14:27:20 OCA PAD AMENDMENT - PROJECT HEADER INFORMATION 08/31/95

Active

Project #: E-25-W48 Cost share #: Rev #: 9
Center # : 10/24-6-R8089-0A0 Center shr #: OCA file #:
Work type : RES
Contract#: 94-041 Mod #: LTR DTD 950826 Document : CONT
Prime #: DE-AC09-89SR18035 Contract entity: GTRC

Subprojects ? : Y CFDA:
Main project #: PE #:

Project unit: MECH ENGR Unit code: 02.010.126
Project director(s):
HERTEL N E MECH ENGR (404)894-3717

Sponsor/division names: ERDA / ATLANTA, GA
Sponsor/division codes: 500 / 221

Award period: 940218 to 950930 (performance) 950930 (reports)

Sponsor amount	New this change	Total to date
Contract value	0.00	278,618.00
Funded	0.00	278,618.00
Cost sharing amount		0.00

Does subcontracting plan apply ?: N

Title: CONSOLIDATED INCINERATION FACILITY HEALTH RISK ASSESSMENT

PROJECT ADMINISTRATION DATA

OCA contact: Jacquelyn L. Bendall 894-4820

Sponsor technical contact

DR. RATIB A. KARAM
(404)894-3600

ERDA
900 ATLANTIC DRIVE
ATLANTA, GA 30332-0425

Sponsor issuing office

CLARA GALASHAW
(404)894-3600

ERDA
900 ATLANTIC DRIVE
ATLANTA, GA 30332-0425

Security class (U,C,S,TS) : U ONR resident rep. is ACO (Y/N): N
Defense priority rating : DOE2 N/A supplemental sheet
Equipment title vests with: Sponsor X GIT

Administrative comments -
ISSUED TO TRANSFER FUNDS IN THE AMOUNT OF $1,533 TO SUBPROJECT E-24-X73.

4-25-54
SR-25-54

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

(1)

NOTICE OF PROJECT CLOSEOUT

Closeout Notice Date 10/27/95

Project No. E-25-W48_____ Center No. 10/24-6-R8089-0A0_

Project Director HERTEL N E_____ School/Lab MECH ENGR_____

Sponsor ERDA/ATLANTA, GA_____

Contract/Grant No. 94-041_____ Contract Entity GTRC

Prime Contract No. DE-AC09-89SR18035_____

Title CONSOLIDATED INCINERATION FACILITY HEALTH RISK ASSESSMENT_____

Effective Completion Date 950930 (Performance) 950930 (Reports)

Closeout Actions Required:	Y/N	Date Submitted
Final Invoice or Copy of Final Invoice	Y	_____
Final Report of Inventions and/or Subcontracts	Y	_____
Government Property Inventory & Related Certificate	Y	_____
Classified Material Certificate	N	_____
Release and Assignment	Y	_____
Other _____	N	_____

Comments_____
NOTE USE DOE FORM FOR PATENT._____

Subproject Under Main Project No. _____

Continues Project No. _____

Distribution Required:

Project Director	Y
Administrative Network Representative	Y
GTRI Accounting/Grants and Contracts	Y
Procurement/Supply Services	Y
Research Property Managment	Y
Research Security Services	N
Reports Coordinator (OCA)	Y
GTRC	Y
Project File	Y
Other _____	N
_____	N

NOTE: Final Patent Questionnaire sent to PDPI.

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year March, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 3/1/94 **To** 3/31/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Initiated Task Order Work.
2. Toured CIF on March 14 to clarify flow streams and hardware.
3. Began summarizing waste streams for CIF feed characterization to develop emissions source.
4. Obtained CET 89 code (see attached description).
5. Obtained CAD-88 mainframe computer code
6. Letters sent to ERDA Independent Review Panel members to select date in May for the first review.

B. Milestones achieved (Based on those identified in the Task Order):

None specified for this time frame.

C. Problems Encountered:

1. Georgia Tech accounts not available until 3/24/94.
2. Encountered lack of data on emissions from compactors.

Attachment
Monthly Report For March 1994

The following list of activities took place in March on the CIF emission estimation include the following:

1. An Environmental Engineering graduate student, Mike Robinson, has been recruited to work on the project, work that will lead to a thesis master's degree. He has begun the work, and will continue through spring, summer, and fall quarters, finishing in December, 1994. The other graduate student on the project, Michelle Coward, is working on the risk assessment.

2. On a second visit to SRS we toured the CIF under construction and now have a clearer picture of the incineration system hardware and flow streams. We have a better handle on incinerator operating parameters as well.

3. Our major efforts to date have been to distill from the volumes of reports and data that we have received an input feed composition (mean and range) for the four waste streams to be delivered to the incinerator: organic liquids (high heating value), aqueous liquids (low heating value), solid wastes, and DWPF (mostly benzene). Our goal is to summarize the waste characterization and incinerator operating conditions in a five to ten page document that we circulate for comment the week of April 11. This will serve as the starting point for the emission estimation.

4. We have obtained a copy of the NASA code CET89 for calculating the complex chemical equilibrium composition of gases and condensed phases for specified thermodynamic states (e.g., T, P). This will be useful in the estimating the speciation and phase of inorganic matter (e.g., metals) in the incinerator and post combustion gas stream. Particle removal efficiencies will depend on particle size distribution, with particular attention given to the partitioning of toxic metals between the fine condensation aerosols and the residual and fragmented particles. The code comes with a large data base. Our next goal will be to get this code up and running.

5. Organic emissions are very sensitive to non-mean reaction conditions, such as transient puffs in batch feed incinerators and rogue droplets in continuous feed systems. Our approach will be to identify classes of organic compounds that can be produced given the types of wastes being fed, then look at measured emissions from other rotary kilns (pilot scale and field) to provide an estimate of organic emissions. Trying to model mixing phenomena with the complex byproduct chemistry to estimate emissions is beyond the scope of this work. Furthermore, this approach is not recommended for organics as that level of detailed modeling has not been shown to be effective in large scale simulations.

In addition to these activities, a literature review was performed in support of the compactor emission source term. Work continues to place the emission fractions found in this literature survey. The methodology report for review for the Independent Review Panel was started and should be finished by 4/8/94. The CAP-88 code mainframe version was received from ORNL and is being compiled for use in the compactor health risk comparison report. Currently we have CAP-88PC working and are doing some preliminary analyses for the dose comparison with it. Letters were sent to members of the ERDA Independent Review Panel to inform them of the funding of the task order and to set up the first review meeting sometime between May 5 and May 23.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

May 11, 1994

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of April, 1994.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA/CSD
J. Mulholland
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year April, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

WSRC Technical
Period of Performance: From 4/1/94 **To** 4/30/94 **Representative** Don Burge

---

A. Project Accomplishments:

1. Prepared methodology working paper.
2. Drafted Compactor/Incinerator Health Impact Comparison.
3. MET89 Code Running.
4. Draft Emissions Report partially complete.

B. Milestones achieved (Based on those identified in the Task Order):

1. Methodology Working Paper delivered to Independent Review Committee.
2. Draft of Health Impacts for Compaction versus Incineration of Job Control Wastes.

C. Problems Encountered:

1. Problems with RADRISK data file for CAP-88 mainframe version.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

June 10, 1994

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of May, 1994.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA/CSD
J. Mulholland
D. Burge
File

Task Order # 94-041 Month/Year May, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 5/1/94 **To** 5/31/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Draft Report on Inorganic Emissions Completed.
2. Independent Review Panel convened on 5/26/94 to review Methodology and Inorganic Emissions Draft Report. (Comments attached.)
3. CAP-88 Mainframe Version running.

B. Milestones achieved (Based on those identified in the Task Order):

1. Review of Methodology.
2. Partial completion of Draft CIF Emissions Report.

C. Problems Encountered:

1. Need additional time to complete estimates of CIF Organic Emission Term.

Comments of Independent Review Panel For
SRS Consolidated Incineration Facility
Meeting Held May 26, 1994
Atlanta, GA

June 3, 1994

C. O. Velzy, Chairman
Panel Members

Dr. R. J. Charbeneau
Dr. R. D. Cox
Dr. C. C. Travis
Dr. F. W. Whicker

1. Dr. Mulholland stated that negligible amounts of mercury in the emission stream will exist in the vapor state since the stream will be cooled to 180°C. At this temperature mercury has a significant vapor pressure. **Accordingly, the panel would like to see a mathematical demonstration that the amount of mercury emissions in the vapor state at 180°C is actually negligible. This should also be done for lead. The Panel further recommends that the predicted metal/radionuclide emission data be compared with actual data from tests of hazardous waste incinerators and/or municipal waste incinerators.**

2. The Panel is not aware of any HEPA filter applications on hazardous waste incinerators (or municipal waste incinerators). Do such installations exist and is there operating data to support the anticipated control efficiencies? If not, what is the basis of the anticipated efficiencies?

3. **The Panel suggests making a two tiered assessment of health impacts from metals/radionuclides.** The first assessment would be the health impacts of the most likely emission projections. The second assessment, perhaps as a part of the sensitivity analysis, would project health impacts at higher emissions than currently anticipated (i.e. perhaps at 3 orders of magnitude higher than presently projected most likely levels) to ascertain what levels of metals/radionuclide concentrations might result in adverse health impacts. These higher emission levels could perhaps result from anticipated future changed operating conditions. This information could provide guidance as to changes in waste composition required to allow future operations at higher waste throughout capacities.

4. **The Panel considers the general methodology and anticipated use of models, as described at this meeting, to be satisfactory. However, we feel that the time frame indicated to mount the programs outlined, become familiar with their application, and effectively and efficiently utilize the programs to be optimistic.** In the interest of shortening this initial application time frame and enhancing the quality of the input, Dr. Whicker has offered to review and evaluate the basic input assumptions and anticipated use of site specific parameters. Dr. Whicker also feels he can be helpful in suggesting use of certain multivariate analysis techniques to investigate the impact of changes in interdependent model parameters.

5. **The Panel feels that it would be desirable to compare predicted mercury and lead emission levels, as dispersed in the environment, to existing background levels.** Other information that may be of interest to the investigators, and may be useful in developing the final report, are several (perhaps 3) studies of impacts of municipal incinerator operation on local background pollutant levels (source of reference: Dr. Curtis Travis). **We also feel that risks from radionuclide emissions should be compared to risks from background levels of naturally occurring radionuclides.**

6. Dose response data for lead may not be available. If this is the case, lead should not be discarded because of the public concern over this metal, especially with respect to adverse health impacts on children. **Because of this concern, the Panel recommends that the specific impact of lead on children be demonstrated.** If the proposed modeling methodology is not capable of this, there is an EPA program that calculates blood lead levels based on soil, water and food intake (source of reference: Dr. Robert Cox).

7. **The Panel recommends that the impact of resuspension of pollutants be considered with respect to the local impact of deposition (both wet and dry).** Such resuspension impacts can be taken into account by rather straight-forward modifications to the basic impact programs (such modifications can be described by Dr. Whicker).

8. Methodology and results of quantification of organic emissions and health impacts have yet to be reviewed and evaluated as they were not yet available.

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year June, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 6/1/94 **To** 6/30/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. CAP-88 Runs performed for compactor and incinerator.
2. Organic emissions study ongoing.

B. Milestones achieved (Based on those identified in the Task Order):

1. Second version of Compactor vs. Incinerator Dose Comparison Report completed.

C. Problems Encountered:

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year July, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 7/1/94 **To** 7/31/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. CAP-88 Runs for total radionuclide dose from CIF.
2. CIF Organic emissions calculations.

B. Milestones achieved (Based on those identified in the Task Order):

1. Draft Report to WSRC on Organic Emissions.
2. Draft Report to WSRC on Total Radionuclide Doses for CIF (CAP-88).
3. Installation of CRRIS code package instituted.

C. Problems Encountered:

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year August, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 8/1/94 **To** 8/31/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Convened Independent Review Panel on 8/8/94 to review:

   a. Changes in Inorganic Emissions Estimates
   b. Organic Emissions Estimates
   c. Drafts of CAP-88 Total Dose Report and Compactor/Incinerator Comparison Report

2. Incorporated Panel's comments and sent revised drafts of the Inorganic Emissions, Organic Emissions and Comparison Report to WSRC. The Comparison Report was substantially rewritten to make it more readable for members of the general public.

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

Substantial effort devoted to the Comparison report set back the implementation and testing of the CRRIS code package.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

October 14, 1994

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of September, 1994.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year September, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 9/1/94 **To** 9/30/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Additional revisions were made to the emissions estimates to differentiate between solid and liquid incinerator feeds.

2. Revision 2 of Compaction Comparison Report (GT/ERDA-94041-001) was submitted.

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

1. Uncovered hidden CRRIS code package problems - delayed implementation of code.

2. Received COMDEP, however, US EPA indicated that there was a major error in it. They are transmitting the corrected version. As a result, COMDEP implementation has been delayed.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

April 10, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of **October, 1994**.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year October, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 10/1/94 **To** 10/31/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

1. Two major revisions to the ANEMOS code were required.
2. One revision to the TERRA code.
3. A major revision to the ANDRO code.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

December 15, 1994

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of November, 1994.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year November, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 11/1/94 **To** 11/30/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Data gathered for final runs on radionuclide risk assessments.

B. Milestones achieved (Based on those identified in the Task Order):

1. Testing of COMDEP with sample problem.

C. Problems Encountered:

1. Bugs in CRRIS code package fixed.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

January 10, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of December, 1994.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year December, 1994

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 12/1/94 **To** 12/31/94 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Preliminary Results of Radiological Assessment reviewed.
2. Site data for Radiological Assessment finalized and reviewed by Dr. F. Ward Whicker for production runs.

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

1. Tritium Concentration computation in TERRA code discovered to be in error and fixed.
2. Miscoded Statements in the resuspension routine of TERRA discovered and recoded.
3. Delay in receipt of contract extension and additional funds has slowed the initiation of the uncertainty analysis.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

February 13, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of January, 1995.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year January, 1995

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 1/1/95 **To** 1/31/95 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. CRRIS codes being used are now all running correctly.

B. Milestones achieved (Based on those identified in the Task Order):

1. CRRIS runs performed. This in input into the draft radionuclide HRA report.

C. Problems Encountered:

1. Data Input to COMP DEP Requires Programs we need to get.
2. Problem with Input Routine to ANDROS code delayed final runs until the end of January.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

April 10, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of March, 1995.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
S. Pederson
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year March, 1995

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 3/1/95 **To** 3/31/95 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Chemical screen performed. Code written for chemical screen work.
2. Sensitivity studies are underway for radionuclides.

B. Milestones achieved (Based on those identified in the Task Order):

1. Screen of toxic chemicals transmitted to WSRC.
2. COMPDEP code now running and data available.

C. Problems Encountered:

1. Radionuclide Final Draft in revision.

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

May 10, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of April, 1995.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
S. Pederson
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year April, 1995

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

WSRC Technical

Period of Performance: From 4/1/95 **To** 4/30/95 **Representative** Don Burge

---

A. Project Accomplishments:

1. Independent Review Panel Meeting 4/21/95 - Radionuclide Draft in good shape.
2. Sensitivity Runs underway.

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

1. Chemical HRA needs inhalation pathway for all chemicals.

E-25-W48 #18

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year May, 1995

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 5/1/95 **To** 5/31/95 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Gathered data for final chemical toxins Health Risk Assessment.
2. Expand Toxic Chemical Health Risk Assessment Code to include all chemical emissions.
3. Sent out final radionuclide HRA draft (except Section 10) for review by ERDA Independent Review Panel Members.

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

June 30, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of June, 1995.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
S. Pederson
P. Dawkins
D. Burge
File

E-20-W48 # 17

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year June, 1995

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 6/1/95 **To** 6/30/95 **WSRC Technical Representative** Don Burge

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A. Project Accomplishments:

1. Final Report submitted on June 29, 1995.

B. Milestones achieved (Based on those identified in the Task Order):

1. Chemical Risk Assessment completed.

C. Problems Encountered:

E-25-W48 #20

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA

404-894-3717

August 23, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of July, 1995.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
S. Pederson
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year July, 1995

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 7/1/95 **To** 7/31/95 **WSRC Technical Representative** Don Burge

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A. Project Accomplishments:

1. Work on QA audit materials.
2. Code manual for toxic chemical HRA being edited.
3. Software and spreadsheet deliverables are being worked on.

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

E-25-W48 #21

Georgia Tech

THE GEORGE W. WOODRUFF SCHOOL OF
MECHANICAL ENGINEERING

Georgia Institute of Technology
Atlanta, Georgia 30332-0405
USA
404-894-3717

September 14, 1995

Dr. Ratib Karam
ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0425

Dear Dr. Karam:

Please find enclosed my Monthly Status Report for Task Order #94-041, "Consolidated Incineration Facility Health Risk Assessment" for the month of August, 1995.

Sincerely,

Nolan E. Hertel

NEH/bc
Enclosures
cc: OCA Reports
J. Mulholland
S. Pederson
P. Dawkins
D. Burge
File

ERDA MONTHLY STATUS REPORT

Task Order # 94-041 Month/Year August, 1995

Send Monthly Status Report by the 10th of each month to:
Dr. Ratib Karam, ERDA
Neely Nuclear Research Center
900 Atlantic Drive
Atlanta, GA 30332-0405

University Georgia Institute of Technology **PI** Dr. Nolan E. Hertel

Project Title Consolidated Incineration Facility Health Risk Assessment

Period of Performance: From 8/1/95 **To** 8/30/95 **WSRC Technical Representative** Don Burge

---

A. Project Accomplishments:

1. Code manual for the Code Risk Assessment.
2. Work continued on spreadsheet documentation for delivery to WSRC.
3. Work continued on preparation for WSRC QA surveillance.

B. Milestones achieved (Based on those identified in the Task Order):

C. Problems Encountered:

COMPARISON OF THE MAXIMUM SRS BOUNDARY DOSE FOR INCINERATION AND COMPACTION OF LOW-LEVEL RADIOACTIVE JOB CONTROL WASTES

Draft Report
Version A

Nolan E. Hertel and H. Michelle Coward
Health Physics Program
G. W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405
(404) 894-3717

James A. Mulholland
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0355
(404)894-1839 or -1695

April 1994

Prepared for the
Westinghouse Savannah River Company
Savannah River Site
Under ERDA Task Order 94-041

ABSTRACT

Estimates of the radionuclide content of job control wastes for the Savannah River Site were used to compute the solid low-level radioactive waste feed for the Consolidated Incineration Facility. These feed rates were used to project radionuclide emission rates for an incinerator and, alternatively, for a compactor. Doses for the resulting compactor and incinerator emissions were computed using CAP-88PC in order to compare the two approaches to treating the job control wastes. The maximum effective dose equivalents on the SRS boundary were estimated to be $7.6(10^{-4})$ and $1.4(10^{-5})$ mrem/y for the incinerator and compactor, respectively. If a complete tritium release was assumed for the compactor (the assumption for the incinerator), the associated effective dose equivalent increased to 2 (10^{-4}) mrem/y.

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TABLES

APPENDICES

COMPARISON OF THE MAXIMUM SRS SITE BOUNDARY DOSE FOR INCINERATION AND COMPACTION OF LOW-LEVEL RADIOACTIVE JOB CONTROL WASTES

1.0 INTRODUCTION

Incineration of hazardous, radioactive waste, and mixed wastes at the Consolidated Incineration Facility (CIF) generated on the Savannah River Site would significantly reduce the volumes and toxicities of such wastes. An alternative to incineration of the solid low-level portion of the waste stream would be compaction and burial of the waste at a low-level radioactive waste disposal facility. The object of this study is to compare the radiological consequences for treating the job control waste by incineration and by compaction.

2.0 METHOD AND MODEL PARAMETERS

2.1 CAP-88PC Code

The CAP88-PC computer code[EPA92] was used to estimate the effective dose equivalent (EDE) from the operation of an incinerator and a compactor. The CAP88-PC code estimates doses due to airborne releases as a result of plume immersion, inhalation, ingestion, and ground deposited radioactivity. The code uses NRC Regulatory Guide 1.109 methodology to compute ingestion doses from the terrestrial food chain pathways and parameters. Atmospheric dispersion is based on a modified Gaussian plume model.

2.2 Exposure Modeling

Doses were calculated for all default exposure scenarios in the CAP-88PC code. The maximally exposed individual was assumed to be at a distance

of 11770 m from the CIF stack in the NNW wind sector.[HA94A] The maximum EDE was calculated using a stack height of 150 ft for the incinerator[DOE88] and a release height of 30 ft for the compactor, a reasonable height for a two-story building.

The following site-specific data were used: an average annual temperature of 18°C, an average annual precipitation rate of 122.4 cm/y, and the site wind speed, stability class, and direction information obtained from WSRC.[HA94A] The fractions of home produced vegetables, milk and meat were 0.700, 0.399, and 0.442, respectively. The remainder of the food was assumed to be grown in the assessment area and not imported. The default agricultural data for South Carolina were used in the code runs.

2.3 Waste Feed Term

The solid low-level waste feed used to determine the radiological emission source terms was the annual job control waste generation rate from the CIF Environmental Assessment Report.[DOE92] In terms of volume, it is 560,000 ft^3/y which represents a mass feed rate of 2,800,000 lbs/y.[DOE92, SRS93] To estimate the feed rates of radionuclides in Ci/y, the maximum expected radioisotope concentrations (μCi/lb) from the revised Table 16 of the NESHAPS application were used.[DOE88, DOE89] The resulting radionuclide feed rates are show in Table 1. In a recent re-evaluation of the CIF waste feeds, the mass feed rate of job control wastes was forecast to be 1,125,000 lbs/y.[SRS93]

3.0 IMPACT OF INCINERATION

The CIF incinerator will have an Air Pollution Control System (APCS) which incorporates a scrubber and a cyclone separator. In addition, the emissions partitioned to the stack will encounter a HEPA filter bank. With the exception of tritium, the radioisotopes which exit the APCS will be attached to

particles. Emission factors for heavy metals can range as high as 50%.[TR89] Travis and Cook report that a mass enrichment occurs for metals, i.e. the concentration of a trace metal (per mass basis) in the particulate emissions from an incinerator is higher than the concentrations of that metal in the waste feed. This enrichment occurs because metals are more likely to condense on the surface of finer particles, and these smaller particles are not as efficiently removed by the APCS.

The original NESHAPS application for the CIF[DOE89] assumed that 20% of the incinerator ash was carried over to the APCS as particulate. Particulate removal efficiencies for the quench chamber and the scrubber were estimated to be 55% and 85.5% using vendor information. So, the amount of metal partitioned to stack emissions was [0.2(1-.55)(1-.855)] or $1.31(10^{-2})$. This approach has the inherent assumption that metals are evenly distributed in the ash regardless of particle size. The HEPA filter efficiency was assumed to be 99.8% for conservatism in that analysis. The actual HEPA filter efficiency of 99.97% for particles down to 0.3μm is insured at SRS by pre-installation testing. So, in the initial NESHAPS application, a decontamination factor of approximately 38,000 was used for the non-tritium radioactivity. This is equivalent to a total emission factor of $2.61(10^{-5})$.

In this work the particulate penetration factor for HEPA filters of 0.002 from the NESHAPS application was retained and is assumed to be appropriate for both the incinerator and the compactor. In future work, the project investigators intend to develop at least a crude particulate distribution for use with particle-size dependent HEPA efficiencies. Turner and Cook indicate that the average emission factors for metals at incinerators with APCSs are in general about 3%.[TR89] This factor will be used in the current study to determine the pre-HEPA filter emission rate. This leads to a total emission factor of $6(10^{-5})$ for non-tritium radionuclides. All the tritium in the

feed is assumed to be released through the incinerator stack in this study. This is conservative as it would be anticipated that some of it will partition to the liquid phase and be removed in the APCS.

In Table 2, dose conversion factors, incinerator emission rates and effective dose equivalents for the maximally exposed individual at the site boundary are tabulated by radionuclide. The dose conversion factors from Ci to mrem at the boundary are based on CAP-88PC code runs. Tritium ingestion and inhalation have been retained as separate quantities since the model is known to be overly conservative for tritium.[HA94b] However, no adjustments to the computed tritium doses have been made. The total EDE is approximately 0.76 μrem/y; approximately 21%, 62%, and 14% of the EDE are due to H-3, other β/γ–emitters categorized as Sr-90 and α-emitters classified as Pu-238, respectively. If the EDE were to be based on the revised forecasts of the job control wastes, it would be reduced to roughly 0.31 μrem/y. Neither of these two dose rates are of concern and are dwarfed in comparison to the maximum offsite dose of 0.46 mrem/y from existing operations in 1988, [DOE92] which itself is trivial compared to background.

4.0 IMPACT OF COMPACTION

In order to determine an emissions factor for compaction, a review of several possible values are presented. A typical compactor has a closed air system that directs airborne emissions to a HEPA filter bank prior to release. In the Safety Evaluation Report for a Babcock and Wilcox facility (a 1500-ton force hydraulic press), a release fraction of 0.01% of the Ci content of each waste container was assumed for non-tritium radionuclides, save for C-14 and I-125.[NRC86a] A HEPA filter efficiency of 99.97% was used to determine particulate penetration of the filter. All the H-3 and C-14 radioactivity present

was assumed to be released completely, a non-tritium emission factor of $3(10^{-8})$. No justification given for the 0.01% release factor.

In a report on the Waste Experimental Reduction Facility (WERF) by EG&G Idaho, Inc., a release fraction of 1% from the compactor was estimated to be a conservative overestimate of the value.[EGG92] Since this facility has two baghouse filters and a HEPA filter bank, particulate emissions penetration factors of 0.1 for each baghouse filter and 0.01 for the HEPA filter bank were used. These values were taken from Table 1 of Appendix D to 40CFR61 "Methods for Estimating Radionuclide Emissions." It is not clear that the effect of two baghouses in series are multiplicative as assumed. The resulting total emission factor was then 10^{-6}.

A further analysis of the WERF data indicates that during operation of the sizing and compaction facility from 1984-1991, waste containing a total of 27.1 Ci was received and processed. During this time period, the release from the facility was typically on the order of several μCi/y. Assuming that 5 μCi/y is a good estimate of the yearly release from the compactor facility during that period, a total emission factor of [7(5μCi)/27.1Ci] or $1.3(10^{-6})$ is obtained. It is reasonable to assume that the previously mentioned factor of 10^{-6} was tailored based on such an assumption. It should be noted that the sizing operation processed 1.39 Ci of the 27.1 Ci feed.

In an attempt to further determine a reasonable total emission factor for a compactor, an alternative approach was investigated.[1] In NUREG/CR-4370, accidents involving the dropping or spilling of radioactive waste containers employ a release fraction of 0.1% of the radioactive contents.[NRC86b] This release fraction is the respirable release fraction assumed appropriate for an accident of moderate severity in Department of Transportation requirements for

[1]Additional reports from two sources have been requested and are still outstanding.

containers performance for the transport of radioactive materials.[FR83] If a HEPA filter efficiency of 99.8% is applied with this release fraction, a total emission factor of $2(10^{-6})$ is obtained. The SRS HEPA filter efficiency has been chosen as a more realistic assessment of filter performance than the EPA value of 0.01.

It appears that a total emissions factor on the order of 10^{-6} is appropriate for compactors. To that end, an emissions factor of $1.3(10^{-6})$ was used in the present work for non-tritium radionuclide releases. The resulting emission rates and EDEs for a compactor facility processing the SRS job control waste stream are reported in Table 3. The dose conversion factors were based on the CAP-88PC runs for the compactor as described in Section 2. Again the EDE values for tritium ingestion and inhalation were broken out. Two EDE values of tritium exposure are reported for ingestion and inhalation. The second value in each case assumes a complete release of tritium from the waste during compaction. This seemed an unlikely occurrence, so another tritium release term was also used in the assessment. In this case an emission fraction of $6.5(10^{-4})$ or $[1.3(10^{-6})/0.002]$ was used for tritium release. The latter approach implies that H-3 is constituted as particulate matter in the wastes but takes no credit for the HEPA filter.

For full release of tritium, the maximum exposed individual at the site boundary receives an EDE of approximately 0.2 μrem/y, 93% resulting from tritium exposure. If the revised feed forecast for job control waste generation was used, this value reduces to about 0.08 μrem/y. When the smaller tritium release value was used, the EDE was approximately $1.4(10^{-2})$ μrem/y with 77% of the dose due to β/γ emitters represented as Sr-90 and 19% due to α-emitters classified as Pu-238. These EDEs are quite low and constitute no health risks. Using the revised forecast results in a value of about $6(10^{-3})$ μrem/y

5.0 COMPARISON AND SUMMARY

For the assumption of partial tritium release from the compactor, the incinerator exposure for the maximally exposed individual on the site boundary is approximately 55 times greater than for the compactor. If a total tritium content release is postulated from the compactor, the incinerator related exposure is now only about four times greater. For both compactor and incinerator scenarios, β/γ emitters represented as Sr-90 and α-emitters classified as Pu-238 are major contributors to the exposure. When a full tritium release is assumed, tritium is also a major contributor to the exposure in both scenarios. None of the resulting EDEs are of significance with respect to health risk.

An improved analysis of the CIF emissions source in terms of particle size distribution could lead to a change in the penetration factor for the HEPA filter. It is anticipated that the forthcoming report on the CIF emissions will provide at least a crude distribution of particle sizes for the CIF. The effective use of such a distribution requires data for HEPA filter efficiency as a function of particle size. A review of such material is under way. It is unlikely that particle size distribution information for a compactor will change the emission rates much since the distribution is most likely that of atmospheric dust.

References

DOE88 "Application for EPA Approval of Construction: Consolidated Incineration Facility," U. S. Department of Energy, September 1988.

DOE89 "EPA Request for Additional Information for Review of Consolidated Incineration Facility (CIF) Construction/Operation Application," Letter to Mr. S. R. Wright, Environmental Division of SRO Office, U.S. Department of Energy, from C. F. Muska, March 19, 1989.

DOE92 "Environmental Assessment: Consolidated Incineration Facility, Savannah River Site," U. S. Department of Energy, Office of Environmental Restoration and Waste Management, DOE/EA-0400, December 1992.

EGG92 D. V. Christensen, J. J. Riedesel, and C. S. Staley, "WERF Emission Sources NESHAPS Monitoring Calculations," EG&G Idaho, Inc., EGG-WMO-10285 (Rev. 2), July 1992.

FR83 "Requirements for Transportation of Radioactive Materials," U. S. Department of Transportation, *Federal Register*, March 10, 1983 (48 FR 10218).

HA94a D. M. Hamby, WSRC, Personal Communication, March 1994.

HA94b D. M. Hamby and L.R. Bauer, "The Vegetation-To-Air Concentration Ratio in a Specific Activity Atmospheric Tritium Model," *Health Physics* 66, 339-342 (1994)..

NRC86a "Safety Evaluation Report Related to the Volume Reduction Services Facility: Babcock & Wilcox, Parks Township, PA," U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Docket 70-364, April 1986.

NRC86b O.I. Oztunali and G. W. Roles, "Update of Part 61 Impacts Analysis Methodology," U. S. Nuclear Regulatory Commission, NUREG/CR-4370, Vol. I, January 1986.

SRS93 "Savannah River Site Consolidated Incineration Facility: Mission Need and Design Capacity Review," Draft B, July 1993.

TR89 C. C. Travis and S. C. Cook, Hazardous Waste Incineration and Human Health, CRC Press, Boston, MA, 1989, pp. 90-91/

Table 1. Job Control Waste Feed Rate Based on Estimates of the CIF Feed Rates [DOE92] and of the Concentrations from the NESHAPS Application.[DOE88]

Nuclide	Concentration (μC/lb)	Feed (Ci/y)
H-3	1.57E+01	4.40E+01
Sr-89	1.98E+00	5.54E+00
Sr-90	2.50E-01	7.00E-01
Y-90	2.50E-01	7.00E-01
Y-91	1.49E+00	4.17E+00
Zr-95	1.45E+00	4.06E+00
Nb-95	4.91E+00	1.37E+01
Ru-106	4.80E-01	1.34E+00
Rh-106	4.80E-01	1.34E+00
Cs-137	7.60E-01	2.13E+00
Ba-137m	7.60E-01	2.13E+00
Ce-144	6.50E-01	1.82E+00
Pr-144m	6.50E-01	1.82E+00
Pr-144	6.50E-01	1.82E+00
Co-60	4.40E-01	1.23E+00
Cr-51	4.95E+01	1.39E+02
Pm-147	2.98E+00	8.34E+00
β/γ as Sr-90[a]	7.28E+01	2.04E+02
α as Pu-238[a]	4.40E-01	1.23E+00
α as Pu-239[a]	1.60E-03	4.48E-03

[a]Other β/γ-emitting radionuclides may be present in small or undetectable quantities and their exposure effects are conservatively overestimated by treating them as Sr-90. [DOE89]

[b]Alpha emitters are classified as either Pu-238 or Pu-239 based on their radiation properties. This is done since Pu-238 and Pu-239 were the principal SRP products and the major alpha-emitting waste contaminants.[DOE89]

Table 2. Yearly Maximum Effective Dose Equivalent at the Site Boundary due to the Incineration of the Job Control Wastes.

Nuclide	Conversion Factor[a] (mrem/Ci)	Incinerator Emissions[b] (Ci/y)	EDE (mrem/y)
H-3 (Ingestion)	3.10E-06	4.40E+01	1.36E-04
H-3 (Inhalation)	5.60E-07	4.40E+01	2.46E-05
Sr-89	5.50E-04	3.33E-04	1.83E-07
Sr-90	3.83E-02	4.20E-05	1.61E-06
Y-90	3.92E-05	4.20E-05	1.65E-09
Y-91	7.10E-04	2.50E-04	1.78E-07
Zr-95	1.03E-02	2.44E-04	2.52E-06
Nb-95	1.30E-03	8.25E-04	1.07E-06
Ru-106	3.84E-03	8.06E-05	3.10E-07
Rh-106	3.03E-29	8.06E-05	2.44E-33
Cs-137	1.33E-02	1.28E-04	1.70E-06
Ba-137m	5.26E-02	1.28E-04	6.72E-06
Ce-144	3.04E-03	1.09E-04	3.32E-07
Pr-144m	2.96E-09	1.09E-04	3.24E-13
Pr-144	7.25E-08	1.09E-04	7.92E-12
Co-60	6.17E-02	7.39E-05	4.56E-06
Cr-51	2.20E-05	8.31E-03	1.83E-07
Pm-147	2.53E-04	5.01E-04	1.26E-07
β/γ as Sr-90	3.89E-02	1.22E-02	4.75E-04
Pu-238	1.42E+00	7.39E-05	1.05E-04
Pu-239	1.60E+00	2.69E-07	4.30E-07
Total			**7.61E-04**

[a]Conversion factors were computed with CAP-88PC for a stack height of 150 feet at a distance of 11700 meters from the stack in the NNW sector.

[b]All the H-3 was assumed to be completely released. For the other nuclides an average metals release fraction of 3% [TR89] and a HEPA filter efficiency of 99.8% [SRS88] were used.

Table 3. Yearly Maximum Effective Dose Equivalent at the Site Boundary due to the Compaction of the Job Control Wastes.

Nuclide	Conversion Factor[a] (mrem/Ci)	Compactor Release[b] (Ci/y)	EDE (mrem/y)
H-3 (Ingestion)	3.51E-06	2.85E-02[c]	9.99E-08 (1.54E-04)[d]
H-3 (Inhalation)	6.49E-07	2.85E-02[c]	1.85E-08 (2.85E-05)[d]
Sr-89	5.70E-04	7.18E-06	4.09E-09
Sr-90	3.97E-02	9.07E-07	3.60E-08
Y-90	4.60E-05	9.07E-07	4.17E-11
Y-91	7.62E-04	5.40E-06	4.11E-09
Zr-95	1.08E-02	5.26E-06	5.68E-08
Nb-95	1.34E-03	1.78E-05	2.39E-08
Ru-106	4.24E-03	1.74E-06	7.38E-09
Rh-106	4.15E-29	1.74E-06	7.23E-35
Cs-137	1.37E-02	2.76E-06	3.78E-08
Ba-137m	5.46E-02	2.76E-06	1.51E-07
Ce-144	3.36E-03	2.36E-06	7.93E-09
Pr-144m	3.65E-09	2.36E-06	8.59E-15
Pr-144	8.63E-08	2.36E-06	2.03E-13
Co-60	6.42E-02	1.60E-06	1.02E-07
Cr-51	2.30E-05	1.79E-04	4.13E-09
Pm-147	2.84E-04	1.08E-05	3.07E-09
β/γ as Sr-90	4.01E-02	2.64E-04	1.06E-05
Pu-238	1.65E+00	1.60E-06	2.63E-06
Pu-239	1.85E+00	5.80E-09	1.07E-08
Total (Full H-3 Release)			**1.38E-05 (1.96E-04)[d]**

[a]Conversion factors were computed with CAP-88PC for a release height of 30 feet at a distance of 11700 meters from the compactor in the NNW sector .

[b]A total release fraction (including HEPA filter) of 1.3E-06 was used for all the nuclides. [EGG92].

[c]There is assumed to be no removal of H-3 by the HEPA filter so a release fraction for H-3 of (1.3E-06/0.002) was used.

[d]For completeness, the number in parenthesis for H-3 is the EDE that resulted if a complete release of H-3 were postulated.

APPENDIX A

GENERAL DATA AND WEATHER FROM CAP-88PC RUNS

VALUES FOR RADIONUCLIDE-DEPENDENT PARAMETERS

Nuclide	Clearance Class	Particle Size (microns)	Scavenging Coefficient (per second)	Dry Deposition Velocity (m/s)
SR-89	D	1.0	1.22E-05	1.80E-03
SR-90	D	1.0	1.22E-05	1.80E-03
Y-90	Y	1.0	1.22E-05	1.80E-03
Y-91	Y	1.0	1.22E-05	1.80E-03
ZR-95	W	1.0	1.22E-05	1.80E-03
NB-95	Y	1.0	1.22E-05	1.80E-03
RU-106	Y	1.0	1.22E-05	1.80E-03
RH-106	Y	1.0	1.22E-05	1.80E-03
CS-137	D	1.0	1.22E-05	1.80E-03
BA-137M	D	1.0	1.22E-05	1.80E-03
CE-144	Y	1.0	1.22E-05	1.80E-03
PR-144M	Y	1.0	1.22E-05	1.80E-03
PR-144	Y	1.0	1.22E-05	1.80E-03
CO-60	Y	1.0	1.22E-05	1.80E-03
CR-51	Y	1.0	1.22E-05	1.80E-03
PM-147	Y	1.0	1.22E-05	1.80E-03
SR-90	D	1.0	1.22E-05	1.80E-03
PU-238	Y	1.0	1.22E-05	1.80E-03
PU-239	Y	1.0	1.22E-05	1.80E-03

VALUES FOR RADIONUCLIDE-DEPENDENT PARAMETERS

	DECAY CONSTANT (PER DAY)			TRANSFER COEFFICIENT	
Nuclide	Radio-active (1)	Surface	Water	Milk (2)	Meat (3)
SR-89	1.37E-02	5.48E-05	0.00E+00	1.50E-03	3.00E-04
SR-90	0.00E+00	5.48E-05	0.00E+00	1.50E-03	3.00E-04
Y-90	2.60E-01	5.48E-05	0.00E+00	2.00E-05	3.00E-04
Y-91	1.19E-02	5.48E-05	0.00E+00	2.00E-05	3.00E-04
ZR-95	1.08E-02	5.48E-05	0.00E+00	3.00E-05	5.50E-03
NB-95	1.98E-02	5.48E-05	0.00E+00	2.00E-02	2.50E-01
RU-106	0.00E+00	5.48E-05	0.00E+00	6.00E-07	2.00E-03
RH-106	2.00E+03	5.48E-05	0.00E+00	1.00E-02	2.00E-03
CS-137	0.00E+00	5.48E-05	0.00E+00	7.00E-03	2.00E-02
BA-137M	3.91E+02	5.48E-05	0.00E+00	3.50E-04	1.50E-04
CE-144	0.00E+00	5.48E-05	0.00E+00	2.00E-05	7.50E-04
PR-144M	1.39E+02	5.48E-05	0.00E+00	2.00E-05	3.00E-04
PR-144	5.78E+01	5.48E-05	0.00E+00	2.00E-05	3.00E-04
CO-60	0.00E+00	5.48E-05	0.00E+00	2.00E-03	2.00E-02
CR-51	2.50E-02	5.48E-05	0.00E+00	1.50E-03	5.50E-03
PM-147	0.00E+00	5.48E-05	0.00E+00	2.00E-05	5.00E-03
SR-90	0.00E+00	5.48E-05	0.00E+00	1.50E-03	3.00E-04
PU-238	0.00E+00	5.48E-05	0.00E+00	1.00E-07	5.00E-07
PU-239	0.00E+00	5.48E-05	0.00E+00	1.00E-07	5.00E-07

FOOTNOTES:
(1) Effective radioactive decay constant in plume; set to zero if less than 1.0E-2

(2) Fraction of animal's daily intake of nuclide which appears in each L of milk (days/L)

(3) Fraction of animal's daily intake of nuclide which appears in each kg of meat (days/kg)

VALUES FOR RADIONUCLIDE-DEPENDENT PARAMETERS

	CONCENTRATION UPTAKE FACTOR		GI UPTAKE FRACTION	
Nuclide	Forage (1)	Edible (2)	Inhalation	Ingestion
SR-89	2.50E+00	1.07E-01	3.00E-01	3.00E-01
SR-90	2.50E+00	1.07E-01	3.00E-01	3.00E-01
Y-90	1.50E-02	2.57E-03	1.00E-04	1.00E-04
Y-91	1.50E-02	2.57E-03	1.00E-04	1.00E-04
ZR-95	2.00E-03	2.14E-04	2.00E-03	2.00E-03
NB-95	2.00E-02	2.14E-03	1.00E-02	1.00E-02
RU-106	7.50E-02	8.56E-03	5.00E-02	5.00E-02
RH-106	1.50E-01	1.71E-02	5.00E-02	5.00E-02
CS-137	8.00E-02	1.28E-02	9.50E-01	9.50E-01
BA-137M	1.50E-01	6.42E-03	1.00E-01	1.00E-01
CE-144	1.00E-02	1.71E-03	3.00E-04	3.00E-04
PR-144M	1.00E-02	1.71E-03	3.00E-04	3.00E-04
PR-144	1.00E-02	1.71E-03	3.00E-04	3.00E-04
CO-60	2.00E-02	3.00E-03	5.00E-02	3.00E-01
CR-51	7.50E-03	1.93E-03	1.00E-01	1.00E-01
PM-147	1.00E-02	1.71E-03	3.00E-04	3.00E-04
SR-90	2.50E+00	1.07E-01	3.00E-01	3.00E-01
PU-238	4.50E-04	1.93E-05	1.00E-03	1.00E-03
PU-239	4.50E-04	1.93E-05	1.00E-04	1.00E-03

FOOTNOTES: (1) Concentration factor for uptake of nuclide from soil for pasture and forage (in pCi/kg dry weight per pCi/kg dry soil)

(2) Concentration factor for uptake of nuclide from soil by edible parts of crops (in pCi/kg wet weight per pCi/kg dry soil)

DECAY CHAIN INGROWTH FACTORS

Nuclide	Parent(s)	Ingrowth Factor(s)
BA-137M	CS-137	3.209E+06

VALUES FOR RADIONUCLIDE-INDEPENDENT PARAMETERS

HUMAN INHALATION RATE	
Cubic centimeters/hr	9.17E+05
SOIL PARAMETERS	
Effective surface density (kg/sq m, dry weight)	
(Assumes 15 cm plow layer)	2.15E+02
BUILDUP TIMES	
For activity in soil (years)	1.00E+02
For radionuclides deposited on ground/water (days)	3.65E+04
DELAY TIMES	
Ingestion of pasture grass by animals (hr)	0.00E+00
Ingestion of stored feed by animals (hr)	2.16E+03
Ingestion of leafy vegetables by man (hr)	3.36E+02
Ingestion of produce by man (hr)	3.36E+02
Transport time from animal feed-milk-man (day)	2.00E+00
Time from slaughter to consumption (day)	2.00E+01
WEATHERING	
Removal rate constant for physical loss (per hr)	2.90E-03
CROP EXPOSURE DURATION	
Pasture grass (hr)	7.20E+02
Crops/leafy vegetables (hr)	1.44E+03
AGRICULTURAL PRODUCTIVITY	
Grass-cow-milk-man pathway (kg/sq m)	2.80E-01
Produce/leafy veg for human consumption (kg/sq m)	7.16E-01
FALLOUT INTERCEPTION FRACTIONS	
Vegetables	2.00E-01
Pasture	5.70E-01
GRAZING PARAMETERS	
Fraction of year animals graze on pasture	4.00E-01
Fraction of daily feed that is pasture grass	
when animal grazes on pasture	4.30E-01

VALUES FOR RADIONUCLIDE-INDEPENDENT PARAMETERS

ANIMAL FEED CONSUMPTION FACTORS	
Contaminated feed/forage (kg/day, dry weight)	1.56E+01
DAIRY PRODUCTIVITY	
Milk production of cow (L/day)	1.10E+01
MEAT ANIMAL SLAUGHTER PARAMETERS	
Muscle mass of animal at slaughter (kg)	2.00E+02
Fraction of herd slaughtered (per day)	3.81E-03
DECONTAMINATION	
Fraction of radioactivity retained after washing for leafy vegetables and produce	5.00E-01
FRACTIONS GROWN IN GARDEN OF INTEREST	
Produce ingested	1.00E+00
Leafy vegetables ingested	1.00E+00
INGESTION RATIOS:	
IMMEDIATE SURROUNDING AREA/TOTAL WITHIN AREA	
Vegetables	7.00E-01
Meat	4.42E-01
Milk	3.99E-01
MINIMUM INGESTION FRACTIONS FROM OUTSIDE AREA (Minimum fractions of food types from outside area listed below are actual fixed values.)	
Vegetables	0.00E+00
Meat	0.00E+00
Milk	0.00E+00
HUMAN FOOD UTILIZATION FACTORS	
Produce ingestion (kg/y)	1.76E+02
Milk ingestion (L/y)	1.12E+02
Meat ingestion (kg/y)	8.50E+01
Leafy vegetable ingestion (kg/y)	1.80E+01
SWIMMING PARAMETERS	
Fraction of time spent swimming	0.00E+00
Dilution factor for water (cm)	1.00E+00

FREQUENCIES OF STABILITY CLASSES (WIND TOWARDS)

	Pasquill Stability Class						
Dir	A	B	C	D	E	F	G
N	0.1780	0.0685	0.1320	0.3910	0.2050	0.0230	0.0017
NNW	0.1880	0.0678	0.1240	0.2900	0.2860	0.0401	0.0035
NW	0.1990	0.0967	0.1370	0.2710	0.2600	0.0353	0.0013
WNW	0.1590	0.0842	0.1530	0.2640	0.2600	0.0770	0.0028
W	0.1630	0.1010	0.1690	0.2510	0.2280	0.0796	0.0081
WSW	0.1260	0.1010	0.2020	0.3380	0.1740	0.0530	0.0052
SW	0.1550	0.0957	0.2250	0.3280	0.1520	0.0405	0.0039
SSW	0.2620	0.1020	0.1610	0.2600	0.1640	0.0500	0.0017
S	0.2530	0.1260	0.1690	0.2190	0.1450	0.0482	0.0400
SSE	0.2240	0.0825	0.1440	0.2280	0.2490	0.0698	0.0032
SE	0.1740	0.0955	0.1690	0.2790	0.2310	0.0501	0.0012
ESE	0.1540	0.1040	0.1850	0.3090	0.2080	0.0400	0.0003
E	0.1750	0.1260	0.2150	0.2180	0.1990	0.0622	0.0048
ENE	0.2400	0.1280	0.1720	0.2000	0.2100	0.0482	0.0008
NE	0.2320	0.1330	0.1950	0.2250	0.1890	0.0244	0.0009
NNE	0.1960	0.1020	0.1620	0.3250	0.1970	0.0169	0.0021
TOT	0.1847	0.1029	0.1755	0.2778	0.2086	0.0475	0.0039

ADDITIONAL WEATHER INFORMATION

Average Air Temperature:	18.0 degrees C
	291.2 K
Precipitation:	122.4 cm/y
Lid Height:	1000 meters
Surface Roughness Length:	0.010 meters
Height Of Wind Measurements:	10.0 meters
Average Wind Speed:	4.100 m/s

Vertical Temperature Gradients:

STABILITY E	0.073 k/m
STABILITY F	0.109 k/m
STABILITY G	0.146 k/m

DRAFT

DOSES FROM ESTIMATED AIR EMISSIONS FOR THE SAVANNAH RIVER SITE CONSOLIDATED INCINERATION FACILITY

Interim Report

Nolan E. Hertel and H. Michelle Coward
Health Physics Program
G. W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405
(404) 894-3717

James A. Mulholland and Michael G. Robinson
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0355
(404)894-1839 or -1695

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ABSTRACT

The radiological impact of air emissions from the Consolidated Incineration Facility (CIF) at the Savannah River Site have been investigated using the CAP-88 computer code. Doses were computed for the nearest onsite worker, not employed at the CIF, and a maximally exposed individual on the nearest site boundary. Two sets of waste feed rates were used in the computations, an older set used in the original CIF NESHAPS application [DOE88, DOE89] and a recently updated set. Each of the sets were used to obtain the total radionuclide emissions from CIF under baseline, best, and worst case incinerator operating conditions. The computed MEI doses for the baseline emissions estimates were $8.5(10^{-4})$ and $7.1(10^{-3})$ mrem/y for the updated and revised feed rates, respectively, and for the onsite worker were 1.1 (10^{-3}) and 9.3 (10^{-3}) mrem/y. These doses, as well as the higher doses associated with the worst emission estimates indicate no radiological health impact from the incinerator for either an MEI on the site boundary or an onsite worker.

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APPENDICES

DOSES FROM ESTIMATED AIR EMISSIONS FOR THE SAVANNAH RIVER SITE CONSOLIDATED INCINERATION

1.0 INTRODUCTION

Incineration of hazardous, radioactive, and mixed wastes, generated on the Savannah River Site at the Consolidated Incineration Facility (CIF) would significantly reduce the volumes and toxicities of such wastes. The radiation doses resulting from the incineration of radioactive waste, to an onsite worker and a maximally exposed individual living on the site boundary are estimated in this report. Two separate estimates of radionuclide feed rates to the CIF are investigated. The first of these feed rates is the one used to estimate boundary dose previously in the CIF Environmental Assessment [DOE92] and the National Emission Standards for Hazardous Air Pollutants (NESHAPS) CIF construction application. [DOE88] The second set of CIF feed rates considered was taken from the CIF Mission Need and Design Capacity Review Report. [SRS93] It represents the latest estimates of the CIF feed stream. Only the radiological impact of the incineration of these two feed streams are addressed in this report.

2.0 METHOD AND MODEL PARAMETERS

2.1 CAP-88 Code Package

The VAX version of the CAP-88 computer code package[1] [EPA90] was used to estimate the effective dose equivalent (EDE) from the incineration of

[1]Available as CCC-542B from the Radiation Shielding Information Center at Oak Ridge National Laboratory. A recent review of the CAP-88 software package may be found in Ref. MO94.

two estimates of the CIF waste feed stream. The CAP-88 code models the dispersion and transport of radionuclides through the terrestrial environment. The AIRDOS2 code is used to compute atmospheric dispersion, radionuclide concentrations in environmental media, and radionuclide intakes. The code DARTAB2 uses the AIRDOS2 output to perform a dose computation based on those radionuclide concentrations and intakes. The CAP-88 code package uses NRC Regulatory Guide 1.109 methodology to compute ingestion doses from the terrestrial food chain pathways and parameters. Atmospheric dispersion is based on a modified Gaussian plume model.

2.2 Exposure Modeling

Effective dose equivalents were calculated with the CAP-88 code for two different individuals: a maximally exposed individual (MEI) living on the site boundary and the nearest on-site worker. The maximally exposed individual was assumed to be a distance of 11770 m from the CIF stack in the NNW wind sector. This boundary location, nearest the CIF, has historically yielded the highest exposures when atmospheric modeling for CIF has been undertaken.[HA94] All the CAP-88 exposure pathways were included in the dose calculation for the MEI.

The onsite worker was assumed to be located 350 m north of the CIF location. This is the nearest location to the CIF where non-CIF workers will be present on a more or less continuous basis.[BU94] The ingestion pathway was not included in the determination of the onsite worker dose. The worker dose

was calculated using the CAP-88 inhalation, air immersion, and ground surface irradiation doses. The worker's inhalation rate was taken to be 1.02 (10^4) m^3/y, an average of the male and female breathing rates for light activity.[SH92] This is in contrast to the MEI inhalation rate of 8.04 (10^3), m^3/y which incorporated an 8-hour resting period. The worker was assumed to be at this location on site for 8 hours per day, 5 days per week for 50 weeks per year. For computing doses due to the incinerator emissions, a stack height of 150 ft (45.7 m) and stack exit velocity of 15.8 m/s were used. [DOE88].

The following site-specific data were used for all dose computations: average annual temperature of 18°C, average annual precipitation rate of 122 cm/y, and the 1987-1991 site wind speed, stability class, and direction information obtained from WSRC.[HA94] In the modeling of ingestion doses, the fractions of home produced vegetables, milk and meat were set to 0.700, 0.399, and 0.442. The remainder of the food was assumed to be imported from outside the assessment area. A portion of a CAP-88 printout displaying other modeling parameters is in Appendix A.

One of the more serious problems with the CAP-88 code is its inability to model radioactive progeny ingrowth.[MO94] Since secular equilibrium is assumed in the CIF feed terms [DOE88, DOE89], this deficiency in CAP-88 can be handled by setting the decay constants of the progeny to that of the parent radionuclides. [MO94] So the decay constants of Y-90, Rh-106, Ba-137m, and Pr-144/Pr-144m were set to those of Sr-90, Ru-106, Cs-137, and Ce-144, respectively.

Two CAP-88 runs (two receptor locations) were performed for 1 Ci/y releases of each radionuclide present in the CIF feed streams. The resulting set of doses for each nuclide are dose conversion factors which can be used to convert from Ci/y emission rates to mrem/y doses. These dose conversion factors are presented in Table 1. The ingestion portion of the MEI dose conversion factors for tritium has been corrected for the SRS humidity.[HA94]

2.3 Waste Feed Term

Two CIF radionuclide feed rates were used in the dose assessment presented in the report. The first feed rate was taken directly from Table 4-2 of the Environmental Assessment. [DOE92] These radionuclide feed rates were determined by SRS personnel by multiplying the maximum annual mass flow of the various CIF waste streams by the maximum expected radionuclide concentrations. [DOE88, DOE89] This feed rate is tabulated in Table 2. Hereafter it will be referred to as the old feed rate.

A new CIF radionuclide feed rate was generated from more recent forecasts of the SRS annual waste generation rates. This feed rate, hereafter referred to as the updated feed rate, was determined by multiplying the revised waste generation rates [SRS93] by the same set of expected maximum radionuclide concentrations.[DOE88, DOE89] This updated radionuclide feed rate is also tabulated in Table 2.

As done in the NESHAPS application [DOE88, DOE89], the treatment of all alpha emitters as either Pu-238 or Pu-239 was retained in this work. This

results in a conservative value for the doses due to alpha emitters. The NESHAPS application's approach also was retained to represent all unspecified β/γ-emitting isotopes as Sr-90. This again results in conservative dose conversion factor for unspecified β/γ emitters.

3.0 INCINERATOR EMISSION SOURCE TERMS

The CIF incinerator will have an Air Pollution Control System (APCS) which incorporates a scrubber and a cyclone separator. In addition, the emissions partitioned to the stack will encounter a HEPA filter bank. With the exception of tritium, the radioisotopes which exit the APCS will be attached to particles. Emission factors for heavy metals can range as high as 50%.[TR89] Travis and Cook report that a mass enrichment occurs for metals during the incineration of wastes, i.e. the concentration of a trace metal (per mass basis) in the particulate emissions from an incinerator is higher than the concentrations of that metal in the waste feed. This enrichment occurs because metals are more likely to condense on the surface of finer particles, and these smaller particles are not as efficiently removed by the APCS.

The original NESHAPS application for the CIF[DOE89] assumed that 20% of the incinerator ash was carried over to the APCS as particulate. Particulate removal efficiencies for the quench chamber and the scrubber were estimated to be 55% and 85.5% using vendor information. So the amount of metal partitioned to stack emissions was [0.2(1-.55)(1-.855)] or $1.31(10^{-2})$. This approach has the inherent assumption that metals are evenly distributed in

the ash regardless of particle size. The HEPA filter efficiency was assumed to be 99.8% for conservatism in that analysis. The actual HEPA filter efficiency of 99.97% for particles down to 0.3μm is insured at SRS by pre-installation testing. So, in the initial NESHAPS application, a decontamination factor of approximately 38,000 was used for the non-tritium radioactivity. This is equivalent to a total emission factor of $2.61(10^{-5})$.

The radionuclide emissions for both the old and updated feed rates were calculated using the emission factors of Mulholland et al.[MUL94] In that work, emission factors for radionuclides were estimated for three release or incinerator operating scenarios: a baseline estimate, a best case estimate, and a worst case estimate. In those estimates, a nominal total fuel and waste composition of 79% carbon (by mass), 9% hydrogen, 6% water, 1% chlorine, and 5% inorganic matter (including metals and trace radionuclides). With the exception of tritium, radionuclide species and phase equilibria are determined at the temperatures characteristic of the combustion environment using the NASA complex chemical equilibrium code CET89. This detailed thermodynamic analysis was coupled with global assumptions regarding particle entrainment, particle inception, and particle growth to estimate the partitioning of the radionuclides in the waste between kiln bottom ash, supermicron flyash, and submicron aerosol particles entering the air pollution control device system. For tritium, total emission fractions were assumed.

Particle collection efficiencies for both submicron and supermicron particles, for three air pollution control devices, a spray quench vessel, a

scrubber/cyclone/demistor system, and a high efficiency filtration system (HEPA filters) were estimated from equipment design specifications by Mulholland et al. Application of the particle collection efficiencies to estimated particle sizes and composition distributions in the combustion gas exhaust stream led to estimates of radionuclide releases as a fraction of the feed. The set of incinerator conditions which were used to derive the three incinerator emission estimates (baseline, best and worst case) are listed in Table 3. The efficiencies used for the air pollution control devices are tabulated in Table 4. The emission factors for the radionuclides in the job control waste stream are shown in Table 5. For the nontritium components of the waste feed, decontamination factors ranging from $4(10^3)$ to $6.7(10^6)$, $7.7(10^4)$ to $6.7(10^7)$, and $2.6(10^2)$ to $2.5(10^3)$ for the baseline, best and worst case estimates are obtained. The emission source terms computed by applying the emission factors of Mulholland et al. both the old and updated CIF feed rates of Table 2 are shown in Table 6.

4.0 RESULTS

4.1 Maximally Exposed Individual

The EDE's computed for the MEI living on the SRS boundary are presented in Table 7 for the 6 emissions estimates. The MEI doses are 8.5 (10^{-4}), 2.0 (10^{-4}) and 1.2 (10^{-2}) mrem/y for the baseline, best, and worst case estimates of incinerator emissions using the updated CIF feed rates.[SRS93] Similarly they are 7.1 (10^{-3}), 1.7 (10^{-3}) and 8.5 (10^{-2}) if the old CIF feed rates are

used.[DOE92] In any case, none of the doses would result in anything but a negligible health effect to any person living on the site boundary.

The old feed rate MEI doses are 8.4, 8.5, and 7.1 times higher than those obtained with the updated feed rate for the baseline, best and worst case emission estimates, respectively. The principal dose-contributing radionuclides are shown in Table 8 for the reported MEI doses. For the baseline and worst case emissions estimates for both feed rates, the vast majority of the dose is attributable to β/γ emitters treated as Sr-90. This indicates that the computed doses for these cases would be much lower if the identify of these β/γ emitting radionuclides were available since Sr-90 leads to overly conservative dose estimate.

4.2. Onsite Worker

The onsite worker EDE's calculated for the six CIF emissions estimates are reported in Table 9. For the updated feed rates, they are 1.1 (10^{-3}), 6.4 (10^{-4}) and 1.9 (10^{-2}) mrem/y for the baseline, best, and worst case emission estimates, respectively. Similarly they are 9.3 (10^{-3}), 5.5 (10^{-3}) and 1.2 (10^{-1}) mrem/y for the old feed rates. The old feed rate doses are 8.5, 8.6, and 6.3 times higher than the updated feed rate doses for the baseline, best, and worst case emission estimates, respectively.

The principal radionuclides contributing to the onsite worker doses are tabulated in Table 10 with their dose contributions in contrast to the MEI dose analysis for the baseline and worst case emission estimates, β/γ emitters

treated as Sr-90 are greatly diminished in their contribution to the total dose while alpha emitters treated as Ru-238 and tritium play a much greater role. This occurs since the Sr-90 ingestion pathway dose is about 25 times the Sr-90 dose due to ^{90}Sr inhalation and immersion dose, the only pathways for onsite worker exposure. Again for any of the emissions estimates the worker dose is inconsequential.

5.0 Summary

Three estimates of radionuclide air emissions from the CIF have been evaluated with respect to an MEI on the SRS boundary and an onsite worker for both the updated and old CIF radionuclide feed rates. The old and updated feed rates led to onsite worker doses of 9.3 (10^{-3}) and 1.1 (10^{-3}) mrem/y and MEI doses of 7.1 (10^{-3}) and 8.5 (10^{-4}) mrem/y, respectively, for the CIF baseline emission estimates. The treatment of unidentified β/γ emitters as Sr-90 leads to a high degree of overconservatism in the MEI doses and to a lesser overconservatism for the worker doses. The treatment of unspecified alpha emitters as Pu-238 leads to a high degree of overconservatism in the worker doses. For all six doses estimates, the doses are negligible with respect to health risks for both the MEI and onsite worker.

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Table 1. Effective Dose Conversion Factors for Maximally Exposed Individual Living on the Site Boundary (11770 m NNW of CIF) and for the Nearest Worker Location (350 m N of CIF) as Determined with CAP-88.

	EDE Conversion Factor (mrem/Ci)	
Nuclide	**MEI on Site Boundary[a]**	**Nearest Worker[b]**
H-3	1.86E-06	6.03E-06
Sr-89	5.43E-04	3.11E-04
Sr-90	2.48E-02	1.06E-02
Y-90	8.10E-04	4.47E-04
Y-91	7.32E-04	2.38E-03
Zr-95	9.37E-04	7.19E-03
Nb-95	6.51E-04	4.00E-03
Ru-106	3.71E-03	2.27E-02
Rh-106	1.04E-03	3.67E-06
Cs-137	4.65E-03	1.47E-03
Ba-137m	8.52E-03	1.29E-05
Ce-144	2.96E-03	1.86E-02
Pr-144m	4.14E-05	1.38E-06
Pr-144	1.23E-04	3.86E-06
Co-60	5.50E-02	5.22E-01
Cr-51	2.11E-05	1.44E-04
Pm-147	2.27E-04	1.86E-03
β/γ as Sr-90	2.48E-02	1.06E-02
Pu-238	1.51E+00	1.51E+01
Pu-239	1.64E+00	1.63E+01

[a] Includes all exposure pathways.

[b] Includes all exposure pathways except ingestion (inhalation, immersion, and ground surface irradiation). The worker was assumed to be exposed for 8 hours per day for 50 work-weeks.

Table 2. Old and Updated CIF Radionuclide Feed Rates Based on Old Estimates of the Mass Feed Rate [DOE92, SRS93], Updated Mass Feed Rates [SRS93] and Maximum Expected Radionuclide Concentrations from the NESHAPS Application.[DOE88, DOE89]

Nuclide	Old Feed (Ci/y)	Updated Feed (Ci/y)
H-3	1.2E+03	1.4E+02
Sr-89	2.1E+01	2.6E+00
Sr-90	2.7E+00	3.3E-01
Y-90	2.7E+00	3.3E-01
Y-91	1.6E+01	2.0E+00
Zr-95	1.7E+01	3.0E+00
Nb-95	5.4E+01	7.6E+00
Ru-106	6.2E+00	1.8E+00
Rh-106	6.2E+00	1.8E+00
Cs-137	8.4E+00	1.2E+00
Ba-137m	8.4E+00	1.2E+00
Ce-144	8.0E+00	1.9E+00
Pr-144m	8.0E+00	1.9E+00
Pr-144	8.0E+00	1.9E+00
Co-60	4.8E+00	5.8E-01
Cr-51	5.4E+02	6.5E+01
Pm-147	3.2E+01	3.9E+00
β/γ as Sr-90[a]	7.9E+02	9.6E+01
α as Pu-238[b]	5.0E+00	9.0E-01
α as Pu-239[b]	1.8E-02	4.4E-03

[a]Other β/γ-emitting radionuclides may be present in small or undetectable quantities and their exposure effects are conservatively overestimated by treating them as Sr-90. [DOE89]

[b]Alpha emitters are classified as either Pu-238 or Pu-239 based on their radiation properties. This is done since Pu-238 and Pu-239 were the principal SRP products and the major alpha-emitting waste contaminants.[DOE89]

Table 3. Incinerator Conditions Used by Mulholland et al. to Generate Radionuclide Release Fractions. [MUL94]

	Baseline Estimate	Best Case	Worst Case
Solids Temperature	900 K	700 K	1100 K
Secondary Combustion Chamber Temperature	1250 K	1100 K	1500 K
Kiln Solids Entrainment Fraction	0.1	0.01	0.25
Fraction to Aerosol Particles	0.5	0.25	0.75
Chloride Formation	Yes	No	Yes
Metal-Ash/Metal Interactions	Yes	Yes	No

Table 4. Removal Fractions for Submicron and Supermicron Particles by the Incinerator Air Pollution Control Devices. [MUL94]

Device	Submicron Removal Efficiency	Supermicron Removal Efficiency
Quench Vessel	0	0.5
Scrubber	0.5	0.99
HEPA Filters	0.99	0.9997

Table 5. Estimated Emission Fractions for CIF for the Three Emissions Estimates Reported by Mulholland et al. [MUL94]

Nuclide	Baseline (Ci_{out}/Ci_{in})	Best (Ci_{out}/Ci_{in})	Worst (Ci_{out}/Ci_{in})
H-3	0.9	7.50E-01	1.00E+00
Sr-89	2.50E-04	1.50E-08	3.80E-03
Sr-90	2.50E-04	1.50E-08	3.80E-03
Y-90	4.00E-07	1.60E-08	9.40E-04
Y-91	4.00E-07	1.60E-08	9.40E-04
Zr-95	1.50E-07	1.50E-08	1.00E-06
Nb-95	3.20E-07	1.50E-08	9.40E-04
Ru-106	4.00E-07	1.60E-08	9.40E-04
Rh-106	2.50E-04	1.30E-05	3.80E-03
Cs-137	2.50E-03	1.30E-03	3.80E-03
Ba-137m	1.50E-07	1.50E-08	9.60E-04
Ce-144	4.00E-07	1.60E-08	9.40E-04
Pr-144m	4.00E-07	1.60E-08	9.40E-04
Pr-144	4.00E-07	1.60E-08	9.40E-04
Co-60	2.50E-04	1.30E-05	3.80E-03
Cr-51	5.00E-05	9.50E-07	4.00E-04
Pm-147	4.00E-07	1.60E-08	9.40E-04
β/γ as Sr-90	2.50E-04	1.50E-08	3.80E-03
Pu-238	4.00E-07	1.60E-08	9.40E-04
Pu-239	4.00E-07	1.60E-08	9.40E-04

Table 6. Estimates of the CIF Emission Rates for the Old and Updated Feed Rates Based using the Three Emission Fraction Estimates Reported by Mulholland et al. [MUL94]

Nuclide	Updated			Old		
	Baseline (Ci/y)	Best (Ci/y)	Worst (Ci/y)	Baseline (Ci/y)	Best (Ci/y)	Worst (Ci/y)
H-3	1.3E+02	1.1E+02	1.4E+02	1.1E+03	9.0E+02	1.2E+03
Sr-89	6.5E-04	4.0E-08	9.8E-03	5.3E-03	3.2E-07	8.0E-02
Sr-90	8.2E-05	5.1E-09	1.2E-03	6.8E-04	4.1E-08	1.0E-02
Y-90	1.3E-07	5.3E-09	3.1E-04	1.1E-06	4.3E-08	2.5E-03
Y-91	7.8E-07	3.2E-08	1.8E-03	6.4E-06	2.6E-07	1.5E-02
Zr-95	4.5E-07	4.5E-08	6.0E-06	2.6E-06	2.6E-07	1.7E-05
Nb-95	2.4E-06	1.1E-07	7.1E-03	1.7E-05	8.1E-07	5.1E-02
Ru-106	7.1E-07	2.8E-08	1.7E-03	2.5E-06	9.9E-08	5.8E-03
Rh-106	4.5E-04	2.2E-05	6.7E-03	1.6E-03	8.1E-05	2.4E-02
Cs-137	2.9E-03	1.4E-03	4.3E-03	2.1E-02	1.1E-02	3.2E-02
Ba-137m	1.8E-07	1.7E-08	1.1E-03	1.3E-06	1.3E-07	8.1E-03
Ce-144	7.8E-07	3.1E-08	1.8E-03	3.2E-06	1.3E-07	7.5E-03
Pr-144m	7.8E-07	3.1E-08	1.8E-03	3.2E-06	1.3E-07	7.5E-03
Pr-144	7.8E-07	3.1E-08	1.8E-03	3.2E-06	1.3E-07	7.5E-03
Co-60	1.5E-04	7.3E-06	2.2E-03	1.2E-03	6.2E-05	1.8E-02
Cr-51	3.3E-03	6.2E-05	2.6E-02	2.7E-02	5.1E-04	2.2E-01
Pm-147	1.5E-06	6.4E-08	3.7E-03	1.3E-05	5.1E-07	3.0E-02
β/γ as Sr-90	2.4E-02	1.5E-06	3.6E-01	2.0E-01	1.2E-05	3.0E+00
Pu-238	3.6E-07	1.5E-08	8.4E-04	2.0E-06	8.0E-08	4.7E-03
Pu-239	1.8E-09	7.1E-11	4.1E-06	7.2E-09	2.9E-10	1.7E-05

Table 7. Effective Dose Equivalents (mrem per year) at the SRS Boundary (11770m NNW of CIF) for the Maximally Exposed Individual for the Three Release Estimates Applied to the Old and Updated CIF Feed Rates.

	Updated			Old		
Nuclide	**Baseline**	**Best**	**Worst**	**Baseline**	**Best**	**Worst**
H-3	2.3E-04	2.0E-04	2.6E-04	2.0E-03	1.7E-03	2.2E-03
Sr-89	3.5E-07	2.2E-11	5.3E-06	2.9E-06	1.7E-10	4.3E-05
Sr-90	2.0E-06	1.3E-10	1.2E-03	1.7E-05	1.0E-09	2.5E-04
Y-90	1.1E-10	4.3E-12	2.5E-07	8.7E-10	3.5E-11	2.1E-06
Y-91	5.7E-10	2.3E-11	1.3E-06	4.7E-09	1.9E-10	1.1E-05
Zr-95	4.2E-10	4.2E-11	5.6E-09	2.4E-09	2.4E-10	1.6E-08
Nb-95	1.6E-09	7.2E-11	4.6E-06	1.1E-08	5.3E-10	3.3E-05
Ru-106	2.6E-09	1.0E-10	6.3E-06	9.2E-09	3.7E-10	2.2E-05
Rh-106	4.7E-07	2.3E-08	7.0E-06	1.6E-06	8.4E-08	2.5E-05
Cs-137	1.3E-05	6.5E-06	2.0E-05	9.8E-05	5.1E-05	1.5E-04
Ba-137m	1.5E-09	1.4E-10	9.4E-06	1.1E-08	1.1E-09	6.9E-05
Ce-144	2.3E-09	9.2E-11	5.3E-06	9.5E-09	3.8E-10	2.2E-05
Pr-144m	3.2E-11	1.3E-12	7.5E-08	1.3E-10	5.3E-12	3.1E-07
Pr-144	9.6E-11	3.8E-12	2.2E-07	3.9E-10	1.6E-11	9.2E-07
Co-60	8.3E-06	4.0E-07	1.2E-04	6.6E-05	3.4E-06	1.0E-03
Cr-51	7.0E-08	1.3E-09	5.5E-07	5.7E-07	1.1E-08	4.6E-06
Pm-147	3.4E-10	1.5E-11	8.4E-07	2.9E-09	1.2E-10	6.8E-06
β/γ as Sr-90	5.9E-04	3.7E-08	8.9E-03	4.9E-03	2.9E-07	7.4E-02
Pu-238	5.4E-07	2.3E-08	1.3E-03	3.0E-06	1.2E-07	7.1E-03
Pu-239	3.0E-09	1.2E-10	6.7E-06	1.2E-08	4.7E-10	2.8E-05
Total	**8.5E-04**	**2.0E-04**	**1.2E-02**	**7.1E-03**	**1.7E-03**	**8.5E-02**

Table 8. Radionuclides Contributing More than 1.0% of the Total MEI Dose for at Least One CIF Emission Estimate.

	Old Feed Rate			Updated Feed Rate		
Nuclides	**Baseline**	**Best**	**Worst**	**Baseline**	**Best**	**Worst**
H-3	28.4%	96.8%	2.6%	27.5%	96.5%	2.2%
Sr-90	0.2%	-	0.3%	0.2%	-	10.4%
Cs-137	1.4%	2.9%	0.2%	1.6%	3.2%	0.2%
Co-60	0.9%	0.2%	1.2%	1.0%	0.2%	1.0%
β/γ as Sr-90	69.0%	-	87.1%	69.5%	-	75.1%
Pu-238	-	-	8.3%	0.1%	-	10.7%

Table 9. Effective Dose Equivalents (mrem per year) for the Nearest On-site Worker Location (350 m N of CIF) for the Three Release Estimates Applied to the Old and Updated CIF Feed Rates.

	Updated			Old		
Nuclide	**Baseline**	**Best**	**Worst**	**Baseline**	**Best**	**Worst**
H-3	7.6E-04	6.3E-04	8.4E-04	6.5E-03	5.4E-03	7.2E-03
Sr-89	2.0E-07	1.2E-11	3.1E-06	1.6E-06	9.8E-11	2.5E-05
Sr-90	8.7E-07	5.4E-11	1.3E-05	7.1E-06	4.3E-10	1.1E-04
Y-90	5.8E-11	2.4E-12	1.4E-07	4.8E-10	1.9E-11	1.1E-06
Y-91	1.9E-09	7.6E-11	4.3E-06	1.5E-08	6.1E-10	3.6E-05
Zr-95	3.2E-09	3.2E-10	4.3E-08	1.8E-08	1.8E-09	1.2E-07
Nb-95	9.6E-09	4.4E-10	2.8E-05	6.9E-08	3.2E-09	2.0E-04
Ru-106	1.6E-08	6.4E-10	3.9E-05	5.6E-08	2.3E-09	1.3E-04
Rh-106	1.7E-09	8.1E-11	2.5E-08	5.7E-09	3.0E-10	8.6E-08
Cs-137	4.3E-06	2.1E-06	6.3E-06	3.1E-05	1.6E-05	4.7E-05
Ba-137m	2.3E-12	2.2E-13	1.4E-08	1.6E-11	1.6E-12	1.0E-07
Ce-144	1.5E-08	5.8E-10	3.4E-05	6.0E-08	2.4E-09	1.4E-04
Pr-144m	1.1E-12	4.3E-14	2.5E-09	4.4E-12	1.8E-13	1.0E-08
Pr-144	3.0E-12	1.2E-13	6.9E-09	1.2E-11	4.9E-13	2.9E-08
Co-60	7.8E-05	3.8E-06	1.1E-03	6.3E-04	3.3E-05	9.5E-03
Cr-51	4.8E-07	8.9E-09	3.7E-06	3.9E-06	7.4E-08	3.1E-05
Pm-147	2.8E-09	1.2E-10	6.9E-06	2.4E-08	9.5E-10	5.6E-05
β/γ as Sr-90	2.5E-04	1.6E-08	3.8E-03	2.1E-03	1.3E-07	3.2E-02
Pu-238	5.4E-06	2.3E-07	1.3E-02	3.0E-05	1.2E-06	7.1E-02
Pu-239	2.9E-08	1.2E-09	6.7E-05	1.2E-07	4.7E-09	2.8E-04
Total	**1.1E-03**	**6.4E-04**	**1.9E-02**	**9.3E-03**	**5.5E-03**	**1.2E-01**

Table 10. Radionuclides Contributing More than 1.0% of the Total Onsite Worker Dose for at Least One CIF Emission Estimate.

	Old Feed Rate			Updated Feed Rate		
Nuclides	**Baseline**	**Best**	**Worst**	**Baseline**	**Best**	**Worst**
H-3	70.0%	99.1%	6.0%	68.9%	99.0%	4.5%
Co-60	6.7%	0.6%	7.9%	7.1%	0.6%	6.1%
β/γ as Sr-90	22.5%	-	26.3%	22.9%	-	20.3%
Pu-238	0.3%	-	58.9%	0.5%	-	67.9%

APPENDIX A

GENERAL DATA AND WEATHER FROM CAP-88PC RUNS

NOLAN E HERTEL
GA TECH

SYNOPSIS REPORT - CAP-88 (1.00)

ID Code: CIF_CIFNNW Date/Time: TUE 5 July, 1994 5:28:06 PM

Facility: SAVANNAH RIVER SITE
Address: ADDRESS
City: AIKEN
State: SC Zipcode:

Source Category: SRS/CIF FACILITIES Source Term: 1986

Comments:
SAVANNAH RIVER SITE, CIF, 11770 M NNW (NEAREST BOUNDARY)

INDIVIDUAL AT MAXIMUM RISK ASSESSEMENT
(RN-222 RISKS EXCLUDED)

Location to the individual: 11770 METERS NORTH NORTHWEST

	GONADS	BREAST	R MAR	LUNGS	THYROID	ENDOST	RMNDR
Organ dose (mrem/yr) :	5.4E-01	1.2E-01	3.1E+00	9.4E+00	1.2E-01	3.6E+01	1.7E+00

ICRP Effective Dose Equivalent (mrem/yr): 3.25E+00
Lifetime Fatal Cancer Risk : 2.70E-05

SOURCE TERM (1986)

Nuclide	Class	Amad	Stack #1 Ci/yr	TOTAL
H-3	*	0.00	1.00E+00	1.00E+00
SR-89	D	1.00	1.00E+00	1.00E+00
SR-90	D	1.00	1.00E+00	1.00E+00
Y-90	Y	1.00	1.00E+00	1.00E+00
Y-91	Y	1.00	1.00E+00	1.00E+00
ZR-95	W	1.00	1.00E+00	1.00E+00
NB-95	Y	1.00	1.00E+00	1.00E+00
RU-106	Y	1.00	1.00E+00	1.00E+00
RH-106	Y	1.00	1.00E+00	1.00E+00
CS-137	D	1.00	1.00E+00	1.00E+00
BA-137M	D	1.00	1.00E+00	1.00E+00
CE-144	Y	1.00	1.00E+00	1.00E+00
PR-144M	Y	1.00	1.00E+00	1.00E+00
PR-144	Y	1.00	1.00E+00	1.00E+00
CO-60	Y	1.00	1.00E+00	1.00E+00
CR-51	Y	1.00	1.00E+00	1.00E+00
PM-147	Y	1.00	1.00E+00	1.00E+00
PU-238	Y	1.00	1.00E+00	1.00E+00
PU-239	Y	1.00	1.00E+00	1.00E+00

SITE INFORMATION

Temperature: 18 C
Rainfall: 122 cm/yr
Mixing Height: 1000 meters

1

EMISSION INFORMATION

Stack Number: 1

Stack Height (meters) : 45.72
Stack Diameter (meters): 0.00
Plume Rise
Momentum (m/sec) :1.58E+01

FOOD SUPPLY FRACTIONS

	Local	Regional	Imported
Vegetable:	0.700	0.000	0.300
Meat:	0.442	0.000	0.558
Milk:	0.399	0.000	0.601

FOOD ARRAYS WERE NOT GENERATED OR SUPPLIED FOR THIS RUN. DEFAULT VALUES USED.

DISTANCES USED FOR MAXIMUM INDIVIDUAL ASSESSMENT

11770

REFERENCE FILE NAMES FOR ASSESSMENT

FILE DIRECTORY

TYPE	IBM EQUIVALENT	VMS FILE
JCL FILE ===>	#.CAA88.CIF(CIFNNW)	CIFNNW.PIN
ALLRAD FILE ===>	#.#.DATA(ALLRAD88)	CAP88:ALLRAD88.DAT
POP FILE ===>	#.CAA88.POPLIB(CIFNNW)	CIFNNW.POP
WIND/STAR FI===>	#.CAA88.STARLIB(CIFNNW)	CIFNNW.WND
PREDA FILE ===>	#.#.LIB(PRDPOP)	CAP88:PRDPOP.DAT
RADRISK FILE===>	#.#.RADRISK( )	CAP88:RADRISK.BIN

DATE TUE 5 July, 1994 5:28:06 PM

MAIN OPTIONS:

CONCEN AND DOSEN	OPTION(1)=0
CIRCULAR GRID	OPTION(2)=1

CONCEN OPTIONS:

SECTOR-AVERAGED	OPTION(3)=0
MOMENTUM-TYPE PLUME	OPTION(4)=1
FIXED DEPOSITION VELOCITY	OPTION(5)=0
PUNCH CONCEN	OPTION(6)=19
POINT SOURCE	OPTION(7)=0
NO PRINT CONCEN MAIN TABLE	OPTION(8)=1
NO PRINT CONCEN CHI/Q TABLES	OPTION(9)=1

0 DOSEN OPTIONS:

INDIVIDUAL ASSESSMENT	LIPO=0
PRINT DOSEN TABLES	NNTB= 1
NO PUNCH DOSES	NRTB=0
DARTAB FILE ONLY	NSTB=2
PRINT DOSE SUMMARY	NTTB=1
NO RN-222 WORKING LEVELS	NUTB=0
READ ORGAN NAMES	NVTB=1
BUILDUP TIME IN SOIL	TSUBB= 30.00 YEARS
	T=1.0957E+04 DAYS

```
      DATE  TUE  5 July,  1994   5:28:06 PM

GRID DATA:
      BOUNDS OF DIRECTION-INDICES   NOL= 2 NOU= 2
       BOUNDS OF DISTANCE-INDICES    NRL= 4 NRU= 4
SQSD=1177.0 (M), COMPUTED FROM IDIST( 4)=11770 (M)
IDIST, THE ARRAY OF RADIAL DISTANCES (M)
    200
    350
    500
  11770
      DATE  TUE  5 July,  1994   5:28:06 PM
      NUMBER OF SOURCES              NUMST=1
      NUMBER OF NUCLIDES             NNUCS=19
        SOURCE #:         1

 HEIGHT                                PH=       45.7
 DIAMETER                              DIA=       0.00
 EXIT VELOCITY                         VEL=        16.
 HEAT RELEASE RATE                     QH=         0.
 NUCLIDE RELEASE RATE, REL (CI/YR)

       1 H-3          1.000
       2 SR-89        1.000
       3 SR-90        1.000
       4 Y-90         1.000
       5 Y-91         1.000
       6 ZR-95        1.000
       7 NB-95        1.000
       8 RU-106       1.000
       9 RH-106       1.000
      10 CS-137       1.000
      11 BA-137M      1.000
      12 CE-144       1.000
      13 PR-144M      1.000
      14 PR-144       1.000
      15 CO-60        1.000
      16 CR-51        1.000
      17 PM-147       1.000
      18 PU-238       1.000
      19 PU-239       1.000
```

DATE TUE 5 July, 1994 5:28:06 PM

INDEX	NAME	ISOL CLASS	LAMSUR 1/D	UPTAKE F1ING	AMAD MICRONS
1	H-3	*	5.48E-05	0.95	0.00
2	SR-89	D	5.48E-05	0.30	1.00
3	SR-90	D	5.48E-05	0.30	1.00
4	Y-90	Y	5.48E-05	0.00	1.00
5	Y-91	Y	5.48E-05	0.00	1.00
6	ZR-95	W	5.48E-05	0.00	1.00
7	NB-95	Y	5.48E-05	0.01	1.00
8	RU-106	Y	5.48E-05	0.05	1.00
9	RH-106	Y	5.48E-05	0.05	1.00
10	CS-137	D	5.48E-05	0.95	1.00
11	BA-137M	D	5.48E-05	0.10	1.00
12	CE-144	Y	5.48E-05	0.00	1.00
13	PR-144M	Y	5.48E-05	0.00	1.00
14	PR-144	Y	5.48E-05	0.00	1.00
15	CO-60	Y	5.48E-05	0.30	1.00
16	CR-51	Y	5.48E-05	0.10	1.00
17	PM-147	Y	5.48E-05	0.00	1.00
18	PU-238	Y	5.48E-05	0.00	1.00
19	PU-239	Y	5.48E-05	0.00	1.00

INDEX	NAME	SC 1/S	VD M/S	VG M/S	ANLAM 1/D
1	H-3	0.00E+00	0.00E+00	0.00E+00	1.55E-04
2	SR-89	1.22E-05	1.80E-03	3.55E-05	1.37E-02
3	SR-90	1.22E-05	1.80E-03	3.55E-05	6.64E-05
4	Y-90	1.22E-05	1.80E-03	3.55E-05	6.52E-05
5	Y-91	1.22E-05	1.80E-03	3.55E-05	1.19E-02
6	ZR-95	1.22E-05	1.80E-03	3.55E-05	1.08E-02
7	NB-95	1.22E-05	1.80E-03	3.55E-05	1.98E-02
8	RU-106	1.22E-05	1.80E-03	3.55E-05	1.88E-03
9	RH-106	1.22E-05	1.80E-03	3.55E-05	1.88E-03
10	CS-137	1.22E-05	1.80E-03	3.55E-05	6.29E-05
11	BA-137M	1.22E-05	1.80E-03	3.55E-05	6.33E-04
12	CE-144	1.22E-05	1.80E-03	3.55E-05	2.44E-03
13	PR-144M	1.22E-05	1.80E-03	3.55E-05	2.44E-03
14	PR-144	1.22E-05	1.80E-03	3.55E-05	2.44E-03
15	CO-60	1.22E-05	1.80E-03	3.55E-05	3.60E-04
16	CR-51	1.22E-05	1.80E-03	3.55E-05	2.50E-02
17	PM-147	1.22E-05	1.80E-03	3.55E-05	7.24E-04
18	PU-238	1.22E-05	1.80E-03	3.55E-05	2.16E-05
19	PU-239	1.22E-05	1.80E-03	3.55E-05	7.86E-08

***NOTE: VG SET TO ZERO FOR AIRDOS UNLESS GREATER THAN 1.000E-02

***NOTE: ANLAM SET TO ZERO FOR AIRDOS UNLESS GREATER THAN 1.000E-02

FOR EACH STABILITY CLASS

	A	B	C	D	E	F	G	PERD
OUDCAT, HARMONIC AVERAGE WIND SPEEDS (WIND TOWARDS)								WIND FREQ.
N	2.455	3.547	4.212	4.297	4.214	4.413	3.620	0.081
NNW	2.348	3.226	3.930	4.303	4.082	4.170	3.783	0.064
NW	2.188	2.969	3.503	3.806	3.960	4.066	4.440	0.051
WNW	2.335	3.169	3.502	3.713	3.976	4.385	4.595	0.047
W	2.473	3.189	3.579	3.589	4.251	4.622	5.110	0.053
WSW	2.558	3.266	3.707	3.664	4.188	4.619	4.080	0.076
SW	2.578	3.513	4.016	3.905	3.897	4.381	4.350	0.091
SSW	2.790	3.858	3.972	3.996	4.365	4.729	5.073	0.059
S	3.221	3.186	3.515	3.837	3.643	3.696	4.147	0.032
SSE	2.755	3.169	3.436	3.118	3.459	3.698	3.660	0.031
SE	2.453	3.718	4.112	3.664	3.544	3.245	4.265	0.037
ESE	2.661	4.461	5.223	3.969	3.827	3.790	4.303	0.066
E	2.681	4.339	4.997	3.951	3.928	3.973	3.015	0.079
ENE	2.734	3.827	4.332	3.987	4.195	4.309	4.178	0.086
NE	2.576	3.819	4.360	4.018	4.183	4.232	3.221	0.079
NNE	2.527	3.630	4.289	4.098	4.125	4.349	3.203	0.069
OUDAV, ARITHMETIC AVERAGE WIND SPEEDS (WIND TOWARDS)								
N	2.698	3.710	4.347	4.402	4.304	4.491	3.654	
NNW	2.585	3.412	4.081	4.411	4.166	4.243	3.810	
NW	2.418	3.135	3.661	3.923	4.041	4.143	4.475	
WNW	2.541	3.337	3.659	3.835	4.064	4.455	4.629	
W	2.659	3.334	3.694	3.703	4.330	4.689	5.130	
WSW	2.742	3.404	3.831	3.777	4.273	4.680	4.100	
SW	2.765	3.637	4.122	3.998	4.007	4.462	4.358	
SSW	2.988	3.982	4.091	4.107	4.457	4.796	5.101	
S	3.402	3.324	3.610	3.922	3.755	3.750	4.157	
SSE	2.952	3.317	3.558	3.248	3.563	3.768	3.693	
SE	2.670	3.875	4.236	3.767	3.643	3.335	4.270	
ESE	2.851	4.598	5.338	4.070	3.902	3.866	4.313	
E	2.881	4.471	5.112	4.045	3.996	4.035	3.010	
ENE	2.916	3.949	4.451	4.079	4.268	4.368	4.206	
NE	2.796	3.945	4.479	4.104	4.263	4.318	3.261	
NNE	2.743	3.783	4.420	4.201	4.199	4.426	3.286	

DATE TUE 5 July, 1994 5:28:06 PM

FOR EACH STABILITY CLASS

	A	B	C	D	E	F	G
FRAW, FREQUENCIES OF STABILITY CLASSES (WIND TOWARDS)							
N	1.55E-01	7.93E-02	1.50E-01	3.30E-01	2.37E-01	4.38E-02	4.20E-03
NNW	1.70E-01	5.67E-02	1.19E-01	3.32E-01	2.77E-01	4.16E-02	3.60E-03
NW	2.21E-01	7.38E-02	1.41E-01	2.88E-01	2.25E-01	4.41E-02	7.20E-03
WNW	2.95E-01	1.09E-01	1.45E-01	2.09E-01	1.75E-01	5.90E-02	9.20E-03
W	2.83E-01	1.23E-01	1.95E-01	1.91E-01	1.73E-01	3.28E-02	1.30E-03
WSW	2.14E-01	1.37E-01	2.55E-01	2.03E-01	1.62E-01	2.84E-02	3.00E-04
SW	1.56E-01	1.18E-01	2.99E-01	2.31E-01	1.59E-01	3.59E-02	1.30E-03
SSW	2.45E-01	1.63E-01	2.16E-01	1.67E-01	1.47E-01	5.74E-02	4.20E-03
S	6.02E-01	1.54E-01	1.06E-01	8.05E-02	4.53E-02	1.01E-02	2.20E-03
SSE	4.21E-01	1.23E-01	1.39E-01	1.29E-01	1.48E-01	3.79E-02	2.20E-03
SE	2.87E-01	1.34E-01	1.84E-01	2.23E-01	1.48E-01	2.29E-02	1.20E-03
ESE	2.47E-01	1.63E-01	2.49E-01	1.97E-01	1.27E-01	1.41E-02	1.40E-03
E	2.61E-01	1.71E-01	2.34E-01	1.99E-01	1.19E-01	1.33E-02	1.20E-03
ENE	2.28E-01	1.55E-01	2.15E-01	1.99E-01	1.61E-01	3.86E-02	4.50E-03
NE	2.14E-01	1.14E-01	1.85E-01	2.39E-01	1.92E-01	4.96E-02	5.80E-03
NNE	1.78E-01	9.40E-02	1.78E-01	2.75E-01	2.24E-01	4.65E-02	4.60E-03
TOT	2.37E-01	1.23E-01	1.98E-01	2.27E-01	1.75E-01	3.66E-02	3.36E-03

HEIGHT OF LID

LIDAI= 1000 (M)

RAINFALL RATE

RR= 122.0 (CM/Y)

AVERAGE AIR TEMPERATURE

TA= 17.8 (DEG C) 291.0 (K)

SURFACE ROUGHNESS LENGTH

Z0= 0.400 (M)

HEIGHT OF WIND MEASUREMENTS

Z= 10.0 (M)

AVERAGE WIND SPEED

UBAR= 3.82 (M/S)

VERTICAL TEMPERATURE GRADIENTS: (TG) (K/M)

STABILITY E 0.073

STABILITY F 0.109

STABILITY G 0.146

NOBCT, NUMBER OF BEEF CATTLE

11770

NNW 4

NOMCT, NUMBER OF MILK CATTLE

11770

NNW 2

INTFC, AREA OF VEGETABLE CROP PRODUCTION (M**2)
11770

NNW 1.00E+04

INTPA, POPULATION
11770

NNW 1

OPTIONS SELECTED FOR DOSE AND INTAKE CALCULATIONS
CALCULATIONS ARE MADE FOR THE MAXIMALLY-EXPOSED INDIVIDUAL.
TABLES FOR EACH NUCLIDE LISTING DOSES BY ORGAN AND PATHWAY
AT EACH ENVIRONMENTAL LOCATION ARE OMITTED.
ORGAN NAMES ARE INPUT.

VALUES FOR RADIONUCLIDE-INDEPENDENT VARIABLES

NUMBER OF NUCLIDES CONSIDERED	19
TIME DELAY--INGESTION OF PASTURE GRASS BY ANIMALS (HR)	0.00E+00
TIME DELAY--INGESTION OF STORED FEED BY ANIMALS (HR)	0.22E+04
TIME DELAY--INGESTION OF LEAFY VEGETABLES BY MAN (HR)	0.24E+02
TIME DELAY--INGESTION OF PRODUCE BY MAN (HR)	0.14E+03
REMOVAL RATE CONSTANT FOR PHYSICAL LOSS BY WEATHERING (PER HOUR)	0.29E-02
PERIOD OF EXPOSURE DURING GROWING SEASON--PASTURE GRASS (HR)	0.72E+03
PERIOD OF EXPOSURE DURING GROWING SEASON-- CROPS OR LEAFY VEGETABLES (HR)	0.17E+04
AGRICULTURAL PRODUCTIVITY BY UNIT AREA (GRASS-COW-MILK-MAN PATHWAY (KG/SQ. METER))	0.18E+01
AGRICULTURAL PRODUCTIVITY BY UNIT AREA (PRODUCE OR LEAFY VEG INGESTED BY MAN (KG/SQ METER))	0.70E+00
FRACTION OF YEAR ANIMALS GRAZE ON PASTURE	0.10E+01
FRACTION OF DAILY FEED THAT IS PASTURE GRASS WHEN ANIMAL GRAZES ON PASTURE	0.66E+00
CONSUMPTION RATE OF CONTAMINATED FEED OR FORAGE BY AN ANIMAL IN KG/DAY (DRY WEIGHT)	0.11E+02
TRANSPORT TIME FROM ANIMAL FEED-MILK-MAN (DAY)	0.30E+01
RATE OF INGESTION OF PRODUCE BY MAN (KG/YR)	0.28E+03
RATE OF INGESTION OF MILK BY MAN (LITERS/YR)	0.23E+03
RATE OF INGESTION OF MEAT BY MAN (KG/YR)	0.81E+02
RATE OF INGESTION OF LEAFY VEGETABLES BY MAN (KG/YR)	0.43E+02
AVERAGE TIME FROM SLAUGHTER OF MEAT ANIMAL TO CONSUMPTION (DAY)	0.60E+01
FRACTION OF PRODUCE INGESTED GROWN IN GARDEN OF INTEREST	0.76E+00
FRACTION OF LEAFY VEGETABLES GROWN IN GARDEN OF INTEREST	0.10E+01
PERIOD OF LONG-TERM BUILDUP FOR ACTIVITY IN SOIL (YEARS)	0.30E+02

EFFECTIVE SURFACE DENSITY OF SOILKG/SQ. M, DRY WEIGHT. (ASSUMES 15 CM PLOW LAYER)	0.24E+03
VEGETABLE INGESTION RATIO-IMMEDIATE SURROUNDING AREA/TOTAL WITHIN AREA	0.10E+01
MEAT INGESTION RATIO-IMMEDIATE SURROUNDING AREA/TOTAL WITHIN AREA	0.10E+01
MILK INGESTION RATIO-IMMEDIATE SURROUNDING AREA/TOTAL WITHIN AREA	0.10E+01
MINIMUM FRACTIONS OF FOOD TYPES FROM OUTSIDE AREA LISTED BELOW ARE ACTUAL FIXED VALUES	
MINIMUM FRACTION VEGETABLES INGESTED FROM OUTSIDE AREA	0.30E+00
MINIMUM FRACTION MEAT INGESTED FROM OUTSIDE AREA	0.56E+00
MINIMUM FRACTION MILK INGESTED FROM OUTSIDE AREA	0.60E+00
INHALATION RATE OF MAN (CUBIC CENTIMETERS/HR)	0.92E+06
BUILDUP TIME FOR RADIONUCLIDES DEPOSITED ON GROUND AND WATER (DAYS)	0.11E+05
DILUTION FACTOR FOR WATER FOR SWIMMING (CM)	0.15E+03
FRACTION OF TIME SPENT SWIMMING	0.40E-01
MUSCLE MASS OF ANIMAL AT SLAUGHTER (KG)	0.20E+03
FRACTION OF ANIMAL HERD SLAUGHTERED PER DAY	0.38E-02
MILK PRODUCTION OF COW (LITERS/DAY)	0.15E+02
FALLOUT INTERCEPTION FRACTION-VEGETABLES	0.20E+00
FALLOUT INTERCEPTION FRACTION-PASTURE	0.57E+00
FRACTION OF RADIOACTIVITY RETAINED ON LEAFY VEGETABLES AND PRODUCE AFTER WASHING	0.50E+00

COMPUTED VALUES FOR THE AREA

TOTAL POPULATION	1.0
TOTAL NUMBER OF MEAT ANIMALS	4
TOTAL NUMBER OF MILK CATTLE	2
TOTAL AREA OF VEGETABLE FOOD CROPS (SQUARE METERS)	0.10E+05
TOTAL MEAT CONSUMPTION (KG PER YEAR)	0.81E+02
TOTAL MEAT PRODUCTION (KG PER YEAR)	0.11E+04
TOTAL MILK CONSUMPTION (LITERS/YEAR)	0.23E+03
TOTAL MILK PRODUCTION (LITERS/YEAR)	0.11E+05
TOTAL VEGETABLE FOOD CONSUMPTION (KG PER YEAR)	0.32E+03
TOTAL VEGETABLE FOOD PRODUCED (KG PER YEAR)	0.70E+04

RESULTS OF DOSE COMPUTATIONS FOR NUCLIDE H-3

AREA COLUMN	ROW	ORGAN	DOSE THROUGH EACH PATHWAY (REMS/YEAR) INHALATION	SUBMERSION IN AIR	SURFACE EXPOSURE	INGESTION	SUBMERSION IN WATER	TOTAL
2	4	EFFEC	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	GONADS	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	BREAST	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	R MARROW	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	LUNG	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	THYROID	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	BON SURF	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	RMNDR	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	INT WALL	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	LIVER	0.531E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.237E-08
2	4	KIDNEYS	0.542E-09	0.000E+00	0.000E+00	0.184E-08	0.000E+00	0.238E-08

*LIST OF INPUT DATA FOR NUCLIDE H-3 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.15E-03
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
DOSE CONVERSION FACTOR FOR FOOD INGESTION (REM-CC/PCI-YEAR)	0.62E+01
DOSE CONVERSION FACTOR FOR WATER INGESTION (REM-CC/PCI-YEAR)	0.57E-01

*LIST OF INPUT DATA FOR NUCLIDE SR-89 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.14E-01
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.15E-02
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.30E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.25E+01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.11E+00
GI UPTAKE FRACTION (INHALATION)	0.30E+00
GI UPTAKE FRACTION (INGESTION)	0.30E+00
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	D

*LIST OF INPUT DATA FOR NUCLIDE SR-90 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.66E-04
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.15E-02
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.30E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.25E+01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.11E+00
GI UPTAKE FRACTION (INHALATION)	0.30E+00
GI UPTAKE FRACTION (INGESTION)	0.30E+00
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	D

*LIST OF INPUT DATA FOR NUCLIDE Y-90 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.65E-04
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-04
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.30E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.15E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.26E-02
GI UPTAKE FRACTION (INHALATION)	0.10E-03
GI UPTAKE FRACTION (INGESTION)	0.10E-03
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE Y-91 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.12E-01
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-04
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.30E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.15E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.26E-02
GI UPTAKE FRACTION (INHALATION)	0.10E-03
GI UPTAKE FRACTION (INGESTION)	0.10E-03
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE ZR-95 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.11E-01
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.30E-04
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.55E-02
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.20E-02
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.21E-03
GI UPTAKE FRACTION (INHALATION)	0.20E-02
GI UPTAKE FRACTION (INGESTION)	0.20E-02
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	W

*LIST OF INPUT DATA FOR NUCLIDE NB-95 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.20E-01
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-01
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.25E+00
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.20E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.21E-02
GI UPTAKE FRACTION (INHALATION)	0.10E-01
GI UPTAKE FRACTION (INGESTION)	0.10E-01
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE RU-106 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.19E-02
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.60E-06
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.20E-02
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.75E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.86E-02
GI UPTAKE FRACTION (INHALATION)	0.50E-01
GI UPTAKE FRACTION (INGESTION)	0.50E-01
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE RH-106 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.19E-02
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.10E-01
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.20E-02
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.15E+00
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.17E-01
GI UPTAKE FRACTION (INHALATION)	0.50E-01
GI UPTAKE FRACTION (INGESTION)	0.50E-01
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE CS-137 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.63E-04
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.70E-02
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.20E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.80E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.13E-01
GI UPTAKE FRACTION (INHALATION)	0.95E+00
GI UPTAKE FRACTION (INGESTION)	0.95E+00
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	D

*LIST OF INPUT DATA FOR NUCLIDE BA-137M *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.63E-03
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.35E-03
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.15E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.15E+00
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.64E-02
GI UPTAKE FRACTION (INHALATION)	0.10E+00
GI UPTAKE FRACTION (INGESTION)	0.10E+00
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	D

*LIST OF INPUT DATA FOR NUCLIDE CE-144 *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.24E-02
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-04
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.75E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.10E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.17E-02
GI UPTAKE FRACTION (INHALATION)	0.30E-03
GI UPTAKE FRACTION (INGESTION)	0.30E-03
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE PR-144M *	
RADIOACTIVE DECAY CONSTANT (PER DAY)	0.24E-02
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-04
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.30E-03

CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.10E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.17E-02
GI UPTAKE FRACTION (INHALATION)	0.30E-03
GI UPTAKE FRACTION (INGESTION)	0.30E-03
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE PR-144 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.24E-02
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-04
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.30E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.10E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.17E-02
GI UPTAKE FRACTION (INHALATION)	0.30E-03
GI UPTAKE FRACTION (INGESTION)	0.30E-03
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE CO-60 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.36E-03
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-02
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.20E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.20E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.30E-02
GI UPTAKE FRACTION (INHALATION)	0.50E-01
GI UPTAKE FRACTION (INGESTION)	0.30E+00

PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE CR-51 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.25E-01
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.15E-02
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.55E-02
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.75E-02
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.19E-02
GI UPTAKE FRACTION (INHALATION)	0.10E+00
GI UPTAKE FRACTION (INGESTION)	0.10E+00
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE PM-147 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.72E-03
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.20E-04
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.50E-02
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.10E-01
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.17E-02
GI UPTAKE FRACTION (INHALATION)	0.30E-03
GI UPTAKE FRACTION (INGESTION)	0.30E-03
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE PU-238 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.22E-04
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.10E-06
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.50E-06
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.45E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.19E-04
GI UPTAKE FRACTION (INHALATION)	0.10E-02
GI UPTAKE FRACTION (INGESTION)	0.10E-02
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

*LIST OF INPUT DATA FOR NUCLIDE PU-239 *

RADIOACTIVE DECAY CONSTANT (PER DAY)	0.79E-07
ENVIRONMENTAL DECAY CONSTANT--SURFACE (PER DAY)	0.55E-04
ENVIRONMENTAL DECAY CONSTANT--WATER (PER DAY)	0.00E+00
AVERAGE FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH L OF MILK (DAYS/L)	0.10E-06
FRACTION OF ANIMAL'S DAILY INTAKE OF NUCLIDE WHICH APPEARS IN EACH KG OF FLESH (DAYS/KG)	0.50E-06
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL FOR PASTURE AND FORAGE (IN PCI/KG DRY WEIGHT PER PCI/KG DRY SOIL)	0.45E-03
CONCENTRATION FACTOR FOR UPTAKE OF NUCLIDE FROM SOIL BY EDIBLE PARTS OF CROPS (IN PCI/KG WET WEIGHT PER PCI/KG DRY SOIL)	0.19E-04
GI UPTAKE FRACTION (INHALATION)	0.10E-03
GI UPTAKE FRACTION (INGESTION)	0.10E-02
PARTICLE SIZE (MICRONS)	0.10E+01
SOLUBILITY CLASS	Y

APPENDIX B

SPREADSHEETS

	A	B	C	D	E	F	G	H	I	J	K	L
1	Nuclide	mrem/Ci	Emissions	EDE	Emissions	EDE	Emissions	EDE	emissions	EDE	Feed	Best
2			(Ci/yr)	(mrem/yr)	(Ci/yr)	(mrem/yr)	(Ci/yr)	(mrem/yr)	Env. Assess.	(mrem/yr)	Env. Assess.	Rel. Fract.
3	H-3	1.86E-06	1.1E+02	2.0E-04	1.3E+02	2.3E-04	1.4E+02	2.6E-04	1.2E+03	2.2E-03	1.2E+03	7.5E-01
4	Sr-89	5.43E-04	4.0E-08	2.2E-11	6.5E-04	3.5E-07	9.8E-03	5.3E-06	6.0E-04	3.3E-07	2.1E+01	1.5E-08
5	Sr-90	2.48E-02	5.1E-09	1.3E-10	8.2E-05	2.0E-06	1.2E-03	1.2E-03	7.6E-05	1.9E-06	2.7E+00	1.5E-08
6	Y-90	8.10E-04	5.3E-09	4.3E-12	1.3E-07	1.1E-10	3.1E-04	2.5E-07	7.6E-05	6.2E-08	2.7E+00	1.6E-08
7	Y-91	7.32E-04	3.2E-08	2.3E-11	7.8E-07	5.7E-10	1.8E-03	1.3E-06	4.5E-04	3.3E-07	1.6E+01	1.6E-08
8	Zr-95	9.37E-04	4.5E-08	4.2E-11	4.5E-07	4.2E-10	6.0E-06	5.6E-09	4.7E-04	4.4E-07	1.7E+01	1.5E-08
9	Nb-95	6.51E-04	1.1E-07	7.2E-11	2.4E-06	1.6E-09	7.1E-03	4.6E-06	1.5E-03	9.8E-07	5.4E+01	1.5E-08
10	Ru-106	3.71E-03	2.8E-08	1.0E-10	7.1E-07	2.6E-09	1.7E-03	6.3E-06	1.8E-04	6.7E-07	6.2E+00	1.6E-08
11	Rh-106	1.04E-03	2.2E-05	2.3E-08	4.5E-04	4.7E-07	6.7E-03	7.0E-06	1.8E-04	1.9E-07	6.2E+00	1.3E-05
12	Cs-137	4.65E-03	1.4E-03	6.5E-06	2.9E-03	1.3E-05	4.3E-03	2.0E-05	2.4E-04	1.1E-06	8.4E+00	1.3E-03
13	Ba-137m	8.52E-03	1.7E-08	1.4E-10	1.8E-07	1.5E-09	1.1E-03	9.4E-06	2.4E-04	2.0E-06	8.4E+00	1.5E-08
14	Ce-144	2.96E-03	3.1E-08	9.2E-11	7.8E-07	2.3E-09	1.8E-03	5.3E-06	2.3E-04	6.8E-07	8.0E+00	1.6E-08
15	Pr-144m	4.14E-05	3.1E-08	1.3E-12	7.8E-07	3.2E-11	1.8E-03	7.5E-08	2.3E-04	9.5E-09	8.0E+00	1.6E-08
16	Pr-144	1.23E-04	3.1E-08	3.8E-12	7.8E-07	9.6E-11	1.8E-03	2.2E-07	2.3E-04	2.8E-08	8.0E+00	1.6E-08
17	Co-60	5.50E-02	7.3E-06	4.0E-07	1.5E-04	8.3E-06	2.2E-03	1.2E-04	1.4E-04	7.7E-06	4.8E+00	1.3E-05
18	Cr-51	2.11E-05	6.2E-05	1.3E-09	3.3E-03	7.0E-08	2.6E-02	5.5E-07	1.5E-02	3.2E-07	5.4E+02	9.5E-07
19	Pm-147	2.27E-04	6.4E-08	1.5E-11	1.5E-06	3.4E-10	3.7E-03	8.4E-07	9.1E-04	2.1E-07	3.2E+01	1.6E-08
20	b/g as Sr-90	2.48E-02	1.5E-06	3.7E-08	2.4E-02	5.9E-04	3.6E-01	8.9E-03	2.2E-02	5.5E-04	7.9E+02	1.5E-08
21	Pu-238	1.51E+00	1.5E-08	2.3E-08	3.6E-07	5.4E-07	8.4E-04	1.3E-03	1.4E-04	2.1E-04	5.0E+00	1.6E-08
22	Pu-239	1.64E+00	7.1E-11	1.2E-10	1.8E-09	3.0E-09	4.1E-06	6.7E-06	5.2E-07	8.5E-07	1.8E-02	1.6E-08
23												
24		NNW	Total	2.0E-04	Total	8.5E-04	Total	1.2E-02	Total	3.0E-03		
25		sector										
26		11770 m	Best Case		Baseline		Worst		DOE/EA-0400		EA feed with Jim's emissio	
27					Estimate		Emissions		Table 4.2			
28												
29	Column B: CAP-88 Dose Conversion Factors for MEI at 11770 m NNW on Boundary											
30	Column C: Radionuclide Emissions for Updated Feed Rate Best Case Release Estimate, Mulholland et al., May 1994, Table 14											
31	Column D: Dose for Best Case Release and Updated CIF Feed (Col. B x Col. C)											
32	Column E: Radionuclide Emissions for Updated Feed Rate Baseline Case Release Estimate, Mulholland et al., May 1994, Table 14											
33	Column F: Dose for Baseline Case Release and Updated CIF Feed (Col. B x Col. E)											
34	Column G: Radionuclide Emissions for Updated Feed Rate Worst Case Release Estimate, Mulholland et al., May 1994, Table 14											
35	Column H: Dose for Worst Case Release and Updated CIF Feed (Col. B x Col. G)											
36	Column I: CIF Emissions From the Environmental Assessment, 1992, Table 4-2											
37	Column J: Dose using Environmental Assessment Emissions (Col. B x Col. I)											
38	Column K: Feed Rate from the Environmental Assessment, Table 4-2, or the OLD Feed Rate											
39	Columns L, M, and N: The Best, Baseline and Worst case emissions or release factors, respectively, from Mulholland et al., May 1994, Table 14											
40	Columns O, P, and Q: The Best, Baseline and Worst case Emissions from CIF using the OLD Feed Rates, Col. K x Col L, Col K x Col M, and Col K x Col N											
41	Columns R, S, and T: The doses for the Best, Baseline and Worst Case Emissions (Old Feed Rates); Col. B X Col. O, Col. B X Col P, Col Q x Col B											
42	Columns V, W, and X: Fractions of Doses due to each radionuclide for the Best, Baseline, and Worst Case Estimates using the Updated Feed, respectively											
43	Col V = Col D / D24, Col W = Col F / F24, Col X = Col H / H24,											
44	Columns Z, AA, and AB: Fractions of Doses due to each radionuclide for the Best, Baseline, and Worst Case Estimates using the OLD Feed, respectively											
45	Col Z = Col R / R24, Col AA = Col S / S24, Col AB = Col T / T24,											
46												
47												

	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	Baseline	Worst	Best	Baseline	Worst	Best	Baseline	Worst		Best	Baseline	Worst	Nuclide
2	Rel. Fract.	Rel. Fract.	Emissions	Emissions	Emissions	EDE	EDE	EDE		Updated	Updated	Updated	
3	9.0E-01	1.0E+00	9.0E+02	1.1E+03	1.2E+03	1.7E-03	2.0E-03	2.2E-03		96.5%	27.5%	2.2%	H-3
4	2.5E-04	3.8E-03	3.2E-07	5.3E-03	8.0E-02	1.7E-10	2.9E-08	4.3E-05		0.0%	0.0%	0.0%	Sr-89
5	2.5E-04	3.8E-03	4.1E-08	6.8E-04	1.0E-02	1.0E-09	1.7E-05	2.5E-04		0.0%	0.2%	10.4%	Sr-90
6	4.0E-07	9.4E-04	4.3E-08	1.1E-06	2.5E-03	3.5E-11	8.7E-10	2.1E-06		0.0%	0.0%	0.0%	Y-90
7	4.0E-07	9.4E-04	2.6E-07	6.4E-06	1.5E-02	1.9E-10	4.7E-09	1.1E-05		0.0%	0.0%	0.0%	Y-91
8	1.5E-07	1.0E-06	2.6E-07	2.6E-06	1.7E-05	2.4E-10	2.4E-09	1.6E-08		0.0%	0.0%	0.0%	Zr-95
9	3.2E-07	9.4E-04	8.1E-07	1.7E-05	5.1E-02	5.3E-10	1.1E-08	3.3E-05		0.0%	0.0%	0.0%	Nb-95
10	4.0E-07	9.4E-04	9.9E-08	2.5E-06	5.8E-03	3.7E-10	9.2E-09	2.2E-05		0.0%	0.0%	0.1%	Ru-106
11	2.5E-04	3.8E-03	8.1E-05	1.6E-03	2.4E-02	8.4E-08	1.6E-06	2.5E-05		0.0%	0.1%	0.1%	Rh-106
12	2.5E-03	3.8E-03	1.1E-02	2.1E-02	3.2E-02	5.1E-05	9.8E-05	1.5E-04		3.2%	1.6%	0.2%	Cs-137
13	1.5E-07	9.6E-04	1.3E-07	1.3E-06	8.1E-03	1.1E-09	1.1E-08	6.9E-05		0.0%	0.0%	0.1%	Ba-137m
14	4.0E-07	9.4E-04	1.3E-07	3.2E-06	7.5E-03	3.8E-10	9.5E-09	2.2E-05		0.0%	0.0%	0.0%	Ce-144
15	4.0E-07	9.4E-04	1.3E-07	3.2E-06	7.5E-03	5.3E-12	1.3E-10	3.1E-07		0.0%	0.0%	0.0%	Pr-144m
16	4.0E-07	9.4E-04	1.3E-07	3.2E-06	7.5E-03	1.6E-11	3.9E-10	9.2E-07		0.0%	0.0%	0.0%	Pr-144
17	2.5E-04	3.8E-03	6.2E-05	1.2E-03	1.8E-02	3.4E-06	6.6E-05	1.0E-03		0.2%	1.0%	1.0%	Co-60
18	5.0E-05	4.0E-04	5.1E-04	2.7E-02	2.2E-01	1.1E-08	5.7E-07	4.6E-06		0.0%	0.0%	0.0%	Cr-51
19	4.0E-07	9.4E-04	5.1E-07	1.3E-05	3.0E-02	1.2E-10	2.9E-09	6.8E-06		0.0%	0.0%	0.0%	Pm-147
20	2.5E-04	3.8E-03	1.2E-05	2.0E-01	3.0E+00	2.9E-07	4.9E-03	7.4E-02		0.0%	69.5%	75.1%	b/g as Sr-90
21	4.0E-07	9.4E-04	8.0E-08	2.0E-06	4.7E-03	1.2E-07	3.0E-06	7.1E-03		0.0%	0.1%	10.7%	Pu-238
22	4.0E-07	9.4E-04	2.9E-10	7.2E-09	1.7E-05	4.7E-10	1.2E-08	2.8E-05		0.0%	0.0%	0.1%	Pu-239
23													
24					Total	1.7E-03	7.1E-03	8.5E-02		100.0%	100.0%	100.0%	
25					(mrem/y)								
26	n factors												
27													
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CIF MEI Dose on SRS Boundary - Total Radionuclide Release

	Z	AA	AB	AC
1	Best	Baseline	Worst	
2	Old	Old	Old	
3	96.8%	28.4%	2.6%	
4	0.0%	0.0%	0.1%	
5	0.0%	0.2%	0.3%	
6	0.0%	0.0%	0.0%	
7	0.0%	0.0%	0.0%	
8	0.0%	0.0%	0.0%	
9	0.0%	0.0%	0.0%	
10	0.0%	0.0%	0.0%	
11	0.0%	0.0%	0.0%	
12	2.9%	1.4%	0.2%	
13	0.0%	0.0%	0.1%	
14	0.0%	0.0%	0.0%	
15	0.0%	0.0%	0.0%	
16	0.0%	0.0%	0.0%	
17	0.2%	0.9%	1.2%	
18	0.0%	0.0%	0.0%	
19	0.0%	0.0%	0.0%	
20	0.0%	69.0%	87.1%	
21	0.0%	0.0%	8.3%	
22	0.0%	0.0%	0.0%	
23				
24	100.0%	100.0%	100.0%	
25				
26				
27				
28				
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	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Nuclide	mrem/Ci	Emissions	EDE	Emissions	EDE	Emissions	EDE	emissions	EDE	Feed	Best	Baseline
2		(work)	(Ci/yr)	(mrem/yr)	(Ci/yr)	(mrem/yr)	(Ci/yr)	(mrem/yr)	Env. Assess.	(mrem/yr)	Env. Assess.	Rel. Fract.	Rel. Fract.
3	H-3	6.0E-06	1.1E+02	6.3E-04	1.3E+02	7.6E-04	1.4E+02	8.4E-04	1.2E+03	7.1E-03	1.2E+03	7.5E-01	9.0E-01
4	Sr-89	3.1E-04	4.0E-08	1.2E-11	6.5E-04	2.0E-07	9.8E-03	3.1E-06	6.0E-04	1.9E-07	2.1E+01	1.5E-08	2.5E-04
5	Sr-90	1.1E-02	5.1E-09	5.4E-11	8.2E-05	8.7E-07	1.2E-03	1.3E-05	7.6E-05	8.0E-07	2.7E+00	1.5E-08	2.5E-04
6	Y-90	4.5E-04	5.3E-09	2.4E-12	1.3E-07	5.8E-11	3.1E-04	1.4E-07	7.6E-05	3.4E-08	2.7E+00	1.6E-08	4.0E-07
7	Y-91	2.4E-03	3.2E-08	7.6E-11	7.8E-07	1.9E-09	1.8E-03	4.3E-06	4.5E-04	1.1E-06	1.6E+01	1.6E-08	4.0E-07
8	Zr-95	7.2E-03	4.5E-08	3.2E-10	4.5E-07	3.2E-09	6.0E-06	4.3E-08	4.7E-04	3.4E-06	1.7E+01	1.5E-08	1.5E-07
9	Nb-95	4.0E-03	1.1E-07	4.4E-10	2.4E-06	9.6E-09	7.1E-03	2.8E-05	1.5E-03	6.0E-06	5.4E+01	1.5E-08	3.2E-07
10	Ru-106	2.3E-02	2.8E-08	6.4E-10	7.1E-07	1.6E-08	1.7E-03	3.9E-05	1.8E-04	4.1E-06	6.2E+00	1.6E-08	4.0E-07
11	Rh-106	3.7E-06	2.2E-05	8.1E-11	4.5E-04	1.7E-09	6.7E-03	2.5E-08	1.8E-04	6.6E-10	6.2E+00	1.3E-05	2.5E-04
12	Cs-137	1.5E-03	1.4E-03	2.1E-06	2.9E-03	4.3E-06	4.3E-03	6.3E-06	2.4E-04	3.5E-07	8.4E+00	1.3E-03	2.5E-03
13	Ba-137m	1.3E-05	1.7E-08	2.2E-13	1.8E-07	2.3E-12	1.1E-03	1.4E-08	2.4E-04	3.1E-09	8.4E+00	1.5E-08	1.5E-07
14	Ce-144	1.9E-02	3.1E-08	5.8E-10	7.8E-07	1.5E-08	1.8E-03	3.4E-05	2.3E-04	4.3E-06	8.0E+00	1.6E-08	4.0E-07
15	Pr-144m	1.4E-06	3.1E-08	4.3E-14	7.8E-07	1.1E-12	1.8E-03	2.5E-09	2.3E-04	3.2E-10	8.0E+00	1.6E-08	4.0E-07
16	Pr-144	3.9E-06	3.1E-08	1.2E-13	7.8E-07	3.0E-12	1.8E-03	6.9E-09	2.3E-04	8.9E-10	8.0E+00	1.6E-08	4.0E-07
17	Co-60	5.2E-01	7.3E-06	3.8E-06	1.5E-04	7.8E-05	2.2E-03	1.1E-03	1.4E-04	7.3E-05	4.8E+00	1.3E-05	2.5E-04
18	Cr-51	1.4E-04	6.2E-05	8.9E-09	3.3E-03	4.8E-07	2.6E-02	3.7E-06	1.5E-02	2.2E-06	5.4E+02	9.5E-07	5.0E-05
19	Pm-147	1.9E-03	6.4E-08	1.2E-10	1.5E-06	2.8E-09	3.7E-03	6.9E-06	9.1E-04	1.7E-06	3.2E+01	1.6E-08	4.0E-07
20	b/g as Sr-90	1.1E-02	1.5E-06	1.6E-08	2.4E-02	2.5E-04	3.6E-01	3.8E-03	2.2E-02	2.3E-04	7.9E+02	1.5E-08	2.5E-04
21	Pu-238	1.5E+01	1.5E-08	2.3E-07	3.6E-07	5.4E-06	8.4E-04	1.3E-02	1.4E-04	2.1E-03	5.0E+00	1.6E-08	4.0E-07
22	Pu-239	1.6E+01	7.1E-11	1.2E-09	1.8E-09	2.9E-08	4.1E-06	6.7E-05	5.2E-07	8.5E-06	1.8E-02	1.6E-08	4.0E-07
23													
24			Total	6.4E-04	Total	1.1E-03	Total	1.9E-02	Total	9.6E-03			
25	worker	N											
26	dose	350 m	Best Case		Baseline		Worst		DOE/EA-0400		EA feed with Jim's emission factors		
27					Estimate		Emissions		Table 4.2				
28													
29	Column B: CAP-88 Dose Conversion Factors for Onsite Worker at 350 m N												
30	Column C: Radionuclide Emissions for Updated Feed Rate Best Case Release Estimate, Mulholland et al., May 1994, Table 14												
31	Column D: Dose for Best Case Release and Updated CIF Feed (Col. B x Col. C)												
32	Column E: Radionuclide Emissions for Updated Feed Rate Baseline Case Release Estimate, Mulholland et al., May 1994, Table 14												
33	Column F: Dose for Baseline Case Release and Updated CIF Feed (Col. B x Col. E)												
34	Column G: Radionuclide Emissions for Updated Feed Rate Worst Case Release Estimate, Mulholland et al., May 1994, Table 14												
35	Column H: Dose for Worst Case Release and Updated CIF Feed (Col. B x Col. G)												
36	Column I: CIF Emissions From the Environmental Assessment, 1992, Table 4-2												
37	Column J: Dose using Environmental Assessment Emissions (Col. B x Col. I)												
38	Column K: Feed Rate from the Environmental Assessment, Table 4-2, or the OLD Feed Rate												
39	Columns L, M, and N: The Best, Baseline and Worst case emissions or release factors, respectively, from Mulholland et al., May 1994, Table 14												
40	Columns O, P, and Q: The Best, Baseline and Worst case Emissions from CIF using the OLD Feed Rates, Col. K x Col L, Col K x Col M, and Col K x Col N												
41	Columns R, S, and T: The doses for the Best, Baseline and Worst Case Emissions (Old Feed Rates); Col. B X Col. O, Col. B X Col P, Col Q x Col B												
42	Columns V, W, and X: Fractions of Doses due to each radionuclide for the Best, Baseline, and Worst Case Estimates using the Updated Feed, respectively												
43	Col V = Col D / D24, Col W = Col F / F24, Col X = Col H / H24,												
44	Columns Z, AA, and AB: Fractions of Doses due to each radionuclide for the Best, Baseline, and Worst Case Estimates using the OLD Feed, respectively												
45	Col Z = Col R / R24, Col AA = Col S / S24, Col AB = Col T / T24,												
46	Column AD: Percent change in Feed from Updated Feed to Old Feed, (Col E- col P)/Col P * 100%												
47	Column AE: Ratio of Updated Feed to OLD Feed, Col E / Col P												

	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Worst	Best	Baseline	Worst	Best	Baseline	Worst		Best	Baseline	Worst	Nuclide	Best	Baseline
2	Rel. Fract.	Emissions	Emissions	Emissions	EDE	EDE	EDE		Update	Update	Update		Old	Old
3	1.0E+00	9.0E+02	1.1E+03	1.2E+03	5.4E-03	6.5E-03	7.2E-03		99.0%	88.9%	4.5%	H-3	99.1%	70.0%
4	3.8E-03	3.2E-07	5.3E-03	8.0E-02	9.8E-11	1.6E-06	2.5E-05		0.0%	0.0%	0.0%	Sr-89	0.0%	0.0%
5	3.8E-03	4.1E-08	6.8E-04	1.0E-02	4.3E-10	7.1E-06	1.1E-04		0.0%	0.1%	0.1%	Sr-90	0.0%	0.1%
6	9.4E-04	4.3E-08	1.1E-06	2.5E-03	1.9E-11	4.8E-10	1.1E-06		0.0%	0.0%	0.0%	Y-90	0.0%	0.0%
7	9.4E-04	2.6E-07	6.4E-06	1.5E-02	6.1E-10	1.5E-08	3.6E-05		0.0%	0.0%	0.0%	Y-91	0.0%	0.0%
8	1.0E-06	2.6E-07	2.6E-06	1.7E-05	1.8E-09	1.8E-08	1.2E-07		0.0%	0.0%	0.0%	Zr-95	0.0%	0.0%
9	9.4E-04	8.1E-07	1.7E-05	5.1E-02	3.2E-09	6.9E-08	2.0E-04		0.0%	0.0%	0.2%	Nb-95	0.0%	0.0%
10	9.4E-04	9.9E-08	2.5E-06	5.8E-03	2.3E-09	5.6E-08	1.3E-04		0.0%	0.0%	0.2%	Ru-106	0.0%	0.0%
11	3.8E-03	8.1E-05	1.6E-03	2.4E-02	3.0E-10	5.7E-09	8.6E-08		0.0%	0.0%	0.0%	Rh-106	0.0%	0.0%
12	3.8E-03	1.1E-02	2.1E-02	3.2E-02	1.6E-05	3.1E-05	4.7E-05		0.3%	0.4%	0.0%	Cs-137	0.3%	0.3%
13	9.6E-04	1.3E-07	1.3E-06	8.1E-03	1.6E-12	1.6E-11	1.0E-07		0.0%	0.0%	0.0%	Ba-137m	0.0%	0.0%
14	9.4E-04	1.3E-07	3.2E-06	7.5E-03	2.4E-09	6.0E-08	1.4E-04		0.0%	0.0%	0.2%	Ce-144	0.0%	0.0%
15	9.4E-04	1.3E-07	3.2E-06	7.5E-03	1.8E-13	4.4E-12	1.0E-08		0.0%	0.0%	0.0%	Pr-144m	0.0%	0.0%
16	9.4E-04	1.3E-07	3.2E-06	7.5E-03	4.9E-13	1.2E-11	2.9E-08		0.0%	0.0%	0.0%	Pr-144	0.0%	0.0%
17	3.8E-03	6.2E-05	1.2E-03	1.8E-02	3.3E-05	6.3E-04	9.5E-03		0.6%	7.1%	6.1%	Co-60	0.6%	6.7%
18	4.0E-04	5.1E-04	2.7E-02	2.2E-01	7.4E-08	3.9E-06	3.1E-05		0.0%	0.0%	0.0%	Cr-51	0.0%	0.0%
19	9.4E-04	5.1E-07	1.3E-05	3.0E-02	9.5E-10	2.4E-08	5.6E-05		0.0%	0.0%	0.0%	Pm-147	0.0%	0.0%
20	3.8E-03	1.2E-05	2.0E-01	3.0E+00	1.3E-07	2.1E-03	3.2E-02		0.0%	22.9%	20.3%	b/g as Sr-90	0.0%	22.5%
21	9.4E-04	8.0E-08	2.0E-06	4.7E-03	1.2E-06	3.0E-05	7.1E-02		0.0%	0.5%	67.9%	Pu-238	0.0%	0.3%
22	9.4E-04	2.9E-10	7.2E-09	1.7E-05	4.7E-09	1.2E-07	2.8E-04		0.0%	0.0%	0.4%	Pu-239	0.0%	0.0%
23														
24				Total	5.5E-03	9.3E-03	1.2E-01		100.0%	100.0%	100.0%	Nuclide	100.0%	100.0%
25				(mrem/y)										
26														
27														
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	AB	AC	AD	AE
1	Worst		Feed	feed
2	Old		(n-o)/old	new/old
3	6.0%		-88.3%	1.2E-01
4	0.0%		-87.6%	1.2E-01
5	0.1%		-87.8%	1.2E-01
6	0.0%		-88.0%	1.2E-01
7	0.0%		-87.8%	1.2E-01
8	0.0%		-82.4%	1.8E-01
9	0.2%		-86.1%	1.4E-01
10	0.1%		-71.4%	2.9E-01
11	0.0%		-71.0%	2.9E-01
12	0.0%		-86.2%	1.4E-01
13	0.0%		-85.7%	1.4E-01
14	0.1%		-75.6%	2.4E-01
15	0.0%		-75.6%	2.4E-01
16	0.0%		-75.6%	2.4E-01
17	7.9%		-87.5%	1.3E-01
18	0.0%		-87.8%	1.2E-01
19	0.0%		-88.3%	1.2E-01
20	26.3%		-87.9%	1.2E-01
21	58.9%		-82.0%	1.8E-01
22	0.2%		-75.0%	2.5E-01
23				
24	100.0%			
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Estimate of Metal and Radionuclide Emissions from the SRS Consolidated Incinerator Facility

DRAFT, 5/23/94

James A. Mulholland and Michael G. Robinson
Environmental Engineering Program
School of Civil & Environmental Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0355
(404) 894-1695

Nolan E. Hertel, H. Michelle Coward, and Duane T. Nakahata
Health Physics Program
G.W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405
(404) 894-3717

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Estimate of Metal and Radionuclide Emissions from the SRS Consolidated Incinerator Facility

Abstract

Stack emissions of toxic metals and radionuclides from the Consolidated Incineration Facility (CIF) at the Savannah River Site (SRS) under normal operating conditions are estimated. A separate report will document the results of an organic byproduct emissions estimate. These estimates provide the source term for a health risk assessment currently being conducted.

The CIF consists of a rotary kiln, a secondary combustion chamber, and an air pollution control system. Three waste streams are to be fed to the rotary kiln: solid wastes, high heating value liquid wastes, and low heating value liquid wastes. A fourth waste stream, Defense Waste Processing Facility (DWPF) benzene, will be fed to the secondary combustion chamber. These streams include low-level radioactive wastes as well as hazardous wastes. An overall elemental waste composition is inferred from available data. Metal and radionuclide species and phase equilibria are determined at the high temperatures characteristic of the combustion environment using the NASA complex chemical equilibrium code CET89. This detailed thermodynamic analysis is coupled with global assumptions regarding particle entrainment (via fragmentation), particle inception (via nucleation), and particle growth (via condensation and coagulation) to estimate the partitioning of metals and radionuclides between kiln bottom ash, supermicron flyash, and submicron aerosol particles entering the air pollution control device system. Particle collection efficiencies by three air pollution control devices - a spray quench vessel, a scrubber/cyclone/demister system, and a high efficiency filtration system - are estimated from equipment design specifications; these efficiencies differentiate between supermicron and submicron particle collection. Applying the particle collection efficiencies to the estimated particle size and composition distribution in the combustion gas exhaust stream, stack emissions of toxic metals and radionuclides are calculated on a fraction of feed basis as well as on an annual basis (based on projected CIF feed rates). A sensitivity analysis is performed to demonstrate the dependence of results on critical parameters, such as waste chlorine content, waste ash content, and combustion temperature. The results are compared with previous estimates and experimental results.

Contents

1. INTRODUCTION

The Consolidated Incineration Facility (CIF) at the Savannah River Site (SRS) is being constructed to incinerate low-level radioactive and hazardous wastes. It will consist of a rotary kiln, a secondary combustion chamber, and an air pollution control system. An estimate of stack emissions of both radionuclides and toxic compounds is needed as a source term in the health risk assessment being conducted. In a previous effort [Application for EPA Approval of Construction, NESHAPS (1988)], allowable emission rates and single point particle collection device efficiencies were used to calculate maximum feed concentrations of radionuclides and toxic metals, assuming 80 percent removal from the combustion system as bottom ash. While this estimate provides an estimate of maximum allowable feed stream concentrations, it does not represent a realistic emission estimate since actual feed rates of waste constituents are likely to differ substantially from the maximum allowable values; furthermore, combustion system bottom ash removal and air pollution control device particle collection will depend on waste composition and combustion conditions.

In this work, waste elemental concentration data, current waste generation rate projections, typical combustion system operating parameters, and particle collection device design specifications are used to estimate metal and radionuclide emissions. An estimate of organic byproduct emissions will be provided in a separate report. Chemical species and phase equilibria under typical combustion conditions are assessed computationally to estimate metal and radionuclide partitioning between a fine condensation aerosol produced by the nucleation of particles from metal vapors during combustion gas quenching (0.01 to 1 μm diameters, typical), larger suspended particles entrained as flyash due to fragmentation (1 to 10 μm), and bottom ash. Particle collection efficiencies as a function of particle size are used to assess pollution control device removal. Submicron particles are difficult to remove from the combustion gas stream and, hence, are disproportionately emitted. A kinetic analysis is not possible due to insufficient waste structure information and kinetic data. Nonetheless, a thermodynamic analysis is appropriate in this case because it is the total metal and radionuclide release from that is desired. In contrast, the emission of trace organic byproducts, and not major combustion product gases (carbon dioxide and water), is needed to account for health risk due to organic emissions; in this case, consideration of kinetic effects is required. The equilibrium approach used here for metal and radionuclide emissions is likely to be conservative in that kinetic effects may limit the vaporization of inorganic compounds and, therefore, the enrichment of submicron aerosols by volatile species.

Results are compared with rotary kiln test data from an Environmental Protection Agency (EPA) incineration research facility (Venkatesh, 1993) and from an Energy and Environmental Research Corporation (EERC) test facility (Burns, 1993). A wide range of combustion conditions and waste feed compositions are considered that will help in the interpretation and extension of trial burn data.

2. OBJECTIVE AND APPROACH

The purpose of this emissions estimate is to provide a source term for the CIF health risk assessment. Figure 1 is a schematic flow diagram of the CIF, with all input and output streams shown. Metals and radionuclides enter the combustion system as waste constituents and are removed as bottom ash, captured by the air pollution control devices, or released to the atmosphere through the stack. The latter poses an exposure risk to those working and living near the CIF.

This stack emissions estimate is carried out in two steps. First, the composition of the combustion exhaust stream is estimated based on an elemental waste composition and typical combustion operating conditions. With available thermodynamic data, the speciation and phase equilibria of metals and radionuclides are predicted using the NASA complex chemical equilibrium code CET89 (Gordon and McBride, 1976). The CIF waste feed stream characterization is described in Section 3, and the operating parameters of the CIF combustion system, consisting of a rotary kiln (or primary combustion chamber, PCC) and an afterburner section (or secondary combustion chamber, SCC), are described in Section 4. Combustion emission estimate results are given in Section 5. In the second step of this analysis, collection efficiencies for submicron particles (0.01 to 1 μm diameter) and supermicron particles (1 to 20 μm diameter) based on collection device design specifications are used to estimate total stack emissions. Particles are removed by a spray quench vessel, a scrubber with cyclone and demister, and a high efficiency particulate air (HEPA) filtration system, as described in Section 6. Results of the emission estimate, calculated as a fraction of waste feed (mass basis), are given in Section 7. In Section 8, a comparison with previous estimates and test results is provided.

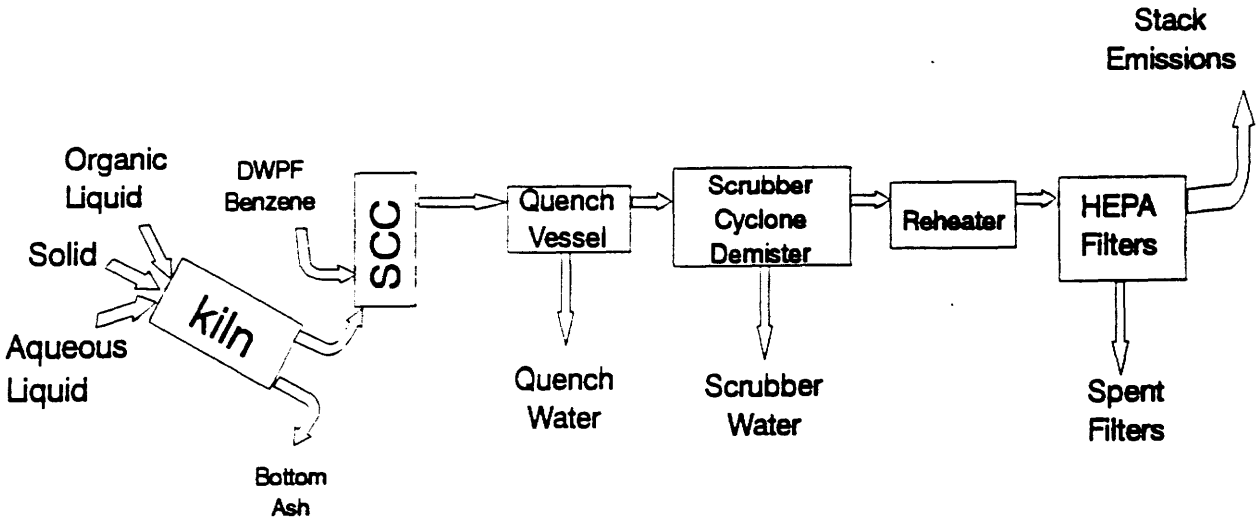

Figure 1. CIF Flow Diagram.

3. WASTE CHARACTERIZATION

Feed Stream Flow Rates

The rotary kiln is designed for simultaneous input of up to four fuel or waste streams. A ram device is used for the batch feeding of solid wastes in 21 inch cube containers. Three high intensity vortex burners are available for the continuous feed of high heating value (HHV) liquids (or organic wastes), low heating value (LHV) liquids (or aqueous wastes), and auxiliary fuel oil. In the SCC, two liquid feed burners can be used to inject Defense Waste Processing Facility (DWPF) liquid (90 percent benzene) and auxiliary fuel oil. Feed rates based on CIF heat input design capacity are given in Table 1. Current waste inventory and generation projections, however, are are different than those of the original design. In these projections (Table 2), it is assumed that the waste inventory is incinerated over three years. For this emission estimation, the annual generation rate data are used (Table 2, column 3).

Table 1. Waste Feed Design Capacity.

Waste	Burner Design Rate[a] (lb/hr)	Heat Input Design Rate[b] (lb/hr)	Availability[b] (percent)	Annual Feed[c] (Mlb/yr)
solids	2025	720	50	3.15
HHV & DWPF liquids	687	302	70	1.85
LHV liquids	950	----	70	----
fuel oil	----	183	70	1.12

[a] Based on burner design (Savannah River Site CIF Report, 1988, pp. B-6,7).
[b] Based on CIF heat input of 18.1 MBtu/hr (Savannah River Site CIF Report, 1993, p. 26).
[c] Yearly rate = hourly rate x (24 x 365 hr/yr) x (% availability/100%).

Table 2. Waste Inventory and Generation Projections.

Waste	Inventory[a] (Mlbs)	Annual Generation[b] Mlb/yr (mass %)	Feed - first 3 years[c] Mlb/yr (mass %)
solids	0.650	1.317 (63.3%)	1.533 (55.3%)
HHV liquids	1.272	0.315 (15.1%)	0.739 (26.7%)
LHV liquids	0.148	0.082 (4.0%)	0.131 (4.7%)
DWPF benzene	0	0.367 (17.6%)	0.367 (13.3%)

[a] CIF startup (1996) forecast (Savannah River Site CIF Report, 1993, pp. 15 & 16).
[b] Forecast (Savannah River Site CIF Report, 1993, p. 17).
[c] Feed during first 3 years = (1/3) x inventory + annual generation.

Elemental Composition

To perform an equilibrium analysis, an overall elemental composition is needed. Detailed information about individual wastes is given in Appendix 8 (Book 2) and Appendix 26 (Book 3) of the Resource Conservation and Recovery Act (RCRA) Permit Renewal Application (Westinghouse Savannah River Company, 1992). Information about different waste groups is also provided in Section III of the Mission Need and Design Capacity Review (Savannah River Site CIF Report, 1993). Here, this detailed information is distilled and combined with the flow rate data to yield a typical overall elemental composition of the waste feed to be delivered to the CIF.

The mass fraction of carbon is determined by estimating the carbon content of each feed stream. The heating value of a fossil fuel or organic waste can be correlated to its carbon and hydrogen content because the heat release by combustion is predominantly due to the conversion of weak O_2 double bonds (119 kcal/mol) to strong carbon-oxygen double bonds (192 kcal/mol, in CO_2) and hydrogen-oxygen single bonds (119 kcal/mol, in H_2O). A carbon atom consumes four times as much oxygen as a hydrogen atom; therefore, to a first approximation, heating value can be correlated to carbon content only. Such a correlation is shown in Figure 2 for fuel oils and coals. Laboratory analyses of several CIF solid waste samples indicate a heating value between 12 and 13 kBtu/lb. Using 7000 kcal/kg (12.5 kBtu/lb), the correlation shown in Figure 2 indicates the solid wastes to have a carbon content of 70 percent by mass. The HHV liquids have a heating value of approximately that of fuel oil; the associated carbon content is 88 percent. The LHV liquids are assumed to contribute negligibly to the overall heating content. The carbon content of DWPF liquid is assumed to be that of benzene (92 percent). Using these values for the individual stream carbon fractions and the projected annual generation mass fractions of the different waste streams (Table 2), the overall carbon content of wastes fed to the CIF is found to be 79 percent by mass.

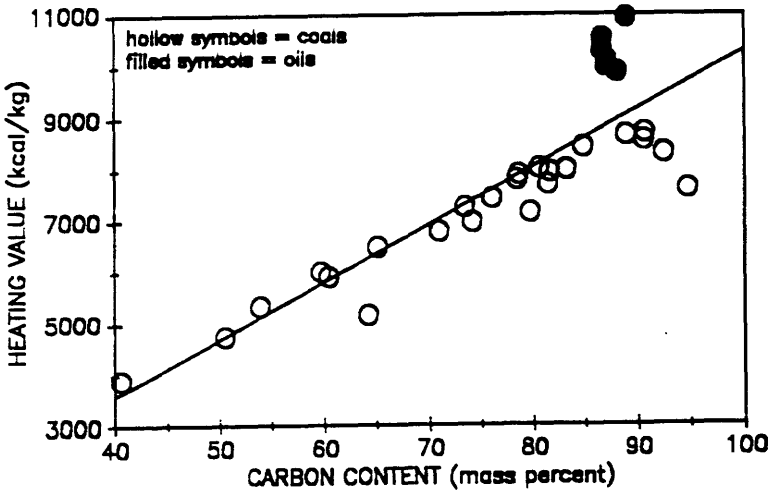

Figure 2. Heating Value and Carbon Content (Bartok and Sarofim, 1991, Appendix).

The hydrogen-to-carbon molar ratio (H/C) in typical solid and liquid fuels and wastes is between 0.5 and 2. Some examples are: 1 for benzene; 2 for long chain paraffins; 1.5 for polyvinyl chloride (PVC); 1.5 to 2 for fuel oils; for coals, depending on moisture content and rank, 0.4 (low moisture, anthracite coals) to 2 (high moisture, lignite coals). The liquid wastes are comprised mostly of contaminated oils (HHV liquids), benzene (DWPF liquids), and water (LHV liquids). The most abundant components of the solid wastes are given in Table 3 of the report by Burns (1993) as 53% paper [$C_6H_{10}O_2$], 25% polyethylene [$(C_2H_2)_n$], 20% latex [$(C_5H_8)_{23}S$], and 2% PVC [$(C_2H_3Cl)_n$]. Based on these composition, the overall H/C molar ratio is calculated to be 1.5. The amount of PVC in the waste, still highly uncertain at this time, does not affect this estimate since it also has a H/C molar ratio of 1.5. For a carbon mass fraction of 0.79, the hydrogen mass fraction would be 0.09. The remaining 12% of the CIF fuel and waste feed is assumed to consist of six percent water (including the four percent aqueous waste fraction), one percent chlorine, and five percent ash. The chlorine and ash concentrations have been estimated by Burns (1993), based on limited waste characterization data that are available. The chlorine mass fraction is based on 2% (mass) PVC in the solid waste stream (corresponding to about 1.1% chlorine content) and 0.5% (mass) chlorine in the liquid waste. The ash fraction must comprise the remaining 5% of the fuel and waste feed, a number that agrees with the estimate in Table 24 of Burns (1993).

Table 3. Composition of Waste Feed Stream to CIF.

	Mass Fraction	Range	Basis
Carbon/Hydrogen:			
C	0.79	0.7 - 0.9	Appendix, Table A-1
H	0.09	0.067 - 0.133	H/C (molar) ~ 1.5
Water:			
H_2O	0.06	0.02 - 0.10	Appendix, Table A-1
Chlorine:			
Cl	0.01	0 - 0.02	Burns (1993), Table 25
Ash:			Burns (1993), Table 24
Al_2O_3	0.01165	0 - 0.0233	
SiO_2	0.01165	0 - 0.0233	
SO_3	0.01165	0 - 0.0233	
Fe_2O_3	0.01165	0 - 0.0233	
other	0.00340	0 - 0.0068	Burns (1993), Table 22

Table 4. Toxic Metal Concentrations in CIF Kiln Feed.

	MW (g/mol)	Feed Rate[a] (lb/yr)	Mass Concentration[b] (ppm mass)
Toxic Metals:			
chromium, Cr	52.0	426	381
nickel, Ni	58.7	478	427
arsenic, As	74.9	0.1	0.089
silver, Ag	107.9	119	106
cadmium, Cd	112.4	3.3	2.9
antimony, Sb	121.8	2.0	1.8
barium, Ba	137.3	1052	940
mercury, Hg	200.6	57	51
thallium, Tl	204.4	2.0	1.8
lead, Pb	207.2	1672	1494

[a] From Burns (1993), Table 22.
[b] Mass concentration (ppm) = feed rate / total feed rate x 10^6 = feed rate (lb/yr) / 1.119.

Table 5. Maximum Radionuclide Concentrations in Waste Feed.

	Specific Activity[a] (Ci/g)	Maximum Concentration[b] (μCi/lb total)	Mass Fraction[c]
H-3	9.67E+3	67.5	1.54E-11
Cr-51	9.24E+4	31.3	7.46E-13
Co-60	1.13E+3	0.28	5.45E-13
Sr-89	2.91E+4	1.25	9.47E-14
Sr-90	1.37E+2	46.2	7.42E-10
Y-90	5.44E+5	0.16	6.47E-16
Y-91	2.45E+4	0.94	8.45E-14
Zr-95	2.10E+4	1.44	1.51E-13
Nb-95	3.92E+4	3.63	2.04E-13
Ru-106	3.34E+3	0.86	5.67E-13
Rh-106	3.56E+9	0.86	5.32E-19
Cs-137	8.68E+1	0.51	1.29E-11
Ba-137m	5.38E+8	0.51	2.09E-18
Ce-144	3.19E+3	0.93	6.42E-13
Pr-144	7.56E+7	0.93	2.71E-17
Pr-144m	1.81E+8	0.93	1.13E-17
Pm-147	9.28E+2	1.89	4.48E-12
Pu-238	1.71E+1	0.43	5.53E-11
Pu-239	6.20E-2	0.0021	7.45E-11

[a] See Appendix, Table A-2.
[b] See Appendix, Table A-3.
[c] Mass fraction = max. concentration x 10^{-6} (Ci/lb) / {specific activity (Ci/g) x 454 (g/lb)}.

The ash includes metals and radionuclides with estimated concentrations given in Table 22 of the report by Burns (1993) and in Table 16 of the Application for EPA Approval of Construction, NESHAPS (Savannah River Site CIF, 1988), respectively; these estimates are listed in Tables 4 and 5, respectively. For radionuclide concentration estimation, specific activity factors are calculated from radioisotope half-life data (see Table A-1, Appendix). Toxic metals and radionuclides make up 0.34 percent of the total feed; the remaining 4.66 percent ash is assumed to be an equal mass mixture of oxides of aluminum (Al_2O_3), silicon (SiO_2), sulfur (SO_3), and iron (Fe_2O_3), typical of coal ash (Linak and Wendt, 1993). Aluminum, silicon, and calcium have been measured as significant components of the CIF waste content. The thermodynamic code is unable to achieve an equilibrium solution with calcium, so iron is used in its place. Sulfur present in the latex waste represents about 0.4% of the solid waste mass; the 1% SO_3 given in Table 3 yields a sulfur mass fraction of 0.4%.

The fuel and waste feed composition described in Tables 3, 4, and 5 is used for the thermodynamic combustion emission estimate. Only the elemental composition is needed for this analysis. Sensitivity of the combustion emissions estimate to the high degree of uncertainty in the input concentrations is evaluated. For the purpose of comparison, data for the inorganic elemental composition of typical coals, municipal solid wastes, and hazardous wastes are shown in Table 6. There is enormous variability between coal types and between waste types. Compared to coals, waste streams are rich in toxic metals, particularly chromium (Cr), nickel (Ni), arsenic (As), cadmium (Cd), and lead (Pb), and chlorine (Cl). On the other hand, coals typically contain mineral deposits with higher concentrations of sulfur (S), silicon (Si), and aluminum (Al) than found in wastes. Metal and mineral ash interactions affects inorganic species volatility, and, hence, flyash particle size distribution and collection (Linak and Wendt, 1993).

The presence of each inorganic element in the CIF waste streams (solids, HHV liquids, LHV liquids, and DWPF benzene) is also indicated in Table 6. In the case of the CIF wastes, the most abundant toxic metals are Pb, barium (Ba), Ni, Cr, silver (Ag), and mercury (Hg), as shown in Table 4. Chlorine is present in significant quantities in many of the CIF wastes. In particular, the solid wastes contain a significant fraction of PVC wastes. The PVC monomer, vinyl chloride, is highly toxic and carcinogenic. The presence of chlorine in incineration wastes can enhance the vaporization of some metals due to the high volatility of many metal chlorides relative to that of the pure metals or metal oxides.

Not all of the elements that appear in Table 6 were included in this assessment of metal emissions from the CIF. Only those present in Tables 3, 4, and 5 were considered, as these have been identified as either the most abundant elements or those most likely to impact the health risk assessment. This elemental composition is used as the input for the thermodynamic analysis.

Table 6. Concentrations of Inorganic Elements.

	MW (g/mol)	In Coals[a] (ppm mass)	In Municipal Wastes[b] (ppm mass)	In Hazardous Wastes[c] (ppm mass)	Detected in CIF Waste Streams[d]
Li	6.9	4-63			solids,LHV
Be	9.0		<2	0.001-7	none
B	10.8	1-230			HHV
F	19.0	1-110			solids,HHV
Na	23.0	100-6,000		ND-110,000	solids
Al	27.0	3,000-23,000		<1-14,000	solids,HHV,LHV
Si	28.1	5,000-41,000			LHV
P	31.0	6-300			HHV,LHV
S	32.1	300-10,000			solids,HHV
Cl	35.5	10-260	% levels		all
Ca	40.1	50-12,300			HHV
Ti	47.9	200-1,800		<0.01-540	HHV,LHV
V	50.9	2-77		<0.01-3,500	HHV
Cr	52.0	100-400	5,000-20,000	0.0-20,000	all
Fe	55.9	340-23,000		<0.1-253,000	HHV,LHV
Co	58.9	1-90	<3-5	0.01-83	solids
Ni	58.7	2-60	9-90	0.0-6,550	solids,LHV
Cu	63.6	3-250		0.0-45,300	HHV,LHV
Zn	65.4	3-80		0.1-17,500	HHV,LHV
As	74.9	1-60		0.0-100,000	solids,HHV
Se	79.0			0.005-52	solids,HHV
Sr	87.6	17-1,000			solids
Y	88.9	3-25		0.01-0.6	solids
Zr	91.2	28-300		0.03-6,000	solids,HHV
Nb	92.9	5-41		0.02-120	solids
Ru	101.1				solids,HHV
Rh	102.9				solids,HHV
Ag	107.9		<3-7	0.0007-20	solids,HHV,LHV
Cd	112.4		4-22	0.0-10,400	all
Sn	118.7	1-400		0.01-140	solids,LHV
Sb	121.8	0.1-30	20	0.1-276	none
Cs	132.9				solids,HHV,DWPF
Ba	137.3	20-1,600	47-447	0.01-8,000	all
Ce	140.1				solids,HHV
Pr	140.9		1-4.4	0.0-220	solids,HHV
Pm	(145)				solids,HHV
Hg	200.6				all
Tl	204.4				none
Pb	207.2	1-60	10,000-150,000	0.0-130,000	solids,HHV,LHV
U	238.0				HHV
Pu	(244)				solids,HHV

[a] From: Hardesty and Pohl (1979).
[b] From: Lisk (1988).
[c] From: Travis and Cook (1989), p. 88.
[d] From: RCRA Permit Renewal Application (WSRC, 1992, Appendix 8).

4. COMBUSTION SYSTEM CHARACTERIZATION

The CIF combustion system consists of a rotary kiln which serves as the primary combustion chamber (PCC) and a secondary combustion chamber (SCC). Emissions from the CIF combustion system will depend on the composition of waste feed as well as the conditions under which combustion occurs. The time and temperature environments of the PCC and SCC are described briefly below.

Rotary Kiln

The PCC is a rotary kiln with a thermal release rate limit of 13 MBtu/hr. It has a slightly tilted horizontal configuration, with an eight foot internal diameter and 25 foot length. The rotation speed has a range of 0.2 to 2.0 rotations per minute, with a solids retention time of between 30 and 90 minutes. The design operating temperature for the rotary kiln (PCC) is 1832°F (1273 K) with at least 100% excess air. A minimum operating temperature of 1400°F (1030 K) is specified. Trial burn tests will be conducted with operating temperatures at the minimum temperature and at 1600°F (1140 K).

Liquid fuels and wastes are fed continuously through high intensity vortex burners that achieve fine atomization. Solids are fed in batch mode by a ram feeder. The temperature of solids in the kiln varies with distance from injection and depth. Solid wastes are either removed from the kiln as bottom ash or carried to the SCC due to vaporization and/or combustion gas stream entrainment of fragments.

Secondary Combustion Chamber

The SCC is connected to the outlet of the kiln. It has a vertical orientation, with seven foot internal diameter and 21 foot vertical length. It has a 5 MBtu/hr thermal rating. The SCC is designed to operate at 2012°F (1373 K) with at least 80% excess air. The residence time in the SCC is at least two seconds. DWPF benzene waste and/or auxiliary fuel oil can be fed to the SCC via high intensity vortex burners.

The combustion gases leaving the SCC enter a quench chamber where rapid cooling to water saturation temperature (373 K) occurs. The air pollution control system is described in Section 6 of this report.

5. COMBUSTION EMISSION ESTIMATE

Metals and radionuclides are either removed from the rotary kiln as bottom ash or are entrained in the combustion gas exhaust stream through vaporization and/or fragmentation mechanisms. The entrained inorganic fraction is further partitioned upon cooling of the combustion gas stream between a fine condensation aerosol and flyash particles. Chemical thermodynamic analysis provides both the equilibrium speciation and the gas and condensed phase fractions of inorganic compounds leaving the combustion system. This thermodynamic approach does not describe the effects of potential incinerator failure modes such as transient puffs from the batch feed incineration of solid wastes (Wendt and Linak, 1988) and rogue droplets from the continuous feed incineration of liquid wastes (Mulholland *et al.*, 1991). These phenomena are typically of short duration or represent a small volume fraction and will have a greater impact on organic emissions than metal and radionuclide emissions.

Methodology

A schematic diagram of processes governing ash particle formation is shown in Figure 3. To estimate the partitioning of inorganic species between bottom ash, flyash, and vapors in the kiln, several assumptions are needed. As a baseline case, a temperature of 900 K (1160°F) for the kiln solids is assumed. This temperature is varied from 700 to 1100 K in the sensitivity analysis. The amount of remaining solid waste that is entrained into the combustion gases by fragmentation depends on the detailed physical and chemical composition of the waste. This information is not known in sufficient detail to model; moreover, the wastes will likely exhibit a range of physical and chemical properties too wide for practical simulation. Therefore, based on the experience in the EPA's Incineration Research Facility in Jefferson, Arkansas (Venkatesh, 1993), an overall partition coefficient for gas stream entrainment of 0.1 for the nonvolatile fraction is assumed. This value is varied from 0.01 to 0.25 in the sensitivity analysis. The gases and entrained particles then enter the SCC where the temperature is increased to a baseline value of 1250 K (1800°F); this temperature is varied from 1100 to 1500 K in the sensitivity analysis. Once coolled in the quench chamber, the combustion gas stream is supersaturated with inorganic vapors which then either undergo nucleation to form new particles or condense on the surface of existing particles. The competition between nucleation and condensation, both driven by the degree of supersaturation, is too complex to model in detail. It is assumed that 50 percent of the inorganic vapors will condense on supermicron flyash particles and 50 percent will contribute to submicron aerosol particle formation and growth. The value of this partition coefficient is varied from 0.25 to 0.75 in the sensitivity analysis.

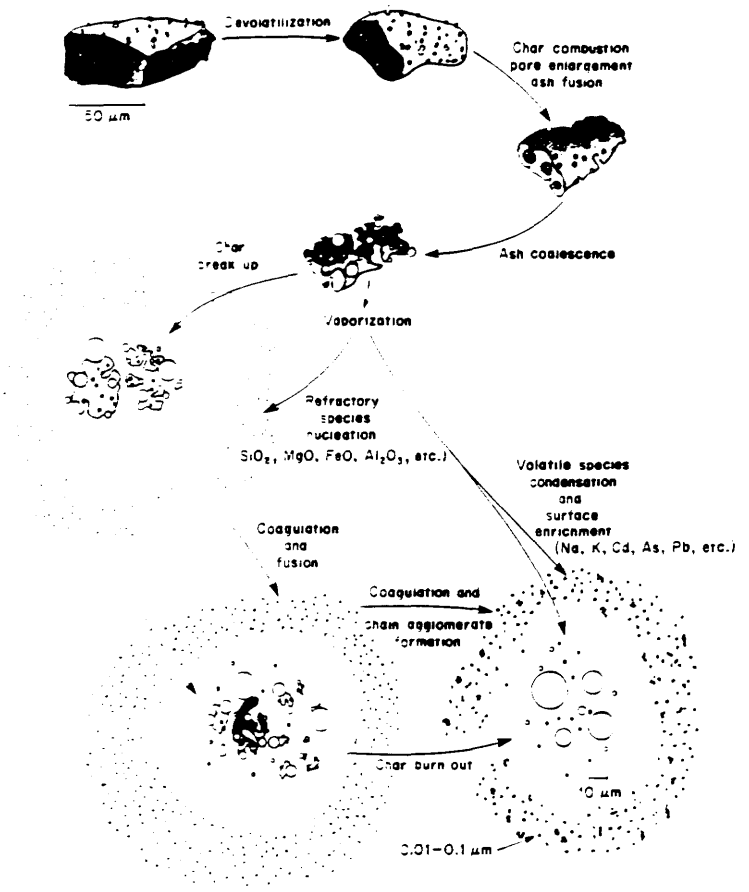

Figure 3. Ash particle formation (Flagan and Seinfeld, 1988, Figure 6.4).

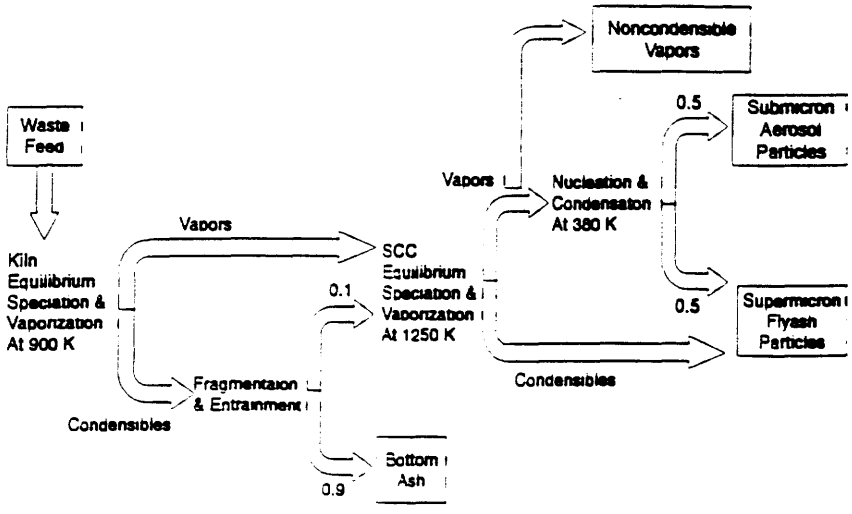

Figure 4. Procedure for Estimating Combustion-generated Particle Fractions.

Calculations of the partitioning of metals and radionuclides between bottom ash, supermicron flyash, and submicron condensation aerosol particles are based on equilibrium speciation and vaporization simulations and the simplifying assumptions concerning subsequent particle inception and growth processes just described. The calculation procedure is depicted in Figure 4. The submicron particle size mode consists of particles ranging from 0.01 to 1 μm; the supermicron mode consists of particles in the range of 1 to 20 μm. These results are used as inputs for the calculation of particle removal by the air pollution control devices (Section 6).

The National Aeronautics and Space Administration (NASA) computer code for the calculation of complex chemical equilibrium, CET89, is used to estimate inorganic element speciation and vaporization (Gordon and McBride, 1976). Baseline conditions and ranges are listed in Table 7. The baseline condition is defined to consist of a total fuel and waste composition of 79% carbon (by mass), 9% hydrogen, 6% water, 1% chlorine, and 5% inorganic matter (including metals and trace radionuclides). These numbers are taken directly from Tables 3, 4, and 5; these values are varied over four orders of magnitude to assess sensitivity. The limitations of this approach include the following:

1. Equilibrium - In many instances, such as in the formation of metal chlorides, kinetic effects may be important and limit the formation of thermodynamically-favored species.

2. Elements - An existing NASA data set is used that contains chemical species containing all of the elements listed in Tables 3, 4, and 5 except the radioisotopes of cobalt (Co), yttrium (Y), ruthenium (Ru), rhodium (Rh), cerium (Ce), praseodymium (Pr), and promethium (Pm). Estimates of the emission of these radionuclides are described in Section 7.

3. Species - The list of chemical species containing a particular element may not be complete for the conditions being studied. A list of species considered in this analysis is given in Table 8.

4. Data - The thermodynamic data provided is often taken from low temperature measurements and extrapolated to high temperatures characteristic of combustion environments.

5. Temperature and Concentrations - Each simulation is run at a single temperature and set of elemental concentrations. In actuality, a waste may experience a range of temperatures depending on its trajectory through the combustor. Wastes will vary in composition as well. Not all of the inorganics will be mixed intimately.

Table 7. Input Conditions for Equilibrium Analysis.

	Baseline Condition	Range
temperature		
kiln solids	900 K	700 - 1100 K
SCC gases	1250 K	1100 - 1500 K
excess air (molar)		
kiln	100%	50 - 150%
SCC	80%	50 - 150%
fuel (mass fraction)		
C	0.79	0.70 - 0.84
H	0.09	0.06 - 0.15
H_2O	0.06	0.02 - 0.10
Cl	0.01	0 - 0.02
ash		
Al_2O_3	0.01165	0 - 0.02
SiO_2	0.01165	0 - 0.02
SO_3	0.01165	0 - 0.02
Fe_2O_3	0.01165	0 - 0.02
metals		
Cr	3.8e-4	3.8e-7 - 3.8e-3
Ni	4.3e-4	4.3e-7 - 4.3e-3
As	8.9e-8	8.9e-11 - 8.9e-7
Ag	1.1e-4	1.1e-7 - 1.1e-3
Cd	2.9e-6	2.9e-9 - 2.9e-5
Sb	1.8e-6	1.8e-9 - 1.8e-5
Ba	9.4e-4	9.4e-7 - 9.4e-3
Hg	5.1e-5	5.1e-8 - 5.1e-4
Tl	1.8e-6	1.8e-9 - 1.8e-5
Pb	1.5e-3	1.5e-6 - 1.5e-2
radionuclides		
H-3	1.5e-11	1.5e-14 - 1.5e-10
Cr-51	7.5e-13	7.5e-16 - 7.5e-12
Sr-89	9.5e-14	9.5e-17 - 9.5e-13
Sr-90	7.4e-10	7.4e-13 - 7.4e-9
Zr-95	1.5e-13	1.5e-16 - 1.5e-12
Nb-95	2.0e-13	2.0e-16 - 2.0e-12
Cs-137	1.3e-11	1.3e-14 - 1.3e-10
Ba-137m	2.1e-18	2.1e-21 - 2.1e-17

Table 8. Metal Species Considered in Equilibrium Analysis.

Element	Species
Cr	Cr,CrCl,$CrCl_2$,CrOCl,$CrCl_3$,$CrOCl_2$,$CrCl_4$,CrO_2Cl,$CrOCl_3$,$CrCl_5$,CrO_2Cl_2,$CrOCl_4$,$CrCl_6$, CrN,CrO,CrOH,CrO_2,CrOOH,$Cr(OH)_2$,CrO_3,$CrO_2(OH)$,$Cr(OH)_3$,$CrO(OH)_2$,$CrO_2(OH)_2$, $Cr(OH)_4$,$CrO(OH)_4$,$Cr(OH)_5$,$Cr(OH)_6$,Cr(S),Cr(L),$CrAsO_4$(S),$Cr_3(AsO_4)_2$(S),CrS_2(S), Cr_7C_3(S),$Cr_{23}C_6$(S),$Cr(CO)_6$(S),$CrCl_2$(S),$CrCl_3$(S),Cr_2FeO_4(S),CrN(S),Cr_2N(S),Cr_2NiO_4(S), CrO_2(S),CrO_3(S),CrO_3(L),Cr_2O_3(S),Cr_2O_3(L),CrS(S),$Cr_2(SO_4)_3$(S),CrSi(S),$CrSi_2$(S), Cr_3Si(S),Cr_5Si_3(S),$BaCrO_4$(S),$NiCr_2O_4$(S)
Ni	Ni,NiCl,$NiCl_2$,NiO,NiO_2H_2,NiS,Ni(S),Ni(L),$NiAl_2O_4$(S),NiAs(S),$NiCl_2$(S),$NiCr_2O_4$(S), $NiFe_2O_4$(S),NiO(S),NiS(S),NiS(L),$NiSO_4$(S),NiS_2(S),NiS_2(L),NiSb(S),NiSi(S),NiSi(L), Ni_2SiO_4(S),$Ni_3(AsO_4)_2$(S),Ni_3S_2(S),Ni_3S_2(L),Ni_3S_4(S),Ni_5As_2(S),Ni_7Si_{13}(S),$Ni_{11}As_8$(S)
As	As,As_2,As_3,As_4,$AsCl_3$,AsH,AsO,As_4O_6,AsS,As_4S_4,As(S),$AsCl_3$(L),As_2O_3(S),As_2O_3(L), As_2O_5(S),As_2S_2(S),As_2S_2(L),As_2S_3(S),As_2S_3(L),As_4S_4(S),As_4S_4(L),$Ba_3(AsO_4)_2$(S), Cd_3As_2(S),$Cd_3(AsO_4)_2$(S),$TlAsO_4$(S),Ag_3AsO_4(S),NiAs(S),$Ni_3(AsO_4)_2$(S),Ni_5As_2(S), $Ni_{11}As_8$(S),$Sr_3(AsO_4)_2$(S)
Sr	Sr,SrCl,$SrCl_2$,SrO,SrOH,SrO_2H_2,SrS,Sr(S),Sr(L),$SrAl_2O_4$(S),$SrCl_2$(S),$SrCl_2$(L),SrC_2(S), $SrCO_3$(S),SrH_2(S),Sr_3N_2(S),SrO(S),SrO(L),SrO_2(S),SrO_2H_2(S),SrO_2H_2(L),SrS(S), $SrSO_4$(S),$SrSiO_3$(S),Sr_2SiO_4(S),$Sr_3(AsO_4)_2$(S)
Zr	Zr,ZrN,ZrO,ZrO_2,Zr(S),Zr(L),ZrN(S),ZrO_2(S),ZrO_2(L)
Nb	Nb,NbO,NbO_2,Nb(S),Nb(L),NbO(S),NbO(L),NbO_2(S),NbO_2(L),Nb_2O_5(S),Nb_2O_5(L)
Ag	Ag,AgCl,Ag(S),Ag(L),AgCl(S),AgCl(L),Ag_3AsO_4(S)
Cd	Cd,CdO,CdS,Cd(S),Cd(L),Cd_3As_2(S),$Cd_3(AsO_4)_2$(S),$CdCO_3$(S),$CdCl_2$(S),$CdCl_2$(L), CdO(S),$CdAl_2O_4$(S),$Cd(OH)_2$(S),$CdSiO_3$(S),CdS(S),$CdSO_4$(S),CdSb(S),CdSb(L)
Sb	Sb,Sb_2,Sb_4,SbCl,$SbCl_3$,$SbCl_5$,SbH_3,SbO,Sb_4O_6,SbS,Sb_2S_3,Sb_2S_4,Sb_3S_2,Sb_4S_3,Sb(S), Sb(L),$SbCl_3$(S),$SbCl_3$(L),Sb_2O_3(S),Sb_2O_3(L),Sb_2O_4(S),Sb_2O_5(S),SbOCl(S),Sb_2S_3(S), Sb_2S_3(L),$Sb_2(SO_4)_3$(S),AlSb(S),AlSb(L),CdSb(S),CdSb(L),NiSb(S)
Cs	Cs,CsCl,CsO,CsOH,Cs_2,Cs_2Cl_2,Cs_2O,$Cs_2O_2H_2$,Cs_2SO_4,Cs(S),Cs(L),CsCl(S),CsCl(L), CsOH(S),CsOH(L),Cs_2SO_4(S),Cs_2SO_4(L)
Ba	Ba,BaCl,$BaCl_2$,BaOH,BaO_2H_2,BaS,Ba(S),Ba(L),$BaAl_2O_4$(S),$BaCl_2$(S),$BaCl_2$(L),$BaCrO_4$(S), BaO(S),BaO(L),BaO_2H_2(S),BaO_2H_2(L),BaS(S),$BaSO_4$(S),$BaSiO_3$(S),$BaSi_2O_5$(S), Ba_2SiO_4(S),$Ba_2Si_3O_8$(S),$Ba_3Al_2O_6$(S),$Ba_3(AsO_4)_2$(S)
Hg	Hg,HgCl,$HgCl_2$,HgO,HgS,Hg(L),HgO(S)
Tl	Tl,TlCl,Tl_2Cl_2,Tl_2O,Tl(S),Tl(L),$TlAsO_4$(S),TlCl(S),TlCl(L),$TlCl_3$(S),Tl_2O(S),Tl_2O(L), Tl_2O_3(S),Tl_2S(S),Tl_2S(L),Tl_2SO_4(S),Tl_2SO_4(L)
Pb	Pb,PbCl,$PbCl_2$,$PbCl_4$,PbO,PbS,Pb_2,Pb(S),Pb(L),$PbCl_2$(S),$PbCl_2$(L),PbO(S),PbO(L), PbO_2(S),PbS(S),PbS(L),$PbSO_4$(S),$PbSO_4$(L),Pb_3O_4(S)

Despite these limitations, this analysis provides the basis for a more realistic estimate of CIF emissions than calculations based on allowable emissions. In general, these equilibrium simulations provide the basis for a conservative estimate of CIF emissions because kinetic effects will tend to reduce the amount of metal in the vapor phase (since the metals are introduced in condensed phases) and, hence, improve metal collection efficiencies.

Metal Speciation, Vaporization, and Partitioning

Results of the equilbrium simulations are summarized in Tables 9 and 10. Four cases are tabulated: baseline, baseline with chlorine removed, baseline with chlorine and ash removed, and baseline with chlorine, ash, and all but one metal removed. In Table 9, metal partitioning between gas and condensed phases at 900 K is shown. Under the baseline condition, silver, antimony, cesium, mercury, thallium, and lead are volatile, chromium and arsenic are semivolatile, and nickel, strontium, zirconium, niobium, cadmium, and barium are nonvolatile. When chlorine is removed from the system, several metals become less volatile, most notably silver, thallium, and lead. This is because the predominant form of each of these metals is the chloride: AgCl, TlCl, and $PbCl_4$ (predominant gas and condensed phase species given in {} in the table). The same phenomenon is observed in Table 10 where a volatile temperature, defined as the temperature at which the metal is distributed equally between gas and condensed phases, is shown. The volatility temperature of many metals, particularly silver, thallium, and lead, increases when chlorine is removed from the system. When ash is removed as well, several metals become more volatile, as evidenced by an increased gas phase fraction (Table 9) and a decreased volatility temperature (Table 10). Increased volatility of strontium, cadmium, barium, thallium, and lead is due to the sulfate (sulfur is present in the ash) being less volatile than the oxide.

A metal can combine not only with ash minerals resulting in decreased volatility, but with other metals as well. This is seen in the case of arsenic. In the presence of cadmium, silver, or barium, metal arsenates are formed that are much less volatile than arsonenic oxide (AsO). Thus, arsenic is not very volatile at 900 K in the presence of other metals but is volatile by itself. Equilibrium results involving interactions between metals present in trace amounts should be interpretted with caution, however, as these effects may be overestimated. It is likely that this chemistry is kinetically limited due to the lack of atomic dispersion of the metals. On the other hand, contact between metals introduced as solids does increase as the solids migrate down the kiln due the shrinking mass of solids.

The effect of the presence of chlorine on metal vaporization may be overestimated as well due to kinetic effects. Most of the chlorine present in the waste will be volatilized as HCl quickly, leaving only small amounts available in the solid phase for interaction with condensed metals. Thus, the equilibrium approach is

conservative in that it predicts a maximum enhancement of vaporization by chlorine, and, hence, a maximum emission.

Table 9. Partitioning of Metals Between Gas and Condensed Phases at 900 K.

Element	Phase	Baseline	No chlorine	No ash and chlorine	No other metals, ash, and chlorine
Cr	g c	0.0164 {$CrO_2(OH)_2$} 0.9836 {Cr_2O_3}	0.0164 {$CrO_2(OH)_2$} 0.9836 {Cr_2O_3}	0.010 {$CrO_2(OH)_2$} 0.990 {$BaCrO_4$, $NiCr_2O_4$}	0.0164 {$CrO_2(OH)_2$} 0.9836 {Cr_2O_3}
Ni	g c	1.2e-5 {$NiCl_2$} 1.000 {$NiFe_2O_4$}	3.3e-8 {NiO_2H_2} 1.000 {$NiFe_2O_4$}	4.9e-7 {NiO_2H_2} 1.000 {NiO}	4.9e-7 {NiO_2H_2} 1.000 {NiO}
As	g c	0.161 {AsO} 0.839 {$Cd_3(AsO_4)_2$}	0.00051 {AsO} 0.99949 {Ag_3AsO_4}	3.0e-5 {AsO} 1.000 {$Cd_3(AsO_4)_2$}	1.000 {AsO} 0.000
Sr	g c	2.2e-7 {$SrCl_2$} 1.000 {$SrSO_4$}	2.0e-13 {SrO_2H_2} 1.000 {$SrSO_4$}	2.4e-8 {SrO_2H_2} 1.000 {$Sr_3(AsO_4)_2$}	1.5e-8 {SrO_2H_2} 1.000 {$SrCO_3$}
Zr	g c	2.0e-20 {ZrO_2} 1.000 {ZrO_2}	2.0e-20 {ZrO_2} 1.000 {ZrO_2}	2.0e-20 {ZrO_2} 1.000 {ZrO_2}	2.0e-20 {ZrO_2} 1.000 {ZrO_2}
Nb	g c	7.7e-16 {NbO_2} 1.000 {Nb_2O_5}	7.7e-16 {NbO_2} 1.000 {Nb_2O_5}	7.7e-16 {NbO_2} 1.000 {Nb_2O_5}	7.7e-16 {NbO_2} 1.000 {Nb_2O_5}
Ag	g c	1.000 {AgCl} 0.000	0.00012 {Ag} 0.99988 {Ag}	0.00012 {Ag} 0.99988 {Ag}	0.00012 {Ag} 0.99988 {Ag}
Cd	g c	1.3e-5 {Cd,CdO} 1.000 {$CdSO_4$}	1.3e-5 {Cd,CdO} 1.000 {$CdSO_4$}	0.0038 {Cd,CdO} 0.9962 {CdO}	0.0038 {Cd,CdO} 0.9962 {CdO}
Sb	g c	1.000 {SbO} 0.000	1.000 {SbO} 0.000	1.000 {SbO} 0.000	1.000 {SbO} 0.000
Cs	g c	1.000 {CsCl} 0.000	1.000 {CsOH} 0.000	1.000 {CsOH} 0.000	1.000 {CsOH} 0.000
Ba	g c	1.4e-14 {$BaCl_2$} 1.000 {$BaSO_4$}	2.9e-20 {BaO_2H_2} 1.000 {$BaSO_4$}	3.2e-16 {BaO_2H_2} 1.000 {$BaCrO_4$}	0.00021 {BaO_2H_2} 0.99979 {BaO_2H_2}
Hg	g c	1.000 {$HgCl_2$,Hg} 0.000	1.000 {Hg,HgO} 0.000	1.000 {Hg,HgO} 0.000	1.000 {Hg,HgO} 0.000
Tl	g c	1.000 {TlCl} 0.000	0.0058 {Tl_2O,Tl} 0.9942 {Tl_2SO_4}	1.000 {Tl_2O,Tl} 0.000	1.000 {Tl_2O,Tl} 0.000
Pb	g c	1.000 {$PbCl_4$} 0.000	1.6e-8 {PbO} 1.000 {$PbSO_4$}	0.00083 {PbO} 0.99917 {PbO}	0.00083 {PbO} 0.99917 {PbO}

Table 10. Volatility Temperature[a] of Metals.

Metal	Baseline	No chlorine	No ash and chlorine	No other metals, ash, and chlorine
Cr	1450 K {g:$CrO_2(OH)_2$;c:Cr_2FeO_4}	1450 K {g:$CrO_2(OH)_2$;c:Cr_2FeO_4}	1500 K {g:$CrO_2(OH)_2$;c:$NiCr_2O_4$}	1450 K {g:$CrO_2(OH)_2$;c:Cr_2O_3}
Ni	1500 K {g:NiO_2H_2;c:$NiFe_2O_4$}	1500 K {g:NiO_2H_2;c:$NiFe_2O_4$}	1700 K {g:NiO_2H_2;c:$NiCr_2O_4$}	1700 K {g:NiO_2H_2;c:NiO}
As	900 K {g:AsO;c:$Cd_3(AsO_4)_2$}	950 K {g:AsO;c:Ag_3AsO_4}	1550 K {g:AsO;c:$Ba_3(AsO_4)_2$}	650 K {g:As_4O_6,AsO;c:As_2O_5}
Sr	1150 K {g:$SrCl_2$;c:$SrSO_4$}	1300 K {g:SrO_2H_2;c:$SrSO_4$}	1050 K {g:SrO_2H_2;c:$Sr_3(AsO_4)_2$}	1050 K {g:SrO_2H_2;c:$SrCO_3$}
Zr	1550 K {g:ZrO_2;c:ZrO_2}	1550 K {g:ZrO_2;c:ZrO_2}	1550 K {g:ZrO_2;c:ZrO_2}	1550 K {g:ZrO_2;c:ZrO_2}
Nb	1350 K {g:NbO_2;c:Nb_2O_5}	1350 K {g:NbO_2;c:Nb_2O_5}	1350 K {g:NbO_2;c:Nb_2O_5}	1350 K {g:NbO_2;c:Nb_2O_5}
Ag	750 K {g:AgCl;c:AgCl}	1150 K {g:Ag;c:Ag}	1150 K {g:Ag;c:Ag}	1150 K {g:Ag;c:Ag}
Cd	1050 K {g:Cd,CdO;c:$CdSiO_3$}	1050 K {g:Cd,CdO;c:$CdSiO_3$}	1000 K {g:Cd,CdO;c:CdO}	1000 K {g:Cd,CdO;c:CdO}
Sb	800 K {g:SbO,$SbCl_3$;c:Sb_2O_4}	850 K {g:SbO;c:Sb_2O_4}	850 K {g:SbO;c:Sb_2O_4}	850 K {g:SbO;c:Sb_2O_4}
Cs	500 K {g:Cs_2Cl_2;c:CsCl}	750 K {g:Cs_2SO_4;c:Cs_2SO_4}	< 400 K {g:CsOH}	< 400 K {g:CsOH}
Ba	1500 K {g:$BaCl_2$;c:$BaSi_2O_5$}	1600 K {g:BaO_2H_2;c:$BaSO_4$}	1250 K {g:BaO_2H_2;c:BaO}	1250 K {g:BaO_2H_2;c:BaO}
Hg	< 400 K {g:$HgCl_2$}	450 K {g:Hg,HgO;c:HgO}	450 K {g:Hg,HgO;c:HgO}	450 K {g:Hg,HgO;c:HgO}
Tl	550 K {g:TlCl;c:$TlAsO_4$}	950 K {g:Tl_2O,Tl;c:Tl_2SO_4}	850 K {g:Tl_2O,Tl;c:Tl_2O_3}	850 K {g:Tl_2O,Tl;c:Tl_2O_3}
Pb	< 400 K {g:$PbCl_4$}	1100 K {g:PbO;c:$PbSO_4$}	1050 K {g:PbO;c:PbO}	1050 K {g:PbO;c:PbO}

[a] Temperature at which the metal is distributed equally between gas and condensed phases.

Combining the results of the equilibrium simulations at 900 K for the kiln solids and 1250 K for the peak gas and flyash temperature (in the SCC) with the partition coefficients shown in Figure 4, the metal fractions in bottom ash, supermicron flyash, and submicron aerosol particles are calculated. Results are given in Table 11 for the baseline condition. These results indicate that nickel, zirconium, niobium, and barium particles are least volatile (and, therefore, easiest to capture); chromium, arsenic, strontium, and cadmium have intermediate volatility; and silver, antimony, cesium, mercury, thallium, and lead are most volatile. If chlorides are not formed, then the volatility of silver, thalium, and lead are reduced, and those metals would be catagorized as semivolatile instead of volatile.

Table 11 also shows estimates of partition coefficients for radionuclides in the CIF wastes for which no thermodynamic data are available at this time. All of these elements (cobalt, yttrium, ruthenium, rhodium, cerium, praseodymium, promethium, and plutonium), which include several rare earth metals, have high boiling points in their pure metal form (given in parentheses in the table). While in the complex system of the CIF wastes there are many chemical species that need to be considered (e.g., oxides, chlorides, sulfates, silicates), there appears to be a weak correlation between pure metal boiling point and CIF waste metal volatility. Consideration of the chlorides shows that cobalt and rhodium may be semivolatile (the boiling point of $CoCl_2$ is 1049°C, and $RhCl_3$ sublimates at 800°C), whereas chlorides of yttrium (YCl_3, 1507°C), praseodymium ($PrCl_2$, 1700°C), and cerium ($CeCl_3$, 1727°C) boil at temperatures far in above the SCC peak temperature (1000°C). To be conservative, cobalt and rhodium are classified as semivolatile (assuming that the chlorides are the predominant species) in this analysis.

The results given in Table 11 describe the partitioning of metals between the supermicron flyash and submicron aerosol entering the pollution control devices.

Table 11. Metal Partitioning in Combustion System.[a]

Metal (boiling point)	Bottom Ash (percent of input)	Supermicron Flyash (percent of input)	Submicron Aerosol (percent of input)
Calculated results			
Cr (2672°C)	88.5	10.5	1.0
Ni (2730°C)	90	10	0.0056
As (613°C)	75.6	12.2	12.2
Sr (1384°C)	90	5	5.0
Zr (4377°C)	90	10	0.00000095
Nb (2468°C)	90	10	0.0033
Ag (2212°C)	0	50	50
Cd (765°C)	90	5	5.0
Sb (1750°C)	0	50	50
Cs (669°C)	0	50	50
Ba (1640°C)	90	10	0.000075
Hg(356.6°C)	0	50	50
Tl (1457°C)	0	50	50
Pb (1740°C)	0	50	50
Estimated results			
Co (2870°C)	90	5	5
Y (3338°C)	90	9.995	0.005
Ru (3900°C)	90	9.995	0.005
Rh (3727°C)	90	5	5
Ce (3426°C)	90	9.995	0.005
Pr (3512°C)	90	9.995	0.005
Pm (2700°C)	90	9.995	0.005
Pu (3232°C)	90	9.995	0.005

[a] Spreadsheet calculations shown in Appendix, Table A-4.

Sensitivity Analysis

Metal speciation and volatility are most dependent on temperature, chlorine content, and coexisting mineral ash and metals. Examples of these dependencies are shown in Figures 5, 6, and 7, respectively. In Figure 5, the gas phase fraction of four metals, antimony, chromium, cadmium, and nickel, are shown as a function of temperature for the baseline composition. Vapor pressures have exponential forms with temperature (e.g., Claussius-Clapeyron equation), and, thus, volatility increases rapidly with temperature up to the boiling point. The results in Figure 5 are shown over ten orders of magnitude of concentrations. Antimony vaporization is driven by the stability of Sb_2O_4(solid), which is mostly decomposed at 800 K. The gas phase concentration of chromium slowly increases with temperature, due in part to the large number of chromium species that are important at these temperatures. Cadmium vaporization is governed by the vapor pressures of the pure metal (Cd) and the oxide (CdO). Nickel is largely nonvolatile, although the chloride ($NiCl_2$) is several orders of magnitude more volatile than the hydroxide (NiO_2H_2).

Study of the results of equilibrium simulations shown in Tables 9 and 10 shows that chlorine has the largest effect on the volatility of silver, thallium, and lead, some effect on the volatility of nickel, strontium, antimony, cesium, barium, and mercury, and no effect on the volatility of chromium, zirconium, niobium, and cadmium. Arsenic exhibits an indirect effect of the presence of chlorine. When chlorine is present, condensed phase arsenic is found mostly in the form of cadmium arsenate ($Cd_3(AsO_4)_2$) at 900 K; silver is found almost entirely as the chloride (AgCl). Without chlorine, the silver is free to combine with arsenic to form condensed phase silver arsenate (Ag_3AsO_4). In Figure 6, the effect of chlorine content (relative to the baseline concentration of one percent by mass) on the gas phase concentrations of thallium, silver, and lead, the metals most affected by chlorine, at 900 K are shown. The different levels of reduced chlorine content required to reduce metal volatility simply reflect the different concentrations of these metals in the waste; lead is present in greatest abundance, followed by silver, then thallium. Under thermodynamic control, where mixing is not an issue, the chlorine level has to be reduced to very low levels to avoid chloride formation. In actual practice, mixing limitations would make reduced chlorine content more effective at higher levels.

Figure 7 shows the effect of the presence of sulfur (a component of the ash) and arsenic on reducing strontium vapor fraction at 900 K. If both are present, reducing sulfur reduces the formation of strontium sulfate ($SrSO_4$) and increases the vapor fraction (as $SrCl_2$) until strontium arsenate solid ($Sr_3(AsO_4)_2$) becomes the dominant species (when the gas phase fraction is about 0.1 percent). Without arsenic, reducing sulfur increases the vapor fraction to about two percent, at which level strontium carbonate solid ($SrCO_3$) has become the dominant species.

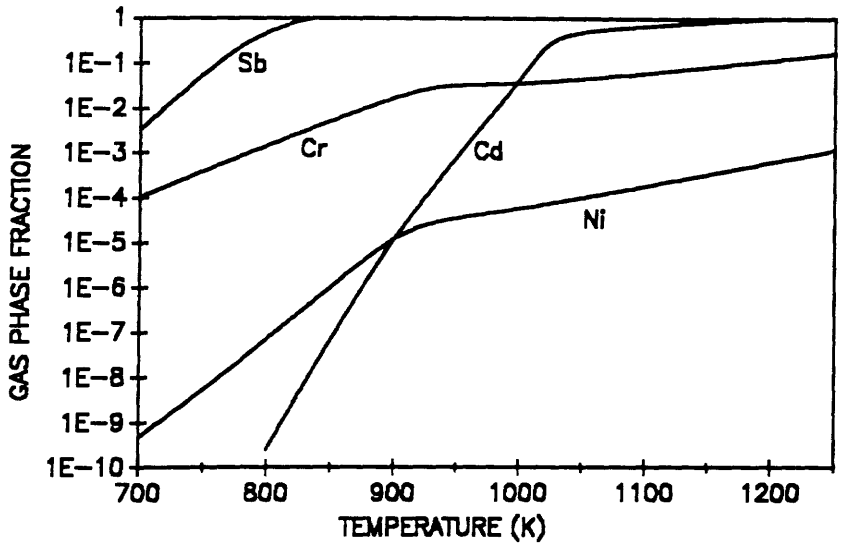

Figure 5. Volatility of four metals as a function of temperature for the baseline composition.

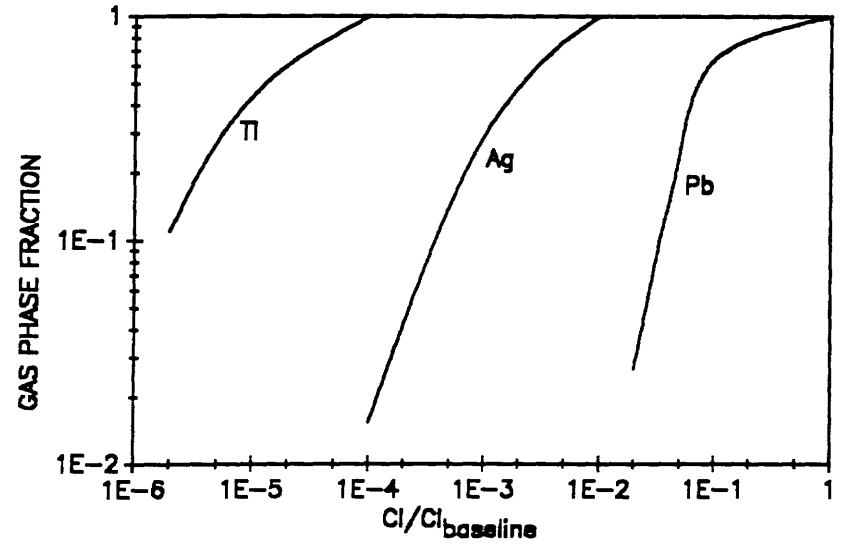

Figure 6. Volatility of three metals as a function of chlorine content for the baseline composition at 900 K.

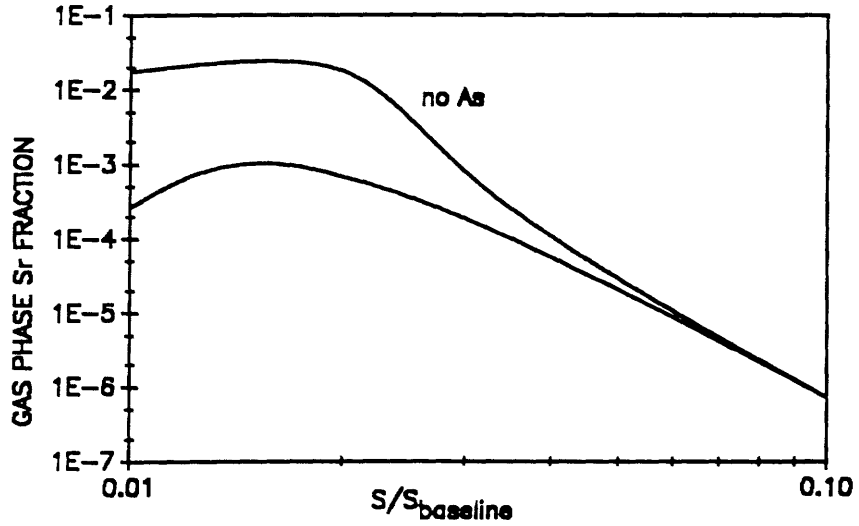

Figure 7. Volatility of strontium for the baseline composition at 900 K.

These results demonstrate that, in general, increasing temperature and increasing chlorine content each increases metal vaporization, and that increasing the number and amounts of minerals and metals tends to reduce metal vaporization. Exceptions to these generalities can be found, particularly in chemically complex systems.

Metal speciation and volatility are also dependent on carbon content, hydrogen content, excess air level, and metal concentration. Sensitivities of metal volatility at 900 K to these parameters are tabulated in Table 12 for all of the metals in the thermodynamic analysis and shown graphically in Figures 8, 9, and 10 for chromium and arsenic. Metals that are completely volatilized under baseline conditions (Ag, Sb, Cs, Hg, Tl, and Pb) are unaffected by changes in carbon content, hydrogen content, and excess air level. Partially vaporized metals are weakly affected these three parameters. Positive numbers in Table 12 indicate that metal volatility increases with increasing carbon content; negative numbers indicate a decrease in metal volatility with increasing carbon content. Changes in carbon content include changes in hydrogen content since the H/C ratio was held constant. For carbon contents ranging from 0.7 to 0.84, metal volatility changes by no more than 13%. For H/C ratios between 1 and 2 and excess air levels ranging from 50 to 150%, metal volatilities changed by no more than 75%. These are small changes compared with the order of magnitude changes of volatility with temperature and, in some cases, chlorine and ash content.

Metal concentrations in the wastes do, of course, affect metal vaporization significantly. The far right column of Table 12 gives the ratio of the mass of metal vaporized at a specified metal content of the waste (ranging from 0.001 of the baseline value to 10 times the baseline value) to the mass of metal vaporized for the baseline condition. Three types of behavior are encountered. Volatile metals that are completely vaporized at 900 K over four orders of magnitude in concentration are Ag, Sb, Cs, Hg, and Tl. Their mass vaporized is equal to the mass input. At the other extreme, nonvolatile metals are those for which the amount of vaporized metal is constant (at the gas saturation level). In this case, the amount of metal vapor does not change as more metal is input with the waste. These metals are Sr, Zr, Nb, and Ba. The remaining metals, Cr, Ni, As, Cd, and Pb, are semivolatile at 900 K over the range of concentrations considered.

Table 12. Sensitivity of Metal Vapor Fraction to Feed Stream Parameters at 900 K.

Metal	Carbon Content (0.7 - 0.84)[a]	H/C (1 - 2)[b]	Excess Air (50 - 150%)[c]	Metal Concentration (0.001 - 10)[d]
Cr	- 2.5%	45%	46%	0.06 - 1
Ni	- 13%	- 73%	0.16%	1 - 1.6
As	10%	11%	- 53%	0.006 - 1
Sr	- 10%	- 64%	42%	1 - 1
Zr	- 0.35%	2.3%	54%	1 - 1
Nb	5.1%	8.3%	37%	1 - 1
Ag	0%	0%	0%	0.001 - 10
Cd	12%	18%	71%	0.8 - 1
Sb	0%	0%	0%	0.001 - 10
Cs	0%	0%	0%	0.001 - 10
Ba	- 11%	- 64%	43%	1 - 1
Hg	0%	0%	0%	0.001 - 10
Tl	0%	0%	0%	0.001 - 10
Pb	0%	0%	0%	0.001 - 9

[a] Percent change in metal vapor fraction for variation in carbon mass fraction from 0.7 to 0.84 (baseline = 0.79).
[b] Percent change in metal vapor fraction for variation in H/C molar ratio from 1 to 2 (baseline = 1.5).
[c] Percent change in metal vapor fraction for variation in excess air from 50% to 150% (baseline = 100%).
[d] Mass of metal vaporized (relative to baseline) for metal concentrations a factor of 0.001 to 10 times the baseline value.

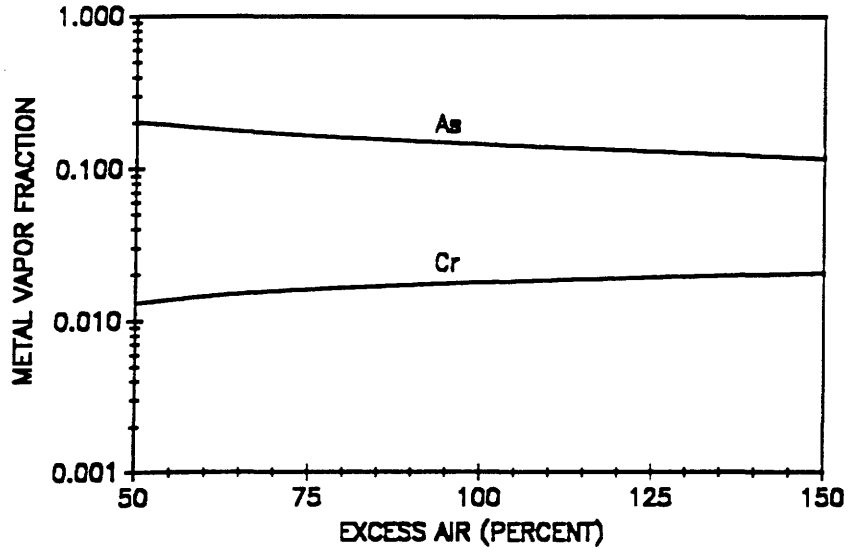

Figure 8. Volatility of chromium and arsenic as a function of excess air level.

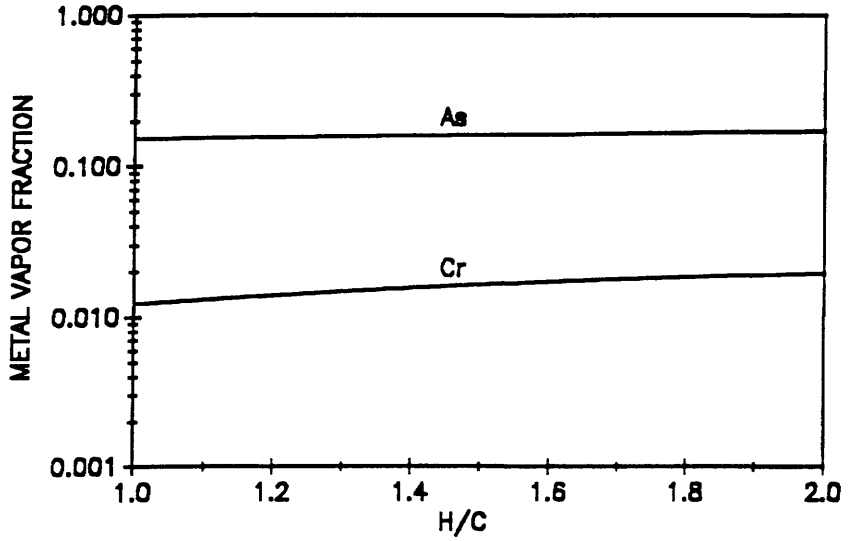

Figure 9. Volatility of chromium and arsenic at 900 K as a function of H/C molar ratio.

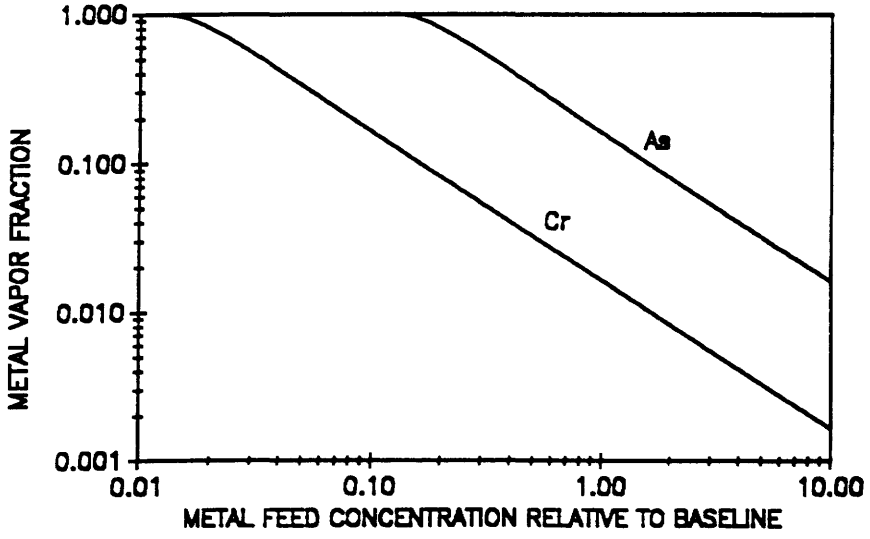

Figure 10. Volatility of chromium and arsenic at 900 K as a function of metal feed concentration.

6. AIR POLLUTION CONTROL SYSTEM CHARACTERIZATION

Having estimated the emissions from the combustion system as a bimodal distribution of supermicron flyash (1 to 20 μm) and submicron aerosol particles (0.01 to 1 μm), an estimate of air pollution control device collection efficiency as a function of particle size is needed. In this analysis, two efficiencies are used for each control device to characterize the collection of the two particle size classes. This approach is summarized in Figure 11.

Quench Vessel

The quench vessel is a spray chamber whose function is to quickly lower the combustion gas temperature and remove large particles and soluble acid gases. A theoretical analysis of a spray chamber shows the dependence of collection efficiency on particle size. A summary of this analysis is provided in Appendix B. Based on this analysis, a collection efficiency of 50 percent for the supermicron flyash particles is assumed, and a 0 percent collection efficiency is assumed for the submicron aerosol particles.

Scrubber/Cyclone/Demister

The Hydro-Sonic Scrubber operates like a highly efficient venturi scrubber. A theoretical analysis of a venturi scrubber is provided in Appendix C to show the dependence of collection efficiency on particle size. Based on this analysis as well as manufacturer data, it is conservatively assumed that 99 percent of the supermicron flyash particles will be captured, and 50 percent of the submicron aerosol particles. In addition, it is assumed that the demister will remove at least 10 percent of the water vapor, and thus 10 percent of the tritium (H-3).

HEPA Filters

Unlike the spray chamber and scrubber, the HEPA filters collect both supermicron particles (by interception and impaction) and submicron particles (by Brownian diffusion) with high efficiency. A theoretical analysis is provided in Appendix D to show this dependence. It is conservatively assumed that the HEPA filters remove 99.97 percent of the supermicron particles (as per the design specifications) and 99 percent of the submicron particles.

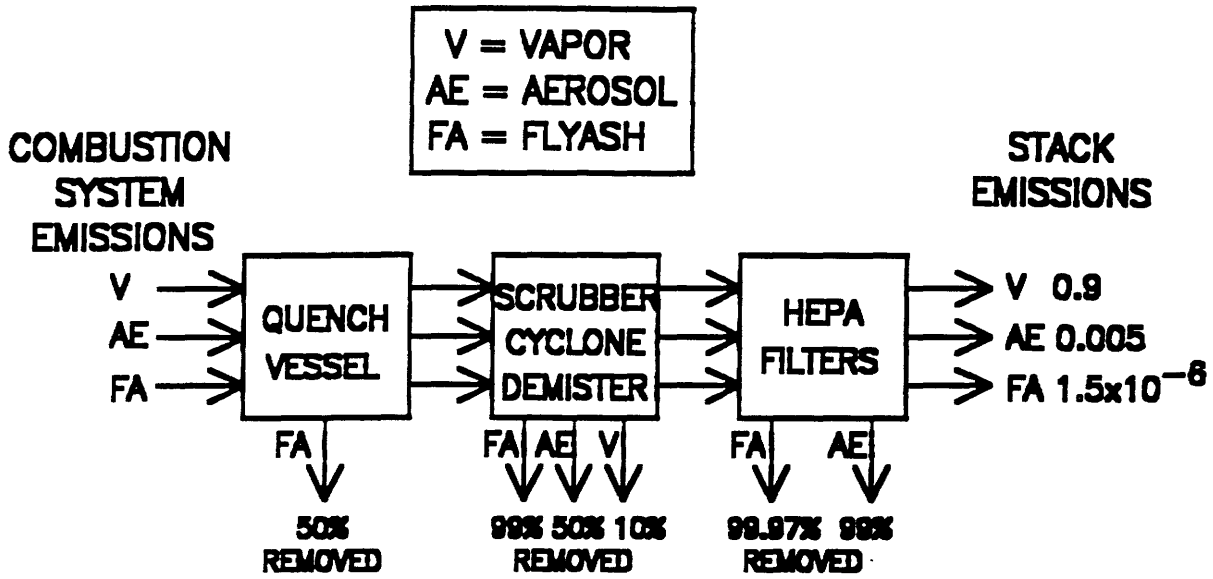

Figure 11. Air Pollution Control Device Performance.

7. STACK EMISSION ESTIMATE

Table 13 contains the results of the metal and radionuclide emission estimate, combining the combustion emission results (Table 11) with the air pollution control device performance data (Figure 8). Stack emission is given on an annual basis as well as on a fraction of waste component input (in parentheses). The inverse of the emission fraction would be the removal factor. Only 10 percent of the tritium (H-3) input is removed as it passes through the air pollution control system as water vapor. Removal factors of all other metals and radionuclides range from 400 for the most volatile species (e.g., mercury) to over 1,000,000 for nonvolatile species (e.g., barium).

Table 13. Estimated Annual Emissions of Metals and Radionuclides from CIF.

	Input	Bottom Ash Removed	Quench Vessel Removed	Scrubber/Cyclone Removed	Filter Removed	Stack Emission
toxic metals (lb/yr)[a]						
Cr	426	377	22.3	24.2	2.3	0.021 (5.0e-5)[c]
Ni	478	430	23.9	23.7	0.25	0.00020 (4.3e-7)
As	0.1	0.0756	0.0061	0.012	0.0061	0.00006 (6.1e-4)
Ag	119	0	30	59.2	29.75	0.30 (2.5e-3)
Cd	3.3	2.97	0.0825	0.164	0.0825	0.00083 (2.5e-4)
Sb	2.0	0	0.50	0.995	0.50	0.0050 (2.5e-3)
Ba	1052	947	52.6	52.1	0.526	0.00016 (1.5e-7)
Hg	57	0	14.25	28.36	14.25	0.14 (2.5e-3)
Tl	2.0	0	0.50	0.995	0.50	0.0050 (2.5e-3)
Pb	1672	0	418	832	418	4.2 (2.5e-3)
radionuclides (Ci/yr)[b]						
H-3	140	0	0	14	0	126 (0.90)
Cr-51	65	57.5	3.41	3.7	0.35	3.3e-3 (5.0e-5)
Co-60	0.58	0.522	0.0145	0.029	0.0145	1.5e-4 (2.5e-4)
Sr-89	2.61	2.35	0.065	0.13	0.065	6.5e-4 (2.5e-4)
Sr-90	96	86.4	2.4	4.8	2.4	2.4e-2 (2.5e-4)
Y-90	0.33	0.297	0.0165	0.016	0.00017	1.3e-7 (4.0e-7)
Y-91	1.96	1.764	0.098	0.097	0.00103	7.8e-7 (4.0e-7)
Zr-95	2.99	2.691	0.15	0.148	0.0015	4.5e-7 (1.5e-7)
Nb-95	7.55	6.795	0.38	0.374	0.0039	2.4e-6 (3.2e-7)
Ru-106	1.78	1.602	0.089	0.088	0.00093	7.1e-7 (4.0e-7)
Rh-106	1.78	1.602	0.0445	0.088	0.0445	4.5e-4 (2.5e-4)
Cs-137	1.15	0	0.2875	0.572	0.2875	2.9e-3 (2.5e-3)
Ba-137m	1.15	1.035	0.0575	0.057	0.00058	1.8e-7 (1.5e-7)
Ce-144	1.94	1.746	0.097	0.096	0.0010	7.8e-7 (4.0e-7)
Pr-144	1.94	1.746	0.097	0.096	0.0010	7.8e-7 (4.0e-7)
Pr-144m	1.94	1.746	0.097	0.096	0.0010	7.8e-7 (4.0e-7)
Pm-147	3.92	3.528	0.196	0.194	0.0021	1.6e-6 (4.0e-7)
Pu-238	0.90	0.81	0.045	0.0446	0.00047	3.6e-7 (4.0e-7)
Pu-239	4.4e-3	0.00396	0.00022	0.00022	2.3e-6	1.8e-9 (4.0e-7)

[a] Based on feed rates from Table 22 of Burns (1993); see also Table 4.
[b] Based on feed rates from the Application for EPA Approval of Construction (SRS CIF, 3/6/89); see also Table A-3, Appendix.
[c] Fraction of feed; see Table A-5.

A best and worst case scenario is assessed. The best case conditions are as follows: no metal chloride formation, low combustion temperatures (700 K for kiln solids and 1100 K in SCC), 1% kiln solids entrainment, and 25% vapor condensation to form submicron aerosol particles. The worst case conditions are as follows: no metal interactions with ash or other metals, high combustion temperatures (1100 K for kiln solids and 1500 K in SCC), 25% kiln solids entrainment, and 75% vapor condensation to form submicron aerosol particles. Estimated stack emissions differ for the best and worst cases by as much as five orders of magnitude for some metals.

Table 14. Metal and Radionuclide Stack Emissions: Best and Worst Case.

	Input	Best Case		Baseline Estimate		Worst Case	
toxic metals (lb/yr)[a]							
Cr	426	4.04e-4	(9.5e-7)[c]	2.1e-2	(5.0e-5)[c]	1.7e-1	(4.0e-4)[c]
Ni	478	7.22e-6	(1.5e-8)	2.0e-4	(4.3e-7)	5.2e-2	(1.1e-4)
As	0.1	1.25e-6	(1.3e-5)	6.1e-5	(6.1e-4)	3.8e-4	(3.8e-3)
Ag	119	1.65e-4	(1.4e-6)	3.0e-1	(2.5e-3)	4.5e-1	(3.8e-3)
Cd	3.3	4.13e-5	(1.3e-5)	8.3e-4	(2.5e-4)	1.2e-2	(3.8e-3)
Sb	2.0	2.58e-5	(1.3e-5)	5.0e-3	(2.5e-3)	7.5e-3	(3.8e-3)
Ba	1052	1.58e-5	(1.5e-8)	1.6e-4	(1.5e-7)	1.01	(9.6e-4)
Hg	57	7.13e-2	(1.3e-3)	1.4e-1	(2.5e-3)	2.1e-1	(3.8e-3)
Tl	2.0	2.50e-5	(1.3e-5)	5.0e-3	(2.5e-3)	7.5e-3	(3.8e-3)
Pb	1672	1.52e-3	(9.1e-7)	4.2	(2.5e-3)	6.27	(3.8e-3)
radionuclides (Ci/yr)[b]							
H-3	140	105	(0.75)	126	(0.90)	140	(1.0)
Cr-51	65	6.2e-5	(9.5e-7)	3.3e-3	(5.0e-5)	2.6e-2	(4.0e-4)
Co-60	0.58	7.3e-6	(1.3e-5)	1.5e-4	(2.5e-4)	2.2e-3	(3.8e-3)
Sr-89	2.61	4.0e-8	(1.5e-8)	6.5e-4	(2.5e-4)	9.8e-3	(3.8e-3)
Sr-90	96	1.5e-6	(1.5e-8)	2.4e-2	(2.5e-4)	3.6e-1	(3.8e-3)
Y-90	0.33	5.3e-9	(1.6e-8)	1.3e-7	(4.0e-7)	3.1e-4	(9.4e-4)
Y-91	1.96	3.2e-8	(1.6e-8)	7.8e-7	(4.0e-7)	1.8e-3	(9.4e-4)
Zr-95	2.99	4.5e-8	(1.5e-8)	4.5e-7	(1.5e-7)	3.0e-6	(1.0e-6)
Nb-95	7.55	1.1e-7	(1.5e-8)	2.4e-6	(3.2e-7)	7.1e-3	(9.4e-4)
Ru-106	1.78	2.8e-8	(1.6e-8)	7.1e-7	(4.0e-7)	1.7e-3	(9.4e-4)
Rh-106	1.78	2.2e-5	(1.3e-5)	4.5e-4	(2.5e-4)	6.7e-3	(3.8e-3)
Cs-137	1.15	1.4e-3	(1.3e-3)	2.9e-3	(2.5e-3)	4.3e-3	(3.8e-3)
Ba-137m	1.15	1.7e-8	(1.5e-8)	1.8e-7	(1.5e-7)	1.1e-3	(9.6e-4)
Ce-144	1.94	3.1e-8	(1.6e-8)	7.8e-7	(4.0e-7)	1.8e-3	(9.4e-4)
Pr-144	1.94	3.1e-8	(1.6e-8)	7.8e-7	(4.0e-7)	1.8e-3	(9.4e-4)
Pr-144m	1.94	3.1e-8	(1.6e-8)	7.8e-7	(4.0e-7)	1.8e-3	(9.4e-4)
Pm-147	3.92	6.4e-8	(1.6e-8)	1.6e-6	(4.0e-7)	3.7e-3	(9.4e-4)
Pu-238	0.90	1.5e-8	(1.6e-8)	3.6e-7	(4.0e-7)	8.4e-4	(9.4e-4)
Pu-239	4.4e-3	7.1e-11	(1.6e-8)	1.8e-9	(4.0e-7)	4.1e-6	(9.4e-4)

[a] Based on feed rates from Table 22 of Burns (1993); see also Table 4.
[b] Based on feed rates from the Application for EPA Approval of Construction (SRS CIF, 3/6/89); see also Table A-3, Appendix.
[c] Fraction of feed; see Tables A-5, A-6, and A-7.

8. COMPARISON WITH PREVIOUS ESTIMATES AND TEST RESULTS

Results of this estimate based on waste elemental composition data, thermodynamic calculations, and two-point air pollution control device removal efficiencies will be compared with previous estimates. Previously, a removal factor of 38,000 was used for all radionuclides except tritium. Here, factors ranging from 400 for volatile metals like mercury and cesium to 6,700,000 for nonvolatile metals like barium and zirconium were calculated.

The equilibrium metal emission calculations reported here will be compared with the experimental results from the EERC tests. The equilibrium calculations appear to be very consistent with EERC data, with the exception of antimony which is semivolatile in this analysis and nonvolatile in the EERC data. It is possible that this difference is due to an insufficient number of antimony containing species in the thermodynamic data base used for these caculations. We will look for more data for antimony speciation, as well as for radionuclides for which we currently have no data.

TO BE CONTINUED

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APPENDIX A:

SPREADSHEET CALCULATIONS

Table A-1. Spreadsheet Calculations for Waste Elemental Composition.

waste stream	solids	HHV	LHV	DWPF	total
generation(klb/yr)	1317	315	82	367	2081
Ffeed	0.632869	0.15137	0.039404	0.176358	1
	max. concentration in waste stream (uCi/lb)				
C	0.72	0.87	0	0.913846	0.748521
fixed C	0.06		0	0	0.037972
H	0.0975	0.10875	0	0.076154	0.091596
H2O	0.04	0	0.99	0	0.064325
Cl	0.01626	0.001	0	0	0.010442
ash	0.06624	0.02025	0.01	0.01	0.047144
total	1	1	1	1	1

Carbon content for solids and HHV liquids from Figure 4
Assume 6% fixed carbon and 4% moisture in solids
Assume solids contain 2% PVC (56.8% Cl in PVC) + 0.5% Cl wastes
Assume H/C (molar) 1.5 (solids and HHV liquids)
Assume LHV liquid waste is 99% water and 1% ash
Assume DWPF is 99% benzene and 1% ash

Table A-2. Spreadsheet Calculations for Radionuclide Specific Activity.

nuclide	MW (g/mol)	half-life (s)	decay constant ln(2)/half-life	specific activity, A (Ci/g)
H-3	3	3.89E+08	1.78E-09	9671.849
Cr-51	51	2394144	2.9E-07	92401.71
Co-60	60	1.66E+08	4.17E-09	1131.012
Sr-89	89	4363200	1.59E-07	29053.96
Sr-90	90	9.15E+08	7.58E-10	137.0734
Y-90	90	230400	3.01E-06	544095.9
Y-91	91	5063040	1.37E-07	24487.68
Zr-95	95	5667840	1.22E-07	20953.63
Nb-95	95	3032640	2.29E-07	39161.2
Ru-106	106	31881600	2.17E-08	3338.524
Rh-106	106	29.9	0.023182	3.56E+09
Cs-134	134	64964160	1.07E-08	1296.05
Cs-137	137	9.49E+08	7.3E-10	86.75745
Ba-137m	137	153	0.00453	5.38E+08
Ce-144	144	24572160	2.82E-08	3188.56
Pr-144	144	1036.8	0.000669	75568874
Pr-144m	144	432	0.001605	1.81E+08
Pm-147	147	82731542	8.38E-09	927.7094
U-235	235	2.22E+16	3.12E-17	2.16E-06
Pu-238	238	2.77E+09	2.51E-10	17.13244
Pu-239	239	7.6E+11	9.12E-13	0.062087

A (Ci/g) = NAv(1/mol)/MW(g/mol) * (ln(2)/half-life(s)) * (Ci/3.7E+10)

Table A-3. Spreadsheet Calculations for Maximum Radionuclide Concentrations.

waste stream	solids	tritiated oil	FMF organic	purex solvent	DWPF	total
generation(klb/yr)	1317	5.8	67.6	27.5	367	2081
Ffeed	0.632869	0.002787	0.032484	0.013215	0.176358	
	maximum concentration in waste stream, C (uCi/lb)					
	C1	C2	C3	C4	C5	Ctotal
H-3	15.7	20640				67.46223
Cr-51	49.49					31.32068
Co-60	0.44					0.278462
Sr-89	1.98					1.25308
Sr-90	73					46.19942
Y-90	0.25					0.158217
Y-91	1.49					0.942975
Zr-95	1.45			39.36		1.437794
Nb-95	4.91			39.36		3.62752
Ru-106	0.48			41.82		0.85642
Rh-106	0.48			41.82		0.85642
Cs-137	0.76			2.46	0.232	0.513489
Ba-137m	0.76			2.46	0.232	0.513489
Ce-144	0.65			39.36		0.931499
Pr-144	0.65			39.36		0.931499
Pr-144m	0.65			39.36		0.931499
Pm-147	2.98					1.885949
Pu-238	0.44			11.56		0.431225
Pu-239	0.0016		0.017	0.042		0.00212

Generation rates based on revised Table 16 of the Application for EPA Approval of Construction (SRS CIF, 3/6/89)
Total generation rate includes 296.1 klb/yr of uncontaminated wastes
Ffeed = generation rate / total generation rate
Ctotal = C1*Ffeed1+C2*Ffeed2+C3*Ffeed3+C4*Ffeed4+C5*Ffeed5

Table A-4. Spreadsheet Calculations for Combustion System Partitioning.

metal	kiln (900 K) Fvkiln	SCC (1250 K) FvSCC	bottom ash Fba	flyash (> 1 um) Ffa	aerosol (< 1 um) Fae
Cr	0.0164	0.172	0.88524	0.104891	0.009869
Ni	1.24E-05	0.00111	0.899989	0.099956	5.55E-05
As	0.16	1	0.756	0.122	0.122
Sr	2.2E-07	1	0.9	0.05	0.05
Zr	2E-20	1.9E-07	0.9	0.1	9.5E-09
Nb	7.7E-16	0.00066	0.9	0.099967	3.3E-05
Ag	1	1	0	0.5	0.5
Cd	1.3E-05	1	0.899988	0.050006	0.050006
Sb	1	1	0	0.5	0.5
Cs	1	1	0	0.5	0.5
Ba	1.4E-14	1.5E-05	0.9	0.099999	7.5E-07
Hg	1	1	0	0.5	0.5
Tl	1	1	0	0.5	0.5
Pb	1	1	0	0.5	0.5

Input Data:
Fvkiln = vapor fraction in kiln (from equilibrium code)
FvSCC = vapor fraction in SCC (from equilibrium code)

Partition Coefficients:
Ffrag = 0.1 = fraction of kiln condensed phase fragmentation
Fcond = 0.5 = fraction of vapor condensing on flyash

Formulas:
Fba = (1-Fvkiln)*(1-Ffrag)
Ffa = (1-Fba)*{(1-FvSCC)+FvSCC*Fcond}
Fae = (1-Fba)*{FvSCC*(1-Fcond)} = 1 - Fba - Ffa

Table A-5. Spreadsheet Calculations for Baseline Stack Emissions Estimate.

metal	bottom ash Fba	flyash (> 1 um) Ffa	aerosol (< 1 um) Fae	quench Fq	scrubber Fs	filter Ff	stack Fst
Cr	0.88524	0.104891	0.009869	0.052445	0.056856	0.00541	4.95E-05
Ni	0.899989	0.099956	5.55E-05	0.049978	0.049506	0.000527	4.27E-07
As	0.756	0.122	0.122	0.061	0.12139	0.061	0.00061
Sr	0.9	0.05	0.05	0.025	0.04975	0.025	0.00025
Zr	0.9	0.1	9.5E-09	0.05	0.0495	0.0005	1.5E-07
Nb	0.9	0.099967	3.3E-05	0.049984	0.0495	0.000516	3.15E-07
Ag	0	0.5	0.5	0.25	0.4975	0.249999	0.002501
Cd	0.899988	0.050006	0.050006	0.025003	0.049756	0.025003	0.00025
Sb	0	0.5	0.5	0.25	0.4975	0.249999	0.002501
Cs	0	0.5	0.5	0.25	0.4975	0.249999	0.002501
Ba	0.9	0.099999	7.5E-07	0.05	0.0495	0.0005	1.54E-07
Hg	0	0.5	0.5	0.25	0.4975	0.249999	0.002501
Tl	0	0.5	0.5	0.25	0.4975	0.249999	0.002501
Pb	0	0.5	0.5	0.25	0.4975	0.249999	0.002501
Estimated:							
Co	0.9	0.05	0.05	0.025	0.04975	0.025	0.00025
Y	0.9	0.09995	5E-05	0.049975	0.0495	0.000524	4E-07
Ru	0.9	0.09995	5E-05	0.049975	0.0495	0.000524	4E-07
Rh	0.9	0.05	0.05	0.025	0.04975	0.025	0.00025
Ce	0.9	0.09995	5E-05	0.049975	0.0495	0.000524	4E-07
Pr	0.9	0.09995	5E-05	0.049975	0.0495	0.000524	4E-07
Pm	0.9	0.09995	5E-05	0.049975	0.0495	0.000524	4E-07
Pu	0.9	0.09995	5E-05	0.049975	0.0495	0.000524	4E-07

Partition Coefficients:

Fqae =	0	= fraction of aerosol removed by quench
Fqfa =	0.5	= fraction of flyash removed by quench
Fsae =	0.5	= fraction of aerosol removed by scrubber
Fsfa =	0.99	= fraction of flyash removed by scrubber
Ffae =	0.99	= fraction of aerosol removed by filter
Fffa =	0.9997	= fraction of flyash removed by filter

Formulas:

Fq = Ffa*Fqfa+Fae*Fqae

Fs = Ffa*(1-Fqfa)*Fsfa+Fae*(1-Fqae)*Fsae

Ff =Ffa*(1-Fqfa)*(1-Fsfa)*Fffa+Fae*(1-Fqae)*(1-Fsae)*Ffae

Fst =Ffa*(1-Fqfa)*(1-Fsfa)*(1-Fffa)+Fae*(1-Fqae)*(1-Fsae)*(1-Ffae)

Table A-6. Spreadsheet Calculations for Best Case Stack Emissions Estimate.

metal	bottom ash Fba	flyash (> 1 um) Ffa	aerosol (< 1 um) Fae	quench Fq	scrubber Fs	filter Ff	stack Fst
Cr	0.989909	0.009904	0.000187	0.004952	0.004996	0.000142	9.48E-07
Ni	0.99	0.01	2.49E-08	0.005	0.00495	5E-05	1.51E-08
As	0.99	0.0075	0.0025	0.00375	0.004963	0.001275	1.25E-05
Sr	0.99	0.01	3.88E-08	0.005	0.00495	5E-05	1.52E-08
Zr	0.99	0.01	1.38E-12	0.005	0.00495	5E-05	1.5E-08
Nb	0.99	0.01	1.13E-10	0.005	0.00495	5E-05	1.5E-08
Ag	0.99	0.009726	0.000275	0.004863	0.004951	0.000184	1.39E-06
Cd	0.99	0.0075	0.0025	0.00375	0.004963	0.001275	1.25E-05
Sb	0.989714	0.007715	0.002572	0.003857	0.005104	0.001311	1.29E-05
Cs	0	0.75	0.25	0.375	0.49625	0.127499	0.001251
Ba	0.99	0.01	3E-16	0.005	0.00495	5E-05	1.5E-08
Hg	0	0.75	0.25	0.375	0.49625	0.127499	0.001251
Tl	0.99	0.0075	0.0025	0.00375	0.004963	0.001275	1.25E-05
Pb	0.99	0.009821	0.00018	0.00491	0.004951	0.000138	9.12E-07
Estimated:							
Co	0.99	0.0075	0.0025	0.00375	0.004963	0.001275	1.25E-05
Y	0.99	0.01	2.5E-07	0.005	0.00495	5.01E-05	1.62E-08
Ru	0.99	0.01	2.5E-07	0.005	0.00495	5.01E-05	1.62E-08
Rh	0.99	0.0075	0.0025	0.00375	0.004963	0.001275	1.25E-05
Ce	0.99	0.01	2.5E-07	0.005	0.00495	5.01E-05	1.62E-08
Pr	0.99	0.01	2.5E-07	0.005	0.00495	5.01E-05	1.62E-08
Pm	0.99	0.01	2.5E-07	0.005	0.00495	5.01E-05	1.62E-08
Pu	0.99	0.01	2.5E-07	0.005	0.00495	5.01E-05	1.62E-08

Partition Coefficients:

Fqae =	0	= fraction of aerosol removed by quench
Fqfa =	0.5	= fraction of flyash removed by quench
Fsae =	0.5	= fraction of aerosol removed by scrubber
Fsfa =	0.99	= fraction of flyash removed by scrubber
Ffae =	0.99	= fraction of aerosol removed by filter
Fffa =	0.9997	= fraction of flyash removed by filter

Formulas:

Fq = Ffa*Fqfa+Fae*Fqae

Fs = Ffa*(1-Fqfa)*Fsfa+Fae*(1-Fqae)*Fsae

Ff =Ffa*(1-Fqfa)*(1-Fsfa)*Fffa+Fae*(1-Fqae)*(1-Fsae)*Ffae

Fst =Ffa*(1-Fqfa)*(1-Fsfa)*(1-Fffa)+Fae*(1-Fqae)*(1-Fsae)*(1-Ffae)

Table A-7. Spreadsheet Calculations for Worst Case Stack Emissions Estimate.

metal	bottom ash Fba	flyash (> 1 um) Ffa	aerosol (< 1 um) Fae	quench Fq	scrubber Fs	filter Ff	stack Fst
Cr	0.694575	0.226396	0.079029	0.113198	0.151581	0.040251	0.000395
Ni	0.742725	0.235471	0.021804	0.117735	0.12746	0.01197	0.000109
As	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Sr	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Zr	0.75	0.249874	0.000126	0.124937	0.123751	0.001312	1.01E-06
Nb	0.75	0.0625	0.1875	0.03125	0.124688	0.093125	0.000938
Ag	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Cd	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Sb	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Cs	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Ba	0.74433	0.063918	0.191752	0.031959	0.127515	0.095237	0.000959
Hg	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Tl	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Pb	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Estimated:							
Co	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Y	0.75	0.0625	0.1875	0.03125	0.124688	0.093125	0.000938
Ru	0.75	0.0625	0.1875	0.03125	0.124688	0.093125	0.000938
Rh	0	0.25	0.75	0.125	0.49875	0.3725	0.00375
Ce	0.75	0.0625	0.1875	0.03125	0.124688	0.093125	0.000938
Pr	0.75	0.0625	0.1875	0.03125	0.124688	0.093125	0.000938
Pm	0.75	0.0625	0.1875	0.03125	0.124688	0.093125	0.000938
Pu	0.75	0.0625	0.1875	0.03125	0.124688	0.093125	0.000938

Partition Coefficients:

Fqae =	0	= fraction of aerosol removed by quench
Fqfa =	0.5	= fraction of flyash removed by quench
Fsae =	0.5	= fraction of aerosol removed by scrubber
Fsfa =	0.99	= fraction of flyash removed by scrubber
Ffae =	0.99	= fraction of aerosol removed by filter
Fffa =	0.9997	= fraction of flyash removed by filter

Formulas:

Fq = Ffa*Fqfa+Fae*Fqae

Fs = Ffa*(1-Fqfa)*Fsfa+Fae*(1-Fqae)*Fsae

Ff =Ffa*(1-Fqfa)*(1-Fsfa)*Fffa+Fae*(1-Fqae)*(1-Fsae)*Ffae

Fst =Ffa*(1-Fqfa)*(1-Fsfa)*(1-Fffa)+Fae*(1-Fqae)*(1-Fsae)*(1-Ffae)

F = Fba + Fq + Fs + Ff + Fst

APPENDIX B:

QUENCH VESSEL ANALYSIS

Quench Vessel Performance Calculations

The main purpose of the quench vessel is to cool the gasses down, but in doing so it also removes some of the larger particles. A quench vessel, for the purpose of removing particles, acts like a spray chamber scrubber. The following equations are used to calculate the removal efficiency of a spray chamber scrubber versus particle size. This analysis is taken almost directly from Cooper and Alley.

Assumptions

1. Stokes flow.
2. Unit density spheres (particle Density = 1g/cc).
3. Countercurrent flow.
4. Liquid drops are normally distributed with a mean diameter of 500 microns.(Cooper and Alley, p.228)
5. Effective gas flow velocity(V_G) = 2 m/s (based on a diameter of approximately 2.4 m and a flow rate of 9.3 m^3/s, at 190 K)
6. Contact zone length(Z) = 4 meters (Cooper and Alley, p. 229)
7. Liquid to gas flow rate (Q_L/Q_G) = 0.001 to 0.01 (Flagen and Sienfeld, p. 459)

Equations:

$$\eta\,(Efficiency) = 1 - P_{td}$$

$$P_{td}(Penetration) = \exp\left(-\frac{3Q_L V_{td} Z \eta_d}{4Q_G r_d (V_{td} - V_G)}\right)$$

Where:

Q_L=*Liquid Volumetric Flow Rate*

Q_G=*Gas Volumetric Flow Rate*

V_{td}=*Terminal Drop Velocity*

Z=*Length of the Contact Zone*

η_d=*Single Drop Efficiency*

r_d=*Water Drop Radius*

V_G=*Gas Velocity*

To find the single drop efficiency the following two equations are used:

$$\eta_d = \left(\frac{K_p}{K_p + 0.7}\right)^2$$

$$K_p = \frac{c\rho_p d_p^2 V_G}{9\mu_G d_d}$$

Where:

K_p=*An Impaction Parameter*

c=*Cunningham Slip Factor*

ρ_p=*Particle Density*

d_p=*Particle Diameter*

μ_G=*Gas Viscosity*

d_d=*Droplet Diameter*

and finally to find the terminal droplet velocity an empirical formula is used:

$$V_{td} = 958\left(1 - \exp\left[-\left(\frac{d_d}{0.171}\right)^{1.147}\right]\right)$$

with d_d in cm and V_{td} in cm/s.

The collection efficiency is sensitive to several variables. The most important are droplet size, gas velocity, and the volumetric liquid to gas ratio. The equations predict that as the droplet size decreases the efficiency increases, there is however an optimum drop size beyond which the efficiency does not continue to increase (Cooper and Alley, p. 228). As the gas velocity increases the efficiency will increase up until the velocity where the terminal drop velocity is less than or equal to the gas velocity, when this happens the drops are forced upwards at the gas velocity and no removal occurs. Increasing the amount of liquid will also increase the efficiency, this value is varied within the range of typical values (see assumptions above), the results are shown in the following table and graph.

Quench Vessel (Spray Chamber Scrubber)

Assumptions

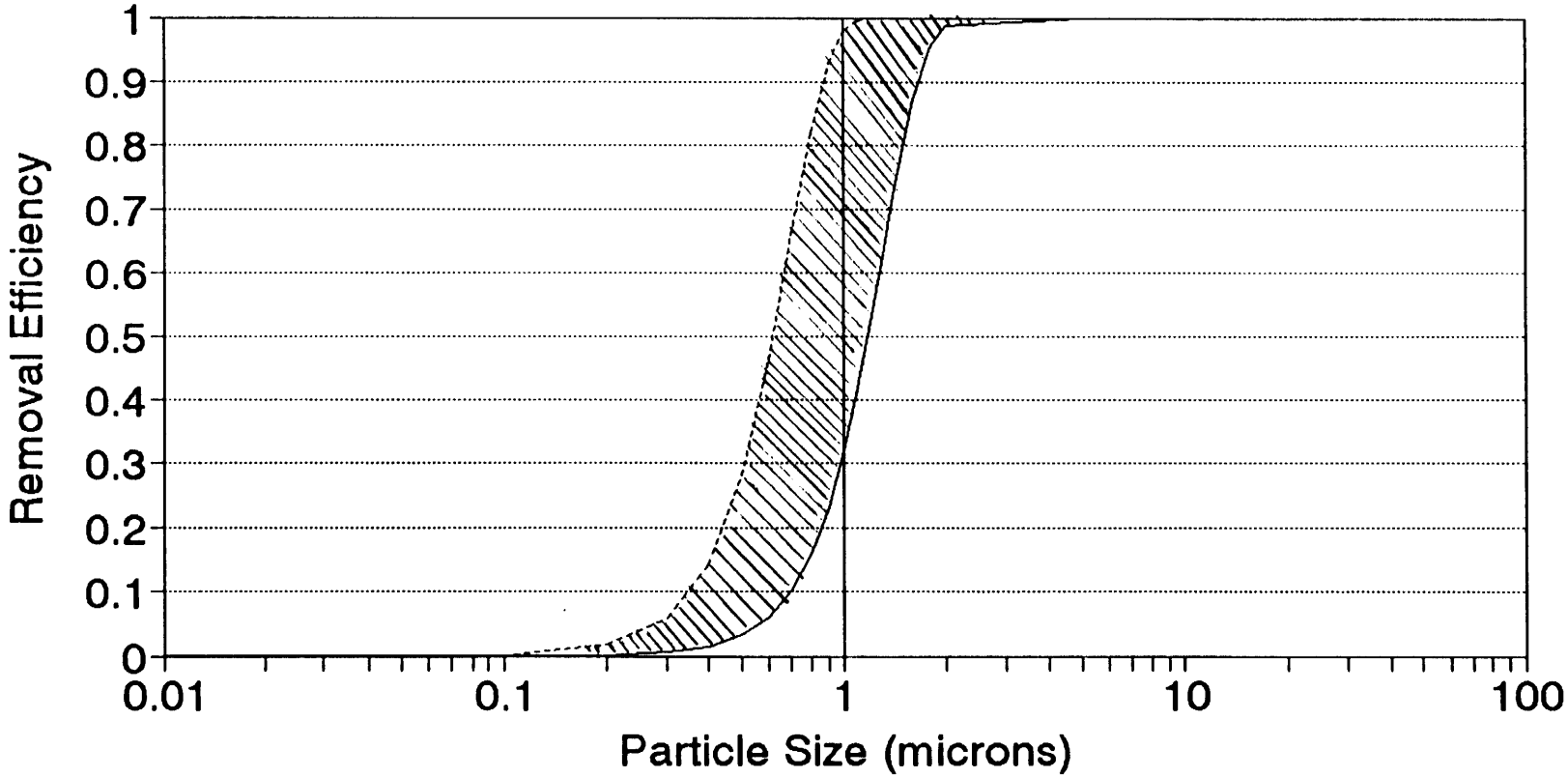
Stokes Flow
unit Density Spheres
Normally Distributed Drops

Drop Diameter(D) =	500	microns	Vt=958{1-exp[-(D/0.171)^1.147]} =	207.4535252 cm/s
Gas Velocity(Vg) =	2	m/s		
Contact Zone(Z) =	4	m		
Liquid:Gas Ratio(Ql/Qg)=	0.001	0.01		
Gas Viscosity(@ T=200 F)=	0.00021	poise		

Particle Size (microns)	Knudsen No.	Cunningham Slip	Impaction Parameter	Single Drop Efficiency	Penatration (Ql/Qg = 0.	Efficiency (Ql/Qg = 0.001)	Efficiency (Ql/Qg = 0.01)
0.01	13.0200	22.1522	0.0000	0.0000	1.0000	0.0000	0.0000
0.1	1.3020	2.8604	0.0006	0.0000	0.9998	0.0002	0.0025
0.2	0.6510	1.8664	0.0016	0.0000	0.9983	0.0017	0.0168
0.3	0.4340	1.5593	0.0030	0.0000	0.9941	0.0059	0.0579
0.4	0.3255	1.4136	0.0048	0.0000	0.9847	0.0153	0.1428
0.5	0.2604	1.3288	0.0070	0.0001	0.9675	0.0325	0.2813
0.6	0.2170	1.2733	0.0097	0.0002	0.9395	0.0605	0.4643
0.7	0.1860	1.2340	0.0128	0.0003	0.8979	0.1021	0.6592
0.8	0.1628	1.2047	0.0163	0.0005	0.8409	0.1591	0.8233
0.9	0.1447	1.1819	0.0203	0.0008	0.7678	0.2322	0.9288
1.0	0.1302	1.1637	0.0246	0.0012	0.6799	0.3201	0.9789
1.1	0.1184	1.1488	0.0294	0.0016	0.5808	0.4192	0.9956
1.2	0.1085	1.1364	0.0346	0.0022	0.4760	0.5240	0.9994
1.3	0.1002	1.1259	0.0403	0.0030	0.3722	0.6278	0.9999
1.4	0.0930	1.1169	0.0463	0.0039	0.2761	0.7239	1.0000
1.5	0.0868	1.1091	0.0528	0.0049	0.1932	0.8068	1.0000
1.6	0.0814	1.1023	0.0597	0.0062	0.1270	0.8730	1.0000
1.8	0.0723	1.0909	0.0748	0.0093	0.0445	0.9555	1.0000
2	0.0651	1.0818	0.0916	0.0134	0.0114	0.9886	1.0000
5	0.0260	1.0327	0.5464	0.1922	0.0000	1.0000	1.0000
10	0.0130	1.0164	2.1510	0.5692	0.0000	1.0000	1.0000
15	0.0087	1.0109	4.8139	0.7622	0.0000	1.0000	1.0000
20	0.0065	1.0082	8.5349	0.8541	0.0000	1.0000	1.0000

Quench Vessel

Removal Efficiency Vs. Particle Size



APPENDIX C:

HYDRO-SONIC SCRUBBER ANALYSIS

Venturi Scrubber

The following equations are used to calculate the removal efficiency of a venturi scrubber versus particle size. This Analysis is taken from Cooper and Alley.

Assumptions
1. Stoke's Flow
2. Unit Density Spheres (particle density = 1g/cc)
3. Normally Distributed Water Drops
4. Volumetric Liquid to Gas Ratio (Q_L/Q_G) is 0.001 to 0.01 (Flagen and Sienfeld, p. 459)
5. A volumetric gas flow rate of 9.3 m^3/s (at 190 K)
6. A Gas Velocity Equal to the Speed of sound, 340 m/s (the scrubber is defined as a hydrosonic venturi scrubber)

Equations:

$$\eta\,(Efficiency) = 1 - P_{td}$$

$$P_{td} = \exp\left[\frac{Q_L V_G \rho_L d_d}{55 Q_G \mu_G}\left(-0.7 + K_p f + 1.4\ln\left(\frac{K_p f = 0.7}{0.7}\right) + \frac{0.49}{0.7 + K_p f}\right)\frac{1}{k_p}\right]$$

Where:

Q_L=*Volumetric Liquid Flow Rate*

Q_G=*Volumetric Gas Flow Rate*

V_G=*Gas Velocity*

ρ_L=*Liquid Density*

d_d=*Sauter Mean Droplet Diameter*

μ_G=*Gas Viscosity*

$$K_p = \textit{Impaction Parameter} = \frac{C\rho_p d_p^2 V_G}{9\mu_G d_d}$$

f=*Empirical Factor* (=0.5 *for hydrophylic particles*)

C=*Cunningam Slip Factor*

ρ_p=*Particle Density*

d_p=*Particle Diameter*

The last equation needed is an empirical relationship for the Sauter mean Droplet Diameter:

$$d_d = \frac{5800}{V_G}\left(\frac{\sigma}{\rho_L}\right)^{0.5} + 597\left(\frac{\mu_L}{\sqrt{\sigma \rho_L}}\right)^{0.45}\left[1000\left(\frac{Q_L}{Q_G}\right)\right]^{1.5}$$

Where:

$$\sigma = Surface\ Tension\left(\frac{dynes}{cm^2}\right)$$

$$\rho_L = \frac{g}{cm^3}$$

$$V_G = \frac{cm}{s}$$

$$\mu_L = poise$$

Factors influencing the collection efficiency of a venturi scrubber include, gas velocity and the volumetric liquid to gas ratio. The gas velocity has a large impact on efficiency, as it increases the collection efficiency will increase and the mean drop diameter will decrease which will increase the efficiency even more. As the liquid to gas ratio is increased the efficiency increase, this is shown in the results in the following table and figure.

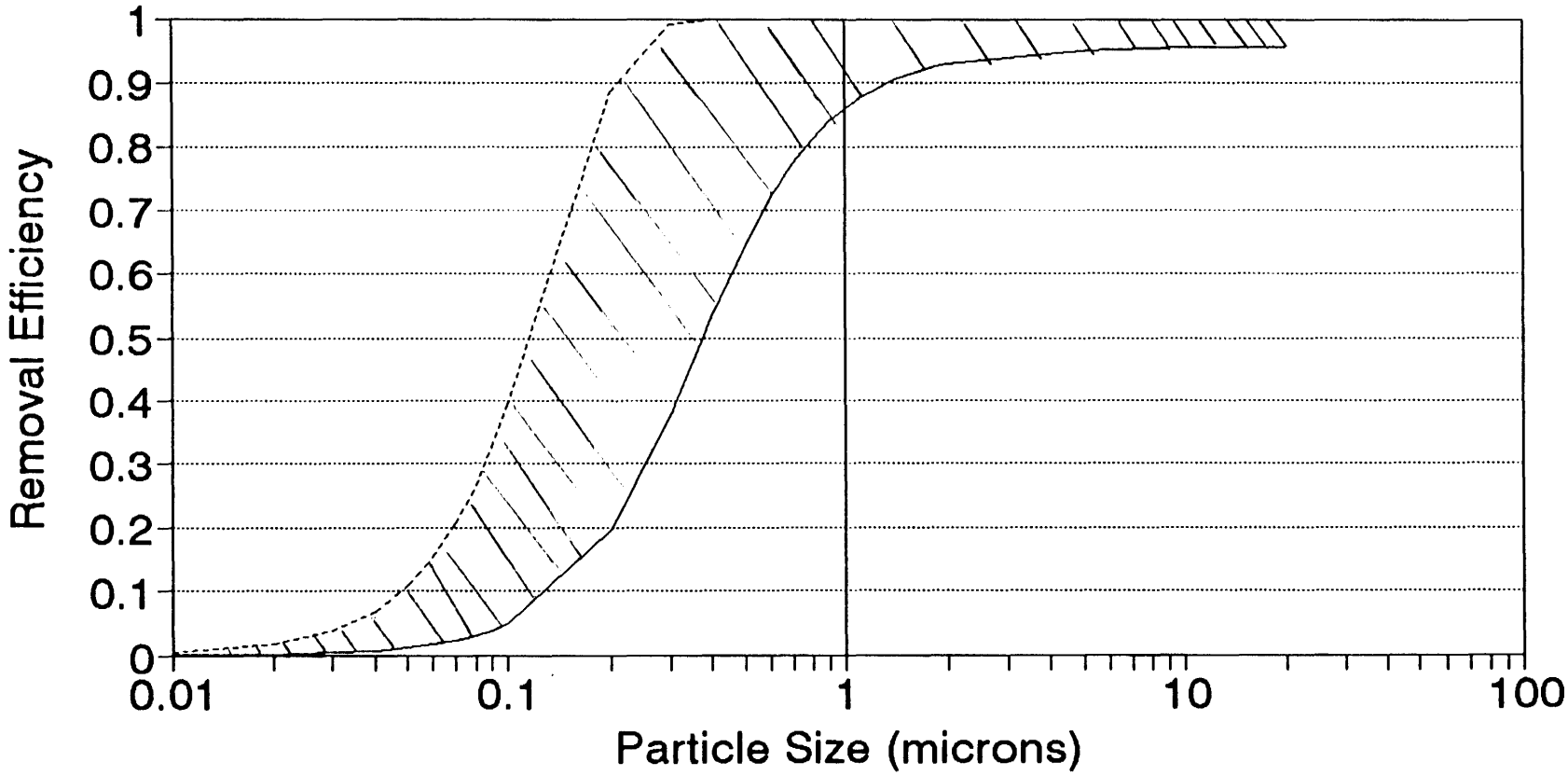
Venturi Scrubber

Assumptions		
Stokes Flow		
unit Density Spheres		
Normally Distributed Drops		
Empirical Factor (f) =	0.5	
Liquid:Gas Ratio(Ql/Qg)=	0.001	0.01
Gas Velocity(Vg) =	350	m/s
Water Surface Tension=	60.1	dynes/cm
Water Density =	1	g/cc
Water Viscosity =	0.00297	poise
Sauter Mean Drop Diameter(D)=	145.7855	microns
Gas Viscosity(@ T=200 F)=	0.00021	poise

Particle Size (microns)	Knudsen No.	Cunningham Slip	Impaction Parameter	Penetration	Efficiency Ql/Qg = 0.001	Efficiency Ql/Qg = 0.01
0.01	13.0200	22.1522	0.0281	0.9996	0.0004	0.0041
0.02	6.5100	11.3822	0.0578	0.9983	0.0017	0.0167
0.03	4.3400	7.8027	0.0892	0.9961	0.0039	0.0382
0.04	3.2550	6.0202	0.1224	0.9929	0.0071	0.0684
0.05	2.6040	4.9559	0.1574	0.9887	0.0113	0.1070
0.06	2.1700	4.2505	0.1944	0.9835	0.0165	0.1535
0.07	1.8600	3.7499	0.2334	0.9771	0.0229	0.2067
0.08	1.6275	3.3769	0.2745	0.9696	0.0304	0.2654
0.09	1.4467	3.0890	0.3178	0.9610	0.0390	0.3281
0.1	1.3020	2.8604	0.3633	0.9513	0.0487	0.3930
0.2	0.6510	1.8664	0.9483	0.8043	0.1957	0.8867
0.3	0.4340	1.5593	1.7826	0.6230	0.3770	0.9912
0.4	0.3255	1.4136	2.8730	0.4687	0.5313	0.9995
0.5	0.2604	1.3288	4.2199	0.3564	0.6436	1.0000
0.6	0.2170	1.2733	5.8228	0.2787	0.7213	1.0000
0.7	0.1860	1.2340	7.6808	0.2251	0.7749	1.0000
0.8	0.1628	1.2047	9.7934	0.1874	0.8126	1.0000
0.9	0.1447	1.1819	12.1604	0.1602	0.8398	1.0000
1.0	0.1302	1.1637	14.7816	0.1401	0.8599	1.0000
1.1	0.1184	1.1488	17.6570	0.1248	0.8752	1.0000
1.2	0.1085	1.1364	20.7865	0.1130	0.8870	1.0000
1.3	0.1002	1.1259	24.1700	0.1037	0.8963	1.0000
1.4	0.0930	1.1169	27.8076	0.0962	0.9038	1.0000
1.6	0.0814	1.1023	35.8449	0.0850	0.9150	1.0000
1.8	0.0723	1.0909	44.8984	0.0771	0.9229	1.0000
2	0.0651	1.0818	54.9682	0.0714	0.9286	1.0000
5	0.0260	1.0327	327.9592	0.0487	0.9513	1.0000
10	0.0130	1.0164	1291.0474	0.0445	0.9555	1.0000
15	0.0087	1.0109	2889.2647	0.0436	0.9564	1.0000
20	0.0065	1.0082	5122.6111	0.0432	0.9568	1.0000

Venturi Scrubber

Removal Efficiency Vs. Particle Size



APPENDIX D:

HEPA FILTER ANALYSIS

HEPA Filters

Filters differ from other air pollution control devices in that they collect particles with very high efficiencies in nearly all size ranges. Typical filters collect particles in the 0.2 to 0.8 micron range at greater than 90 percent, collecting all others at a greater rate. While HEPA filters are defined as collecting particles in this range at greater than 99 percent, collecting all others at a greater percentage(Tillery, M.I.). The following equations are used to calculate the removal efficiency of the HEPA filters. These calculations are based on those for standard filters and do not take into account the fact that the filter media in a HEPA type filter is curved around a corrugated spacer. Also several assumptions are made to simplify the calculations, these two factors cause the calculated efficiencies to be slightly less than what is actually attained by the filter. True efficiencies can only be attained through direct experiments(Tillery, M.I.). The following analysis is based on Flagen and Sienfeld chapter 7.

Assumptions
1. Stoke's Flow
2. Unit Density Spheres (particle density = 1 g/cc)
3. A Fiber Diameter of 3.5 microns (Tillery, M.I.)
4. Filters are 2 m X 2 m (Tillery, M.I.)

Equations:

$$\eta\,(Overall Efficiency) = 1 - \exp\left(\frac{4}{\pi}\left(\frac{\alpha}{1-\alpha}\right)\frac{\eta_f Z}{D_f}\right)$$

Where:

α=*Bed Porosity*

Z=Bed Depth

η_f=*Single Fiber Efficiency*

D_f=*Single Fiber Diameter*

The single fiber efficiency term is a function of three physical phenomena. For very small particles (less than about 0.3 microns in diameter) the mean free path is large and diffusion onto the fibers accounts for collection of the particles. For larger particles (greater than about 0.3 microns in diameter) interception and impaction cause collection. First to find the component due to diffusion,

$$\eta_{dif}=3.68A_f^{\frac{1}{3}}Pe^{-\frac{2}{3}}$$

Where:

$$A_f=\frac{1}{2K_u}$$

$$K_u=KuabaraNo.=\alpha-\frac{3}{4}-\frac{\alpha^2}{4}-\frac{1}{2}\ln(\alpha)$$

$$Pe=Peckley\ No.=\frac{D_fU_\infty}{D}$$

α=*Bed Porosity*

D_f=*Average Fiber Diameter*

U_∞=*Superficial Gas Velocity*

$$D=Brownian\ Diffusion\ Coeficient=\frac{K_BTC}{3\pi\mu D_p}$$

K_B=*Boltman's Constant*

T=*Absolute Temperature*

C=*Cunningham Slip Factor*

μ=*Gas Viscosity*

D_p=*Particle Diameter*

The components due to interception and impaction are solved for by solving two simultaneous equations,

$$Let\ \eta_{intp+imp}=\frac{2Y_1}{D_f}\quad ;\ X=1+\frac{2Y_2}{D_f}$$

$$\eta_{intp+imp}=\frac{1}{2K_u}X\left[2\ln(X)-1+\alpha+\frac{1-\frac{\alpha}{2}}{X^2}-\frac{\alpha}{2}X^2\right]$$

$$\eta_{intp+inp}=\left(1+\frac{D_p}{D_f}\right)+Stk\sqrt{\alpha}\left[\left(1+\frac{\eta_{intp+imp}}{X-1}\right)(X-\eta_{intp+imp})\right]$$
$$\left[1-\exp\left(-\frac{1}{Stk\sqrt{\alpha}}\left(1+\frac{\eta_{intp+imp}}{X-1}\right)^{-1}\right)\right]-(X-\eta_{intp+imp})$$

Where:

$$Stk=\frac{C\rho_p D_p^2 V_G}{18\mu_G D_f}$$

Y_1 and Y_2 are physical parameters dealing with distances between particles and filter fibers. Finally the single fiber Efficiency is found as:

$$\eta_f=\eta_{dif}+\eta_{intp+imp}$$

The single fiber diameter, superficial gas velocity, bed porosity, and depth have a strong effect on the collection efficiency of filters. As the fiber diameter decreases the surface area of the filter increases which relates to a higher efficiency. The superficial gas velocity effects the rate of diffusion and the lower the velocity the higher the efficiency. As the bed depth is increased the efficiency of the bed increases, this phenomena is used to compensate for the fact that these calculations do not model the shape of a HEPA type filter. The results are shown on the next two pages.

HEPA Filters

Assumptions

Stoke's Flow

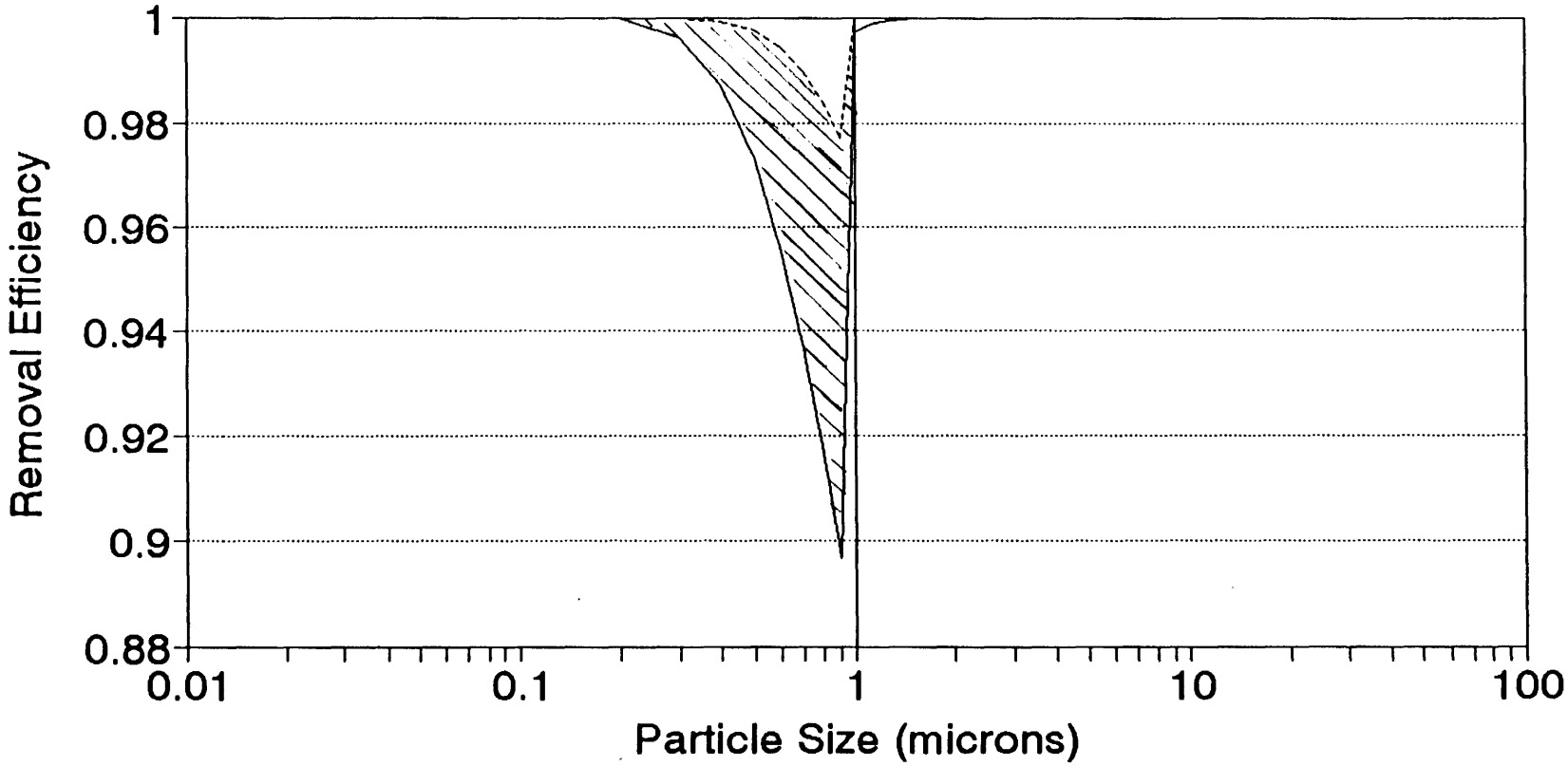
Cross sectional Area of one filter = 4 m^2

Unit Density Spheres	1	g/cc	
Df =	3.5	microns	
Porosity =	0.1		
Bed Depth Z =	1500	2500	microns
Vg =	50	m/min	
Gas Viscosity =	0.00025	poise	
Kuabara Number =	0.498793		
Flow Field parameter Af=	1.002421		

Particle Size microns	Knudsen No.	Cunningham Slip	Terminal Velocity (cm/s)	Stoke's Number	Diffusivity (cm^2/s)	Peckley Number	Diffusion Fiber Eff.	1+2*Y2/2	Int. & Imp. Fiber Eff.			Single Fiber Eff.	Efficiency (Z = 0.15 cm)	Efficiency (Z = 0.15
0.01	13.0200	22.1522	4.82E-06	6.79E-11	4.93E-04	0.5916	1.0000	1.00	7.24E-06	0.000859	-0.0009	1.0000	1	1
0.02	6.5100	11.3822	9.92E-06	2.87E-10	1.27E-04	2.3027	1.0000	1.00	3.64E-05	0.001251	-0.0012	1.0000	1	1
0.03	4.3400	7.8027	1.53E-05	6.82E-10	5.79E-05	5.0386	1.2531	1.01	7.59E-05	0.002147	-0.0021	1.2532	1	1
0.04	3.2550	6.0202	2.10E-05	1.28E-09	3.35E-05	8.7074	0.8702	1.01	0.00013	0.003058	-0.0029	0.8703	1	1
0.05	2.6040	4.9559	2.70E-05	2.12E-09	2.21E-05	13.2214	0.6587	1.01	0.000197	0.003983	-0.0038	0.6589	1	1
0.06	2.1700	4.2505	3.33E-05	3.24E-09	1.58E-05	18.4988	0.5265	1.01	0.000279	0.004922	-0.0046	0.5268	1	1
0.07	1.8600	3.7499	4.00E-05	4.67E-09	1.19E-05	24.4635	0.4370	1.01	0.000375	0.005875	-0.0055	0.4374	1	1
0.08	1.6275	3.3769	4.71E-05	6.46E-09	9.39E-06	31.0458	0.3728	1.02	0.000485	0.006842	-0.0064	0.3733	1	1
0.09	1.4467	3.0890	5.45E-05	8.66E-09	7.64E-06	38.1823	0.3248	1.02	0.000609	0.007823	-0.0072	0.3254	0.999999997	1
0.1	1.3020	2.8604	6.23E-05	1.13E-08	6.37E-06	45.8157	0.2876	1.02	0.000609	0.010681	-0.0101	0.2883	0.999999974	1
0.2	0.6510	1.8664	1.63E-04	7.71E-08	2.08E-06	140.4325	0.1363	1.02	0.000609	0.039252	-0.0386	0.1369	0.999751968	0.999999
0.3	0.4340	1.5593	3.06E-04	2.72E-07	1.16E-06	252.1307	0.0923	1.02	0.000609	0.067824	-0.0672	0.0929	0.996418586	0.999916
0.4	0.3255	1.4136	4.93E-04	7.07E-07	7.87E-07	370.8276	0.0714	1.02	0.000609	0.096395	-0.0958	0.0720	0.987261717	0.999305
0.5	0.2604	1.3288	7.23E-04	1.53E-06	5.92E-07	493.0945	0.0590	1.02	0.000609	0.124967	-0.1244	0.0596	0.973072835	0.997581
0.6	0.2170	1.2733	9.98E-04	2.91E-06	4.72E-07	617.5196	0.0508	1.02	0.000609	0.153539	-0.1529	0.0514	0.955677229	0.994449
0.7	0.1860	1.2340	1.32E-03	5.06E-06	3.92E-07	743.3906	0.0449	1.02	0.000609	0.182111	-0.1815	0.0455	0.936583615	0.989915
0.8	0.1628	1.2047	1.68E-03	8.22E-06	3.35E-07	870.2891	0.0404	1.02	0.000609	0.210683	-0.2101	0.0410	0.916810735	0.984147
0.9	0.1447	1.1819	2.08E-03	1.27E-05	2.92E-07	997.9442	0.0369	1.02	0.000609	0.239256	-0.2386	0.0375	0.89699748	0.977367
1.00	0.1302	1.1637	2.53E-03	1.87E-05	2.59E-07	1126.17	0.0340	1.20	0.06929	0.148507	-0.0852	0.0973	0.997261149	0.999946
1.10	0.1184	1.1488	3.03E-03	2.67E-05	2.32E-07	1254.84	0.0317	1.22	0.075599	0.169389	-0.0938	0.1073	0.998501045	0.99998
1.20	0.1085	1.1364	3.56E-03	3.70E-05	2.11E-07	1383.85	0.0297	1.24	0.088838	0.191201	-0.1024	0.1185	0.999241735	0.999994
1.50	0.0868	1.1091	5.43E-03	8.61E-05	1.65E-07	1772.36	0.0251	1.30	0.13382	0.261906	-0.1281	0.1590	0.999934815	1
2.00	0.0651	1.0818	9.42E-03	2.59E-04	1.20E-07	2422.74	0.0204	1.40	0.224638	0.395612	-0.1710	0.2451	0.999999647	1
3.00	0.0434	1.0546	2.07E-02	1.25E-03	7.82E-08	3728.10	0.0153	1.60	0.455392	0.712293	-0.2569	0.4707	1	1
4.00	0.0326	1.0409	3.63E-02	3.84E-03	5.79E-08	5035.93	0.0125	1.80	0.737936	1.080437	-0.3431	0.7499	1	1
5.00	0.0260	1.0327	5.62E-02	9.22E-03	4.60E-08	6344.79	0.0107	1.90	0.892529	1.424248	-0.5317	0.9033	1	1
10	0.0130	1.0164	2.21E-01	1.43E-01	2.26E-08	12893.92	0.0067	1.90	0.892529	2.937704	-2.0452	0.8992	1	1
20.00	0.0065	1.0082	8.78E-01	2.25E+00	1.12E-08	25997.16	0.0042	1.95	0.974461	6.440625	-5.4662	0.9787	1	1

HEPA Filter

Removal Efficiency Vs. Particle Size



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HEALTH RISK ASSESSMENT FOR THE SAVANNAH RIVER SITE CONSOLIDATED INCINERATION FACILITY

PART 1: RADIONUCLIDES

DRAFT

Nolan E. Hertel and H. Michelle Coward
Health Physics Program
G. W. Woodruff School of Mechanical Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0405
(404) 894-3717

James A. Mulholland and Michael G. Robinson
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0355
(404)894-1839 or -1695

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SUMMARY

The Consolidated Incineration Facility (CIF) is now under construction at the Savannah River Site (SRS). This facility will incinerate hazardous, radioactive and mixed wastes generated at the SRS. The objective of this report is to estimate the radiation doses which might result from the CIF radionuclide air emissions and the associated health risk. Doses and health risks are reported for four scenarios:

- An on-site worker who works 300 m North of the CIF and is exposed by inhalation and immersion in the contaminant plume as well as irradiation by radionuclides deposited on the ground.
- A subsistence farmer who lives at the nearest site boundary from the CIF, namely 11770 m NNW of the CIF. The farmer is likewise exposed by the inhalation, immersion, and ground surface pathways but in addition consumes contaminated food. The farmer consumes food at the maximum consumption rates previously observed in a survey of the SRS region and produces most of his food at the location where he lives. What food he does not produce, he obtains from other locations in the assessment region contaminated by radionuclide emissions from the CIF.
- A maximally exposed individual (MEI) who also lives at the nearest site boundary with respect to the CIF. The MEI also consumes food at maximum rates and grows a majority of his food at the location where he lives. The remainder of his food is imported from an uncontaminated area.
- The average individual has average food consumption rates for the SRS region and grows very little of his food at the location where he resides. A fraction of this

individual's food is grown in the assessment region, but a majority of it is imported from uncontaminated areas. The dose for such an average individual was computed from the nearest site boundary out to a radius of 50 miles (80,500 m).

Three estimates of the radionuclide air emissions from the CIF incinerator have previously reported by the authors: a baseline emissions estimate, a low emissions estimate, and a high emissions estimate. The baseline estimates were based on an extensive study of the possible inorganic emissions from the CIF incinerator and are radionuclide specific. The high and low incinerator emissions estimates were based on sensitivity studies, and do not reflect the range of operating conditions at the CIF. In the present radionuclide risk assessment, the high and baseline emissions estimates have been used to ensure that the most conservative upper bound on risk was attained.

The summary table which follows shows representative lifetime risks and the doses due to the CIF air emissions calculated in this study. For comparison, the radiation-related risks for wearing eyeglasses and being exposed to the average U.S. background radiation level for a lifetime are also tabulated. For risks and doses reported in the table, a lifetime was assumed to be 70 years for the MEI, subsistence farmer, and the average individual. This assumption implicitly assumes that these individuals live at the same location for 70 years and the beginning of their life coincides with the startup of the CIF. The CIF is assumed to close after 30 years of operation as planned. These individuals continue to live at the same locations for another 40 years and are exposed to residual radioactivity in the environment left from the operation of the CIF.

The on-site worker risks and doses reported in the table are based on a 50 week per year, 40 hour per week work schedule. His "lifetime" risks and doses are based on an exposure time of 45

years and he begins work the same day the CIF begins operation. For a completeness, risks and doses are also reported for the ingestion of 25 mg of soil per day. This is the average soil ingestion rate of an adult in the United States. The maximum soil ingestion rate would be about 50 mg per day.

	Lifetime Risk of Death	CIF Lifetime Effective Dose Equivalent (mrem)
Onsite worker (300 m N)		
Baseline Emissions Estimate	0.0000012	2.4
High Emissions Estimate	0.0000037	7.4
Subsistence Farmer (11,770 m NNW)		
Baseline Emissions Estimate	0.00000022	0.44
High Emissions Estimate	0.0000011	2.3
MEI (11,770 m NNW)		
Baseline Emissions Estimate	0.00000012	0.24
High Emissions Estimate	0.00000094	1.9
Average Individual (Baseline Emissions Estimate)		
11,770 m NNW	0.0000001	0.20
32,200 m NNW	0.000000041	0.081
16,100 m NE	0.000000087	0.17
32,200 m NE	0.000000047	
Soil Ingestion (11,770 m NNW)		
Baseline Emissions Estimate	0.000000015	0.029
	0.0000001	0.21
Wearing Eyeglasses	0.00000035	0.7
Total Background Radiation (Natural and Manmade Sources)	0.013	25,200

The risk estimates for individuals living offsite for the radionuclide air emissions are at least 11,800 times lower than the lifetime risk for being exposed to the background radiation dose for an average member of the U.S. population. Except for the high emissions estimates used in the subsistence farmer and MEI scenarios, the lifetime risk resulting from wearing eyeglasses is greater then the lifetime risk of being exposed to radionuclide air emissions from the CIF. All the computed lifetime risks are much less than the allowable EPA total incremental risk of 10^{-5}. So the health risk impact due to the emission of radionuclides from the CIF is negligible.

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1.0. INTRODUCTION

In the late 1980s, several separate programs existed at the Savannah River Site (SRS) to reduce waste volumes with the net result being that two incinerators were planned.[SRS 93] Cost effectiveness and similarity in use ultimately resulted in the combination of these two incineration programs into the Consolidated Incineration Facility (CIF). The CIF originally was designated for treatment of waste produced by activities supporting the defense operations of the United States. Since its conception the defense operations have been downsized; however, waste volumes are anticipated to increase with increasing environmental restoration and decontamination/decommissioning activities at SRS. Incineration of hazardous, radioactive, and mixed wastes are planned for the Consolidated Incineration Facility (CIF), scheduled to begin preliminary operation in 1995.

The Savannah River Site is a Department of Energy (DOE) owned complex occupying approximately three hundred square miles.[DOE 92] Heavy industrial areas compose less than five percent of the total SRS area. The CIF has been constructed within an industrial area, H Area, located near the center of the site. The closest site boundary to the CIF is about 7.5 miles (11,770 m) away towards the NNW. Public access on site is strictly controlled. The city of Augusta Georgia, is the only population area exceeding 25,000 within an 80 km radius of the CIF.

A health risk assessment (HRA) has been performed to assess the impact of the projected 30 year operation of the CIF. The health risks of the radioactive air emissions from the incinerator were investigated and are reported in this document.

2.0. INCINERATOR EMISSIONS SOURCE TERM

An analysis of the incineration of the projected waste feed to the CIF was performed to provide estimates of the emissions rates of radionuclides from the incinerator.[MUL 94] This radionuclide emission source term is the starting point for the CIF health risk assessment. This health risk assessment addressed only the air emissions from the stack and was not directed at any fugitive emissions from the CIF waste storage areas or the impact of the subsequent disposal of the resulting ash. After the source or release term is determined, the fate of the released radionuclides in the environment that could lead to public exposures was modeled.

2.1. CIF Radionuclide Waste Feed

A CIF radionuclide feed rate was generated from recent forecasts of the SRS annual waste generation rates. This feed rate was determined by multiplying the waste generation rates [SRS 93] by the set of expected maximum radionuclide concentrations used in the NESHAPS application.[DOE 88, DOE 89] This radionuclide feed rate for the CIF is shown in Table 1.

As in the NESHAPS application [DOE 88, DOE 89], the treatment of all alpha emitters as either Pu-238 or Pu-239 was retained in this work. This results in a conservative overestimation of the doses due to unspecified alpha emitters in the waste feed. The NESHAPS application's approach of representing all unspecified β/γ-emitting isotopes as Sr-90 also was retained. This again results in conservative overestimation of dose for the unspecified β/γ emitters in the waste feed.

An analysis of the waste feed composition was performed by Mulholland et al. [MUL 94] to create three estimates of the CIF stack radionuclides air emissions. The design and operation of the incinerator have been used to the extent possible in these emission estimates.

2.2. CIF Combustion System [MUL 92]

The CIF combustion system consists of a primary combustion chamber (PCC) and secondary combustion chamber (SCC). The primary combustion chamber is a rotary kiln chamber slightly tilted from the horizontal plane. Liquid fuels and wastes are continuously fed by high intensity vortex burners acting as atomizers. Solids are fed in batch mode by a ram feeder. Either solid waste is removed as bottom ash, or it is carried to the secondary combustion chamber via vaporization and/or fragment entrainment. Entrained solid waste is divided between flyash particles and condensation aerosols upon cooling. The secondary combustion chamber is connected to the outlet of the kiln. Additional waste and/or auxiliary fuel oil are fed to the secondary combustion chamber system by high intensity vortex burners.

Mulholland et al. estimated the partitioning of combustion waste between kiln bottom ash, submicron aerosol particles, and supermicron flyash. The submicron particle size ranges from 0.01 to 1 μm with the supermicron particles being in the range of 1 to 20 μm. With the exception of tritium, phase equilibria and radionuclide species leaving the combustion system were determined using the National Aeronautics and Space Administration's complex chemical equilibrium code CET 89.[GOR 76]

Characteristic temperatures of the CIF combustion system were combined with universal assumptions concerning particle entrainment, inception, and growth for this thermodynamic analysis. Three estimates for emissions were reported: a baseline emission estimate, a low emissions estimate, and a high emissions estimate. In Table 2 the incinerator operating conditions used for these estimates are given. It should be noted that the operating conditions for the high emissions estimate are based on the results of sensitivity studies rather than expected operating conditions.

2.3. Air Pollution Control System

The air pollution control system (APCS) consists of a quench vessel, a scrubber/cyclone/demister/ and a bank of High Efficiency Particulate Filters (HEPA). The efficiency of each component in the air pollution control system is dependent upon particle size. In their analysis, Mulholland et al. based the majority of the particle removal calculations upon theoretical analysis of the component/particle interaction. Particle sizes determined from the thermodynamic analysis of the combustion system were the inputs for APCS component calculations.

From the secondary combustion chamber, the combustion gas enters the quench vessel. The quench vessel is a spray chamber utilized to quickly lower the temperature to 370 K. Removal efficiencies of 0% for submicron particles and 50% for supermicron particles were used. It also was estimated that the quench vessel would remove 10% of the metal vapor and water vapors.

Since the Hydro-Sonic Scrubber functions as a highly efficient venturi scrubber, laboratory data from several venturi scrubbers as well as a theoretical analysis to predict

its collection efficiency. The removal efficiencies for submicron and supermicron particles were chosen as 50% and 99%, respectively.

The HEPA filter bank collects submicron particles by Brownian diffusion and supermicron particles by interception and impaction. From both theoretical analysis and design specifications, conservative removal estimates of 99% for the submicron particles and 99.97% for the supermicron particles were made. Table 3 summarizes the removal factors for the APCS components.

After passing through the APCS, the remaining radionuclides are emitted to the environment through the stack. Combining the emission estimates from the combustion system and air pollution control devices, Mulholland et al. arrived at the air emission estimates for each radionuclide based upon its annual feed rate.[SRS 93] The radionuclide emission factors and emission rates are tabulated in Table 4.

2.3. Tritium Emissions

Total emission fractions from the combustion system were assumed for tritium. A 100% tritium emission was assumed for the high emission estimate. The baseline emission estimate was selected to be a 90% tritium release, allowing for water vapor removal in the quench vessel. To establish a reasonable low emissions estimate, a release of seventy-five percent was chosen.

3.0. ENVIRONMENTAL PATHWAYS

Environmental pathways are the routes of the contaminant through the biosphere from the release point to human exposure locations. Since the emissions from the CIF are stack releases, an atmospheric transport model was used to compute contaminant

concentrations in air. People may be exposed directly by immersion in the contaminated air or by inhalation of the contaminated air. Additionally, the contaminant was deposited by wet and dry deposition mechanisms on the soil and vegetation in the vicinity of the CIF stack. After deposition on and incorporation in the soil, humans may be directly irradiated by radiations emanating from the soil or indirectly by the transfer of the radionuclides through the human food chain.

3.1. Atmospheric Model

When contaminants are emitted to the atmosphere, they enter the planetary boundary layer, or mixing height layer. This layer usually ranges from 200 to 2000 meters.[TILL 83] Meteorological conditions such as local wind patterns and temperature gradients within the mixing height layer create turbulent conditions that diffuse and transport the radionuclides. The mixing height changes with the meteorological conditions so it is common to use both an average morning mixing height and an average afternoon mixing height when doing atmospheric transport computations.

The top of the mixing layer acts as a boundary for dispersing materials. When the radionuclides reach the top of the mixing height layer, they are reflected downward by these inversions. They also are reflected upward from the ground surface. As distance increases from the source, the contaminants become uniformly mixed in the vertical direction..

Since exact mathematical equations are not available to model turbulent diffusion because of its complexity, statistical equations are used that assume the vertical and horizontal plume cross sections follow a Gaussian distribution depending on the amount of

turbulence. These diffusion models also depend on the pollutant's emission rate and the release height.

3.2. Removal Mechanisms

Once the radionuclide is in the atmosphere, several removal mechanism may affect its residence time there. The two general classifications of removal mechanisms are wet deposition and dry deposition. Wet deposition is the removal of the particles by precipitation. The particles may come in contact with the precipitation as the cloud is being formed, called rainout, or may be removed by falling precipitation below the cloud, called washout. Dry deposition consists of such things as gravitational settling and ground or vegetative contact.

After deposition onto a surface, a particle may be resuspended. Resuspension includes the particles rolling across the surface, bouncing to become airborne for short distances, and becoming suspended into the air for thousands of meters. Factors such as particle size, wind velocity, and soil migration affect resuspension actions.

4.0. METHODOLOGY

Exposure scenarios were chosen to model the impact of the CIF releases. The scenarios then were expanded to fully utilize parameters in the computer codes chosen for modeling. The computer codes were used to produce effective dose equivalents for unit releases of the source radionuclides. These doses per unit emission were then multiplied by the appropriate emission rate to obtain the effective dose equivalents.

4.1. CRRIS Code Package

The Computerized Radiological Risk Investigation System for Assessing Doses and Health Risks from Atmospheric Releases of Radionuclides (CRRIS) was chosen for this work. It is a modeling package developed at the Oak Ridge National Laboratory. [ORNL 1988] Eight integrated computer codes are available to model atmospheric releases of radionuclides, their subsequent fate in the environment, and compute the resulting dose to an individual or a population. The codes can be used independently or in groups. For this work, the ANEMOS, TERRA, and ANDROS codes were used. The data and code options used with these three codes for this study are described in Appendix A

The ANEMOS code estimates air concentrations and ground deposition rates of the radionuclides, and their radioactive progeny if they exist, released to the environment using a modified Gaussian plume model. In calculating the air concentrations, ANEMOS was used with SRS site-specific meteorological and topographical data.[BUR 94A, SIM 94A]

The air concentrations and deposition rates from ANEMOS are input into the TERRA code to compute the radionuclide concentrations in soil, edible produce, beef and milk. The effect of the resuspension of the radionuclides from the surface soil was included in the TERRA runs. The TERRA code computes the environmental concentrations for a prescribed assessment time. The buildup of the radionuclides and their progeny in the soil are explicitly included in the computation. The assessment time is the number of years since the startup of the CIF for which doses are desired. For assessment times greater than the thirty year operation period of the CIF, only the plant uptake and resuspension of

residual radionuclides in the soil are available to drive the dose computations. Doses were computed in some exposure scenarios for assessment times of up through 70 years after CIF startup (40 years after its operation ceases).

Radionuclide specific parameters are used in the TERRA code. These include such items as soil-to-plant concentration ratios, ingestion-to-meat transfer for beef, ingestion-to-milk transfer for milk cows, and soil-water distribution coefficients. Changes to these values are described in Appendix A. The CRRIS package uses the AGDATA data base [ORNL 87], an agricultural data base for the United States on a 1/2 degree longitude by 1/2 degree latitude grid. It includes such items as vegetation and livestock lifetimes, vegetation yields, morning and afternoon mixing heights, and humidity as well as population and demographic information. Agricultural parameters in the TERRA input files were changed to reflect recent SRS region data.[HAM 91, HAM 92, HAM 93, HAM 94B]

As the last step in the dose computation, the ANDROS code uses the environmental concentrations computed in the TERRA code to calculate individual or population doses. The ANDROS code calculates doses to user selected organs and a weighted average of these organ doses. The organ weights were selected in this study to compute the effective dose equivalent as per ICRP Publication-26.[ICRP 77] Ingestion, inhalation, air immersion, and ground surface exposure pathways were used this study.

4.2. Exposure Modeling

4.2.1. Assessment Area

The assessment area was defined to be the region out to a radius of fifty miles (80.5 km) from the CIF. The assessment area was subdivided using concentric rings beginning with the nearest point on the site boundary of 11770 m. The radii of the concentric rings were 11770, 16100, 32200, 48300, 64400, and 80500 m, respectively. Combining the sixteen cardinal directions with the concentric rings yields assessment sectors. Since no residential or agricultural activities occur on-site, assessment sectors were not established for locations closer to the CIF than 11,770 m. Doses were computed in this study for individuals located at the six distances offsite and at each of the 16 compass directions at each distance. The data used to compute food contamination, etc. used the sectors defined by these distances and directions.

4.2.2. Ingestion Parameters

Ingestion parameters for individuals consist of consumption rates by food type and intake fractions. Consumption rates for different food types were changed for each scenario to reflect SRS regional data. Maximum and average food consumption values were obtained from *Land and Water Use Characteristics in the Vicinity of Savannah River Site* [HAM 91], see Appendix A. The location at which the food production occurred was taken into account by the use of intake fractions. Three food intake fractions are used to define the fractions of food grown locally, within the assessment area, and imported from outside the assessment area (uncontaminated food).

4.3. Scenarios

Exposure modeling consisted of defining exposure scenarios of individuals in terms of location with respect to the CIF and food ingestion patterns. The scenarios used in this work are:

(1) the worker scenario,

(2) the maximally exposed individual (MEI) scenario,

(3) the subsistence farmer scenario, and

(4) the average individual scenario.

The scenarios are briefly summarized in Table 5 and discussed in the following subsections.

4.3.1. Worker Scenario

The worker was assumed to spend all his working hours at a distance of 350 meter to the North of the CIF. This is the nearest non-CIF worker location at SRS.[BUR 94B] Only inhalation, air immersion, and ground surface exposures were considered for the worker. Ingestion was ignored since he does not eat food grown on the site. The worker was assumed to be at this location for 8 hours per day, 5 days per week for 50 weeks per year. Worker doses were calculated for assessment times of 1, 10, 20 and 30 years.

4.3.2. MEI Scenario

The maximally exposed individual (MEI) was located at 11770 meter to the NNW of the CIF. Historically, this location has yielded the highest doses offsite for atmospheric modeling of the CIF. Maximum food consumption rates were used with the majority of the food being home grown. The intake fractions used are shown in Table 6. The home

grown fractions were adopted from CAP-88 default values [US EPA 90A] with the remaining food consumed assumed to be from outside the assessment area. The MEI doses were computed for assessment times of 1, 10, 20, and 30 years.

4.3.3. Subsistence Farmer Scenario

The subsistence farmer scenario assumed the farmer was located on the site boundary at a distance of 11,770 m to the NNW of the CIF. The same maximum food consumption rates as for the MEI were used; however, different food intake fractions were used. The farmer's intake fractions were adopted from the U.S. Environmental Protection Agency's *Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Waste.*[US EPA 94] All the food was assumed to be grown within the assessment area, with the vast majority being home grown, (see Table 7). The subsistence farmer scenario doses were computed for assessment times of 1, 10, 20, and 30 years.

4.3.4. Average Individual Scenario

The dose for the average individual scenario were calculated at all 96 locations indicated in Section 4.2.1. Average food consumption rates for the SRS region were used in this scenario rather than maximum consumption rates, see Appendix A. The intake fractions used in the scenario are shown in Table 8. The CAP-88 urban intake fraction values were used for the local intake fractions.[US EPA 90A] Data in the Environmental Protection Agency's *Methodology for Assessing Indirect Exposure to Incinerator Emissions* [US EPA 90B] were used to produce the assessment area intake fractions with the exception of the milk fraction which was taken from the data of Hamby [HAM 91].

Doses for the average individual scenario were computed for assessment times of 1, 10, 20, 30, 31, 35, 45, 52, 60 and 70 years. The assessment times of 31 and 35 years were chosen to view the changes associated with short half-life radionuclides.

4.4. Soil Ingestion Pathway

In addition to the exposure scenarios discussed in the previous subsections, the EPA methodology for assessing health risks for combustor chemical emissions requires that a soil ingestion exposure pathway be investigated.[US EPA 90B] For most individuals ingestion of soil occurs incidentally rather than intentionally. This pathway was investigated using the soil concentrations computed for a mass balance in the upper 1 cm of soil for the TERRA code runs. An average soil ingestion rate of 25 mg/d is appropriate for the average individual, while a value of 50 mg/d has been estimated for an adult with more frequent hand-to mouth contact, such as a smoker.[US EPA 90B, LAG 87] Soil ingestion doses have been computed from the soil concentrations at 11770 m NNW of the CIF for assessment times of 1, 10, 20, 30, 31, 35, 45, 52, 60 and 70 years.

4.5. Fatal Cancer Risks

Although the conversion of low doses of radiation at low dose rates to cancer fatality risks is an extremely questionable and controversial conversion, the computed radiation exposures were converted to risk. This facilitates a comparison of the radiation health risks with the hazardous health risks for the CIF. To make the conversion, the conversion factor from dose to cancer risk recommended the International Commission on Radiological Protection in Publication 60 was used.[ICRP 91] Their recommended value is 0.05 Sv^{-1} or, in more appropriate units for the present study, $5(10^{-7})$ $mrem^{-1}$.

5.0. RESULTS AND DISCUSSION

A few general statements about the computed doses are in order. The air immersion pathway turned out to result in doses to humans that is always a factor of 1,000 to 10,000 lower than the other pathway doses for both the baseline and the high emissions estimates. This is a result of the low air concentrations resulting from the CIF as well as the characteristics of the emitted nuclides. Therefore, following discussion of doses from the CIF does not report results for the air immersion pathway.

The ground surface pathway and the inhalation pathway doses are distributed by assessment location in the same proportions between emitted radionuclides for the different scenarios. The differences between the subsistence farmer, the MEI, and the average individual scenario doses are due to differences in the ingestion pathways. After the shutdown of the CIF, the inhalation dose is reduced by several orders of magnitude and becomes an insignificant fraction of the total dose. This is true since after shutdown, air concentrations are driven solely by resuspension of contaminated soil. So the scenario doses after the thirtieth year (last year) of operation are almost totally distributed between the ingestion and ground surface irradiation doses.

5.1. Worker Exposure Scenario Doses

The worker yearly doses and risks from CIF radionuclide air emissions for assessment times up through 30 years are shown in Figures 1 and 2 for the baseline and high emission estimates, respectively. The inhalation dose is constant since its driven by a constant CIF radionuclide emission rate per year. The doses and cancer risks are shown in Table 9. Shown in Figures 3 and 4 are the respective breakdowns of the yearly dose for assessment

times up through 30 years by radionuclide. For the 30th or last year of projected CIF operation, the percentage contributions of the major dose-contributing radionuclides to the total dose, the inhalation dose and the ground surface irradiation doses are given in Table 10.

5.2. Nearest Boundary Doses

As previously noted, the nearest site boundary at 11,770 m NNW has historically yielded the highest doses in CIF studies. Although doses computed at 11,770 m NE would give the highest doses, doses are not reported for this location as it is on site. The doses for the MEI, subsistence farmer and the average individual at 11,770 m NNW will be discussed in this section. Of the pathways modeled, only the ingestion pathway for these scenarios yield different doses as the inhalation and ground surface pathway doses are only dictated by soil and air radionuclide concentrations at the boundary location.

5.2.1. Inhalation Dose

The distribution of the inhalation doses by principal dose-contributing radionuclides is shown in Figures 5 and 6 for the baseline and high emissions estimate, respectively. Note that for the high emissions estimate, nearly a factor of 10 increase over the dose for the baseline emissions estimate occurs. Also note the large increase in contribution to the total inhalation dose by Pu-238. In Figure 6, assessment times from 30 years to 70 years demonstrate the effect of resuspending residual radioactivity in the soil. The resuspension effect is quite small and due almost exclusively to the resuspension of Pu-238. In Table 11, the inhalation dose during the thirtieth year of CIF operation is tabulated with the contributions of the principal dose-contributing radionuclides.

5.2.2. Ingestion Pathway

For assessment times up through 30 years the subsistence farmer ingestion doses for the baseline and high emissions estimates are shown in Figures 7 and 8 by principal-dose-contributing radionuclides, respectively. The high emission estimate results in a dose about four times higher than the dose for the baseline emission estimates. The same breakdown of the ingestion doses for the MEI scenario are shown in Figures 9 and 10. Again, the high emissions estimate increases the dose over the baseline emissions dose estimate by almost a factor of 4.

In Figures 11 and 12, the ingestion dose for the average individual scenario are broken down by principal radionuclides. The high emissions estimate again increases the dose by over a factor of 4 from the baseline emissions estimate. Doses are shown for assessment times up through 70 years for the average individual scenario. The 70 year assessment time represents a period of 40 years after closure of the CIF and serves to demonstrate the effect of residual radioactivity in the soil and its uptake through the food chain. The two key dose-contributing radionuclides after shutdown are Cs-137 and the β/γ waste stream treated as Sr-90.

In Table 12, the ingestion doses resulting from three stream scenarios are broken down by principal dose-contributing nuclides for the two emission estimates. Even though the consumption rates and usage fractions are quite different between the scenarios, the percentage breakdowns by nuclides for each scenario dose are quite similar for a given emission estimate. For example, the tritium (H-3) ingestion dose contributions are 22.4%,

19.0%, and 19.2% for the average individual, subsistence farmer, and MEI scenarios, respectively.

5.2.3. Ground Surface Irradiation

The ground surface irradiation dose is the dose to an individual being irradiated by radionuclides that buildup in the soil during CIF operation. After the shutdown of the CIF, this irradiation is a result of the residual radionuclides in the soil. This dose is the same for all three offsite scenarios. For assessment times up through 70 years, the ground surfaces doses are shown in Figures 13 and 14 by principal dose-contributing radionuclides for the baseline and high emissions estimates. The primary ground surface dose contributor is Cs-137 for both emissions estimates. For assessment times after closure, the decay and removal of the radionuclides in the soil with time is readily apparent. For the thirtieth year of CIF operation, the total dose and the doses by principal dose-contributing radionuclides are tabulated with their percentage contributions to the total ground surface dose.

5.2.4. Total Doses

The total dose for the average individual scenario and the baseline emissions estimate is broken down by pathway in Figure 15 for the 11,770 m NNW location. As stated previously, the air immersion dose is so low it cannot be resolved on the graph. As expected, the ingestion and ground surface irradiation doses become dominant after the CIF closure with the ground surface irradiation pathway being the main dose contributor after closure. This scenario total dose is further broken down by principal radionuclide in Figure 16. The radionuclide dependence tracks the results for the individual pathways, i.e.

for the ground surface irradiation pathway Cs-137 is dominant, etc. In Table 14, the total doses, with the contributions by principal dose-contributing radionuclides, for all three scenarios and the two emission estimates are tabulated for the thirtieth year of operation.

5.3. Soil Ingestion Dose

The effective dose equivalents from ingesting 25 mg of soil per day found at 11,770 m NNW of the CIF are plotted in Figures 17 and 18 for the baseline and high emissions estimates, respectively. These doses are shown for assessment times up through 70 years. The isotope Pu-238 plays a much greater role in soil ingestion for the high emissions estimate than in food ingestion. Plutonium-238 is rather immobile in the soil and not taken up by plants so it is more important in the direct consumption of soil than it is for the food ingestion pathway. The soil ingestion total doses and breakdown by principal radionuclide are given in Table 15 for the thirtieth year of operation.

5.4. Average Individual Scenario - Assessment Region

The doses for the average individual scenario computed at a distance of 16,100 m and 32,200 m from the CIF in all compass directions are plotted in Figures 19 and 20, respectively, for assessment times of 1, 10, 20, and 30 years. The doses largely echo the wind direction frequencies for the SRS region. The lowest doses are south of the CIF and the highest doses are in the NE direction. The doses in the NE direction are only slightly higher than those in the NNW, N and NNE directions. In Figure 21, the doses for the average individual scenario are plotted at distances of 16.1 km, 32.2 km, 48.3 km, 64.4 km, and 80.5 km from the CIF and for the 16 cardinal compass directions for the thirtieth year of operation. As expected the dose diminishes with distance in all directions. As a

further demonstration of this distribution, the same doses are shown as a contour plot in Figure 22.

6.0. HEALTH RISK ASSESSMENT

The maximum effective dose equivalents for each of the four scenarios and for 25 mg/d soil ingestion are given in Table 16 along with the accompanying yearly cancer fatality risk based on 5 x 10^{-7} /mrem. [ICRP 91] The doses and risks reported are all for an assessment time of 30 years. This represents the peak concentrations of the radionuclides in the soil. Also shown in Table 16 are the average yearly background radiation doses for a person in the United States, [NCRP 90] and the associated cancer fatality risk. Several doses for other activities are reported to place the doses from this assessment into perspective. All of the yearly doses and risks computed by the scenarios are in the same range or much less than those from wearing eyeglasses, except for the high emissions onsite worker dose.

The lifetime risks* associated with the scenarios computed in this risk assessment are presented in Table 17 along with the total dose used to calculate them. The lifetime is assumed to be 70 years [US EPA 90B] except for the onsite worker who was assumed to be employed in the same location on the SRS for 45 years. The offsite lifetime risks assume that the individual was present for all thirty years of CIF operation and continued to live at the same location for another 40 years after the closure of the CIF. This contrasts with the median residence time for a homeowner of 30 years. [US EPA 90B] It must be emphasized that the scenarios used to calculate the doses and the subsequent health risks of operating the CIF are in and of themselves conservative overestimates of

* The lifetime risks in Table 17 are to be interpreted as follows. The lifetime fatality risk of all cancers is 0.19. This means that 19 out of 100 persons will die of cancer; consequently, any individual's risk of dying of cancer is 19 out of 100.

human behavior. In addition the exposure times considered are also overestimates. The lifetime risk of being exposed to the other sources of radiation cited in Table 16 are included in Table 17 for comparison. In addition the lifetime risks for other activities have been added to Table 17 for comparison.[TR 89]

The health impact of radioactive air emissions from the incinerator are negligible for all cases. The total incremental risk from the high-end individual, in terms of exposure, should not exceed 10^{-5} according to the EPA.[US EPA 94] Even the onsite worker scenario dose for the high emissions estimate does not approach this level of risk. To further place the CIF-related risks and doses in perspective, the average member of the U.S. population receives a dose of 360 mrem/y due to background radiation.[NCRP 90] Approximately 82% of the average individual's background dose derives from natural sources: radon, cosmic rays from outer space, radioactive materials in soil and rocks, and naturally occurring radionuclides inside the human body. This background radiation lifetime risk is more than 3500 times greater than the largest computed lifetime risk for the CIF estimate. The risk for this dose, the onsite worker dose for the high emissions estimate, is only about 11 times higher than the lifetime cancer fatality risk for wearing eyeglasses.

A person could well argue that below some value, the risk becomes so low that it has only mathematical meaning--that the risk is so low as to be zero in reality. This would be akin to the change in the taste of a cake by the placing an additional grain of sugar to the two cups required by the recipe. The dose due to wearing eyeglasses fits into this category as certainly do the lifetime risks associated with the operation of the CIF, particularly those due to the offsite radionuclide exposures.

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Table 1.

CIF Radionuclide Feed Rates Based on Recent Mass Feed Rates [SRS 93] and Maximum Expected Radionuclide Concentrations from the NESHAPS Application.[DOE 88, DOE 89]

Nuclide	Feed(Ci/y)
H-3	1.4E+02
Sr-89	2.6E+00
Sr-90	3.3E-01
Y-90	3.3E-01
Y-91	2.0E+00
Zr-95	3.0E+00
Nb-95	7.6E+00
Ru-106	1.8E+00
Rh-106	1.8E+00
Cs-137	1.2E+00
Ba-137m	1.2E+00
Ce-144	1.9E+00
Pr-144m	1.9E+00
Pr-144	1.9E+00
Co-60	5.8E-01
Cr-51	6.5E+01
Pm-147	3.9E+00
β/γ as Sr-90[a]	9.6E+01
α as Pu-238[b]	9.0E-01
α as Pu-239[b]	4.4E-03

[a] Other β/γ-emitting radionuclides may be present in small or undetectable quantities and their exposure effects are conservatively overestimated by treating them as Sr-90. [DOE 89]

[b] Alpha emitters are classified as either Pu-238 or Pu-239 based on their radiation properties. This is done since Pu-238 and Pu-239 were the principal SRP products and the major alpha-emitting waste contaminants.[DOE 89]

Table 2.

Incinerator Operating Conditions Used by Mulholland et al. to Generate Radionuclide Emissions Factors [MUL 94]

Parameter	Baseline Emissions Estimate	Low Emissions Estimate	High Emissions Estimate
Kiln Solids Temperature	1100 K	900 K	1250 K
Secondary Combustion Chamber Temperature	1250 K	1100 K	1500 K
Temperature after Quench	370 K	350 K	400 K
Kiln Solids Entrainment Fraction	0.1	0.01	0.25
Fraction to Aerosol Particles	0.5	0.25	0.75
Chloride Formation	Yes	No	Yes
Metal-Ash/Metal Interactions	Yes	Yes	No

Table 3.

Removal Fractions for Submicron and Supermicron Particles by the Incinerator Air Pollution Control Devices

Device	Submicron Removal Efficiency	Supermicron Removal Efficiency
Quench Vessel	0	0.5
Scrubber	0.5	0.99
HEPA Filters	0.99	0.9997

Table 4.

Metal and Radionuclide Stack Emission Factors $\left(\frac{Ci \text{ emitted}}{Ci \text{ input}}\right)$ and Rates (Ci/y)

Radionuclides	Lower Limit Fraction (Rate)	Baseline Estimate Fraction (Rate)	Upper Limit Fraction (Rate)
H-3	0.75 (105)	0.90 (126)	1.0 (140)
Cr-51	3.9E-6 (2.5E-4)	9.7E-5 (6.3E-3)	3.4E-4 (2.2E-2)
Co-60	1.3E-5 (7.3E-6)	2.5E-4 (1.5E-4)	4.7E-3 (2.8E-3)
Sr-89	1.5E-8 (3.9E-8)	7.0E-4 (6.5E-3)	3.8E-3 (9.8E-3)
Sr-90	1.5E-8 (1.4E-6)	7.0E-4 (2.4E-1)	3.8E-3 (3.6E-1)
Y-90	1.5E-8 (5.0E-9)	2.0E-7 (6.6E-8)	5.0E-4 (1.7E-4)
Y-91	1.5E-8 (2.9E-8)	2.0E-7 (3.9E-7)	5.0E-4 (9.8E-4)
ZR-95	5.5E-7 (1.7E-6)	6.4E-7 (1.9E-6)	1.2E-4 (3.6E-4)
Nb-95	2.3E-7 (1.7E-6)	7.2E-7 (5.4E-6)	1.3E-3 (1.0E-2)
Ru-106	9.7E-7 (1.7E-6)	1.4E-6 (2.4E-6)	1.5E-3 (2.6E-3)
Rh-106	8.1E-4 (1.4E-3)	1.7E-3 (3.0E-3)	4.7E-3 (8.4E-3)
Cs-137	1.3E-3 (1.4E-3)	2.5E-3 (2.9E-3)	5.7E-3 (6.5E-3)
Ba-137m	1.1E-7 (1.3E-7)	1.5E-7 (1.7E-7)	2.4E-4 (2.8E-3)
Ce-144	8.4E-7 (1.6E-6)	1.2E-6 (2.3E-6)	1.3E-3 (2.5E-3)
Pr-144	8.4E-7 (1.6E-6)	1.2E-6 (2.3E-6)	1.3E-3 (2.5E-3)
Pr-144m	8.4E-7 (1.6E-6)	1.2E-6 (2.3E-6)	1.3E-3 (2.5E-3)
Pm-147	1.5E-8 (5.9E-8)	2.0E-7 (7.8E-7)	5.0E-4 (2.0E-3)
Pu-238	5.4E-7 (4.9E-7)	8.4E-7 (7.5E-7)	1.0E-3 (9.3E-4)
Pu-239	7.9E-7 (3.5E-9)	1.1E-6 (5.0E-9)	1.3E-3 (5.6E-6)
β/γ as Sr-90	1.5E-8 (1.4E-6)	7.0E-4 (2.4E-1)	3.8E-3 (3.6E-1)

Table 5.

Exposure Modeling Scenarios for Thirty Year Assessment Time

Scenario	Assessment Sector	Food Consumption Rates	Food Intake
On-site Worker	350 meters North	N/A	N/A
Maximally Exposed Individual (MEI)	11770 meters NNW on Site Boundary	Maximum	Most locally grown; remainder imported
Subsistence Farmer	11770 meters NNW on Site Boundary	Maximum	Majority locally grown; remainder from Assessment Area
Average Individual	11770 meters 16100 meters 32200 meters 48300 meters 64400 meters & 80500 meters at all 16 cardinal compass directions	Average	Large fraction grown inside the assessment area; small locally grown fraction: remainder imported

Table 6.

Food Intake Fractions for the MEI Scenario.

Food Type	Locally Grown	Grown in Assessment Area	Imported
Leafy Vegetables	0.70	0.00	0.30
Exposed Vegetables	0.70	0.00	0.30
Protected Vegetables	0.70	0.00	0.30
Grain	0.70	0.00	0.30
Beef	0.44	0.00	0.56
Milk	0.44	0.00	0.56

Table 7.

Food Intake Fractions for the Subsistence Farmer Scenario

Food Type	Locally Grown	Grown in Assessment Area	Imported
Leafy Vegetables	0.95	0.05	0.00
Exposed Vegetables	0.95	0.05	0.00
Protected Vegetables	0.95	0.05	0.00
Grain	0.95	0.05	0.00
Beef	0.44	0.56	0.00
Milk	0.40	0.60	0.00

Table 8.

Food Intake Fractions for the Average Individual Scenario

Food Type	Locally Grown	Grown in Assessment Area	Imported
Leafy Vegetables	0.08	0.18	0.74
Exposed Vegetables	0.08	0.26	0.66
Protected Vegetables	0.08	0.24	0.68
Grain	0.08	0.37	0.55
Beef	0.08	0.00	0.92
Milk	0.12	0.61	0.27

Table 9.

On-Site Non-CIF Worker Effective Dose Equivalents and Associated Cancer Fatality Risks for an Assessment Time of 30 Years (Last Year of Operation)

	Effective Dose Equivalent (mrem/y)	Cancer Fatality Risks per Year
Baseline Emissions Estimate	3.6E-02	1.8E-08
High Emissions Estimate	2.0E-01	1.0E-07

Table 10.

Radionuclides Contributing at Least 1% of the Worker Total Effective Dose Equivalent, Inhalation Pathway Effective Dose Equivalent, and Ground Surface Irradiation Effective Dose Equivalent during the 30th Year of Operation (Last Year).

Emissions Estimate	Radionuclide	Percentage of Total Dose	Percentage of Inhalation Pathway Dose	Percentage of Ground Surface Irradiation Pathway Dose
Baseline	H-3	25.0%	59.2%	---
	Cs-137	56.0%	---	96.9%
	β/γ as Sr-90	16.9%	40.0 %	---
	Co-60	1.8%		3.0%
High				
	H-3	5.0%	7.3%	---
	Cs-137	23.2%	---	74.2%
	β/γ as Sr-90	16.6	24.2%	---
	Ru-106	0.44%	---	1.3%
	Pu-238	45.9%	66.8%	---
	Nb-95	1.6%	---	4.9%
	Co-60	6.13%	---	18.9

Table 11.

Inhalation Pathway Effective Dose Equivalent at 11770 m NNW of the CIF during the 30th Year of Operation and the Radionuclides Contributing at Least 1% of the Dose. This dose and its distribution are the same for the MEI, Subsistence Farmer and Average Individual Scenarios.

Emissions Estimate	Radionuclide	Effective Dose Equivalent (mrem/y)	Percentage of Pathway Dose	Cancer Fatality Risk per Year
Baseline	All	1.87E-03		9.4E-10
	H-3	1.11E-03	59.2%	
	β/γ as Sr-90	0.75E-03	40.0 %	
High	All	1.67E-02		8.4E-9
	H-3	0.12E-02	7.4%	
	β/γ as Sr-90	0.41E-02	24.3%	
	Pu-238	1.12E-02	66.8%	

Table 12.

Ingestion Pathway Effective Dose Equivalent at 11770 m NNW of the CIF during the 30th Year of Operation and the Radionuclides Contributing at Least 1% of the Dose for the MEI, Subsistence Farmer and Average Individual Scenarios.

Emissions Estimate	Radionuclide	Average Individual Effective Dose Equivalent (mrem/y)	Subsistence Farmer Effective Dose Equivalent (mrem/y)	MEI Effective Dose Equivalent (mrem/y)
Baseline	All	9.42E-04	8.02E-03	5.98E-03
	H-3	2.11E-04	1.53E-03	1.15E-03
		(22.4%)[+]	(19.0%)	(19.2%)
	Cs-137	3.25E-04	2.69E-03	2.03E-03
		(34.5%)	(33.5%)	(34.0%)
	β/γ as Sr-90	4.04E-04	3.79E-03	2.79E-03
		(42.9%)	(47.2%)	(46.6%)
High	All	3.26E-03	2.95E-02	2.17E-02
	H-3	0.23E-03	0.17E-02	0.13E-02
		(7.2%)	(5.8%)	(5.9%)
	Cs-137	0.74E-03	0.61E-02	0.46E-02
		(22.7%)	(20.8%)	(21.4%)
	β/γ as Sr-90	2.19E-03	2.06E-02	1.51E-02
		(67.2%)	(69.8%)	(69.8%)
	Pu-238	0.05E-03	0.07E-02	0.05E-02
		(1.6%)	(2.4%)	(2.4%)

[+] (xx%) Percent Contribution: Read as xx% of the Effective Dose Equivalent

Table 13.

Ground Surface Irradiation Pathway Effective Dose Equivalent at 11770 m NNW of the CIF during the 30th Year of Operation and the Radionuclides Contributing at Least 1% of the Dose. This dose and its distribution are the same for the MEI, Subsistence Farmer and Average Individual Scenarios.

Emissions Estimate	Radionuclide	Effective Dose Equivalent (mrem/y)	Percentage of Pathway Dose
Baseline	All	2.55E-03	
	Cs-137	2.47-03	96.9%
	Co-60	0.08E-03	3.0 %
High	All	7.59E-03	
	Nb-95	0.37E-03	4.9%
	Ru-106	0.01E-03	1.3%
	Cs-137	5.63e-03	74.2%
	Co-60	1.43E-03	18.9%

Table 14.

Total Effective Dose Equivalent at 11,770 m NNW of the CIF During the 30th Year of Operation by Scenario and Radionuclides Contributing at Least 1% of the Total Dose

Emissions Estimate	Radionuclide	Average Individual Scenario (mrem/y)	Subsistence Farmer Scenario (mrem/y)	MEI Scenario (mrem/y)
Baseline	All	5.36E-03	1.24E-02	1.04E-02
	H-3	1.32E-03 +(24.6%)	0.26E-02 (21.2%)	0.23E-02 (21.7%)
	Cs-137	2.79E-03 (52.1%)	0.52E-02 (41.5%)	0.45E-02 (43.3%)
	Co-60	0.08E-03 (1.5%)	--- ---	--- ---
	β/γ as Sr-90	1.15E-03 (21.5%)	0.45E-02 (36.4%)	0.35E-02 (34.0%)
High	All	2.76E-02	5.38E-02	4.6E-02
	H-3	0.15E-02 (5.3%)	0.29E-02 (5.4%)	0.25E-02 (5.4%)
	Nb-95	0.04E-02 (1.5%)	0.06E-02 (1.1%)	--- ---
	Cs-137	0.64E-02 (23.1%)	1.18E-02 (21.9%)	1.03E-02 (22.3%)
	Co-60	0.15E-02 (5.4%)	0.16E-02 (2.9%)	0.16E-02 (3.4%)
	β/γ as Sr-90	0.63E-02 (22.7%)	2.46E-02 (45.8%)	1.92E-02 (41.7%)
	Pu-238	1.12E-02 (40.7%)	1.19E-02 (22.1%)	1.17E-02 (25.4%)

Table 15.

Effective Dose Equivalent at 11770 m NNW of the CIF during the 30th Year of Operation for the Ingestion of 25 mg of Soil per Day and the Radionuclides Contributing at Least 1% of the Dose. This dose and its distribution are the same for the MEI, Subsistence Farmer and Average Individual Scenarios.

Emissions Estimate	Radionuclide	Effective Dose Equivalent (mrem/y)	Percentage of Pathway Dose
Baseline	All	5.04E-04	
	Cs-137	0.45E-04	9.0%
	β/γ as Sr-90	4.56E-04	90.4%
High	All	4.55E-03	
	Pu-238	1.94E-03	42.7%
	Cs-137	0.10E-03	2.3%
	β/γ as Sr-90	2.47-03	54.3%

Table 16

The Maximum Yearly Effective Dose Equivalents for the Four CIF Scenarios, a Soil Ingestion of 25 mg/day, and Doses for Other Activities. The Maximum Effective Dose Equivalents Occur During the 30th (Final) Year of Operation

	Effective Dose Equivalent (mrem/y)	Risk ($year^{-1}$)
Onsite Worker (300 m N)		
Baseline Emissions Estimate	0.036	1.8E-08
High Emissions Estimate	0.20	1.0E-07
Subsistence Farmer (11,770 m NNW)		
Baseline Emissions Estimate	0.012	6.2E-09
High Emissions Estimate	0.054	2.7E-08
MEI (11,770 m NNW)		
Baseline Emissions Estimate	0.010	5.2E-09
High Emissions Estimate	0.046	2.3E-08
Average Individual (Baseline Emissions Estimate)		
11,770 m NNW	0.0054	2.7E-09
16,100 m NNW	0.0040	2.0E-09
32,200 m NNW	0.0022	1.1E-09
16,100 m NE	0.0046	2.3E-09
32,200 m NE	0.0025	1.2E-09
Soil Ingestion (11,770 m NNW), 25 mg/day		
Baseline Estimate	0.00050	2.5E-10
High Emissions Estimate	0.00046	2.3E-09
Background Radiation[a]		
Natural Sources Only	300	1.5E-04
Natural and Manmade Sources	360	1.8E-04
Chest X-ray[b] (modern equipment)	10	5.0E-06
One-way Airplane Flight from New York City to Los Angeles[a]	2.5	1.3E-06
Wearing Eyeglasses (Ophthalmic Glass)[c]	0.01	5.0E-09

[a] [NCRP 90]
[b] [TSP 92]
[c] [SH 92]

Table 17

Lifetime Risks of Death

	Lifetime Risk[a]	Total Dose (mrem)
Onsite Worker[b] (300 m N)		
Baseline Emissions Estimate	0.0000012	2.4
High Emissions Estimate	0.0000037	7.4
Subsistence Farmer[c] (11,770 m NNW)		
Baseline Emissions Estimate	0.00000022	0.44
High Emissions Estimate	0.0000011	2.3
MEI[c] (11,770m NNW)		
Baseline Emissions Estimate	0.00000012	0.24
High Emissions Estimate	0.00000094	1.9
Average Individual (Baseline)		
11,770 m NNW	0.0000001	0.20
16,100 m NNW	0.000000076	0.15
32,200 m NNW	0.000000041	0.081
16,100 NE	0.000000087	0.17
32,200 NE	0.000000047	0.093
Soil Ingestion (11,770 m NNW)		
Baseline Emissions Estimate	0.000000015	0.029
High Emissions Estimate	0.0000001	0.21
Background Radiation		
Natural Sources Only	0.011	21,000
Natural and Manmade Sources	0.013	25,200
Chest X-ray (modern equipment)	0.0035	700
One-way Airplane flight from New York City to Los Angeles	0.000088	175
Wearing Eyeglasses	0.00000035	0.70
All Home Accidents[d]	0.0077	
Lightning[d]	0.000035	
Motor Vehicles[d]	0.12	
Smoking, all effects[d]	0.21	
Eating four tablespoons of peanut butter per day[d]	0.00056	

[a] 70-year lifetime for CIF results, it is based on the integrated dose from 0 - 70 years.

[b] Worker Integrated 45-year dose [assessment times 0 - 45 years]

[c] Integrated Dose after closure, determined based on average individual scenario after closure on a nuclide-by-nuclide basis.

[d] From Ref [TR 89]

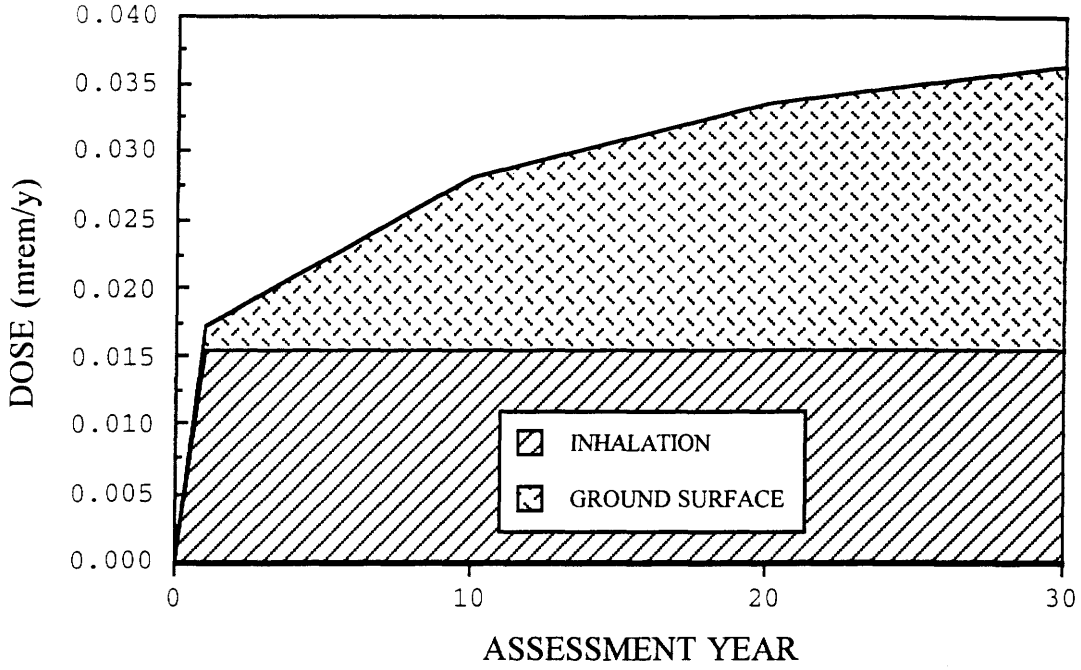

Figure 1. The Effective Dose Equivalent by Pathway for the On-Site Worker Scenario for Assessment Times Through 30 Years and the Baseline Emissions Estimate.

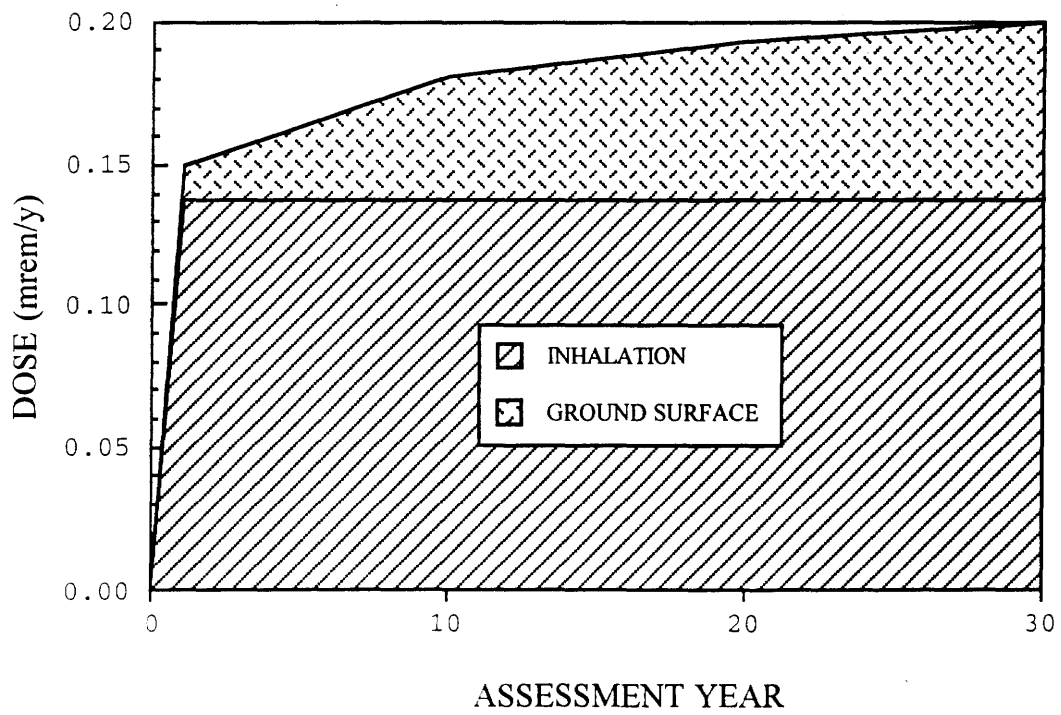

Figure 2. The Effective Dose Equivalent by Pathway for the On-Site Worker Scenario for Assessment Times Through 30 Years and the High Emissions Estimate.

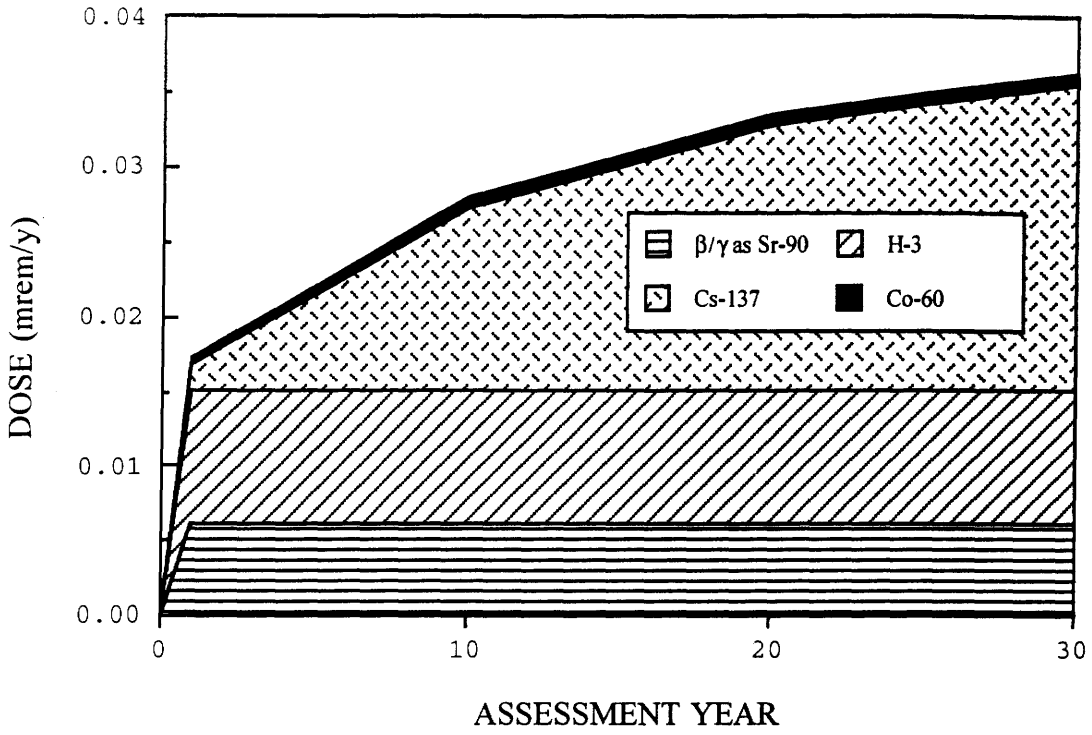

Figure 3. The On-Site Worker Scenario (350 m NNW) Effective Dose Equivalent by Principal Nuclide for Assessment Times Through 30 Years and the CIF Baseline Emissions Estimate.

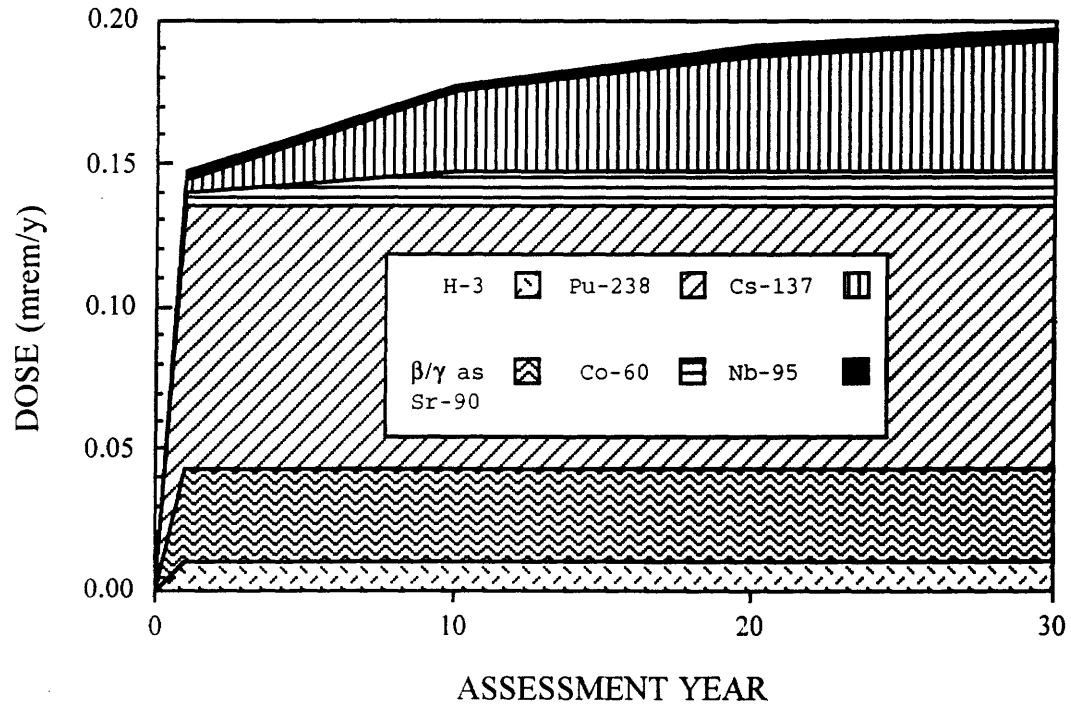

Figure 4. The On-Site Worker Scenario (350 m NNW) Effective Dose Equivalent by Principal Nuclide for Assessment Times Through 30 Years and the CIF High Emissions Estimate.

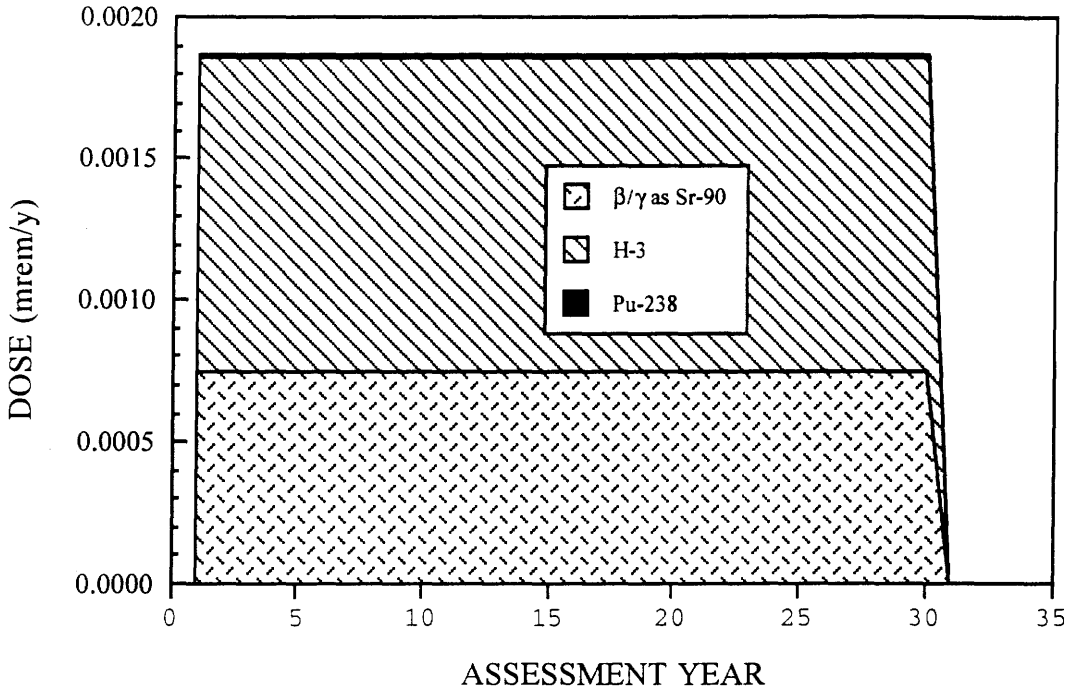

Figure 5. Inhalation Pathway Effective Dose Equivalent for the Baseline Emissions Estimate by Principal Contributing Radionclides for a Person located at 11770 m NNW of the CIF as a Function of Assessment Year. The CIF will cease operation after 30 years. After that time, only resuspension of radionuclides from the soil can contribute to the inhalation dose.

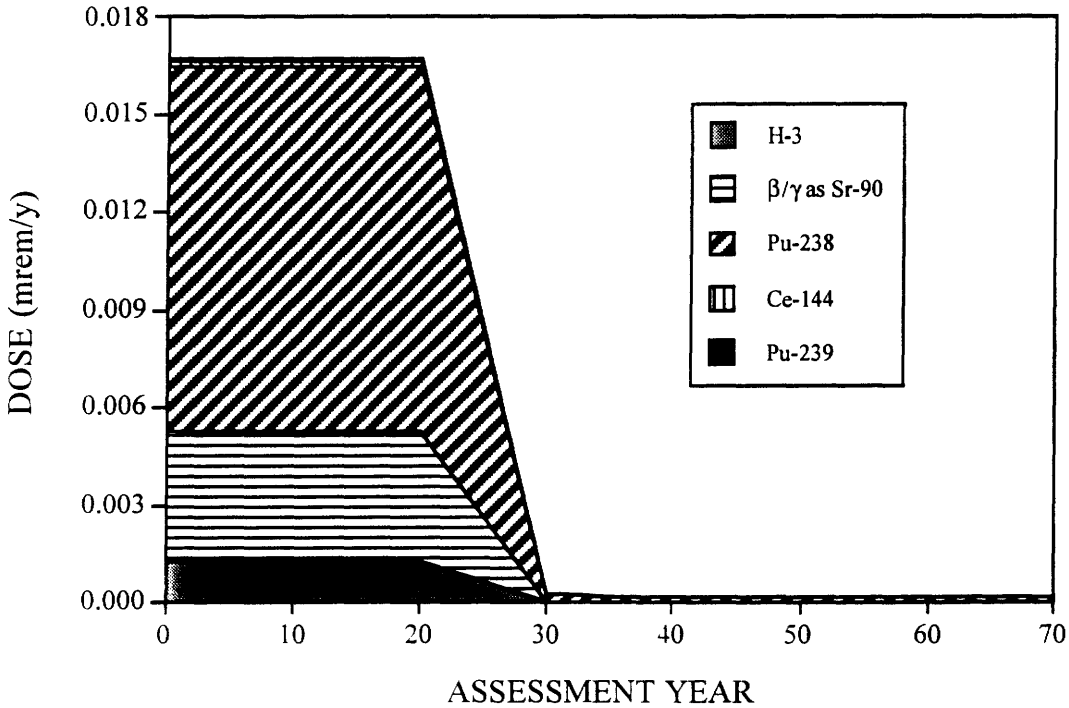

Figure 6. Inhalation Pathway Effective Dose Equivalent for the High Emissions Estimate by Principal Contributing Radionclides for a Person located at 11770 m NNW of the CIF as a Function of Assessment Year. The CIF will cease operation after 30 years. After that time, only resuspension of radionuclides from the soil can contribute to the inhalation dose.

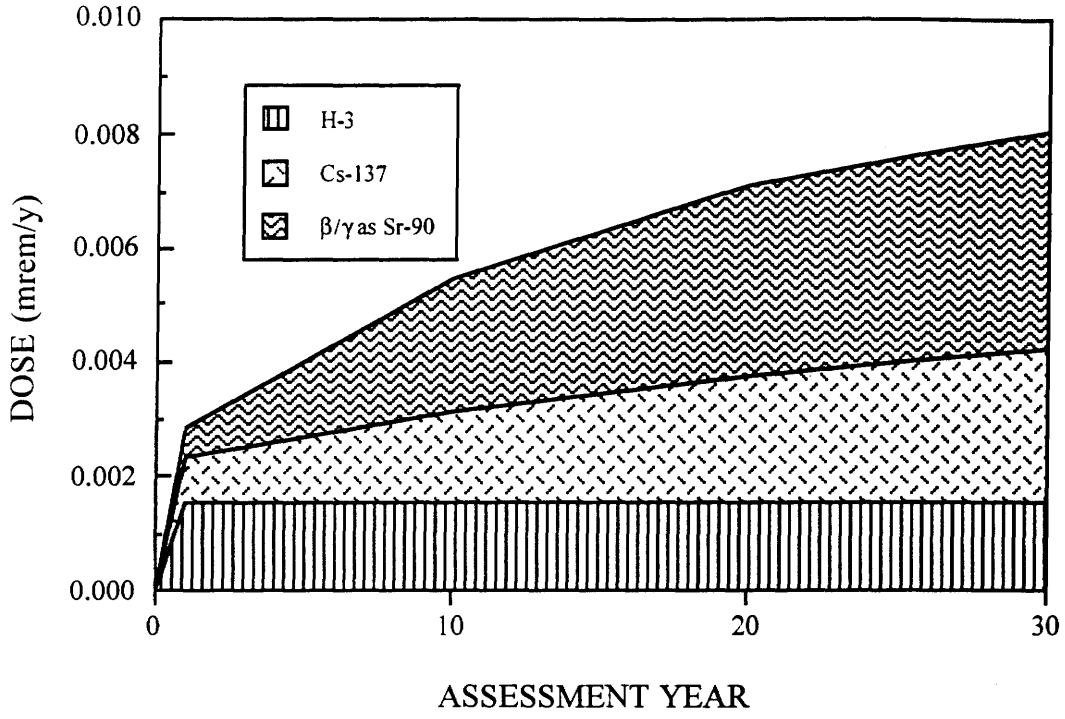

Figure 7. Subsistence Farmer Scenario Ingestion Pathway Effective Dose Equivalent for the Baseline Emissions Estimate by Principal Contributing Radionclides at 11770 m NNW of the CIF Through Assessment Year 30. The CIF will cease operation after 30 years.

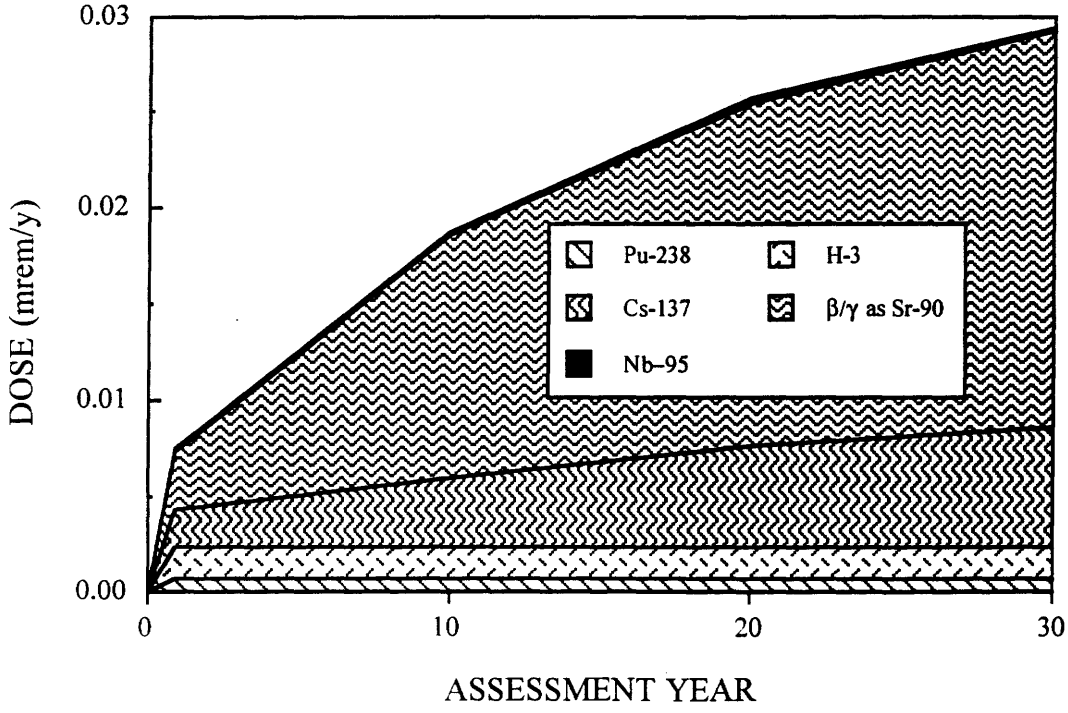

Figure 8. Subsistence Farmer Scenario Ingestion Pathway Effective Dose Equivalent for the High Emissions Estimate by Principal Contributing Radionclides at 11770 m NNW of the CIF Up Through Assessment Year 30. The CIF will cease operation after 30 years.

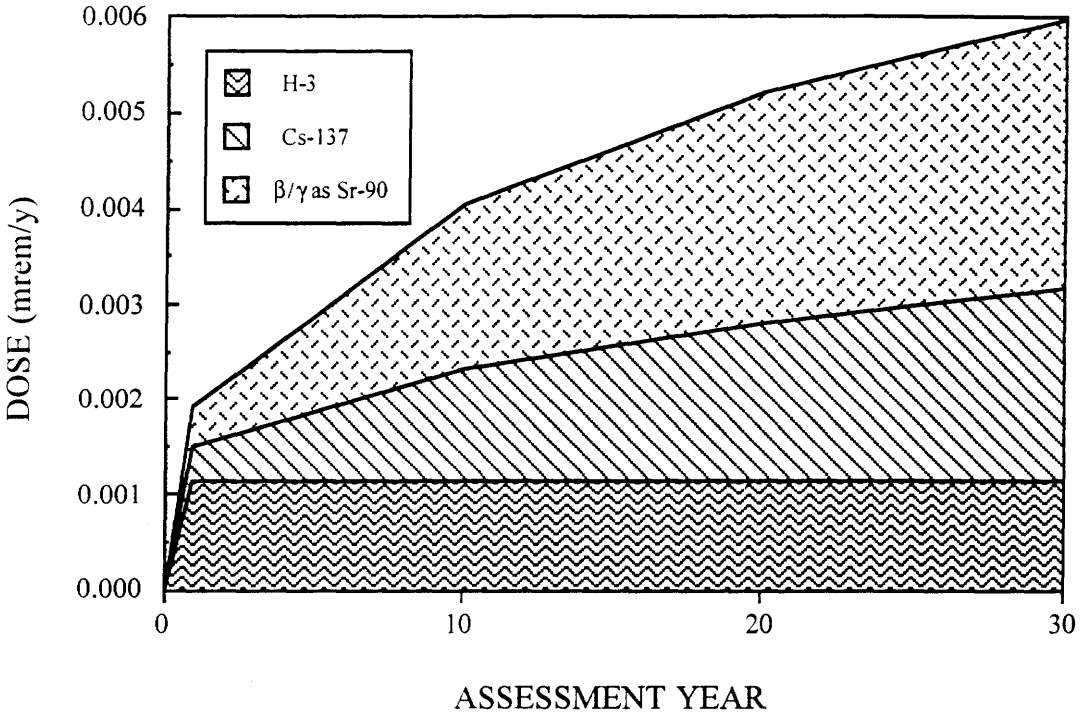

Figure 9. MEI Scenario Ingestion Pathway Effective Dose Equivalent for the Baseline Emissions Estimate by Principal Contributing Radionclides at 11770 m NNW of the CIF Up Through Assessment Year 30. The CIF will cease operation after 30 years.

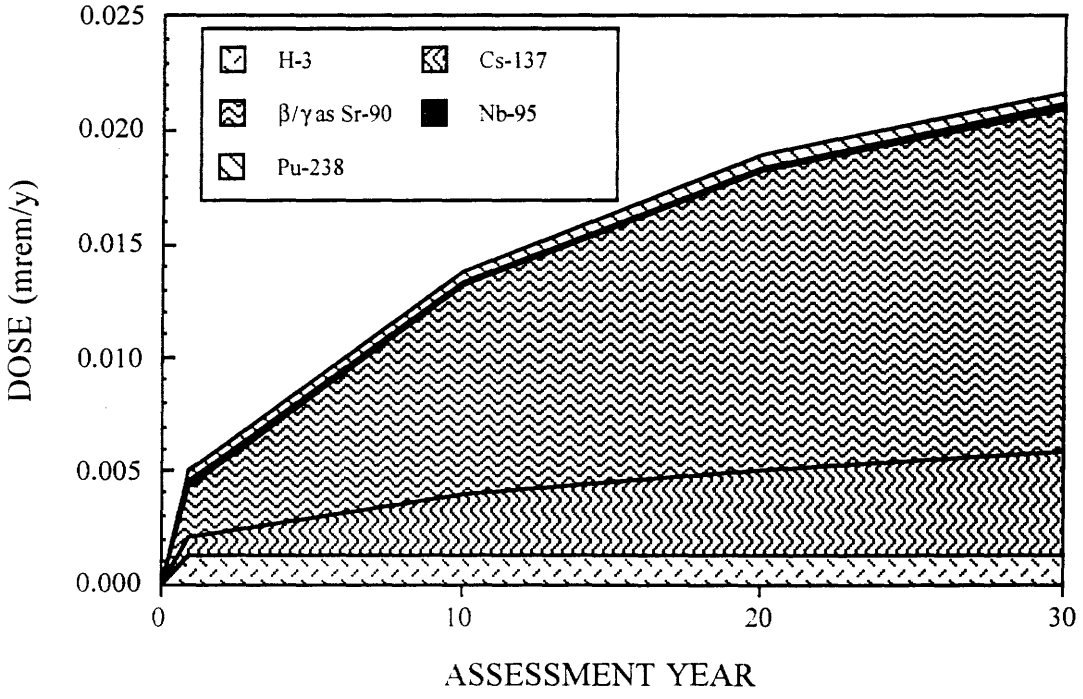

Figure 10. MEI Scenario Ingestion Pathway Effective Dose Equivalent for the High Emissions Estimate by Principal Contributing Radionclides at 11770 m NNW of the CIF Up Through Assessment Year 30. The CIF will cease operation after 30 years.

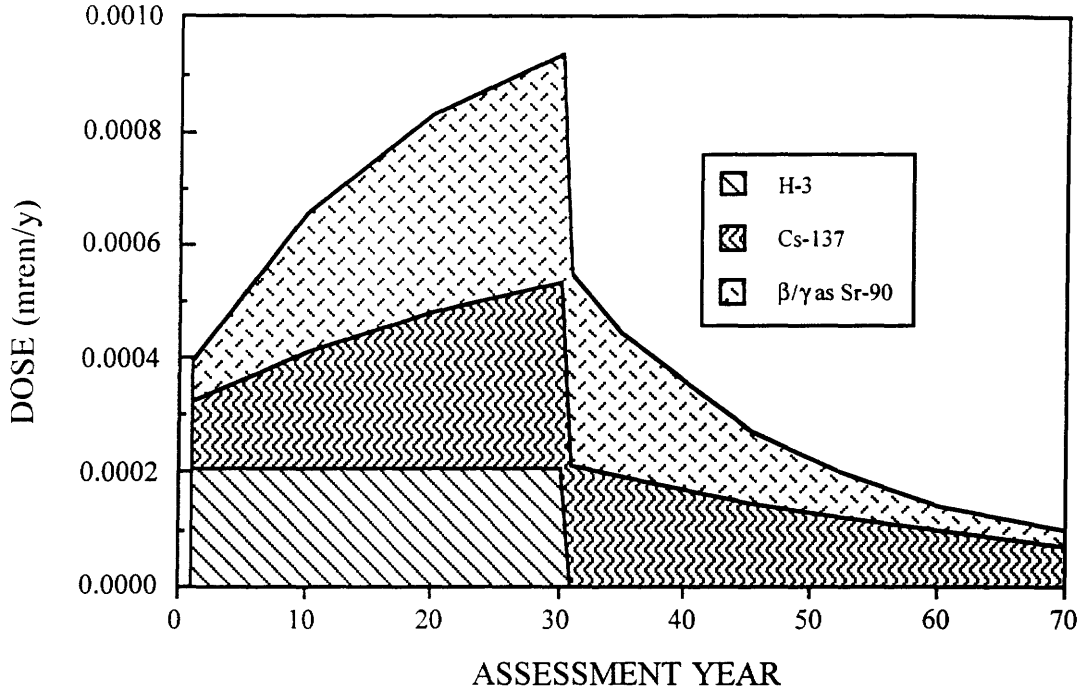

Figure 11. Average Individual Scenario Ingestion Effective Dose Equivalent for the Baseline Emissions Estimate by Principal Dose-Contributing Radionuclide at 11770 m NNW of the CIF Up Through Assessment Year 70. The CIF will cease operation after 30 years.

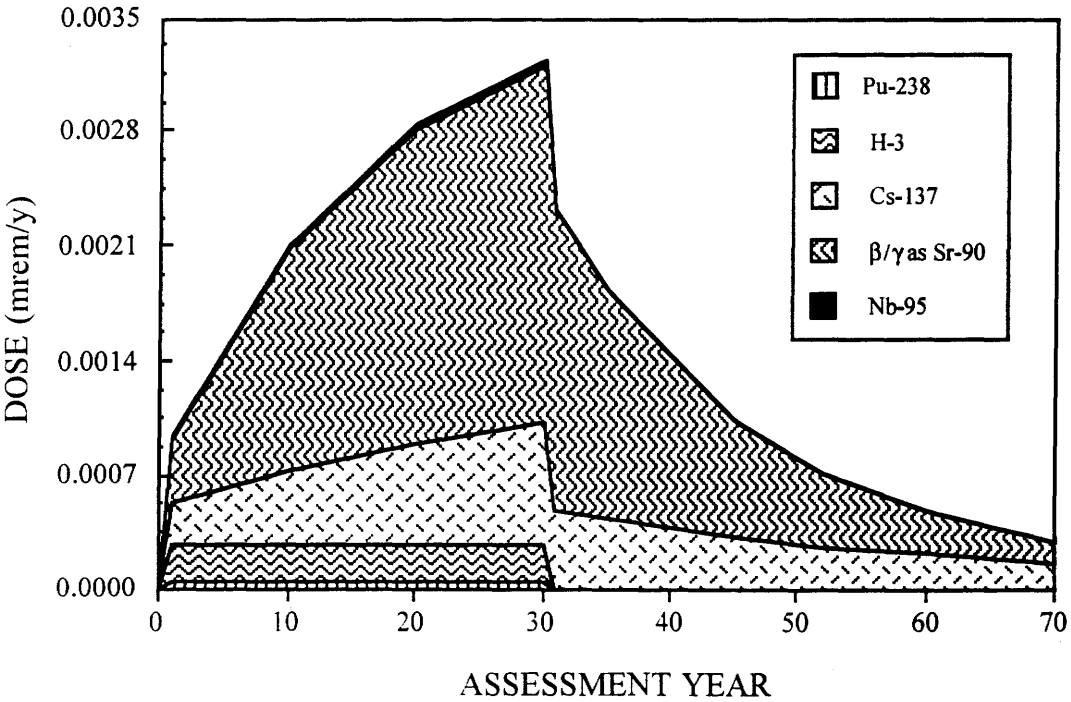

Figure 12. Average Individual Scenario Ingestion Effective Dose Equivalent for the High Emissions Estimate by Principal Dose-Contributing Radionuclide at 11770 m NNW of the CIF Up Through Assessment Year 70. The CIF will cease operation after 30 years.

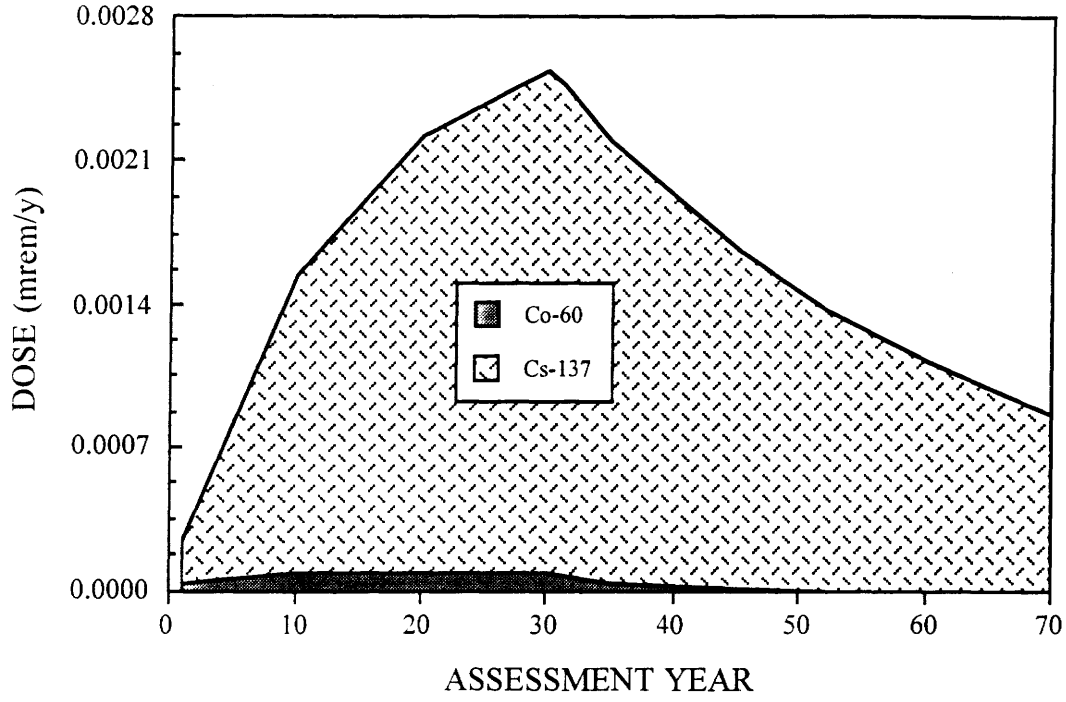

Figure 13. Ground Surface Irradiation Pathway Effective Dose Equivalent for the Baseline Emissions Estimate by Principal Contributing Radionclides at 11770 m NNW of the CIF Up Through Assessment Year 30. The CIF will cease operation after 70 years.

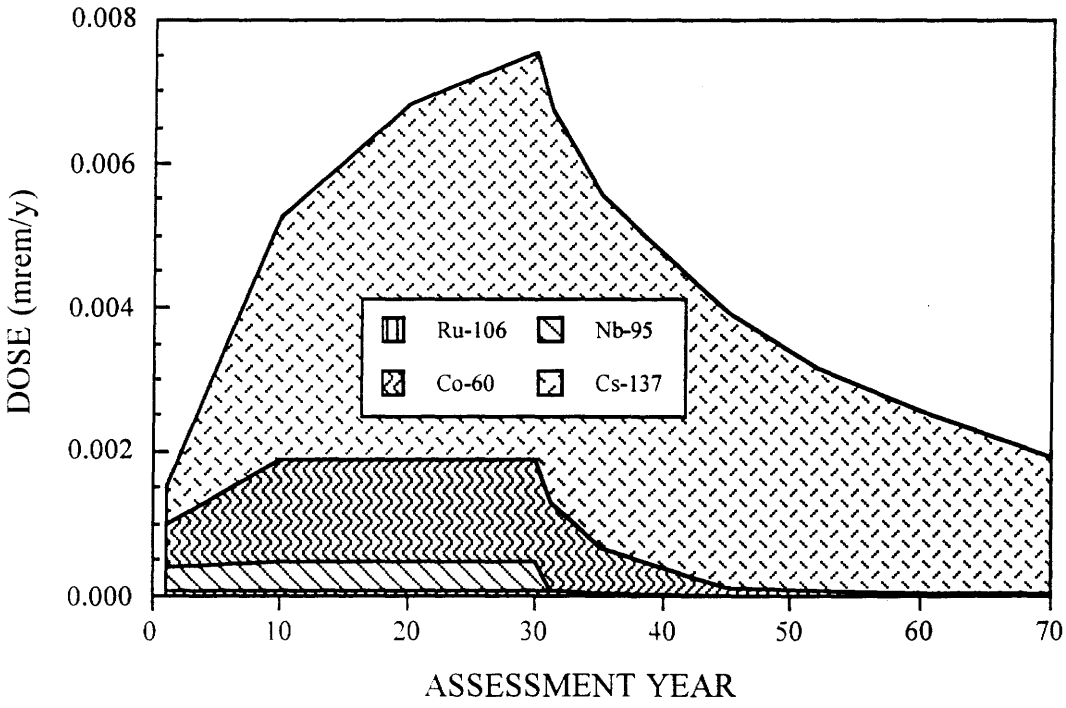

Figure 14. Ground Surface Irradiation Pathway Effective Dose Equivalent for the High Emissions Estimate by Principal Contributing Radionclides at 11770 m NNW of the CIF Up Through Assessment Year 70. The CIF will cease operation after 30 years.

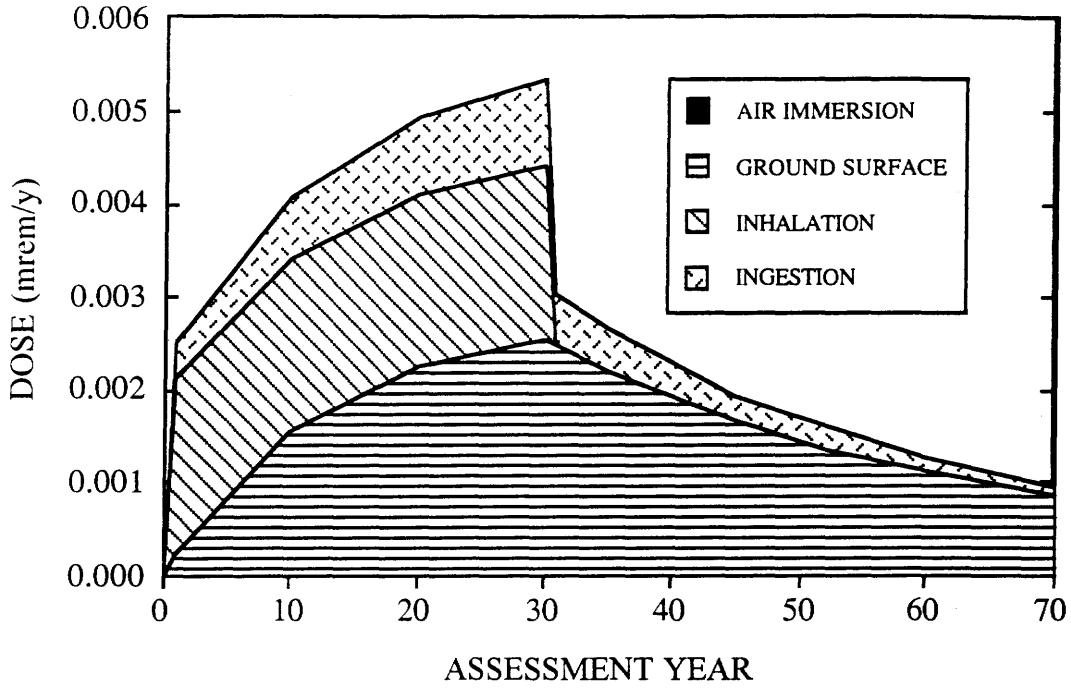

Figure 15. Average Individual Scenario Total Effective Dose Equivalent for the Baseline Emissions Estimate by Pathway at 11770 m NNW of the CIF Up Through Assessment Year 30. The CIF will cease operation after 70 years.

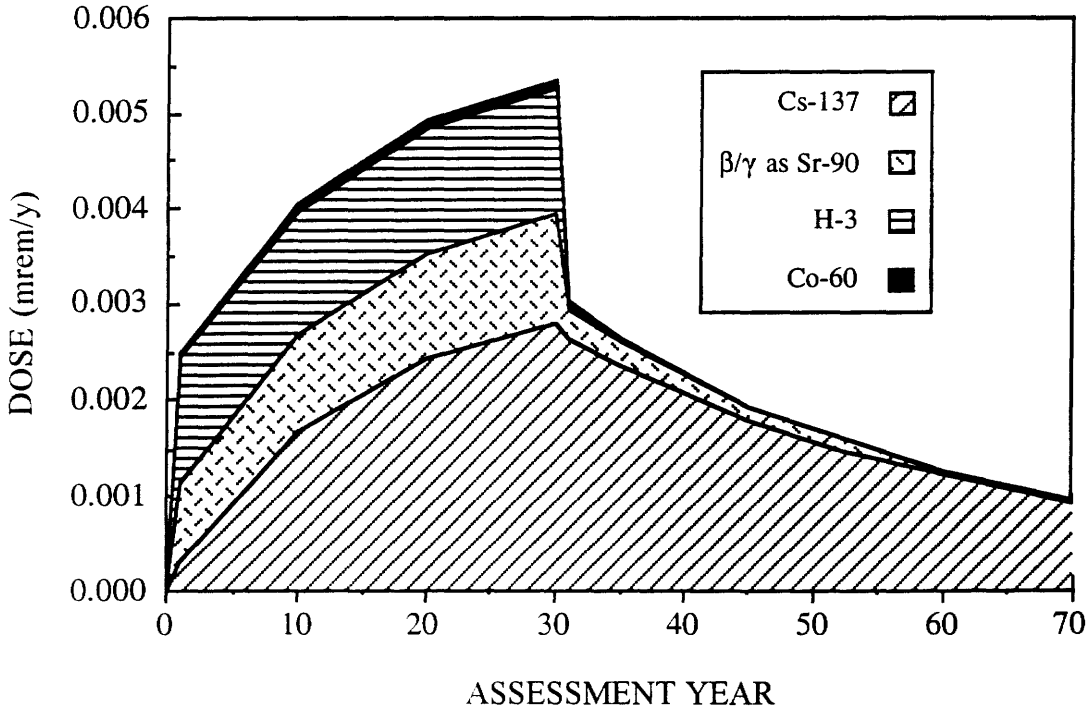

Figure 16. Average Individual Scenario Total Effective Dose Equivalent for the Baseline Emissions Estimate by Principal Dose-Contributing Radionuclide at 11770 m NNW of the CIF Up Through Assessment Year 70. The CIF will cease operation after 30 years.

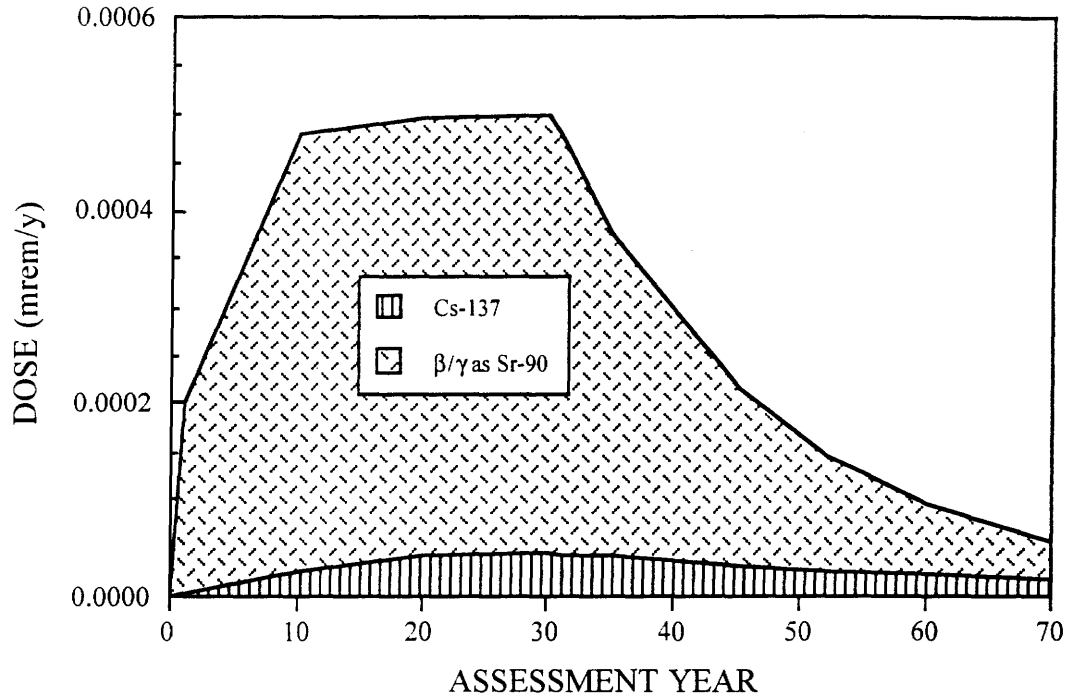

Figure 17. Effective Dose Equivalent for the Ingestion of 25 mg of Soil per day for the Baseline Emissions Estimate by Principal Dose-Contributing Radionuclide at 11770 m NNW of the CIF Up Through Assessment Year 70. The CIF will cease operation after 30 years.

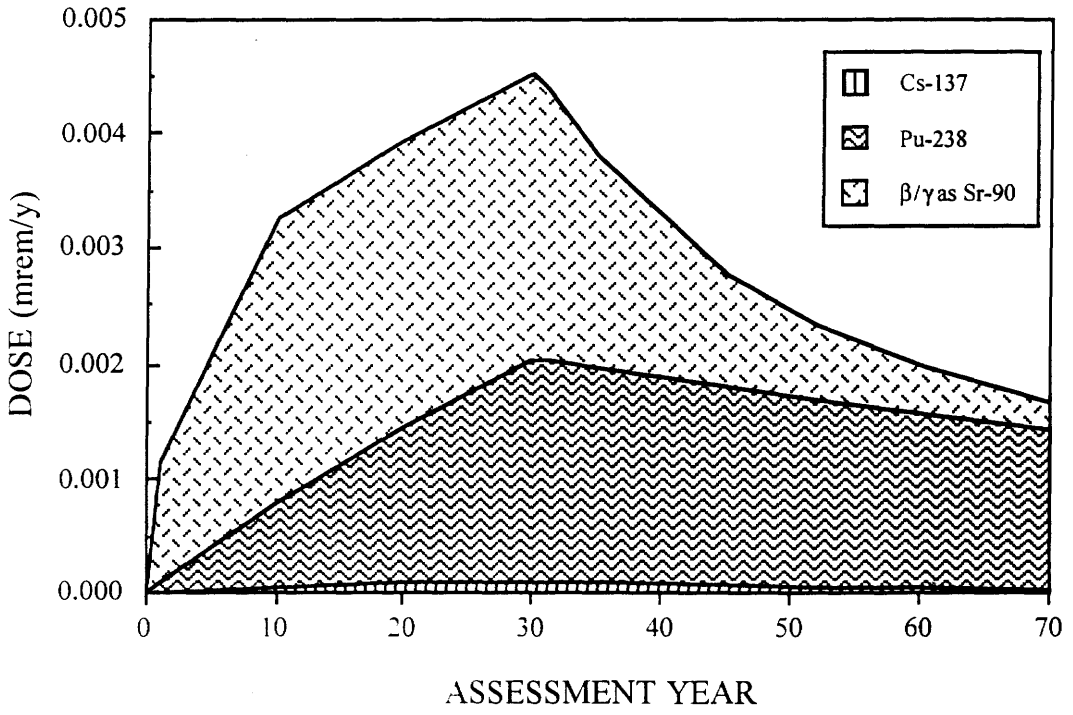

Figure 18. Effective Dose Equivalent for the Ingestion of 25 mg of Soil per day for the High Emissions Estimate by Principal Dose-Contributing Radionuclide at 11770 m NNW of the CIF Up Through Assessment Year 70. The CIF will cease operation after 30 years.

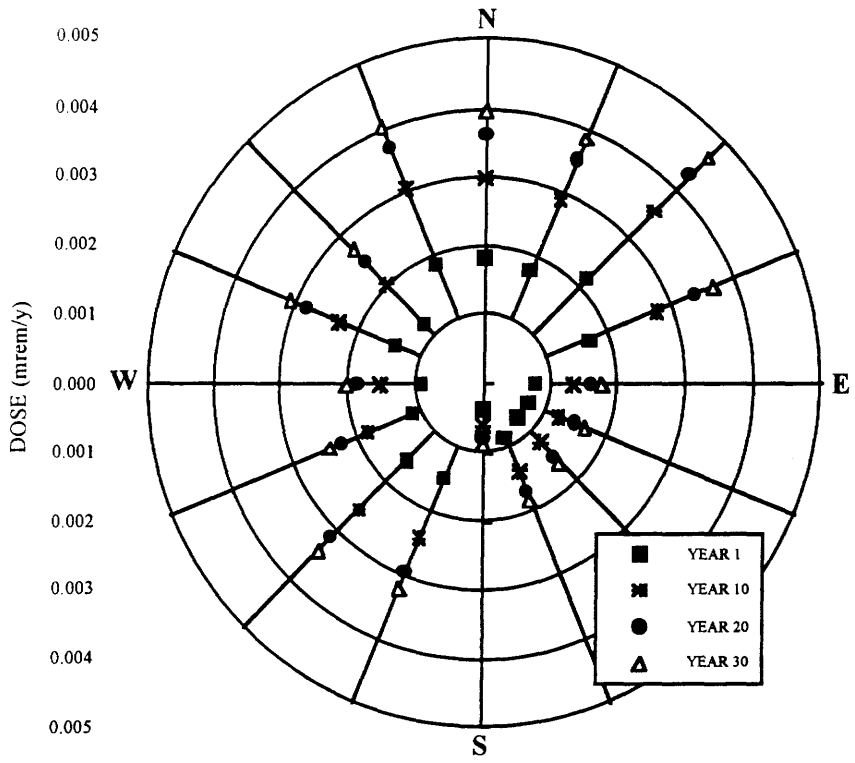

Figure 19. The Average Individual Scenario Effective Dose Equivalent at a Distance of 16,100 m for the 16 Cardinal Compass Directions from the CIF by Assessment Year Through 30 Years of Operation. The dose distributions follow the wind frequency pattern when adjusted for stability class effects.

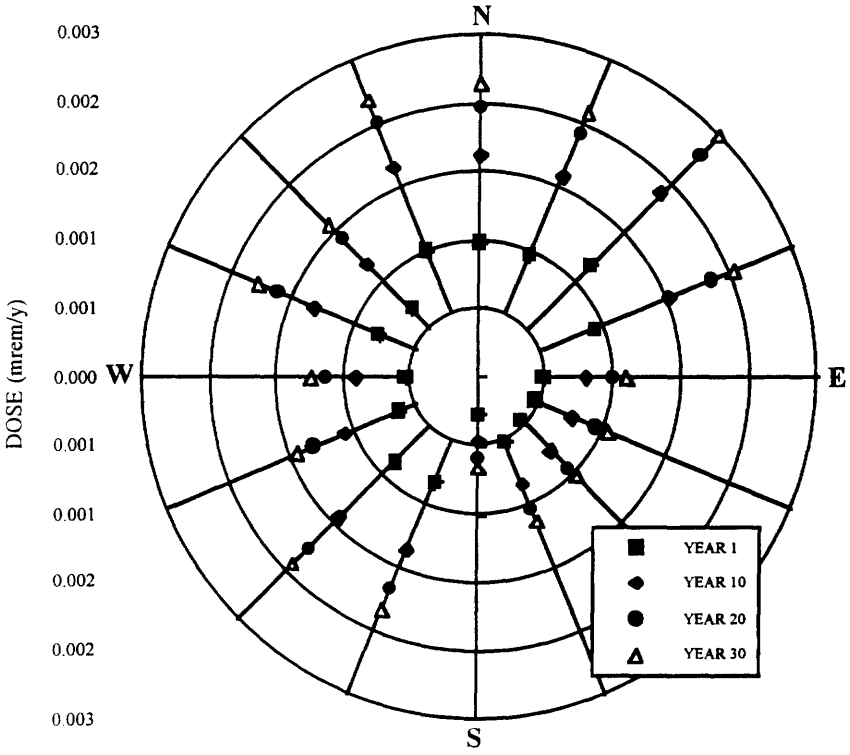

Figure 20. The Average Individual Scenario Effective Dose Equivalent at a Distance of 32,200 m for the 16 Cardinal Compass Directions from the CIF by Assessment Year Through 30 Years of Operation. The dose distributions follow the wind frequency pattern when adjusted for stability class effects.

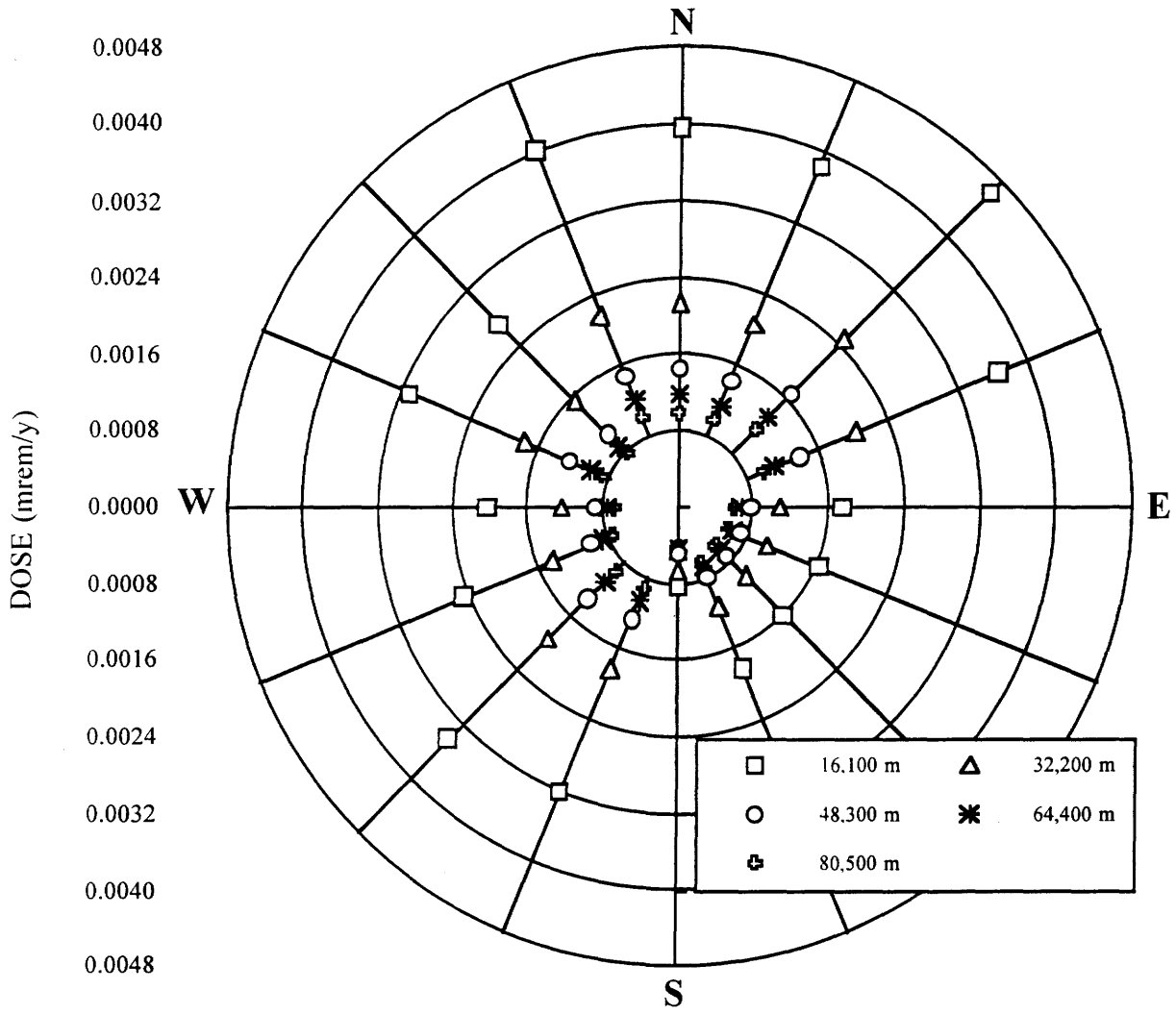

Figure 21. The Average Individual Scenario Effective Dose Equivalent for a 30 Year Assessment Period from 16,100 m (10 miles) to 80,500 m (50 miles) for the 16 Cardinal Compass Directions from the CIF. The dose distributions follow the wind frequency pattern when adjusted for stability class effects.

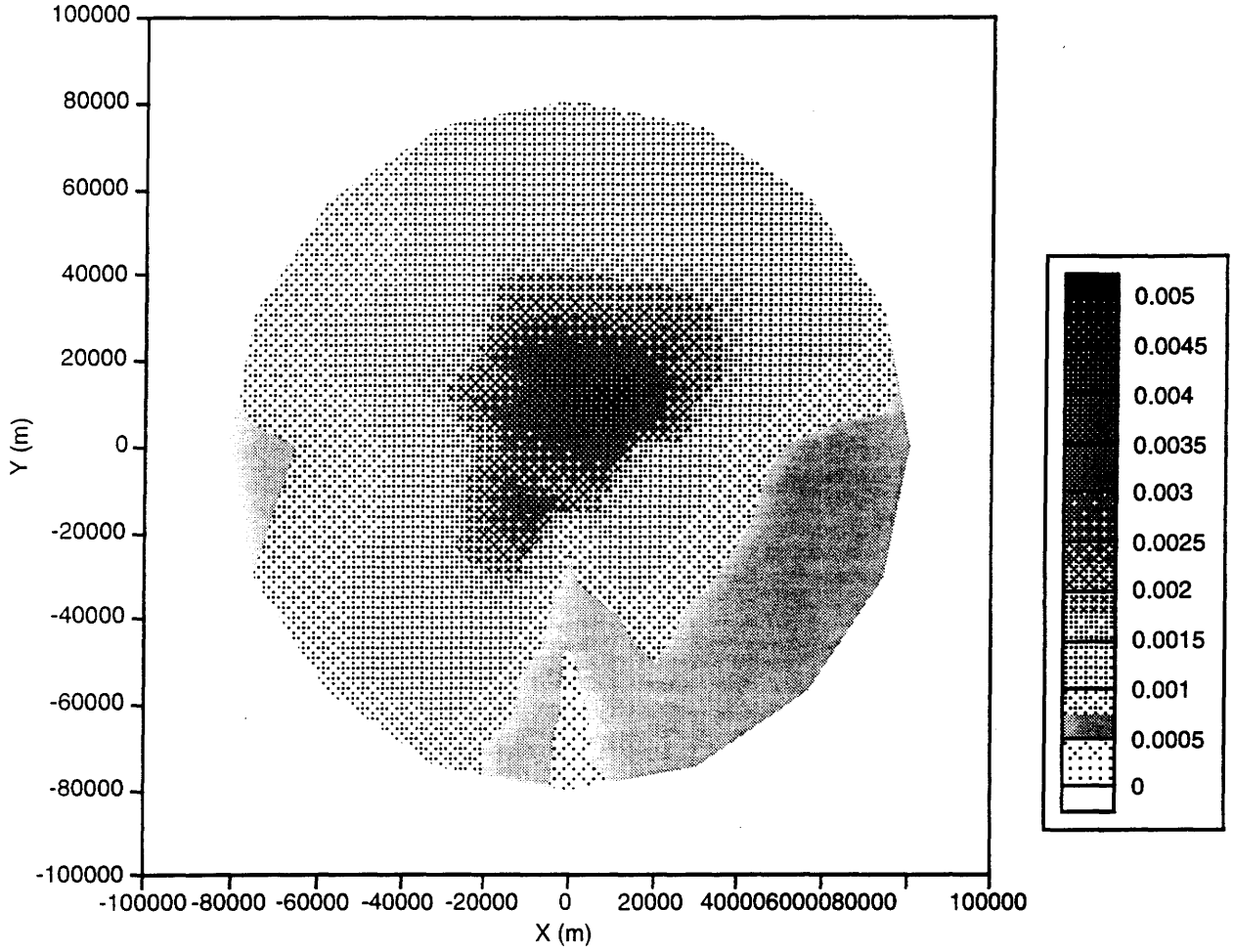

Figure 22. Average Individual Effective Dose Equivalent (mrem/y) Contour for an Assessment Time of 30 Years. The contour extends out to 80.500 m from the CIF, located at X=0 and Y=0 m. The direction North is towards the top of the page.

APPENDIX A

CRRIS INPUT DATA CHANGES AND SIGNIFICANT OPTION SELECTIONS

ANEMOS

Distances/Directions

11770, 16100, 32200, 48300, 64000, and 80500 meters in 16 cardinal compass directions

Radionuclide Data

The following radionuclides were modeled. The release rate was set to 1 Ci/sec. A value of 1 μm was used for the nuclide particle diameter with the exception of tritium which was zero because it's a gas. β/γ as Sr-90 was chosen to model additional β/γ emitting nuclides because of SRS activities.

H-3, Cr-51, Co-60, Sr-89, Sr-90, Y-90, Y-91, ZR-95, Nb-95, Ru-106, Rh-106, Cs-137, Ba-137m, Ce-144, Pr-144, Pr-144m, Pm-147, Pu-238, Pu-239, β/γ as Sr-90

Latitude and Longitude

33.29 degrees latitude and 81.64 degrees longitude.[DOE 88]

Stack Data

The stack height was set to 45.72 meters.[DOE 88] The effective height calculation in ANEMOS was found to be incorrectly functioning by N.E. Hertel. So, no plume rise was used, this is conservative.

Default stack exit velocity:	0.001 m/s.
Stack inner diameter:	0 meters.
Stack exit temperature:	18 degrees Celsius.

Deposition Data

The option to calculate dry deposition removal rates was selected. The code computed values for minimum gravitational settling were used or 0.0 if less than 0.01 m/sec. Deposition velocities for the radionuclide were set to 0.01 m/sec. For tritium it was set to 0 because it is a gas.

Terrain Data

The terrain surface roughness length was set to 0.4 meters. [HA 94A] A copy of terrain data used for the actual distances, supplied by D. Burge, is provided in Table A-1. [BU 94A] Values at 7 miles were used to represent 11770 meters (~7.5 miles). Remaining terrain data distances correspond identically to 10, 20, 30, 40, and 50 miles.

Meteorological Data

Ambient air temperature was set to 18 degrees Celsius.[DOE 88] The default air density of 1.317e-3 g/cm^3 was used at. Morning and afternoon mixing heights of 400 and 1400 meters were used, taken from AGDATA base.[ORNL 87] The annual rainfall was set to 1224 mm.[DOE 88]

The average rainfall rate is assumed by the code to occur during atmospheric stability classes C and D. It is 9.23E-8 m/s since stability classes C and D occur 42% of the time [the total average rainfall = .42 x 114 in/yr = 122 cm/yr].

Wind speed data for SRS was used. [SIM 94A]. This data was reported in terms of the six wind speed classes and seven stability classes for the 16 cardinal directions. (Six wind speed classes: 1.0, 3.0, 5.0, 7.0, 10.0, and 13.0 m/s. Seven stability classes: A, B, C, D, E, F, G.) The height of the wind speed measurements reported by SRS was 62 meters. This data was averaged over the five-year period from 1987 - 1991 and was gathered from the H Area meteorological tower.

Table A-1

Table of Maximum Relative Terrain Heights Out to Listed Distances by Compass Sector, Feet Above Grade Elevation (With Respect to Grade Elevation = 256 ft. Above Mean-Sea-Level at Base of Stack)

miles	n	nne	ne	ene	e	ese	se	sse	s	ssw	sw	ws w	w	wn w	nw	nn w
1	44	14	24	44	44	44	44	44	44	44	44	44	44	44	44	44
2	44	44	44	44	44	45	58	44	44	44	44	44	44	44	44	44
3	44	44	44	44	44	84	84	80	44	44	44	44	44	44	44	44
4	44	44	44	44	44	84	84	80	44	44	44	44	44	44	77	47
5	57	59	46	44	44	84	84	80	44	44	44	44	44	44	97	104
6	73	64	53	44	44	84	84	80	44	44	44	44	65	71	110	128
7	74	64	58	57	44	84	84	80	44	44	44	44	94	107	144	144
8	76	83	60	67	44	84	84	80	44	44	44	44	94	115	144	171
9	90	107	84	74	44	84	84	80	44	44	44	44	94	115	144	201
10	144	144	115	82	44	84	84	80	44	44	44	44	94	144	154	204
12	191	149	144	90	44	84	84	80	44	44	44	44	94	144	154	204
14	194	159	145	99	44	84	84	80	44	44	44	44	94	144	169	231
16	208	192	145	101	44	84	84	80	44	44	44	44	94	144	173	244
18	247	192	145	101	44	84	84	80	44	44	44	44	94	144	204	274
20	255	192	145	101	44	84	84	80	44	44	44	54	94	144	204	277
25	284	227	172	101	44	84	84	80	44	44	63	94	139	144	244	294
30	312	274	225	101	44	84	84	80	44	84	114	94	207	244	304	354
35	354	274	225	101	44	84	84	80	44	94	114	154	264	284	304	412
40	404	306	244	101	44	84	84	80	44	94	144	184	264	284	304	414
45	424	394	284	101	44	84	84	80	44	94	144	184	264	284	304	414
50	424	394	284	135	44	84	84	80	44	94	144	184	274	344	304	414

TERRA

Assessment Time

The following assessment times were used: 1, 10, 20, 30, 31, 35, 45, 52, 60, 70 years for the average individual scenario and 1, 10, 20, and 30 years for the MEI, subsistence farmer, and worker scenarios.

Length of Facility Operation/Soil Buildup Time

The length of time the facility operates is 30 years. For assessment times greater than 30 years, radionuclides concentrations in the soil will diminish because no radionuclides are being emitted from the CIF.

Resuspension

The soil resuspension option was selected.

Changes were made to the following radionuclide parameters (default values were used otherwise):

Soil-to-plant bioaccumulation factor in vegetative portions of plants:

Sr	1.60e00	Whicker memorandum [WH 94A]
Cs	6.40e-01	Whicker memorandum [WH 94A]
Th	3.50e-04	Whicker memorandum [WH 94A]
U	1.20e-03	Whicker memorandum [WH 94A]
Pu	5.70e-04	Whicker memorandum [WH 94A]
Co	7.88e-01	Whicker analysis of Cummins' report [WH 94C, CU 94]

Soil-to-plant bioaccumulation factor in reproductive portions of plants:

Sr	1.33e00	Whicker analysis of Cummins' Data [WH 94C, CU 94]
Cs	6.20e-01	Whicker memorandum [WH 94A]
Th	9.20e-05	Whicker memorandum [WH 94A]
U	2.90e-04	Whicker memorandum [WH 94A]
Pu	9.20e-05	Whicker memorandum [WH 94A]
Co	2.76e-01	Whicker analysis of Cummins' Data [WH 94C, CU 94]

H_2O Content of Soil

The volumetric water content of soil was set to 0.3 $m\ell/cm^3$.[LOO 87]

Soil Depth for Exposure Calculations

The depth of soil at which soil exposure concentrations was 1 cm default. This soil depth is also used to perform soil ingestion doses.

Air Dust Loading

An air dust loading value of 40 $\mu g/m^3$ in the SRS resuspension model was used.[WHI 94C]

Soil Bulk Density

The soil bulk density was set to 1.6 g/cm^3.[LOO 87]

Hydrogen Fraction

The fraction of hydrogen derived from atmospheric air was set to 0.54.[HA 94B]

Vegetation Exposure Time

The time between germination and harvest of exposed produce was set to 70 days. The time between germination and harvest of hay feed was set to 30 days.[HA 91]

All other values were the TERRA default values.

Summary of SITE (AGDATA) Database Changes [ORNL 87]

From distance 11770 to 80500 m (off-site locations), the numbers of milk and beef cows, production of leafy, exposed, and protected vegetables as well as production of grain for human consumption were taken from Hamby. [HA 91] The yield of leafy vegetables was changed to reflect Hamby's value of 0.7 kg/m^2. Both the cattle and calf inventory and the number of cattle on feed sold was set equal to zero under the assumption that these were included in the livestock numbers.

The population numbers were changed using 1990 census data. [SIM 94B]

Average absolute annual humidity was 11.25 g/m^3.[HA 93]

All other site data used were default values in the AGDATA collection.

ANDROS

Food Storage Time

The storage time for beef and milk was set to 6 and 3 days respectively.[HA 91]

Effective Dose Equivalent

The time in years for which the internal dose factors are selected was set to 50 as recommended by ICRP 26.[ICRP 77]

Milk Production

The annual production of milk per milk cow was set to 5475 kg.[HA 91]

Cow Weight

The average weight per head of cow was set to 452 kg to be consistent with values from TERRA.

Organ Weighted Averages

The organ dose weighting factors used reflected ICRP Publication 26 methodology.[ICRP 77]

Organ	Weighting Factor
Bone	0.03
Testes	0.125
Breast	0.15
Ovaries	0.125
Red Marrow	0.12
Pulmonary	0.12
Thyroid	0.03
Other	0.30

Consumption Parameters (kg/yr)

	Default	Average	Maximum
Leafy	14	21	43
Exposed	30	43*	74*
Protected	56	80*	138*
Grain	75	37	64
Beef	65	43	81
Milk	112	120	230

The consumption parameters were derived from Hamby. [HA 91]

Intake Fractions

Production Area

F1 Within the local sector (home grown) of the dose calculation.
F2 Within the total assessment area.
F3 Imported from outside the assessment area.

	Farmer			MEI			Average Individual		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
Leafy	0.95	0.05	0.00	0.70	0.00	0.30	0.08	0.18	0.74
Exposed	0.95	0.05	0.00	0.70	0.00	0.30	0.08	0.26	0.66
Protected	0.95	0.05	0.00	0.70	0.00	0.30	0.08	0.24	0.68
Grain	0.95	0.05	0.00	0.70	0.00	0.30	0.08	0.37	0.55
Beef	0.44	0.56	0.00	0.44	0.00	0.56	0.08	0.00	0.92
Milk	0.40	0.60	0.00	0.44	0.00	0.56	0.12	0.61	0.27

The intake values were derived from the following sources. The farmer fractions were from *EPA Draft Guidance for Performing Screening Level Risk Analysis at Combustion Facilities Burning Hazardous Waste.*[US EPA 94] The MEI, Maximally exposed individual, fractions were CAP-88 default values, with F2 and F3 switched.[US EPA 90A] F1 for the average individual was from Cap-88 urban values. F2 was from the EPA *Methodology for Assessing Health Risks Associated with Indirect Exposures to Combustor Emissions Interim Final* [US EPA 90B] with the exception that F2 for milk was an averaged number from *Land and Water Use Characteristics in the Vicinity of Savannah River Site (U).*[HA 91] F3 was calculated so that the fractions would sum to unity.