

PRAIRIE ISLAND NUCLEAR GENERATING PLANT

UNIT 1 AND 2

Main Control Room Habitability Study

NUREG - 0737

PREPARED BY:

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1.0 INTRODUCTION

Due to the toxicity of commonly used chemicals, which may be transported near the Prairie Island Nuclear Generating Station by railroad, highway or the nearby Mississippi river, a survey was performed to predict which chemicals may become hazardous in the event of a spill. This analysis is specifically required and modeled to conform to the guidance set forth by the Nuclear Regulatory Guide 1.78⁽¹⁾ and NUREG 0570⁽²⁾. The purpose of this analysis is to determine which chemicals are shipped near the site and which chemicals must be monitored in order to prevent concentration in the control room for reaching toxic levels in the event of an accident.

2.0 REGULATORY GUIDE 1.78

Regulatory Guide 1.78 discusses the requirements and guidelines to be used for determining the toxicity of chemicals in the control room following a postulated accident. The guidelines for determining the toxicity of a given chemical include shipment frequencies, distance from source to site, and general properties of the chemical such as vapor pressure and its toxicity limit.

Two types of standard limits are considered in defining hazardous concentrations. One is the threshold limit value (TLV), defined as the concentration below which a worker may be exposed for 8 hours a day, 5 days a week without adverse health effects. Another limit is the short term exposure limit (STEL), which is defined as the maximum concentration to which workers can be exposed for 15 minutes without suffering from irritation, tissue damage, or narcosis leading to accident proneness or reduction of work efficiency. The effects of concentrations between the TLV and STEL are not generally predictable. Both these limits are considered in the analyses.

The NRC guidelines for shipment frequencies provide the maximum number of shipments which can pass by the site before the chemical is to be examined for toxicity limits in the control room. For trucks (highway shipments), the minimum number of shipments is 10 per year. Railroad traffic has a minimum number of 30 shipments per year and barges have a minimum number of 50 shipments per year.

The distance from the transportation mode, railroad, highway or barge also controls whether the mode is to be examined for shipments of toxic chemicals. Highway US 61, the Chicago -

Milwaukee - St. Paul and Pacific Railroad (CMSTP & PRR), the Burlington Northern Railroad (BNRR) and barge traffic on the Mississippi River are all within 5 miles of the Prairie Island Plant, as shown on Figure 1, and should be considered as possible toxic chemical sources for evaluations of the Prairie Island plant.

3.0 TRANSPORTATION ROUTES CONSIDERED

The Mississippi River is navigable by barges up to Minneapolis, thus river traffic is expected to travel past Prairie Island. The Mississippi river runs next to the plant site, at the closest approach of 1/4 mile to the control room air intake. But, as seen on Figure 2, the closest navigable portion of the Mississippi River would be approximately 1/2 mile from the control room air intake.

The BNRR has a two track trunk line on the east side of the Mississippi River approximately 2 miles from the control room air intake. The CMSTP & PRR has a two track trunk line on the west side of the plant 1/2 mile from the control room air intake. Both lines connect the Minneapolis - St. Paul area with points east, principally the cities of Chicago and Milwaukee.

Highway US 61 runs approximately 2 1/2 miles from the control room air intake. This road connects Red Wing to Minneapolis - St. Paul. Chemicals travelling on the road to Minneapolis - St. Paul were not expected to travel on US 61, since major interstates connect Minneapolis - St. Paul with points east and south. Therefore, only traffic between Minneapolis - St. Paul and the Red Wing area need to be considered. There are no producers or major users of chemicals in the Red Wing area (14), therefore US 61 is not considered further in the report.

4.0 SOURCES AND DATA FOR CHEMICALS

The list of chemicals to be initially considered as potentially hazardous was drawn from several sources in a wide range of industries. The majority of the chemicals which are to be examined are given as a partial list from Regulatory Guide 1.78⁽¹⁾ and NUREG 0570⁽²⁾. Also, two other sources were found to list hazardous chemicals - the Association of American Railroads under Specifications for Tank Cars and the Committee on Safety of Nuclear Installations Organization⁽⁵⁾. A complete list of the hazardous chemicals listed from the above sources are given in Table 1.

Additional information concerning the physical properties was obtained along with the above list of chemicals. This includes the molecular weight, boiling point, density, heat of vaporization, vapor pressure, diffusion coefficient and the threshold limit value. These chemical properties along with the critical pressure and temperature of some of the chemicals are given in Table 2 using references 2 and 5 through 13.

5.0 CONTROL ROOM TOXIC CONCENTRATIONS:

The models developed to calculate the concentration of toxic chemicals in the control room in the event of an accident are consistent with the models described in NUREG-0570. A description of the model used to determine the control room toxic concentrations is given in Appendix A. These include a consideration of the following factors:

- a. There is a failure of one container of toxic chemicals being shipped on a barge or tank car releasing all of its contents to the surroundings. Instantaneously, a puff of that fraction of the chemical which would flash to a gas at atmospheric pressure is released. The remaining chemical is assumed to spread uniformly on the ground and evaporate as a function of time due to the heat acquired from the sun, ground and surroundings. Further, no losses of chemicals are assumed to occur as a result of absorption into the ground, flow into the river, cleanup operations, or chemical reactions.
- b. From the geography of the area near Prairie Island, a spill from a railroad is assumed to spread roughly over a circular area. A spill from a barge is conservatively assumed to spread over a circular area on the Mississippi.
- c. The initial puff due to flashing as well as the continuous plume due to evaporation is transported and diluted by the wind to impact on the control room air inlet. The atmospheric dilution factors are calculated using the methodology of R.G. 1.78 and NUREG-0570, with partial building wake effects conservatively considered.
- d. To determine which chemicals need monitoring, the control room ventilation systems were assumed to continue normal operation of the analysis. The chemical concentrations as a function of time were calculated and the maximum levels determined. These were compared to the Threshold Limit Values (TLV) published by the American Conference of Governmental Industrial Hygienists (ACGIH). Where TLVs were not available, toxicity limits were obtained from available literature.

- e. Concentrations were calculated as a function of time for eight hours following the accident to compare with the published 8 hour TLV levels for all cases. For conservativeness, the maximum concentrations reached in the 8 hour period were compared to the TLV levels to determine which chemicals need monitoring.

The control room ventilation system is designed to draw 2000 cfm of outside air into the control room ventilation envelope, which has a volume of 116,840 ft³. At present, there are no toxic chemical monitors installed to alarm in the control room, therefore it was assumed that the control room ventilation system operates continuously at the design flow rates throughout the duration of the accident.

6.0 METHODOLOGY

Two railroad lines and the Mississippi River need to be examined for the shipment of hazardous chemicals as stated in Section 2. The specific location of railroads and the river are shown in the Prairie Island off-site map in Figure 1.

The railroad analysis was performed by generating an initial list of chemicals to be examined. This was done by assuming the maximum load on a railroad car, for each chemical in Table 1, as a 13,750 gallon tank car. Then, a computer evaluation was run using the models in Appendix A, and 98 chemicals which could pose a problem to the operators were listed as a result. These chemicals are shown on Table 3. At this point, Burlington Northern Company of St. Paul, Minnesota, was also contacted and asked to examine their shipments through the area of Prairie Island Site for quantities and shipment frequencies of the hazardous chemicals⁽¹⁵⁾. The results of their survey are given in Table 4; and shows 2 chemicals which may be hazardous. The CMSTP & PRR was similarly contacted⁽¹⁶⁾ and the results of their survey is shown in Table 5.

A survey of barge traffic on the Mississippi River was performed using Reference 17. The tonnage shipped is given for sections of the Mississippi River, and for the survey, the section from Minneapolis to the mouth of the Missouri is used. Conservatively, all traffic in this section is assumed to pass by Prairie Island, with the exception of upbound traffic going to the Illinois River. The amount of chemicals shipped is shown on Table 6. Chemicals are shipped on barges with capacity of 1500-3000 tons with shipments generally using the larger barges. Therefore, a

barge size limit of 3000 tons was used to determine the shipment frequency. Table 7 shows the chemicals whose shipment frequency exceeds 50 shipments per year.

The effects on the control room habitability from an accident involving chemicals stored on site was also evaluated. The chemicals stored on site are shown in Table 8.

7.0 RESULTS

Nine of the chemicals found by the survey near Prairie Island (Tables 4, 5 and 7), were found to be shipped in quantities and shipment frequencies which may affect the control room habitability. These chemicals are shipped on the BNRR, CMSTP & PRR and by barge on the Mississippi River. Of the chemicals stored on site, only chlorine and hydrazine are potentially dangerous.

An analysis of these chemicals was performed using the assumptions and models of Section 5 and Appendix A. The chemicals shipped by the BNRR are assumed to be contained by 30 ton tank cars to determine the net weight of the chemicals. Of the chemicals shipped by barge, only gasoline and distillate fuel oil are considered further, since fertilizers are generally non-toxic and shipped in dry bulk fashion. Some of the fertilizers are shipped in ammonia tanks. A calculation of the ammonia concentration in the control room was not performed for this case because our results for the railroad car shipment evaluation already indicate that ammonia needs to be detected. The effects of an accidental release of on site stored chlorine were assumed to occur at its storage location, 100 meters from the fresh air intake. Hydrazine was assumed to be spilled in the turbine building, where the vapors were taken up by the ventilation system, exhausted at the roof and then entrained by the control room ventilation system.

The results of the analysis, shown on Table 9, show that four chemicals; chlorine, ammonia, formaldehyde and hydrochloric acid spilled near Prairie Island would produce concentrations in the control room well above the TLV levels if no provisions for isolation are available.

Therefore, to ensure that the control room habitability requirements of R.G. 1.78 are met, the control room needs to be isolated on receipt of high concentration alarm from one of these chemicals.

8.0 RECOMMENDATIONS

Table 9 shows that 4 chemicals would exceed TLV levels in the control room if an accidental release occurred, thus necessitating the addition of monitors to detect toxic concentrations of these chemicals.

The monitors would need to be set to isolate the control room at a sufficiently low level to ensure that adequate time (2 minutes is specified by footnote 6 of Regulatory Guide 1.78) is available for the control room operators to put on breathing masks. The TLV levels for the chemicals can be used as the monitor set point. If the control room is isolated when the TLV is reached at the monitor location, the operators will have adequate time to don breathing apparatus before the concentrations in the control room reach the STEL levels. Possible monitor set points, TLV and STEL levels are shown on Table 10.

To ensure rapid detection so that the operators have adequate time, the location of the monitors and the monitor response times are important. Monitors should be placed in the ductwork as close as possible to the fresh air intakes, and upstream of the isolation dampers, so that hazardous chemicals are detected at the earliest time possible. The maximum response time should be governed by the time required for the concentration in the control room to reach the TLV levels after they have been reached at the monitor location.

A monitor for chlorine, which is stored on site, could be placed near the storage tank, thus assuring ample time for the operators to take protective action. Monitors for the other chemicals would have to be located at the fresh air intake.

Monitor system response time (the time needed for the monitor to act and isolation dampers to close) need to be evaluated to ensure that operators have adequate time to take protective actions. Monitor response times along with the detector levels should be used to determine which monitor systems will be used.

Figure 3 illustrates the effects of a typical hazardous chemical spill on the control room atmosphere. If the control room is not isolated, the control room air concentration quickly approaches the air concentration at the control room fresh air inlet. The monitor for the isolation mode is set to isolate when the air concentration at the inlet reaches

the TLV level (time T_0). The monitor system requires a certain time to detect the chemicals and isolate the control room. Isolation is achieved at the time T_{ISO} . The control room concentration continues to increase due to inleakage from the outside air. At time T_{STEL} , the control room concentration reaches the STEL level. As described above, the monitor and the isolation response time ($T_{ISO}-T_0$) should allow at least 2 minutes for the time period $T_{STEL} - T_{ISO}$.

REFERENCES

1. Regulatory Guide 1.78, dated June 1974.
2. NUREG-0570, "Toxic Vapor Concentrations in the Control Room following a Postulated Accidental Release", James Wing, June 1979.
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14. Red Wing Area Chamber of Commerce - Manufacturers.
15. Letter John E. Baker, Bechtel to R. Griffin, Burlington Northern Inc., "Hazardous Chemicals Survey, P.O. 10040-M30-SBC, Northern States Power Co., Prairie Island Station", 3 Dec. 1980. (DCN 3494).
16. Letter C. B. Hogg, Bechtel to R. W. Riedl, CMSTP & PRR "Prairie Island Nuclear Generating Station, Northern States Power Co., Request for Hazardous Materials Shipments" 11 Dec. 1980, (DCN 3565).
17. Waterborne Commerce of the U.S., Calendar Year 1977, Department of the Army Corp of Engineers - Part 2 Waterways & Harbors; Gulf Coast, Mississippi River System.
18. Telecon Jorge Schulz, Bechtel to Glenn Banks, Corp of Engineers, 8 Jan. 1981.
19. Telecon Jorge Schulz, Bechtel to Neil Schuester, American Waterway Operators, 12 Jan. 1981.

TABLE 1
HAZARDOUS CHEMICAL SOURCES

	(1) AAR <u>TANK CAR</u>	(2) R.G.	(3) <u>NUREG-0570</u>	(4) <u>CSNI</u>
Acetaldehyde		X	X	
Acetic Anhydride			X	X
Acetone		X	X	
Acetone Cyanchydrin			X	
Acrolein	X		X	
Acrylonitrile		X	X	
Aliphatic Mercaptan Mixtures	X	(See individual	Mercaptans)	
Allyl Chloride	X		X	
Ammonia	X	X	X	
Amyl Mercaptan	X			
Aniline		X	X	
Antinock Compound	X	(See Tetramethyl lead)	lead & Tetraethyl lead)	
Arsine			X	
Benzene		X	X	
Benzyl Chloride	X			
Butane				X
Bromine	X		X	
Bromobenzl Cyanide (6)			X	
Butadiene	X	X	X	
Butanol			X	
Butenes		X		
Butyl Mercaptan	X			
Carbon Dioxide	X	X	X	
Carbon Disulfide			X	
Carbon Monoxide	X	X	X	
Carbon Tetrachloride			X	
Chlorine	X	X	X	
Chlorine Trifluoride	X			
Chloroacetyl Chloride	X			
Chloropicrin	X			
Chloroprene	X			
CNB (6)			X	
CNC (6)			X	
CNS (6)			X	
Cresol			X	
Cumene Hydroperoxide	X			
Cyanogen Chloride (6)		X		
Cyclohexane				X

TABLE 1 (Continued)

	(1) AAR <u>TANK CAR</u>	(2) R.G.	(3) <u>NUREG-0570</u>	(4) <u>CSNI</u>
Diethylamine			X	
Di-isopropyl Benzene				
Hydroperoxide	X			
Difluoroethane	X			
Dimethylamine	X			
Dimethyl Dichlorosilane	X			
Dimethyl Ether	X			
Dimethylformamide			X	
Dimethyl Hydrazine	X			
Diphenylchloroarsine ⁽⁶⁾			X	
Diphenylcyanoarsine ⁽⁶⁾			X	
Diphosgene ⁽⁶⁾			X	
Epichlorohydrin			X	
Ethane	X			
Ethyl Acetate			X	
Ethyl Benzene			X	
Ethyl Chloride		X	X	
Ethylchloroarsine ⁽⁶⁾			X	
Ethylchlorosilane	X			
Ethylene Dichloride		X	X	
Ethylene Oxide	X	X	X	
Ethyl Ether		X	X	
Ethyl Mercaptan	X			
Ethyl Trichlorosilane	X			
Ethylene	X			
Ethylene Glycol				X
Fluorine		X	X	
Formaldehyde		X	X	
Formic Acid	X			
Gasoline				
Helium		X	X	
Hexylene Glycol			X	
Hydrazine	X		X	
Hydrochloric Acid	X		X	
Hydrogen	X			
Hydrogen Cyanide	X	X	X	
Hydrogen Fluoride	X		X	
Hydrogen Peroxide	X			
Hydrogen Sulfide	X	X	X	

TABLE 1 (Continued)

	(1) AAR <u>TANK CAR</u>	(2) <u>R.G.</u>	(3) <u>NUREG 0570</u>	(4) <u>CSNI</u>
Isopropyl Alcohol			X	
Isopropylamine			X	
Isopropyl Mercaptan	X			
Lewisite ⁽⁶⁾			X	
Liquified Natural Gas	X			
Liquified Petroleum Gas	X			
Mercaptans	X (See individual Mercaptans)			
Methane	X			
Methanol		X	X	
Methyl Chloride	X			
Methyl Dichloroarsine ⁽⁶⁾			X	
Methyl Dichlorosilane	X			
Methyl Trichlorosilane	X			
Methyl Mercaptan	X			
Monochloroacetic Acid	X			
Monochlorodifluoromethane	X			
Monomethyl Amine	X			
Mustard Gas ⁽⁶⁾			X	
Mustard - Lewisite Mixture ⁽⁶⁾			X	
Muriatic Acid (Hydrochloric Acid)	X			X
Methyl Formate				
Nitric Acid	X		X	
Nitrogen		X	X	
Nitrogen Dioxide	X			
Nitrogen Mustard (HN-1) ⁽⁶⁾			X	
Nitrogen Mustard (HN-2) ⁽⁶⁾			X	
Nitrogen Mustard (HN-3) ⁽⁶⁾			X	
Nitrogen Peroxide	X			
Nitrogen Tetroxide	X			
Nitrosyl Chloride	X			
Oleum (Sulfuric Acid, Fuming)	X			
Parathion				X
Paramethane Hydroperoxide	X			
Pentaborane-9 ⁽⁶⁾			X	
Perchloryl Fluoride			X	
Phenol			X	
Phenbdichloroarsine ⁽⁶⁾			X	
Phosgene	X		X	
Phosgene Oxime ⁽⁶⁾			X	
Pentaborane ⁽⁶⁾				

TABLE 1 (Continued)

	(1) AAR	(2)	(3)	(4)
	<u>TANK CAR</u>	<u>R.G.</u>	<u>NUREG 0570</u>	<u>CSNI</u>
Phosphorus	X			
Phosphorus Oxybromide	X			
Phosphorus Oxychloride	X			
Phosphorus Trichloride	X			
Potassium Nitrate/ Sodium Nitrate	X			
Propionaldehyde			X	
Propylene Oxide			X	
Propyl Mercaptan	X			
Pyroforic Liquids	X			
Propane				
Sarin ⁽⁶⁾			X	
Sodium	X			
Sodium Chlorite (Sol.)	X			
Soman ⁽⁶⁾			X	
Styrene			X	
Sulfur Dioxide	X	X	X	
Sulfuric Acid	X	X	X	
Sulfur Trioxide	X			
Sodium Oxide		X		
Tabun ⁽⁶⁾			X	
Tetraethyl Lead			X	
Tetramethyl Lead			X	
Thiophosphoryl Chloride	X			
Titanium Tetrachloride	X			
Toluene			X	
Trichloroethylene			X	
Trichlorosilane	X			
Trifluorochloroethylene	X			
Trimethylamine	X			
Trimethylchlorosilane	X			
Vinyl Acetate			X	
Vinyl Chloride	X	X	X	
Vinyl Fluoride	X			
Vinyl Methylether	X			
Vinyl Pyridine				
Vinyl Trichlorosilane	X			
Xylene		X	X	

- NOTES:
- (1) Reference 4
 - (2) Reference 1
 - (3) Reference 3
 - (4) Reference 2
 - (5) Reference 5
 - (6) Military poison gases, Ref. 6

TABLE 2

PHYSICAL PROPERTIES OF TOXIC CHEMICALS

CHEMICAL	TLV	MW	BP	DENS	CP	IV	VP	DIFF	TCRIT	PCRIT	TYPE
ACETALDEHYDE	1.00+02	44.1	20.2	.783	.510	138.2	7.600+02	.1030			2
ACETIC ANHYDRIDE	5.00+00	102.1	140.0	1.057	.398	92.	1.000+01	.0750	569.00	46.20	2
ACETONE	1.00+03	58.1	56.2	.791	.528	128.1	4.000+02	.1340			2
ACETONE CYANOHYDRIN	1.00+01	85.1	82.0	.932			8.000+01	.0802	496.10	42.00	2
ACROLEIN	1.00+01	56.1	52.5	.841	.511	126.1	4.750+02	.0911	506.00	51.00	2
ACRYLONITRILE	2.00+01	53.1	77.3	.806	.500		2.250+02	.0845	536.00	45.00	2
ALLYL CHLORIDE	1.00+00	76.5	45.0	.938	.313	90.5	6.500+02	.0830	513.50	46.50	2
AMMONIA	2.50+01	17.0	-33.4	.674	1.100	327.4					1
AMYL MERCAPTAN	1.00+01	104.2	126.6	.842			1.380+01	.0936	321.00	34.50	2
ANILINE	5.00+00	93.1	184.4	1.022	.521	103.7	1.500+00	.0790			2
ARSINE	5.00+02	77.9	-62.5	1.604	.283	51.2					1
BENZENE	1.00+01	78.1	80.1	.880	.419	103.6	1.900+02	.0770			2
BENZYL CHLORIDE	1.00+00	126.8	179.0	1.103	.223	76.0	1.300+00	.0810			2
BROMINE	1.00+01	159.8	58.7	3.120	.107	44.9	3.800+02	.1090			2
BROMOBENZYL CYANIDE	6.10+01	196.0	242.0	1.470		55.7	7.000+02	.0539	737.40	35.50	2
BUTADIENE	1.00+03	54.1	-4.1	.621	.545	99.8					1
BUTANE	5.00+03	58.1	-8	.601	.564	92.0					1
BUTANOL	1.00+02	74.1	117.5	.810	.563	141.3	1.800+01	.0920			2
BUTENE	1.43+05	56.1	-6.3	.595	.355	93.4					1
BUTYL MERCAPTAN	5.00+01	90.2	98.0	.836		45.9	4.800+01	.0714	563.20	38.90	2
CARBON DIOXIDE	5.00+03	44.0	-78.5	.468	.184	83.2					1
CARBON DISULFIDE	2.00+01	76.1	46.5	1.293	.241	84.1	6.350+02	.1090			2
CARBON MONOXIDE	5.00+01	28.0	-191.5		.515	51.6					3
CARBON TETRACHLORIDE	1.00+01	153.8	76.8	1.597	.201	47.3	2.110+02	.0810			2
CHLORINE	1.00+00	70.9	-34.1	1.570	.226	68.8					1
CHLORINE TRIFLUORIDE	1.00+01	92.5	11.8	1.770	.303	71.2					1
CHLOROACETYL CHLORIDE	5.00+02	112.9	105.0	1.495			2.320+01	.0760	579.90	50.40	2
CHLOROPICRIN	1.00+01	164.4	112.0	1.692			4.000+01	.0695	582.00	44.10	2
CHLOROPRENE	2.50+01	88.5	59.4	.956			6.770+02	.0771	525.50	42.00	2
CNB	5.00+02	119.7	75.0	1.140			1.200+02				2
CNC	5.00+02	129.6	60.0	1.400			1.270+02				2
CNS	5.00+02	144.5	60.0	1.470			1.270+02				2
CRESOL	5.00+00	108.1	198.0	1.010	.550	102.9	1.000+00	.0678	704.60	50.80	2
CUMENE HYDROPEROXIDE	1.00+00	152.2	153.0	1.050			2.500+01	.0629	576.10	33.70	2
CYANOGEN CHLORIDE	3.00+01	61.5	13.1	1.218	.358	103.0					1
CYCLOHEXANE	3.00+02	84.2	80.7	.779	.432	93.8	1.060+02	.0738			2
DIETHYL AMINE	2.50+01	73.1	55.5	.685	.564	96.4	4.250+02	.1090			2
DIFLUOROETHANE	1.43+05	66.1	-26.5	1.004	.333	78.0					1
DIMETHYL AMINE	1.00+01	45.1	6.9	.680	.724	130.5					1
DIMETHYL DICHLOROSILANE	5.00+00	129.1	70.0	1.100			1.080+02	.0676	519.80	33.10	2
DIMETHYL ETHER	4.00+02	46.1	-23.7	.661	.535	111.6					1
DIMETHYL FORMAMIDE	1.00+01	73.1	153.0	.953		155.4	3.700+00	.0706	647.10	43.70	2
DIMETHYL HYDRAZINE	5.00+01	60.1	63.3	.782			1.570+02	.0902	521.90	53.60	2
DIPHENYL CHLOROARSINE	5.00+02	264.5	307.0	1.387		56.6	1.600+03				2
DIPHENYL CYANOARSINE	5.00+02	255.0	290.0	1.320		79.3	5.000+05				2
DIPHOSGENE	1.00+01	197.9	127.0	1.660			1.030+01				2
EPICHLOROHYDRIN	5.00+00	92.5	116.1	1.181			4.000+01	.0709	596.00	42.00	2
ETHANE	1.43+05	30.7	-88.6	.446	.321	117.0					1
ETHYL ACETATE	4.00+02	88.1	77.2	.895	.459	102.0	1.860+02	.0935			2
ETHYL BENZENE	1.00+02	106.2	136.2	.867	.409	35.1	2.000+01	.0810			2

TABLE 2 (Cont)

PHYSICAL PROPERTIES OF TOXIC CHEMICALS

CHEMICAL	TLV	MW	RP	DENS	CP	HV	VP	DIFF	ICRIT	PCRIT	TYPE
ETHYL CHLORIDE	1.00+03	64.1	12.3	.924	.368	90.6					1
ETHYL DICHLOROARSINE	7.00-02	174.9	156.0	1.690		52.5	9.500+00		520.30	33.10	2
ETHYL DICHLOROSILANE	5.00+00	129.1	70.3	2.000			1.080+02	.0675			2
ETHYLENE	1.43+05	28.0	-103.8	.610	.371	115.4					1
ETHYLENE DICHLORIDE	1.00+01	99.0	83.5	1.253	.301	77.3	1.650+02	.0803	561.00	53.00	2
ETHYLENE GLYCOL	1.00+02	62.1	197.5	1.113	.561	258.0	5.000-02	.0904	645.00	76.00	2
ETHYLENE OXIDE	5.00+01	44.1	10.7	.897	.476	138.5					1
ETHYL ETHER	4.00+02	74.1	34.6	.708	.547	87.9	4.420+02	.0955			2
ETHYL MERCAPTAN	5.00-01	62.1	36.2	.839	.278	105.0	5.270+02	.0925	499.00	54.20	2
ETHYL TRICHLOROSILANE	5.00+00	163.5	99.5	1.240	.367	39.8	2.550+01	.0756	573.60	53.10	2
FLUORINE	1.00+00	38.0	-188.3				1.980+02	.1289	408.00	65.00	2
FORMALDEHYDE	2.00+00	30.0	97.0	1.100			4.000+01	.1066	580.00	86.40	2
FORMIC ACID	5.00+00	46.0	100.8	1.227			4.000+01				2
GASOLINE	5.00+02	110.0	99.0	.700							3
HELIUM	1.43+05	4.0	-268.9		.860	4.8					3
HEXYLENE GLYCOL	2.50+01	118.2	197.1	.923	.537	151.0	3.000-01	.0708	620.90	47.50	2
HYDRAZINE	1.00-01	32.0	113.5	1.008	.740	305.0	3.000+01	.1298	653.00	145.00	2
HYDROCHLORIC ACID	5.00+00	36.5	-85.0	1.194	.900	103.1					1
HYDROGEN	1.43+05	2.0	-252.8		.231	108.0					3
HYDROGEN CYANIDE	1.00+01	27.0	25.7	.687	.627	747.0	4.000+02	.2120			2
HYDROGEN FLUORIDE	3.00+00	20.0	19.5	1.003	.610	80.5	7.600+02	.1334	461.00	64.00	2
HYDROGEN PEROXIDE	1.00+00	34.0	107.0	1.710			1.000+00				2
HYDROGEN SULFIDE	1.00+01	34.1	-60.8	.993	.478	131.0					1
ISOPROPYL ALCOHOL	4.00+02	60.1	80.3	.785	.780	159.4	1.060+02	.1060			2
ISOPROPYL AMINE	5.00+00	59.1	32.4	.694	.385	110.0	1.550+02	.0929	476.00	50.00	2
ISOPROPYL MERCAPTAN	1.00+01	76.0	51.0	.814			1.220+02	.0792	532.20	43.60	2
LEWISITE	6.00-02	207.4	190.0	1.890		58.0	1.000+00				2
METHANE	1.43+05	16.0	-161.5		.495	121.9					3
METHANOL	2.00+02	32.0	64.7	.792	.600	262.8	2.600+02	.1620			2
METHYL CHLORIDE	1.00+02	50.5	-23.7	.918	.381	101.3					1
METHYL DICHLOROARSINE	7.00-02	160.9	133.0	1.830		49.0	1.000+01				2
METHYL DICHLOROSILANE	5.00+00	115.0	41.0	1.100			3.600+02	.0750	487.90	37.70	2
METHYL FORMATE	1.00+02	60.1	31.5	.980	.516	112.4	5.000+02	.0976	487.20	59.20	2
METHYL MERCAPTAN	5.00-01	48.1	7.6	.868	.439	122.1					1
METHYL TRICHLOROSILANE	5.00+00	149.5	66.5	1.280			1.400+02	.0686	516.40	35.00	2
MONOCHLOROACETIC ACID		94.5	101.1	1.070			1.689+01	.0836	555.20	57.10	2
MONOCHLORODIFLUOROMETHANE		80.5	-40.8	1.194	.300	55.8					1
MONOMETHYL AMINE	1.00+01	31.1	-6.8	.662	.784	198.6					1
MUSTARD GAS	7.00-02	159.1	227.8	1.270			4.000-01				2
MUSTARD-LEWISITE MIXTURE	7.00-02	178.5	190.0	1.660			58.0	1.000+00			2
NITRIC ACID	2.00+00	63.0	120.5	1.410	.615	114.9	1.000+01	.1048	574.50	93.70	2
NITROGEN	1.43+05	28.0	-195.8	.806	.474	47.5					1
NITROGEN DIOXIDE (HN-1)	5.00+00	46.0	21.0	1.491			5.650+02	.1329	431.40	100.00	2
NITROGEN MUSTARD (HN-2)	7.00-02	170.1	85.0	1.090			77.0	5.000-01			2
NITROGEN MUSTARD (HN-3)	7.00-02	156.1	75.0	1.150			78.8	1.160+00			2
NITROGEN PEROXIDE	7.00-02	204.5	137.0	1.240			72.0	3.800-02			3
NITROGEN TETROXIDE	2.50+01	30.0	-151.8		.238	109.7					2
NITROGEN TRIOXIDE	5.00+00	46.0	21.0	1.491	.360	99.0	5.650+02	.1329	431.40	100.00	2
NITROSYL CHLORIDE	1.00+01	65.5	-5.8	1.250	.230	91.6					1
PARAMETHANE HYDROPEROXIDE		48.0	40.0	1.997			3.700+02	.1158	464.00	77.50	2

TABLE 2 (Cont)

PHYSICAL PROPERTIES OF TOXIC CHEMICALS

[illegible]

Table 2

TLV=THRESHOLD LIMIT VALUE (PPM)
MW=MOLECULAR WEIGHT (GM/MOLE)
BP=BOILING POINT (DEGREE CENTIGRADE)
DENS=DENSITY OF LIQUID (GM/CM³)
CP=HEAT CAPACITY OF LIQUID (CAL/GM-DEGREE CENT)
HV=HEAT OF VAPORIZATION (CAL/GM)
VP=VAPOR PRESSURE OF LIQUID (MM-HG)
DIFF= DIFFUSION COEFFICIENT (CM²/SEC)
TCRIT=CRITICAL TEMPERATURE (DEGREE KELVIN)
PCRIT=CRITICAL PRESSURE (ATM)
TYPE=TYPE OF CHEMICAL
1=LOW-BOILING POINT
2=NORMAL-BOILING POINT
3=COMPRESSED GAS

Table 3

List Of Chemicals To Be Reviewed For Number
Of Yearly Shipments And Container Shipping Size

Acetaldehyde	Diphosgene	Nitrogen Dioxide
Acetic Anhydride	Epichlorohydrin	Nitrogen Mustard (HN1)
Acrolein	Ethyl Chloride	Nitrogen Mustard (HN2)
Acrylonitrile	Ethyl Dichloroarsine	Nitrogen Peroxide
Allyl Chloride	Ethyl Dichlorosilane	Nitrogen Tetroxide
Ammonia	Ethylene Dichloride	Nitrosyl Chloride
Amyl Merlaptan	Ethylene Oxide	Pentaborane
Arsine	Ethyl Ether	Pentaborane - 9
Benzene	Ethyl Mercaptan	Perchloryl Fluoride
Benzyl Chloride	Ethyl Trichlorosilane	Phenyldichloroarsine
Bromine	Fluorine	Phosgene
Butadiene	Formaldehyde	Phosphorus Oxychloride
Butane	Formic Acid	Phosphorus Trichloride
Butyl Mercaptan	Hydrazine	Propionaldehyde
Carbon Dioxide	Hydrochloric Acid	Propylene Oxide
Carbon Disulfide	Hydrogen Cyanide	Propyl Mercaptan
Carbon Monoxide	Hydrogen Fluoride	Sarin
Carbon Tetrachloride	Hydrogen Peroxide	Soman
Chlorine	Hydrogen Sulfide	Sulfur Dioxide
Chlorine Trifluoride	Isopropyl Amine	Sulfur Trioxide
Chloroacetyl Chloride	Isopropyl Mercaptan	Tabun
Chloropicrin	Lewisite	Tetraethyl Lead
Chloroprene	Methanol	Tetramethyl Lead
CNB	Methyl Chloride	Titanium Tetrachloride
CNC	Methyl Dichloroarsine	Trichloroethylene
CNS	Methyl Dichlorosilane	Trichlorosilane
Cumene Hydroperoxide	Methyl Formate	Trimethylamine
Cyanogen Chloride	Methyl Mercaptan	Trimethyl Chlorosilane
Diethyl Amine	Methyl Trichlorosilane	Vinyl Aetate
Dimethyl Amine	Monomethyl Amine	Vinyl Chloride
Dimethyl Dichlorosilane	Mustard Gas	Vinyl Piridine
Dimethyl Ether	Mustard Lewisite Mixture	Vinyl Trichlorosilane
Dimethyl Hydrazine	Nitric Acid	

Table 4

Chemicals Shipped By Burlington Northern Past Prairie Island
(1 July 1979 - 5 July 1980)

Chemical	Number Of Shipments	Gross Weight of Shipment (tons)	
		Average	Maximum
Acetaldehyde	21	87.6	111
Ammonia, Anhydrous ⁽¹⁾	526	126.6	132.5
Carbon Bisulfide or Carbon Disulfide	1	30	30
Chlorine	15	88.3	98
Chlorine Trifluoride	1	32	32
Dimethyl Amine, Anhydrous	11	83.9	124
Hydrocyanic Acid	1	41	41
Hydrofluoric Acid, Anhydrous	8	53.9	76
Hydrochloric Acid (1)	162	90.2	127.9
Hydrochloric Acid Mixture	1	71	71
Hydrogen Sulfide	29	117.5	124.8
Irritating Agent, N.O.S.	1	30	30
Monochlorodifluoro Methane	2	119.5	127
Nitric Acid	4	51.5	51.5
Sulfur Dioxide	13	66.6	85
Vinyl Acetate	4	90.3	108
Vinyl Chloride	1	131	131

chemicals shipped over 30 time/year need to be evaluated to determine the effect of an accidental spill on the control room operators

TABLE 5

CHEMICALS SHIPPED BY CNSTP & PRR PAST PRAIRIE ISLAND FOR 1980

<u>Chemical</u>	<u>Number of Shipments</u>	<u>Container Maximum</u>	<u>Size (Gallons) Minimum</u>
Chlorine ⁽¹⁾	44	18,000	12,000
Hydrofluoric Acid	9	11,000	10,000
Formaldehyde ⁽¹⁾	34	21,000	10,500

1. Chemicals shipped over 30 times/year need to be evaluated to determine the effect of an accidental spill on the control room operators.

Table 6

Barge Traffic On The Mississippi River
Past Prairie Island. Calendar Year 1977

Chemical	Tonnage	Shipment Frequency (shipments/year)
Alcohols	50131	17
Benzene And Toluene	109942	37
Sulfuric Acid	31037	10
Basic Chemicals And Products	577533	193
Nitrogenous Chemical Fertilizers	532410	177
Potassic Chemical Fertilizers	23714	8
Phosphatic Chemical Fertilizers	97700	33
Fertilizer And Materials	606711	202
Miscellaneous Chemical Products	9862	3
Gasoline	2718821	906
Jet Fuel	107506	36
Kerosene	25373	8
Distillate Fuel Oil	1337511	446
Naphta, Petroleum Solvents	63102	21
Liquified Gases	55325	18

Shipment frequencies were calculated using 3000 tons/barge capacity.

Table 7
Chemicals Shipped By Barge Which Exceed
50 Shipment/Year

Basic Chemicals And Products

Nitrogenous Chemical Fertilizers (Ammonia)

Fertilizer And Materials

Gasoline

Distillate Fuel Oil

Table 8
Chemicals Stored On Site

Chemical	Number Of Containers	Container Size	Location
Chlorine	6	1 Ton	100 meters
Ammonium Hydroxide	10	55 gal	Turbine Building
Sulfuric Acid	1	5000 gal	Turbine Building
Hydrazine	8	35 gal	Turbine Building
Sodium Hydroxide	1	5000 gal	Turbine Building

Table 9

FINAL ANALYSIS RESULTS

Chemical	Quantity	TLV	Maximum Control Room Concentration (ppm)
Ammonia	102 tons	25	1531
Hydrochloric Acid	98 tons	5	1569
Chlorine (on site)	1 ton	1	733.7
Chlorine (CMSTP & PRR)	18,000 gal.	1	6100
Hydrazine	35 gal	0.1	0.0064
Gasoline	3000 tons	500	360.7
Distillate Fuel Oil	3000 tons	200	23.60
Formaldehyde	21,000 gal.	2	328.1

Table 10
Monitor Setpoints And Toxicity Levels

Chemical	Monitor Set Point (ppm)	TLV (ppm)	STEL (ppm)
Ammonia	25	25	35
Chlorine (1)	1	1	15
Formaldehyde	1	2	2
Hydrochloric Acid	5	5	10

(1) The STEL for chlorine was obtained from R. G. 1.95 (2-minute level).



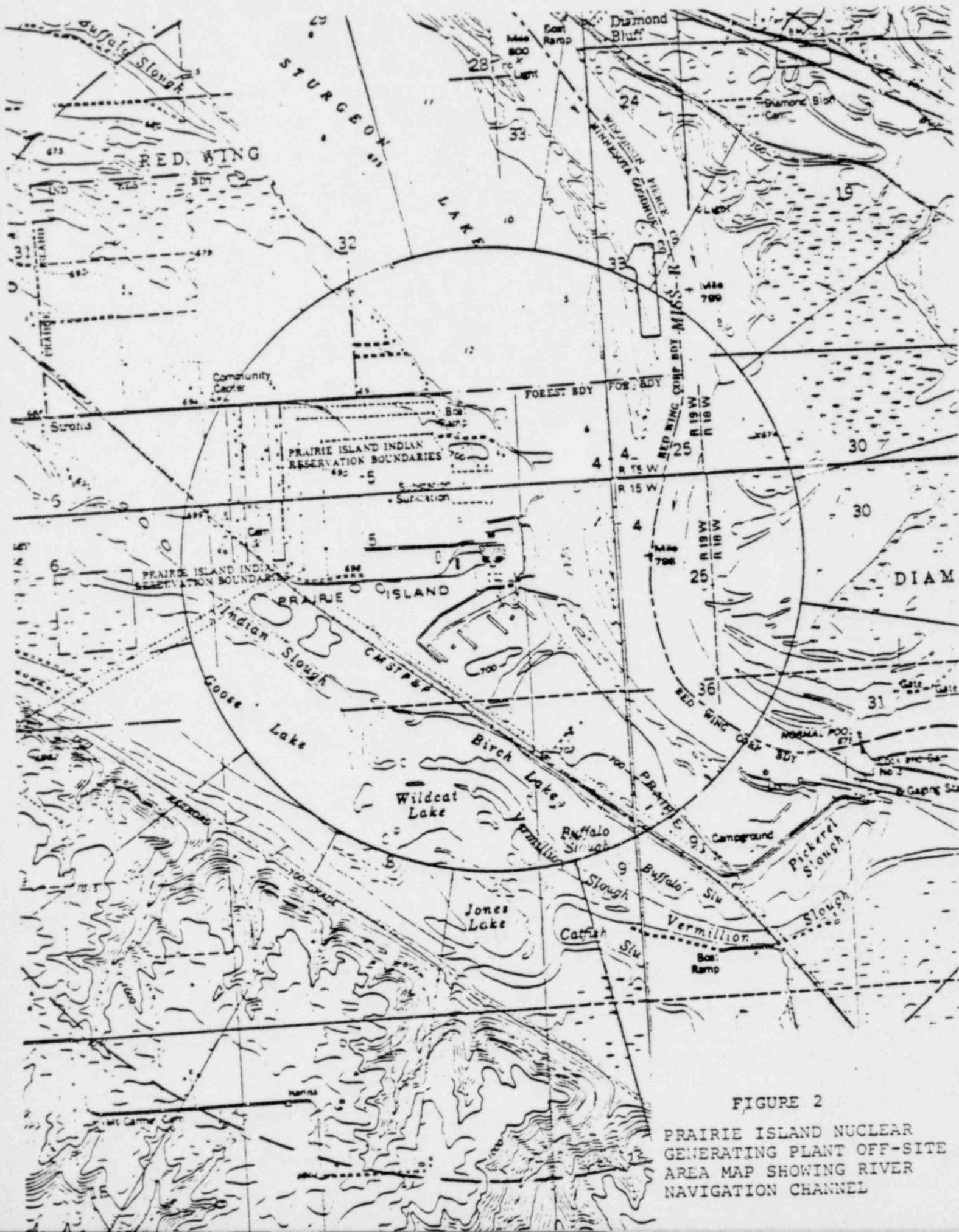
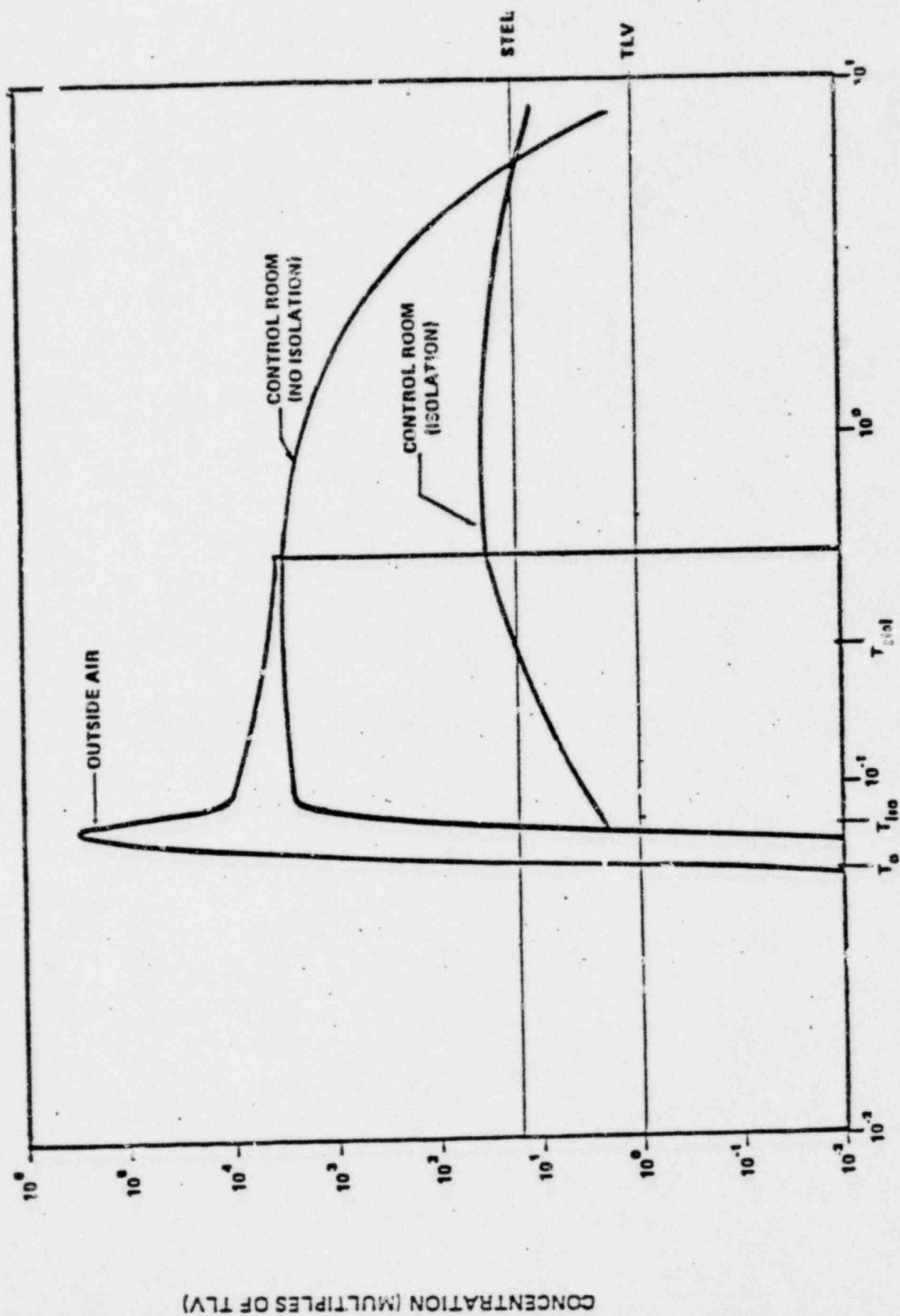


FIG 3 - CONTROL ROOM CONCENTRATION FOR A TYPICAL CHEMICAL



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APPENDIX A

Toxic Vapor Concentrations in the
Control Room - Models

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A.1 INTRODUCTION

The models used to calculate the concentrations of toxic chemicals in the control room atmosphere are consistent with the models described in NUREG-0570.

Several conservative assumptions consistent with NUREG-0570 were made to calculate the concentrations of toxic vapor. Some of these are:

1. The entire inventory or cargo in one container is released.
2. The area of the spill, as predicted by eg. (2.3-1) spreads until a depth of 1 cm for the spill is achieved.
3. The vapor, in the form of a puff or plume, moves directly towards the air intake of the control room.

It should be pointed out that the probabilistic nature of the catastrophic spill of toxic chemicals, during transportation and in storage, is not considered here. That is, the frequency of shipment and cargo size of each toxic chemical past the Prairie Island site, the accident rates of on-site release and of each shipment type, the distribution of wind speeds and directions, and the uncertainty of the weather conditions will not be included in the assessment of vapor concentrations.

A.2 MASS TRANSFER FROM SPILL TO ATMOSPHERE

The volatility of a substance is a direct function of its vapor pressure. Compressed gases, liquified gases, and many liquids have sufficiently high vapor pressures so that when released to the atmosphere, they will either vaporize or evaporate. For compressed gases and liquified gases and those liquids where normal boiling points are far below the ambient temperature, instantaneous flashing will first take place. The remaining liquid will vaporize by drawing heat from the surroundings. On the other hand, if the normal boiling point is above the ambient temperature, the liquid will evaporate into the atmosphere.

A.2.1 Low Boiling-Point-Liquids and Compressed Gases

For simplicity, a low boiling point liquid is considered to be a compressed gas, liquified gas, or a liquid whose boiling point is below the ambient temperature.

A.2.1.1 Instantaneous (PUFF) Release

For liquified gases and low boiling point liquids, the heat balance in the instantaneous puff formation assuming an adiabatic change is given by:

$$m_T C_p (T_a - T_b) = m_{VO} H_v \quad (2.1-1)$$

where:

- m_T = total initial mass (g)
- C_p = heat capacity of the liquid (cal/g-°C)
- T_a = ambient temperature (°C)

T_b = normal boiling point of the liquid ($^{\circ}\text{C}$) $< T_a$
 m_{v0} = mass of the instantaneously vaporized liquid (g)
 H_v = heat of vaporization of the liquid (cal/g)

A.2.1.2 Vaporization

As a result of flashing, the temperature of the remaining fluid is reduced below ambient levels. The remaining liquid, $(m_T - m_{v0})$, will vaporize by absorption of heat from atmospheric radiation, solar radiation, convection of air, and ground conduction.

The rate of total heat transfer, in cal/sec from all of these sources can be described as follows (NUREG-0570 p. 9).

$$\frac{dQ}{dt} = A(t) (q_r + q_c + q_a) \quad (2.1-2)$$

where:

$A(t)$ = area of the spill (m^2)
 q_r = solar and atmospheric radiation fluxes ($\text{cal}/\text{m}^2\text{-sec}$)
 q_c = heat flux due to force convection of air over the spill ($\text{cal}/\text{m}^2\text{-sec}$)
 q_d = heat transfer due to earth conduction ($\text{cal}/\text{m}^2\text{-sec}$)

Various values at different locations in the southwestern region have been measured for q_r . The maximum values are (Roosevelt Reservoir AR) $115 \text{ cal}/\text{m}^2\text{-sec}$ and $97 \text{ cal}/\text{m}^2\text{-sec}$ for atmospheric and solar radiation, respectively for a total q_r of $212 \text{ cal}/\text{m}^2\text{-sec}$ (NUREG-0570, P. 7).

The heat flux, q_c , due to forced convection of air over the spill is (NUREG-0570, p. 8):

$$q_c = h_c (T_a - T_b) \quad (2.1-3)$$

where a value of $1.6 \text{ cal/m}^2\text{-sec } ^\circ\text{C}$ is used for h_c (NUREG-0570, p. 8).

The heat transfer by earth conduction, q_d , is given by the following relation (NUREG-0570, p. 9).

$$q_d = 197 (T_E - T_b) / t^{1/2} \quad (2.1-4)$$

where

T_E = ground temperature ($^\circ\text{C}$)

t = time (sec)

For T_E , the ambient temperature T_a is used.

Placing all of the above relations into 2.1-2, we obtain

$$\frac{dQ}{dt} = A(t) \left\{ 212 + 1.6 (T_a - T_b) + 197 (T_a - T_b) / t^{1/2} \right\} \quad (2.1-5)$$

The vaporization rate, dm_v/dt , in g/sec, is then

$$\frac{dm_v}{dt} = \frac{1}{H_v} \left(\frac{dQ}{dt} \right) \quad (2.1-6)$$

$$= \frac{A(t)}{H_v} \left\{ 212 + \left(1.6 + \frac{197}{t^{1/2}} \right) (T_a - T_b) \right\} \quad (2.1-7)$$

where m_v = mass of the vapor

A.2.2 Normal Boiling-Point-Liquids

When exposed to the atmosphere, the liquids with normal boiling points above the ambient temperature will evaporate by diffusion into the air. The main driving force here is the vapor pressure difference, i.e., concentration gradient, between the liquid phase and the air.

A.2.2.1 Evaporation Rates

The evaporation of a liquid at ambient temperature in an open space with wind can be described as a mass transfer process by forced convection.

The evaporation rate can be calculated by the following formulae (NUREG-0570, p. 12)

$$\frac{dm_v}{dt} = h_d M A(t) (P_s - P_a) / R_g (T_a + 273.16) \quad (2.2-1)$$

where, for laminar flow,

$$h_d = 0.664 \frac{D}{L} (Re)^{1/2} (Sc)^{1/3} \quad (2.2-2)$$

- $A(t)$ = area of spill (cm^2)
- Re = Reynold number = $L u_0 / \mu$
- Sc = Schmidt number = $\mu / D \rho$
- h_d = mass transfer coefficient (cm/sec)
- R_g = universal gas constant
- u = wind speed (cm/sec)
- ρ = density of air (g/cm^3)
- μ = viscosity of air ($g/cm-sec$)
- M = molecular weight of liquid ($g/mole$)

P_s = saturation vapor pressure of the liquid at temperature T_a (mm Hg)
 P_a = actual vapor pressure of the liquid in air
 L = characteristic length (cm)
 D = diffusion coefficient (cm²/sec)

P_a is normally zero for all liquids. The diameter of the spill is used as the characteristic length L . Since the spill reaches its maximum dimensions quickly, the maximum diameter of the spill is used.

A.2.2.2 Diffusion Coefficient

The diffusion coefficients of the liquid into air are given for a few compounds in NUREG-0570 pp. 31-33. The diffusion coefficient, D_{AB} , of a gas A diffusing into a gas B may also be estimated by (Bird, et al., p. 511):

$$D_{AB} = 0.0018583 \frac{(T_a + 273.16)^{3/2} \left(\frac{1}{M_A} + \frac{1}{M_B} \right)^{1/2}}{P \sigma_{AB}^2 \Omega_{AB}} \quad (2.2-3)$$

where

M_A = molecular weight of gas A (g/mole)
 M_B = molecular weight of gas B (g/mole)
 P = atmospheric pressure (atm)
 σ = Lennard-Jones parameter
 Ω_{AB} = dimensionless function of temperature and intermolecular potential field E_{AB}

The Lennard-Jones parameters are empirically estimated to be:

$$\sigma_{AB} = (\sigma_A + \sigma_B) / 2 \quad (2.2-4)$$

$$\epsilon_{AB} = \sqrt{\epsilon_A \epsilon_B} \quad (2.2-5)$$

Ω_{AB} is tabulated as a function of $k(T+273.16)/\epsilon_{AB}$ by Bird, et. al.

ϵ/k and σ for each gas can be estimated using the following relations (Bird, et. al. p. 22).

$$\epsilon/k = 0.77 T_c \quad (2.2-6)$$

$$\sigma = 2.44 \left(\frac{T_c}{P_c} \right)^{1/3} \quad (2.2-7)$$

for diffusion in air, the following parameters are used

$$\begin{aligned} \sigma_A &= 3.617 \text{ \AA} \\ \epsilon_{A/k} &= 97 \text{ }^\circ\text{K} \\ M_A &= 28.84 \text{ g/mole} \\ P &= 1 \text{ atmosphere} \end{aligned}$$

For chemicals where T_c and P_c were unobtainable, a diffusion coefficient of $0.2 \text{ cm}^2/\text{sec}$ was used.

A.2.3 Spill Area

The rate of mass transfer, i.e., vaporization or evaporation, of a liquid into the atmosphere is, among other things, directly proportional to the surface area of the spill. Initially, the liquid is assumed to be in the shape of a cylinder, with the height equal to the radius of the base. The liquid is assumed to spread quickly by gravity to a thin pancake. The surface area, A , is given by (NUREG-0570, p. 4):

$$A(t) = \pi \left\{ r_0^2 + 2t \left[\frac{gV_0}{\pi} \frac{(\rho_e - \rho)}{\rho_e} \right]^{1/2} \right\} \quad (2.3-1)$$

$$\text{and } V_0 = \pi r_0^3 \quad (2.3-2)$$

where

- r_0 = initial radius of the spill (cm)
- g = gravitational constant = 981 cm/sec²
- V_0 = volume of the spill (cm³)
- P_1 = density of the liquid (g/cm³)
- p = density of air (g/cm³)
- t = time (sec)

The surface area, however, does not in reality expand indefinitely as eq. (2.3-1) indicates, but a maximum surface area is reached at some time. If the spill occurs on a surface that will restrict the spread of the spill, then the maximum area of the spill can be calculated. In cases where the condition of the ground cannot be accurately determined, a depth of 1 cm for the spill is assumed.

It should be noted that V_0 is the volume of the liquid spill remaining after instantaneous flashing to puff has taken place and is given by

$$V_0 = \frac{m_T - m_{V_0}}{P_1} \quad (2.3-3)$$

A.3 VAPOR DISPERSION

The vapor from instantaneous flashing (puff) and from continuous vaporization or evaporation (plume) moves in the direction of the wind, and disperses by diffusion into the atmosphere. The dispersion is assumed to follow a Gaussian distribution for short travel times (a few minutes to one hour). That is, an individual puff may or may not be well-described by a Gaussian formulation, but an ensemble of puffs is assumed to disperse in a Gaussian function. This diffusion model is applicable only to the vapors whose densities do not differ greatly from that of air (Slade). The wind is assumed to be in the direction from the source of spill to the control room air intake. It should be noted that the topography between the source and receptor is ignored in this treatment.

A.3.1 Instantaneous (Puff) Release

The diffusion equation for an instantaneous puff with a finite initial volume and a receptor at the air intake is given by the following equation (NUREG-0570, p. 18)

$$\frac{X}{Q} (\text{puff}) = (2\pi)^{-3/2} (\sigma_{XI}\sigma_{YI}\sigma_{ZI})^{-1} \exp \left\{ -\frac{1}{2} \left(\frac{x^2}{\sigma_{XI}^2} + \frac{y^2}{\sigma_{YI}^2} \right) \right\} \\ \cdot \left\{ \exp \left(-\frac{1}{2} \frac{(z-h)^2}{\sigma_{ZI}^2} \right) + \exp \left(-\frac{1}{2} \frac{(z+h)^2}{\sigma_{ZI}^2} \right) \right\} \quad (3.1-1)$$

X/Q (puff) is given in m^{-3}

σ_{XI} , σ_{YI} , σ_{ZI} = adjusted standard deviations of the puff concentration in the horizontal along-wind (X), horizontal cross-wind (Y), and vertical cross-wind directions (Z), respectively (m).

x, y, z = distances from the puff center in the X, Y, and z directions, respectively (m). z is also the effective above-ground elevation of the receptor, e.g., the fresh-air intake of a control room.

h = effective above-ground elevation of the source.

To account for the initial volume of the puff, it is assumed that

$$\sigma_{XI}^2 = \sigma_{XI}^{\prime 2} + \sigma_o^2 \quad (3.1-2)$$

$$\sigma_{YI}^2 = \sigma_{YI}^{\prime 2} + \sigma_o^2 \quad (3.1-3)$$

$$\sigma_{ZI}^2 = \sigma_{ZI}^{\prime 2} + \sigma_o^2 \quad (3.1-4)$$

$$\sigma_{XI}^2 = \sigma_{YI}^2 \quad (3.1-5)$$

and letting $x = x_o - ut$

$$\sigma_o = \left[m_{VO} / (2^{1/2} \pi^{3/2} \rho_V) \right]^{1/3}$$

where

σ_o = initial standard deviation of the puff (m)

σ_{XI}' , σ_{YI}' , σ_{ZI}' = standard deviation of puff concentration in the X, Y, and Z directions, respectively (m)

m_{VO} = mass of the instantaneously released puff (g)

ρ_V = density of the puff (g/m^3)

x_o = ground distance between the source of spill and receptor (m)

u = wind speed (m/sec)

t = time after release (sec)

The density of the puff is calculated using the ideal gas law.

$$PV = nRT \quad (3.1-6)$$

and the relation between density and volume

$$\rho_v = \frac{M \cdot n}{V} \quad (3.1-7)$$

which leads to:

$$\rho_v = \frac{M \cdot P}{RT} \quad (3.1-8)$$

where

M = molecular weight (gm/mole)

P = atmospheric pressure (atm)

n = number of moles

R = universal gas constant $8.205 \times 10^{-5} \frac{\text{atm} \cdot \text{m}^3}{\text{mole} \cdot ^\circ\text{K}}$

T = ambient temperature, $^\circ\text{K}$

V = volume (m^3)

Then, Eq. (3.1-1) may be used for the calculation of the center-line concentration where $y = 0$.

Since the control room air intakes are located 22.9 meters above ground level, heavier than air vapor must overcome gravity to rise to the intake, while lighter than air vapors will reach the intake easily. To account conservatively for this effect, the puff dispersion, Eq. (3.1-1) is modified as follows:

For the vapors much heavier than air, the puff centerline is assumed to move up the hill to the ground level elevation of the plant. Dilution will occur due to the puff rising up the hill, but no credit was taken to account for this effect, $z=h=0$ is used in Eq. (3.1-1). For vapors much lighter than air, the puff centerline is assumed to move directly to the level of the air intake, therefore h is replaced by z in Eq. (3.1-1).

A.3.2 Continuous Plume Diffusion

The diffusion equation for the continuous release of a plume with a finite initial volume and a receptor at z above the ground level is given by the following equation (Slade, p. 99):

$$\begin{aligned} X/Q(\text{cont}) = (2\pi u \sigma_y \sigma_z)^{-1} \cdot \exp \left\{ \frac{-y^2}{2\sigma_y^2} \right\} \left\{ \exp \left[-\frac{(z-h)^2}{2\sigma_z^2} \right] \right. \\ \left. + \exp \left[-\frac{(z+h)^2}{2\sigma_z^2} \right] \right\} \end{aligned} \quad (3.2-1)$$

where

$X/Q(\text{cont})$ is given in sec/m^3

σ_y, σ_z = standard deviations of the plume concentrations in the y and z direction, respectively.

To give credit for the finite initial size of the spill, σ_y here is replaced by $(\sigma_y^2 + \sigma_{y0}^2)^{1/2}$, where σ_{y0} is the effective width of the spill. Although the distribution of a circular spill of a liquid in the cross-wind direction is not a normal function (it is of the form $P = (1 - F^2)^{1/2}$, where $-1.0 \leq F \leq 1.0$), σ_{y0} may be approximated by the following method (NUREG-0570, p. 20).

$$\sigma_{y0} \approx r \pi^{1/2} / 4.3 \quad (3.2-2)$$

where r = radius of the spill. Similarly, σ_z may be replaced by $(\sigma_z^2 + \sigma_{z0}^2)^{1/2}$ to account for the building effect. σ_{z0}^2 may be approximated by the following method:

$$\sigma_{z0}^2 = \frac{.5z^2}{\pi} \quad (3.2-3)$$

Again, to account for the differences for heavier than air and lighter than air vapors, $z = h = 0$ is used in Eq. (3.2-2) for vapors heavier than air. For vapors lighter than air, h is replaced by z in Eq. (3.2-1).

A.3.3 Standard Deviations and Stability Conditions

The stability categories, i.e., the Pasquill's types of weather conditions, are defined as:

<u>Pasquill's Stability Category</u>	<u>Weather Condition</u>
A	extremely unstable
B	moderately unstable
C	slightly unstable
D	neutral
E	slightly stable
F	moderately stable
G	extremely stable

Although the Pasquill-Gifford curves are appropriate only for plumes, they may be assumed to be applicable for estimating the puff dispersion coefficients. Using the Pasquill-Gifford curves (Slade, pp. 102 and 103) a functional dependence for σ_y and σ_z was developed of the form:

$$\log_{10} \sigma = A + B \log_{10} x + C (\log_{10} x)^2 + D (\log_{10} x)^3 \quad (3.3-1)$$

where x is the distance from the spill to the control room
air intake in km

The coefficients are as follows:

Coefficients for σ_y

Pasquill Stability	A	B	C	D
A	2.3237	0.89182	0.00028741	-0.01228
B	2.1556	0.91347	0.028256	-0.02334
C	2.0142	0.91977	-0.0022985	-0.008289
D	1.8288	0.92394	-0.0056984	-0.0062276
E	1.7006	0.92826	-0.0017835	-0.009115
F	1.5289	0.92159	-0.011057	-0.0032318
G(x in m)	-1.6212	1.0648	-0.014857	-0.0020555

Coefficients for σ_z

Pasquill Stability	A	B	C	D
A	2.7301	2.6383	1.68666	0.59749
B	2.1003	1.3655	0.407576	0.0888029
C	1.8087	0.87272	-0.06512	0.00184558
D	1.4901	0.72583	-0.093465	0.011157
E	1.3284	0.67969	-0.10332	-0.0005092
F	1.1391	0.65602	-0.12889	0.0037608
G(x in m)	-1.8981	1.1243	-0.036447	-0.0086351

A.4 CONTROL ROOM CONCENTRATIONS

The concentrations of the toxic chemical, C_{CR} , in g/m^3 , in the control room, at any instant, is calculated by solving the following differential equation:

$$\frac{dC_{CR}(t)}{dt} = \lambda_I X(t) - \lambda_O C_{CR}(t) \quad (4-1)$$

where

- λ_I is the control room air inflow rate, (sec^{-1})
- λ_O is the control room air exhaust rate (sec^{-1})
- $X(t)$ is the concentration outside the air intake (g/m^3)
- $C_{CR}(t)$ is the concentration in the control room (g/m^3)
- t in seconds

The control room air inflow rate, λ_I , is given by:

$$\lambda_I = \frac{F_I}{V_{CR} \cdot 60} \quad (4-2)$$

and similarly, λ_O , is given by:

$$\lambda_O = \frac{F_O}{V_{CR} \cdot 60} \quad (4-3)$$

where

- V_{CR} is the control room volume (ft^3)
- F_I is the control room air intake flow (cfm)
- F_O is the control room air exhaust flow (cfm)

The concentration of the toxic chemical, $X(t)$, at the air intake just outside the control room is the sum of the puff and plume concentration at any instance and is given by:

$$X(t) = m_{VO} \frac{X}{Q} \text{puff}(t) + \left(\frac{dmv}{dt} \right) \frac{X}{Q} \text{cont}(t) \quad (4-4)$$

where m_{VO} is given by Eq. (2.1-1), $\frac{X}{Q} \text{puff}(t)$ is given Eq. (3.1-1).

$\frac{dmv}{dt}$ is zero for $t < \frac{D}{u}$ and is given by Eq. (2.1-7) for any time thereafter. $\frac{X}{Q} \text{cont}(t)$ is also zero for $t < \frac{D}{u}$ and is given by Eq. (3.2-1) for any time thereafter.

The concentration of the toxic chemical at any time, t , in the control room is given by the following solution of Eq. (4-1):

$$C_{CR}(t) = e^{-\lambda_0 t} \int_0^t e^{\lambda_0 t'} \lambda_I X(t') dt \quad (4-5)$$

A.5 CONCENTRATIONS IN PARTS PER MILLION (ppm)

A convenient method of presenting concentrations of toxic gases in the atmosphere is in units of parts per million (ppm).

To convert to ppm from gm/m³, we use the ideal gas law:

$$PV = nRT \quad (5-1)$$

where for a volume V, n moles of total gases are present. The number of moles of toxic gases is given by:

$$n_i = \frac{C(\text{gm/m}^3) \cdot V}{MW} \quad (5-2)$$

where C(gm/m³) is the concentration in gm/m³
V is the volume in consideration, m³
MW is the gram-molecular weight of the substance (gm/mole)

The concentration in ppm is then given by:

$$C(\text{ppm}) = \frac{n_i \times 10^6}{n} = \frac{C(\text{gm/m}^3) \cdot R \cdot T \times 10^6}{MW \cdot P} \quad (5-3)$$

where R = gas constant $8.205 \times 10^{-5} \frac{\text{atm-m}^3}{\text{mole-}^\circ\text{K}}$

T = ambient temperature, °K.

P = atmospheric pressure (1 atm).

A.6 REFERENCES

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- J. Wing, "Toxic Vapor Concentrations in the Control Room Following a Postulated Accidental Release", NUREG-0570, U.S. NRC, Washington, D.C. (1979).
- R. B. Byrd, W. E. Stewart, W. N. Lightfoot, "Transport Phenomena", John Wiley & Sons, N. Y. (1960).

APPENDIX B

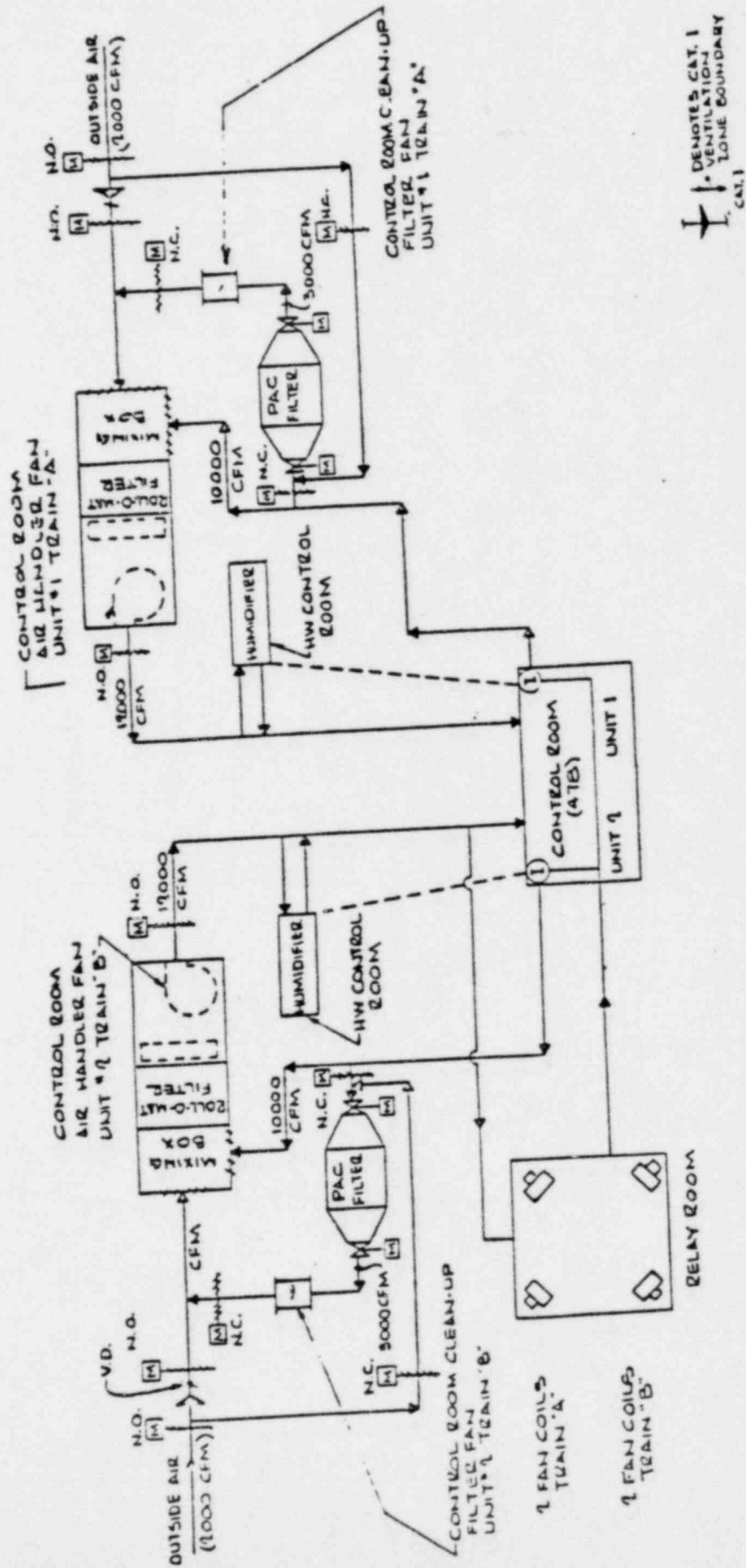
Included in Appendix B are control room and other system characteristics required by NUREG-0737 Section III.D.3.4, Attachment 1 related to the toxic chemical study to aid in an independent evaluation as required by NUREG-0737.

The habitability of the control room during a DBA is discussed in Section II titled Prairie Island Control Room Design Basis Accident Radiological Study.

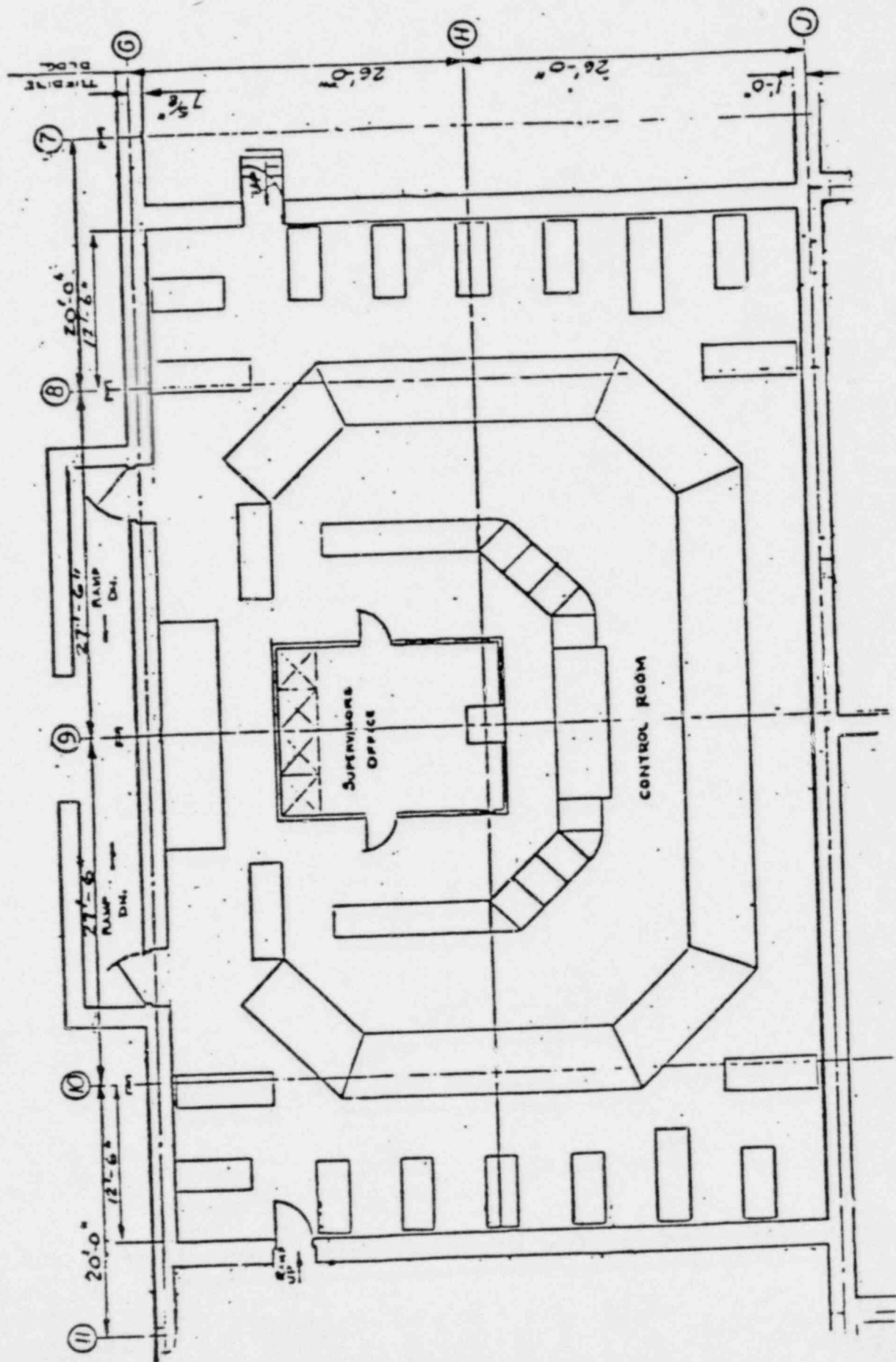
Control room characteristics

- | | |
|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| air volume control room | - 116,840 ft ³ to false floor to false ceiling. (143,030 ft ³ including plenum space)
air volumes do not allow for equipment volume but do include the relay and computer rooms serviced by this air. |
| infiltration leakage rate | - zero in normal and high radiation condition (control room is pressurized). Zero (est.) in isolation mode, 100% recirc., no pressurization. (Control room has no walls or doors exposed to the outside air.) |
| high efficiency particulate air (HEPA) filter and charcoal absorber efficiencies | - HEPA 99.97% on 0.3 micron particles
Charcoal Adsorber-Elemental Iodine 95%
- Organic Iodine 95%
(Both charcoal adsorber efficiencies per 2" bed depth) |
| Closest distance between containment and air intake | - 65 ft. from main control room air intake to reactor building wall. |
| Automatic isolation capability | - damper closing time, damper leakage and area
damper closing time - 7.5-15 sec. |
| at 1" W.G. | 12" dia. = 0.79 ft ² - normal air intake opening - assumed leakage = 12 cfm* |
| | 20" x 16" = 2.22 ft ² - fresh air intake opening - assumed leakage = 23 cfm* |
| | 20" x 16" = 2.22 ft ² - exhaust opening - assumed leakage = 23 cfm* |

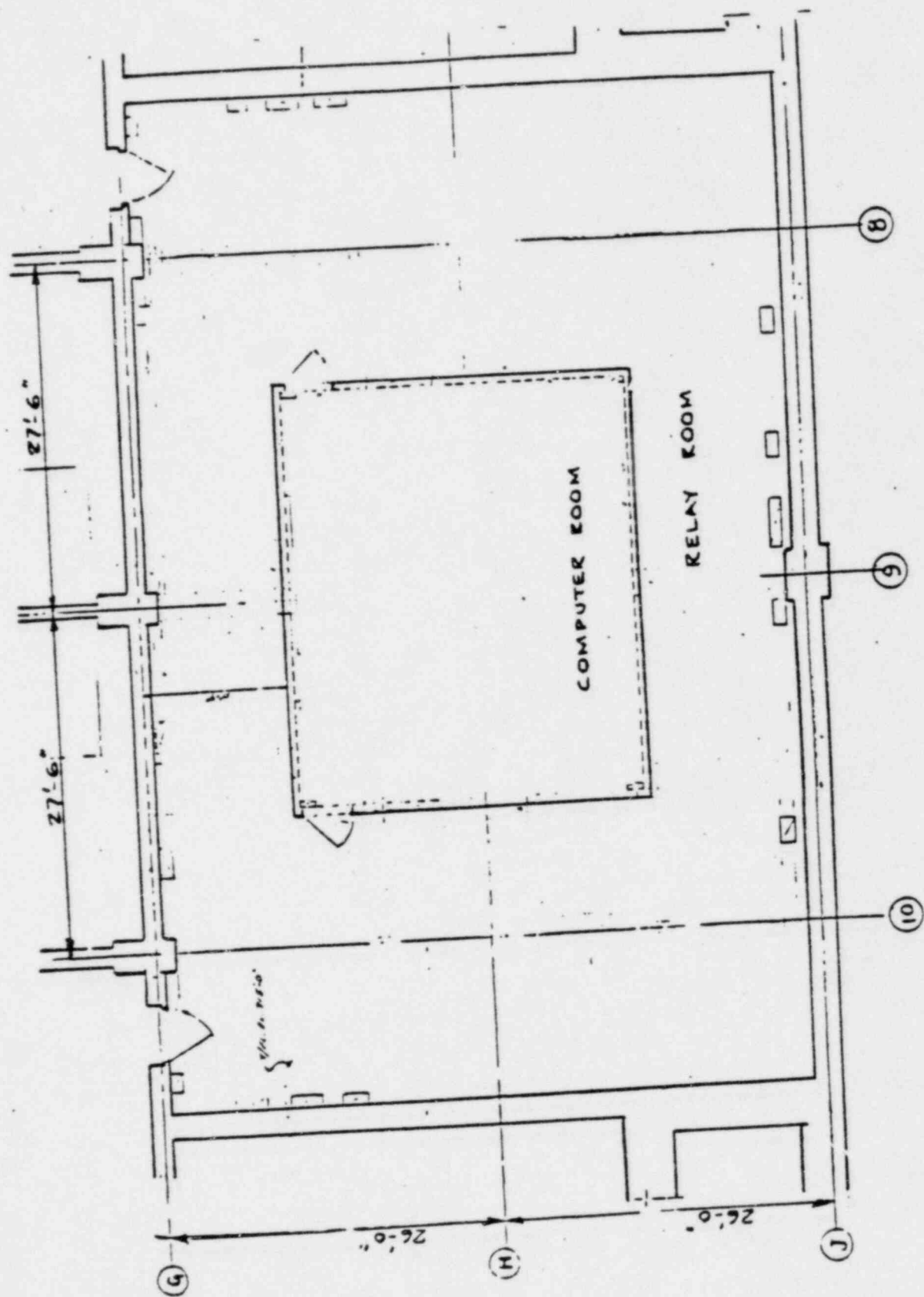
*Assuming Class II type, equivalent and no credit for the two in series.



FLOW DIAGRAM
CONTROL ROOM AIR CONDITIONING



CONTROL ROOM



COMPUTER & RELAY ROOM

SECTION II

PRAIRIE ISLAND CONTROL ROOM
DESIGN BASIC ACCIDENT RADIOLOGICAL STUDY

1.0 CONTROL ROOM SHIELDING (DIRECT RADIATION)

The control room design has been reviewed to determine the direct radiation dose rates in the event of a Design Basis Accident (D.B.A.). This design review was performed in conjunction with the requirements of NUREG-0737.

The design review determined the dose rates in the control room from various systems that, as a result of an accident, may contain highly radioactive fluids. Systems that were evaluated included the following: Residual Heat Removal (RHR), Safety Injection (SI), Containment Spray (CS), Auxiliary Building Special Ventilation (ABSVS), Shield Building Ventilation (SBVS), Chemical and Volume Control System (CVCS), and the Containment Vessel itself. Due to the physical arrangement of the systems, the sources assumed within these systems and the existing shielding, only the CVCS and the Containment Vessel contribute any significant amount to the DBA radiation levels in the control room.

The activity levels in the RHR, SI, and CS systems have been conservatively assumed. It was assumed that 100% of the core equilibrium noble gas inventory and 50% of the core equilibrium halogen inventory had been diluted into the combined volume of the Reactor Coolant System and the Refueling Water Storage tank (RWST). This assumes that the water in the RWST has been injected and that the RHR recirculation mode is in use. This is conservative because the dose rates are based on a time = 0 activity and assumed no degassing of the recirculation water by the blowdown into containment.

The containment was assumed to have 100% of the core equilibrium noble gas inventory and 50% of the equilibrium halogen inventory uniformly mixed within the containment atmosphere.

The build-up of radioisotopes on the Shield Building Ventilation System charcoal beds was modeled using the design criteria leakage of 0.25 w/o per day from the containment to the SBVS. The Auxiliary Building Special Ventilation System dose rates were based on the RHR pump seal failure in conjunction with the 0.1 w/o per day leakage from containment which by passed the SBVS and was deposited on the ABSVS charcoal beds.

The dose rates from the Chemical and Volume Control System have been calculated assuming letdown was isolated after a gap activity release accident. The Letdown System should not be used in a high activity situation. The letdown portion of the CVCS will be isolated at a predetermined radioactivity level in the event of large fuel failure. With the addition

of the Head Vent System letdown will not be required to mitigate the accident. Isolating the Letdown System also eliminates the need for analyzing the dose rates from the Waste Gas Systems.

Dose rates in the control room at time = 0 have been calculated giving credit for the existing shielding. Credit was given for the Shield Building, Control Room walls, and the walls and floors within the Auxiliary Building. The resultant dose rates at time = 0 in the control room show that the room is adequately shielded for direct radiation in an accident situation. The maximum dose rate of 20 mrem/hr occurs in the corner of the control room behind the control board nearest the CVCS piping. Approximately 6 mrem/hr would be encountered in front of the control board nearest the affected unit. The rest of the Control Room would be at or less than 1 mrem/hr at time = 0.

The dose rates from containment decay quite rapidly. The dose rates at 1 hour, 2 hours, and 8 hours are expected to be 43%, 30% and 12% respectively of the time = 0 dose rates.

Calculations have been made by Fluor Power Services for the dose to Control Room Operators in a Maximum Hypothetical Accident. These calculations were based on source terms of TID-14844. No credit was taken for shadow shielding provided by the structures around various components in the Auxiliary Building, and Control Room occupancy after the event of 4-40 hour weeks. A dose of approximately 1 rem resulted from these calculations. The actual dose should be much less due to the shielding provided by the Auxiliary Building structure. However, the maximum dose of 1 rem shows that the control room is adequately shielded for direct radiation in an accident situation.

2.0 Control Room Airborne Doses

2.1 General Licensing Consideration

The requirements to show acceptable post LOCA doses in the Control Room (CR), (NRC's letter of 5/7/80) result in the need to evaluate the DBA-LOCA and the subsequent pathways for release of radioactivity.

The dose calculations were performed to show compliance of the Control Room (CR) with GDC 19.

2.2 Methodology

The guidelines given in SRP 6.4 and R.G. 1.3 were used with an exception of the X/Q s for CR and TSC. Atmospheric dispersion factors are based on the Halitsky Methodology from Meteorology and Atomic Energy 1968, as discussed in Section

2.2.1 Assumptions and Bases

Regulatory Guide 1.4 was used to determine activity levels in the containment following a DBA-LOCA. Activity releases are based on a containment leakage rate of 0.25% per day for the first day and 0.125% per day thereafter. Table 1 lists the assumptions and parameters used in the analysis.

The majority of the containment leakage will be collected in the shield building and exhausted to the atmosphere through the 95% efficient SBVS filters as an elevated release from the main stack. However, there exist certain release pathways from the containment which will bypass the SBVS filters. The bypass leakage was quantified by assuming that 1% of the primary containment leakage bypasses both the SBVS and the HBSVS systems directly to the atmosphere.

2.2.2 Atmospheric Dispersion Factor (X/Q)

The following discussion is an explanation of the reasons for the use of the Halitsky X/Q methodology and a value of $K_C=2.5$ instead of the Murphy methodology (Ref. 2) which SRP 6.4 suggests as an interim position.

Historically, the preliminary work on building wake X/Q s was based on a series of wind tunnel tests by James Halitsky et al. Halitsky summarized these results in Meteorology and Atomic Energy in 1968 (Ref. 1). In 1974 K. Murphy and K. Campe of NRC published their paper based on a survey of existing data. This X/Q methodology which

presented equations without derivation or justification, was adopted as the interim methodology in SRP 6.4 in 1975. Since that time a series of actual building wake X/Q measurements have been conducted at Rancho Seco (Ref. 3) and several other papers have been published documenting the results of additional wind tunnel tests.

Reviews of the Murphy Eq. 6 and discussions with the author over the years have determined that the building wake correction factor, $(K+2)/A$, and $K=3/(S/d)^{1.4}$ were derived from the Halitsky data in Figure 37 of Ref. 2 from Murphy's paper. The Halitsky data was from wind tunnel tests on a model of the EBR-II rounded (PWR Type) containment and the validity of the data was limited to $.5 < S/d < 3$ (Ref. 1, Sect. 5.5.5.2). The origin and reason for the +2 in $K+2$ is not known. All other formulations use K only, and for situations where K is less than 1 the use of $K+2$ imposes an unrealistic limit on the X/Q .

For the Prairie Island plant, the building complex is composed of low, square edged buildings and two cylindrical shield buildings. For the HVAC intake on the Auxiliary Building roof, the intake will be subject to a building wake caused by the portion of the shield building above the roof of the Turbine Building-Auxiliary Building complex.

Since the Murphy methodology is overly conservative, a survey of the literature was undertaken. It was found that the Halitsky wind tunnel test data (Ref. 1, Section 5.5.5) conservatively overestimated K values "by factors of up to possibly 10". Given this conservatism, it was felt that the use of a reasonable K value from the Halitsky data should be acceptable. A review of Figures 5.29c from M&AE (Ref. 1) resulted in K values in the 2 to 3 range. A value of $K=2.5$ was chosen to get a X/Q of 5.33×10^{-3} . Information from other sources, as indicated below, has also shown that this should be a conservative value.

In a paper by Walker (Ref. 4), control room X/Q 's were experimentally determined for floating power plants in wind tunnel tests. Different intake and exhaust combinations were considered. Using the data for intake 6, and stack A exhaust, (in Ref. 4) X/Q values of 2.95×10^{-5} and 3.73×10^{-5} were found after adjusting the wind speed from 1.5 m/sec to 0.6 m/sec. These values are approximately two orders of magnitude lower than the conservatively calculated value for Prairie Island.

In a wind tunnel test by Hatcher (Ref. 5), a model industrial complex was used to test dispersions due to the wake. Data obtained from their tests show that K has a value less than 1, and decreases as the test points are moved closer to the structure. Meroney and Yang (Ref. 6) in a study to determine optimum stack heights, show that for short stacks (6/5 of building height), K reaches a value of approximately 0.2 and decreases closer to the building. They concluded that the Halitsky methodology was "overly conservative". These recent experimental tests show that K = 2.5 used to determine the \bar{X}/Q for Prairie Island is a conservative estimate by, at least, a factor of 2 and possibly by 10 or more.

Field tests were made on the Rancho Seco facility (Ref. 3), and $u\text{-}\bar{X}/Q$ were obtained. Data from round topped containment releases and square edged auxiliary building releases were used to simulate the Prairie Island case. Measured $u\text{-}\bar{X}/Q$ values ranging from $8.07 \times 10^{-4} \text{ m}^{-2}$ to approximately 1×10^{-6} were found. Although most values of $u\text{-}\bar{X}/Q$ were in the 10^{-5} m^{-2} range for those cases approximating the Prairie Island configuration, the worst Rancho Seco case value of 8.07×10^{-4} at Pasquill G and 1.8 m/sec with a building area of 2050 m^2 is used for comparison purposes. When adjusted to the Prairie Island conditions with a wind speed of 0.6 m/sec and an area of 782 m^2 a \bar{X}/Q of 5.53×10^{-3} , which is 1.5 times smaller than the value 5.33×10^{-3} calculated for Prairie Island using the Halitsky wind tunnel data.

It was concluded that sufficient data and field tests exist to give a reasonable assurance that the chosen \bar{X}/Q is a conservative one, over and above the conservatism implied by using the 5th percentile wind speed and wind direction factors.

2.2.3 Results

The radiological exposures in the CR are included in Table 2. The doses fall within the GDC 19 guidelines values.

2.2.4 References

1. D. H. Slade, ed., Meteorology and Atomic Energy - TID 24190 (1968).
2. K. G. Murphy and K. M. Compe, "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19", 13th AFC Air Cleaning Conference.
3. S. J. Hart, G. E., J. H. Cate, C. R. Dickson, N. R. Ricks, G. M. Ackerman, and J. F. Sagendorf, "Rancho Seco Building Wake Effects on Atmospheric Diffusion, NOAA Technical Memorandum, ERL ARL-69, (1977).
4. Walker, D. H., R. N. Nassano, M. A. Capo, 1976: "Control Room Ventilation Intake Selection for the Floating Nuclear Power Plant", 14th ERDA Air Cleaning Conference.
5. Hatcher, R. N., R. N. Meroney, J. A. Peterka, K. Kothari, 1978: "Dispersion in the Wake of a Model Industrial Complex", NUREG-0373.
6. Meroney, R.N., and B. T. Yang, 1971: "Wind Tunnel Study on Gaseous Mixing due to Various Stack Heights and Injection Rates Above an Isolated Structure", FDDL Report CER 71-72 RNM-BTY16, Colorado State Univ.

TABLE 1

LOSS-OF-COOLANT ACCIDENT: PARAMETERS
TABULATED FOR POSTULATED ACCIDENT ANALYSES

	<u>DESIGN</u> <u>BASIS</u> <u>ASSUMPTIONS</u>
I. Data and Assumptions Used to Estimate Radioactive Sources from Postulated Accidents	
A. Power Level (MWt)	1721.4
B. Burnup	NA
C. Fission Products Released from Fuel (fuel damaged)	100%
D. Iodine Fractions	
(1) Organic	0.04
(2) Elemental	0.91
(3) Particulate	0.05
II. Data and Assumptions Used to Estimate Activity Released	
A. Primary Containment Leak Rate (%/day)	0.25 (0-1 day) 0.125 (1-180 days)
B. No mixing is assumed to occur in the shield building prior to release to the atmosphere	
C. Bypass leakage (% of primary containment leak rate)	1
D. SBVS Adsorption and Filtration Efficiencies (%)	
(1) Organic iodines	95
(2) Elemental iodine	95
(3) Particulate iodine	95
(4) Particulate fission products	95
III. Dispersion (sec/m ³):	
A. CR - Building Wake \bar{X}/Q for Time Intervals of	
(1) 0-8 hrs	5.33 x 10 ⁻³
(2) 8-24 hrs	3.14 x 10 ⁻³
(3) 1-4 days	2.00 x 10 ⁻³
(4) 4-30 days	8.79 x 10 ⁻⁴
(5) 30-180 days	4.40 x 10 ⁻⁴

TABLE 1 (Continued)

	DESIGN BASIS <u>ASSUMPTIONS</u>
IV. Data for CR:	
A. Volume of CR (ft ³)	116,840
B. Recirculation Rate through Charcoal Filters	3,000
C. Efficiency of Charcoal (%) Adsorber	95
D. Unfiltered Inleakage Rate (h ⁻¹)	0.06
E. Occupancy Factors:	
0-1 day	1.0
1-4 days	0.6
4-30 days	0.4
30-180 days	0.4

TABLE 2

AIRBORNE ACTIVITY INSIDE THE CONTROL ROOM
DOSES FROM A DBA LOCA (0-180) DAYS

	Thyroid	Whole Body	Skin
Doses (REM)	15.4	1.0	26.9
GDC 19 Dose Guidelines (REM)	30	5	30
			75*

*If protective clothing is worn