NUREG/CR-3786
SAND84-0978
AN
Printed August 1984

A Review of Regulatory Requirements Governing Control Room Habitability Systems

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Prepared by
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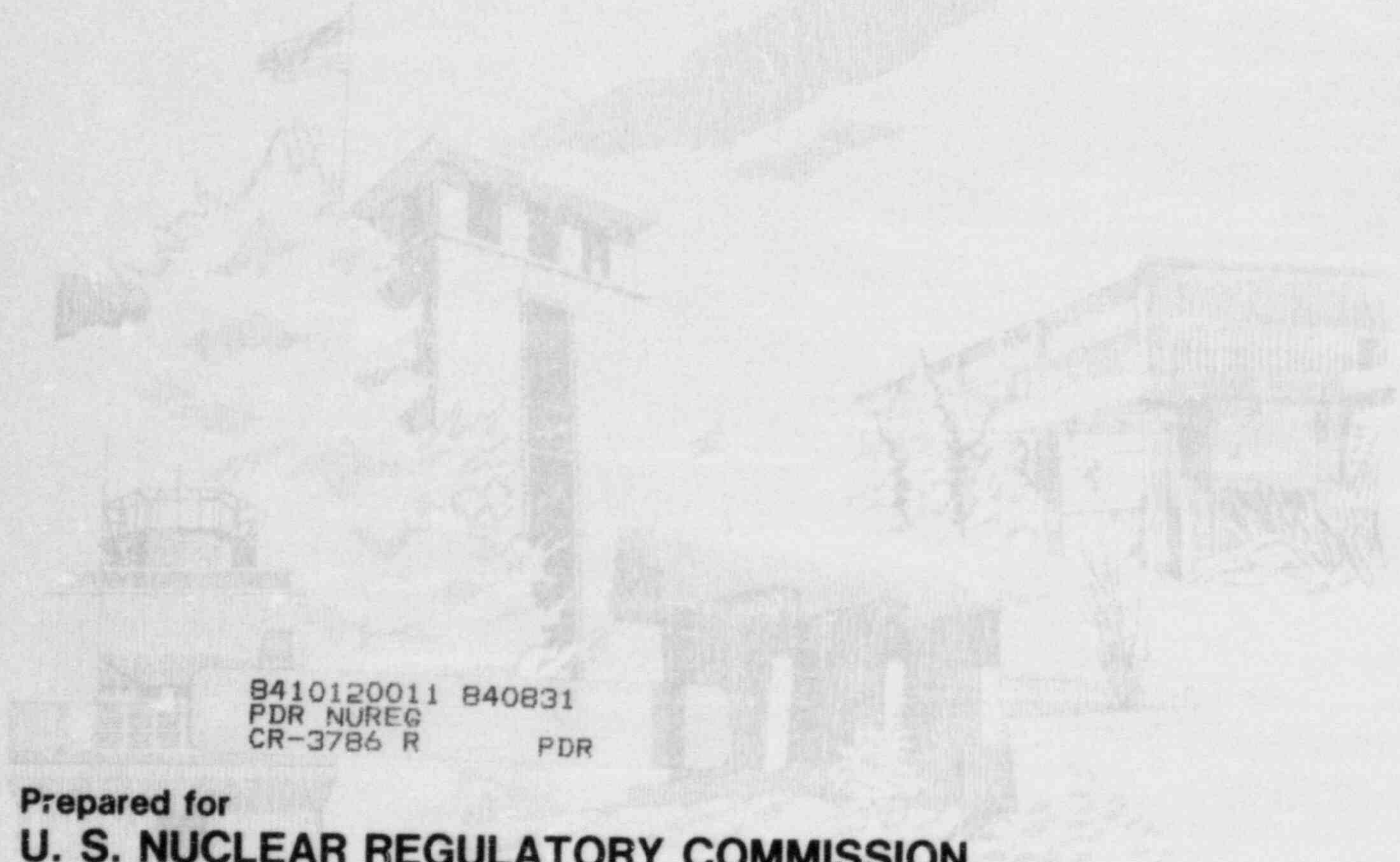
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789



Prepared for
U. S. NUCLEAR REGULATORY COMMISSION

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NUREG/CR-378
SAND84-0978
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Prepared for
Instrumentation and Control Branch
Division of Facility Operations
Office of Nuclear Regulatory Research
U. S. Nuclear Regulatory Commission
Washington, DC 20555
Under Interagency Agreement DOE-40-550-75
NRC Fin No. A-1377

Abstract

This report reviews applicable guides, standards, and codes which govern the design, manufacture, selection, installation, and surveillance practices for components and systems important to control room habitability. It covers the fundamental guidance contained in General Design Criteria, Regulatory Guides, and applicable sections of the Standard Review Plan, as well as numerous documents referenced by this guidance.

Instances are cited where the present guidance is misleading, contradictory, or vague. In some cases, the problems in the guidance result from inadequate technical bases; in other cases, the problems result from several documents which are not completely consistent.

To independently assess the suitability of the regulatory guide which covers accidental chlorine releases, a computer program was developed to calculate chlorine concentrations in the control room following chlorine release. Although problems with the assumptions used to develop the guide were found, the conservative nature of the chlorine calculations appears to adequately compensate for these problems.

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Executive Summary

This report presents the results of a documentation review of applicable guides, standards, and codes which govern the design, manufacture, selection, installation, and surveillance practices for components and systems which are important to control room habitability (CRH). The review concentrates on systems for temperature and humidity control, radiation control, toxic agent detection and control, and smoke control. Items which are excluded from this review include noise, illumination, and fire control systems.

This review traces the standards, beginning with applicable Regulatory Guide (RG) and Standard Review Plan (SRP) sections and proceeding to industry standards. It determines what requirements are invoked by the RGs and the SRP, as well as the standards they reference. Further, this review evaluates the requirements indirectly required by 10CFR50, 10CFR100, and the RGs for sound engineering practice. As a result of this review, additional guidance and requirements needed to enhance CRH functional specifications, equipment specifications, and testing requirements are outlined.

The General Design Criteria (GDC) in 10CFR50 Appendix A are the basis for CRH system regulatory guidance. The applicable GDC include GDC 2, GDC 4, GDC 5, GDC 19, and GDC 60; the applicable RGs include RG 1.52, RG 1.78, and RG 1.95; and the applicable portions of the SRP include Sec. 6.4, Sec. 6.5.1, and Sec. 9.4. The RGs often reference industry standards. In some instances, multiple subreferences follow in the referenced document.

Several areas of CRH system design are not adequately covered in the existing guidance. These include the necessity and capability of a smoke purge system, specifications for accident temperature limits, and guidance for the configuration of the normal heating, ventilation, and air conditioning system with respect to the emergency air filtration system. Many other areas have guidance which is misleading, contradictory, or vague. For example, based on current guidance, we developed a scenario for a control room design which appears to meet all the applicable regulations from both the designer's point of view and the reviewer's point of view. However, this design could result in chlorine concentrations in the control room three to five times greater than the toxicity limit when calculated in accordance with the currently accepted method. However, we believe that the current method of calculation is sufficiently conservative to prevent concentrations above the toxicity limit from actually occurring in control rooms.

We obtained and evaluated unpublished calculations used to develop a table in RG 1.95 which gives the maximum inventory of chlorine allowed at a given distance from various types of control rooms. The major shortcoming of the table is that the assumptions used in its derivation are not outlined in the regulatory guidance. In certain cases, a utility could unknowingly take redundant credit for allowances already built into the table. A computer program was written to independently calculate the chlorine concentrations in the control room following an accidental chlorine release. We found that the values were reasonably suitable, and in many cases conservative, when applied correctly. Chlorine concentrations for operable and inoperable chlorine detectors were calculated with the program. With inoperable

detectors, chlorine concentrations ranging from 3 to as high as 85 times the toxicity limit may occur. Again, however, the calculations appear extremely conservative in most cases.

This study points out the large number of documents containing specifications for CRH system design. The system requirements encompass not only all the documents covered in this review, but also numerous other documents that are beyond the scope of this review. Verifying that all CRH design requirements have been met by doing a brief design review is difficult. A single detailed document covering all aspects of CRH would clearly improve regulatory guidance.

As part of the recommendations for improving CRH systems, we propose an alternative method to pressurize the control room during the the most severe part of a radiological accident or a hazardous gas release. By reducing the amount of control room air conditioning, the increasing temperature will pressurize the control room. We show that for a specific plant's leakage characteristics, the control room can be maintained at 1/8-inch water gage for about 20 minutes with a temperature rise of only 10°F, based on ideal gas expansion of the control room air. This pressurization scheme could provide protection during the most severe part of an accident and give the operators time to take more permanent measures, such as using protective clothing and breathing apparatus.

Other recommendations include the following: 1) define technical bases for a control room smoke removal system, including a design basis smoke production and required smoke removal rate, 2) define control room accident temperature limits for habitability and good job performance, 3) include a review of system configuration in the Standard Review Plan, 4) develop criteria and methods for isolation valve leakage testing, 5) initiate control room isolation when an earthquake is detected, 6) include in the guidance all the assumptions used in the chlorine analysis, and 7) consider criteria for reviewing CRH component reliability.

1.0 INTRODUCTION

1.1 Objectives

The purpose of this report is to present the findings of a review of applicable guides, standards, and codes which govern the design, manufacture, selection, installation, and surveillance practices for components and systems which are important to control room habitability (CRH). This review emphasizes systems for temperature and humidity control, radiation control, toxic agent detection and control, and smoke control. Excluded from this review are the topics of noise, illumination, and fire control systems. Specific emphasis is directed towards the ability of components and systems to meet all applicable guidance and to perform their intended functions during normal operation, as well as during any credible postulated accident. Documents reviewed include the Code of Federal Regulations (CFR), applicable Regulatory Guides (RG), and applicable sections of the Standard Review Plan (SRP), as well as industry standards which are referenced in these documents.

1.2 Summary of Review

The General Design Criteria (GDC) contained in 10CFR50 Appendix A provide the basis for regulation of the CRH systems. To implement this regulatory basis, RGs have been developed to provide guidelines acceptable to the NRC for meeting the GDC. The RGs provide more detail than the GDC, but they often reference industry standards. The reference process may then continue through several subreferences.

This review traces the standards, generally beginning with applicable RG and SRP sections and proceeding to industry standards. It describes requirements specified by the RGs and the SRP, as well as the standards they reference. Further, this review evaluates the requirements indirectly required by 10CFR50 and the RGs for sound engineering practice. Finally, further guidance and requirements needed to more adequately prescribe the functional specifications, equipment specifications, and testing requirements for CRH systems are discussed.

A brief description of the regulations is presented in Appendix A with certain sections singled out for comment in the main body of the report.

1.3 Primary Documents Reviewed

The GDC in 10CFR50 Appendix A are the basis for regulation of CRH systems. GDC 2 (1) presents the design basis for protection against natural phenomenon for systems which are safety-related. GDC 4 (2) covers environmental and missile design bases and generally states that equipment "important to safety" should be able to function in design-basis environments and should not be affected by missiles or other dynamic effects. GDC 5 (3) applies only to plants with more than one unit. It specifies that an accident at one unit should not impair the ability of shared safety-related equipment to perform intended functions at the other unit(s). GDC 19 (4) specifies that a control room (CR) shall be provided from where action can be taken to keep the plant in a safe condition. Further, GDC 19 (4) limits the exposure of personnel to five rem during any accident. GDC 60 (5) specifies that radioactive release to the environment shall be controlled.

Three RGs govern most of the CRH system design and functional specifications. These are RG 1.52 (6), RG 1.78 (7), and RG 1.95 (8). RG 1.52 (6) governs atmosphere cleanup units required to mitigate the consequences of a design basis accident. RG 1.78 (7) and RG 1.95 (8) both cover CR protection during postulated hazardous chemical releases. RG 1.78 (7) addresses hazardous chemicals in general, while RG 1.95 (8) specifically addresses accidental chlorine releases. Not covered in this review are more general RGs, such as RG 1.76 (9) on the design basis tornado and RGs 1.3 (10), 1.4 (11), and 1.5 (12) on the radiological consequences of accidents.

SRP 6.4 (13) covers the review of the CRH systems for radiation and toxic gas protection; SRP 6.5.1 (14) covers the review of the ESF atmosphere cleanup systems; and SRP 9.4.1 (15) covers the review of the CR area ventilation system.

2.0 HVAC SYSTEM DESIGN GUIDANCE

Except for CR isolation, the RGs give no specific guidance for the design of the CR heating, ventilation, and air conditioning (HVAC) system. GDC 19 (4) requires a habitable CR under all conditions, but no other information is given in the required guidance for designing CR HVAC systems. Three areas relating to the normal HVAC system which are mentioned, but not adequately covered, in the guidance are as follows: (1) the necessity and capability of a smoke exhaust system, (2) the CR accident temperature limits, and (3) guidance for configuration of the CR HVAC system and its interrelationship to the engineered-safety-feature (ESF) air cleanup system.

2.1 Smoke Control-RG 1.120 and BTP CMEB 9.5-1

RG 1.120 (16) and Branch Technical Position (BTP) CMEB 9.5-1 (17) (formerly BTP ASB 9.5-1) specify under the topic of "Ventilation" that the method for combustion products removal should be established during the initial stages of plant design and that the use of the normal ventilation system is acceptable for smoke removal if it is "available and capable." However, RG 1.120 (16) and BTP CMEB 9.5-1 (17) do not provide a basis for evaluating the smoke removal capability. NFPA 204 (18) is referenced for additional guidance on smoke control. However, NFPA 204 (18) is not directly applicable. It is concerned only with the venting of burning areas, generally through roof vents. Nuclear power plant CRs do not use this concept because of other requirements, such as leaktight construction, CR isolation capability, and radiological limitations.

In the same RG and BTP under "Control Room Complex," use of the normal ventilation system is allowed for removing smoke generated in the CR, provided that the recirculation portion of the normal ventilation system can be isolated and purge air can be used on a once-through basis.

The single failure criterion is apparently not applicable to smoke removal systems because the normal ventilation system is not required as an ESF. Figure 1 shows an example of an actual design which does not satisfy the single failure criterion when the system is operating in the smoke removal mode. The failure of any one of the normal inlet or exhaust isolation valves, for example, would result in the closing of that valve (isolation valves fail closed) and the complete loss of smoke removal capability. Also, no guidance for sizing the system (i.e. smoke removal rates or number of air changes per hour) is given in the RG and BTP. A review of several plant designs (see Table 1) indicates smoke removal capabilities from almost none to more than 25,000 CFM, illustrating the wide variations in current systems and the need for some sizing basis for CR smoke removal systems.

2.2 Temperature and Humidity Control-NUREG-0700, STS, and SRP

Good engineering practice suggests CR temperature limits within the guidelines for human comfort and job performance, such as those given in Sec. 3 of Industrial Ventilation (19). NUREG-0700 (20) addresses CR temperature limits by referencing the American Society of Heating, Refrigeration, and Air Conditioning Engineers comfort standards. However, NUREG-0700 (20) is not a guide which must be followed in design; it is a review document. NUREG-0700 (20) also specifies that CR relative humidity be maintained between 20% and 60%.

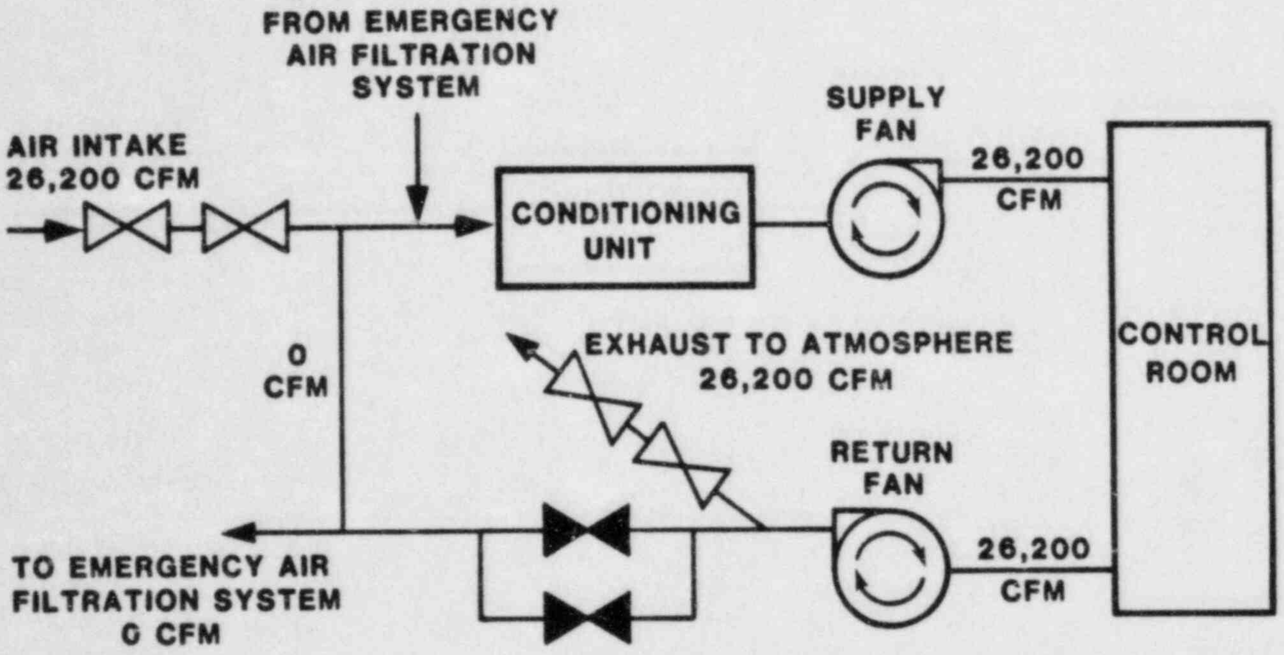

Figure 1: Example of HVAC System Operating in the Smoke Removal Mode and Not Satisfying the Single Failure Criterion. For example, if either of the air intake or exhaust valves failed, the smoke purge capability would be lost.

Note: The redundant conditioning unit, air supply fan, and air return fan are not shown.

Table 1: Example Data from FSAR of Several Plants

	Plant A	Plant B	Plant C	Plant D	Plant E	Plant F
Approximate Initial Operation (year)	1984	1973	1980	1979	1975	1981
Volume of CR envelope (cu. ft.)	126,000	?	253,000	?	81,000	220,000
Design Temperature (°F)	76	75	72	75	75	70-75*
Design Relative Humidity (%)	50	50	50	50	50	?
Normal Air Intake (CFM)	2,100	920	2,000	3,200	3,190	2,200
Pressurization Makeup Air Intake (CFM)	525	920	0**	200	150	200
Air Filtration (CFM)	3,000	1,840	4,000	4,000	3,200	4,000
Calculated Isolated Air Exchange Rate (changes/hr)	?	?	0.009	?	?	0.012
Smoke Removal (CFM)	26,200	920	8,200	?	13,500#	3,040
Smoke Removal (changes/hr)	12.5	?	1.9	?	10.0#	0.83
Normal Supply Airflow (CFM)	26,200	9,200	33,320	36,000	22,660	39,230

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* 70°F in winter, 75°F in summer

** 0 CFM for first ten minutes, manual control of filtered makeup thereafter

\# System appears to have provisions for only 3490 CFM of makeup air

These temperature and humidity specifications may also be intended for accident conditions. However, humidity control systems are generally not classified as safety-related and hence, need not be operable under accident conditions. Design guidance for the maximum permissible CR temperature is briefly covered in the Standard Technical Specifications (STS) (21,22,23,24) for each of the four major types of plants currently operating in the U.S. The pertinent technical specification in each of these documents states that the CR temperature be monitored once every 12 hours as one of the conditions to verify that the CR emergency air cleanup system is operable. The STS do not explain how CR temperature monitoring ensures emergency air cleanup system operability. A temperature limit of 120°F is given for illustrative purposes in all four documents. A specific value is supposed be determined for each plant in accordance with the technical bases given in the STS; however, it appears that some plants adopted the value of 120°F.

The technical bases for specifying temperature limits, according to the STS for PWRs (21,22,23), is that the temperature should not exceed the continuous duty temperature limits of CR equipment and the CR should remain habitable for operations personnel. The only technical basis for BWRs (24) is that the CR remain habitable for operations personnel; no equipment temperature limits are considered. Establishing equipment temperature limits is addressed in equipment qualification. However, establishing temperature limits for habitability and good job performance (not part of the STS) requires additional attention. Habitability is defined in SRP Sec. 6.4 (13) as the adequate protection of plant operators against the effects of accidental releases of toxic and radioactive gases. SRP Sec. 9.4.1 (15) further provides that the Auxiliary Systems Branch review the safety-related portions of the CR area ventilation system to ensure that a suitable ambient temperature for CR personnel and equipment is maintained. However, a "suitable" ambient temperature is never defined. The often used limit of 120°F appears to have been established for equipment rather than for good operator performance.

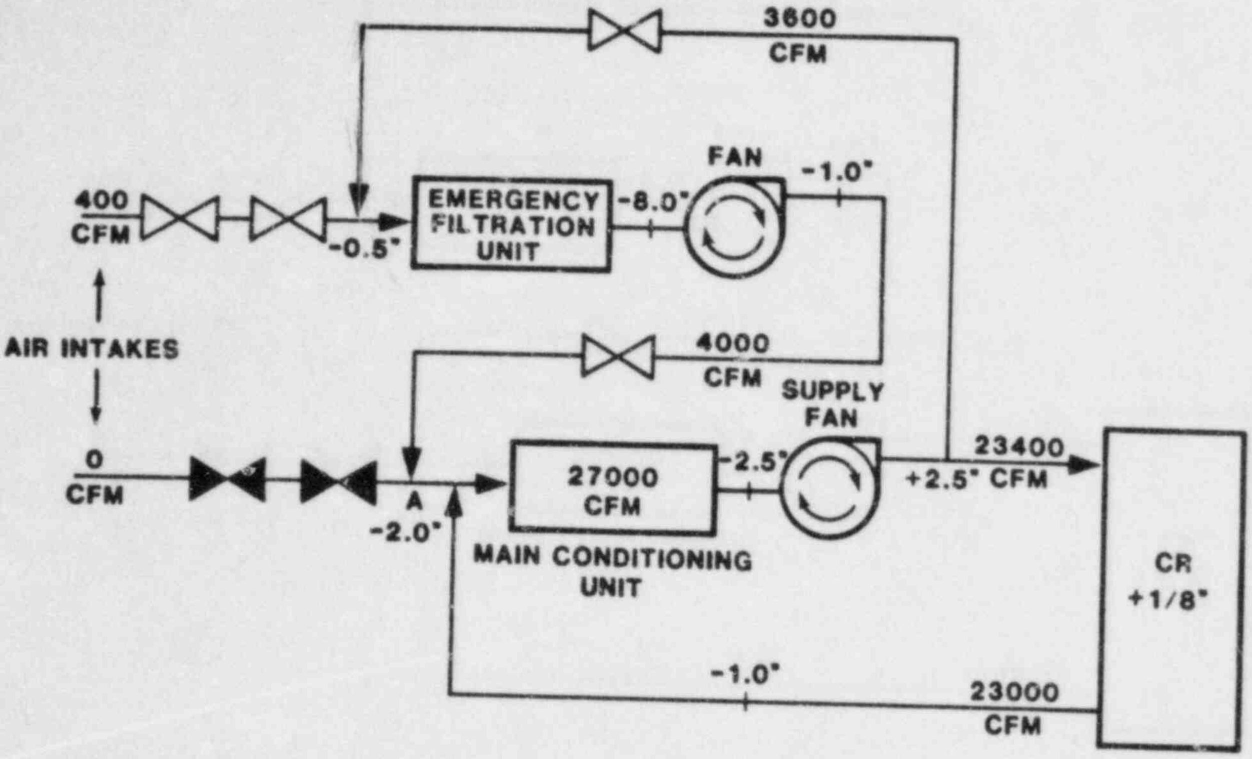
2.3 System Configuration-RG 1.52

The ESF air filtration system must meet the requirements of Sec. C.2.a of RG 1.52 (6). This section defines the sequential order for component arrangement in the ESF air filtration system. However, guidance for the CR HVAC system configuration and its relationship to the ESF air filtration system is absent.

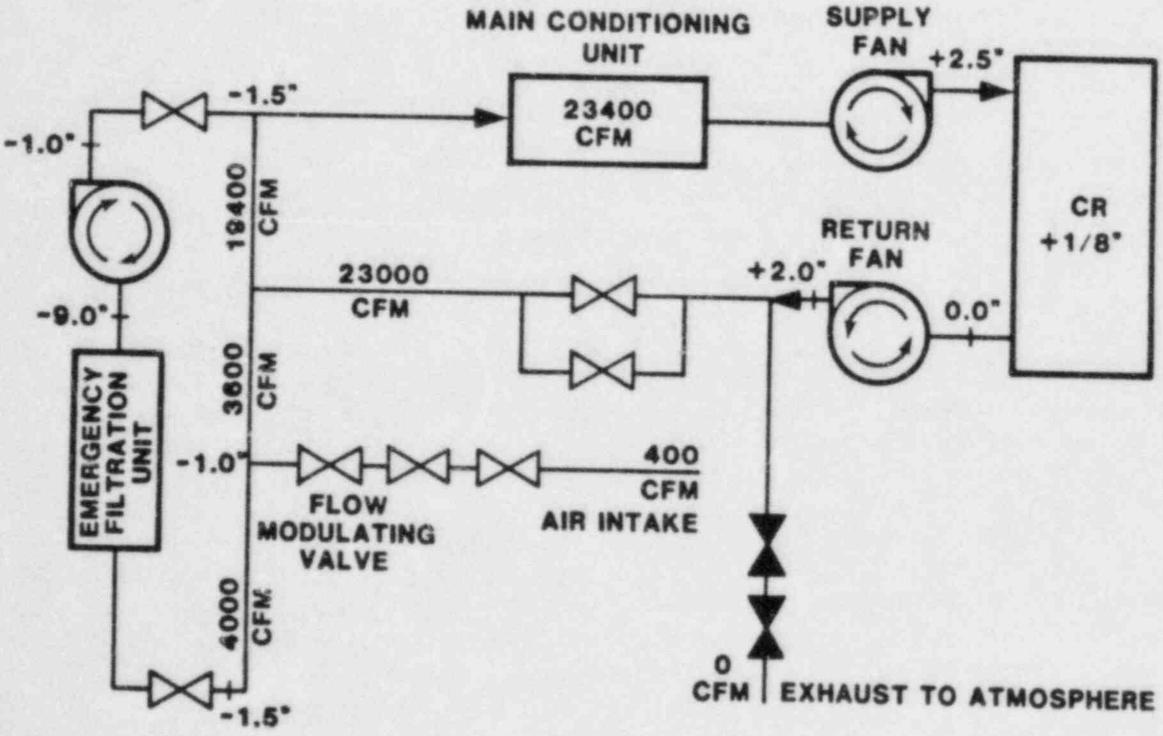
A review of many CR designs (25) revealed that charcoal filter flow capacities varied from 1,000 CFM to 43,500 CFM with depths from the usual 2 inches to as much as 18 inches. Part of this variation is likely a result of inadequate system configurations. Poor configurations may enhance inleakage, require multiple filtrations of already clean air, or require increased flowrates to compensate for the lack of adequate control of the system balance (if only on-off control is used).

Figure 2 shows examples of a good system and a poor system, both operating in the pressurization/filtration mode, and both capable of meeting current system requirements. Typical approximate water gage pressures are shown for both designs. The design in Figure 2a has the advantage of only requiring two fans. However, with this configuration, the point labelled A is at a large negative pressure with respect to the atmosphere, thus promoting unfiltered inleakage through the normal air intake isolation valves. Also much of the ductwork is at a negative pressure with respect to ambient. The design in Figure 2b incorporates well-selected (based on pressure vs. flow characteristics) and well-placed fans to minimize unfiltered inleakage to the system. The return air fan is placed close to the CR to keep the negative pressure section of duct short. The normal air intake also functions as the emergency air intake by using a flow control valve to reduce the flow during emergency operation. Consequently, the potential for unfiltered inleakage is greatly reduced. During emergency operation with CR pressurization, intake air is desired. During CR isolation with filtered, recirculated air, leakage past the air intake isolation valves will be filtered before entering the CR. In both modes of operation, the filtered portion of the recirculated air is not cooled in the main conditioning unit, allowing better relative humidity control in the emergency air cleanup unit. Finally, the second design is much better suited for forced draft smoke removal. However, to meet the single failure criterion, it would require dual inlets and outlets and several more valves.

To prevent the regulations from becoming overly prescriptive and causing a loss of creativity in design, system configuration could be covered in the review process. SRP 9.4.1 (15), which covers the review process for the CR HVAC system, is briefly described in Appendix A. This section should include specific review procedures to evaluate system configurations.



a) POOR DESIGN



b) BETTER DESIGN

Figure 2: Examples of a Poor and a Better System Configuration. Both systems are operating in the pressurization/filtration mode. Note the water gage pressures given for illustration purposes at various locations, the fan placement with respect to the CR, the air intakes and exhausts, and the point from where recirculated air is extracted for filtration.

3.0 ESF ATMOSPHERE CLEANUP SYSTEM DESIGN GUIDANCE FOR RADIATION PROTECTION

3.1 RG 1.52-"Design, Testing, and Maintenance Criteria for Post-Accident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants"

3.1.1 Introduction

RG 1.52 (6) governs ESF atmosphere cleanup system air filtration and adsorption units. In five of six FSARs reviewed, the normal HVAC system is part of the emergency system. The sixth system used a completely separate normal CR HVAC system (not ESF) and emergency filtration and cooling system (ESF). Section B of RG 1.52 (6) references ERDA 76-21 (26) as "a comprehensive review of air filtration systems. It is not a standard but a guide that discusses several acceptable design alternatives." A description of RG 1.52 (6) is included in Appendix A. The following comments apply to specific sections:

3.1.2 Section C.1-Environmental Design Criteria

The only potential problem areas in this section are that the effect of smoke on components is not specifically covered by the RG and the temperatures that components may be exposed to in a fire are not defined.

3.1.3 Section C.2-System Design Criteria

C.2.a) The wording of this section should allow the use of ducts, valves, and instrumentation "as necessary to meet the system requirements."

C.2.b) This section is not clear as to whether (and to what extent) each train of the CR ESF air filtration system must individually be protected from missile sources or whether it is sufficient to insure that common missile sources cannot simultaneously affect both trains.

C.2.c) This section specifies that "all components of an ESF atmosphere cleanup system should be designated Seismic Category I ... if failure of a component would lead to release of significant quantities of fission products to the working or outdoor environment." In general, housings and ductwork are the only components of the CR ESF air cleanup system which meet this failure criterion since other components are generally redundant and isolatable. Thus, this section implies that only housings and ductwork require Seismic Class I design. Contrary to this interpretation, GDC 2 (1), 10CFR100 Appendix A (27), and SRP 9.4.1 (15) all imply that the complete emergency HVAC system and the ESF air filtration system must have Seismic Category I components. The obvious intent of the guidance is to have all safety-related components Seismic Category 1, and thus the wording of RG 1.52 (6) needs clarification to make it consistent. It should be noted that the FSARs reviewed specified Seismic Category I components for all emergency system components.

C.2.1) This section states that "housing and ductwork should be designed to exhibit on test a maximum total leakage rate as defined in Section 4.12 of ANSI N509 (28)." RG 1.52 (6) continues with "duct and housing leak tests should be performed in accordance with the provisions of Section 6 of ANSI N510 (29)."

Section 6 of ANSI N510 (29), "Duct and Housing Leak Test," is difficult to interpret. A housing and duct leak test is implied by the title and the purpose, but the procedure is not clear. The following two examples illustrate the ambiguity in the procedure:

1) Section 6.1 states, in part, that "...if the presence of leaks is shown, the leaks are then located..., after which the housing is retested..." It never mentions the ducts.

2) Section 6.3.2 specifies that all duct openings and penetrations should be sealed, but does not specify whether they should be sealed at the housing, at the air inlets and exhausts to the system, or at some other point. If the intent of this test is to seal the ducts at all inlet and exhaust points of the entire system, the standard should be appropriately worded and the coverage of the section should include all components which comprise the system fixed pressure boundary. It should be noted that sealing the ducts at all entry and exhaust points may be very difficult because of their number and type of construction (often louvered).

The misinterpretation of this test could lead to a failure to test the ductwork correctly and the possibility of unknown leakage paths into the CR.

Section C.3.n) continues the guidance on ductwork testing by reference to Sec. 5.10 of ANSI N509 (28), which references the ANSI N510 (29) leakage test discussed above and adds the additional requirement of a fan pressure test. The requirement is only to test ductwork for five minutes at the fan design pressure. The failure specification is that "upon completion of the pressure test, ductwork exhibiting permanent distortion or breach of integrity shall be repaired or replaced." If any of the ductwork fails this simple test, the capability of the ducts to function for 40 years should be questioned.

Additional comments on Sec. C.2 which are based in part on Kovach's (30) comments at the NRC CRH workshop include:

C.2.d) According to Kovach (30), experimental data indicates that HEPA filters would be damaged before a pressure relief valve would open.

C.2.f) This section states that "for ease of maintenance, a filter layout of three HEPA filters high and ten wide is preferred." Section C.2.j then specifies that "each (ESF atmosphere cleanup) train should be designed and installed in a manner that permits replacement of the train as an intact unit or as a minimum number of segmented sections without removal of individual components." The requirement of Sec. C.2.j is difficult to meet if the requirement of C.2.f is met along with the requirement for welding the filter mounting frames and frame-to-housing seals. The layout of filters is again covered in Sec. C.3.f by reference to Sec. 4.4 of ERDA 76-21 (26). This reference should be cited under Sec. C.2.f, not Sec. C.3.f.

3.1.4 Section C.3-Component Design Criteria and Qualification Criteria

A chart of the parts of this section and a tracing of the referenced standards is presented in Table 2. Not all sections were traced completely, but the primary references were reviewed in all cases. Examples of secondary references beyond the scope of this review include those on noise ratings, material and coating specifications, welding codes, nameplate requirements, and procedures for testing properties. A description of each subsection and its references is included in Appendix A. Comments on specific sections follow:

C.3.b) The temperature limit of 225°F required by reference to Sec. 5.5 of ANSI N509 (28) is far above what should be specified for the conditions expected in the CR air cleanup system. Even with air entering at 100% RH and 100°F, an exit air temperature of 120°F will lower the RH to less than 70%.

Additional guidance which should be given in this section is that recirculated air to be filtered should not be precooled by the main conditioning system because cooling increases the RH at the inlet to the air heaters. An example of an actual system which precools the air is shown in a paper by Porembski (42).

C.3.d) The requirements invoked by this section seem generally adequate, if not excessive in some cases, for CRH HEPA filters. However, the one problem area would be if the filters were used in a system after preheating the air to 225°F (the maximum temperature for the air heater outlet according to Sec. 5.5 of ANSI N509 (28)). With extended operation at this temperature, the filters would be operating above their qualification temperature for continuous operation (see Table A-1 in Appendix A). The possibility of this condition illustrates the need to reduce the air outlet temperature limit requirement for preheaters.

C.3.e) Kovach (30) pointed out that this section omits the frame testing requirements of Sec. 7 of ANSI N510 (29). Although not absolutely necessary since leaks would be detected in subsequent HEPA and adsorber testing, the frame tests should be conducted prior to HEPA and adsorber installation to allow identification and repair of frame leaks. Leak paths found after installation of these components require that they be removed to permit welding repairs to be made on the frames, causing unnecessary handling of the components. The frame test is included in the 1980 version of ANSI-N510 (29), but the 1976 version was the one in effect when RG 1.52 (6) was issued.

C.3.i) The accuracy of the required amount of adsorbent based on the criterion of this section is limited by the accuracy of the iodine source terms.

C.3.l) Ductwork connections are never mentioned in either section of ANSI N509 (28), even though this section implies that they are.

3.1.5 Section C.5-In-Place Testing Criteria

C.5.a) The visual inspection of the ESF atmosphere cleanup system in accordance with Sec. 5 of ANSI N510 (29) requires, in part, that deficiencies found either be repaired or reported to responsible personnel (before any other

Table 2   Tracing of References in Section C. 3 of RG 1.52

RG 1.52 Section	Component	References	References	References
C.3.a	Demisters	UL 900 (31)*		
		Sec. 5.4 ANSI N509 (28)	MSAR-71-45 ** NYO-3250-6 Sec. 4.2 ANSI N509 (28)	
C.3.b	Air Heaters	Sec. 5.5 ANSI N509 (28)	Sec. 4.5 ANSI N509 (28)	Sec. 4.2(k) ANSI N509 (28) Sec. 5.10.3 ANSI N509 (28) Sec. 4.8.3 ANSI N509 (28)
C.3.c	Prefilters	Sec. 5.3 ANSI N509 (28)	ARI 680 UL 900 (31) ASHRAE Std. 52	
C.3.d	HEPA filters	Sec. 5.1 ANSI N509 (28)	MIL-F-51068 (32) MIL-F-51069 (33) UL 586 (34)	
		MIL-F-51068 (32) MIL-F-282 (35)		
C.c.e	Filter and adsorber mounting frames	Sec. 5.6.3 ANSI N509 (28)	Sec. 4.3 ERDA 76-21 (26) Table 4.2 ERDA 76-21 (26) Sec. 6.2.1 ERDA 76-21 (26)	
C.3.g	Filter housings	Sec 5.6 ANSI N509 (28)	Sec. 4 ANSI N509 (28) Sec. 7.3 ANSI N509 (28)	
			Sec. 8.3 ANSI N510 (29)	Section 9 of Industrial Ventilation (19)
			Sec. 6 ANSI N510 (29) Various ASTM material and coating standards	
C.3.h	Water drains	Sec. 4.5.8 ERDA 76-21 (26)		
C.3.i	Carbon batches and adsorber system	Table 5.1 ANSI N509 (28)	Nine ASTM test procedures for properties	
C.3.j	Adsorber cells	Sec. 5.2 ANSI N509 (28)	AACC CS-8T IPA Designer, Specifiers, and Buyers Handbook for Perforated Metals	
C.3.l	System fan, its mounting, and ductwork connections	Sec. 5.7 ANSI N509 (28)	AMCA 201 (36) Sec. 4.2 ANSI N509 (28) AMCA 99 Sec. 5.6.4 ANSI N509 (28) AMCA 210 (37) AMCA 211A AMCA 300 AMCA 301	
		Sec. 5.8 ANSI N509 (28)	NEMA MG-1 IEEE 112A IEEE 85 IEEE 323 (38) IEEE 334 (39) IEEE 344 (40)	
C.3.n	Ductwork	Sec. 5.10 ANSI N509 (28)	SMACNA-High Pressure Duct Construction Standards Sec. 7.3 ANSI N509 (28) ASTM standards for various materials	
C.3.p	Dampers	Sec. 5.9 ANSI N509 (28)	AMCA 500 ASME/ANSI B.31.1 (41) Sec. 5.10.3.3 ANSI N509 (28) IEEE 323 (38) IEEE 334 (39) Sec. 4.8 ANSI N509 (28) ANSI N510 (29)	

* Documents with references were acquired for this review.

** Unreferenced documents use the following acronyms: MSAR and NYO are U.S. Atomic Energy Commission documents, ARI - Air Conditioning and Refrigeration Institute, ASTM - American Society for Testing and Materials, AACC - American Association for Contamination Control, AMCA - Air Movement and Control Association, SMACNA - Sheet Metal and Air Conditioning Contractors' National Association, Inc., and NEMA - National Electrical Manufacturers' Association.

test is started). Thus, the visual inspection and subsequent corrective action may change the condition of the system being tested, causing results of subsequent tests to not indicate the true condition of the system.

3.1.6 Section C.6-Laboratory Testing of Activated Carbon

C.6.a) One testing requirement of this section states that "if the activated carbon fails to meet any of the above conditions (which includes testing of representative samples of used activated carbon), it should not be used in engineered-safety-feature adsorbers." This statement needs the wording clarified since it implies testing used material before deciding if the material may be used.

3.2 SRP 6.5.1-ESF Atmosphere Cleanup Systems

SRP 6.5.1 (14) covers the review of the ESF atmosphere cleanup system. A brief description of this section is included in Appendix A.

A potential problem with this section is that the review procedure to evaluate if the amount of adsorbent conforms to Sec. C.3.i of RG 1.52 (6) specifies that the Accident Evaluation Branch will calculate the filter loadings of all the iodine isotopes only upon request from the Effluent Treatment Systems Branch. Otherwise, the amount of adsorbent calculated by the licensee is apparently accepted without question.

4.0 GUIDANCE FOR CALCULATING AND MEASURING AIR EXCHANGE RATES

RG 1.78 (7) specifies that a CR isolated air exchange rate is calculated by adding the leak rate based on a 1/8-inch water gage pressure differential across all leak paths to the leakage contribution from valves and dampers at their actual pressure differential and the leakage contribution from the opening and closing of doors. RG 1.78 (7) also specifies that the flowrate necessary to pressurize the CR to 1/8-inch water gage be calculated by adding the leak rate based on a 1/4-inch water gage pressure differential across all leak paths to the contribution from opening and closing doors; leakage across valves and dampers at their actual pressure differential is not considered in this case.

RG 1.95 (8) specifies the criterion for testing as "the gross leakage characteristics should be determined by pressurizing the control room to 1/8-inch water gage and determining the pressurization flowrate. For air exchange rates of less than 0.06 per hour, periodic verification testing should be performed." The intent of these tests seems to be that if the measured flowrate required to pressurize the CR to 1/8-inch water gage is less than 0.06 air changes per hour, then the periodic testing is required. However, this interpretation conflicts with the guidance of SRP 6.4 (13) which requires periodic verification of CR pressurization if the pressurization flowrate is less than 0.25 air changes per hour. Trying to interpret the guidance in a consistent manner yields the following explanation:

1) If the calculated isolated air exchange rate is less than 0.06 per hour, periodic verification testing is required.

2) If the calculated or measured pressurization air exchange rate is less than 0.25 per hour, periodic verification testing is required.

3) The acceptance test to verify both of the above air exchange rates is that the CR can be maintained at 1/8-inch water gage with the design pressurization flowrate, that is, the calculated flowrate assuming a 1/4-inch water gage pressure differential across all leak paths.

The rationale for the acceptance criterion would be that if the calculated flowrate based on 1/4-inch water gage pressure differential is sufficient to maintain the CR at 1/8-inch water gage, then the calculated flowrate based on 1/8-inch water gage pressure differential should adequately represent the isolated air exchange rate of the CR. This interpretation of the intended guidance is logical and is substantiated by the following guidance of SRP 6.4 (13) for evaluating the radiological consequences for an isolated CR:

a) The calculated value (of isolated air exchange rate) is found by adding 1/2 of the leak rate based on 1/8-inch water gage pressurization to the leakage contribution from valves and dampers at their actual pressure differential and the contribution from opening and closing doors.

b) Calculations are acceptable except for very low infiltration rates. If the calculated value is less than 0.06 air changes per hour, periodic verification testing is required per RG 1.95 (8).

Although only specifically applicable to radiological consequences, this guidance appears to be applicable to hazardous chemical calculations also because of the reference to the periodic verification test of RG 1.95 (8). However, the calculation of isolated air exchange rate given in a) conflicts with the guidance of RG 1.78 (7) by allowing the use of 1/2 of the leak rate based on 1/8-inch water gage pressurization as the base infiltration rate; RG 1.78 (7) does not allow the factor of 1/2. The calculations in b) allow a calculated isolated air exchange rate down to 0.06 per hour to be used without periodic verification. Unpublished calculations used to derive Table 1 of RG 1.95 (8) specify the same criterion for using a calculated isolated air exchange rate, but they are referring to the isolated air exchange rate calculated in accordance with RG 1.78 (7).

The guidance governing air exchange rates contains some conflicting, missing, and unclear guidance. However, even when interpreted liberally, the chlorine guidance should not cause inadequate CR designs based on improperly determined air exchange rates. However, two related items could potentially cause problems. First, as discussed in Section 4.1 of this report, the guidance does not adequately address the testing of leakage across valves and dampers. Second, the values of permissible chlorine inventory given in Table 1 of RG 1.95 (8) are based on an air exchange rate which is a factor of 8 lower than that determined by the licensee. This reduction factor (the K factor discussed in Appendix B) may take redundant credit for some of the same factors already allowed for in the existing guidance, such as the factor of 1/2 in SRP 6.4 (13) and the acceptance criterion of b) above.

4.1 Effect of Valves, Dampers, and Ductwork on Testing Air Exchange Rates

A major problem in testing the CR pressurization flowrate is that the testing will not reveal the correct amount of leakage occurring at valves, dampers, and ductwork which are normally subjected to pressure differentials greater than 1/8-inch w.g. In fact, very severe leakage could go undetected. One possible test method would be to do the test with the HVAC system running and the CR isolated. In this case, inleakage occurring through valves, dampers, and ductwork at negative pressure would make the measured makeup flowrate less than the actual makeup rate by the amount of the inleakage. A second possible test method would be to shut the HVAC system off during the test. This method would have a similar problem for the valves, dampers, and ductwork normally exposed to positive pressure differentials greater than 1/8-inch water gage. Outleakage occurring at these components will enhance inleakage by reducing the CR pressure. However, during pressurization testing, the components will be exposed to only 1/8-inch water gage, with leak rates appearing lower than in the actual case. A second biasing effect of shutting down the HVAC system is that the CR air heating will help to pressurize the CR and lower the measured makeup flowrate.

5.0 CHEMICAL RELEASE GUIDANCE

5.1 RG 1.78-"Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Hazardous Chemical Release"

A brief description of RG 1.78 (7) is included in Appendix A. Specific comments follow:

C.15) This section requires that emergency procedures to be initiated during a hazardous chemical release be written and that "criteria should be defined for the isolation of the CR, the use of protective breathing apparatus or other protective measures, and for orderly shutdown or scram." Criteria for CR isolation and the use of protective equipment is fairly well covered by this RG. However, criteria for initiating orderly shutdown or scram of the reactor is never mentioned outside of Sec. C.15. As the statement appears in the RG, it allows the individual plant the freedom to decide what chemical release situations warrant reactor shutdown. Since an unsafe condition is threatening the CR, shutdown of the reactor would generally be considered mandatory. However, a hazardous chemical release may occur when the reactor requires little operator action. Leaving the reactor operating at steady state might be the best course of action since the operators would likely be under stress from the presence of the chemical and from wearing self-contained breathing apparatus which could interfere with their work. On the other hand, a seismic event might require shutdown of the reactor concurrent with a hazardous chemical release caused by the seismic event. The guidance should outline the specific action to be taken in response to the various situations involving chemical releases. One improvement for this RG might be to include a requirement for the CR to be isolated immediately upon detection of a seismic event. Subsequent hazardous chemical releases would be much less likely to have a dangerous effect in the CR, increasing the safety of shutting down the reactor, when necessary.

5.2 RG 1.95-"Protection of Nuclear Power Plant Control Room Operators Against an Accidental Chlorine Release"

A brief description of RG 1.95 (8) is included in Appendix A. The following are some specific comments:

C.3) Section C.3 specifies that "if there are several chlorine containers, only the failure of the largest container is normally considered unless the containers are interconnected in such a manner that failure of a single container could cause a chlorine release from several containers." The apparent intent is that this statement applies to multiple chlorine containers at a given location. If true, this intent should be specified explicitly since other interpretations are possible, such as only the largest container in the area being considered. Better wording would include "if there are several containers at a given distance..." Additionally, this section should indicate that a given chlorine inventory need not be considered under normal circumstances if a larger inventory is located closer to the CR. The justification for these two statements is that the guidance assumes that the CR acts as a point receptor and the path to the CR is a straight line.

Section C.3 also gives the maximum allowable weight of chlorine which may be stored at a given distance from the CR. Using RG assumptions and

methodology, a BASIC computer program was developed to evaluate the values given in Table 1 of RG 1.95 (8). The model uses the diffusion equation of RG 1.78 (7) for an instantaneous puff release plus several derived equations given in Appendix C. Using the information given in the RGs, we were unable to verify the values in RG 1.95 (8). Consequently, we contacted the NRC who provided a copy of unpublished calculations which were used to derive the table. A complete description of these calculations is discussed in Appendix B since the calculations were not published with the RG. In retrospect, the main reasons that we could not verify Table 1 of RG 1.95 (8) include the following:
1) The unpublished procedure allows the isolated air exchange rate to be estimated by dividing the air exchange rate necessary to pressurize the CR to 1/8-inch water gage by a factor of eight (the K factor-see Appendix B).
2) The unpublished procedure did not use a consistent atmospheric dispersion assumption for all the calculations, but this inconsistency is conservative if the table is used for Pasquill Stability Criterion F. (Pasquill Stability Criterion is a measure of the atmospheric dispersion conditions: Type E is slightly stable, Type F is moderately stable, and Type G is extremely stable.)
3) The unpublished procedure used simplified approximations to the actual equations given in RG 1.78 (7).

C.6) The same comments apply to this section that applied to Sec. C.15 of RG 1.78 (7).

5.3 SRP 6.4-Control Room Habitability System

SRP 6.4 (13) covers the review of CRH systems to mitigate the consequences of hazardous chemical and radioactive material releases. A brief description of this section is included in Appendix A.

5.4 Computer Analysis and Discussion of the Values in Table 1 of RG 1.95

The computer program of Appendix C was run to obtain the peak two-minute concentrations for various scenarios. Table 3 gives the results of this analysis by giving the following information: 1) the maximum allowable inventories of single containers (either shipping or storage) for the various CR types at various distances as given in RG 1.95 (8) and a reference to the equation numbers from Appendix B used to calculate these values. (The 2000 meter column does not have any referenced equations because the 2000 meter analysis was not included in the calculations we received.) 2) the peak two-minute concentrations which would be encountered in the CR if the chlorine detectors operated properly given the chlorine inventories from RG 1.95 (8) and using K factors of 1 and 8. 3) the peak two-minute concentrations which would be encountered in the CR given the chlorine inventories from RG 1.95 (8), using K factors of 1 and 8, and assuming that the chlorine detectors failed, the operators detected the chlorine at 3 ppm, and they isolated the CR within five seconds.

Table 3 shows that, when a K factor of 8 is used with the detectors functioning properly (as was used to develop the weights in RG 1.95 (8)), the values in Table 1 of RG 1.95 (8) are generally conservative, that is, the peak concentration inside the CR remains below 45 mg/m^3 (15 ppm). However, they are occasionally not conservative. For example, the peak two-minute CR concentration for a Type IV CR at 300 meters is only 10 mg/m^3, well below the

Table 3 Maximum Allowable Inventory of Chlorine and Peak CR Concentrations as a Function of Distance of the Source from the CR and CR Type.

		Distance (m)				
CR Type		100	200	300	500	2000
I	a)	.5 (B-2)	2 (B-2)	4 (B-2)	10 (B-2)	1200
	b)	42	49	48	42	14
	c)	120	140	140	110	250
	d)	43	49	49	43	110
	e)	130	140	140	140	290
II	a)	1 (B-2)	5 (B-2)	12 (B-4)	40 (B-4)	3400
	b)	44	38	10	13	31
	c)	140	200	220	290	130
	d)	49	69	80	110	250
	e)	150	200	230	290	340
III	a)	2 (B-2)	6 (B-2)	14 (B-2)	36 (B-4)	2700
	b)	45	41	46	28	26
	c)	130	120	130	140	180
	d)	88	81	91	95	210
	e)	140	130	150	150	300
IV	a)	6 (B-2)	20 (B-2)	60 (B-4)	230 (B-4)	32000
	b)	59	20	10	14	27
	c)	190	200	270	380	100
	d)	59	57	80	110	220
	e)	190	200	270	380	340
V	a)	8 (B-6)	20 (B-6)	50 (B-6)	120 (B-6)	5000
	b)	33	28	34	35	39
	c)	980	860	1100	1100	400
	d)	260	230	270	280	310
	e)	980	870	1100	1100	540
VI	a)	70 (B-6)	180 (B-6)	380 (B-6)	1300 (B-6)	60000
	b)	30	33	35	33	35
	c)	3300	3700	3900	3800	340
	d)	240	270	280	260	280
	e)	3300	3700	3900	3800	530

* Data in each block is tabulated as follows:

a) Maximum allowable inventory of chlorine (1000 lbs.) The numbers in parenthesis refer to the equations in Appendix B which were used to obtain the values for maximum inventory of chlorine

b) Peak two-minute CR concentration for the chlorine inventory in a) and assuming that detectors function properly and using K = 8 (mg/m^3)

c) Peak two-minute CR concentration for the chlorine inventory in a) and assuming that K = 8, the detectors fail, operator detection occurs at 3 ppm, and the operator initiates detection within 5 seconds after the concentration reaches 3 ppm (mg/m^3).

d) Peak two-minute CR concentration for the chlorine inventory in a) and assuming that detectors function properly and using K = 1 (mg/m^3).

e) Peak two-minute CR concentration for the chlorine inventory in a) and assuming that K = 1, the detectors fail, operator detection occurs at 3 ppm, and the operator initiates detection within 5 seconds after the concentration reaches 3 ppm (mg/m^3).

toxicity limit of 45 mg/m^3. On the other hand, the peak two-minute concentration for a Type IV CR at 100 meters is 59 mg/m^3 , somewhat above the toxicity limit. The variation in the results occurs because of several opposing factors which are discussed in Appendix D.

5.5 Problem Areas and Conservatisms in Table 1 of RG 1.95

The fundamental problem noted in the analysis of RG 1.95 (8) is that the method of obtaining the values in Table 1 is not outlined in the guide. Without knowing how the values were determined, complying with the intent of the guide may be difficult. The specific assumptions used to derive the table and their potential effects are outlined in Appendix E. Examples of the assumptions include a specific wind speed, atmospheric dispersion, air intake height, and the suitability of scaling.

Even with all the potential problem areas noted in Appendix E, the chlorine calculations appear sufficiently conservative to prevent operator incapacitation under virtually all conceivable chlorine releases. A summary of the conservatisms of the chlorine calculations is given in Appendix F.

5.5.1 Example of Guidance Which Could Lead to an Apparently Inadequate Design

To illustrate the potential effects of some of the problems noted in Appendix E, a hypothetical scenario which could occur and give the appearance of meeting all the applicable regulations was developed. In fact, this design would lead to chlorine concentrations above the allowable levels when calculated in accordance with the currently accepted (conservative) methodology. The details of the hypothetical design are given in Appendix G.

With an air intake height of 8 meters, an isolated air exchange rate of 0.06 (the value which should be used), and the allowable chlorine inventories from Table 1 of RG 1.95 (8), the computer program discussed in Appendix C (which includes the K factor of 8) yields the following peak two-minute CR concentrations for the design of Appendix G:

200 mg/m^3 at 100 meters
160 mg/m^3 at 200 meters
140 mg/m^3 at 300 meters
130 mg/m^3 at 500 meters
140 mg/m^3 at 2000 meters

Obviously, all these values are well above the toxicity limit of 45 mg/m^3. Thus, for this example, a CR design which appears to meet all the established guidance does not limit the chlorine concentrations to less than the toxicity limit according to the accepted calculational method. It should be noted that this analysis does not include any potential effects of using the K factor without determining its suitability (see Appendix B for more detail about the K factor), of valve and damper leakage at actual design pressures, of maximum windspeeds different than 7 m/s, and of contributions from personnel ingress and egress.

6.0 SRP REVIEW OF COMPONENT RELIABILITY

None of the applicable sections of the SRP give any specific review criteria for the evaluation of CRH component reliability. The only review criterion is that single failures not cause a loss of safety function for safety-related CRH systems. The referenced RG 1.52 (6) generally provides component design and qualification criteria for the ESF air cleanup system components through a series of subreferences. However, requirements that are referenced only through a series of other documents leading back to the SRP could easily be lost or forgotten during the review. Further, no criteria are given for CR HVAC components since RG 1.52 (6) does not cover the CR HVAC system.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations of this study are as follows:

1) In some areas, there is insufficient guidance for the system functional specifications. The three specific areas cited in this report are smoke removal systems, specifications for CR accident temperature limits, and guidance or review procedures on system configurations. The recommendations for each area are as follows:

   a) For smoke removal systems, the major problem appears to be inadequate technical bases. Some specification for a design basis smoke production would allow estimation of a required flowrate for a smoke removal system. Current designs have smoke removal capabilities which differ greatly from one another. For example, the data in Table 1 shows that in the six plants reviewed, smoke removal capability ranged from 0.83 to 12.5 air changes per hour. The two FSARs with the highest values showed no evidence of the system's capability to replenish the CR with makeup air when in the smoke removal mode.

   b) Maximum permissible CR accident temperature limits should be based on a specific criterion, such as the equivalent temperature (ET), as given in the charts of Industrial Ventilation (19). A maximum ET should be specified for CRH on a continuous basis during emergency operation. An ET of 85 under typical conditions during a loss of HVAC would correspond to a temperature of about 110°F at 20% RH. This is an approximate point which would be passed through during a constant absolute humidity temperature increase from a design point of 75°F and 50% RH. The ET of 85 corresponds approximately to the highest value that can be tolerated in daily work by healthy, acclimated men wearing warm weather clothing and doing light, sedentary activities during the summer season (19). It should be noted, however, that the ET of 85 is based on idealistic conditions which do not account for any margin nor for increased anxiety and activity levels which operators might experience during abnormal plant operation. Under these conditions, a lower value of ET should be used.

   c) Some attention should be given to the configuration of the normal HVAC system and the emergency filtration system. The best place for additional attention seems to be in the review process where poor design practices could be challenged without making the regulations overly prescriptive. The SRP should reflect the level of review of system configuration.

2) For the components covered by this study, there appears to be sufficient component design criteria if all the applicable guidelines are followed. However, much of the guidance is removed from the mainstream documents and is included only by reference. This situation makes the design job difficult and complicates the review of compliance.

3) Many minor problems in wording are evident in the RG and other standards, but the general intent is usually clear.

4) Improved testing methods and requirements for CRH systems need to be developed. Of primary importance are leak rate requirements and testing methods for isolation valves and testing of CR air exchange rates.

5) The CR should be isolated immediately upon detection of a seismic event, since this would be a likely time for a hazardous chemical release as well as a reactor incident.

6) According to the accepted method of calculation, a chlorine release near some plants could potentially incapacitate operators before they had time to don self-contained breathing apparatus. The chance of operator incapacitation would obviously be the greatest if the chlorine detection system failed, but based on the current regulations as given in RG 1.78 (7) and RG 1.95 (8), the possibility exists for exceeding the toxicity limit during the first two minutes even with properly functioning detectors. However, the chlorine calculations appear sufficiently conservative to prevent any possibility of operator incapacitation in a real case if the detectors function properly. The RGs should be revised as necessary to ensure that all assumptions and methods are clearly outlined.

7) Criteria for reviewing CRH system component reliability should be considered. However, these criteria may be of secondary importance since the CRH systems are generally exposed only to mild environments.

8) Many documents are involved with the CRH systems design and review. The design of a system involves not only all the documents referenced in this review, but also numerous other documents that were considered beyond the scope of this review. Verifying that all the specific requirements have been met by doing a brief design review is nearly impossible. A single, consistent, detailed document which covers all aspects of CRH would improve the current regulatory practices.

9) An alternative method for pressurizing the CR during a radioactive gas release or a hazardous chemical release would be to shut down or reduce the amount of air conditioning and allow the rising temperature to pressurize the CR. An analysis of the feasibility of this type of system together with advantages which it could offer is given in Appendix H.

9.0 REFERENCES

The following references apply to the appendices, as well as to the main body of the report:

1) 10 CFR Part 50, Appendix A, General Design Criterion 2, "Design Bases for Protection Against Natural Phenomena."

2) 10 CFR Part 50, Appendix A, General Design Criterion 4, "Environmental and Missile Design Bases."

3) 10 CFR Part 50, Appendix A, General Design Criterion 5, "Sharing of Structures, Systems, and Components."

4) 10 CFR Part 50, Appendix A, General Design Criterion 19, "Control Room."

5) 10 CFR Part 50, Appendix A, General Design Criterion 60, "Control of Release of Radioactive Materials to the Environment."

6) Regulatory Guide 1.52, "Design, Testing, and Maintenance Criteria for Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants."

7) Regulatory Guide 1.78, "Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release."

8) Regulatory Guide 1.95, "Protection of Nuclear Power Plant Control Room Operators Against an Accidental Chlorine Release."

9) Regulatory Guide 1.76, "Design Basis Tornado for Nuclear Power Plants."

10) Regulatory Guide 1.3, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Water Reactors."

11) Regulatory Guide 1.4, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors."

12) Regulatory Guide 1.5, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Steam Line Break Accident for Boiling Water Reactors."

13) NUREG-0800, "Standard Review Plan," Section 6.4, "Control Room Habitability System."

14) NUREG-0800, "Standard Review Plan," Section 6.5.1, "ESF Atmosphere Cleanup Systems."

15) NUREG-0800, "Standard Review Plan," Section 9.4.1, "Control Room Area Ventilation System."

16) Regulatory Guide 1.120, "Fire Protection Guidelines for Nuclear Power Plants."

17) NUREG-0800, "Standard Review Plan," Branch Technical Position CMEB 9.5-1, "Guidelines for Fire Protection for Nuclear Power Plants."

18) "Smoke and Heat Venting Guide," National Fire Protection Association NFPA 204.

19) Industrial Ventilation, A Manual of Recommended Practices, 17th Edition, American Conference of Governmental Industrial Hygienists, 1982.

20) NUREG-0700, "Guidelines for Control Room Design Reviews", U. S. Nuclear Regulatory Commission, September,1981.

21) NUREG-0103, "Standard Technical Specifications for Babcock and Wilcox Pressurized Water Reactors."

22) NUREG-0212, "Standard Technical Specifications for Combustion Engineering Pressurized Water Reactors."

23) NUREG-0452, "Standard Technical Specifications for Westinghouse Pressurized Water Reactors."

24) NUREG-0123, "Standard Technical Specifications for General Electric Boiling Water Reactors."

25) Murphy, K. G. and K. M. Campe, "Nuclear Power Plant Control Room Ventilation System Design for Meeting General Criterion 19," 13th Atomic Energy Commission Air Cleaning Conference, 1976.

26) Burchsted, C. A., J. E. Kahn, and A. B. Fuller, "Nuclear Air Cleaning Handbook," Energy Research and Development Administration ERDA 76-21.

27) 10 CFR Part 100, "Reactor Siting Criteria," Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants."

28) "Nuclear Power Plant Air Cleaning Units and Components," American National Standard ANSI/ASME N509.

29) "Testing of Nuclear Air Cleaning Systems," American National Standard ANSI/ASME N510.

30) Kovach, J. Louis, "Memorandum for the NRC Workshop on Control Room Habitability," Presented at the NRC Workshop on Control Room Habitability, Harpers Ferry, West Virginia, November 29 and 30, 1983.

31) "Safety Standards for Air Filter Units," Underwriters' Laboratories, Inc. UL 900.

32) "Filter, Particulate, High-Efficiency, Fire Resistant," Military Standard MIL-F-51068.

33) "Filter Medium, Fire Resistant, High-Efficiency," Military Standard MIL-F-51079.

34) "Safety Standards for High-Efficiency Particulate Air Filter Units," Underwriters' Laboratories, Inc. UL 586.

35) "Filter Units, Protective Clothing, Gas Mask Components and Related Products: Performance-Test Methods," Military Standard MIL-STD-282.

36) "Fan Application Manual," Air Movement and Control Association AMCA 201.

37) "Test Code for Air Moving Devices," Air Movement and Control Association AMCA 210.

38) "General Guide for Qualifying Class 1E Electrical Equipment for Nuclear Power Generating Stations," Institute of Electrical and Electronic Engineers IEEE 323.

39) "Guide for Type Testing of Continuous Duty Class 1 Motors Installed Inside the Containment of Nuclear Power Generating Stations," Institute of Electrical and Electronic Engineers IEEE 334.

40) "Recommended Practice for Seismic Qualification of Class 1E Equipment in Nuclear Power Generating Stations," Institute of Electrical and Electronic Engineers IEEE 344.

41) "Power Piping Code," American Society of Mechanical Engineers ASME/ANSI B31.1.

42) Porembski, Ted, "Some Observed System Configurations and Their Effects on Functional Results," Presented at the NRC Workshop on Control Room Habitability, Harpers Ferry, West Virginia, November 29 and 30, 1983.

43) Regulatory Guide 1.25, "Assumptions for Evaluating the Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors."

44) "Clarification of TMI Action Plan Requirements," NUREG-0737, Item III.D.3.4, "Control Room Habitability," November, 1980.

45) Regulatory Guide 1.29, "Seismic Design Classification."

46) Regulatory Guide 1.140, "Design, Testing, and Maintenance Criteria for Normal Ventilation Exhaust System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants."

47) Wing, James, "Toxic Vapor Concentrations in the Control Room Following a Postulated Accidental Release," NUREG-0570, June 1979.

48) "Chlorine Manual", The Chlorine Institute,Inc., Fourth Edition, 1969.

49) Clarke, R. H., "A Model of Short and Medium Range Dispersion of Radionuclides Released to the Atmosphere", National Radiation Protection Board, Oxfordshire, England, 1979.

50) Ornberg, Miller, and McDonald, Slide Presentation at the NRC Workshop on Control Room Habitability, Harpers Ferry, West Virginia, November 29 and 30, 1983.

APPENDICES

APPENDIX A--Summary of Selected Regulations Concerning CRH

A.1 RG 1.52-"Design, Testing, and Maintenance Criteria for Post-Accident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water-Cooled Nuclear Power Plants"

A.1.1 Section C.1-Environmental Design Criteria

This section generally states that equipment should be designed to withstand the worst postulated conditions of temperature, pressure, humidity, and radiation which it might encounter. The radiation source terms must be consistent with the guidance of RG 1.3 (10), RG 1.4 (11), and RG 1.25 (43).

A.1.2 Section C.2-System Design Criteria

Included in this section are system requirements for redundancy, physical separation, Seismic Category I design, protection from pressure surges and radiation effects, power supplies and instrumentation, and protection of outdoor air intakes.

A.1.3 Section C.3-Component Design Criteria

C.3.a) This section specifies that demisters should be designed, constructed, and tested according to Sec. 5.4 of ANSI N509 (28) and that they should meet UL 900 (31) Class 1 requirements. The basic requirement of Sec. 5.4 of ANSI N509 (28) is that demisters "be proven to be capable of removing at least 99% by weight of the entrained moisture in an airstream containing approximately 1.5 to 2 lb. of entrained water per 1000 cu. ft. and at least 99% by count of the 5 to 10 μm-diameter droplets, without visible carryover, when operated at rated capacity." Qualification according to MSAR-71-45, NYO-3250-6, or an equivalent program is also required. UL Class 1 requires that the units "when clean, do not contribute fuel when attacked by flame and emit only negligible amounts of smoke."

C.3.b) This section specifies that air heaters should be designed, constructed and tested according to Sec. 5.5 of ANSI N509 (28). ANSI N509 (28) requires that the heaters be electric, be capable of reducing the relative humidity (RH) of the inlet air to 70% before entering the prefilters, and not increase the exit air temperature above 225°F.

C.3.c) This section specifies that prefilters be designed, constructed, and tested according to Sec. 5.3 of ANSI N509 (28). The basic requirements of Sec. 5.3 are that prefilters be replaceable, extended media, dry-type filters which are UL Class 1, meet the requirements for Group III filters in ARI 680, have an average dust-spot efficiency of 45%, and have an airflow capacity equal to or greater than HEPA filters which have the same face area.

C.3.d) This section refers to Sec. 5.1 of ANSI N509 (28) for the design, construction, and testing of HEPA filters and to MIL-F-51068 (32) and MIL-STD-282 (35) for dicotyl phthalate (DOP) penetration testing. Section 5.1 of ANSI N509 (28) basically requires that HEPA filters meet the construction, material, test, and qualification requirements of MIL-F-51068 (32) and comply with UL 586 (34). UL 586 (34) generally does not require anything beyond what MIL-F-51068 (32) requires. The requirements of MIL-F-51068 (32) are given in Table A-1.

C.3.e) ANSI N509 (28), Sec. 5.6.3, referred to for filter and adsorber mounting frame design and construction, requires all-welded construction of the frame and welding of the seals to the housing. Other requirements in ANSI N509 (28) are basically structural.

C.3.f) This section covers the arrangement of filter and adsorber banks. Since arrangement is neither a component design criteria nor a qualification testing requirement, this section should really be included in Sec. C.2, "System Design Criteria." Nevertheless, this section refers to Sec. 4.4 of ERDA 76-21 (26), which gives some guidelines for the size and arrangement of the filter and adsorber banks.

C.3.g) This section refers to Sec. 5.6 of ANSI N509 (28) for the construction and design of system filter housings, including floors and doors. Most of Sec. 5.6 of ANSI N509 (28) deals with structural and mechanical design. One requirement is that the layout of the housing and banks of components provide for uniform airflow through each unit (within ±20% of the average of the bank).

C.3.h) This section refers to Sec. 4.5.8 of ERDA 76-21 (26) for guidance on the design of water drains. The major requirement in ERDA 76-21 (26) is that the drains be designed such that no bypassing of filters or adsorbers can occur.

C.3.i) This section requires that each batch of impregnated activated carbon meet the qualification and batch test requirements of Table 5 of ANSI N509 (28) and be limited to 350 ft^3. Further, the adsorber section should be designed for an average atmospheric residence time of 0.25 seconds per 2 inches of adsorber thickness and a maximum loading of 2.5 mg. of total iodine per gram of activated carbon.

C.3.j) This section refers to Sec. 5.2 of ANSI N509 (28) which basically repeats the requirements of Sec. C.3.i of RG 1.52 (6), but adds some structural requirements and some requirements from AACC CS-8T (for different adsorber types).

C.3.k) This section requires a cooling mechanism for the adsorber section to negate the effects of radioactivity-induced heat.

C.3.l) This section specifies that the system fan, its mounting, and the ductwork connections should be designed, constructed, and tested according to Sec. 5.7 and Sec. 5.8 of ANSI N509 (28). Section 5.7 of ANSI N509 (28) deals with fan selection based on the system characteristic curve, rating and testing of fans, and balancing and vibration. Section 5.8 deals with fan motor selection, testing, rating, and qualification.

Table A-1: MIL-F-51068 Requirements for 1000 CFM HEPA Filters

Test	Specification
a) DOP smoke penetration	0.03% at rated flow and at 20% of rated airflow.
b) Resistance to airflow	1.0 inch of water.
c) Resistance to rough handling	Meet above conditions after 15 minutes at 0.75 inch total amplitude at 200 cycles per minute.
d) Resistance to pressure	Condition at 95 ±5°F and 95±5% relative humidity for 24 hours. Run water spray test at 95±5°F and 95±5% relative humidity for a minimum of one hour with 1±1/4 pound of airborne water droplets per 1000 CFM of nominal rated filter capacity run through the filter to produce a pressure drop of 10±0.2 inches of water. Fifteen minutes after the test, the filter must meet the DOP smoke penetration test at 20% of rated airflow.
e) Resistance to heated air	After passing 700±50°F air through the filter for a minimum of five minutes, the filter must have a DOP smoke penetration not exceeding 3.0%.
f) Spot flame resistance	After removal of test flame, the filter shall have no sustained flaming on the downstream face and no flame transmitted to mounting components when the test is conducted according to ANSI B132.1.
g) Resistance to environmental exposure	After each of two cycles consisting of one week arctic (-65°F), one week desert (160°F and 10% relative humidity), and one week tropical (113°F and 88% relative humidity), the filter must meet the requirements of tests a) and b). After a third identical cycle, the filters must meet the requirements of test c).

C.3.m) This section requires that the fan or blower be able to operate in its postulated environment, including radiation. This is partially required by the previous section, which by reference to ANSI N509 (28) requires that the fan motor be qualified to IEEE 323 (38).

C.3.n) This section requires that ductwork be designed, constructed, and tested in accordance with Sec. 5.10 of ANSI N509 (28). ANSI N509 (28) gives requirements for structural integrity, welding, materials, coating, testing, and balancing. The testing required is that of ANSI N510 (29), already required by Sec. C.2.1 of RG 1.52 (6).

C.3.o) This section requires straightening vanes as necessary to ensure representative airflow measurements and uniform flow distribution to cleanup components. The implication is that if the system cannot pass the airflow uniformity test of Sec. C.5.b of RG 1.52 (6), then the straightening vanes are required.

C.3.p) This section specifies that dampers be designed, constructed, and tested in accordance with Sec. 5.9 of ANSI N509 (28). Sec. 5.9 of ANSI N509 (28) gives a thorough set of requirements for the following: a) damper classifications such as function, construction, and leakage classes; b) design considerations such as flow characteristics, dimensions, and operating and fail positions; c) design requirements for each construction class; d) welding requirements; e) damper operator requirements, including their qualification to IEEE 323 (38) and IEEE 334 (39); f) position indication requirements, including qualification to IEEE 323 (38); and g) testing requirements for flow characteristics, pressure drops, and leakage.

A.1.4 Section C.4-Maintenance

This section provides guidance on system maintenance. Sections C.4.a and C.4.b deal with dimensional considerations and accessibility of components to be considered in the design stage. Section C.4.c requires permanent test probes in accordance with Sec. 4.11 of ANSI N509 (28). Section C.4.d requires operation of the system for at least ten hours per month with the heaters on (if so equipped) to reduce the buildup of moisture on cleanup components. Finally, although not really a maintenance criterion, Sec. C.4.e requires that cleanup components not be installed before active construction is completed.

A.1.5 Section C.5-In-Place Testing Criteria

C.5.a) This section requires the performance of a visual inspection of the ESF atmosphere cleanup system should be done in accordance with Sec. 5 of ANSI N510 (29) before performing other tests.

C.5.b) This section requires that the airflow to each unit be tested for uniformity (within ±20% of average for the whole bank) according to Sec. 9 of Industrial Ventilation (19) and Sec. 8 of ANSI N510 (29).

C.5.c) This section gives the requirements for testing frequency for HEPA filters.

C.5.d) This section gives the requirements for testing frequency for adsorbers. Additionally, this section specifies that adsorbers be leak tested with a gaseous halogenated hydrocarbon refrigerant in accordance with Sec. 12 of ANSI N510 (29) to ensure that bypass leakage through the adsorber is less than 0.05%.

A.1.6 Section C.6-Laboratory Testing Criteria for Activated Carbon

This section discusses laboratory tests for activated carbon. The only requirement not previously covered is that representative samples of used activated carbon be subjected to laboratory tests for iodine removal efficiency. This section also refers to Appendix A of ANSI N509 (28) for the design of samplers to get representative samples of used activated carbon.

A.2 RG 1.78-Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Hazardous Chemical Release

RG 1.78 (7) presents assumptions which are to be used in evaluation of CRH during a postulated hazardous chemical release. This guide also specifies the criteria for determining if a hazardous chemical must be considered in the evaluation of CRH. The criteria are based on the toxicity limit of the chemical, distance of the chemical source from the CR air inlets, CR type (based on air exchange rates), and meteorological conditions. For chemicals closer than 0.3 miles from the CR inlet, the guide requires consideration of any chemical which is present in weights over 100 lb. The guide covers both fixed sources and frequent shipments via mobile sources. Toxicity limits used for the analysis are the maximum concentrations that the average human can tolerate for two minutes without physical incapacitation. Section C.5 requires consideration of both a maximum concentration chemical accident and a maximum concentration-duration accident, the former for a large-scale rupture of a storage or shipping container and the latter for the failure of the largest safety relief valve of a storage or shipping container. Section C.7 requires consideration of the capability to isolate the CR with particular emphasis on the time required for isolation, the detection method for each chemical, various air flow rates, the volume of the CR envelope, and the time required for the concentration of the chemical to build from the detection concentration to the toxicity limit. However, it does not rule out alternatives other than isolation for meeting the requirements of the RG. Sections C.8-C.10 govern assumptions for calculating the CR infiltration rate and the amount of makeup air required for pressurization. For any system for which credit is taken in hazardous chemical removal, Sec. C.11 requires that the dynamic removal capability be substantiated with experimental basis. Section C.12 specifies what concurrent accidents involving chemical releases should be considered. Section C.13 requires self-contained breathing apparatus and protective clothing, if necessary, for CR operators if the toxicity limit for any chemical may be exceeded. Section C.14 requires that the single failure criterion be met for detection instrumentation, isolation systems, filtration equipment, air supply equipment, and protective clothing. Section C.15 requires that emergency procedures to be initiated during a hazardous chemical release be written and that "criteria should be defined for the isolation of the CR, the use of protective breathing apparatus or other protective measures, and for orderly shutdown or scram."

A.3 RG 1.95-Protection of Nuclear Power Plant Control Room Operators Against an Accidental Chlorine Release

RG 1.95 (8) is basically RG 1.78 (7) repeated and expanded for protection from chlorine only. This guide was developed to provide protection from onsite releases, but its provisions are expected to be adequate for an offsite release also. Sections C.1-C.3 quantify the maximum allowable shipping and storage inventories of chlorine for various types of CRs as a function of the distance from the CR. Section C.4 describes specific design, qualification, testing, and maintenance criteria for the chlorine detection and protection system, including meeting the single failure criterion. Section C.5 requires determination of the gross leakage characteristics of the CR by pressurizing the CR to 1/8-inch water gage and determining the pressurization flowrate. Periodic verification testing is required for isolated air exchange rates of less than 0.06 per hour. The 0.06 value is chosen to represent a value typical of CRs with normal leakage construction features. It is low enough that minor changes in the leaktightness of the CR may significantly change the air exchange rate; consequently, any claimed value lower than 0.06 is required to be verified at least biannually. Section C.6 essentially repeats Sec. C.15 of RG 1.78 (7).

A.4 Standard Review Plan

A.4.1 SRP Section 6.4-Control Room Habitability System

SRP 6.4 (13) gives guidelines for the review of the CRH systems. A brief summary of the areas for review includes the CR envelope (what areas need to be included); carbon dioxide buildup and adequacy of self-contained breathing apparatus; ventilation system layout and functional design (including flowrates and filter efficiencies); physical locations of potential radioactive contaminant sources with respect to the CR; radiation shielding in the CR; and radiation doses and toxic gas concentrations. The system's acceptance criteria are that it meet GDC 4 (2), GDC 5 (3), GDC 19 (4), and item III.D.3.4 of NUREG-0737 (44). The basic requirements to meet these acceptance criteria are as follows:

a) The CR emergency zone should generally include areas requiring operator access during an accident, while excluding all other areas.

b) The ventilation system should have leaktight dampers to isolate the CR, and all active components of the system should meet the single failure criterion.

c) If the CR is to be pressurized during a radiation emergency, periodic verification of the makeup airflow capacity, periodic verification of CR pressurization, and/or calculations at the construction permit stage to verify CR pressurization capability are required for different types of CRs based on the makeup air changes per hour required.

d) Radiation sources should generally be at least 100 feet laterally and 50 feet vertically from the CR and potential toxic gas sources should be at distances in accordance with RG 1.78 (7) and RG 1.95 (8).

e) For any postulated accident, the dose to CR personnel should not exceed 5 rem whole body gamma, 30 rem thyroid, and 30 rem beta skin.

f) The exposures to toxic gases should be defined and used to determine the adequacy of protection provisions provided in the CR.

The specific review procedures are intended to verify that the acceptance criteria are met. Included is information for evaluating the different CR types and performing an independent analysis of the doses to CR personnel. Conclusions are made based on meeting the GDC by meeting the applicable provisions of RG 1.52 (6), RG 1.78 (7), and RG 1.95 (8). By meeting these RG, compliance with Item III.D.3.4 of NUREG-0737 (44) is assumed.

A.4.2 SRP Section 6.5.1-"ESF Atmosphere Cleanup Systems"

SRP 6.5.1 (14) covers the review of the ESF atmosphere cleanup systems. The CR air cleaning system is reviewed with respect to the following areas: 1) system design, design objectives, and design criteria; 2) environmental design criteria; 3) component design criteria and qualification; 4) design provisions for maintenance; 5) design criteria for in-place testing; and 6) laboratory testing of activated carbon adsorbent. The acceptance criteria for the CR air cleaning system are based on the system meeting GDC 19 (4) by meeting the regulatory positions of RG 1.52 (6). The minimum requirements for instrumentation are also given. The components of the system are required to meet the guidance of ANSI N509 (28) with testing according to the requirements of ANSI N510 (29). In addition, the STS (21, 22, 23, 24) require periodic testing of the total bypass leakage past the HEPA filters and charcoal adsorbers. Including leakage through the system diverting valves, the total leakage must be less than 1% when the system is operating at the design flowrate.

A.4.3 SRP Section 9.4.1-"Control Room Area Ventilation System"

SRP 9.4.1 (15) gives guidelines for review of the CR area ventilation system. The areas for review include the capability of the safety-related portions of the system to maintain CRH during all postulated conditions; to meet the single failure criterion; to not be affected by the failure of nonseismic Category I equipment; to maintain a suitable ambient temperature for personnel and equipment; to detect, filter, or expedite the safe discharge of airborne contaminants in the CR; and to detect and isolate portions of the system in the event of fires, failures, or malfunctions. Additional review areas are protection from natural phenomenon, missiles, and pipe breaks. The acceptance criteria are based on meeting GDC 2 (1) by meeting the applicable sections of RG 1.29 (45), meeting GDC 4 (2), meeting GDC 5 (3), meeting GDC 19 (4) by meeting the applicable sections of RG 1.78 (7) and RG 1.95 (8), and meeting GDC 60 (5) by meeting RG 1.52 (6) and RG 1.140 (46).

The review procedure includes verification that ambient temperature limits are specified, that the loss of any active component will not cause a loss of safety function, that isolation of the essential portions of the system is possible, that essential portions of the system are seismic Category I, that provisions have been made for in-service test and inspection, and that failure of nonessential equipment will not preclude operation of the system. Additional review includes verification of protection from missiles and natural phenomenon.

APPENDIX B--Summary of the Procedure Used to Derive Table 1 of RG 1.95

B.1 Qualitative Description of Procedure

The first step of the procedure is to calculate and plot peak outside chlorine concentrations as a function of distance from the CR and quantity released. These calculations are based on the lower of two concentrations calculated as follows:

a) A calculation of the peak concentration at ground level using the diffusion equation in Appendix B of RG 1.78 (7). (Ground level is used to account conservatively for building wake effects even though the CR air intake is generally well above ground level.) or

b) A calculation of the peak concentration at ground level assuming uniform mixing between the ground and the elevation of the fresh air intake. Except for the calculation of the uniform concentration, the air intake is again assumed to be at ground level. An equation similar to the diffusion equation in Appendix B to RG 1.78 (7) and an assumed CR air intake elevation of 15 meters is used to determine the uniform concentration. The rationale for using the uniform dispersion assumption is that for small releases at short distances, the vertical standard deviation of the puff is small and the puff should remain close to the ground. Thus, the assumption that the CR air intake is at ground level would result in very high outside concentrations. In reality, however, the CR air intake is usually at a high elevation where it should not see these high concentrations.

The second step of the procedure is to use one of two different methods to calculate the peak allowable outside concentration based on an allowable inside concentration of 45 mg/m^3. The first method is to use one of two equations (either equation B-2 or B-4 of Sec. B.2) based on a relatively high windspeed which causes the peak CR concentration to occur primarily from normal air intake prior to CR isolation. The first equation is used when the windspeed necessary to maximize the peak CR concentration is less than 7 m/s. Otherwise, a slightly modified version of the equation is used, which limits the windspeed to 7 m/s. The second method is based on lower windspeeds which cause the peak CR concentration to result primarily from infiltration following isolation. It requires input of the isolated air exchange rate, which is supposed to be based on the flowrate necessary to pressurize the CR to 1/8-inch water gage. This flowrate must be verified by an acceptance test and, for flowrates less than 0.06 air changes per hour, periodic field testing. Since the flowrate required to pressurize the CR to 1/8-inch water gage is supposedly greater than the actual isolated air exchange rate, the procedure introduces a factor of 8 reduction to the 1/8-inch water gage flowrate to arrive at an estimate of the actual isolated air exchange rate.

The final step in the procedure is to select the lower value from the two methods of calculating the peak allowable outside concentration for each given distance and CR type. Using this outside concentration, the maximum allowable inventory of chlorine at a given distance may be found from the plots of peak outside concentration vs. quantity released and distance.

B.2 Equations Used in the Model

B.2.1 Peak Outside Concentration as a Function of Distance from the CR

The peak outside concentration as a function of distance and quantity released is calculated using the lower of the X/Q from the following equations:

$$X/Q = 1/[6.28*(\sigma_H^2 + \sigma_I^2)*H] \tag{B-1a}$$

$$X/Q = 1/[7.87*(\sigma_H^2 + \sigma_I^2)*(\sigma_V^2 + \sigma_I^2)^{1/2}] \tag{B-1b}$$

where X/Q = the unit concentration at coordinates x,y,z from the center of the puff($1/m^3$).
σ_H = horizontal standard deviation of the puff (m).
σ_V = vertical standard deviation of the puff (m).
σ_I = initial standard deviation of the puff as given by equation C-1 of Appendix C (m).
H = CR air intake height (m).

B.2.2 Allowable Peak Outside Concentration

Based on a peak allowable inside concentration of 45 mg/m^3 during the first two minutes after the operators are made aware of the presence of chlorine, two methods are used to calculate the peak allowable concentration outside the CR for each CR type. The first method considers a high windspeed case and assumes a linear buildup of external concentration from the detection level of 5 ppm to the peak concentration in a time period equal to the CR isolation time. Note that this calculation implies a windspeed that moves the puff at a rate which raises the outside concentration from 5 ppm to the peak value in the isolation time. The actual velocity implied is explicitly calculated only by knowing the puff distribution as a function of distance from the center of the puff. The equation for this distribution is given in Appendix B to RG 1.78 (7) and is used in the analysis of Appendix C of this paper. The resulting equation (derivable similarly to equation C-14 of Appendix C but assuming a linear buildup of outside concentration) is:

$$X_1 = R_1*\Delta t*X_O/7.2^{*} \tag{B-2}$$

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[*] Derivation of equation B-2--The equation for outside concentration as a function of time is $C_o = X_O/\Delta t*t$ for 5 ppm $< C_O < X_O$. Using equation C-12 of Appendix C with $R = B$ (for no filtration) gives $dC/dt + RC = R*X_O*t/\Delta t$. The solution is $C = R*X_O/\Delta t*e^{-R*t}[e^{R*t}/R^2*(R*t - 1) + const.]$. Evaluating the constant by setting $C = 0$ at $t = 0$ gives $const. = 1/R^2$. The desired concentration occurs when $t = \Delta t$ and is thus: $C = X_O/(R*\Delta t)*[R*\Delta t - 1 + e^{-R*\Delta t}]$. Approximating e^{-R*t} for small values of $R*t$ gives: $C = X_O/(R*\Delta t)*[R*\Delta t - 1 + 1 - R*\Delta t + R^2*\Delta t^2/2] = R*\Delta t*X_O/2$. To make the units consistent: $C(mg/m^3) = R(1/hr)*\Delta t(sec)*X_O(g/m^3)/2*(hr/3600\ sec)*(1000mg/g) = R*\Delta t*X_O/7.2$.

where X_1 = CR concentration at isolation (mg/m^3)
R_1 = normal air exchange rate (hr^{-1})
Δt = isolation time (seconds)
X_0 = peak outside concentration (g/m^3)
7.2 = combined coefficient and conversion factor for consistent units

Equation B-2 is used unless:

$$\Delta t/(0.64*\sigma)< 1.0 \qquad \text{(B-3)}$$

where $\sigma = (\sigma_H{}^2 + \sigma_I{}^2)^{1/2}$

Though not explicitly stated in the procedure, equation B-3 apparently assumes that chlorine detection of 5 ppm will occur at a distance of about 4.5 standard deviations from the puff center. Based on this assumption, the velocity implied by equation B-2 will exceed 7 m/s when equation B-3 is satisfied. Note that the actual windspeed implied is not necessarily greater than 7 m/s; only the assumption that detection occurs at 4.5 standard deviations from the center of the puff gives a velocity greater than 7 m/s. When equation B-3 is satisfied, equation B-2 is modified to the following equation (also derivable similarly to equation C-14 of Appendix C):

$$X_1' = (R_1*\Delta t^2*X_0)/(4.7*\sigma) \qquad \text{(B-4)}$$

Equation B-4 effectively limits the peak two-minute CR concentration by preventing the peak outside concentration from occurring until after CR isolation is completed. The maximum outside concentration before CR isolation is governed by the amount of the puff that can move past the CR air intake in the isolation time assuming a windspeed of 7 m/s. Included in the derivation of equation B-4 is the assumption that the windspeed is 7 m/s (approximately the 90 to 95% windspeed at an average site).

The second method, based on lower windspeeds, also assumes a linear buildup of concentration from five ppm to the peak concentration, but in two minutes instead of the isolation time. The equation is:

$$X_2 = [(R_1*\Delta t^2)/432 + (17*R_2)/K]*X_0 \qquad \text{(B-5)}$$

where X_2 = CR concentration at isolation (mg/m^3).
R_2 = isolated air exchange rate as evaluated by the licensee at CR pressurization of 1/8 inch water gage (hr^{-1}).
K_2 = buildup reduction factor (function of how R_2 is determined and how much of the inleakage comes from internal control building zones).

The first term of this equation accounts for the CR concentration resulting from normal air intake prior to isolation, while the second term accounts for the contribution from inleakage following isolation. Since R_2 is the inleakage based on pressurization of the CR to 1/8-inch water gage and does not represent the true isolated air exchange rate, the K factor is introduced to attempt to correct for this fact. However, the allowance for the K factor is never pointed out in the RG. In the unpublished calculations, the bases for the K factor are the following: a) the peak wind pressure at the side of a large building with a windspeed of 5 m/s is about 0.068-inch water gage, about half the 1/8-inch water gage used to determine R_2. b) the sides of the building not exposed to direct wind effects should have lower positive pressures or even negative pressure, which would reduce the inleakage from these areas. c) some of the CR inleakage occurs from inside the building. Based on these three factors, correction factors were chosen as follows:

	Correction factor
Wind pressure	2
Pressure distribution over building	2
Allowance for internal inleakage	2

Thus a K of 8 was used (2x2x2). The apparent justification for each factor of 2 is as follows: a) the wind pressure at the side of a large building should rarely exceed 1/2 of the 1/8-inch water gage used in the determination of the infiltration rate, so a factor of 2 reduction is allowed to account for the lower pressure differential. b) the wind pressure should only significantly affect one wall of the building with the other walls generally exposed to lower positive pressures or even negative pressures. Since the lower pressures should occur on at least 1/2 of the building, a factor of 2 is allowed for this effect. c) In most CR designs very few direct openings exist to the outside (where the highest chlorine concentrations will occur). CR are typically interior rooms in other larger buildings, and hence a final factor of 2 is allowed to account for the inleakage which should occur from less contaminated interior areas of the surrounding building. A lower limit on R_2 of 0.015 air changes per hour was set based on a potential barometric pressure change of 1 inch of mercury in a 12-hour period. With a K value of 8, equation B-5 becomes:

$$X_2 = [(R_1*\Delta t^2)/432 + 2.12*R_2]*X_0 \qquad \text{(B-6)}$$

This equation was developed to ensure that the CR is sufficiently leaktight in terms of expected infiltration. The derivation is similar to the derivation of equation C-14 of Appendix C with the following changes: 1) an equation similar to C-12 is used twice, once for the normal air intake and once for the inleakage following isolation. 2) a linear buildup from 5 ppm to the peak concentration is used rather than the Gaussian buildup used to derive equation C-14.

B.2.3 Maximum Allowable Chlorine Inventory as a Function of Distance

Based on the lower of the two allowable outside concentrations calculated from the two methods outlined above, the maximum allowable chlorine inventory was determined from plots of the data obtained using equations B-1a and B-1b.

When using equation B-3, the initial standard deviation is not known since the chlorine inventory is not known. The procedure assumes that the initial standard deviation is zero. This assumption is conservative because it assumes that the puff is less spread out than it really is. Equation B-3 also requires knowledge of the horizontal standard deviation of the puff, which is given in Appendix B to RG 1.78 (7). Apparently, the procedure used the horizontal standard deviations for Pasquill Stability Criterion G for equations B-3 and B-4, while using Pasquill Stability Criterion F when determining the standard deviations for use in equations B-1a and B-1b. RG 1.95 (8) is not clear as to what Stability Criterion the table applies to. Presumably, Type F is the intended Criterion (the one used for Table C-2 of RG 1.78 (7)). If this is actually the case, then the inconsistency of using different stability criteria is conservative because using Type G stability limits the dispersion of the puff more than Type F. The assumptions of zero initial standard deviation and Pasquill Stability Type G affect the calculation of peak outside concentration only when equation B-4 is used, since the other equations for peak outside concentration do not involve standard deviations.

APPENDIX C--Computer Program to Evaluate the Chlorine Calculations Used to Develop Table 1 of RG 1.95

C.1 Introduction

A program was developed on an IBM Personal Computer to independently assess the adequacy of the values in Table 1 of RG 1.95 (8). A further purpose of the program was to evaluate the effects of failure of the chlorine detectors to function properly. The program calculates the peak concentration in the CR within the first two minutes following detection of the chlorine (two minutes is considered to be sufficient time to allow trained operators to don self-contained breathing apparatus). According to RG 1.95 (8), the peak chlorine concentration in the CR should not exceed 15 ppm (45 mg/m^3) during the first two minutes. The program considers the effects of the instantaneous release only since the subsequent continuous plume (comprised of the continuing vaporization of the remaining liquid) is not expected to contribute significantly to the peak two-minute concentration.

Appendix B to RG 1.78 (7) presents the diffusion model for an instantaneous release and states that windspeed should be chosen to maximize the two-minute concentration in the CR and the meteorological stability criterion should be that exceeded only five percent of the time. Normally, the criterion is Pasquill Stability Type F. The program follows RG 1.78 (7) for the puff diffusion calculation for Pasquill Stability Type F. Approximate equations were fit to the standard deviation curves presented in Appendix B of RG 1.78 (7) for use in the diffusion equations.

C.2 Outside Concentration

The initial standard deviation (in meters) of the instantaneous puff release, σ_I, is given by RG 1.78 (7) as:

$$\sigma_I = (Q_I/(7.87*\rho))^{1/3} \qquad \text{(C-1)}$$

where Q_I = quantity instantaneously vaporized (g)
ρ = density of the gas at standard conditions (g/m^3)

The horizontal and vertical standard deviations (in meters), σ_H and σ_V, respectively, are calculated from the following approximate equations which were fit to the curves of Appendix B of RG 1.78 (7):

$$\sigma_H = 10^{**}(0.914*\log(D) - 1.205) \quad 100<D<10000 \text{ m.}$$

$$\sigma_V = 10^{**}(0.717*\log(D) - 1.0532) \quad 100<D<2200 \text{ m.} \qquad \text{(C-2)}$$

$$\sigma_V = 10^{**}(0.1603*\log(D) + 0.8062) \quad 2200<D<10000 \text{ m.}$$

where D = distance from release point to the CR (m)

The diffusion equation for a ground level puff release in RG 1.78 (7) is given by:

$$C_O(x,y,z) = A*\exp\{-0.5*[(x^2 + y^2)/(\sigma_H^2 + \sigma_I^2) + (z^2/(\sigma_V^2 + \sigma_I^2))]\}$$

$$\text{with} \quad A = Q_I/[7.87*(\sigma_H^2 + \sigma_I^2)*(\sigma_V^2 + \sigma_I^2)^{1/2}] \qquad \text{(C-3)}$$

where $C_O(x,y,z)$ = the concentration outside the CR at location x,y,z from the center of the puff (g/m^3).
x,y,z = distance from the puff center in the horizontal alongwind, horizontal crosswind, and vertical crosswind directions (m).

For a worst case analysis, 25% of the contents of a container are assumed to be released instantaneously and the centerline of the puff is assumed to remain in line with the CR such that y = 0. According to NUREG-0570 (47), the fresh air intakes for nuclear power plants are usually located on the top or sides of buildings. However, to account conservatively for building wake effects on vapors much heavier than air (such as chlorine), equation C-3 is modified by setting z = 0. An example of a building wake effect would be a high ground level concentration of chlorine being swept up the side of a building to the CR fresh air inlet. The x value in equation C-3 is a function of windspeed and is the distance from the CR to the center of the puff:

$$x = D - v*t \qquad \text{(C-4)}$$

where v = windspeed (m/s).
t = time from initial puff release (s)

Thus, equation C-3 becomes:

$$C_O(t) = A*\exp\{-0.5*[(D - v*t)^2/(\sigma_H^2 + \sigma_I^2)]\} \qquad \text{(C-5)}$$

where $C_O(t)$ = concentration outside the CR as a function of time (g/m^3)

C.3 Inside Concentration

A differential equation relating the inside concentration to the outside concentration may be easily derived. The mass rate of change of chlorine in the CR, dm/dt in g/s, is given by:

$$dm/dt = m_i - m_e \qquad \text{(C-6)}$$

where m_i = mass rate into the CR (g/s).
m_e = mass rate out of the CR (g/s).

The mass rate into the CR is given by:

$$m_i = C_O * V_{IN} \qquad \text{(C-7)}$$

where V_{IN} = volume flowrate of outside air into the CR (m^3/s)

Prior to isolation, V_{IN} is the normal air inlet flowrate. Following isolation, V_{IN} is the infiltration rate. The mass rate leaving the CR is made up of two components, the exfiltration and any removal from filtration of recirculated CR air:

$$m_e = C*V_{OUT} + C*V_f*(\eta/100) \qquad (C-8)$$

where C = concentration inside the CR (g/m^3)
V_{OUT} = rate of exfiltration = V_{IN} (m^3/s)
V_f = filtration rate (m^3/s)
η = filtration efficiency for chlorine (%)

Substituting equations C-7 and C-8 into C-6 gives:

$$dm/dt = C_O*V_{IN} - C*(V_{IN} + V_f*\eta/100) \qquad (C-9)$$

Dividing equation C-9 by the volume of the CR, V, in m^3, gives:

$$dC/dt = C_O*V_{IN}/V - C*[(V_{IN}/V) + (V_f/V*\eta/100)] \qquad (C-10)$$

For simplicity define:

$$R = V_{IN}/V \qquad \text{and} \qquad B = V_{IN}/V + (V_f/V)*(\eta/100) \qquad (C-11)$$

R and B will be constants at any given time but will be different for the normal and isolated conditions. Equation C-10 then becomes:

$$dC/dt + BC = RC_O \qquad (C-12)$$

where both C_O and C are functions of time. Substituting equation C-5 into C-12:

$$dC/dt + BC = R*A*\exp[-0.5*(D - v*t)^2/(\sigma_H{}^2 + \sigma_I{}^2)] \qquad (C-13)$$

The solution to equation C-13 is:

$$C = \exp(-B*t) \quad \exp(B*t)*A*R*\exp[-0.5*(D - v*t)^2/(\sigma_H{}^2 + \sigma_I{}^2)]dt \qquad (C-14)$$

which gives the concentration inside the CR as a function of time. Equation C-14 requires a numerical integration which the computer program performs.

C.4 Listing of Program

This section provides a source listing of the computer program. It should be noted that when using the program for a K factor of 1, R2 and B2 in lines 270 and 275 will have the factor of 8 removed.

```
10 INPUT "SUPPRESS SCREEN PRINTING OF CONCENTRATIONS (1=YES,
0=NO)";SUPP
20 INPUT "HEIGHT OF CONTROL ROOM AIR INTAKE(M)";H
30 INPUT "QUANTITY VAPORIZED (G)";QV
40 INPUT "DENSITY OF GAS AT STD CONDITIONS (G/M**3)";DS
50 INPUT "DISTANCE TO CONTROL ROOM (M)";D
60 INPUT "NORMAL OUTSIDE AIR EXCHANGE RATE (CHANGES/HR)";VN
70 INPUT "ISOLATED AIR EXCHANGE RATE (CHANGES/HR)";VI
80 INPUT "CONTROL ROOM VOLUME (FT**3)";CR
90 INPUT "FILTRATION EFFICIENCY FOR CONTAMINANT (%)";EF
100 EF=EF/100
110 INPUT "FILTRATION RATE (CFM)";VF
120 INPUT "ISOLATION TIME (SEC)";IS
130 INPUT "DETECTION MECH WORKS (1=YES,0=NO)?";YN
140 IF YN<.5 THEN GOTO 170
150 INPUT "AT WHAT CONCENTRATION (G/M**3)?";DC
160 GOTO 200
170 INPUT "HUMAN DETECTION AT WHAT CONCENTRATION (G/M**3)? "
;HD
180 INPUT "HUMAN RESRONSE TIME TO INITIATE ISOLATION (SEC) "
;OT
190 REM CALC. STANDARD DEVIATIONS.
200 SI=(QV/(7.87*DS))^.333333
210 SH=10^(.914*.4343*LOG(D)-1.205)
220 IF D>2200 THEN SV=10^(.1603*.4343*LOG(D)+.8062)
230 IF D<=2200 THEN SV=10^(.717*.4343*LOG(D)-1.0532)
240 VMIN=SH/30:INCRE=(SH/12-VMIN)/8
250 PRINT SV,SH,VMIN,INCRE
260 REM CALC. PEAK OUTSIDE CONCENTRATION.
270 CPA=QV/(7.87*(SH*SH+SI*SI)*(SV*SV+SI*SI)^.5)
280 CPB=QV/(6.28*(SH*SH+SI*SI)*H)
290 IF CPA<CPB THEN CP=CPA ELSE CP=CPB
300 PRINT "CPA=",CPA,"CPB=",CPB,"CP=",CP
310 R1=VN/3600:R2=VI/3600/8
320 B1=(VN/3600+EF*VF/60!/CR):B2=(VI/3600/8+EF*VF/CR/60!)
330 MAXCIMAX=0!:TSS=0:RRR=0:RST=0:RTV=0:INCRE1=0:INCRE2=0:IN
CRE3=0
350 FOR XV=1 TO 100
360 IF RRR<.5 AND XV>10 THEN RRR=1:INCRE1=INCRE*2
370 IF RST<.5 AND XV>15 THEN RST=1:INCRE2=INCRE1*2
380 IF RTV<.5 AND XV>20 THEN RTV=1:INCRE3=INCRE2*4
390 IT=IS
400 REM CALC. WIND VELOCITY.
410 V=VMIN+(XV+1)*INCRE+(XV-10)*INCRE1+(XV-15)*INCRE2+(XV-20
)*INCRE3
420 TF=100:T=0!
430 SH1=(SH*SH+SI*SI)^.5
440 REM SET THE INITIAL TIME TO WHERE THE CLOUD IS JUST
450 REM ENTERING THE AREA OF THE CONTROL ROOM.
460 IF D>(7*SH1) THEN T=(D-(7*SH1))/V
470 REM SET INITIAL TIME INCREMENT BASED ON THE HORIZONTAL
```

```
475 REM STANDARD DEVIATION.
480 DT=SH/(10*V)
490 REM INITIALIZE VARIABLES.
500 I=1:G=0!:SU=0!:GG=0!:CO=0!:AD=0!:CI=0!:EXPOS=0!
510 TT=0!:TDET=0!:TISOL=0!:RVT=0!:HH=0!:TMAX=0!:CIMAX=0!
520 REM CALC. CONSTANT PORTION OF EXPONENT.
530 EX=-.5/(SH*SH+SI*SI)
540 G=GG:T=T+DT:DX=D-V*T:CO=CP*EXP(DX*EX*DX)
550 REM KEEP TRACK OF PEAK TWO MINUTE CONCENTRATION.
560 IF CI>CIMAX THEN CIMAX=CI:TMAX=T
570 REM AFTER ISOLATION, GO TO CALC. FOR ISOLATED CASE.
580 IF I>2.5 THEN GOTO 990
590 REM IF BETWEEN DETECTION AND COMPLETE ISOLATION, GO TO
600 REM CALC. FOR ISOLATION IN PROGRESS CASE.
610 IF I>1.5 THEN GOTO 850
620 REM IF NOT YET DETECTED, CONTINUE BY CALCULATING THE NEX
T INCREMENT
630 REM OF THE INTEGRAL TO FIND THE INSIDE CONCENTRATION.
640 GG=EXP(B1*T)*R1*CO
650 AD=.5*(G+GG)*DT
660 SU=SU+AD
670 REM CALC. INSIDE CONCENTRATION AT TIME T.
680 CI=EXP(-B1*T)*SU
690 IF (CO>1E-36) AND (SUPP<.5) THEN PRINT USING "##.###^^^^
";T,CI,CO,EXPOS
700 REM WHEN THE OUTDOOR CONCENTRATION REACHES 0.00001, SET
710 REM TIME INCREMENT TO 0.5 SECONDS.
720 IF TT>.9 THEN GOTO 750 ELSE IF CO>.00001 THEN TT=1:DT=.5
730 REM IF DETECTORS WORK AND THE OUTDOOR CONC.>THE DETECTIO
N THRESHOLD
740 REM THEN DETECTION IS ACCOMPLISHED.
750 IF (YN>.5) AND (CO>DC) THEN I=2
760 REM IF DETECTORS FAIL AND THE INDOOR CONC.>HUMAN DETECTI
ON THRESHOLD
770 REM THEN DETECTION IS ACCOMPLISHED.  ALSO INCREASE THE I
SOLATION
780 REM TIME BY THE OPERATOR RESPONSE TIME.
790 IF (YN<.5) AND (CI>HD) THEN I=2:IT=IT+DT
800 REM FOLLOWING DETECTION, SET TIME INCREMENT (IF NEW ONE
IS DESIRED)
810 REM AND GO TO CALC. FOR ISOLATION IN PROGRESS CASE.
820 IF I>1.5 THEN DT=.5:GOTO 1540
830 GOTO 540
840 REM DO CALC. FOR ISOLATION IN PROGRESS CASE--SAME AS
845 REM ABOVE, BUT KEEP TRACK OF TIME TO FINISH ISOLATION.
850 GG=EXP(B1*T)*R1*CO
860 AD=.5*(G+GG)*DT
870 SU=SU+AD:CI=EXP(-B1*T)*SU
880 IF SUPP<.5 THEN PRINT USING "##.###^^^^";T,CI,CO,EXPOS
890 REM KEEP TRACK OF WHEN ISOLATION IS COMPLETED.
900 IT=IT-DT
910 REM IF THE REMAINING TIME TO ISOLATION IS LESS THAN 0.05
```

```
920 REM SECONDS, ISOLATION IS CONSIDERED TO BE COMPLETED
930 IF IT<.05 THEN I=3
940 REM SET ENDING TIME TO TWO MINUTES BEYOND WHEN ISOLATION
945 REM IS COMPLETE.
950 IF I>2.9 THEN TF=TDET+119.5
960 REM SET TIME INCREMENT TO 2.5 SEC FOR REMAINDER OF TIME.
970 IF I>2.9 THEN DT=2.5:GOTO 1510
980 GOTO 540
990 GG=EXP(B2*T)*R2*CO
1000 REM DO CALC. FOR ISOLATED CASE.  SAME AS BEFORE BUT
1005 REM USE ISOLATED PROPERTIES.
1010 AD=.5*(G+GG)*DT:SU=SU+AD:CI=EXP(-B2*T)*SU
1020 IF SUPP<.5 THEN PRINT USING "##.###^^^^";T,CI,CO,EXPOS
1030 REM AFTER FINAL TWO MINUTES, EXIT.
1040 IF T>TF THEN GOTO 1070
1050 GOTO 540
1060 REM PRINTING RESULTS, CHANGING DATA, AND RERUNNING.
1070 LPRINT USING "PEAK EXPOSURE OF #.###^^^^ G/CUBIC METER"
;CIMAX
1080 LPRINT USING "TIME OF PEAK EXPOSURE IS ####.## SECONDS"
;TMAX
1090 LPRINT USING "WINDSPEED= ##.## M/S";V
1100 LPRINT USING "DETECTION AT ####.## SECONDS";TDET
1110 LPRINT USING "ISOLATION COMPLETE AT ####.## SECONDS";TI
SOL
1120 IF V>6.99 THEN GOTO 1140
1130 NEXT XV
1140 LPRINT USING "CONTROL ROOM AIR INLET HEIGHT= ###.# M.";
H
1150 LPRINT USING "PEAK OUTSIDE CONCENTRATION= ####.## G/CUB
IC METER";CP
1160 LPRINT USING "QUANTITY VAPORIZED= #.####^^^^ GRAMS";QV
1170 LPRINT USING "DENSITY OF GAS= #####.## G/CUBIC METER";D
S
1180 LPRINT USING "DISTANCE FROM CONTROL ROOM= #####.# METER
S";D
1190 LPRINT USING "NORMAL AIR EXCHANGE RATE= ##.### CHANGES/
HOUR";VN
1200 LPRINT USING "ISOLATED AIR EXCHANGE RATE= ##.#### CHANG
ES/HOUR";VI
1210 LPRINT USING "CONTROL ROOM VOLUME= ####### CU. FT.";CR
1220 LPRINT USING "FILTRATION EFFICIENCY= ###.# ";EF
1230 LPRINT USING "FILTRATION RATE= ###### CFM";VF
1240 LPRINT USING "ISOLATION TIME= ###.# SECONDS";IS
1250 IF YN<.5 THEN LPRINT USING "DETECTION FAILS---HUMAN DET
ECTION AT ##.#### G/
CUBIC METER";HD
1260 IF YN<.5 THEN LPRINT USING "HUMAN RESPONSE TIME= ###.#
SECONDS";OT ELSE LPR
INT USING "DETECTION WORKS AT ##.##### G/CUBIC METER";DC
1270 LPRINT :LPRINT :LPRINT
1280 CLS
```

```
1290 PRINT:PRINT "TO CHANGE A VARIABLE, TYPE NUMBER      CORR
ESPONDING "
1295 PRINT "TO THE ONE YOU WOULD LIKE CHANGED."
1300 PRINT "       1=QUANTITY VAPORIZED"
1310 PRINT "       2=DENSITY OF GAS"
1320 PRINT "       3=DISTANCE FROM CONTROL ROOM"
1330 PRINT "       4=AIR INTAKE HEIGHT"
1340 PRINT "       5=NORMAL AIR EXCHANGE RATE"
1350 PRINT "       6=ISOLATED AIR EXCHANGE RATE"
1360 PRINT "       7=CONTROL ROOM VOLUME"
1370 PRINT "       8=FILTRATION EFFICIENCY"
1380 PRINT "       9=FILTRATION RATE"
1390 PRINT "       10=ISOLATION TIME"
1400 PRINT "       11=DETECTION WORKS (1=YES,0=NO)"
1410 PRINT "       12=NEW DETECTION THRESHOLD"
1420 PRINT "       13=NEW HUMAN DETECTION THRESHOLD"
1430 PRINT "       14=NEW HUMAN RESPONSE TIME"
1440 PRINT "       15=SUPRESS SCREEN PRINTING"
1450 PRINT "       16=ALL CHANGES COMPLETE"
1460 PRINT "       17=QUIT"
1470 INPUT "ENTER NUMBER (1-17)";CHAN
1480 ON CHAN GOTO 1560,1570,1580,1590,1600,1610,1620,1630,

     1640,1650,1660,1670,1680,1690,1700,1710,1720
1490 GOTO 1280
1500 REM KEEP TRACK OF ISOLATION COMPLETED TIME.
1510 IF RVT>.9 THEN GOTO 540
1520 RVT=1:TISOL=T:GOTO 540
1530 REM KEEP TRACK OF DETECTION COMPLETED TIME.
1540 IF HH>.9 THEN GOTO 540
1550 HH=1:TDET=T:GOTO 540
1560 INPUT "NEW QUANTITY VAPORIZED";QV:GOTO 1280
1570 INPUT "NEW DENSITY";DS:GOTO 1280
1580 INPUT "NEW DISTANCE";D:GOTO 1280
1590 INPUT "NEW HEIGHT";H:GOTO 1280
1600 INPUT "NEW NORMAL AIR EXCHANGE RATE";VN:GOTO 1280
1610 INPUT "NEW ISOLATED AIR EXCHANGE RATE";VI:GOTO 1280
1620 INPUT "NEW CONTROL ROOM VOLUME";CR:GOTO 1280
1630 INPUT "NEW FILTRATION EFFICIENCY";EF:GOTO 1280
1640 INPUT "NEW FILTRATION RATE";VF:GOTO 1280
1650 INPUT "NEW ISOLATION TIME";IS:GOTO 1280
1660 INPUT "DETECTION WORKS (1=YES,0=NO)";YN:GOTO 1280
1670 INPUT "NEW INSTRUMENT DETECTION THRESHOLD";DC:GOTO 1280
1680 INPUT "NEW HUMAN DETECTION THRESHOLD";HD:GOTO 1280
1690 INPUT "NEW HUMAN RESPONSE TIME";OT:GOTO 1280
1700 INPUT "SUPPRESS SCREEN PRINTING (1=YES,0=NO)?";SUPP:GOT
O 1280
1710 GOTO 200
1730 END
```

APPENDIX D--Factors Affecting the Level of Conservatism of Table 1 of RG 1.95

In all cases, the NRC method assumes a linear buildup of outside concentration from 5 ppm to the peak value. This assumption is an approximation to the more realistic Gaussian concentration distribution with both an increasing and a decreasing interval of outside concentrations. The linear buildup assumption conservatively approximates only the front half, or increasing part of the distribution; it ignores the back half, or decreasing part of the distribution and therefore becomes non-conservative after the peak concentration passes the air intake.

When using equations B-2 and B-4 in Appendix B, the important factor governing the inside concentration is the time average concentration outside the CR. The passage of the whole puff (from a given concentration on the increasing side of the curve to the same concentration on the decreasing side of the curve) within the isolation time would result in a time average concentration exactly equal to the time average concentration resulting from passage of only half the puff during the isolation time (from the given concentration to the peak concentration). However, passage of greater than one half the puff, but less than the whole puff, will result in higher time average concentrations than passage of the whole puff.

To illustrate the effects of the linear approximations, Figure D-1 shows a comparison of the front half of a Gaussian curve and three possible linear approximations to this curve, typical of those used in the calculations. The actual linear approximation which is inherently used in the method varies with the quantity released, the distance of the source from the CR, and the equations above which govern the values in Table 1 of RG 1.95 (8). When using equation B-4, a very conservative result in the allowable chlorine inventory results because of the two related assumptions that the initial standard deviation of the puff is zero and the Pasquill Stability Criterion is Type G and because the linear approximation to the Gaussian curve becomes very conservative. When using equation B-2, the linear approximation is similar to line AA or line BB on Fig. D-1; when using equation B-4, the concentration is assumed to follow a line similar to line CC, but not necessarily all the way to the peak concentration since the windspeed is limited to 7 m/s when using equation B-4. The beginning part of the line CC approximation is especially conservative with respect to the actual case.

In addition to not accounting for the back side of the Gaussian distribution, another non-conservative factor in the above equations is that the effects of infiltration following isolation are not accounted for in equation B-2 and B-4. However, this contribution is generally expected to be small when equations B-2 or B-4 is used because the high windspeeds inherent in these equations make the cloud passage time short.

Equation B-6 turns out to be conservative for all cases where it was used (see Table 3). Similar to equations B-2 and B-4, equation B-6 uses a conservative estimate to the front half of a Gaussian distribution but does not include any effects of the back half of the Gaussian distribution.

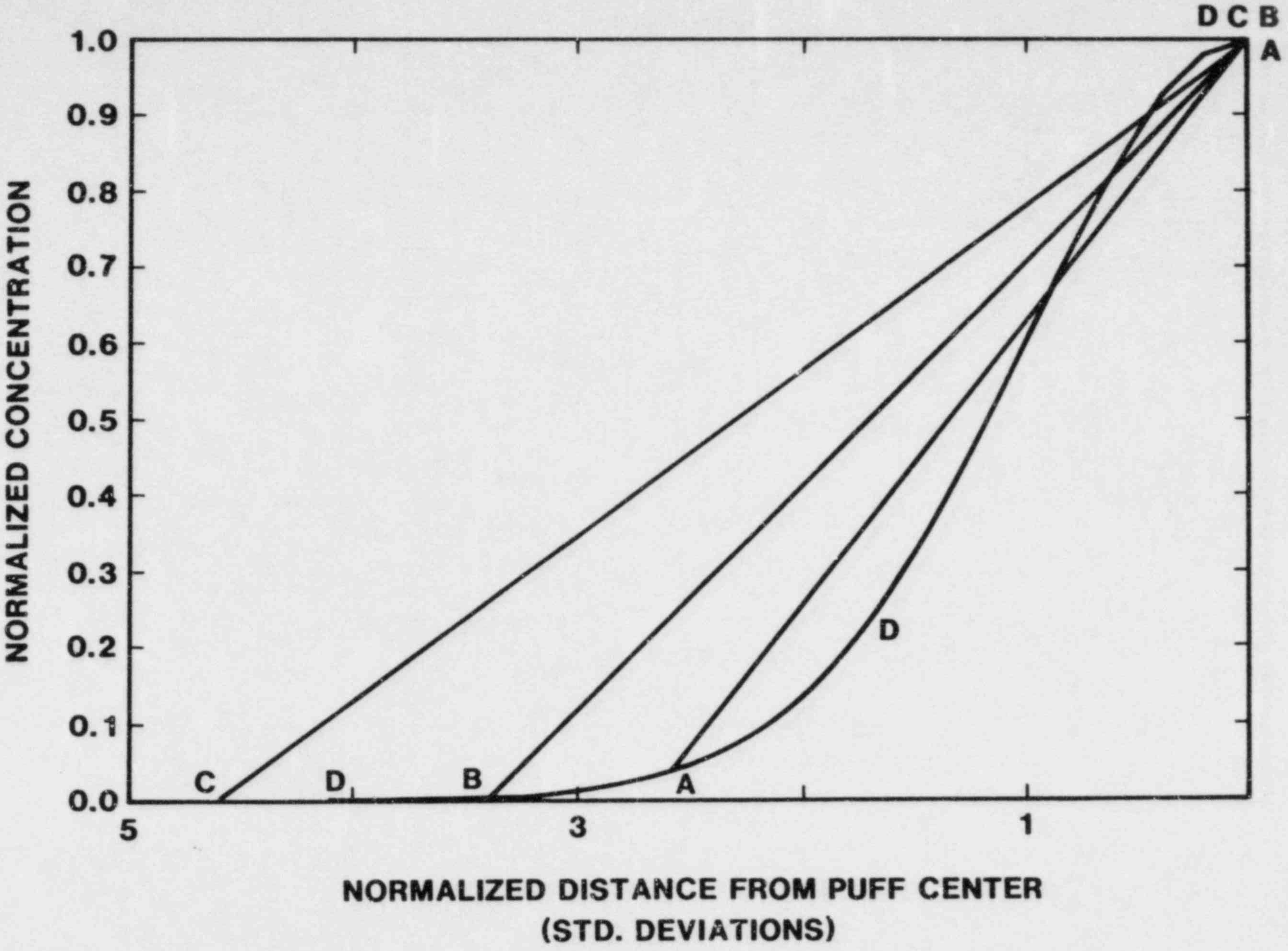

Figure D-1: Comparison of Three Different Linear Approximations (AA, BB, and CC) to a Gaussian Curve (DDD)

It should be noted that scaling for maximum permissible inventory of chlorine according to Pasquill Stability Criterion seems to be allowed according to Appendix A of RG 1.78 (7). Based on spot checks using scaled values from Table 1 of RG 1.95 (8) in the computer program discussed in Appendix C, the scaling factors for Pasquill Stability Criterion given in RG 1.78 (7) appear to be reasonable for scaling the values in Table 1 of RG 1.95 (8).

APPENDIX E--Assumptions Used for Table 1 of RG 1.95 and Their Possible Effects

The following assumptions used to derive Table 1 of RG 1.95 (8) are not adequately outlined in the regulations to prevent misinterpretation or non-compliance with the intent of the guide:

1) The values for RG 1.95 assume a CR air intake height of 15 meters with no provisions for determining the allowable weights of chlorine for other heights. In general, heights above 15 meters make Table 1 of RG 1.95 (8) more conservative, and heights below 15 meters make Table 1 of RG 1.95 (8) less conservative.

2) The K value of 8 is never mentioned in the guide nor is any provision made to evaluate the adequacy of this factor for a particular plant in the design or review process. For example:

   (a) All major leak paths at a particular plant may be on one side of the building, negating the factor of 2 for pressure distribution over the building (see Appendix B for an explanation of how the K factor was obtained).

   (b) The internal leakage factor may not be suitable for a particular plant (see Appendix B for an explanation of how the K factor was obtained).

   A problem caused by not mentioning the factor of 8 in the RG is that a designer may attempt to use a similar reduction factor in determining the plant's isolated air exchange rate and then proceed to use Table 1 of RG 1.95 (8), which has the reduction factor already built into it. An apparent example of this was noted in a particular plant's FSAR. The plant had specified about 0.055 air changes per hour as the maximum makeup flowrate to maintain 1/8-inch w.g. in the CR. This value is apparently based on a calculation of the flowrate necessary to maintain the CR at 1/4-inch water gage (in accordance with Sec. C.9 of RG 1.78 (7)). However, an isolated air exchange rate of 0.012 per hour was claimed based on a calculation of the flowrate necessary to maintain the CR at 1/8-inch water gage. The value of 0.012 air changes per hour was used to determine compliance with RG 1.95 (8). Because the isolated air exchange rate is claimed to be less than 0.06 per hour, periodic verification testing is required in accordance with Sec. C.5 of RG 1.95 (8). However, it is not clear what the acceptance criterion is for passing the test. The correct acceptance criterion when using RG 1.95 (8) is the claimed isolated air exchange rate (0.012 in this case). However, it appears from the plant's FSAR that the intended acceptance criterion to be used is 0.055 per hour, which in essence, takes credit for effects already allowed for in the K factor built into Table 1 of RG 1.95 (8).

   Another plant was permitted to use a 1/16-inch w.g. pressure differential for calculating inleakage across those leakpaths not exposed to direct wind effects. This is, in essence, taking some credit for reduced inleakage resulting from the effects of wind pressure and pressure distribution over the building before using RG 1.95 (8); RG 1.95 (8) already includes credit for these effects in the K factor (see Appendix B concerning the K factor).

3) The values in Table 1 of RG 1.95 (8) assume a maximum windspeed of 7 m/s with no mention of this fact nor any way to correct for other values of maximum windspeed. In general, lower windspeeds will make Table 1 of RG 1.95 (8) more conservative and higher values of windspeed will make Table 1 of RG 1.95 (8) less conservative.

4) According to RG 1.78 (7), personnel ingress and egress is generally assumed to account for an additional 10 cfm of air exchange for CRs without airlocks, but this is never mentioned in RG 1.95 (8). Apparently, the 10 cfm is supposed to be added to both the calculated and measured values of air exchange rate, although it is not clear from FSARs that this is always done when the allowable chlorine inventory is determined from RG 1.95 (8). However, if the doors open into interior corridors which are expected to have low chlorine concentrations with respect to the outside, the contribution from ingress and egress would not significantly affect the peak two-minute CR chlorine concentration.

5) Scaling the maximum permissible inventory of chlorine according to air exchange rate seems to be allowed according to Appendix A of RG 1.78 (7). This can be extremely non-conservative for upward scaling of weights if the scaling is based on only one air exchange rate (i.e. either normal or isolated). For example, if a CR has an isolated air exchange rate of 0.03 per hour, it would not necessarily qualify to double the weights compared to a similar CR with an isolated air exchange rate of 0.06 per hour. Improper scaling for isolated air exchange rate occurs when the normal air exchange rate and the isolation time are the parameters that govern the allowable storage of chlorine. Since equations B-2 and B-4 do not contain isolated air exchange rate as a parameter, a change in the isolated air exchange rate will have no effect on the allowable chlorine inventory until equation B-6 becomes the governing equation. Based on this observation, there may be no significant benefit to reducing the CR isolated air exchange rate in some cases (as far as chlorine protection is concerned). Generally, to double a chlorine inventory from Table 1 of RG 1.95 (8) without a complete analysis such as the one in Appendix C, halving of the isolated air exchange rate and either the isolation time or the normal air exchange rate should be sufficient. For example, a CR with a normal air exchange rate of 0.5 per hour, an isolation time of 10 seconds, and an isolated air exchange rate of 0.03 per hour should qualify to double the allowable chlorine inventories for a Type I CR given in RG 1.95 (8). Scaling downward, on the other hand, is conservative. It should be noted that even if both the normal and isolated air exchange rates are double those of a particular CR type, only one factor of two reduction in allowable chlorine inventory is necessary.

APPENDIX F--Conservative Nature of Chlorine Calculations

Many conservative assumptions and calculations are used in the evaluation of potential chlorine releases. The following specific items could contribute to a significant degree of conservatism in the calculations:

a) The assumption that the chlorine vessel ruptures and releases all its contents instantly is obviously conservative.

b) The assumption that 25% of the release is instantaneously vaporized is conservative for most releases. At 70°F, only about 17% would flash to vapor (48). Higher temperatures would increase the quantity flashed and lower temperatures would decrease the quantity flashed.

c) The wind direction is assumed to be directly toward the control room from the release point.

d) The atmospheric dispersion is assumed to be that exceeded only 5% of the time.

e) The windspeed is supposed to be chosen to maximize the two-minute concentration. (This requirement was not followed exactly in RG 1.95 (8) since only two windspeeds were evaluated for each case, one high value and one low value--see Appendix B for more detail.)

f) A study of atmospheric dispersion in England (49) showed that having Pasquill Stability Criteria more stable than Type D (neutral) is very uncommon during daylight hours, regardless of the windspeed. Further, with windspeeds greater than 5 m/s (even at night), the Pasquill Stability Criteria will rarely be more stable than Type E. Thus, the values in Table 1 of RG 1.95 (8), which are based on Stability Type F (or G) and a concurrent 7 m/s maximum windspeed, are likely to be quite conservative in many cases.

g) Except for uniform concentration calculations which use an air intake height of 15 meters, the air intake is assumed to be at ground level where the highest chlorine concentrations occur. In reality, control room air intakes are well above ground level where they would not be expected to see such high concentrations.

h) The infiltration rate during the first two minutes after control room isolation appears very conservative for some plants because the control room is so well protected from direct exposure to outside air. The main source of infiltration is through the control room isolation valves which are exposed to negative pressure differentials.

i) The toxicity limit of 15 ppm appears to be somewhat conservative. One plant's FSAR quotes an immediately dangerous to life or health (IDLH) value as 25 ppm. The IDLH value is supposed to be the concentration from which one could escape within 30 minutes without any escape-impairing symptoms or irreversible health effects. Another plant's FSAR stated that it becomes highly dangerous to be exposed to chlorine concentrations of 40-60 ppm for 30 minutes. The RG 1.78 (7) value of 15 ppm is supposed to be the maximum concentration that can be tolerated for two minutes without physical incapacitation of the average human (i.e., severe coughing, eye burn, or severe skin irritation). The evidence quoted in the two plant's FSARs tends to dispute the 15 ppm limit.

j) Even in the remote event that a chlorine release led to complete incapacitation of all personnel at the site, the probability of any danger to the health and safety of the public would still be minimal because the reactor could operate unmanned for several hours under most circumstances.

APPENDIX G--Hypothetical CR Design Used in Section 5.5.1

Suppose the following conditions, some of which are based on the data for plant E in Table 1, occurred during the design and construction process:

a) A leakage calculation for the CR produces an isolated air exchange rate of 0.015 per hour based on the method of SRP 6.4.III.3.d.(2).(i) (13).

b) An acceptance test is to be performed to verify that the CR can be maintained at 1/8-inch w.g. with a makeup rate calculated in accordance with Sec. C.9 of RG 1.78 (7). This RG requires that the flowrate required to pressurize the CR to 1/8-inch w.g. be calculated based on a positive pressure differential of 1/4-inch water gage between the CR and adjacent areas. For this example, a value of 0.060 air changes per hour is reasonable based on the FSAR information given for plant E in Table 1. Since the pressurization flow of 0.06 air changes per hour is less than 0.25 air changes per hour, according to SRP Sec. 6.4.II.3.c. (13) it would require periodic field testing to ensure that 1/8-inch water gage can be maintained in the CR with the design pressurization flowrate.

c) A pressurization rate of less than or equal to 0.06 air changes per hour is used as the acceptance criteria for verifying that the CR can be maintained at 1/8-inch water gage.

d) Table 1 of RG 1.95 (8) is used with the calculated isolated air exchange rate of 0.015 air changes per hour to determine the allowable chlorine inventory at a given distance from the CR (see Table 3 of this paper for the values given in the RG). Assuming that the CR has remote detection capability, the values for a Type VI CR are used.

e) The CR inlet is actually only 8 meters above the ground, but RG 1.95 (8) does not require any correction for this fact.

For this situation, the isolated air exchange rate to use in calculating the maximum chlorine inventory should be the air exchange rate necessary to maintain the CR at 1/8-inch water gage with respect to adjacent areas. For this example, 0.06 air changes per hour should be used because this is the value used for the acceptance criterion in item c) above. A factor of 8 is built into Table 1 of RG 1.95 (8) to account for the fact that the actual isolated air exchange rate should be less than 0.06. However, what appears to be done in some cases is to use the calculated value of isolated air exchange rate (0.015 in this example) to determine compliance with RG 1.95 (8).

APPENDIX H--Feasibility of a Temperature-Rise Pressurization System

Based on calculations by Ornberg, Miller, and McDonald (50) for loss of HVAC with normal operational loads in one particular CR, a temperature of 100°F would be reached in about 400 seconds (less than seven minutes) from an initial temperature of 73°F. With the HVAC operating at reduced capacity, this temperature rise could be accomplished in any amount of time greater than seven minutes. To illustrate the feasibility of pressurizing the CR using the temperature rise method, a short analysis was conducted. Assuming that the CR air is an ideal gas and no outleakage occurs, the temperature required to pressurize the CR to 1/8-inch water gage (w.g.) above the surrounding area is about T = 400.125 inch w.g. / 400 inch w.g. * 533 R = 533.17 R or about a 0.17°F increase in temperature. This increase would occur during the first few seconds and make the zero outleakage assumption reasonable for a reasonably leaktight CR, since the amount of time for outleakage would be small. Using numbers from any specific FSAR, the rate of temperature rise required to keep the CR pressurized can be estimated. For one particular plant, the following numbers are specified: a CR envelope of 220,000 cubic feet and a maximum makeup air requirement of 200 CFM for pressurization. To a good approximation, the temperature rise requirement will be linear over the range of 73.17°F to 100°F. The total volume available for outleakage during the temperature rise at constant pressure is calculated from the ideal gas relations and is V = [(560 R / 533.17 R) - 1] * 220,000 ft^3 = 11071 ft^3. For a 200 CFM maximum air makeup requirement, 11071 ft^3 will last a minimum of 11071 ft^3 / 200 CFM = 55.4 minutes, well within the capability of an existing arrangement. The uniform temperature rise rate required is about 26.83°F / 55.4 minutes = 0.48°F per minute. Pressurization through temperature rise can be effectively coupled with present methods of radiation and hazardous chemical protection to produce an improved system. Current systems often use either a pressurization or an isolation and recirculation scheme. SRP 6.4.III.3.d.3 (13) addresses these two protection methods as to which is to be preferred and whether pressurization should be automatic or manual. Each different type of system has particular advantages and disadvantages, but no system is best for all cases. A system which appears to significantly improve on the current methods is as follows:

a) During any accident, either hazardous chemical or radiological, the CR would be immediately isolated, put in the recirculation/filtration mode, and pressurized using the temperature rise method for approximately 20 minutes, allowing an acceptable temperature rise of 10°F (higher temperature rises for less leaktight CRs).

b) For a radiological emergency, the CR would then be maintained at the higher temperature with filtered makeup air introduced through the emergency makeup units to maintain pressurization. Recirculated air would continue to be filtered in the emergency units to remove any contaminants which may have entered the CR.

c) For a hazardous chemical release, the CR would remain in the isolation and recirculation/filtration mode at the higher temperature until the hazard passed.

Particular advantages of this type of a system include:

a) The system could be fully automatic, not requiring any operator decisions such as when to pressurize the CR or which inlet of a dual inlet system to utilize. The automation is particularly beneficial during an accident in which the operator is preoccupied with maintaining the reactor in a safe condition.

b) Complete isolation of the system following detection of high radiation levels in the intake air limits the buildup of noble gases (not filterable). Pressurization limits the amount of unfiltered inleakage.

c) Complete isolation of the system during a hazardous chemical release (similar to many current systems) avoids significant challenges to the filtration system. Superior to current systems, this system also provides pressurization which limits the inleakage of contaminated air.

d) Filtered makeup air for pressurization is delayed for approximately 20 minutes following the detection of high radiation in the CR intake air. This delay provides protection during the high radiation part of the emergency and provides time for other protective measures to be used, yet still maintains the CR temperature well within guidelines for human habitability and equipment operability.

e) Filtered, recirculated air is provided during all emergency modes to cleanup any contamination which may enter the CR envelope (similar to many current systems). Contaminated air in the CR would be expected to result primarily from delays in the isolation of the CR at the beginning of the emergency and a small amount of unfiltered inleakage.

f) Very little additional equipment from what is currently used, and in some cases less equipment, is required for this type of system, making all associated costs minimal. For example, the requirements for the emergency filtration and adsorption system might be lower, thus lowering the necessary air flow capacity of this system.

g) Many problems cited in this review would be eliminated, such as the suitability of the K factor of eight.

The only real disadvantage of this system is the temperature rise of the CR by about 10°F (or more, depending on the CR type) during the most serious 20 minutes of an emergency.

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NRC FORM 335
(2-84)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1 REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)
NUREG/CR-3786
SAND84-0978

2 TITLE AND SUBTITLE
A Review of Regulatory Requirements Governing
Control Room Habitability Systems

3 LEAVE BLANK

4 DATE REPORT COMPLETED
MONTH: June
YEAR: 1984

5 AUTHOR(S)
Mark J. Jacobus

6 DATE REPORT ISSUED
MONTH: August
YEAR: 1984

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Sandia National Laboratories
Division 6445
PO Box 5800
Albuquerque, NM 87185

8 PROJECT/TASK/WORK UNIT NUMBER

9 FIN OR GRANT NUMBER
A-1377

10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Division of Facility Operations
Office of Nuclear Regulatory Research
US Nuclear Regulatory Commission
Washington, DC 20555

11a TYPE OF REPORT

b PERIOD COVERED (Inclusive dates)

12 SUPPLEMENTARY NOTES

13 ABSTRACT (200 words or less)

This report reviews applicable guides, standards, and codes which govern the design, manufacture, selection, installation, and surveillance practices for components and systems important to control room habitability. It covers the fundamental guidance contained in General Design Criteria, Regulatory Guides, and applicable sections of the Standard Review Plan, as well as numerous documents referenced by this guidance.

Instances are cited where the present guidance is misleading, contradictory, or vague. In some cases, the problems in the guidance result from inadequate technical bases; in other cases, the problems result from several documents which are not completely consistent.

To independently assess the suitability of the regulatory guide which covers accidental chlorine releases, a computer program was developed to calculate chlorine concentrations in the control room following chlorine release. Although problems with the assumptions used to develop the guide were found, the conservative nature of the chlorine calculations appears to adequately compensate for these problems.

14 DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS

b. IDENTIFIERS/OPEN-ENDED TERMS

15 AVAILABILITY STATEMENT
Unlimited

16 SECURITY CLASSIFICATION
(This page)
Unclassified
(This report)
Unclassified

17 NUMBER OF PAGES

18 PRICE

Org.	Bldg.	Name	Rec'd by	Org.	Bldg.	Name	Rec'd by

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US NRC
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