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Analysis Approach and Data Package for Mayak Public Doses

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August 2013

Pacific Northwest
NATIONAL LABORATORY

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Data Supporting the Calculation of Representative Doses to Members of the Public from Airborne Releases of ^{131}I at the Mayak Production Association from 1948 through 1972

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SUMMARY

Historical activities at facilities producing nuclear materials for weapons released radioactivity into the air and water. Past studies in the United States have evaluated the release, atmospheric transport and environmental accumulation of ^{131}I from the nuclear facilities at Hanford in Washington State and the resulting dose to members of the public (Farris et al. 1994). A multi-year dose reconstruction effort (Mokrov et al. 2004) is also being conducted to produce representative dose estimates for members of the public living near Mayak, Russia, from atmospheric releases of ^{131}I at the facilities of the Mayak Production Association.

The approach to calculating individual doses to members of the public from historical releases of airborne ^{131}I has the following general steps:

- Construct estimates of releases of ^{131}I to the air from production facilities.
- Model the transport of ^{131}I in the air and subsequent deposition on the ground and vegetation.
- Model the accumulation of ^{131}I in soil, water and food products (environmental media).
- Calculate the dose for an individual by matching the appropriate lifestyle and consumption data for the individual to the concentrations of ^{131}I in environmental media at their residence location.

A number of computer codes were developed to facilitate the study of airborne ^{131}I emissions at Hanford. Of particular interest is DESCARTES code that modeled accumulation of ^{131}I in environmental media (Miley et al. 1994). In addition, the CIDER computer code estimated annual doses to individuals (Eslinger et al. 1994) using the equations and parameters specific to Hanford (Snyder et al. 1994).

Several of the computer codes developed to model ^{131}I releases from Hanford are general enough to be used for other facilities. Additional codes have been developed, including the new individual dose code CiderF (Eslinger and Napier 2013), and applied to historical releases of ^{131}I from Mayak. This document provides a data package that identifies computer code runs and associated input and output files prepared for the purpose of calculating doses to members of the public from atmospheric releases of ^{131}I at the Mayak Production Association for the time period 1948 through 1972.

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1.0 Introduction

1.1 Purpose

This computational activity was conducted to produce representative dose estimates for members of the public living near Mayak, Russia, from atmospheric releases of ^{131}I from the Mayak Production Association. This activity is part of a multi-year dose reconstruction effort (Mokrov et al. 2004). This document outlines the approach, code runs and data sets needed to calculate doses for members of the public living in or near Ozersk, Russia. It does not produce a complete suite of dose estimates or interpret the doses.

The approach to calculating individual doses to members of the public from historical releases of airborne ^{131}I has the following general steps:

- Construct estimates of releases of ^{131}I to the air from production facilities.
- Model the transport of ^{131}I in the air and subsequent deposition on the ground and vegetation.
- Model the accumulation of ^{131}I in soil, water and food products (environmental media).
- Calculate the dose for an individual by matching the appropriate lifestyle and consumption data for the individual to the concentrations of ^{131}I in environmental media at their residence location.

The sequence of calculations uses release estimates from facilities and atmospheric transport modeling to calculate ^{131}I concentrations in environmental media (air, soil, and food products) on a grid of locations. The model region (grid of locations) is large enough to include the production of agricultural products supplied to residents of Ozersk from the collective farms identified in Figure 1 of (Mokrov et al. 2007a).

Some milk and leafy vegetable products consumed by residents of Ozersk came from a production and distribution system (collective farms) rather than being produced at the location where an individual lived. Therefore, the following two steps are used:

- **Leafy Vegetable Distribution**. A commercial distribution system for leafy vegetables is defined. This allows a city resident to eat leafy vegetables produced at a different location (a collective farm, for example).
- **Milk Distribution**: Milk was produced at private farms, collective farms and also from backyard animals. A milk distribution system is defined where a collective farm produces milk (called a creamery in the user guide for the DESCARTES code) and then supplies that milk to city residents (called a grocery in the user guide for the DESCARTES code). This technique models the movement of milk products from farms to consumers.

Three suites of calculations are identified in this analysis log. The first suite uses best estimates of all input parameters (best estimate case). The second suite uses stochastic inputs in a Monte Carlo approach to provide uncertainty estimates in the doses (stochastic case). A third suite uses stochastic releases and stochastic atmospheric transport, but best estimates for all other parameters (mono case).

1.2 Data Availability

The series of milestone reports produced by the U.S.-Russian Joint Coordinating Committee on Radiation Effects Research, Project 1.4, (Rovny et al. 2009; Mokrov et al. 2009; Anspaugh and Napier 2009; Mokrov et al. 2008a; Mokrov et al. 2008b; Napier et al. 2008; Mokrov et al. 2007a; Mokrov et al. 2007b; Mokrov and Beregich 2006; Mokrov et al. 2004; Drozhko and Khokhryakov 2003) generally contain the data needed to run the suite of codes. Some of the data in those reports reference data collected for the Hanford Dose Reconstruction Project (Snyder et al. 1994). We note the source of any auxiliary data in later sections.

The historical atmospheric data needed to run the RATCHET code (Ramsdell Jr. et al. 1994) to produce air concentrations and surface deposition of ^{131}I were not available at the time of this calculation. Instead, this calculation uses the HYSPLIT code (Draxler and Hess 1998). Meteorological data suitable for use with HYSPLIT are available on a web server (GDAS 2012).

Many of the data files or spreadsheets referenced in this document are provided in an electronic data package. See Section 7.0 for an overview of the electronic data package contents.

1.3 Summary of Computer Code Runs

The computer codes used in this calculation are identified in Table 1.1. The codes in Table 1.1 with documentation by Miley or Draxler have been tested extensively. The other codes have not been subjected to a formal testing process. A 64 bit version of Windows is required for the codes executing on a Windows platform.

Table 1.1 Computer Codes Used in the Analysis

Code	Platform	Documentation	Version	Revision
srcSetupRuns	Linux	(Eslinger and Napier 2013)	M.01.001	24 Apr 2003
QsubRuns	Linux	(Eslinger and Napier 2013)	3.04.001	3 Apr 2013
HYSPLIT	Linux	(Draxler et al. 2012)	Serial	February 2013
AirGrid	Linux	Eslinger and Napier 2013)	1.00.004	16 Jul 2013
AirCombGrid	Linux	(Eslinger and Napier 2013)	1.00.002	20 Jun 2013
AirCombGridView	Windows	(Eslinger and Napier 2013)	1.01.003	24 Jun 2013
DESCARTES	Windows	(Miley et al. 1994)	4.004	16 Jul 2013
ADIETP	Windows	(Miley et al. 1994)	3.1.B	29 Nov 2012
FrostpUno	Windows	(Eslinger and Napier 2013)	4.0.1	16 Jul 2013
RECIPE	Windows	(Miley et al. 1994)	3.1.B	30 Nov 2012
CiderF	Windows	(Eslinger and Napier 2013)	1.03.016	12 Jun 2013
CiderView	Windows	(Eslinger and Napier 2013)	1.02.002	24 Jun 2013

The following sequence of computer code runs is required to build a new concentration data set for the dose code and to generate doses to individuals. Detailed information supporting the code runs is provided in later sections of this document. Indented bullets in the following list identify runs of support codes that assist the code in the previous bullet:

- Run the HYSPLIT code multiple times to produce air concentration and surface deposition values across a large domain.
    - Run the srcSetupRuns code to set up the individual HYSPLIT input files
    - Run the QsubRuns code to schedule execution of the all of the HYSPLIT runs using unit releases
    - Run the AirGrid code to convert large HYSPLIT output files into small files containing concentrations and depositions only at the locations used in the dose codes
    - Run the AirCombGrid code to combine multiple output files written by the AirGrid code into two files containing air concentration and deposition data that are scaled for historical facility releases

- Run the DESCARTES code to produce concentrations in plant product media; animal product media (beef, goats, eggs, and poultry); herd and individual cow milk media; creamery and grocery milk media; commercial leafy vegetable media, and surface soil.
    - Run the FrostpUno code to generate frost date libraries for each modeled year
    - Run the ADIETP program to generate animal diet libraries
    - Run the FrostpUno code to generate feeding season date libraries
    - Run the RECIPE program to generate the recipe for milk cow feeding regimes contributing to creamery milk at each node
    - Run the RECIPE program to generate the recipe for which nodes supply milk to each creamery
    - Run the RECIPE program to generate the recipe for which creameries supply milk to which grocery stores
    - Run the RECIPE program to generate the recipe for which nodes supply commercial leafy vegetables to consumption nodes

- Run the CiderF code to produce dose estimates
    - Run the CiderView code to produce maps in KML format for viewing in Google Earth (Google 2013)

2.0 Base Problem Definition

Incorporation of the existing data into model inputs uses several base assumptions. The base assumptions are addressed in this section.

2.1 Time Period

Data on the monthly releases of ^{131}I to the atmosphere are provided in (Mokrov et al. 2008a). Reactor A began operation in June, 1948, and the first processing runs at B plant occurred in December, 1948. Tabulated data for monthly releases from the production stacks are provided from 1948 through 1967, and graphical results based on monitoring data are shown for later years. The releases in early years are much higher than in later years, with very small releases occurring after 1972. Therefore, this suite of calculations uses a time period beginning in June, 1948, and extending through December, 1972.

2.2 Environmental Concentration Averaging Time

The DESCARTES code can export the concentrations of ^{131}I in air, soil and food products for use in the CiderF code on a daily, weekly or monthly basis. The anticipated use of the CiderF code is to calculate annual or lifetime dose and this quantity should not be highly sensitive to daily fluctuations in concentrations about an average monthly concentration. Therefore, this analysis uses monthly outputs from DESCARTES (averaged over all days in the month).

An auxiliary analysis, not otherwise documented, was conducted to examine the assumption of using monthly average concentrations. The annual dose to an individual living in Ozersk in 1948 calculated on daily outputs from DESCARTES differs from annual doses calculated from monthly outputs from DESCARTES by a relative amount of 0.2% or less.

2.3 Dose Model Region

The dose model region is local to Ozersk and is large enough to include the production of agricultural products potentially consumed by residents of Ozersk. Food production areas supplying agricultural products for the residents of Ozersk are provided in Figure 1 of (Mokrov et al. 2007a). To ensure the dose model locations are consistent across all of the computer codes, a grid of locations (a point on this grid is called a node in the code documentation) is adopted. This grid consists of a rectangular region around the production facilities and an irregularly shaped region that covers the Techa River from near the release facilities to its discharge into the Iset River. The rectangular portion of the grid (node numbers 1 through 516) has the following characteristics:

- North to south extent: North Latitude 55.1° to 55.95° in steps of 0.05°
- East to west extent: East longitude 60.0° to 62.1° in steps of 0.1°

A portion of the region near Ozersk is divided into a finer resolution grid:

- North to south extent: North Latitude 55.5° to 55.8° in steps of 0.025°
- East to west extent: East longitude 60.5° to 61.1° in steps of 0.05°

The resulting dose model grid contains 618 locations and is shown overlain on a local aerial view in Figure 2.1. The dose model domain covers a region about 16,000 km^2 in size.

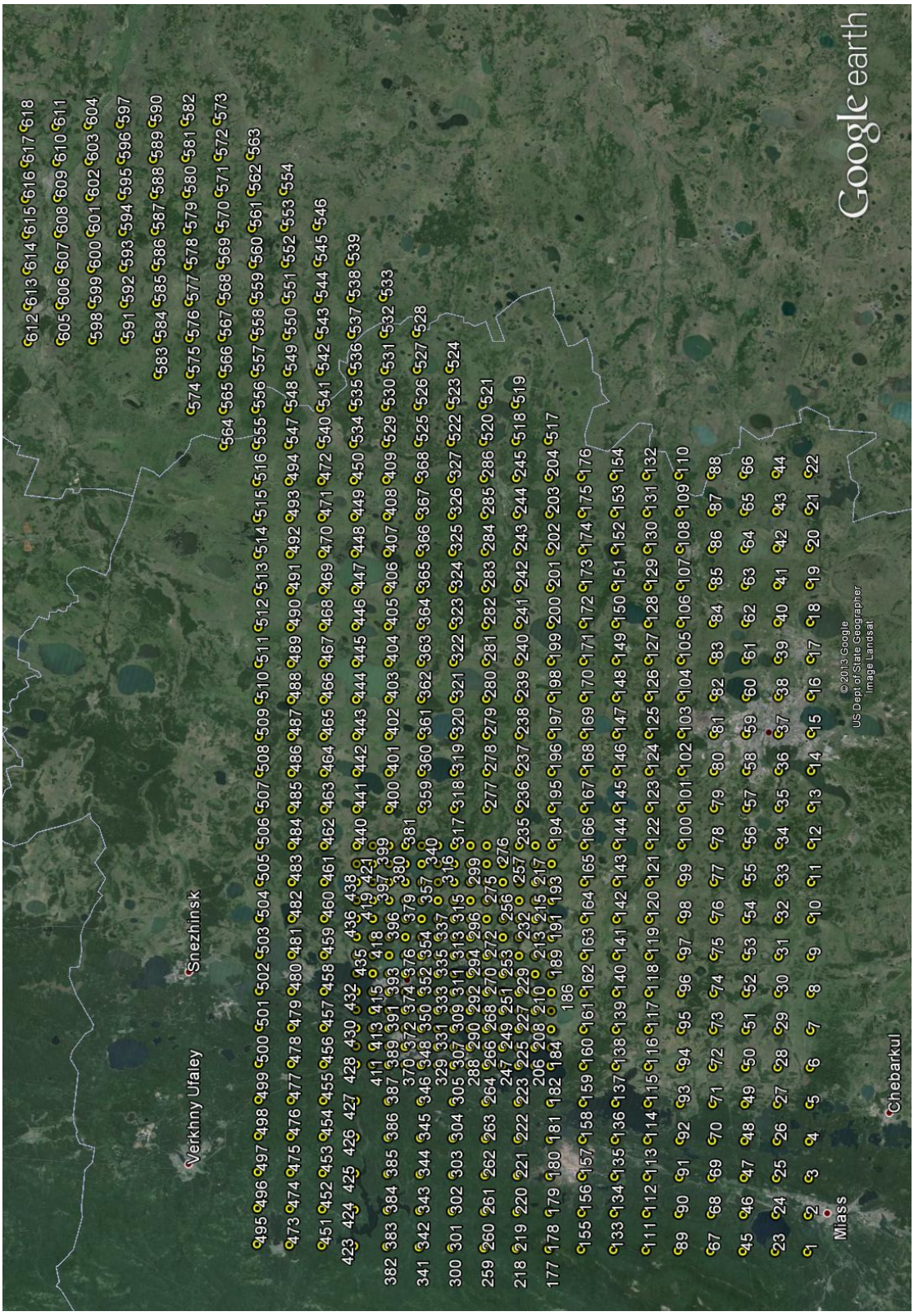

Figure 2.1 Computational Grid for the Dose Model

The spreadsheet named **Grid.xlsx** contains the information needed to produce the NODE keywords used by the AirGrid, AirCombGrid, AirCombGridView and CiderView codes. The keywords are produced in the spreadsheet and they can be copied and pasted into the text input files for these codes. The AirCombGridView and CiderView codes produce contoured outputs in KML format that can be viewed using Google Earth (Google 2013). Two additional files are provided for the convenience of showing the node locations in Google Earth. These files are the following:

- **MayakGridNumbered.kmz** This zipped KML file can be opened directly with Google Earth. It contains icons for the 618 node locations that are labeled with the node numbers.
- **MayakGrid.kmz** This zipped KML file can be opened directly with Google Earth. It contains icons for the 618 node locations but it does not include the node numbers.

Figure 2.1 shows the dose model domain with the file **MayakGridNumbered.kmz**. This display can be useful for identifying the node number associated with the location where an individual lived.

2.4 Commercial Foods

Although the modeling domain is large enough to cover many of the towns around Ozersk, including Chelyabinsk, commercial food production information is available only for residents of Ozersk. Food production areas supplying agricultural products for the residents of Ozersk are provided in Figure 1 of (Mokrov et al. 2007a). In this suite of calculations, a creamery (see the DESCARTES user's guide (Miley et al. 1994) for the use of creameries) is synonymous with a collective farm.

Further information about commercial food production and distribution are provided in later sections. See section 5.3 for information about production of commercial leafy vegetables. See sections 5.4 and 5.5 for information about the production and distribution of milk.

2.5 Memory and Disk Space Requirements

Example memory and disk space usage for the DESCARTES and CiderF codes are provided in the following sections.

2.5.1 DESCARTES Memory and Disk Space Requirements

The DESCARTES code performs dynamic memory allocation, so different runs will use different amounts of memory. A run using 1 realization on a domain of 618 nodes utilized 7 Mb of memory. A run of 250 realizations on a domain of 618 nodes used 225 Mb of memory.

A stochastic run of DESCARTES using 250 realizations on 618 nodes for the years 1948 through 1972 requires about 10.3 Gb of disk space for input files. In addition, the output files occupy another 4 Gb of disk space.

A determinist run of DESCARTES (1 realization) on 618 nodes for the years 1948 through 1972 requires about 169 Mb of disk space for input files. In addition, the output files occupy another 96.2 Mb of disk space.

2.5.2 CiderF Memory and Disk Space Requirements

The CiderF code performs dynamic memory allocation, so different runs will use different amounts of memory. For example, a run of individual cases using 1 realization on the time period 1948 through 1972 utilized 36 Mb of memory. In contrast, a map run of 250 realizations for a domain with 618 nodes utilized 342 Mb of memory when only annual maps are output. A map run that totals doses on the time period 1948 through 1972 utilized 781 Mb of memory.

The CiderF code can be executed multiple times after the air transport and environmental accumulation codes have been run without rerunning the previous codes. A number of data files output by the DESCARTES code are used as input to CiderF. The disk space requirements for these data files depend on the options selected in DESCARTES. Disk space requirements for several cases using 618 nodes on the time period 1948 through 1972 are as follows:

- A single realization case requires about 96 Mb of disk space for CiderF input files.
- A single realization case requires about 265 Mb of disk space for input files for both DESCARTES and CiderF.
- A 250 realization case requires about 4 Gb of disk space for CiderF input files.
- A 250 realization case requires about 14.3 Gb of disk space for input files for both DESCARTES and CiderF.

2.6 Modeling Cases

Results identified in this document are calculated for both deterministic and stochastic runs. The runs are grouped in the following fashion:

- **Best Estimate Case**: Deterministic runs (one realization) are performed using "best estimates" for each input parameter. The "best estimates" are chosen as representative (mean, median or single value based on expert judgment) values rather than bounding values. The atmospheric transport model uses an average χ/Q field.
- **Stochastic Case**: The stochastic runs are based on the available data ranges or statistical definitions of a large number of input variables. Specifics of the stochastic definitions will be supplied in later document sections.

3.0 Atmospheric Transport using the HYSPLIT Code

We do not have access to detailed meteorological data for the Mayak region in 1948 through 1972, however, detailed meteorological data since 2007 are available (GDAS 2012). Therefore, a two-step approach is adopted. First, the parallel version (February 2013) of the HYSPLIT computer code for Linux is used to produce time sequences of ^{131}I air concentration and deposition assuming unit releases on a daily basis using meteorological data from 2007 through 2011. Second, the historical release ^{131}I rates from each facility are used to combine the unit release results into time sequences of surface deposition and air concentrations for 1948 through 1972.

These results are representative of air movement around Mayak during the different months of the year, but they will not exactly match with "real" air movement in any specific year in the dose modeling time period. The user instructions for the AirCombGrid code (section 6 of (Eslinger and Napier 2013)) contains further information on this technique. In summary, χ/Q values for the years 2007 through 2011 are applied to the years 1948 through 1972.

3.1 Forms of Iodine

The released ^{131}I can propagate in organic, elemental or particulate forms (see section 4.4 for more information). The HYSPLIT code can model all of these modes, but not the interchange between the forms. Thus, each HYSPLIT run used a unit source of all three forms. The air concentration and ground deposition of each form were tracked separately. The parameters governing the deposition rates are an input to HYSPLIT. Although the specific values of the deposition rates may have a significant impact on the environmental concentrations, implementing them in a fully stochastic manner requires making a prohibitive number of HYSPLIT runs. Therefore, to limit the computational burden, fixed nominal values are used for these HYSPLIT parameters. The nominal values are as follows:

- Organic (**Orgn**): Model organic iodine as a gas, with no wet deposition and no dry deposition.
- Elemental (**Elem**): Model elemental iodine as a depositing gas.
    - Settling velocity = 10 cm/s
- Particulates (**Part**): Model particulate iodine, where the deposition is affected by both wet and dry mechanisms.
    - Settling velocity = 1 cm/s
    - Wet deposition in-cloud = 4E4 (g Iodine/L air to g Iodine/L in rain at surface)
    - Wet removal below cloud = 5E-5 (1/s) time removal constant

3.2 HYSPLIT Modeling Domain

The HYSPLIT model computational grid is centered at north latitude 55.5° and east longitude 61.0° with a span of 4° in latitude and 8° in longitude using 0.025° increments in both latitude and longitude. The air transport domain is much larger than the dose domain to account for movement of air across the domain of interest.

Although air patterns can sometimes cause a released plume to return to the local region days after it is released, the concentration levels in such plumes are typically much lower than in the original plume.

Therefore, for purposes of computational efficiency, individual plumes are only tracked for 96 hours after they are released.

3.3 Release Facility Locations

The different reactors and radiochemical facilities operated on different time periods. We model daily releases from the facilities and then use a post processing step to overlay scaled individual releases into appropriate time sequences (1948 through 1972). Unit source terms are modeled from the following facilities: A, AI, AV1, AV2, AV3, OK (combined) reactors, and radiochemical plants B and DB. The geographic locations of the facilities and the height of the release stacks are provided in Table 3.1. These release points are also captured in the spreadsheet named **Release_Points.xlsx**. A snapshot of a Google Earth (Google 2013) image showing the facility locations is provided in Figure 3.1.

Table 3.1 Facility Locations for Release Modeling

ID	Latitude (deg)	Longitude (deg)	Stack Height (m)	Description
A	55.70194444	60.78305556	95	A Reactor
AI	55.70166667	60.78055556	95	AI Reactor
AV3	55.70388889	60.78277778	95	AV3 Reactor
AV1	55.705	60.81138889	80	AV1 Reactor
AV2	55.70666667	60.80305556	80	AV2 Reactor
OK	55.69888889	60.7825	80	OK Reactor Complex
B	55.68805556	60.79888889	150	B Plant Stacks
DB	55.69722222	60.80416667	150	DB Plant Stacks

For viewing convenience, the information in Table 3.1 is also provided in a file named **MayakFacilities.kml**. This file can be opened directly in Google Earth.

Figure 3.1 Facility Locations for Release Modeling

3.4 HYSPLIT Runs

Setting up and executing the HYSPLIT runs has the following general steps. First, a keyword file is prepared for the srcSetupRunsMayak code. In the user's guide (Eslinger and Napier 2013), this code is simply called srcSetupRuns. Execution of the code creates run directories and prepares control files for HYSPLIT. Then, the QsubRuns code uses files prepared by the srcSetupRuns code to submit individual HYSPLIT jobs to a batch queue. Each of three runs of the srcSetupRuns code uses a slightly different keyword file. The modifications are the release stack height and the list of facilities to model. The three runs of the srcSetupRuns code are identified in Table 3.2. A total of 14,632 runs of the HYSPLIT code were required to model 8 release locations every day for just over five years. Each HYSPLIT run was followed by a run of a utility program that converted the binary HYSPLIT output file to ASCII format.

Table 3.2 Runs of the srcSetupRunsMayak code (HYSPLIT run preparation)

Purpose	Stack Height (m)	Keyword File	Station List File
Reactors: AV1, AV2, OK	80	Mayak.kwd	Station_List_Reactor80.txt
Reactors: A, AI, AV3	95	Mayak.kwd	Station_List_Reactor95.txt
Radiochemical plants: B, DB	150	Mayak.kwd	Station_List_Plants150.txt

The HYSPLIT code can be run in puff or particle modes. The 3-D particle mode for both vertical and horizontal air movement is used in all of the HYSPLIT runs. Each run used 250,000 particles.

The release facilities are located within a region about 2 km across and this is a very small region when considering atmospheric transport for hundreds of km. However, a few preliminary runs of the air transport model indicated that modeled air concentrations in Ozersk were sensitive to both the release height and the release point location. Therefore, atmospheric transport was modeled for each facility separately rather than combining the facilities into groups with the same release height.

An example keyword file for the srcSetupRunsMayak code is provided in Table 3.3.

Table 3.3 Example Keyword File for the srcSetupRuns Code

```
FILE REPORT "Mayak.rpt"
USER "Paul W. Eslinger"
OPERATE LINUX
FILE METMAP="/files0/atm/metdata/gdas1/Date_File_Map.txt"
FILE LOCATION "/files0/atm/Mayak/setup/Station_List_Plants150.txt"
RELEASE SINGLE
DATE BEGIN="2006-12-29 00:00:00"  END="2011-12-31" DAY
OPTION HYSPLIT
FILE RUNDIR="/files0/atm/Mayak/Hysplit/"
HYSPLIT
  HOURS    =  96
  CONHOUR  =  24
  SRCHOUR  =  24
  SRCRATE  = 0.0416667
  DECAY    =   8.0207
  LATDEL   =   0.025
  LONDEL   =   0.025
  LATSPAN  =    4.0
  LONSPAN  =    8.0
  CENTERDE = 0.025
  PARTICLE =  250000
  ID       = "Sgas"
  CONLEVEL = 100.0
  SRCHIGH  = 150.0
  EXEC    = "/share/apps/hysplit.0113/trunk/exec/hycs_std"
  ASCDATA = "/files0/atm/Mayak/setup/"
  SETUP   = "/files0/atm/Mayak/setup/"
OPTION ASCII
FILE ASCEXEC = "/share/apps/hysplit/exec/con2asc"
END
```

4.0 Runs of the AirCombGrid Code

The reactors and radiochemical facilities operated at different time periods. The AirCombGrid code applies individual releases from facilities (from 1948 through 1972) onto the results of the air transport modeling performed with unit release assumptions. The AirCombGrid code writes air concentration and air deposition files in the correct format for use in the DESCARTES code.

4.1 AirGrid Utility Code

The AirGrid code is used to register the concentrations and depositions produced by the HYSPLIT code on the set of locations (nodes) to be used in the AirCombGrid, DESCARTES and CiderF codes. This intermediate step greatly reduces the amount of I/O needed in the AirCombGrid code relative to reading HYSPLIT produced files directly.

The AirGrid code was used with the input file named AirGrid.kwd. This code executed on the Linux cluster where the HYSPLIT code was used. The AriGrid run finished in about 6 hours.

4.2 Keyword Files

The two runs of the AirCombGrid code are identified in Table 4.1. The best estimate case ran in about 3 hours. The stochastic case ran in about 3.5 hours.

Table 4.1 Runs of the AirCombGrid Code

Purpose	Keyword File
Best Estimate Case	Best.kwd
Stochastic Case	Stochastic.kwd

4.3 Release Source Terms

Monthly releases of ^{131}I are available (Mokrov et al. 2008a), on pages 23-24 for the D and DB radiochemical plants. Annual releases from the reactors are provided in Table 4.1 of the same report. Some release data for 1968 through 1972 can be derived from the stack monitoring values of the same report. The typical use of CiderF is to calculate annual or lifetime doses, so using monthly source terms from the largest releases should not cause a significant loss of information.

Deterministic release estimates use the best estimate monthly values, implemented as constant daily releases for each day in the month. If published monthly values are not available, then the annual values are divided into equal releases for each day. Stochastic releases are implemented as a scaling factor (triangular distribution on [minimum, best estimate, maximum]) for the annual releases.

The keyword files identified in Table 4.1contain source entries for every month a facility operated. Preparation of the release keywords is performed in a spreadsheet and then the keywords are copied and pasted into the text keyword files. The spreadsheet is named **Release_Keywords.xlsx** and it contains a

separate sheet for every release facility. Stochastic keywords are located in column S of each facility sheet and best estimate keywords are located in column U of each facility sheet.

The AirCombGrid code generates monthly and annual releases from every facility. The monthly releases for each realization are scaled to match the annual release for that realization.

Best estimate values for the monthly releases (Ci) by facility, as output by the AirCombGrid code, are provided in Figure 4.1. As expected, releases from the radiochemical processing plants B and DB dominate the releases. The best estimate annual releases for all active facilities, as output by the AirCombGrid code, are provided in Figure 4.2.

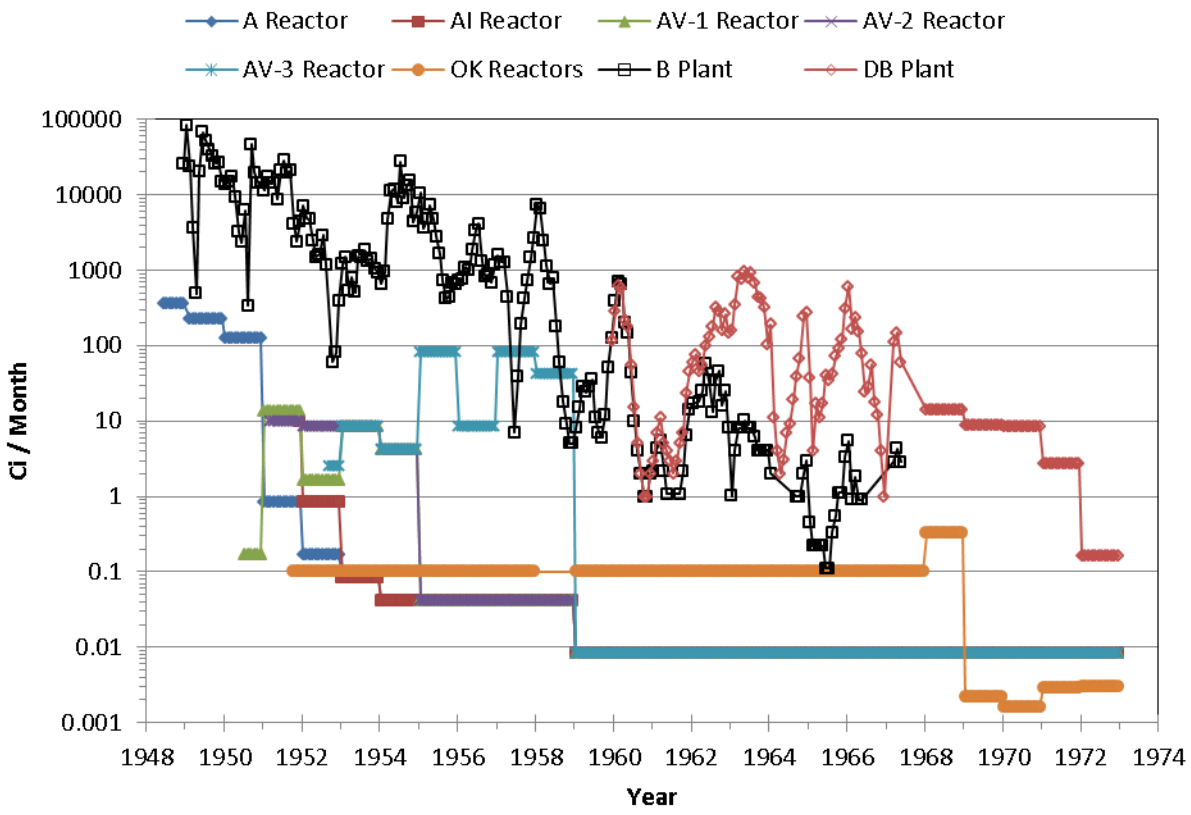

Figure 4.1 Monthly Best Estimate Atmospheric Releases of ^{131}I by Facility

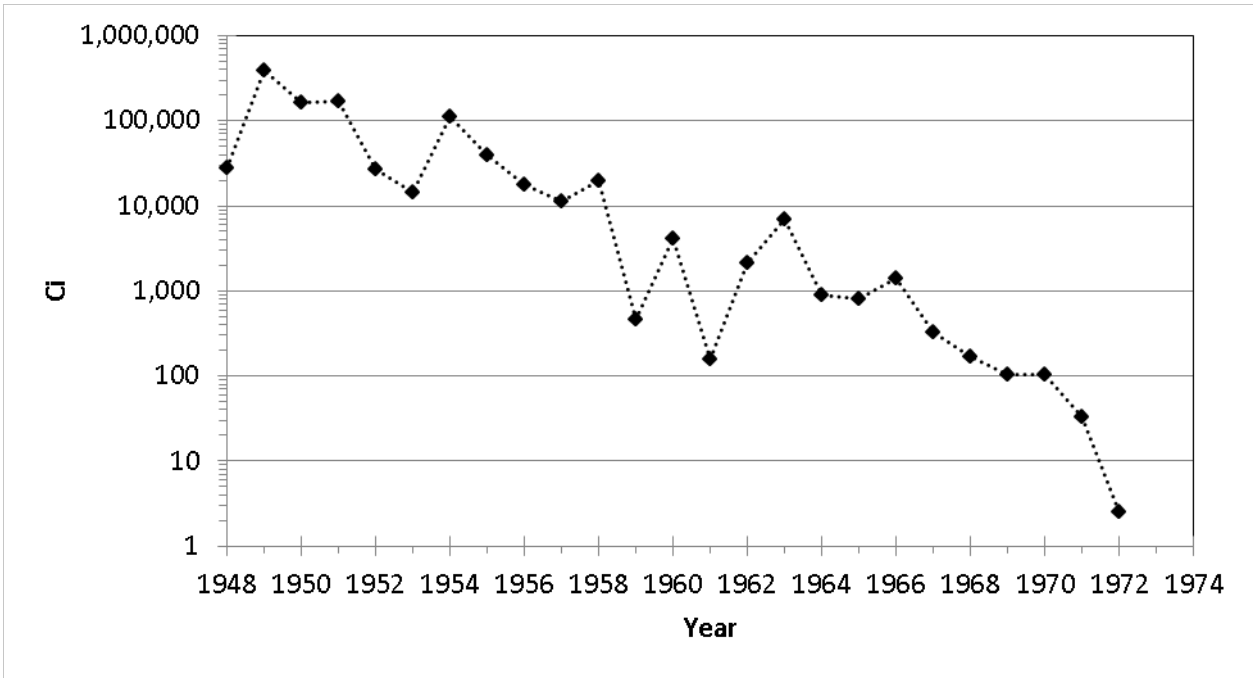

Figure 4.2 Annual Best Estimate Atmospheric Releases of ^{131}I

Summary statistics on the total release of ^{131}I (Ci) to the air by facility for the years 1948 through 1972 are provided in Table 4.2. The summary was developed from the 250 realization stochastic case.

Table 4.2 Summary Statistics on Total Release (Ci) by Facility for a 250 Realization Run

Facility	Minimum	25th Percentile	Median	75th Percentile	Maximum	Standard Deviation
A	5,432	6,173	6,503	6,778	7,620	437.4
AI	20.39	23.67	24.74	25.73	29.91	1.565
AV1	275.1	316.7	334.1	345.9	385.0	21.03
AV2	285.3	335.2	351.3	367.1	400.1	21.17
AV3	2,294	2,613	2,751	2,866	3,228	180.6
B	844,300	940,000	982,500	1,022,900	1,141,900	56,790
DB	12,310	13,900	14,520	15,080	16,890	840.1
OK	20.29	21.74	22.17	22.59	24.22	0.6507

4.4 Iodine Speciation

The speciation fraction algorithm for ^{131}I embedded in the AirCombGrid code is taken from (Napier et al. 2008). The algorithm has two steps. First, the fraction of ^{131}I in each form is sampled uniformly from within its specific range. Second, the three fractions are normalized so the total equals one. The fractions of each form are defined as follows:

- elemental iodine, uniformly distributed on (0.10, 0.45),
- organic iodine, uniformly distributed on (0.20, 0.35), and
- particulate iodine, uniformly distributed on (0.20, 0.65).

Summary statistics on the iodine speciation fractions from the 250 realization run of the AirCombGrid are provided in Table 4.3. For any single realization, the speciation fractions of the three iodine types sum to one. However, the summary statistics in Table 4.3 are provided for each iodine type individually over the set of 250 values. The statistics (percentiles, standard deviation, mean, etc.) only sum to one over the three iodine types for the mean. Speciation fractions for the best estimate run uses 0.44 for particles, 0.29 for the organic form and 0.27 for the elemental form. These values are approximately the mean values from the stochastic set of 250 speciation fractions.

Table 4.3 Summary Statistics on Iodine Speciation Fractions Based on 250 Realizations

Statistic	Particulate	Organic	Elemental
Minimum	0.2287	0.1696	0.1024
1% Level	0.2337	0.1723	0.1126
5% Level	0.2927	0.2045	0.1307
10% Level	0.3108	0.2188	0.1472
25% Level	0.3689	0.2457	0.1902
Median	0.4414	0.2850	0.2576
75% Level	0.5078	0.3343	0.3361
90% Level	0.5610	0.3896	0.3901
95% Level	0.5875	0.4130	0.4233
99% Level	0.6391	0.4480	0.4726
Maximum	0.6433	0.5040	0.4986
Mean	0.4391	0.2953	0.2656
St. Dev.	0.0932	0.0644	0.0915

4.5 Example Results from the AirCombGrid Code

Example results from the AirCombGrid code (displayed as interpolated contours) are provided in Figure 4.3 for December 1948 for the best estimate case. The top pane shows the average air concentration over the month and the bottom pane shows the month-end decay corrected total deposition. The activity units in these plots are Bq, rather than Ci used elsewhere in this document. The plots were produced using the AirCombGridView code and the keyword files named conc.kwd and depo.kwd. These files are located in the directory Mayak\Best\AirCombGrid in the electronic data package.

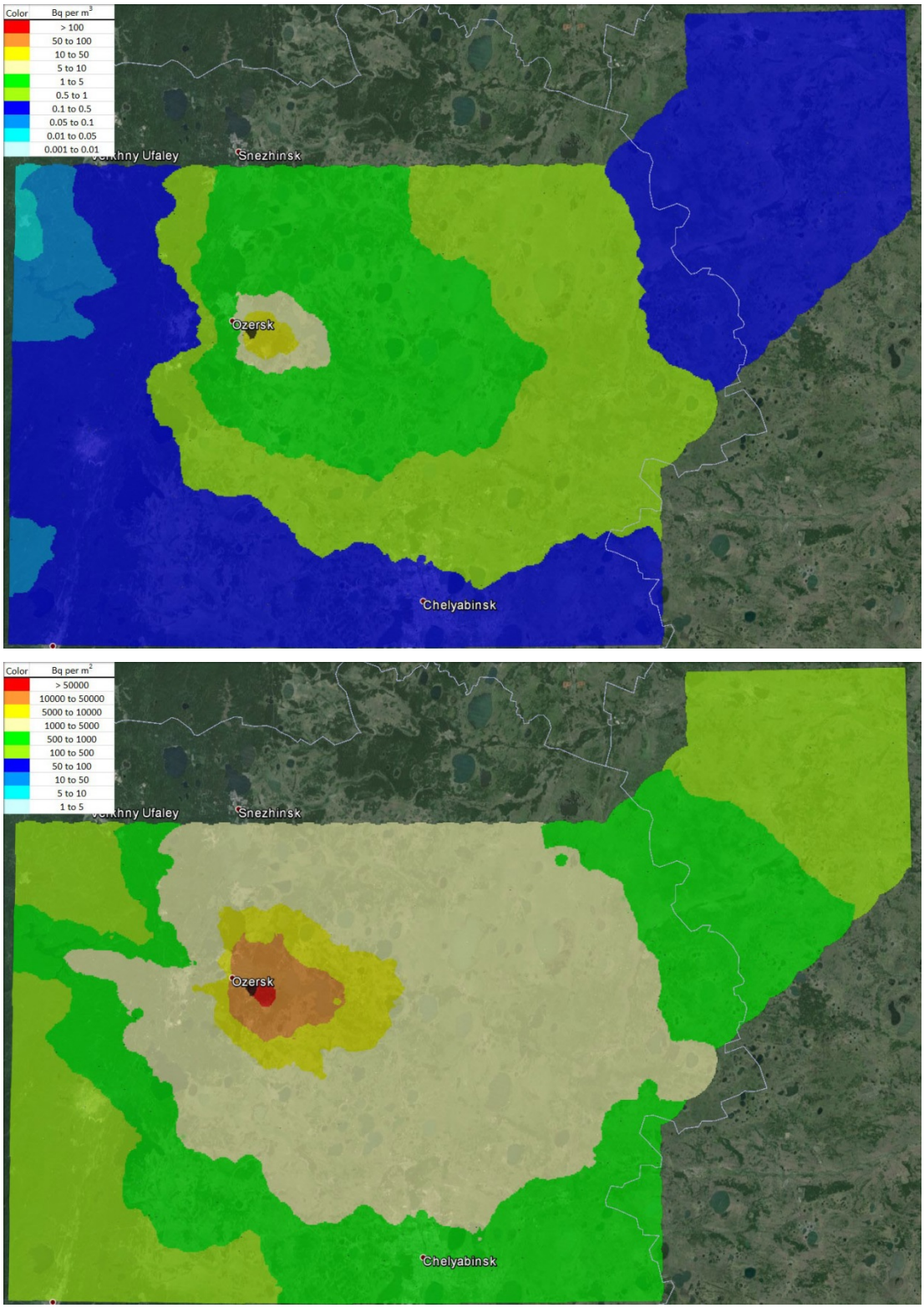

Figure 4.3 Example best estimate results from the AirCombGrid code for December 1948. Monthly average air concentration (Bq/m^3) (top pane) and month-end total decay corrected deposition (Bq/m^2) (bottom pane).

5.0 Runs of DESCARTES and Preprocessor Codes

A suite of preprocessors is used to prepare data sets for the DESCARTES code for best estimate or stochastic data sets. The following three major cases were run in DESCARTES:

- **Best Estimate Case**: All DESCARTES parameters were set to best estimate values and the best estimate case from the AirCombGrid code is used (1 realization).
- **Stochastic Case**: A full set of stochastic inputs (250 realizations) is used in DESCARTES and the stochastic case from the AirCombGrid code.
- **Mono Case**: All DESCARTES parameters were set to best estimate values and the stochastic case from the AirCombGrid code is used. This 250 realization case is used to determine the variability in doses solely due to stochastic releases and stochastic air transport.

5.1 FrostpUno: Frost Date Libraries

A separate library file containing frost dates is required for each model year when computing plant-related concentrations. These files are produced by the utility code FrostpUno. FrostpUno is a modification of the FROSTP code (Miley et al. 1994) that applies the same definition of frost dates for all locations in the dose model domain and multiple years. The code writes a file of randomized frost dates for every model year. The code runs are identified in Table 5.1.

Table 5.1 Keyword Files and Runs for the FrostpUno Code

Purpose	Keyword File
Best Estimate Case	FrostBest.kwd
Stochastic Case	FrostStoc.kwd
Mono Case	FrostMono.kwd

Historical weather information for Baladino Airport, Chelyabinsk, Russian Federation is available on the web (WeatherSpark 2012). Reading from the interactive graph, reproduced here as static Figure 5.1, for averages on the "dashboard" at that website, one can obtain the following range of dates. Last spring frost (overnight low reached down to 32 °F): average day is April 12 (Julian day 102); 10% are as early as March 30 (Julian day 89); 10% are as late as May 2 (Julian day 122). First fall frost (overnight low reached down to 32 °F): average day is October 24 (Julian day 297); 10% are as early as October 2 (Julian day 275); 10% are as late as November 10 (Julian day 314).

The best estimate run uses a spring frost date of April 12 (Julian day 102) and a fall frost date of October 24 (Julian day 297). These dates are applied to all dose model locations. The same dates are used for every year.

The stochastic runs use uniform distributions for the frost dates. The spring date is uniform on the range (89,122) and the fall date is uniform on the range (275,314). These same stochastic definitions are used at all locations for every year.

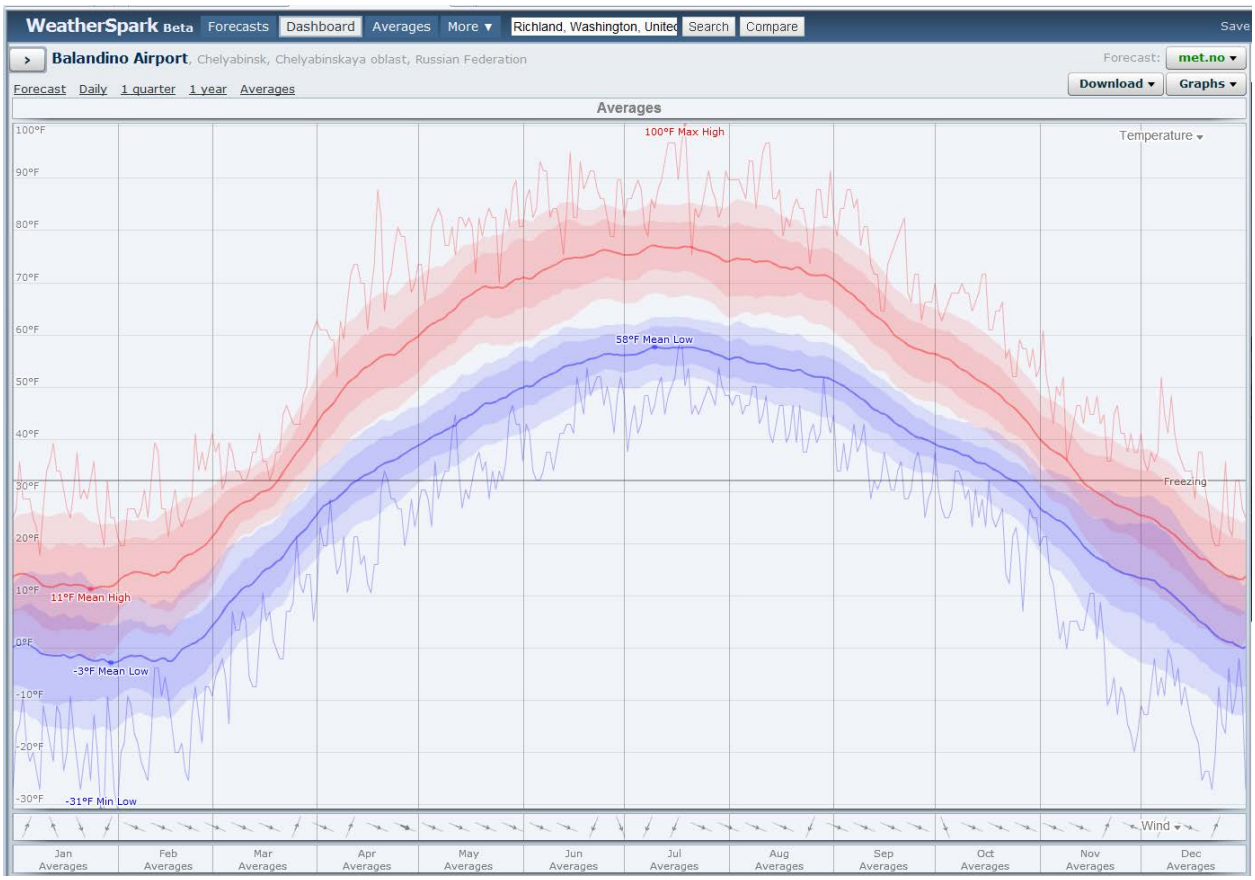

Figure 5.1 Historical temperature data for Balandino Airport, Chelyabinsk, Russian Federation

A suite of library files containing temperatures that trigger changes between animal feeding season dates is required when computing animal product concentrations. Generally, these library files are produced by the utility code FrostpUno. General feeding season dates are available (Mokrov et al. 2007a), section 3 and more information is provided in Appendix B of (Rovny et al. 2009). However, little or no date information is available for any specific year. Thus, the frost dates described in Section 5.1 are used to trigger feeding season changes.

We do note that average monthly temperatures for the Argayash weather station are available (Table A.3.3 of (Drozhko and Khokhryakov 2003)) for 1949 through 1972. Even though we didn't take this approach, the April and October data could be used to shift the overall average dates to account for cooler and warmer months than the overall average. If this approach were used, one would probably reduce the stochastic ranges to a week on either side of the shifted average.

5.2 ADIETP: Animal Diet Libraries

A series of library files containing daily animal diet information is required for computing concentrations of animal products in DESCARTES. The library files were generated using the utility program ADIETP. The ADIETP code reads a keyword file and outputs a randomized library containing daily diet information. The runs that generated the library files are identified in Table 5.2. Although the animal

feeding regimes are allowed to change from year to year, this analysis uses the same feeding regime every year. General animal consumption information is available (Mokrov et al. 2007a), sections 3 and 4. Additional information is provided in Appendix A of (Rovny et al. 2009).

Table 5.2 Keyword Files and Runs for the ADIETP Code

Animal	Case	Keyword File
Poultry	Best Estimate	PoulDietBest.kwd
Poultry	Stochastic	PoulDietStoc.kwd
Poultry	Mono	PoulDietMono.kwd
Beef	Best Estimate	BeefDietBest.kwd
Beef	Stochastic	BeefDietStoc.kwd
Beef	Mono	BeefDietMono.kwd
Goat	Best Estimate	GoatDietBest.kwd
Goat	Stochastic	GoatDietStoc.kwd
Goat	Mono	GoatDietMono.kwd
Milk Cow	Best Estimate	CowDietBest.kwd
Milk Cow	Stochastic	CowDietStoc.kwd
Milk Cow	Mono	CowDietMono.kwd

5.3 RECIPE: Commercial Leafy Vegetables

The commercial distribution system for leafy vegetables (defined by which production locations supplied vegetables to consumption locations) is specified in the form of a "recipe" for every year in the simulation. These "recipes" are generated by the utility program RECIPE. The RECIPE code is controlled by a keyword file and outputs a report file and two files for use in the DESCARTES code. The keyword files are identified in Table 5.3.

Table 5.3 Keyword Files for the RECIPE code for Commercial Leafy Vegetables

Best Estimate Case	Stochastic Case	Mono Case	Year
VegRecipe1948Best.kwd	VegRecipe1948Stoc.kwd	VegRecipe1948Mono.kwd	1948
VegRecipe1949Best.kwd	VegRecipe1949Stoc.kwd	VegRecipe1949Mono.kwd	1949
VegRecipe1950Best.kwd	VegRecipe1950Stoc.kwd	VegRecipe1950Mono.kwd	1950
VegRecipe1951Best.kwd	VegRecipe1951Stoc.kwd	VegRecipe1951Mono.kwd	1951
VegRecipe1952Best.kwd	VegRecipe1952Stoc.kwd	VegRecipe1952Mono.kwd	1952
VegRecipe1953Best.kwd	VegRecipe1953Stoc.kwd	VegRecipe1953Mono.kwd	1953
VegRecipe1954Best.kwd	VegRecipe1954Stoc.kwd	VegRecipe1954Mono.kwd	1954
VegRecipe1955Best.kwd	VegRecipe1955Stoc.kwd	VegRecipe1955Mono.kwd	1955
VegRecipe1956Best.kwd	VegRecipe1956Stoc.kwd	VegRecipe1956Mono.kwd	1956
VegRecipe1957Best.kwd	VegRecipe1957Stoc.kwd	VegRecipe1957Mono.kwd	1957
VegRecipe1958Best.kwd	VegRecipe1958Stoc.kwd	VegRecipe1958Mono.kwd	1958
VegRecipe1959Best.kwd	VegRecipe1959Stoc.kwd	VegRecipe1959Mono.kwd	1959
VegRecipe1960Best.kwd	VegRecipe1960Stoc.kwd	VegRecipe1960Mono.kwd	1960

Best Estimate Case	Stochastic Case	Mono Case	Year
VegRecipe1961Best.kwd	VegRecipe1961Stoc.kwd	VegRecipe1961Mono.kwd	1961
VegRecipe1962Best.kwd	VegRecipe1962Stoc.kwd	VegRecipe1962Mono.kwd	1962
VegRecipe1963Best.kwd	VegRecipe1963Stoc.kwd	VegRecipe1963Mono.kwd	1963
VegRecipe1964Best.kwd	VegRecipe1964Stoc.kwd	VegRecipe1964Mono.kwd	1964
VegRecipe1965Best.kwd	VegRecipe1965Stoc.kwd	VegRecipe1965Mono.kwd	1965
VegRecipe1966Best.kwd	VegRecipe1966Stoc.kwd	VegRecipe1966Mono.kwd	1966

According to (Mokrov et al. 2007a), page 20, leafy vegetables were mainly produced by associations of gardeners and in private gardens. Vegetable products from collective farms had only a minor role in consumption for Ozersk residents. However, DESCARTES requires a commercial leafy vegetable distribution system to assign production locations to any garden or farm not located in the same grid cell as the primary residence of the individual. Due to a lack of information, the same production fractions by collective farm are used for commercial leafy vegetables as were used for milk production. In addition, every year after 1956 used the production information for 1956. The spreadsheet **Mayak_Recipes.xlsx** (see Section 7.1 for further information) can be used to build the keyword files. The CiderF code can select either locally produced or commercial vegetables for a dose calculation.

5.4 RECIPE: Nodes Supplying Milk to Creameries

A series of runs of the utility program RECIPE were performed to build libraries of information about which locations (nodes) produced milk for each commercial creamery. In this context, a commercial creamery is equivalent to a collective farm. These files are identified in Table 5.4.

Table 5.4 Keyword Files for the RECIPE code for Creamery Milk Production

Best Estimate Case	Stochastic Case	Mono Case	Year
Cream1948Best.kwd	Cream1948Stoc.kwd	Cream1948Mono.kwd	1948
Cream1949Best.kwd	Cream1949Stoc.kwd	Cream1949Mono.kwd	1949
Cream1950Best.kwd	Cream1950Stoc.kwd	Cream1950Mono.kwd	1950
Cream1951Best.kwd	Cream1951Stoc.kwd	Cream1951Mono.kwd	1951
Cream1952Best.kwd	Cream1952Stoc.kwd	Cream1952Mono.kwd	1952
Cream1953Best.kwd	Cream1953Stoc.kwd	Cream1953Mono.kwd	1953
Cream1954Best.kwd	Cream1954Stoc.kwd	Cream1954Mono.kwd	1954
Cream1955Best.kwd	Cream1955Stoc.kwd	Cream1955Mono.kwd	1955
Cream1956Best.kwd	Cream1956Stoc.kwd	Cream1956Mono.kwd	1956
Cream1957Best.kwd	Cream1957Stoc.kwd	Cream1957Mono.kwd	1957
Cream1958Best.kwd	Cream1958Stoc.kwd	Cream1958Mono.kwd	1958
Cream1959Best.kwd	Cream1959Stoc.kwd	Cream1959Mono.kwd	1959
Cream1960Best.kwd	Cream1960Stoc.kwd	Cream1960Mono.kwd	1960
Cream1961Best.kwd	Cream1961Stoc.kwd	Cream1961Mono.kwd	1961
Cream1962Best.kwd	Cream1962Stoc.kwd	Cream1962Mono.kwd	1962
Cream1963Best.kwd	Cream1963Stoc.kwd	Cream1963Mono.kwd	1963

Best Estimate Case	Stochastic Case	Mono Case	Year
Cream1964Best.kwd	Cream1964Stoc.kwd	Cream1964Mono.kwd	1964
Cream1965Best.kwd	Cream1965Stoc.kwd	Cream1965Mono.kwd	1965
Cream1966Best.kwd	Cream1966Stoc.kwd	Cream1966Mono.kwd	1966

Data needed for this suite of files are provided in Table 2 of (Mokrov et al. 2007a). Also, the map of nodes shown in Figure 2.1 is used to identify which nodes are within the boundaries of each collective farm. In addition, every year after 1966 used the information for 1966. The spreadsheet **Mayak_Recipes.xlsx** can be used to build the keyword files.

5.5 RECIPE: Creameries Supplying Grocery Milk

A series of runs of the utility program RECIPE are needed to build libraries of information about which creameries (collective farms) contributed to grocery milk consumed at each location. These files are identified in Table 5.5.

Table 5.5 Keyword Files for the RECIPE code for Grocery Milk Recipes

Best Estimate Case	Stochastic Case	Mono Case	Year
MilkDist1948Best.kwd	MilkDist1948Stoc.kwd	MilkDist1948Mono.kwd	1948
MilkDist1949Best.kwd	MilkDist1949Stoc.kwd	MilkDist1949Mono.kwd	1949
MilkDist1950Best.kwd	MilkDist1950Stoc.kwd	MilkDist1950Mono.kwd	1950
MilkDist1951Best.kwd	MilkDist1951Stoc.kwd	MilkDist1951Mono.kwd	1951
MilkDist1952Best.kwd	MilkDist1952Stoc.kwd	MilkDist1952Mono.kwd	1952
MilkDist1953Best.kwd	MilkDist1953Stoc.kwd	MilkDist1953Mono.kwd	1953
MilkDist1954Best.kwd	MilkDist1954Stoc.kwd	MilkDist1954Mono.kwd	1954
MilkDist1955Best.kwd	MilkDist1955Stoc.kwd	MilkDist1955Mono.kwd	1955
MilkDist1956Best.kwd	MilkDist1956Stoc.kwd	MilkDist1956Mono.kwd	1956
MilkDist1957Best.kwd	MilkDist1957Stoc.kwd	MilkDist1957Mono.kwd	1957
MilkDist1958Best.kwd	MilkDist1958Stoc.kwd	MilkDist1958Mono.kwd	1958
MilkDist1959Best.kwd	MilkDist1959Stoc.kwd	MilkDist1959Mono.kwd	1959
MilkDist1960Best.kwd	MilkDist1960Stoc.kwd	MilkDist1960Mono.kwd	1960
MilkDist1961Best.kwd	MilkDist1961Stoc.kwd	MilkDist1961Mono.kwd	1961
MilkDist1962Best.kwd	MilkDist1962Stoc.kwd	MilkDist1962Mono.kwd	1962
MilkDist1963Best.kwd	MilkDist1963Stoc.kwd	MilkDist1963Mono.kwd	1963
MilkDist1964Best.kwd	MilkDist1964Stoc.kwd	MilkDist1964Mono.kwd	1964
MilkDist1965Best.kwd	MilkDist1965Stoc.kwd	MilkDist1965Mono.kwd	1965
MilkDist1966Best.kwd	MilkDist1966Stoc.kwd	MilkDist1966Mono.kwd	1966

This application treated creameries (collective farms) as milk suppliers to grocery stores. Data needed for this suite of files is provided in Table 2 of (Mokrov et al. 2007a). Grocery milk was only computed for consumption at Ozersk. Residents of the city were assumed to live at one of five dose model nodes (390,

391, 392, 414, or 415). In addition, every year after 1966 used the production information for 1966. The spreadsheet **Mayak_Recipes.xlsx** can be used to build the keyword files.

5.6 RECIPE: Feeding Regimes Active for Creamery Milk

A run of the utility program RECIPE is needed to build a library of information about which cow feeding regimes were active at nodes that supply commercial milk to creameries. The required files are identified in Table 5.6.

Table 5.6 Keyword Files and Runs for the RECIPE Code

Purpose	Keyword File
Best Estimate Case	FregimesBest.kwd
Stochastic Case	FregimesStoc.kwd
Mono Case	FregimesMono.kwd

Bovine feeding practices varied slightly by location and year. See section 4 in (Mokrov et al. 2007a) and also (Rovny et al. 2009). However, this variation in feeding practices was slight enough, given the animal food products computed by DESCARTES, that only one feeding regime was identified. The other three possible animal feeding regimes that can be used in the DESCARTES and CiderF codes were not utilized.

5.7 Runs of the DESCARTES Code

Three runs of the DESCARTES code were made. The keyword files for these runs are identified in Table 5.7. Each of these runs produces a suite of 27 "media" files containing concentrations in a variety of media that will be used in the CiderF code. The preprocessors identified in Sections 5.1 through 5.6 prepared multiple input files used in each run of the DESCARTES code.

Table 5.7 Keyword Files and Runs for the DESCARTES Code

Purpose	Keyword File	Data Package Directory
Best Estimate Case	Best.kwd	\Mayak\Best
Stochastic Case	Stochastic.kwd	\Mayak\Stochastic
Mono Case	Mono.kwd	\Mayak\Mono

6.0 Runs of the CiderF Code

The general approach for the dose calculations is to define a handful of reference individuals and perform runs to show the dose distributions by year and total. The CiderF code was used to generate doses for the time period of interest.

The CiderF code can generate doses in two different modes. The individual mode allows the user to calculate doses for one or more individuals. The individual lives in user specified locations and eats either a reference diet or a user specified special diet. The primary output of the code is the dose to the individual. The second mode, the map mode, applies the same characteristics to an individual living at every single node in the dose domain. For example, one can obtain the dose to a five year old child using rural lifestyle assumptions at every node in the domain.

The keyword inputs for CiderF are divided into two files. One file (the factors keyword file) contains information that does not vary even if doses are calculated for more than one individual. The other file (case keyword file) contains the minimal set of keywords needed to define individual dose cases or a map case. Information that does not change by dose case was collected in the **Mayak_ref_Diet.xlsx** spreadsheet to facilitate generating keyword inputs for the codes.

6.1 Reference Information

Dietary information and recommended lifestyle and exposure information is provided in (Rovny et al. 2009). Although that document contains a large amount of information about the habits and activities of individuals living near Ozersk in the past, no specific dose code was identified before the information was collected. Thus, some information, especially dietary information, was not in the format needed by the CiderF code.

Entries in the reference keyword files include the following types of information:

- Specific consumption sources and rates for each reference diet
- Breathing rates
- Fraction of time spent outdoors
- Dose factors for external, inhalation and ingestion exposure
- Holdup times by food categories
- Food processing loss fractions, and
- Dry to wet ratios for food types.

The four “reference” factors keyword files identified in Table 6.1 were prepared for the CiderF code using the information in the spreadsheet **Mayak_ref_Diet.xlsx**. These four files are located in directory **\Mayak\Kwd\RefDiet** of the data package. There are a large number of keyword entries in each of these files. The relationship between the specific keywords and the spreadsheet entries used to develop the keywords are captured in comments in the keyword file.

The best estimate, stochastic and mono cases are optimized for local vegetable consumption. In addition, rural lifestyles default to local cow milk production and urban lifestyles default to grocery milk from

collective farms. The worker case defaults to locally produced cow milk and consumption of local vegetables. In the default data sets, commercial milk products and commercial leafy vegetables are available only in Ozersk. Specifically, this means that commercial products are only available for people living at nodes 390, 391, 392, 414 and 415. These locations are identified in Figure 2.1 or the file "**MayakGridNumbered.kmz**" can be opened in Google Earth to zoom in on the identified locations.

Table 6.1 Reference Diet, Lifestyle and Exposure Factors Keyword Files for CiderF Code

Purpose	Keyword File
Best Estimate Case	MayakFactorsBest.kwd
Stochastic Case	MayakFactorsStoc.kwd
Mono Case	MayakFactorsMono.kwd
Stochastic Worker Case	MayakFactorsWorkerStoc.kwd

The CiderF dose code uses the concept of reference and special diets. A series of reference diets are defined for a variety of ages, lifestyle activities and residence type. All runs of the CiderF code use the reference diets unless the consumption pattern is modified by a case-specific special diet. A total of 14 reference diets are defined. The mapping of the reference diets to lifestyle activities is provided in Table 6.2.

Table 6.2 Reference Diet Definitions by Lifestyle Categories

Diet ID	Lifestyle Categories
RefDiet001	Child, 0 to 6 months
RefDiet002	Child, >6 months to 2 year
RefDiet003	Child, rural, >2 years to 7 years
RefDiet004	Child, urban, >2 years to 7 years
RefDiet005	Child, rural, >7 years to 12 years
RefDiet006	Child, urban, >7 years to 12 years
RefDiet007	Child, rural, >12 years to 17 years
RefDiet008	Child, urban, >12 years to 17 years
RefDiet009	Adult, rural
RefDiet010	Adult, urban
RefDiet011	Suckling child, 0 to 6 months
RefDiet012	Suckling child, >6 months to 2 year
RefDiet013	Adult, rural, pregnant/nursing female
RefDiet014	Adult, urban, pregnant/nursing female

6.2 Example Dose Map Runs

A run of the CiderF code using best estimate parameters was performed in map mode for a rural child that was five years old. Separate map cases in the run modeled a child that was 5 in 1948, a child that was 5 in 1949, and a child that was 5 for every year from 1950 through 1972. The keyword files for this run are identified in Table 6.3. Also identified is the keyword file for a graphics postprocessor named CiderView. The postprocessor produces a KML file of dose contours suitable for viewing in Google Earth. These files are located in the directory **\Mayak\Best\Cases\Child5** in the data package.

Table 6.3 Keyword Files for the Best Estimate Map Run of the CiderF Code

Purpose	Keyword File
CiderF Keyword File	Child5Best.kwd
Reference Information Keyword File	MayakFactorsBest.kwd
CiderView Keyword File	Child5View.kwd

An example output of the CiderView code (as visualized in Google Earth) for the best estimate run is provided in Figure 6.1 for a child who is 5 years old in 1949. The values plotted are thyroid dose (rad). All of the release facilities are in the dark colored region that is located southeast of Ozersk. The map domain in the figure uses only the rectangular portion of the dose grid.

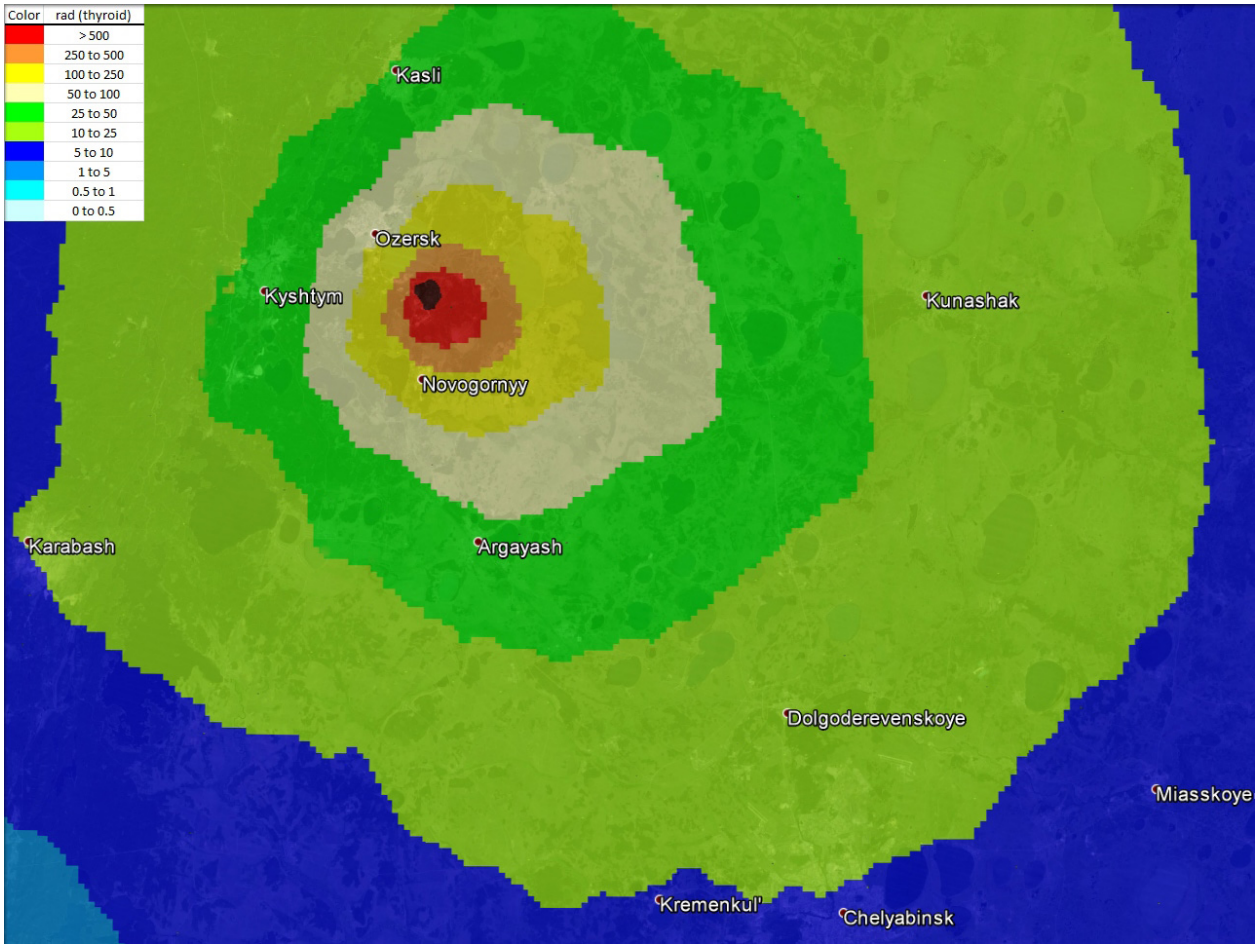

Figure 6.1 Best Estimate Thyroid Dose (rad) for a Rural 5-Year-Old Child in 1949

A run of the dose code using stochastic parameters was also performed in map mode for a rural child that was five years old for every year from 1950 through 1972. The keyword files for this run are identified in Table 6.4. Also identified is the keyword file for the graphics postprocessor CiderView.

Table 6.4 Keyword Files for the Stochastic Map Run for a Rural Child

Purpose	Keyword File
CiderF Keyword File	Child5Stoc.kwd
Reference Information Keyword File	MayakFactorsStoc.kwd
CiderView Keyword File	Child5View.kwd

An example output of the CiderView code for a stochastic run is provided in Figure 6.2 for a child who is 5 years old in 1949. The values plotted are thyroid dose (rad). The values in the top pane of the figure show the 1% level of the stochastic doses at each location. The values in the bottom pane show the 99% level of the stochastic doses at each location.

Another run of the CiderF dose code using stochastic parameters was performed in map mode for a male worker. The worker was assumed to be born in 1928 and the computed doses are for inhalation exposure for the entire time period of 1948 through 1972. The keyword files for this run are identified in Table 6.5. Also identified is the keyword file for the graphics postprocessor CiderView. The data files for this case are located in the **\Mayak\Stochastic\Maps\Worker** directory of the data package.

Table 6.5 Keyword Files for the Stochastic Map Run for a Worker

Purpose	Keyword File
CiderF Keyword File	WorkerBYCowStoc.kwd
Reference Information Keyword File	MayakFactorsWorkerStoc.kwd
CiderView Keyword File	WorkerBYCowView.kwd

An example output of the CiderView code for the worker case is provided in Figure 6.3. The values plotted are the median thyroid dose (Gy) due to inhalation, summed over the years 1948 through 1972. This particular plot shows the inhalation doses for the central region of the grid as well as the portion of the domain that follows the path of the Techa River to the northeast.

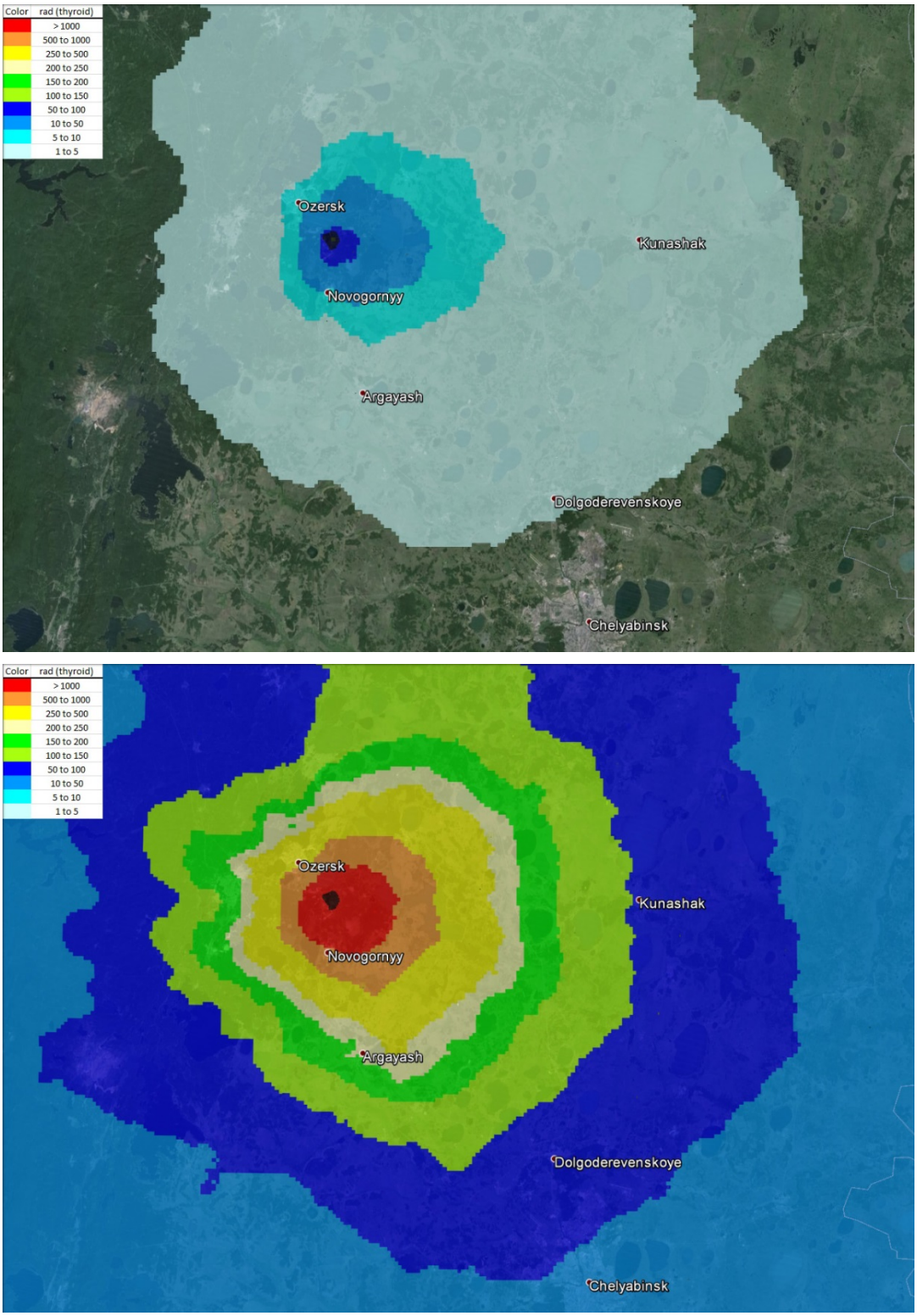

Figure 6.2 Stochastic Thyroid Dose (rad) for a Rural 5 Year Old Child in 1949 (1% level in top pane, 99% level in bottom pane)

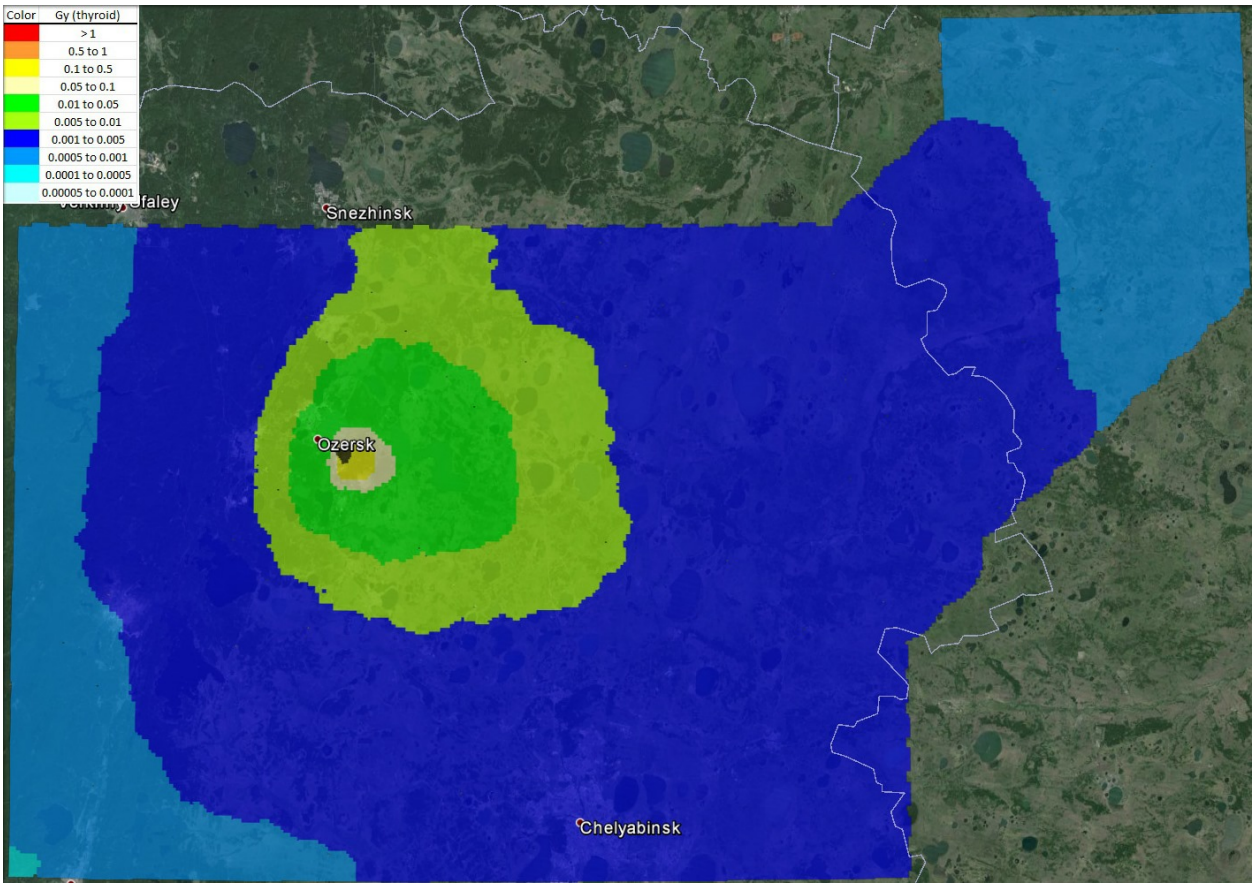

Figure 6.3 Median Thyroid Dose (Gy) for a Local Worker Due to Inhalation Totaled over the Years 1948 through 1972

6.3 Example Individual Dose Runs

Three example individual case runs were performed for an individual living in Ozersk. These three runs all model a five year old child using rural lifestyle assumptions. The runs differ in how they treat the atmospheric runs and the parameters describing the individual. The primary features of the three cases identified in Table 6.6 are the following:

- **Best Estimate Case**: Single realization case using best estimate values for release, accumulation, and individual parameters along with averaged atmospheric transport results.
- **Stochastic Case**: Two-hundred fifty realization run using stochastic descriptions for release, accumulation, and individual parameters along with stochastic atmospheric transport results.
- **Mono Case**: Two-hundred fifty realization run using stochastic descriptions for release and stochastic atmospheric transport results but best estimates for environmental accumulation and individual dose parameters.

Table 6.6 Keyword Files for Map Cases Using the CiderF Code

Purpose	Release	Atmospheric	Individual	Reference Keyword File
Best Estimate Case	Stochastic	Averaged	Best Estimate	MayakFactorsBest.kwd
Stochastic Case	Stochastic	Stochastic	Stochastic	MayakFactorsStoc.kwd
Mono Case	Stochastic	Stochastic	Best Estimate	MayakFactorsMono.kwd

As an example calculation, the percent of the variability in the estimated thyroid doses that can be attributed to the variability in release and atmospheric transport for a 5 year old child living in Ozersk in 1950 is shown in Table 6.7. The percent values listed in the first column of the table are based on the ratio of standard deviations of dose by pathway. The divisor uses doses from the full stochastic run (Stochastic Case). The numerator uses doses from the Mono case, thus release and atmospheric transport are stochastic but environmental accumulation and individual exposure parameters are set at fixed best estimate values. Also included is the mean dose from the stochastic case. For the mono case, the child eats 80 grams of beef a day and drinks 0.425 L of fresh milk per day.

Table 6.7 Percent of Variability in Thyroid Dose to a 5 Year Old Child Living in Ozersk in 1950 Attributable to Variability in Facility Releases and Atmospheric Transport

Percent of Variability	Mean Dose (rad)	Percent of Total Dose	Dose Pathway
47.4%	33.57	NA	Total
63.5%	0.001413	0.004%	External
18.4%	0.4150	1.236%	Inhalation
53.2%	2.902	8.64%	Beef ingestion
51.2%	0.09373	0.279%	Leafy vegetable ingestion
62.4%	0.01527	0.045%	Other vegetable ingestion
45.7%	0.08590	0.256%	Fruit ingestion
84.4%	0.004783	0.014%	Grain ingestion
45.2%	0.001326	0.004%	Poultry ingestion
36.1%	0.2824	0.841%	Eggs ingestion
48.6%	29.77	88.68%	Milk Ingestion

An example comparison of the best estimate run and the stochastic run for a five year old male child living in Ozersk in different years is provided in Figure 6.4. The boxes in the plots show the 25%, median and 75% levels of the stochastic doses. The cross marks on the tails shows the 5% and 95% levels of dose. The tails extend to the 1% and 99% levels of dose. The triangles show the minimum and maximum levels of dose. The red dots are the corresponding results from the best estimate case. As expected, the dose values follow the trend of the annual releases shown in Figure 4.2. The spreadsheet named **Child5_Ozersk.xlsm** was used to compile the plot data. The macro named BuildPlot was used to create the curves because Excel does not provide a function to develop this type of plot.

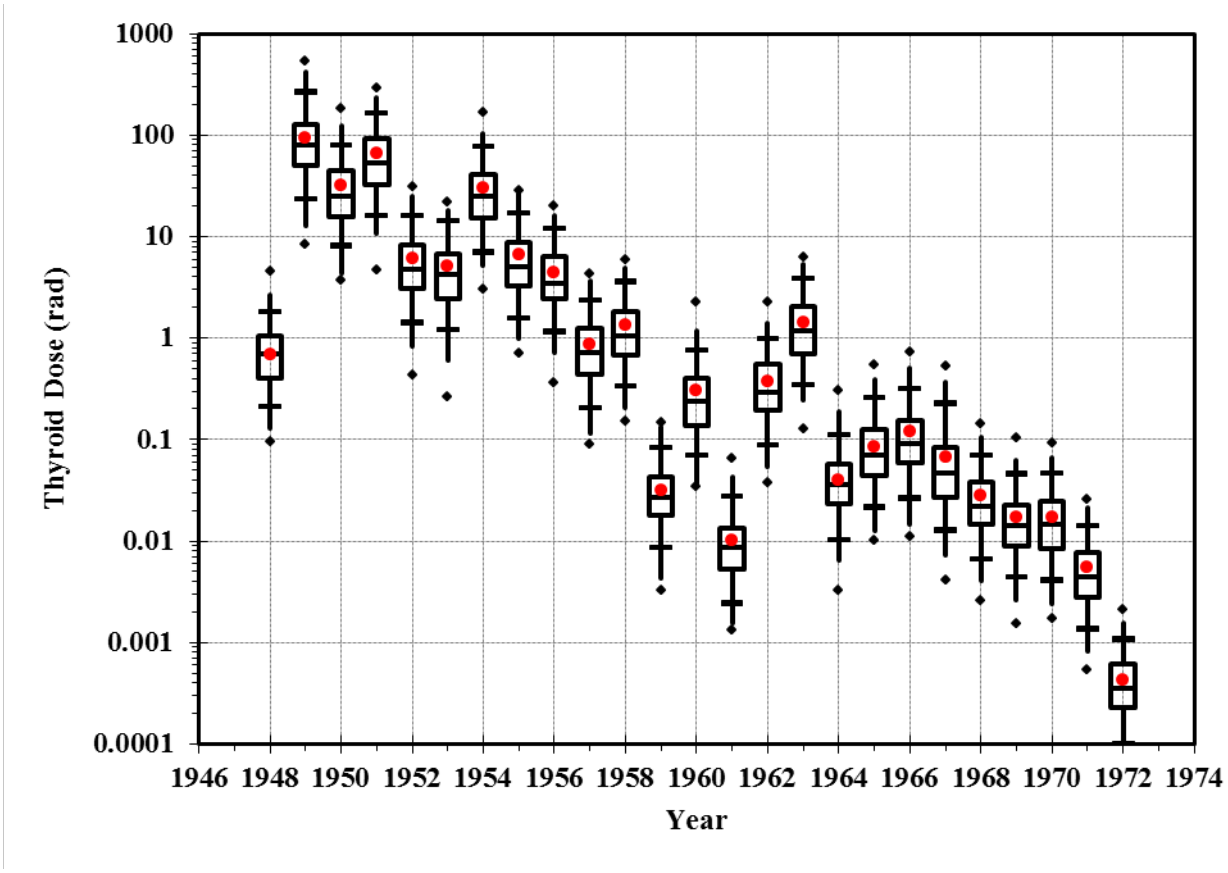

Figure 6.4 Annual Thyroid Dose for a 5 Year Old Male Child Living in Ozersk

Another example calculation examined the variability in the full stochastic case for a 5-year old male child living in Ozersk in 1949. In this case, a regression analysis determined that the variability in the internal dose factor accounted for 63% of the variability in the total thyroid dose. The scatterplot in Figure 6.5 shows the effect of the internal dose factor on the total dose. The spreadsheet named **Child5_Sensitivity.xlsx** was used to perform the regression and compile the plot data. For 1949, about 85.5% of the dose is from milk ingestion and another 10.8% is from beef ingestion. Total ingestion is 98.275% of the dose, inhalation is 1.717%, and external is the remaining 0.007%.

We expanded the regression analysis on the doses for 1949 to include the total yearly stochastic releases from A reactor and B plant. Including these variables causes the R^2 to increase to 65.1% and the included variable coefficient is statistically significant. Thus, the variation in annual releases adds to the explanation of total variability. If the speciation fractions (particulate and elemental) are included in the regression setting, the R-square goes up to 68.1% and both coefficients are statistically significant. It seems likely that the variability in the meteorological data is the remaining big driver in variability. Unfortunately, there isn't any simple way to describe that variability for use in a regression analysis.

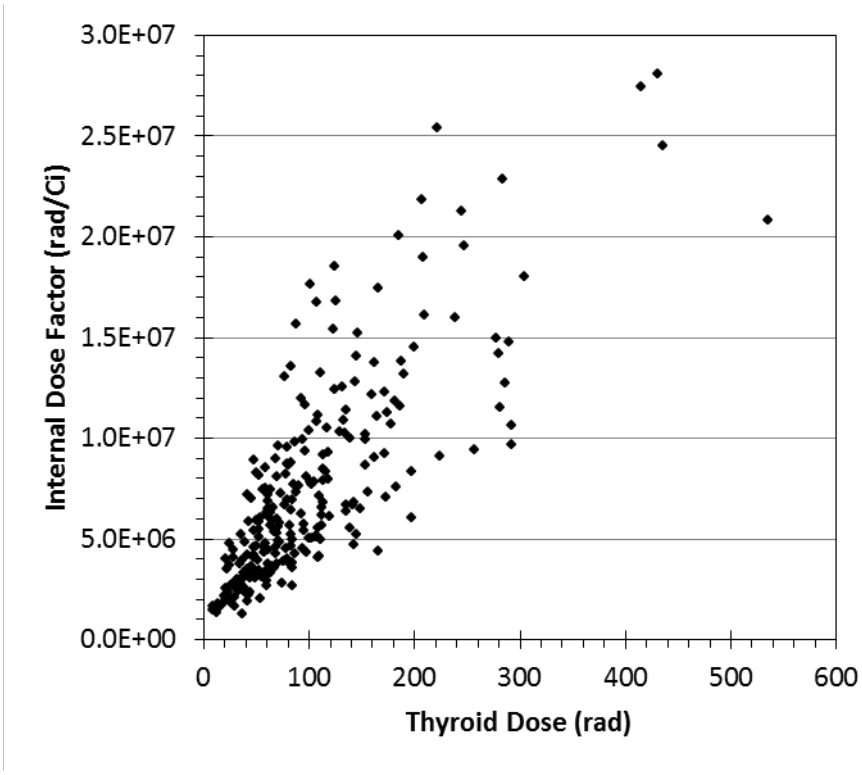

Figure 6.5 Scatterplot of Thyroid Dose to a 5 Year Old Child Living in Ozersk in 1949 against the Internal Dose Conversion Factor

7.0 Data Package

A data package has been prepared to accompany this document. The data package contains outputs of the AirCombGrid Code (see Table 1.1) and inputs and outputs for all subsequent codes in the modeling sequence. In addition, executable codes (Windows 64-bit versions) of the codes are provided. The purpose of the data package is to provide the input files and executable codes necessary to recreate all of the results given in this document, subsequent to the execution of the AirGridComb code. The data package is provided in a directory structure as follows:

Mayak: Top level directory

- **Best**: Information for best estimate runs, including inputs and outputs of the DESCARTES code
  - **AirCombGrid**: Keyword inputs and output files from the AirCombGrid code
  - **Cases**: Directory structure for individual cases
  - **Maps**: Directory structure for map cases
- **Codes**: Executable codes
- **DataReports**: PDF's of the milestone reports used to develop the input data for the environmental accumulation and dose codes
- **Kwd**: Information and spreadsheets for preparing keywords
  - **AnimalDiets**: Keywords and data files for animal diets
  - **FrostpUno**: Keywords and data files for frost dates
  - **Recipe**: Keywords and data files for commercial leafy vegetables, grocery milk and creamery milk production
  - **RefDiet**: Keywords files for reference diets
- **Mono**: Information for the "mono" runs, including inputs and outputs of the DESCARTES code.
  - **Cases**: Directory structure for individual cases
- **Spreadsheets**: Copies of Excel spreadsheets containing information to assist with preparing code inputs and analyzing output results
- **Stochastic**: Information for the stochastic runs, including inputs and outputs of the DESCARTES code
  - **AirCombGrid**: Keyword inputs and output files from the AirCombGrid code
  - **Cases**: Directory structure for individual cases
  - **Maps**: Directory structure for map cases

The data package (in the directory **Mayak**) contains 2,461 files in 24 folders and uses 19.1 Gb of disk space.

7.1 Spreadsheets

Several spreadsheets are used to facilitate preparing inputs in the format needed by the computer codes. Other spreadsheets are used to analyze run results. These spreadsheets are located in the **Mayak\Spreadsheets** directory and contain the following information:

Best_Release.xlsx – This spreadsheet contains inventory data output by the AirCombGrid for the best estimate case. This spreadsheet was used to develop Figure 4.1and Figure 4.2.

Child5_Ozersk.xlsm – This macro-enabled spreadsheet contains information from CiderF best estimate, stochastic and mono runs used to build the box and whisker plot given in Figure 6.4. This spreadsheet was also used to produce Table 6.7.

Child5_Sensitivity.xlsm – This spreadsheet contains information on the sensitivity analysis for a child in Ozersk in 1949 discussed in Section 6.3 and it was used to generate the scatterplot in Figure 6.5.

Grid.xlsx – This spreadsheet contains information used to build the NODE keywords for the 618 nodes in the dose domain.

Legend.xlsm – This macro-enabled spreadsheet generates KMLCOLOR and KMLLEGEND keywords for the AirCombGridView and CiderView codes. It also generates the associated legend that can be saved into a graphics file.

Mayak_Recipes.xlsx – This spreadsheet collects information for production and distribution "recipes" of commercial leafy vegetables and commercial milk (collective farms and grocery stores). Best estimate and stochastic keywords are generated for use in the RECIPE code. Keywords for different years are generated by entering a different row number in cell K1 of the "Dairy-Cream", "Grocery" and "Leafy" sheets.

Mayak_Ref_Diet.xlsx – This spreadsheet collects the information on reference diets and the other data needed for the CiderF Factors Keyword file (see Section 8.7 of the CiderF user's Guide). Best estimate and stochastic keywords are generated for use in the CiderF code.

Release_Keywords.xlsx – This spreadsheet collects the information on the monthly releases from the eight facilities. Best estimate and stochastic keywords are generated for use in the AirCombGrid code.

Release_Points.xlsx – This spreadsheet collects information on the release points and operational periods for the eight facilities.

Stochastic_Release.xlsx – This spreadsheet contains inventory data output by the AirCombGrid for the stochastic case. This spreadsheet was used to develop Table 4.2.

7.2 Code Execution

Many of the subdirectories in the data package contain batch files named "run.bat". These batch files can be executed by double clicking on them. If the data package is copied to a location where Mayak is the top level directory on the drive, then the run.bat files can generally be executed without modification. One exception is that some file names in the keyword files for AirCombGridView and CiderView must be changed to fully resolved path names so Google Earth can find the files. The batch files will generate the input library files for DESCARTES and CiderF and also execute these two codes.

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