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Simulation of Atmospheric Dispersion of a Radioactive Plume Including Sensible Heat (U)

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Abstract

A postulated fire scenario in a Savannah River Site (SRS) laboratory facility could result in release of radioactive materials to the environment. The Technology Center is located in the general proximity of the site boundary. The relatively short distance to potential offsite receptors makes it important to consider the effects of plume rise and the effects of the sensible heat of the escaping combustion products. The potential consequences from the airborne release are calculated with the MACCS, Version 1.5.11.1, computer code. Calculation of atmospheric dispersion without consideration of plume rise results in a monotonically decreasing dose response. When the plume rise is modeled in the dose calculation, the results show that the cloud touchdown point and the location of highest off-site dose do not follow a monotonically decreasing pattern.

Introduction

The laboratory facility consists of several buildings and structures housing laboratories and offices. Many of the laboratories are equipped for radiological operations. The facility is located within a short distance from the public boundary of SRS. The safety program requires analysis of potential accidents, including a postulated full facility fire that engulfs and destroys the entire main laboratory building, producing a radioactive plume of combustion products. It is with the dispersion of the radioactive plume, including sensible heat effects, that the current simulation analysis is concerned.

Accident Description

The airborne release of radioactive materials from the main laboratory building resulting from a full facility fire is considered. Fire suppression equipment installed in the building is assumed to fail. Two distinct source terms are considered: the unmitigated and the mitigated source terms. In the unmitigated source term, all protective features, both active and passive, are assumed to fail and be breached. The mitigated source term assumes that passive protective measures are not challenged sufficiently to result in failure. Each source term has an immediate phase and a resuspension release phase that extend over five separate building segments. Radioactive dose receptors are the maximum exposed offsite individual (MOI) using 95% sector independent meteorology, and the 100 meter occupationally exposed person (OEP), using 50% sector independent meteorology.

The potential consequences from the airborne release are calculated with the MACCS computer code.[1-4]

Each source term results from two distinct release plumes. In the initial plume, the fire sensible heat is considered to increase the initial atmospheric dispersion. This has drastic effects on the radiological dose: the thermal plume tends to reduce doses at close distances while increasing doses at farther distances when compared to doses calculated assuming a standard Gaussian plume distribution. The second plume includes the smoldering stage of the fire after most of the combustible material has been consumed, resulting in a plume with no sensible heat.

CALCULATIONAL METHOD

The source term of each plume was determined by performing a fire protection analysis. The source term identified major dose contributors (eg. Fission products, tritium, transuranics) from the inventory database. Most radionuclides of concern were found in the MACCS code radioisotope library[1]. For radioisotopes not available in the MACCS library, the source term was modified to include radioisotopes with similar dose to activity ratios. A typical modified source term is presented in Table 1.

The radiological analysis was performed using the MELCOR Accident Computer Code System (MACCS), version 1.5.11.1. MACCS was developed by Sandia National Laboratory under support from the United Stated Nuclear Regulatory Commission (USNRC). MACCS Version 1.5.11.1 is a maintenance release version of the MACCS 1.5.11 code, the primary probabilistic consequence assessment (PCA) code used by the USNRC.

MACCS is executed in a three-step sequence on a VAX computer under the VMS operating system. Air and ground concentrations, plume size, and timing information for all plume segments as a function of downwind distance are calculated by the first calculational module, **ATMOS**. The next module, **EARLY,** calculates the consequences due to exposure to radiation in the emergency phase of the accident that extends to seven days. The last module, **CHRONC,** calculates the consequences due to exposure to radiation subsequent to the emergency phase of the postulated accident and computes other accident consequences such as decontamination factors and economic effects. The **CHRONC** module was not used in the current analysis.

ATMOS INPUT

The ATMOS module uses two input files: an input data file and a yearly meteorological data file. The following are the major assumptions used in the analysis:

1) The radial ring endpoints are at prescribed distances ranging from 0.20 km to 32.00 km

2) The wake effects of the building are not considered.

3) At some point in the fire accident sequence the building is assumed to collapse.

4) The release height is 0 meters.

5) The activity released from the postulated accidents is as provided in the representative source term shown in Table 1.

6) Radioactive material is assumed to be released over a 5 hour period for the initial plume. The second plume is assumed to be released for 20 hours.

7) In the first plume a sensible heat of 20 MW is assumed. No sensible heat is included in the second plume.

8) Only dry deposition of non-noble gas radionuclides is considered. The deposition velocity is equal to 0.1 cm/s for all particle groups which include particle sizes ranging from 0.2 µm to 0.4 µm.

9) Latin Hypercube Sampling (LHS) with 10 samples per bin was assumed.

10) A soil surface roughness of 100 cm is assumed.

The meteorological data files used include hourly meteorological tower data obtained with measured windspeed height of 10 meters and collected in the 1987-91 time period.

EARLY INPUT

The EARLY module uses two different input files: the input data file and the dose conversion factor file. The following are the major assumptions used in the EARLY module:

1) The DOE occupational breathing rate[5] equal to 3.33 10^{-4} cubic meters per second applies.

2) No shielding is considered.

3) No evacuation and/or sheltering is considered.

Analysis results include the centerline effective dose equivalent (EDE) at 100m, and at the site boundary. Releases were assumed from the segment midpoints of the facility located at distances ranging from 650 m to 850 m from the site boundary.

A dose conversion factor file (DCF), updated to include DCF values for tritium oxide, was also input into the EARLY module.

RESULTS

For the laboratory facility fire accident, the onsite individual OEP centerline EDE at 100 meters using 50% meteorology and MOI centerline EDE using 95% meteorology at the closest boundary are given in Table 2.

The OEP centerline EDE results show that the total dose to the occupationally exposed worker under unmitigated accident conditions is equal to 10.5 rem. This dose is mostly due to the source terms calculated for two wings of the facility. Under mitigated conditions, the total dose to the occupationally exposed worker is reduced to 2 rem. This dose is mostly due to the source terms calculated for two other wings of the facility.

The MOI results show that the total dose to the maximum exposed offsite individual under unmitigated accident conditions is equal to 3.2 rem. This dose is mainly due to source terms calculated for two facility segments. Under mitigated accident conditions, the total dose to the maximum exposed offsite individual is reduced to 0.5 rem. This dose is mostly due to source terms calculated for two other facility segments.

The results also show that, in general, the resuspension phase of the fire yields OEP and MOI doses which exceed the immediate doses for both unmitigated and mitigated accident conditions.

Figure 1 shows the variations of the MOI dose with distance under mitigated accident conditions for the total facility, and for each facility component. The highest MOI dose occurs at the site boundary, although a second but slightly lower MOI occurs at about 3 km from the point of release. This slightly elevated dose is due to the dispersion effects induced by the 20 MW plume sensible heat modeled in the initial release.

Figures 2 and 3 show the relative contributions from each phase of the release versus distance under mitigated accident conditions for two laboratory segments. The results clearly show that the resuspension phase of the fire accident yields doses that are higher than immediate doses, for distances smaller than about 1 km from the point of release. At larger distances, however, the doses due to immediate release dominate as the thermal effects included in the plume dispersion model result in doses that exceed doses resulting from the resuspension plume model.

CONCLUSIONS

A MACCS-based simulation analysis of the atmospheric dispersion of the radioactive plume, including sensible heat, was used to determine the consequences of a postulated full facility fire accident at the SRS laboratory facility. Two distinct source terms were considered: the unmitigated and the mitigated source terms. Each source term included an immediate phase and a resuspension release phase for each component of the facility.

The receptors analyzed were the MOI using 95% meteorology data and the 100m OEP using 50% meteorology data. The results included the determination of the total dose to the occupationally exposed worker and the total dose to the maximum exposed offsite individual under mitigated and unmitigated accident conditions. Representative results of the dose calculated as a function of distance from the point of release were also obtained. These results outlined the relative importance of the dispersion effects induced by the plume sensible heat and other effects, such as resuspension, on the total calculated dose.

REFERENCES

1 D.I. Chanin, J.L. Sprung, L.T. Ritchie, and H-N Jow. *MELCOR Accident Consequence Code System (MACCS), Volume 1. User's Guide*, Sandia National Laboratory, Albuquerque, NM. NUREG/CR-4691 (SAND86-1562) (February 1990).

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3 J.A. Rollistin, D.I. Chanin, and H-N Jow. *MELCOR Accident Consequence Code System (MACCS), Volume 3. Programmer's Reference Manual*, Sandia National Laboratory, Albuquerque, NM. NUREG/CR-4691 (SAND86-1562) (February 1990).

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5 U.S. Department of Energy. *Radiation Protection for Occupational Workers*, U.S. Department of Energy, Washington, DC, Order DOE 5480.11 (July 1989).

Table 1. Representative Source Term

Mitigated Full Facility Fire - Resuspension

E-Wing Source Term

	Isotope	T 1/2 (yr)	Inhalation DCF (mrem/uCi)	Substitute Isotope	Postulated Release	Modified Release
	Am-241	**4.58E+02**	**5.20E-01**		**1.08E-04**	**1.16E-04**
*	Am-243	7.95E+03	5.20E-01	Am-241	7.66E-06	
	Ce-144	**3.19E+03**	**3.50E-04**		**7.35E-07**	**7.35E-07**
*	Cf-249			Cm-244	0.00E+00	
*	Cf-252	2.65E+00	1.30E-01	Cm-244	2.06E-04	
	Cm-244	**1.76E+01**	**2.70E-01**		**3.43E-03**	**3.64E-03**
*	Cm-246	5.50E+03	5.40E-01	Pu-239	1.29E-05	
	Co-60	**5.26E+00**	**1.40E-04**		**2.61E-03**	**2.61E-03**
	Cs-137	**3.00E+01**	**3.20E-05**		**4.61E-02**	**4.61E-02**
	H-3	**1.23E+01**	**9.45E-08**		**0.00E+00**	**0.00E+00**
*	Np-237	2.14E+06	4.90E-01	Pu-239	1.39E-07	
	Pu-238	**8.64E+01**	**4.60E-01**		**8.56E-04**	**8.56E-04**
	Pu-239	**2.44E+04**	**5.10E-01**		**4.46E-04**	**4.59E-04**
	Pu-241	**1.32E+01**	**1.00E-02**		**0.00E+00**	**0.00E+00**
*	Pu-242	3.79E+05	4.80E-01	Pu-239	0.00E+00	
	Sr-90	**2.77E+01**	**1.30E-03**		**4.62E-02**	**4.62E-02**
*	Th-232	1.41E+10	1.60E+00	Cm-244	8.46E-10	
*	U-235	7.10E+08	1.20E-01	Cm-244	5.44E-09	
*	U-238	4.51E+09	1.20E-01	Cm-244	2.59E-08	
				total	1.00E-01	1.00E-01

* Isotope not included in MACCS library

Table 2. Technology Center Full Facility Fire Consequences (rem)

	MOI	Unmitigated		**OEP** @ 100 m	Unmitigated	
	Immediate	Resuspension	Total	Immediate	Resuspension	Total
B-Wing	7.10E-02	1.77E-01	2.48E-01	5.15E-03	7.42E-01	7.47E-01
C-Wing	1.17E-01	3.01E-01	4.18E-01	1.01E-02	1.78E+00	1.79E+00
D-Wing	7.13E-05	2.11E-04	2.82E-04	5.15E-06	1.05E-03	1.06E-03
E-Wing	3.18E-01	1.42E+00	1.75E+00	1.75E-02	5.35E+00	5.37E+00
F-Wing	7.15E-02	7.03E-01	7.75E-01	5.04E-03	2.61E+00	2.62E+00
		Total	3.19E+00		Total	1.05E+01
	MOI	Mitigated		**OEP** @ 100 m	Mitigated	
	Immediate	Resuspension	Total	Immediate	Resuspension	Total
B-Wing	2.82E-02	1.02E-01	1.30E-01	2.07E-03	7.29E-01	7.31E-01
C-Wing	5.55E-02	2.01E-01	2.57E-01	5.04E-03	1.07E+00	1.08E+00
D-Wing	5.59E-05	5.02E-06	6.09E-05	5.15E-06	2.12E-05	2.64E-05
E-Wing	2.06E-02	2.35E-02	4.41E-02	1.00E-03	1.05E-01	1.06E-01
F-Wing	6.36E-02	1.25E-02	7.61E-02	3.15E-03	5.28E-02	5.60E-02
		Total	5.07E-01		Total	1.97E+00

FIGURE 1. DOSE-DISTANCE PLOT FOR MITIGATED TECHNOLOGY CENTER FIRE RELEASE - ALL WINGS USING 95% (MOI) METEOROLOGY DATA

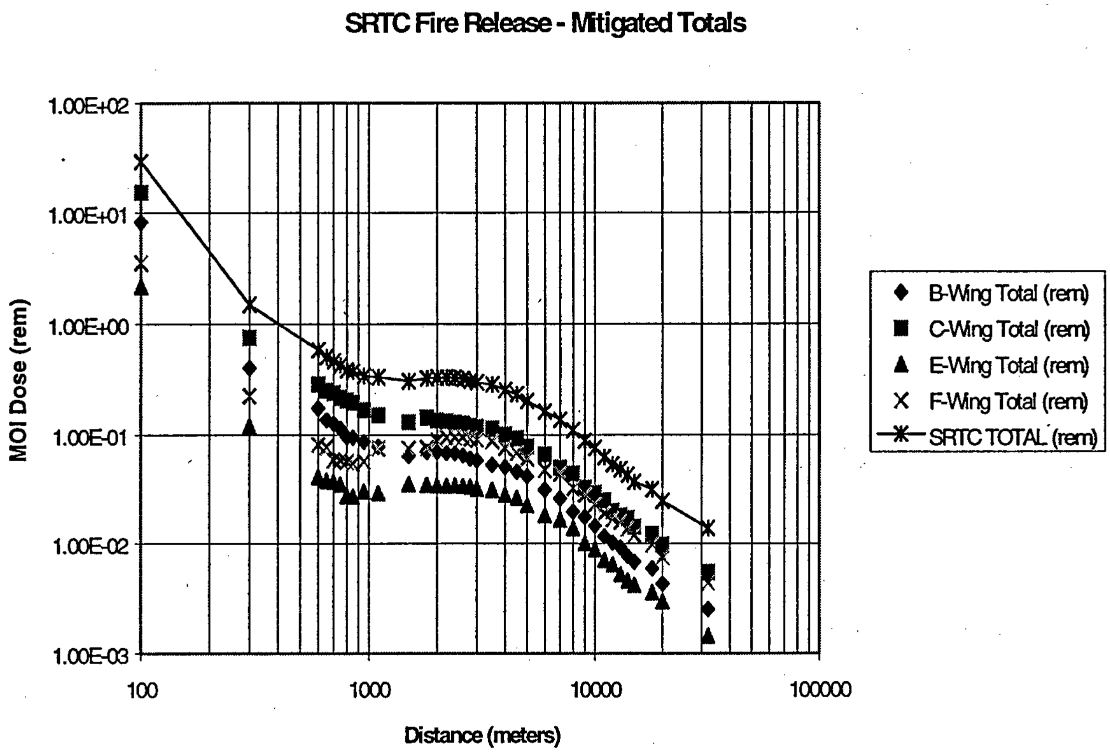


FIGURE 2. DOSE-DISTANCE PLOT FOR MITIGATED TECHNOLOGY CENTER FIRE RELEASE - B-WING ONLY USING 95% (MOI) METEOROLOGY DATA

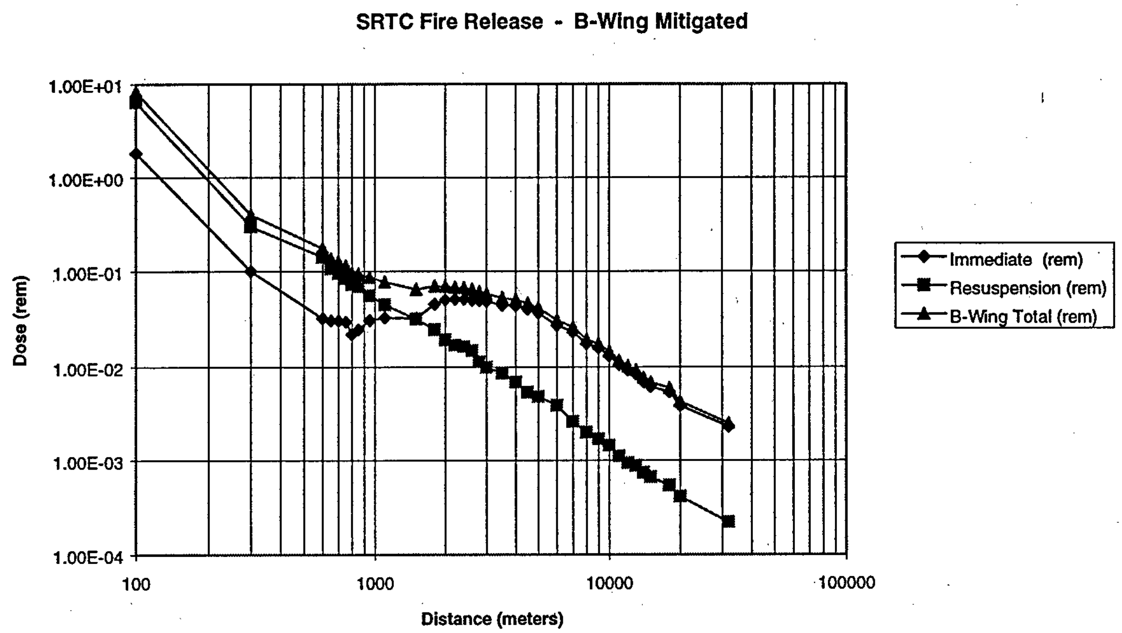
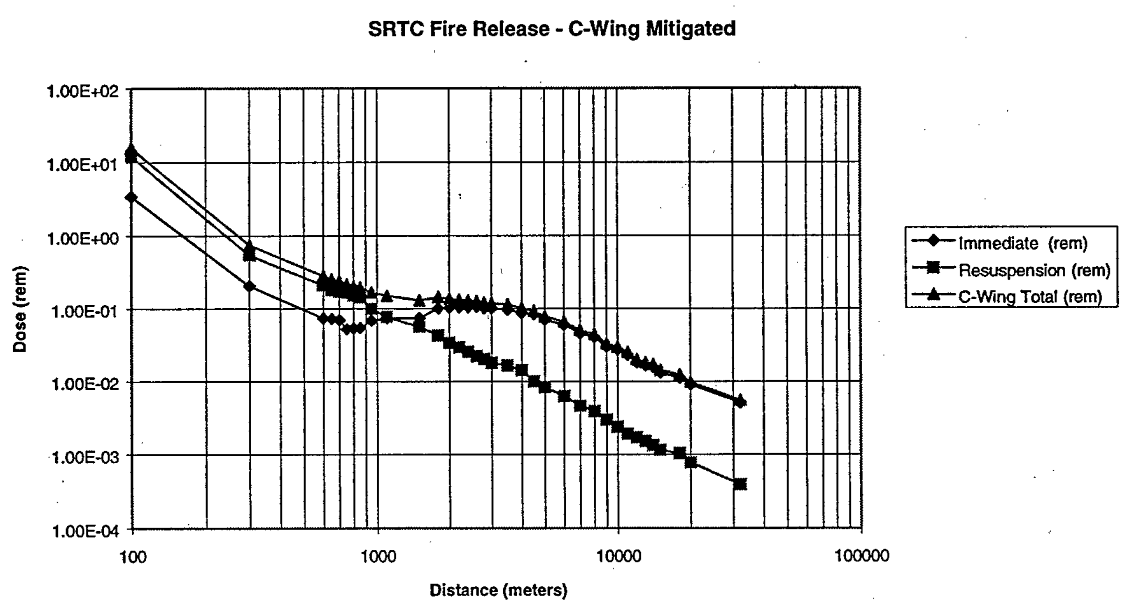


FIGURE 3. DOSE-DISTANCE PLOT FOR MITIGATED TECHNOLOGY CENTER FIRE RELEASE - C-WING ONLY USING 95% (MOI) METEOROLOGY DATA



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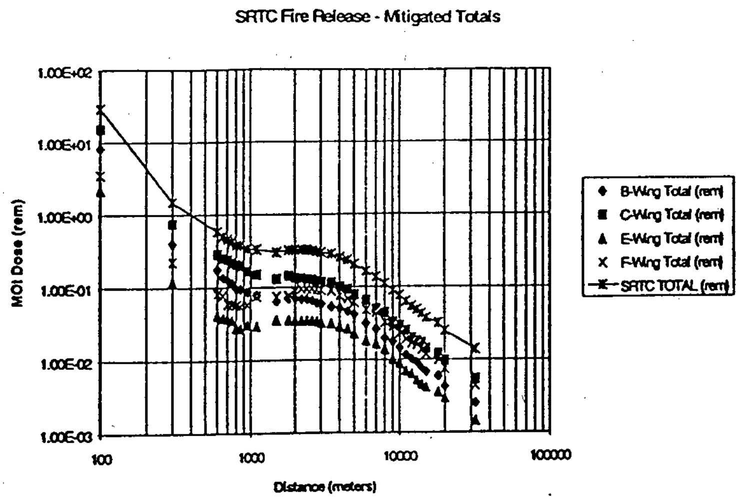


FIGURE 2. DOSE-DISTANCE PLOT FOR MITIGATED TECHNOLOGY CENTER FIRE RELEASE - B-WING ONLY USING 95% (MOI) METEOROLOGY DATA

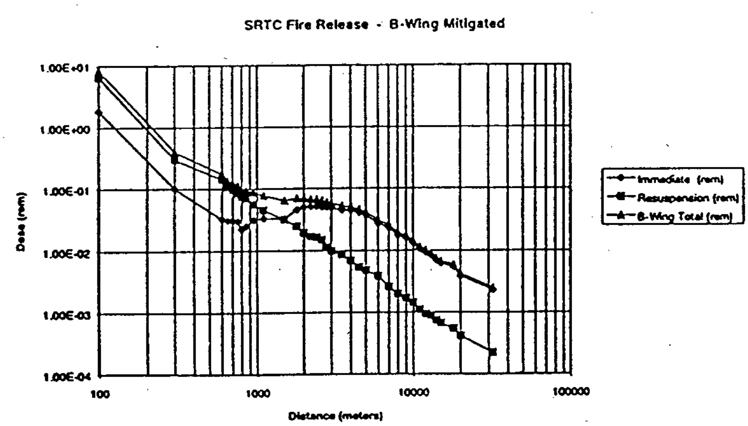
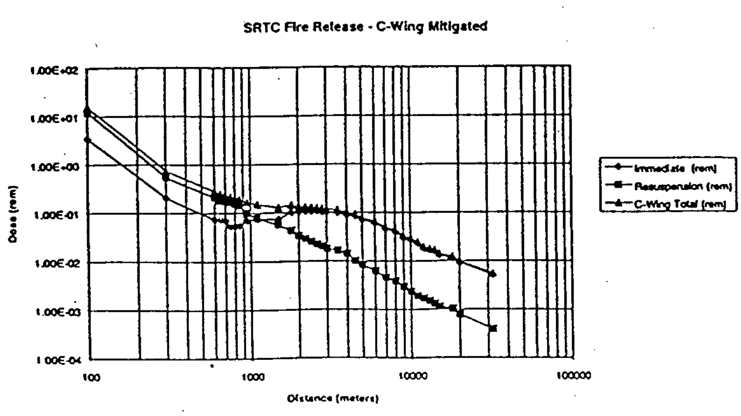


FIGURE 3. DOSE-DISTANCE PLOT FOR MITIGATED TECHNOLOGY CENTER FIRE RELEASE - C-WING ONLY USING 95% (MOI) METEOROLOGY DATA



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