1	1	Leaf	CRL	165.47	176.30	10.83
64	Carob		1	1	Stem	CRS	121.76	156.82	35.06
64	Carob		1	1	Fruit	CRF	231.98	266.71	34.73
64	Carob		1	2	Leaf	CRL	171.90	188.99	17.09
64	Carob		1	2	Stem	CRS	121.97	148.85	26.88
64	Carob		1	2	Fruit	CRF	232.14	254.36	22.22
64	Carob		1	3	Leaf	CRL	172.16	195.07	22.91
64	Carob		1	3	Stem	CRS	121.78	160.40	38.62
64	Carob		1	3	Fruit	CRF	232.81	263.30	30.49
65	Carob		2	4	Leaf	CRL	120.98	137.95	16.97
65	Carob		2	4	Stem	CRS	120.59	154.03	33.44
65	Carob		2	4	Fruit	CRF	141.62	189.46	47.84
65	Carob		2	5	Leaf	CRL	122.02	139.42	17.40
65	Carob		2	5	Stem	CRS	121.74	160.95	39.21
65	Carob		2	5	Fruit	CRF	232.49	281.17	48.68
65	Carob		2	6	Leaf	CRL			0.00
65	Carob		2	6	Stem	CRS	121.85	162.46	40.61
65	Carob		2	6	Fruit	CRF	232.57	284.93	52.36
50	Fig		1	1	Leaf	FIL	192.83	206.54	13.71
50	Fig		1	1	Stem	FIS	121.34	139.83	18.49
50	Fig		1	1	Fruit	FIF	219.72	227.23	7.51
50	Fig		1	2	Leaf	FIL	165.40	177.13	11.73
50	Fig		1	2	Stem	FIS	232.13	242.79	10.66
50	Fig		1	2	Fruit	FIF	218.73	227.48	8.75
51	Fig		2	3	Leaf	FIL	170.38	181.41	11.03
51	Fig		2	3	Stem	FIS	232.88	253.36	20.48
51	Fig		2	3	Fruit	FIF	219.46	227.51	8.05

52	Fig		3	4	Leaf	FIL	192.80	201.81	9.01
52	Fig		3	4	Stem	FIS	141.13	157.72	16.59
52	Fig		3	4	Fruit	FIF	219.39	240.29	20.90
53	Fig		4	5	Leaf	FIL	191.48	209.00	17.52
53	Fig		4	5	Stem	FIS	121.32	145.88	24.56
53	Fig		4	5	Fruit	FIF	219.75	235.73	15.98
54	Fig		5	6	Leaf	FIL	166.33	177.76	11.43
54	Fig		5	6	Stem	FIS	121.39	135.75	14.36
54	Fig		5	6	Fruit	FIF	219.53	244.14	24.61
75	Grape		1	1	Leaf	GR1L	192.94	209.75	16.81
75	Grape		1	1	Stem	GR1S	191.99	196.80	4.81
75	Grape		1	1	Fruit	GR1F	191.98	200.18	8.20
75	Grape		1	2	Leaf	GR1L	191.79	206.11	14.32
75	Grape		1	2	Stem	GR1S			0.00
75	Grape		1	2	Fruit	GR1F	121.56	129.95	8.39
75	Grape		2	3	Leaf	GR2L	166.93	176.39	9.46
75	Grape		2	3	Stem	GR2S	192.71	198.99	6.28
75	Grape		2	3	Fruit	GR2F	191.71	216.52	24.81
75	Grape		2	4	Leaf	GR2L	192.59	207.21	14.62
75	Grape		2	4	Stem	GR2S	192.45	194.72	2.27
75	Grape		2	4	Fruit	GR2F			0.00
47	Nectarine		1	1	Leaf	NCL	192.38	201.96	9.58
47	Nectarine		1	1	Stem	NCS	121.22	137.25	16.03
47	Nectarine		1	1	Fruit	NCF			0.00
48	Nectarine		2	2	Leaf	NCL	166.80	177.81	11.01
48	Nectarine		2	2	Stem	NCS	141.06	168.23	27.17
48	Nectarine		2	2	Fruit	NCF			0.00
49	Nectarine		3	3	Leaf	NCL	165.50	177.23	11.73
49	Nectarine		3	3	Stem	NCS	121.88	153.33	31.45
49	Nectarine		3	3	Fruit	NCF	141.95	208.42	66.47
73	Oat	Feed		1	All	FOL-FOS	231.84	354.22	122.38
73	Oat	Feed		2	All	FOL-FOS	232.80	306.62	73.82
73	Oat	Feed		3	All	FOL-FOS	232.16	289.56	57.40
73	Oat	Feed		4	All	FOL-FOS	232.70	296.61	63.91
73	Oat	Feed		5	All	FOL-FOS	232.86	288.27	55.41
73	Oat	Feed		6	All	FOL-FOS	232.99	327.22	94.23
73	Oat	Feed		7	All	FOL-FOS	231.87	283.16	51.29
73	Oat	Feed		8	All	FOL-FOS	231.63	295.48	63.85
56	Pecan-UNKNOWN		1	1	Leaf	PCL	122.10	132.22	10.12
56	Pecan		1	1	Stem	PCS	121.24	134.80	13.56
56	Pecan		1	1	Fruit	PCF	142.16	163.38	21.22
66	Pistachio-grafted	Grafted	1	1	Leaf	GPL	121.65	135.62	13.97
66	Pistachio-grafted	Grafted	1	1	Stem	GPS	121.81	145.64	23.83
66	Pistachio-grafted	Grafted	1	1	Fruit	GPF	232.87	280.02	47.15
66	Pistachio-grafted	Grafted	1	2	Leaf	GPL	122.02	132.62	10.60

66	Pistachio-grafted	Grafted	1	2	Stem	GPS	122.09	162.91	40.82
66	Pistachio-grafted	Grafted	1	2	Fruit	GPF	167.29	213.96	46.67
67	Pistachio-grafted	Grafted	2	3	Leaf	GPL	166.53	182.93	16.40
67	Pistachio-grafted	Grafted	2	3	Stem	GPS	192.61	222.61	30.00
67	Pistachio-grafted	Grafted	2	3	Fruit	GPF	141.95	182.45	40.50
67	Pistachio-grafted	Grafted	2	4	Leaf	GPL	165.99	183.71	17.72
67	Pistachio-grafted	Grafted	2	4	Stem	GPS	120.40	167.29	46.89
67	Pistachio-grafted	Grafted	2	4	Fruit	GPF	141.69	156.64	14.95
68	Pistachio-grafted	Grafted	3	5	Leaf	GPL	121.60	149.77	28.17
68	Pistachio-grafted	Grafted	3	5	Stem	GPS	121.47	167.40	45.93
68	Pistachio-grafted	Grafted	3	5	Fruit	GPF	142.21	182.34	40.13
69	Pistachio-grafted	Grafted	4	6	Leaf	GPL	121.65	143.78	22.13
69	Pistachio-grafted	Grafted	4	6	Stem	GPS	121.03	171.87	50.84
69	Pistachio-grafted	Grafted	4	6	Fruit	GPF	141.91	159.88	17.97
70	Pistachio-natural	Natural	1	1	Leaf	NPL	172.13	191.55	19.42
70	Pistachio-natural	Natural	1	1	Stem	NPS	232.94	282.62	49.68
70	Pistachio-natural	Natural	1	1	Fruit	NPF	231.92	272.46	40.54
70	Pistachio-natural	Natural	1	2	Leaf	NPL	170.67	191.55	20.88
70	Pistachio-natural	Natural	1	2	Stem	NPS	121.58	168.13	46.55
70	Pistachio-natural	Natural	1	2	Fruit	NPF	232.08	267.19	35.11
71	Pistachio-natural	Natural	2	3	Leaf	NPL	170.93	196.07	25.14
71	Pistachio-natural	Natural	2	3	Stem	NPS	141.93	190.20	48.27
71	Pistachio-natural	Natural	2	3	Fruit	NPF	232.73	278.22	45.49
71	Pistachio-natural	Natural	2	4	Leaf	NPL	172.26	203.81	31.55
71	Pistachio-natural	Natural	2	4	Stem	NPS	142.13	191.87	49.74
71	Pistachio-natural	Natural	2	4	Fruit	NPF	232.23	280.86	48.63
72	Pistachio-natural	Natural	3	5	Leaf	NPL	191.56	200.72	9.16
72	Pistachio-natural	Natural	3	5	Stem	NPS	141.85	166.01	24.16
72	Pistachio-natural	Natural	3	5	Fruit	NPF	232.18	250.73	18.55
72	Pistachio-natural	Natural	3	6	Leaf	NPL	170.66	180.21	9.55

72	Pistachio-natural	Natural	3	6	Stem	NPS	120.87	154.17	33.30
72	Pistachio-natural	Natural	3	6	Fruit	NPF	232.76	282.80	50.04
39	Pomegranate		1	1	Leaf	POL	192.25	205.46	13.21
39	Pomegranate		1	1	Stem	POS	141.12	150.93	9.81
39	Pomegranate		1	1	Fruit	POF	192.66	294.59	101.93
40	Pomegranate		2	2	Leaf	POL	171.67	181.69	10.02
40	Pomegranate		2	2	Stem	POS	122.12	133.11	10.99
40	Pomegranate		2	2	Fruit	POF	218.59	306.87	88.28
41	Pomegranate		3	3	Leaf	POL	171.88	179.97	8.09
41	Pomegranate		3	3	Stem	POS	121.69	139.67	17.98
41	Pomegranate		3	3	Fruit	POF	232.89	349.07	116.18
42	Pomegranate		4	4	Leaf	POL	171.77	179.15	7.38
42	Pomegranate		4	4	Stem	POS	121.51	137.59	16.08
42	Pomegranate		4	4	Fruit	POF	191.66	246.84	55.18
43	Pomegranate		5	5	Leaf	POL	191.66	201.04	9.38
43	Pomegranate		5	5	Stem	POS	122.09	128.39	6.30
43	Pomegranate		5	5	Fruit	POF	231.94	364.86	132.92
43	Pomegranate		5	6	Leaf	POL	171.69	178.64	6.95
43	Pomegranate		5	6	Stem	POS	121.79	134.27	12.48
43	Pomegranate		5	6	Fruit	POF	232.88	333.31	100.43
	Carob		3	6	Leaf	CRL	120.33	133.11	12.78
	Grape		1	1	Fruit	GRF	232.05	241.11	9.06
	Grape		2	2	Fruit	GRF	232.35	245.07	12.72
	Nectarine		1	4	Leaf	NCL	121.47	138.99	17.52
	Nectarine		3	6	leaf	NCL	121.62	135.50	13.88
	Nectarine		3		leaf	NCL	122.15	140.53	18.38
	Nectarine		3		Stem	NCL	120.83	129.81	8.98
	Nectarine		1	4	Stems	NCS	141.03	172.17	31.14
	Nectarine		3	5	Stems	NCS	232.20	261.29	29.09
	Nectarine		3	6	Stem	NCS	121.74	147.11	25.37
	Apricot- fruit collected from ground				Fruit	ARF	192.27	316.12	123.85

Appendix B

IAEA Critical analysis : Arguments for revising the IAEA TRS No. 364

IAEA/EMRAS

Revision of the IAEA Technical Reports Series No. 364 : Handbook of parameter values for the prediction of radionuclide transfer in temperate environments

Critical analysis : Arguments for revising the IAEA TRS No. 364

Pascal Santucci, Gabi Voigt, DRAFT, 4th November 2004
comments included : Shigeo Uchida, Sylvie Roussel-Debet

1. Introduction

Most of the safety, performance, or radiological impact assessments concerning either actual or potential releases, when they comprise biosphere calculations, use parameters such as transfer or accumulation factors requiring their associated values. One international example is the IAEA SRS No. 19 (2001) on the assessment of routine releases. If future assessment purposes are currently considered, such as those linked to overall environmental impact assessments (Hunter, 2001), most of the current biosphere models still need such parameters and associated values.

In the literature, as said by Whicker et al. (1999), overall syntheses are not very numerous (e.g. the well known Coughtrey, Jackson and Thorne, 1985). One important document is widely used by the scientific community : the IAEA Technical Reports Series No. 364, "Handbook of parameter values for the prediction of radionuclide transfer in temperate environments", published in collaboration with the International Union of Radioecologists (IUR) in 1994. Its contents reflected radioecological results up to 1992. TRS 364 is widely used as a major source of information, because it addresses numerous environmental transfer parameters and radionuclides. It is therefore quoted in numerous impact assessments, even if amended or completed by the scientific community (radiation protection, radioecology). Moreover, many radiation protection models need to predict transfer of a large number of radionuclides. This requires information on transfer of many less mobile radionuclides, which do not usually comprise an important component of discharges or dose. Such information is often sparse and difficult to collate. TRS 364 provides an important source of such information, and is one of the key cited sources for many models. It is thus essential that such information is kept up-to-date and that any relevant recent literature is included, especially considering the paucity of existing data sources.

Since 1992, new data have also been produced, such as post-Chernobyl information (Shaw, 2001), and new experimental results (e.g. lysimeter studies), potentially completing the existing data and syntheses, which are now more than 10 years old. A number of high quality critical reviews have been produced in recent years for some of the transfer parameter values which merit consideration. International programmes have also been devoted to the construction and validation of radioecological models : BIOMOVS, IAEA/VAMP, IAEA/BIOMASS, European Frameworks, etc. It is then assumed that there is sufficient new information available to warrant reconsideration of a significant proportion of the values given in TRS 364.

As a consequence, there are arguments for updating TRS 364 and extending it, in terms of compartments, processes and radionuclides, and even for improving its current contents, because a critical analysis can highlight some weaknesses. This explains why the IAEA decided in 2003 to include the revision of TRS 364, as a topic of the EMRAS programme, "Environmental modelling for radiation safety".

2. Justification for the performance of an updated synthesis at an international level

Behind the necessity to take into account progress of science and knowledge, one question is to know to what extent it is useful or necessary to sustain an international work on that field, rather than letting individuals manage the existing information.

During the IAEA/BIOMASS programme, a group was devoted to the issue regarding data selection for biosphere assessment models. It showed that even if biosphere parameters cannot be considered as "constant" as the ICRP dose coefficients, they can be tabulated : as default values when well characterised : this could be the case for IUR soil-to-plant transfer factors, according to broad crop groups ; as example values or representative values, directly used if the parameter is not much important in the assessment ; as a starting point if the parameter appears critical (link with sensitivity and uncertainty analyses).

Compilation and tabulation of data is then useful, but if the people in charge of such a work have limited expertise (scope) and little resources, there is a risk of introducing biases during the process of data selection (see discussion about expert judgment, e.g. Thorne&Williams, 1992) :

- Representativeness of data, e.g. : individuals are insensitive to sample size : the same weight, or level of confidence, can be attributed to parameter values for which there are much or little data (issue when the assessment addresses a broad spectrum of radionuclides) ; individuals are over-sensitive to information, even when information is not related to data : see discussions about site-specific data.

- Availability of data, e.g. : individuals favour the easily available and understandable information : it is a question of review management, but also of institutional culture ; individuals can misinterpret the co-occurrence of naturally associated characteristics : the influence of potential co-factors could then be assumed rather than tested.

- Anchoring, e.g. : individuals have difficulties to depart from initial values they know, even if the assessment context requires it ; individuals have the tendency to underestimate the range of variation of a parameter.

From these arguments, it follows that : review and syntheses performed by individuals or small groups will generally be limited in scope (few compartments and processes) for a given assessment context. The recourse to structured elicitation exercises appear interesting, but it is resource consuming and past experience has shown that it is difficult to systematically implement them (US/NRC&EU on COSYMA, BIOMASS on data selection) ; according to some participants, their intrinsic value may even look doubtful ... An intermediate way is to try to build syntheses and databases at an international level : access to a large audience with various backgrounds and levels of expertise, optimisation of resources by the sharing of the overall effort (e.g. by ecological field) and the already existing material (reviews, bibliographic material, databases).

3. General features of the revision of IAEA TRS No. 364

Due to the large audience and use of TRS 364, there is a need to keep such a document as relevant, accurate and consistent as possible : relevant first, because the purpose is to cover various assessment contexts such as routine releases and accidental conditions, atmospheric and liquid releases, etc. It should be accurate because mistakes should be corrected and avoided, up-to-date science should be incorporated (this could be difficult when data is scarce, as is the case for less mobile radionuclides). And last, it should be consistent : consistency between tables should be ensured, especially with regards to the list of radionuclides considered, all the more since integrated assessments require it.

An assessment of the quality of data obtained is of paramount importance to assure that the suggested best estimates of the environmental parameters can be used in generic predictive models. In an ideal world, a critical evaluation of data would include a statistical analysis of the data. However, because of the availability of resources, this was not attempted in TRS 364, and it may be difficult to carry it out in a revision.

In practice, the expected values and ranges given in TRS 364 are based on a variety of different approaches which are not clearly specified for each value. They comprise statistical analysis, expert judgement or sometimes only a single experiment. For some of the tables (e.g. animal transfers) the approach has been specified for each value ; it is recommended to extend this approach to all other tables as far as possible.

Uncertainty should be mostly addressed by giving ranges of variation ; in some cases probability density functions could be built through the performance of statistical analyses of databases (e.g. on some Kds and soil-to-plant transfer factors). The question should be raised about the extrapolation of their statistical results to other categories (e.g. confidence intervals extrapolated from one radionuclide to another). When data is scarce or missing, a discussion should be held concerning the use of chemical analogues as a way of completing the tables. Variability could be reduced by revising classification systems (e.g. crop groups) and introducing co-factors (e.g. with Kds, soil-to-plant TFs).

Steady state models are routinely used for dose assessment, for screening purposes and operational releases. Information in the TRS 364 is directly relevant for such models, when time dependency in transfers is neglected. Many dynamic models are intended for dose assessment in emergency situations. For such models, often both empirical (using classification of systems) and semi-mechanistic approaches are used. The availability and applicability of improved dynamic models based largely on mechanistic information is limited. In general, such models have only been developed for a small number of radionuclides (notably caesium and strontium), in particular types of system, such as caesium behaviour in soils, forests or freshwaters or metabolically based models of animals. Such models have the additional advantage of being able to include the effect of countermeasures in a mechanistic way and complement other more generalised models used for radiation protection purposes. It is therefore important to consider whether the continued use of empirical transfer values is always justified and appropriate.

For an accurate mathematical description of dynamic processes a multi-compartment model, in which the material fluxes are described by mechanism-based rate equations, is essential. Such dynamic models apply to cycling of radionuclides in ecosystems, retention and accumulation, migration and leaching. It is recognised that complex dynamic models, all the more because they often lack consensus and large validation, are outside of the scope of a revised TRS 364. An exception is made for dynamic one-compartment models in which processes can be modelled by a half-life concept. The dynamics of some of these processes are so important, that neglecting them would be a serious shortcoming of the new TRS. A consideration of changes with time in terrestrial and aquatic systems, expressed as ecological half-lives in different food products and reflecting processes involved in the long-term transfer from soil to vegetation, provides an important improvement for modelling.

Nomenclature should be tested against official documents such as ICRU 65 (2001) "Quantities, Units and Terms in Radioecology" : it contains a list of units and quantities frequently used in the field of radioecology, and tries to harmonise these units derived from varying different disciplines such as ecology, chemistry, medicine or physics.

4. Analysis and completion of the existing TRS 364

4.1. Methodology

Section by section (based on ecological domains), the methodology for reviewing the current synthesis is the following : list the processes of interest ; review the modelling aspects, in terms of compartments and processes, minimum model representation, alternative modelling, potential co-factors ; analyse the radionuclides currently taken into account ; consider the classification systems ; highlight weaknesses and mistakes ; and check the availability of new data for selection and inclusion in a new TRS.

When rewritten, the sections will be articulated according to a main text devoted to explaining the main processes involved, with the usual associated parameters, co-factors influencing some processes or the determination of parameters values, and key equations used for describing and assessing the transfers. The IAEA SRS 19 could be a basic reference for simple modelling. Besides, tables of transfer coefficients will be displayed, with values depending on species (or groups of species), environmental conditions, co-factors, etc. The references used will be quoted.

4.2. Agricultural systems - Foliar interception, retention and translocation

Foliar interception is a prominent process after initial release from a nuclear facility. The section is not clear enough and not self-sufficient for building the intended model structure. It shows strong link with plant characteristics, at least because the plant stage of development is a very important factor. For contamination of surfaces, three deposition pathways are considered : direct dry or wet deposition and resuspension processes. With regard to the latter, only the soil adhesion to vegetation is considered since it may affect the ingestion dose.

The interception values for dry deposition refer to experimental work mostly performed in the early nineteen seventies. Values relating to wet deposition refer mainly to two references published in 1965 and 1977. Meanwhile, much more data has become available which needs to be included, such as experimental and post Chernobyl studies. Also information on the seasonality of intercepted fractions relating to the biomass of different plant species could be greatly improved (in TRS 364 only one reference is given). Instead of providing individual experimental results, a critical compilation of values showing the dependence of intercepted fractions on the precipitation intensity, time lack, season and plant species should be tabulated. It has also been deemed useful to introduce deposition velocities. Since there is a requirement arising from the waste assessment field, irrigation processes, considered as a particular case of the wet deposition, should also be introduced.

Under accidental conditions, parameter values should not be averaged over the year. With such a context, the physico-chemical features of the source-term may be of importance (granularity, solubility). The amount of rainfall should also be specified. The European RODOS programme could be an important source of information.

In TRS 364, the processes of foliar absorption, translocation and retention need to be clearly distinguished. In TRS 364, a collation of different translocation coefficients for crops with time dependencies before harvest are given, however conclusions or recommendations on which values to use are not provided. The aim should be to derive generic parameter values from a review of revised data compilation. In addition, the conclusions and recommendations in IAEA/ TECDOC 857 (1996) should also be considered.

New data can be added on the transfer to fruit. Inclusion of time dependency in trees and understory vegetation (berries) and retention in the canopy information on interception and translocation might be useful as their features are different from the other crop groups.

4.3. Agricultural systems - Soil retention and migration : Kds

The current classifications of soil systems used in TRS364 are rather simplistic and limited to only four categories: sand, loam, clay and peat ; they are somewhat inadequate to account for the soil parameters that govern the behaviours of different RN. The values were based on a relatively low number of experiments for a limited number of soils within each category. In recent years the number of data for each category has greatly increased, and analysis of the data distribution has shown a high variability and high degree of overlap. Revised classification systems are currently developed which are based on mechanistic information including consideration of parameter values such as pH, soil nutrient status, % clay, exchangeable K and Ca in soil, moisture content of soil, organic matter content and the time that a radionuclide is present in a soil. Numerous multiregression analyses have been developed and give reasonable predictions on a local scale but have not been proven on a world-wide scale. At least for some radionuclides (e.g. Cs, Sr, U, Tc) a semi mechanistic approach should be used.

4.4. Agricultural systems - Uptake from soil to plant

At the time that TRS 364 was prepared, the IUR had already introduced “crop groups” as cereals, green vegetables, root crops, etc. It was, however, not yet then possible to use these crop groups to provide expected uptake parameters, so separate transfer values were provided for wheat, barley, rye, etc. These crop groups should now be introduced.

Currently, data given on soil-to-plant transfer factors given in TRS 364 generally uses three approaches :

For Cs and Sr, separate values are given for different soil categories (sand, loam, clay and peat) with a pH constraint. In recent years, the number of data for Cs and Sr has greatly increased, and analysis of the data distribution has shown a high variability and high degree of overlap. Revised classification systems are currently being developed which are based on mechanistic information including consideration of parameter values of co-factors, such as pH, soil nutrient status, % clay, exchangeable K and Ca in soil, moisture content of soil, organic matter content and the time that a radionuclide is present in a soil, in consistency with those adopted for Kds.

For Pu, Am and many other radionuclides, soil type is not considered. The data have largely been collated between 1980 and 1990. For some of them, e.g. Pu, Am, Co, Mn, Tc, Zn, new data are available. For others it is doubtful that sufficient values for updating tables are available.

Less frequently studied radionuclides are generally based on much older literature. There are probably few data available.

Both for the second and third group it is probably worthwhile to consider the uptake data of stable elements. In particular, heavy metals have received considerable recent attention.

4.5. Agricultural systems - Transfer from feed to animal products

This section could be improved by a review of recent literature even if new data are more difficult to find than for plants. For many of the radionuclides, the tabulated data are based on a compilation originating from databases more than 20 years old. The intake rates of feedstuff by animals are based on European conditions only and should be supplemented by data for other areas of the world. Some FAO activities and results could be of use.

For ingestion doses the application of equilibrium transfer coefficients for animal products is inappropriate for radionuclides with long biological half-lives. Therefore, in TRS 364 some transfer coefficients were modified to account for a known lack of non-equilibrium. This approach needs to be extended, possibly by providing half-life information, and evaluated. Furthermore for strontium, iodine and caesium information on biological half-lives is available and can be compiled.

A statistical analysis of the data is not possible for TRS 364 because many of the values came from reviews using extensive data and individual data sets which were not available. Supplementation of recent data with these reviews was attempted, but was only possible using expert judgement. For some selected radionuclides a statistical analysis could be performed since sufficient data and data sets are available. However this would be extremely time consuming and is unrealistic. It is therefore recommended to use recently published reviews where statistical analysis have been attempted.

In the last decade detailed and improved information on the influence of stable analogues for caesium, strontium and iodine has become available and should be considered for inclusion in revision of TRS 364.

4.6. Freshwater systems

This chapter should be rewritten and enhanced in terms of compartments and processes included, and environmental conditions, in consistency with the IAEA SRS 19 ; in particular, bottom sediments and water particles should be distinguished, as well as trophic levels for fish.

Concerning partition coefficient suspended matter/water : The adsorption and desorption processes of radionuclides by suspended matter strongly influences the behaviour of radioactive substances in freshwater systems. Consequently, considerable research has been carried out on these processes. The most common and simple approach for modelling the adsorption/ desorption processes at equilibrium is based on the partition coefficient Kd. The correlation between the partition coefficient and the chemical characteristics of the water body should be described. A variety of researchers have demonstrated that non reversible adsorption processes are of importance for some radionuclides, notably caesium. A table of non reversible fraction rates for caesium in different freshwater ecosystems should be included.

Concerning other relevant migration processes and parameters : Among the various processes occurring in water bodies the thermal stratification phenomena of deep lake water may strongly influence the concentration of any floating material in the water column. Stratification and de-stratification have a marked seasonal behaviour which can result, even for steady state releases, in significant seasonal variation in contamination levels in water and fish. During the stratification period, the diffusion of dissolved radionuclides in the upper layer of lake water (epilimnion) to the bottom water layer (hypolimnion) is prevented by the presence of an intermediate layer (thermocline) that shows a marked temperature gradient. To be able to model the above process, effective diffusion coefficients are needed. Furthermore, more data are required for parameters of migration from water column to bottom sediments possibly including migration velocity.

In TRS 364, the table concerning fish is based on a large database for a wide range of elements. However, the method of selection for the expected values is not specified and appears to be inconsistent. However, data are quite comprehensive and might be supplemented by a few recent literature reviews on concentration factors for the edible portion of fish in freshwater environments.

4.7. Semi-natural ecosystems : forests

It is important to include semi-natural ecosystems for caesium because the range of products harvested differs greatly from other ecosystems and the rate of transfer to food products is often much higher than for other ecosystems. Furthermore, the ecological half-lives of caesium in many products harvested from these ecosystems is much longer than in agricultural systems. For some populations, consumption of semi-natural products is common, for others it is confined to certain special groups. For both cases, such consumption can form a major proportion of ingestion dose in the mid-long term after deposition.

The section on semi-natural ecosystems in TRS 364 was largely based on simple aggregated transfer coefficients, since the inherent variability and complexity of such systems make predictions using other approaches difficult. Recently, some dynamic models have been developed which allow the estimation of transfer to certain forest products, but the number of products considered is limited. It is therefore recommended that the same parameter should be used in the revision to be able to include as wide a range of products as possible. The extension of the radionuclide spectrum should also be sought. Fortunately, data availability has greatly increased since 1992, largely from the considerable focus in both Europe and the CIS on caesium transfer to forest products.

Some game species and humans consume large quantities of mushrooms which can take up large quantities of Cs. Mushroom consumption can therefore be a dominant pathway for the ingestion of caesium. Currently much more data on mushroom transfer have now become available. For arctic systems significant improvement of TRS 364 is now possible for quantifying transfer of caesium to reindeers and its time dependency, based on a review carried out under the Arctic Monitoring and Assessment Programme (AMAP).

Recent analysis of transfer to macrofungi suggested that it is not statistically valid to give separate values for individual mushroom species, as done in TRS 364. Instead, tag values for ecological categories could be more appropriate (mycorhizal, saprophitic and parasitic). Reviews of tag values are now available for many products and it should be possible to acquire or carry out statistical analysis of data for many products. In addition, improved ecological half-life data are available for many products, notably reindeer, moose, roe deer and wild boar, and should now be reported.

Descriptive text on the transfer processes for each food product could be substantially improved and extended. Mushroom species with consistently higher transfer values than the mean for their ecological category could be identified (e.g. Rozites caparata). In addition, it may be possible to give some information on the dependency on soil type for a few mushroom species.

4.8. Food processing

There are a lot of tables, but they are particularly useful in a context of accidental management. It is recommended to simplify them by focusing on the most efficient processes for radioactivity reduction. For instance, one could focus on the processing of dairy products and mushrooms.

5. Extension of TRS 364 in scope, compartments and processes

5.1. Radioelements

At a methodological level, a discussion on chemical analogy should be introduced as a way to overcome the lack of data for some radionuclides, especially if consistency between the tables should be reached.

There are so-called "special" radionuclides such as ^{3}H, ^{14}C, maybe even iodine or chlorine. If possible, it is suggested to keep their specificity, provided that data could feed the tables. Specific models should be explicited.

5.2. Climate conditions

TRS 364 was limited to temperate climatic zones because, at the time, few data from other climatic zones were available. Since 1992, new data on both arctic regions and tropical environments have become available. From this new data it appears that the climate itself seems to have little direct influence on radioecological transfer parameters, but that nevertheless the impact of the climate on other important parameters is large. Climate and parent rock material determine, to a large extent, the development of soil type.

In tropical areas, several soil types occur in which radionuclide uptake by crops consistently deviate from the expected values given in TRS 364. Under these hot and wet conditions almost all organic material which reaches the soil surface decomposes rapidly; the accumulation of soil organic matter is therefore minimal, and there is rapid recycling into the vegetation. In temperate zones, the decomposition of organic debris is slower and accumulation of soil organic matter can be larger than the rate of decomposition resulting in highly organic soils.

In arctic regions, ammonium, which is formed during decomposition of organic matter, may not be completely oxidised, leaving it available for competition with radionuclide cations. Ammonium has a five fold higher affinity than potassium for illitic adsorption sites; this influences the fixation of caesium.

Such examples show that if at least fundamental processes are well documented, their dependence on temperature could be taken into account.

5.3. Asian food-chains

Because agricultural products and food customs in Asian countries are different from those in temperate ones, it is expected that the critical foods differ as well. In European and North American countries, livestock products including meat, eggs, and milk make a big contribution, while, in Asian countries, agricultural products including cereals and vegetables are the main contributors.

It has also been suggested to extend TRS 364 by introducing Asian food chains. Such food-chains refer to several climate conditions, from temperate to tropical. Some crops are grown under particular conditions, as is the case for flooded rice.

The FAO/IAEA, in cooperation with IUR, has established various programmes which are of use for feeding a new TRS : namely, those entitled "Transfer of radionuclides from air, soil, and freshwater to the foodchain of man in tropical and sub-tropical environments" (1993-1997), and "The Classification of Soil Systems on the Basis of Transfer Factors of Radionuclides from Soil to Reference Plants" (1999-2003).

5.4. Secondary pathways of contamination

Atmospheric resuspension and wash-off should be introduced as new processes because they are prominent secondary pathways of contamination.

Wash-off amounts to roughly less than $1\%.y^{-1}$ for Cs and Sr : it is not important in terms of losses (in a short term period), but it is very important for the secondary contamination of rivers. It depends on amount of water, soil cover, slope or profile. Erosion is included in wash-off. There is a competition with vertical migration, which is an argument for time-dependency. In recent years, many attempts have been carried out to develop new approaches which allow modellers to predict radionuclide migration from catchments by using more simple generic models including half-lives and transfer factors. Due to the data available in the international literature following the Chernobyl accident, it is possible to produce a limited, but somewhat instructive, list of half-lives and transfer factors mainly for ^{90}Sr and ^{137}Cs. This list could be helpful for generic models applicable to both steady state and dynamic conditions.

Resuspension and soil adhesion are relevant when soil to plant transfer factors are low (slow transfers). However, soil adhesion should not be taken too seriously due to the interaction with food processing (washing, peeling, etc.).

6. Revision of TRS 364 in practice ...*(we are waiting for organisation by section)*

- The revision of TRS 364 is one of the main activities of the IAEA programme EMRAS (Environmental modelling for radiation safety), 2003-2006(7)

- The overall work plan is the following (per year) :
    - September 2003, EMRAS plenary : about 20 participants ; agreement on work and milestones
    - November 2004, EMRAS plenary : first draft on the critical analysis of TRS 364, synthesis on new available data, draft of computerised database
    - End 2005, EMRAS plenary : final documents on the TRS critical analysis and on data availability, draft of TRS concerning already included parameters, draft on new parameters/ processes to be included, draft CD-rom with new data
    - End 2006, EMRAS plenary : draft of overall new TRS, draft 2 of CD-rom with source data

    2007 : finalisation of TRS

- Material :
    - nearly 90% of the TRS 364 references have been recovered (about 200)
    - about 400 new references of interest have been found (later than 1992), including reviews and syntheses ; the grey literature should not be discarded if valuable (institutional reports) which is the case with some overall syntheses
    - some databases : IUR for soil-to-plant transfers, IAEA CRP on tropical systems, EU RadFlux multi-compartments too, national databases (NRPB, IRSN) on Kds, soil-to-plant TFs, animals, food processing

- Collaboration with IUR :
    - TRS 364 was issued in collaboration with IUR
    - most of the IAEA/EMRAS participants belong to IUR
    - the well known database on soil-to-plant TFs was managed by IUR ; IUR was a co-sponsor of RadFlux
    - there are IUR working groups of interest for the revision (radioecology of rice, radioecology and waste (special radionuclides)), which explains that this revision is also an IUR activity
    - an official agreement between IAEA and IUR is about to be reached, as a way to benefit also from the IUR audience

7. Conclusion

The revision of the IAEA TRS No. 364, "Handbook of parameter values for the prediction of radionuclide transfer in temperate environments", published in collaboration with the IUR, is an ambitious effort which is required by the progress of radioecology, expected by numerous users, and made possible by an international collaboration launched through the IAEA/EMRAS programme.

Since such an activity demands expertise and resources, all institutions, all experts are welcome to contribute and participate through the existing channels : IAEA/EMRAS, IUR or even personal contacts.

8. References

Coughtrey, P.J., Jackson, D., Thorne, M.C., 1985. Radionuclide Distribution and Transport in Terrestrial and Aquatic Ecosystems - A compendium of data. Balkema, A.A. Publishers, Rotterdam, Netherland.

Hunter, G., 2001. Developments in radioecology in the new millennium. Journal of Environmental Radioactivity 56 (2001) 1-6.

IAEA, 1994. Handbook of parameter values for the prediction of radionuclide transfer in temperate environments. IAEA Technical Reports Series No. 364. International Atomic Energy Agency, Vienna, Austria.

IAEA, 1996. Modelling of radionuclide interception and loss processes in vegetation and of transfer in semi-natural ecosystems. TECDOC No. 857, Second report of the VAMP Terrestrial Working Group. International Atomic Energy Agency, Vienna, Austria.

IAEA, 2001. Generic models for use in assessing the impact of discharges of radioactive substances to the environment. IAEA Safety Reports Series No. 19. International Atomic Energy Agency, Vienna, Austria.

ICRU, 2001. Report 65 : Quantities, Units and Terms in Radioecology. Journal of the ICRU, vol. 1, n° 2. International Commission on Radiation Units and Measurements, Nuclear Technology Publishing, Ashford, England.

Shaw, G., 2001. Radioecology – How did we get here and what do we do now ? Journal of Environmental Radioactivity 54 (2001) 305-309.

Thorne M.C., Williams M.R., 1992. A review of expert judgment techniques with reference to nuclear safety. Progress in Nuclear Energy, Vol. 27, No. 2/3, pp. 83-254.

Whicker F.W., Shaw, G., Voigt, G., Holm, E., 1999. Radioactive contamination : state of the science and its application to predictive models. Environmental Pollution 100 (1999) 133-149.