NUREG/CR-6624

Recommendations for Revision of Regulatory Guide 1.78

Pacific Northwest National Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

PDR NUREG 6624 R

DF02

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U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER *(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)*

NUREG/CR-6624

2. TITLE AND SUBTITLE

Recommendations for Revision of Regulatory Guide 1.78

3. DATE REPORT PUBLISHED

MONTH	YEAR
November	1999

4. FIN OR GRANT NUMBER

W6308

5. AUTHOR(S)

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6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

September 1998-September 1999

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Systems Analysis and Regulatory Efectiveness
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

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11. ABSTRACT *(200 words or less)*

To ensure safe operation of commercial nuclear power plants, control room operators must be protected from dangers arising from possible exposure to hazardous chemicals that may be discharged as a result of equipment failure, operator errors, or events external to plant operation. Conditions must exist where accidental exposure to such materials still allows the operators to operate the plant safely. Regulatory Guide 1.78 provides guidance in assessing the control room habitability of the control room during and after a postulated external release of hazardous chemicals from mobile or stationary sources, offsite or onsite. This report provides recommendations for revising the Regulatory Guide 1.78 in two areas, namely, control room ventilation flow modeling and toxicity limit. Additionally, the report provides a value and impact analysis associated with the revision of Regulatory Guide 1.78.

In the area of ventilation flow modeling, the report recommends the use of the HABIT code, in particular, the EXTRAN module of the code. EXTRAN represents an improvement in atmospheric dispersion modeling. In the area of toxicity limits, the report recommends the use of National Institute for Occupational Safety and Health (NIOSH) Immediately Dangerous to Life and Health (IDLH) concentration values. The IDLH values, based on a 30-minute exposure level, is defined as one that is likely to cause death or immediate delayed permanent adverse health effects if no protection is afforded within 30 minutes. Control room operators are expected to use protective measures within 2 minutes after the detection of hazardous chemicals so that they will not be subjected to prolonged exposure at the IDLH concentration levels. Thus, the IDLH limits represent reasonable values to provide adequate margin of safety in protecting control room operators.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Regulatory Guide 1.78, Regulatory Guide 1.95, control room habitability, hazardous chemical release, toxic chemical release, chlorine, toxicity limits, immediately dangerous to life and health (IDLH) odor threshold, control room ventilation flow, air dispersion modeling, Gaussian plume model, meteorology, frequent shipment criterion, transportation accident statistics, value/impact assessment, regulatory efficiency

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page) unclassified

(This Report) unclassified

15. NUMBER OF PAGES

16. PRICE

NUREG/CR-6624

Recommendations for Revision of Regulatory Guide 1.78

Manuscript Completed: October 1999
Date Published: November 1999

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NRC Job Code W6308

Abstract

To ensure safe operation of commercial nuclear power plants, control room operators must be protected from dangers arising from possible exposure to hazardous chemicals that may be discharged as a result of equipment failure, operator errors, or events external to plant operation. Conditions must exist where accidental exposure to such materials still allows the operators to operate the plant safely. Protective emergency limits should be based on levels that will allow operators to function while fresh-air mask and protective clothing are donned (two-minute limit), and for up to eight hours afterward if the toxic material is not eliminated. Regulatory Guide 1.78 provides toxicity limits for 27 example chemicals used in or near reactor control rooms. This document needs to be updated and expanded to include more chemicals. This project was initiated to provide updated 2-minute limits based on the Immediately Dangerous to Life or Health (IDLH) values established by the National Institute for Occupational Safety and Health (NIOSH) as operator response limits in for Regulatory Guide 1.78.

A review of the 1994 revised NIOSH IDLH concentrations was conducted for the purpose of using the IDLH to replace and expand the toxicity limits in NRC Regulatory Guide 1.78. A list of IDLH values was provided for chemicals listed in the 1994 draft of the (NIOSH) documentation for IDLH concentrations. It was concluded that the IDLH values represent reasonable limits to provide adequate time to don protective apparel and will provide an adequate margin of safety for protecting the operators. In general, the revised NIOSH IDLH values are recommended for replacing the chemical toxicity limits in Regulatory Guide 1.78. Where these values were determined to be inadequate, values from other sources were recommended for some chemicals.

A review of more recent transportation accident statistics was conducted to determine if the definitions of frequent shipments in Regulatory Guide 1.78 are still valid. It is recommended that the current definitions of frequent shipments be retained as screening criteria to determine the hazardous chemicals that must be considered in evaluating the habitability of control rooms during postulated hazardous chemical releases. However, a clarification in the Regulatory Guide 1.78 language should be provided to indicate that the criteria refer to total shipments irrespective of the nature of chemicals. The technical basis for this conclusion is described in this report.

A significant amount of research has been conducted that improves the meteorological and ventilation flow models presented in Regulatory Guide 1.78. This research has resulted in development of a modular control room habitability evaluation software package name HABIT. Of most interest to Regulatory Guide 1.78 is a HABIT module called EXTRAN that calculates atmospheric concentrations of radioactive and toxic chemical materials that would result from a release event. EXTRAN represents an improvement in technology relative to the Regulatory Guide 1.78 atmospheric dispersion model as it combines procedures for estimating the amount of airborne material, a Gaussian puff model, and the most recent building wake diffusion coefficient algorithms. Consequently, it is recommended that Regulatory Positions C.5 and C.6 as well as Appendix B of Regulatory Guide 1.78 be revised to incorporate these improvements in meteorological and ventilation flow models.

The values and impacts associated with the revision of Regulatory Guide 1.78 have been addressed in a primarily qualitative manner. Any increase in industry costs associated with the revisions are estimated to be offset by potential for cost savings that could result from a decrease in the requirements for control room habitability systems as a result of revising the toxicity limits. The proposed revision also represents an improvement of knowledge as the revision incorporates updated toxicity limits and a more comprehensive list of hazardous chemicals. An increase in regulatory efficiency is an important attribute for this proposed regulatory action. It is as such noted but not quantified.

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Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienist
AEC	Atomic Energy Commission
AIHA	American Industrial Hygiene Association
CDF	core damage frequency
CHEM	Computer code of toxic chemicals in control room
DOT	Department of Transportation
EEGL	Emergency Exposure Guideline Level
EPA	Environmental Protection Agency
ERPG	Emergency Response Planning Guideline
EXTRAN	Computer codes for estimating concentrations of substances at control room air intakes
FEMA	Federal Emergency Management Agency
FHA	Federal Highway Administration
FRA	Federal Railroad Administration
HABIT	Computer codes for evaluation of control room habitability
IDLH	Immediately dangerous to life or health
LEL	lower explosive limit
m	meter
mg	milligram
NAS	National Academy of Sciences
NIOSH	National Institute of Occupational Safety and Health
NRC	Nuclear Regulatory Commission
NUREG/CR	Nuclear Regulatory Commission Contractor Report
OSHA	Occupational Safety and Health Administration
PEL	permissible exposure level
PNNL	Pacific Northwest National Laboratory
ppm	parts per million
RY	reactor year
REL	recommended exposure limit
SAR	Safety Analysis Report
SCP	Standards Completion Program
SCBA	self-contained breathing apparatus
TLV	threshold limit values
VIA	value-impact assessment

1.0 Introduction

Criterion 4 of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CRF Part 50, "Licensing of Production and Utilization Facilities" requires that "... structures, systems and components important to safety be designed to accommodate the effects of and to be compatible with the environmental conditions associated with operation maintenance, testing and postulated accidents." Criterion 19, "Control Room," requires that a control room be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions, and to either maintain or shut down the reactor safely under accident conditions.

Control room operators could be exposed to high levels of hazardous chemicals that may be discharged as a result of equipment failure, operator errors, or events external to plant operation. Under these circumstances, measures must be in place to allow them to continue to safely operate the plant. It is expected that trained operators could don protective apparel within 2 minutes. Thus, protective emergency limits should be based on levels that will allow operators to function during a 2-minute period while they put on respirators and protective clothing.

Regulatory Guide 1.78, "Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release" AEC, 1974) and Regulatory Guide 1.95, "Protection of Nuclear Plant Operators Against and Accidental Chlorine Release" (NRC, 1977) identified 27 commonly encountered hazardous chemicals including chlorine and set 2-minute exposure concentration limits for these chemicals. The 2-minute limits in the Regulatory Guides are outdated for some hazardous chemicals. In addition, some NRC licensees have requested use of Immediately Dangerous to Life of Health (IDLH) concentrations set by the National Institute of Occupational Safety and Health (NIOSH) for the 2-minute limits.

Much of the guidance in Regulatory Guide 1.78 and Regulatory Guide 1.95 are similar with regard to the requirements of nuclear power plants to operate safely under normal conditions and accident conditions. Combining these two documents in a revised Regulatory Guide 1.78 will likely result in a reduced burden to licensees without compromizing the safety of control room operators.

The purpose of the work described in this report is to provide the technical basis to revise Regulatory Guide 1.78. This includes an update of toxicity limits, clarification of the definition of "frequent shipment", and a revision to atmospheric dispersion modeling. The report addresses the results of the four major tasks of the project as described below.

1) The purpose of the first task (Section 2) was to update the toxicity limits of hazardous chemicals using IDLH values in the NIOSH "Pocket Guide to Chemical Hazards" and to evaluate the appropriateness of IDLH concentrations to replace existing toxicity limits in Regulatory Guide 1.78.

2) The second task (Section 3) re-examined the basis for hazardous chemical shipment frequencies. Specifically, the objective was to examine more recent transportation accident statistics in order to provide a clarification of the term "frequent shipment".

3) The objective of the third task (Section 4) was to provide a technical basis for recommending revisions of the meteorological and control room ventilation flow models for use in revising Regulatory Guide 1.78.

4) Finally, a value/impact assessment (Section 5) was performed to provide technical evaluations of the benefits (values) and costs (impacts) of the proposed revision to Regulatory Guide 1.78.

A summary of recommended revisions to Regulatory Guide 1.78 is provided is Section 6 based on the findings outlined in the task sections.

2.0 Evaluation of NIOSH IDLH Values for Assessing Control Room Habitability

2.1 Background

To ensure safe operation of commercial nuclear power plants, control room personnel (operators) must be protected from dangers arising from possible exposure to hazardous chemicals. It is imperative that exposures be less than those that would prevent them from safely operating the plant. It is expected that trained operators could put on protective apparel within 2 minutes. Thus, protective emergency limits should be based on exposure levels that will allow operators to function during a 2-minute period while respirators and protective clothing are donned.

In Regulatory Guide 1.78 and Regulatory Guide 1.95, 27 hazardous chemicals were identified and 2-minute exposure concentration limits set for control rooms. Also, NUREG/CR-5669 provided 2-minute limits for five hazardous materials of special interest. The 2-minute limits in the Regulatory Guides are outdated for some hazardous chemicals. In addition, some Nuclear Regulatory Commission (NRC) licensees have requested use of the Immediately Dangerous to Life or Health (IDLH) concentrations established by the National Institute of Occupational Safety and Health (NIOSH) for the 2-minute limit.

One objective of this task is to evaluate the revised NIOSH IDLH concentrations (Ludwig et al., 1994) for the purpose of using the IDLH to replace the toxicity limits in Regulatory Guide 1.78 (AEC, 1974). Another objective is to provide an updated list of toxicity limits of chemicals listed in NIOSH's "Documentation for Immediately Dangerous to Life or Health Concentrations (IDLH)" (Ludwig et al., 1994) and published in NIOSH's *Pocket Guide to Chemical Hazards* (NIOSH, 1997) for revising the current Regulatory Guide 1.78 (AEC, 1974).

IDLH values, published regularly since 1981 by NIOSH in the updated versions "*Pocket Guide to Chemical Hazards*," (NIOSH, 1997) were originally determined for the purpose of respirator selection criteria as part of Standards Completion Program (SCP). This became the original basis for the NIOSH/Occupational Safety and Health Administration (OSHA) Occupational Health Guidelines for Chemical Hazards (NIOSH/OSHA 1981). The IDLH values were based on effects that might result from a 30-minute exposure, although this was not to imply that the worker should remain in an adverse work environment any longer than necessary. NIOSH originally defined IDLH concentrations as "... the maximum concentration from which, in the event of respirator failure, one could escape within 30 minutes without a respirator and without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects" (NIOSH, 1997). The SCP IDLH concentrations were developed in the mid-1970s and first published by NIOSH in 1981.

There were several limitations to these values as originally developed. The IDLH values were developed from reviews of secondary literature without review of the original reports, documentation was not published for the individual IDLH values selected, and peer reviews of the work were never performed. The adequacy of SCP IDLH to protect the worker from acute exposure to some toxic compounds was seriously questioned (Alexeeff, et al., 1989). Because of these limitations and criticisms, NIOSH revised the SCP IDLH values and published them in the recent editions of the NIOSH *Pocket Guide to Chemical Hazards* (NIOSH, 1997). In addition, NIOSH published the documentation for the development of original SCP IDLH and the revised IDLH values (Ludwig et al., 1994).

2.2 Current NIOSH Use of IDLH Standards

Current NIOSH definition for an IDLH is any condition "... that poses a threat of exposure to airborne contaminations when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment" (Ludwig et al., 1994; NIOSH, 1997). The purpose for an IDLH is to ensure that a worker can escape from a given contaminated environment in the event of failure of the respiratory protection equipment. For entry into IDLH atmospheres, it is the intention of NIOSH that a self-contained breathing apparatus equipped with full face piece and operated in a pressure-demand or other positive-pressure mode would be selected.

IDLH values influence the selection of respirators for non-emergency controlled conditions, when the occupational exposure limit is close to the IDLH. Under these conditions, selection of respiratory protection with lower levels of protection may be used, especially if monitoring data is available. However, respiratory protection that gives the highest level of protection must be used when the IDLH value is reached or exceeded. Respiratory protection which offers the highest level of protection is a full face piece with a positive pressure or pressure demand self-contained breathing apparatus (SCBA) or a supplied-air respirator with a full face piece operated either in a pressure demand or other pressure mode in combination with an auxiliary SCBA.

NIOSH is currently evaluating more recent toxicological data for use in future IDLH recommendations. Thus the currently revised IDLH values could undergo further revision as this evaluation is completed.

2.3 NIOSH Documentation Process

Revised NIOSH IDLH documentation (Ludwig et al., 1994) used to support the revised IDLH values were evaluated for their appropriateness to replace and add to those in the current Regulatory Guide 1.78 for the 2-minute time required to don protective breathing apparatus in reactor control rooms.

The NIOSH documentation for IDLH represents a compilation of the sources of information and the rationale for IDLH used by NIOSH in the original Standards Completion Program (SCP) in the early 1970s. This document also includes a review and revision of the original SCP IDLH for each chemical evaluated. Although the documentation for the IDLH is now published and the IDLH values have been revised, in many cases little change was made to the original SCP documentation on which the revised values were based. In order to evaluate the applicability of the revised values for the needs of the NRC, it is necessary to understand the purpose for which the IDLH were developed and the process and the criteria used by NIOSH to derive the revised IDLH.

IDLH were originally established and are still intended by NIOSH to be used as one of several selection criteria in the NIOSH Respirator Decision Logic for the selection of respiratory protection equipment. The purpose of IDLH as stated by NIOSH is ". . . to ensure that workers can escape from a contaminated environment should respiratory protection equipment fail." At the onset, this definition more closely meets the NRC's intended use better than criteria used in the development of other exposure limits such as threshold limit values (TLV), permissible exposure level (PEL), Emergency Response Planning Guidelines (ERPG), Emergency Exposure Guideline Level (EEGL), etc.

The toxicity criteria for determining the revised IDLH used the original SCP IDLH and applied newer methodology outlined by NIOSH. This approach followed a hierarchy such that acute human data, if available, were considered first, followed by acute animal inhalation data, then finally acute animal oral toxicity data. When acute data were lacking, chronic data, although not directly applicable to emergency exposures, were used. In some cases, the IDLH concentrations were based on surrogate chemicals. Secondary references were the primary source of the toxicological data. After a revised IDLH value was developed, the value was compared to other existing guidelines or exposure limits for consensus. Other criteria were that the revised IDLH could not be set greater than 2000 times the NIOSH Recommended Exposure Limit (REL) or OSHA PEL, and they not be greater than the original SCP IDLH. Finally, making this documentation available to the scientific community gives more validity to the IDLH values.

Some of the same criticisms pertain to the process for establishing the revised IDLH values as for the original SCP process. The actual documentation supporting the revised IDLH was performed with less rigor than, for example, the documentation required for developing other short-term exposure guidelines, such as the American Industrial Hygiene Association's (AIHA). NIOSH relied heavily on secondary references rather than including primary references. The number of supporting documents for many of the NIOSH IDLH is typically small and typically fairly old, indicating that a recent, exhaustive literature search may not have been performed in all cases.

Not all IDLH values were derived directly from the toxicological data, as NIOSH developed a "preliminary" IDLH and then, in some cases, applied a safety factor of at least 10 to derive the revised IDLH. Thus NIOSH used criteria other than toxicity to derive a portion of the IDLH. As an example, NIOSH a-priori made the decision to limit the revised IDLH for flammable gases to no greater than 10 percent of the lower explosive limit (LEL), typically a percentage concentration in air.

One of the factors potentially used to modify the preliminary IDLH was an indicator of severe respiratory irritation. While this may be an important factor for escape, it may result in a revised IDLH not representative of a life threatening situation.

The revised IDLH are typically much more conservative than the original SCP IDLH. This conservatism was obviously intentional on NIOSH's part and is the result of several factors: 1) the lack of acute toxicity data in humans, 2) the use of safety factors (typically a factor of 10), 3) the use of criteria other than toxicity (such as data from surrogate chemicals), and 4) a more conservative interpretation of the toxicity data. In particular, the revised IDLH for the flammable liquids and gases are dramatically lower than those values for the SCP IDLH. The industrial standard for restricted entry into an "explosive" atmosphere was, for decades, 25 percent of the LEL. Because of a new OSHA regulation, the revised NIOSH IDLH are set at 10 percent of the LEL (typically thousands of ppm in air) (Ludwig et al., 1994; NIOSH, 1997).

Despite the conservatism of the revised IDLH, most of the values are many times greater than typical occupational exposure limits or other short-term exposure guidelines. In addition, the revised IDLH are still intended to represent a hazardous atmosphere from which escape is possible within 30 minutes. Consequently, they represent reasonable limits to use for providing adequate time to don protective apparel because they will provide conservative protection yet ample flexibility. Given that a control room operator is expected to don a respirator within 2 minutes, the revised IDLH are conservative for the NRC's needs. This is particularly the case for the flammable gases and liquids, for which the IDLH values are set at 10% of the explosive concentration, far below their expected life-threatening toxicity level. Finally, using the IDLH values as a response criteria for donning respirators by reactor control room personnel will meet the intent of the original IDLH and will provide an adequate margin of safety for protecting the operators while providing greater flexibility. A list of the revised LDLH values are presented in Appendix A.

The relationship between the current NRC toxicity limits (Reg. Guide 1.98) and the NIOSH IDLH's is difficult to access. The toxicity limits were adapted from SAX (1968), a secondary reference, but documentation describing the process used to establish these values are not available. It appears, however, that primary references were not used. Many values are whole number multiples of the PEL (2, 4, 5, times the PEL for example). These 2-minute limits are also obviously outdated. The toxicity limits are based on a 2-minute exposure, whereas the IDLH values are based on a 30-minute exposure. Another difference is that the toxicity limits were defined in terms of time required to don respirators in an emergency, whereas the IDLH's were defined in terms of time required to exit a contaminated area in the event of a respirator failure. This 30-minute limit does not give license, however, to remain in an adverse work environment any longer than necessary to escape.

2.4 Other Existing Emergency Exposure Guidelines and Standards

A number of occupational emergency exposure guidelines and standards have been developed by government agencies and private associations to address health and safety issues in and outside the workplace. Some, such as the TLV (developed by the American Conference of Governmental Industrial Hygienist [ACGIH]), the Workplace Environmental Exposure Levels (developed by AIHA), the PEL (developed by OSHA), and the REL (developed by the NIOSH) are inappropriate for emergency response. These values were developed for the protection of workers and are based on repeated daily exposures in the workplace over a lifetime. These guidelines provide administrative protection against acute and chronic health effects usually over an 8-hour workday. PEL's or REL's have not been established for known human carcinogens and OSHA and NIOSH recommend that engineering controls such as respirators provide protection in the workplace for these chemicals.

Several guidelines have been developed for use in emergency situations involving a single exposure to substances in occupational or community environments. The National Research Council has established emergency guidelines for approximately 40 chemicals for the military (NAS, 1983-88). More recently, AIHA introduced the concept of ERPG for potential releases of chemicals in the community (AIHA, 1988-93) These guidelines are useful primarily for emergency planning and response. ERPG-3 is the worst-case guideline and is defined as "... the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects." ERPG-2 is set at a level where irreversible or serious health effects would not be expected from a 1-hour exposure and ERPG-1 identifies a concentration that does not pose a health risk to members of the community.

Compared to the IDLH, the ERPG were developed with more vigor in terms of documentation, peer review and use of current primary references. They were also derived directly from the toxicological data without the explicit use of safety factors. Unfortunately, ERPG have been established for only a few chemicals. These guidelines were established to provide a level of safety for a period of 1 hour for emergency situations where the use of protective equipment would not be anticipated. Table 2.1 compares ERPG-3 values with the revised IDLH concentrations and

Regulatory Guide toxicity limits in those cases where ERPG levels have been established. This comparison demonstrates the conservativeness of the IDLH concentrations for these compounds and suggests that they would provide ample protection if used as toxicity limits in the revised Regulatory Guide.

2.5 Odor Thresholds

The detection of chemicals by smell is a significant warning for people to protect themselves from chemical contaminants. The ability of the general population to detect specific chemical odors is influenced by the wide variability of different persons' olfactory capability, to some degree their previous experience with the chemical, and their degree of awareness or consciousness of their surroundings at the time (Amoore and Hautala, 1983.) Odor thresholds have been established for chemicals having experimental data that meets the evaluation criteria developed by AIHA and for which occupational health standards have been established (AIHA, 1989). In general, the lower the odor threshold compared to the IDLH, the greater the likelihood of the chemical being detected before an IDLH level is reached. Comparing AIHA odor threshold levels and NIOSH IDLH values (for the over 90 chemicals for which both are established) shows in all cases, except for acetonitrile, carbon tetrachloride and 1,1,2-trichloroethane, that the IDLH values are greater than the odor threshold levels (Appendix B). This means that in most cases a person would be warned of adverse atmospheres by smell before the IDLH concentration was reached. However, several chemicals not listed by AIHA for a number of reasons, including a lack of data, are not readily detected by odor. Examples include carbon dioxide, carbon monoxide, chlorine dioxide, formic acid, methycyclohexanol, and propane.

Odor thresholds have limited use for triggering the donning of respirators for the intended use of Regulatory Guide 1.78. Odor thresholds are not highly correlated with toxicity of chemicals, vary widely by different individuals for the same chemical and do not always lend themselves to chemical identification. In addition individuals vary in their sensitivity to different odorants. AIHA states that caution should be taken in relying on the use of odor alone as a warning of potentially hazardous exposures. However, respirators may provide relief from odor and irritation to the nose and eyes when exposure data are lacking.

2.6 Discussion and Recommendations

The revised IDLH concentrations are recommended for use in the updated Regulatory Guide 1.78. The IDLH values were developed for respirator selection for a large number of chemicals, whereas other exposure guidelines have been developed for occupational or public emergency purposes without regard to respirators. In addition, other standards are developed for only a limited number of chemicals. The revised IDLH values are generally conservative enough to provide an adequate margin of safety. There may be a few specific cases where a value other than the IDLH would be more appropriate, but overall the IDLH is the most appropriate guideline for this purpose. The revised IDLH values are listed in Appendix A. Several special cases are also considered below.

It is recommended, however, that respirator donning time of 2 minutes be retained. The 30-minute escape time for the IDLH concentrations are maximium times and it is intended that every effort be made to exit immediately. A 2-minute limit would provide an extra margin of safety in the use of IDLHs in the updated Regulatory Guide 1.78. IDLH values should be used in the context of a trigger point for the donning of respirators for control room operators. These levels should in no way be used to imply an upper limit of safety to replace occupational standards set by OSHA.

Four of the revised IDLH are lower than the corresponding limits in the current Regulatory Guide 1.78 (Table 1): Chlorine, ethyl chloride (based on 10% LEL), ethylene dichloride (based on one human study), and hydrogen sulfide (based on a person's ability to become desensitized to chemical odor or "olfactory fatigue" at 100 ppm). In addition, there is no IDLH set for vinyl chloride (also in Regulatory 1.78) because NIOSH considers this compound a known human carcinogen and has not established a REL. NIOSH recommends that respirators be worn at any detectable concentration when there is no REL and therefore has not established an IDLH.

An evaluation of exposure limits for ammonia, chlorine, Halon, and sulfur dioxide for nuclear reactor control room habitability was recently performed and published as NUREG/CR-5669 (Malhum and Sasser, 1991). This evaluation specifically addressed the limits for Regulatory Guide 1.78, and rationale and documentation were developed to support the recommendations. The exposure limits recommended in NUREG/CR-5669 for ammonia

Table 2.1. Comparison of ERPGs with IDLHs and Regulatory Guide 1.78 Toxicity Limits for Selected Chemicals

Chemical	Regulatory Guide 1.78	ERPG-3	IDLH
Acetaldehyde	200 ppm	-	2000 ppm
Acetone	2000 ppm	-	2500 ppm
Acrolein	-	3 ppm	2 ppm
Acrylonitrile	40 ppm	-	85 ppm
Allyl chloride	-	300 ppm	250 ppm
Ammonia	100 (300)* ppm	1000 ppm	300 ppm
Aniline	10 ppm	-	100 ppm
Benzene	50 ppm	-	500 ppm
Benzyl chloride	-	25 ppm	10 ppm
Bromine	-	5 ppm	3 ppm
1,3-Butadiene	1000 ppm	5000 ppm	2000 ppm
Carbon dioxide	10000 ppm	-	40000 ppm
Carbon disulfide		5000 ppm	500 ppm
Carbon monoxide	1000 ppm	-	1200 ppm
Carbon tetrachloride	-	750 ppm	200 ppm
Chlorine	15 (30)* ppm	20 ppm	10 ppm
Chlorine trifloride	-	10 ppm	20 ppm
Chloropicrin	0.2 ppm	3 ppm	2 ppm
Crotonaldehyde	10 ppm	10 ppm	50 ppm
Dimethylamine	100 ppm	500 ppm	500 ppm
Epichlorohydrin	20 ppm	100 ppm	75 ppm
Ethyl chloride	10000 ppm	-	3800 ppm
Ethyl ether	800 ppm	-	1900 ppm
Ethylene dichloride	100 ppm	-	50 ppm
Ethylene oxide	200 ppm	500 ppm	800 ppm
Fluorine	2 ppm	-	25 ppm
Formaldehyde	10 ppm	25 ppm	20 ppm
Hydrogen chloride	-	100 ppm	50 ppm
Hydrogen cyanide	20 ppm	25 ppm	50 ppm
Hydrogen fluoride	-	50 ppm	30 ppm
Hydrogen sulfide	500 ppm	100 ppm	100 ppm
Methyl alcohol	400 ppm	5000 ppm	6000 ppm
Methyl iodide	-	125 ppm	100 ppm
Methyl mercaptan	-	100 ppm	150 ppm
Phenol	-	200 ppm	250 ppm
Phosgene	-	1 ppm	2 ppm
Sodium oxide	2 mg/m^3	-	-
Sulfur dioxide	5 ppm	15 ppm	100 ppm
Sulfuric acid	2 mg/m^3	30 mg/m^3	15 mg/m^3
Vinyl chloride	1000 ppm	-	-
Xylene	400 ppm	-	900 ppm

* NUREG/CR-5669 recommended limit in parenthesis

and sulfur dioxide are the same as the revised IDLH concentrations. The chlorine and Halon 1301 values differ between the two evaluations. The revised IDLH for chlorine is 10 ppm compared to the NUREG/CR-5669 exposure limit of 30 ppm. For Halon 1301 the IDLH is 4% whereas the NUREG/CR-5669 exposure limit is 5%. We recommend using the NUREG/CR-5669 limit for chlorine and Halon 1301, since the NUREG/CR-5669 supporting documentation is based on recent peer-review documentation (Malhum and Sasser, 1991) performed for the NRC. However, for consistency, the IDLH values could be used for these two chemicals as they are more-conservative than the NUREG/CR-5669 values. IDLH concentration is not listed for Halon 1211, therefore it is recommended that the value recommended in NUREG/CR-5669 be retained.

A recommended toxicity limit was not established for 15 carcinogens (12 listed in Appendix B of NIOSH pocket guide) because the IDLH have never been developed by NIOSH. Instead of setting exposure limits (PEL, REL, IDLH, etc.), government agencies require the use of engineering controls, work practices, and personal protective equipment to provide protection against these chemicals. No other existing standard is available which would be appropriate to use as toxicity limits for Regulatory Guide 1.78.

IDLH are not available for three additional chemicals (octachloronaphthalene, pentachloro- naphthalene, and trichloronaphthalene) listed in NIOSH documentation (AEC, 1974) because sufficient acute toxicity data or appropriate data for surrogate chemicals were not available. In view of this absence of data, no attempt was made to develop toxicity limits for these chemicals.

The alternative to using the revised IDLH for providing respiratory donning trigger levels would be to develop more toxicologically based limits using a more rigorous process . This would be a very time-consuming, resource-intensive process given the large number of revised IDLH and is not recommended.

2.7 Conclusions

The NIOSH "Documentation for Immediately Dangerous to Life or Health Concentrations," was evaluated in order to provide a basis for a recommendation that the revised NIOSH IDLH replace the chemical limits in the Regulatory Guide 1.78, "Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release," as control room habitability limits. A discussion of the NIOSH document and conclusions and recommendation are included. In general, the revised IDLH values are recommended for replacing the toxicity limits in Regulatory Guide 1.78. The IDLH concentrations are conservative and should provide ample protection if used as toxicity limits in the revised Regulatory Guide.

3.0 Evaluation of Frequent Shipment Screening Criteria

3.1 Introduction and Summary

The objective of this section is to re-examine the basis for hazardous chemical shipment frequencies referenced in Regulatory Guide 1.78, *Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release* (AEC 1974). Specifically, the objective is to examine transportation accident statistics referenced in Regulatory Guide 1.78 to determine if the definitions of "frequent shipments" are still valid. Based on the guidance in Regulatory Guide 1.78, licensees perform a two-level screening analysis to identify postulated transportation accidents that could affect control room habitability. The first screen eliminates hazardous chemicals that are not shipped within 5 mi. of the control room. The second screening is performed based on shipment frequency. If there are shipments passing within 5 mi. of the control room but they are not frequent, as defined in the Regulatory Guide, no calculations are necessary. The definitions of frequent shipments given in the Regulatory Guide were derived using the truck, rail, and barge accident statistics presented in WASH-1238 (AEC 1972). This section examines the definitions of frequent shipments in light of more recent transportation accident rate data and provides clarification of the definitions.

Reviews were conducted of accident rate data in WASH-1238 (AEC 1972) and several recent studies to determine if an update of Regulatory Guide 1.78 would be recommended. In summary, it is recommended that the current definitions of frequent shipments be retained as screening criteria to determine the hazardous chemicals that must be considered in evaluating the habitability of control rooms during postulated hazardous chemical releases. However, a clarification in the Regulatory Guide language will be provided to indicate that the criteria refer to total shipments irrespective of the nature of chemicals. The technical basis for this conclusion is described in the following sections.

3.2 Review of Transportation Accident Data

A review of readily-available transportation accident data was conducted, the results of which are summarized in the following sections. The accident rates and conditional spill probabilities identified during the review are presented in Table 3.1. Note that some of the reports reviewed here addressed accident rates and conditional probabilities of accidents involving radioactive materials. A few reports are described that address hazardous chemical transportation accidents. It was necessary to make assumptions to apply the accident data on radioactive material shipments to hazardous chemical shipments. These assumptions are specified where necessary in the following sections.

3.2.1 WASH-1238

Accident Rates

The WASH-1238 (AEC 1972) accident rates for truck travel were taken from 1969 accident statistics published by the Federal Highway Administration (FHA). The truck accident rates were based on accidents defined as "reportable" by the FHA. This included accidents that resulted in fatalities, injuries, and property damage in excess of $250. The data for truck accidents involved "for-hire" carriers only and were indicated to include only "large motor carriers." For hazardous materials, the accident rate was 1.69 accidents per million vehicle miles.

Federal Railroad Administration (FRA) accident statistics were used to calculate rail accident rates. For the FRA, reportable accidents were defined as those involving fatalities, injuries, and property damage in excess of $750. The rail accident rates were determined by dividing the total number of reportable rail accidents by the total number of train-miles traveled in 1969. This was converted to the rate per railcar-mile by dividing the rate per train-mile by an average of 70 cars per train. The result was an overall accident rate of 0.14 accidents per million car miles. Of this overall accident rate, the rate for other than grade-crossing accidents was about 0.08 accidents per million car miles. Since an average of 10 cars are involved in each non-grade-crossing accident, the overall accident rate for other than grade-crossing accidents was estimated to be 0.8 accidents per million car miles.

Table 3.1. Summary of Transportation Accident Statistics

	WASH-1238	NUREG-0170	SLA-74-0001	NUREG/CR-4829	PNL Risk Studies	Handbook
Accident Rate (accidents/mi.)						
Truck	1.69E-06	1.69E-06	2.5E-06	6.4E-06	2.5E-06	2E-06
Rail[a]	8.0E-07	1.5E-06	1.5E-06	1.7E-06	1.4E-06	6E-07
Barge	1.8E-06	9.8E-06	Not given	Not given	Not given	1.5E-06[b]
Conditional Spill Probability						
Truck	0.18	0.09	0.023	0.0383	0.012 – 0.025	0.08
Rail	0.10	0.2	0.10	0.0537	0.008 – 0.067	0.075
Barge	0.025	0.023	Not given	Not given	Not given	0.03 – 0.1

(a) Accidents per railcar-mi

(b) Rate for collisions and groundings on lakes, rivers, and intercoastal waterways

Barge accident rates given in WASH-1238 were based on statistics compiled by the U.S. Coast Guard for the year 1970. The accident rate given was 1.8 accidents per million barge-miles. They appear to represent collision and grounding incidents on inland waterways.

Conditional Release Probabilities

The accident rates given above include all severities of accidents, ranging from minor collisions that do not threaten the integrity of the cargo container to extreme accidents that demolish the vehicle and release all of its contents. Of interest to Regulatory Guide 1.78 are accidents that result in a substantial release of contents that could threaten the plant operators and safe shutdown of the plant. WASH-1238 divided the accidents into five severity categories, including minor, moderate, severe, extra severe, and extreme. Conditional probabilities of each severity category were developed based on previous studies and analyses of the accident data to characterize the potential effects of impact, puncture, and fire conditions produced in the accidents.

In WASH-1238, the frequencies of encountering the five severity categories were given for truck, rail, and barge accidents. The study also gave the general accident rates for these three transportation modes. Therefore, the conditional probabilities of the five severity categories can be calculated by dividing the severity category frequencies by the general accident rate. Of interest here are the severity categories that could result in a significant release. For conservatism, this is assumed to be all severity categories except minor accidents. Following the calculation procedure given above, the conditional probabilities of significant releases were calculated as follows:

- Truck: 0.18 (18% of truck accidents involve conditions defined as moderate, severe, extra severe, and extreme that could potentially result in a significant release of cargo).
- Rail: 0.10
- Barge: 0.025

3.2.2 NUREG-0170

This report provides accident rates and conditional probabilities of the severities of truck and rail accidents involving radioactive materials.

Accident Rates

The overall accident rate for motor carriers transporting radioactive materials used in NUREG-0170 was 1.06E-06 accidents/km (1.71E-06 accidents/mi), nearly the same as the truck accident rate given in WASH-1238. The rail accident rate was given as 9.3E-07 railcar accidents per railcar-km (1.5E-06 railcar accidents per railcar-mi). For barge accidents, the rate given was 6.06E-06 accidents/km (9.8E-06 accidents/mi).

Conditional Release Probabilities

In NUREG-0170, eight categories were established and associated conditional probabilities were developed to characterize the severities of accidents. It is assumed here that the severity categories I and II represent minor accidents that would not threaten the integrity of a hazardous material shipping container and thus would not result in a significant release of cargo. If these two severity categories are excluded, the conditional probabilities of significant releases, given an accident occurs, are as follows:

- Truck: 0.09
- Rail: 0.20
- Barge: 0.023

3.2.3 SLA-74-0001

This document (Clarke et al. 1976) was prepared in the late 1970s to describe the severities and conditional probabilities of air, highway, and rail accidents involving small Type B packages transporting radioactive materials.[1] Analytical models were developed and statistical analyses were performed to describe potential accident environments that a package may be subjected to during an accident and the probabilities of encountering these environments.

Accident Rates

The accident rates given in the report are as follows:

- Truck: 2.5E-06 accidents/mi.
- Rail: 1.5E-06 accidents per car mile.

Conditional Release Probabilities

The probabilities of exceeding five severity categories, including minor, moderate, severe, extra severe, and extreme accident environments, were given in SLA-74-0001. For this study, it was assumed that minor accidents would not result in a significant release of a hazardous cargo. The conditional probabilities of the other four categories were summed to develop the conditional release probabilities given below:

- Truck: 0.023
- Rail: 0.10

3.2.4 NUREG/CR-4829

This report (Fischer et al. 1987) was prepared to evaluate the responses of commercial spent nuclear fuel shipping casks to severe truck and rail accidents and assess the level of safety to the public during the shipment of this material. Water transport was not addressed.

Accident Rates

The "Modal Study" (NUREG/CR-4829; Fischer et al. 1987) used accident rates developed from data published by the American Petroleum Institute (API) for heavy trucks (tractor/semi-trailers). Fischer et al. (1987) also reviewed FHA data for the years 1973 to 1981. This represents an improvement over the WASH-1238 truck accident data because it incorporates the imposition of the national speed limit in 1973 and also included accident and mileage data for private carriers (i.e., companies transporting their own goods in their own, or leased, vehicles). However,

[1] Type B packages must be designed to withstand impact, puncture, fire, and immersion accident conditions. See 10 CFR 71 for complete definition of Type B packaging standards.

because the API data was for vehicles most closely-resembling the size, weight, and operating characteristics of trucks that would be transporting spent fuel (the focus of the study), Fischer et al. (1987) opted to use the API data. The accident rate developed by Fischer et al. (1987) from the API data was 6.4E-06/mile.

The rail data in Fischer et al. (1987) were taken from FRA accident statistics compiled for the years 1975 to 1982. Reporting thresholds (dollar damage) were increased by the FRA to account for inflation beginning in 1975. Fischer et al. (1987) differed from WASH-1238 in that it did not convert the rates to a per-railcar-mile basis but rather left them as per train-mile. This assumption overstates the accident rate by implying that, if an accident occurs, it will involve the railcar of interest (in this case it would involve a spent fuel shipping container). It does not account for the many train accidents that do not result in damage to all of the cars on the train. The accident rate developed by Fischer et al. (1987) was 1.7E-06/rail-car-mile after conversion assuming an average of 70 cars per train and 10 cars are involved in each accident.

Conditional Release Probabilities

One of the focuses of Fischer et al. (1987) was to develop conditional probabilities of a range of accident severities for truck and rail transport of commercial spent nuclear fuel. To do so, the analysts reviewed accident reports, police reports, etc., and developed analytical models of package response to a range of accident conditions suggested in the reports. They then performed detailed statistical analyses to characterize the probabilities of encountering this range of accident environments. Based on event trees developed by Fischer et al. (1987) and the event outcomes that were labeled as "significant" events, the following conditional probabilities of significant releases were calculated:

- Truck: 0.0383
- Rail: 0.0537

These probabilities are based on qualitative descriptions given by Fischer et al. (1987). More complete descriptions of the outcomes of the "significant" events are needed to accurately characterize the conditional release probabilities. However, they appear to line up relatively well with the probabilities taken from other studies.

3.2.5 PNL Risk Studies

In the late 1970s and early 1980s, the Pacific Northwest Laboratory (PNL) developed risk models and quantified the risks of transporting various hazardous cargoes, including propane (Geffen et al. 1980), gasoline (Rhoads et al. 1978), chlorine (Andrews et al. 1980), and several radioactive materials. The analyses included development of failure thresholds for the shipping containers and assessments of the probabilities of encountering accident conditions that exceeded these thresholds. The accident rates and conditional probabilities given in the PNL studies of the hazardous chemical cargoes are given below.

Accident Rates

The overall accident rates given in the PNL studies were not cargo-dependent. Therefore, the same accident rates were used in all three hazardous chemical transportation risk assessments. These are:

- Truck: 2.5E-06 accidents/mi
- Rail: 1.4E-06 accidents/railcar-mi

The actual rail accident rate used in these assessments was 6.2E-06 train accidents/train-km. Assuming there are, on average, 70 cars per train and that 10 railcars are involved in each accident, as was done in NUREG-0170 and other studies, the rail accident rate shown above was calculated.

Conditional Release Probabilities

The conditional probabilities of "significant" or "substantial" releases given in the PNL risk studies were assumed to be representative of the probabilities of accidental releases that could affect control room habitability. The calculations leading to the conditional probabilities of substantial or significant releases are presented below:

- Rail transport of chlorine: Predicted 1.8 substantial release accidents/yr and 150 total accidents/yr. Conditional probability = 1.8/150 = 0.012.
- Truck transport of propane: Predicted 14 significant release accidents/yr and 570 total accidents/yr. Conditional probability = 14/570 = 0.025.
- Rail transport of propane: Predicted 0.5 significant release accidents/yr (1 every 2 yrs) and 60 total accidents/yr. Conditional probability = 0.5/60 = 0.0083.
- Truck transport of gasoline: Predicted one in 15 accidents will involve a significant release. Conditional probability = 1/15 = 0.067.

Note that the cargo-dependent conditional probabilities arise from the different types of cargo containers that are used to transport the three types of hazardous chemicals. In addition, the conditional probabilities are dependent on the cargo's response to mechanical and thermal accident environments.

3.2.6 FEMA/DOT/EPA Handbook

A Handbook has been developed by the Federal Emergency Management Agency (FEMA), U.S. Department of Transportation (DOT), and U.S. Environmental Protection Agency (EPA), that provides methods for evaluating the frequencies and consequences of potential releases of hazardous materials from fixed facilities and transportation systems. The transportation accident rate data and conditional spill probabilities from that document are summarized in this section.

Accident Rates

For the truck accident rates, FEMA/DOT/EPA (1988) reviewed a number of publications and recommended that rates be used that were derived from FHA data for trucks carrying bulk quantities of hazardous materials. The Handbook gave suggested accident rates for truck shipments but also indicated that local data, if available, would be more representative of the actual transport conditions of interest.

The FEMA/DOT/EPA Handbook used FRA data as the basis for their rail accident rates. One advantage of the Handbook-derived rail accident rates is that it converts the overall accident rate (per train-mile) to the accident rate per railcar-mile by multiplying the overall rate by a 20% factor that accounts for the average fraction of railcars in a train that are damaged in an accident. This more accurately accounts for multiple-railcar accidents and would be more representative of the hazards to control room personnel from railcar accidents. Furthermore, the accident rates in the Handbook were derived from more recent statistics than both Fischer et al. (1987) and AEC (1972) and would therefore reflect the effects of improved truck and rail safety equipment, braking systems, computerized switching, and other safety improvements.

The barge accident rate suggested in the Handbook was derived from reviewing a number of sources but were predominantly based on U.S. Coast Guard data. Reports from as recent as 1983 were referenced. Therefore, the Handbook represents more recent, and probably more representative, accident data than WASH-1238. The Handbook data is more inclusive than the WASH-1238 data as it includes collisions, groundings, and ramming incidents. This is different than WASH-1238 which included only the time when the barges were moving, thus excluding accidents while the vessels were moored or docked and may also exclude collisions and groundings that occur in harbors and bays.

Conditional Release Probabilities

The Handbook gives conditional release probabilities for truck, rail, and marine vessel accidents and spill size distributions for pipeline accidents. The conditional probabilities for truck, rail, and barge accidents were derived from reviews of accident data and other sources. The results are summarized below:

- Truck:

Conditional spill probability	0.2
Spill size distribution -	0.6 for 10% loss of cargo 0.2 for 30% of cargo 0.2 for 100% of cargo

  Assuming that spills that amount to less than 10% of the cargo would not represent a significant hazard to control room operators, the conditional probability of spill large enough to threaten safe shutdown of a nuclear power plant is 0.2 x 0.4 = 0.08.

- Rail:

Conditional spill probability	0.15
Spill size distribution -	0.5 for 10% loss of cargo 0.2 for 30% of cargo 0.3 for 100% of cargo

  Assuming that spills that amount to less than 10% of the cargo would not represent a significant hazard to control room operators, the conditional probability of spill large enough to threaten safe shutdown of a nuclear power plant is 0.15 x 0.5 = 0.075.

- Marine:

Conditional spill probability	0.15 if using one rate regardless of vessel 0.05 for double-hulled/double-bottomed vessels
Spill size distribution	0.35 for 10% loss of 1 tank or compartment 0.35 for 30% loss 0.30 for 100% loss

Again assuming that spills that amount to less than 10% of a tank or compartment pose no significant threat to nuclear plant control room operators, the conditional probability of an accident large enough to threaten safe shutdown of a nuclear power plant is 0.15 x 0.65 = 0.098 (round to 0.1) if using one rate regardless of the vessel type or 0.05 x 0.65 = 0.03 for double-hulled/double-bottomed vessels.

3.2.7 Department of Transportation - Bureau of Transportation Statistics

Two reports from the Department of Transportation - Bureau of Transportation Statistics (DOT-BTS) were reviewed to identify trends in accident rates that could affect the conclusions of this study. The BTS annually prepares a report to the U.S. Congress on the state of the U.S. transportation system, including transportation accident, fatality, injury, and property damage statistics. This report is *Transportation Statistics Annual Report, 1998* (DOT 1998a). The basis for the statistical data presented in this report are contained *in National Transportation Statistics, 1998* (DOT 1998b).

The data presented in these two documents is not directly comparable to the accident rate data presented in Table 3.1. This is because the data in Table 3.1 focus on heavy combination truck accident statistics whereas the DOT statistics referred to above include all motor vehicles (including passenger cars, delivery vans, motorcycles, etc. in addition to large trucks). However, it may be used to illustrate trends in accident rates that could affect the conclusions regarding the accident rate data presented in WASH-1238. Highway accident rates given in DOT (1998b) are plotted as a function of time in Figure 3.1. Figure 3.2 presents a similar illustration for rail accident rates. It can be seen that both motor vehicle and rail accident rates are generally declining over time. However, the downward trend in motor vehicle accident rates shown in Figure 3.1 is illustrative of a general downward trend in truck accident rates.

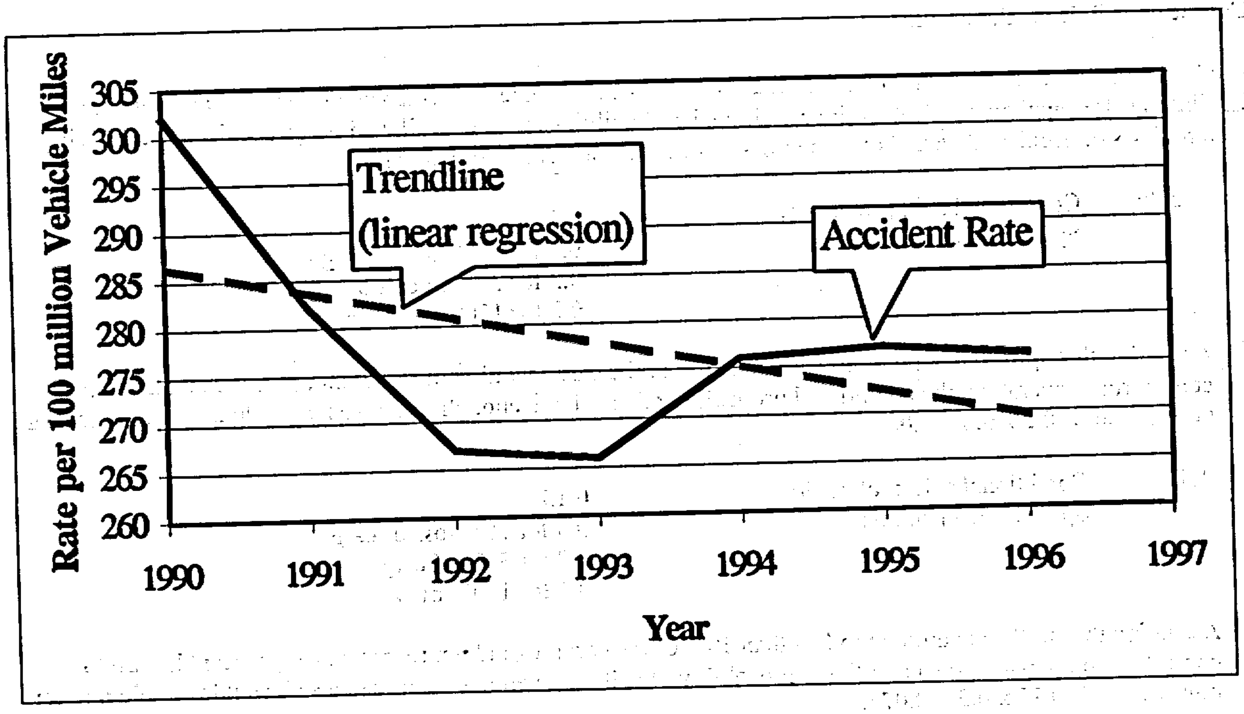

Figure 3.1. Motor Vehicle Accident Rate Trend From 1990 to 1996

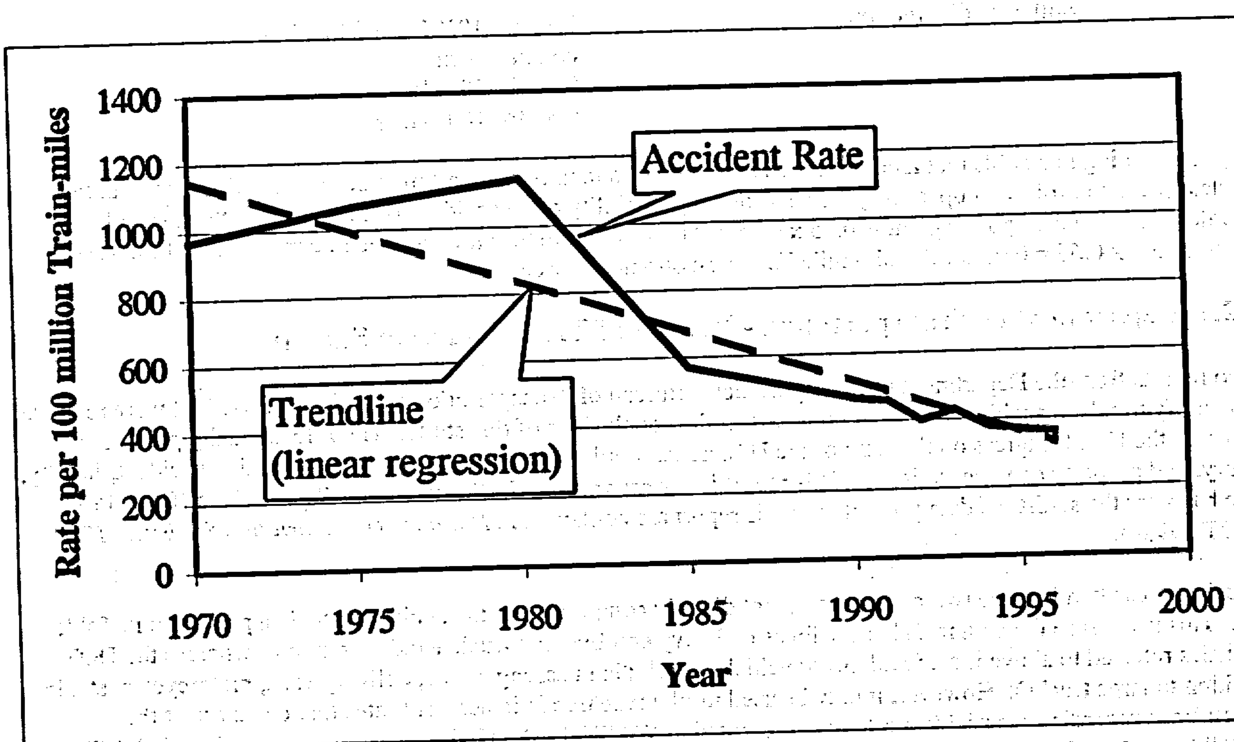

Figure 3.2. Trend in Rail Accident Rates, 1970 to 1996.

Water transportation accident rates are not provided in DOT (1998a and 1998b) so a plot similar to Figures 3.1 and 3.2 could not be prepared. However, the number of fatalities and accidents involving water transport are provided in DOT (1998a). A downward trend in the number of fatalities and number of accidents by year is also evident from the water transportation accident statistics.

3.3 Definition of Frequent Shipments

Regulatory Guide 1.78 provides two levels of screening to determine the hazardous chemicals that must be considered in the evaluation of control room habitability. The first level is the distance from the nearest highway, railway, or waterway over which hazardous chemicals are transported. If there are no shipments of hazardous materials passing within 5 mi. of the control room, no calculations are necessary. The second set of screening criteria is related to shipment frequencies. If there are shipments passing within 5 mi. of the control room but they are not frequent, as defined in Regulatory Guide 1.78, no calculations are necessary. However, if there are shipments passing within 5 mi. of the control room and they are frequent, then calculations of toxic chemical concentrations in the control room are necessary to demonstrate that the operators are protected. This section examines the definitions of frequent shipments in light of more recent accident data, and provides further clarification of the definitions.

Regulatory Guide 1.78 contains a definition of frequent shipments that must be considered in the evaluation of control room habitability (Regulatory Position 2). These are 10 per year for truck traffic, 30 per year for rail, and 50 per year for barges. Hazardous materials that are shipped at these frequencies or greater (within 5 miles of the plant) must be considered. The Regulatory Guide indicates these frequencies reflect WASH-1238.

The shipment frequency screening criteria were derived to provide a relatively simple method of screening out non-credible hazardous chemical transportation accidents from control room habitability considerations. The screening criteria were developed, in part, so that fluctuations in accident rates over time would not make it necessary to revise them. As can be seen from the accident rate data given in Table 3.1, the accident rates varied little from one study to another. Truck and rail accident rates were found to be within a factor of three from highest to lowest and barge/marine vessel accident rates were less than a factor of two apart. Furthermore, a review of accident data given in DOT (1998a and 1998b) indicates general downward trends in motor vehicle, rail, and water transportation accidents. Use of current accident rate data would most likely increase the definition of frequent shipments, resulting in a less-conservative screening analysis.

Sixteen reactor Safety Analysis Reports (SARs) were reviewed to determine how the shipment frequency screening criteria were used in the past. Insights from this review were used to determine if shipment frequencies are effective screening criteria and if the screening methodology needs clarification. The analysis of transportation accidents appears in Section 2.2.3 of the SARs and is sometimes summarized in Section 6.4 ("Habitability Systems"). A summary of the information relevant to the use of the shipment frequency criteria is provided in Table 3.2. The results of the analyses are used to define design-basis accidents that the plants must withstand.

All of the SARs reviewed provided information on the distances between the site and the nearest roads, rail lines, and navigable waterways. The most frequently-used argument against incorporating transportation accidents involving releases of specific hazardous materials into the design basis was the distance criteria. All of the SARs reviewed argued that the distances exceeded NRC criteria for at least one mode, barge being the most commonly screened mode based on separation distance. Thus, in most SARs, the shipment frequency criteria are applied to truck and rail shipments of hazardous chemicals.

Eleven of the sixteen SARs indicated analyses were performed to determine the frequencies of movements of hazardous materials. Often the information presented in the SAR consisted of a summary of a survey performed to identify hazardous chemicals shipped to, from, or near the site but the actual analyses were not incorporated into the SARs. Based on these analyses, which included comparisons of the frequencies of movements as well as the quantities transported to the Regulatory Guide criteria, the licensees selected one or more specific materials to evaluate. They then performed analyses to determine the concentrations of the chemicals that could reach the

Table 3.2. Summary of FSAR Applications of Regulatory Guide 1.78 Shipment Frequency Criteria

Plant Name	Summary of Transportation Accident Screening Analyses
Seabrook	Hazardous material transport data not available; surveyed industrial facilities within 5 mi. of plant to characterize hazardous material shipments. Probabilistic analysis concluded that accidents involving nearby transportation facilities would not affect safe operation of the plant and their frequencies are <1E-07/yr.
Byron	Surveyed industries within 10 mi. of the plant to establish type, quantities, and shipment frequencies for hazardous materials. Screened offsite shipments of toxic chemicals based on shipment frequency. Chlorine detectors provided due to onsite chlorine storage.
Limerick	Surveyed industrial facilities within 5 mi. of site. Evaluated 153 chemicals. Shipment frequency screening eliminated all but 6 hazardous chemicals. Provided detection and control room isolation capabilities for all 6 chemicals.
Vogtle	Screening analysis of shipment frequencies performed; concluded that transportation accidents involving hazardous chemicals within 5 mi. of the site have acceptably low probabilities. Several potential chemical releases analyzed and the calculated toxic concentrations did not exceed limits.
Perry	Performed screening based on frequency and quantity. Eliminated all but two hazardous chemicals shipped within 5 mi. of the plant.
Clinton	Eliminated all truck shipments of hazardous materials based on frequency. Survey found 19 chemicals transported by rail that exceeded 30 shipments/yr. Further screening performed based on low vapor pressures, low toxicity, eliminating asphyxiants.
Fermi	No screening performed because no roads, rail lines, or navigable waterways within 5 mi. of site (except site access road and rail spur).
Hope Creek	Survey determined that two chemicals transported by barge exceeded shipment frequency criteria. No other toxic or hazardous chemicals are regularly stored, used, or transported within 5 mi. of the site.
Millstone 3	Screened out highway shipments based on separation distance. For rail, screened out all chemicals except two, one of which (chlorine) is stored onsite in rail tank cars for water treatment.
Watts Bar	Screened truck shipments based on frequency. No rail line within 5 mi. of the site except the site access line. Barge accidents involving toxic chemicals screened out, except for smoke.
River Bend	Screened out all offsite shipments except for 2 hazardous materials; performed toxic concentration calculations for those 2 chemicals.
Beaver Valley	No screening based on shipment frequency was apparent. Survey identified 341 hazardous chemicals transported within 5 mi. of site; eliminated all but 119 based on low vapor pressure, solid physical form. Remaining chemicals screened based on probabilities of accidents less than 1E-06/yr.
South Texas	No screening based on shipment frequency was apparent. Evaluated all hazardous chemicals shipped to/from and stored at the plant.
Palo Verde	Survey performed to identify hazardous chemical shipments on rail line near site. Chlorine shipments screened based on frequency; others screened based on quantities being below Regulatory Guide 1.78 allowable weights for releases 4.2 mi. from the plant. All highway shipments screened out based on distance between plant and nearest highway where hazardous materials would be transported.
Shearon Harris	Screened hazardous chemical truck and rail shipments based on Regulatory Guide 1.78 shipment frequency criteria. Determined that frequencies of rail and truck accidents involving significant hazardous chemical releases below 1E-07/yr.
Nine Mile Point	Surveyed industries within 6.2 mi. of plant to identify potential hazardous chemicals. Used shipment frequency screening criteria then identified several chemicals for dispersion analysis.

control room intake (or other air intake). Five of the SARs concluded that the distances and frequencies of movements were such that Regulatory Guide 1.78 criteria were met for all hazardous chemical shipments. Six additional SARs screened out either truck or rail shipments based on the shipment frequency criteria. The SARs also perform analyses of explosions associated with transport of explosives, flammable gases, etc., as required by Regulatory Guide 1.91 (NRC 1978). Analyses of chlorine releases were also performed as required by Regulatory Guide 1.95 (NRC 1977). For the SARs in which the distance criteria were not met for one or more transport modes, hazardous material shipment quantities for the highways, rail lines, or waterways within 5 miles of the site were tabulated. They then used the criteria in Regulatory Guide 1.78 to identify the hazardous chemical releases that could affect control room habitability.

The review determined that most SARs contained some application of the shipment screening methodology to determine which hazardous chemicals should be included in their control room habitability evaluations. All of the SARs that applied shipment screening criteria acknowledged that obtaining hazardous chemical shipment frequencies was difficult but comprehensive surveys of shippers, manufacturing facilities, ports, and other likely hazardous chemical users were performed to establish a reasonable and defensible baseline. Based on these surveys, the licensees performed credible shipment screening assessments and appear to have appropriately identified which, if any, hazardous chemical shipments should be the subject of control room habitability evaluations.

3.4 Recommended Revisions To Regulatory Guide 1.78

The accident rate data that were used to derive the definitions of frequent shipments in Regulatory Guide 1.78 were examined relative to recent accident rate data to determine if an update to the Regulatory Guide is warranted. It was observed that the accident rates given in the recent studies are relatively close to each other and to the accident rates used in Regulatory Guide 1.78. The spread between the highest and lowest accident rates shown in Table 3.1 is small. A general downward trend in accident rates for motor vehicle, rail, and water transportation was also observed over time. Based on this review, it is recommended that the screening criteria based on distance from the control room and frequency of hazardous chemical shipments within 5 mi of the control room be retained in Regulatory Guide 1.78. The definitions of frequent shipments given in Regulatory Guide 1.78 are recommended to be retained in their present form. If revised, the definitions, which were derived from accident rate data given in WASH-1238, would most likely be increased to higher levels of traffic, due to generally decreasing trends in highway, rail, and water transportation accident rates. However, clarification of the definition of frequent shipments is recommended to be added to Regulatory Position C.2. The clarification should indicate that the total shipment frequency (i.e., the sum of the frequencies of all hazardous chemical shipments by transport mode) regardless of the type of chemical should not exceed the specified number given for each transport mode.

4.0 Revision of Meteorological And Flow Models

4.1 Introduction

Significant progress has been made in modeling capabilities since the publication of Regulatory Guide 1.78. The purpose of this task is to provide the technical basis for recommending revisions to Regulatory Guide 1.78 with regard to the meteorological and control room ventilation flow models.

4.2 Description of Revised Models

The meteorological and ventilation flow models used in Regulatory Guide 1.78 are outdated and do not reflect the current technology that had been developed since it's publication. The NRC has sponsored a number of research and development programs to improve the capability to model exposures of nuclear power plant control room personnel to radioactive material and toxic chemicals. This research has resulted in development of a software package named HABIT (Stage 1996, Ramsdell and Stage 1998). HABIT is an integrated set of computer codes designed for control room habitability assessments. The major modules within HABIT include the HABIT main window, which controls the execution of the other modules, and EXTRAN, CHEM, TACT5, FPFP_2, and CONHAB. Each module calculates a specific component required to estimate radiological doses and toxic chemical exposures in the control room.

Of most relevance to Regulatory Guide 1.78 is the EXTRAN component of the HABIT software package. EXTRAN (Ramsdell 1991), for EXternal TRANsport of toxic chemicals, calculates atmospheric chemical concentrations that would result from a release of a toxic chemical. The present atmospheric dispersion model described in Appendix B of Regulatory Guide 1.78 does not predict the variations in concentrations in building wakes associated with changes in meteorological conditions. EXTRAN represents an improvement in technology relative to the Regulatory Guide 1.78 atmospheric dispersion models as it combines procedures for estimating the amount of airborne material, a Gaussian puff model, and the most recent of the building-wake diffusion coefficient algorithms (Ramsdell 1995).

4.3 Recommended Revision to Regulatory Guide 1.78

It is recommended that Regulatory Positions C.5 and C.6 be revised to read as outlined below. It is also recommended that Appendix B be replaced with a descriptions of the models and algorithms used by the EXTRAN computer code to model atmospheric dispersion and predict the concentrations of radioactive materials or toxic chemicals at the control room intake. The revised Appendix B is described following Regulatory Positions C.5 and C.6.

Regulatory Position C.5. Chemical Release Amounts

The EXTRAN and CHEM portions of the HABIT computer codes (Stage, 1996 and Ramsdell, 1991) may be used to estimate the rates of release, atmospheric dispersion, and subsequent concentrations of toxic chemicals at the control room intake. If another computer program is used, it should consider physical processes similar to those considered in CHEM and EXTRAN.

Two types of industrial accidents should be considered for each source of hazardous chemicals: maximum concentration chemical accidents and maximum concentration-duration chemical accidents.

a. For a maximum concentration accident the quantity of the chemical to be considered is the instantaneous release of the total contents of one of the following (1) the largest storage container falling within the guidelines of Table C-2 and located at a nearby facility, (2) the largest shipping container (or for multiple containers of equal size, the failure of only one container unless the failure of that container could lead to successive failures) falling within the guidelines of Table C-2 and frequently transported near the site, or (3) the largest container stored onsite (normally the total release from this container unless the containers are interconnected in such a manner that a single failure could cause a release from several containers).

For chemicals that are not gases at 100 F and normal atmospheric pressure but are liquids with vapor pressures in excess of 10 torr, consideration should be given to the rate of flashing and boiloff to determine the rate of release to the atmosphere and the appropriate time duration of the release. In situations where liquid pools may form on the ground or other surfaces, evaporation from such pools should also be considered.

b. For a maximum concentration-duration accident, the continuous release of hazardous chemicals from the largest safety relief valve in a stationary, mobile, or onsite source falling within the guidelines of Table C-2 should be considered. Guidance on the atmospheric diffusion model is presented in Regulatory Guide 1.3, *Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Boiling Water Reactors*," and Regulatory Guide 1.4, *Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Pressurized Water Reactors*

Regulatory Position C.6. Atmospheric Dispersion

The atmospheric diffusion model to be used in the evaluation should be the same as or similar to the model presented in Chapter 6 of NUREG/CR-6210, *Computer Codes for Evaluation of Control Room Habitability (HABIT)* (Stage 1996, Ramsdell and Stage 1998) and presented in Appendix B of this guide. The model in the appendix allows for dispersion in the vertical direction when the distance between the release point and the control room is small. The model assumes uniform mixing between the ground and the elevation of the fresh air inlet (a 15-m elevation from ground level is assumed).

The value of the atmospheric dilution factor between the release point and the control room that is used in the analysis should be the value that is exceeded only 5% of the time. Techniques for determining this value may be found in Ramsdell (1995, 1997).

When the boiloff or a slow leak is analyzed, the effects of density on vertical diffusion may be considered if adequately substantiated by reference to data from experiments. Density effects of heavier-than-air gases should not be considered for releases of a violent nature or for release material that becomes entrained in the turbulent air near buildings.

In evaluating dispersion, formulas should be used that give a good representation of data for low wind cases (Ramsdell, 1994).

Additional credit due to building wake or other dispersive phenomena may be allowed, depending on the properties of the released gas, the method of release, and the intervening topology or structures.

Appendix B

The following was extracted from the software documentation for the Control Room Habitability Package (HABIT) (Stage 1996) and HABIT V1.1 (Ramsdell and Stage 1998).

Transport and Diffusion

EXTRAN, one of the components of the HABIT software package, models dispersion of toxic chemicals in the environment. EXTRAN includes a Gaussian puff dispersion model. This approach was selected because puff models permit more realistic treatment of temporal variations in release terms and concentrations. It is consistent with the Gaussian plume models used by the NRC for other licensing applications and the puff models used for emergency response applications.

Puff Model

The derivation of Gaussian plume model starts with a specific solution to the one-dimensional diffusion equation. A three-dimensional puff diffusion model is then produced by superposition of solutions to the one-dimensional equation. If it is assumed that diffusion proceeds independently in the longitudinal, lateral and vertical directions and that the center of the puff is at position x_o, y_o, z_o then, in the absence of boundaries, the concentration at position x, y, z is given by

$$C(x,y,z) = \frac{Q}{[(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z]}\exp\left[\frac{-0.5(x-x_0)^2}{\sigma_x^2}\right]\exp\left[\frac{-0.5(y-y_0)^2}{\sigma_y^2}\right]\exp\left[\frac{-0.5(z-z_0)^2}{\sigma_z^2}\right] \quad \text{(B.1)}$$

where

C(x,y,z)	=	the concentration at x,y,z
Q	=	the mass of material in the puff
σ_x, σ_y, σ_z	=	diffusion coefficients in the longitudinal, lateral and vertical directions.

The diffusion coefficients are characteristic dimensions of the puff. They are functions of the distance (or time) from the release point, the atmospheric stability, and the surface roughness.

Next, a Cartesian coordinate system is defined that has its origin at the ground directly below the release point with the x-axis parallel to the wind vector, the y-axis directed cross wind, and the z-axis vertical. With this definition, the center of the puff can now be allowed to move with the wind. At any moment t following the release, the coordinates of the center of the puff are $x_o = Ut$, $y_o = 0$, $z_o = h$ where U is the wind speed and h is the height of release. This results in

$$C(x,y,z) = \frac{Q}{[(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z]}\exp\left[\frac{-0.5(x-Ut)^2}{\sigma_x^2}\right]\exp\left[\frac{-0.5(y-y_0)^2}{\sigma_y^2}\right]\exp\left[\frac{-0.5(z-h)^2}{\sigma_z^2}\right] \quad \text{(B.2)}$$

The final step in derivation of the plume model is integration of Equation (B.2) from t = 0 to t = ∞. This step makes the plume model a steady-state model. The time delay between the source and the receptor does not appear explicitly in the model, and temporal variations in the source can only be modeled by assuming a sequence of steady-state releases.

The puff model alternative chosen for EXTRAN stops at Equation (B.2). Using the puff model, a plume is approximated by releasing a sequence of puffs at small time intervals. The concentration at a point in the plume is then calculated by summation of the concentrations at the point resulting from all puffs. In essence, the integration that leads to the plume model is replaced by

$$C(x,y,z) = \sum_i C_i \quad \text{(B.3)}$$

where C(x,y,z) is the concentration at x, y, z and the C_i are the contributions to the total concentration of the individual puffs given by Equation (B.2). It is common to assume that σ_x and σ_y are equal and to substitute σ_y for σ_x. Equations (B.2) and (B.3) retain the ability to model the temporal variation in concentrations at an air intake realistically because the concentration will not increase until a puff approaches the receptor, and the values of Q may be varied as a function of time.

The accuracy of the puff approximation can be checked by modeling a steady-state release. It is a function of the distance between puffs. The approximation can be made as accurate as desired by reducing this distance. Ramsdell, et al. (1983) show that if the distance between adjacent puffs is less than σ_y, concentrations estimated by the puff model are within one or two percent of those estimated by a plume model. Puff release rates in EXTRAN are adjusted to maintain this accuracy.

Equation (B.2) assumes that the diffusion takes place without the interference of boundaries. That assumption is not tenable for releases at or near ground level. It is common to assume that the ground acts as a reflecting surface. This assumption is incorporated into puff and plume models by assuming an imaginary second source of equal strength located at or below ground at a level equal to the negative of the release height. Concentrations are then computed by adding the contributions from the real and imaginary sources. Mathematically this is accomplished by replacing the term

$$\exp\left[\frac{-0.5(z-h)^2}{\sigma_z^2}\right]$$

in Equation (B.2) with

$$\exp\left[\frac{-0.5(z-h)^2}{\sigma_z^2}\right]+\exp\left[\frac{-0.5(z+h)^2}{\sigma_z^2}\right]$$

Source Term

Concentrations in the puffs are directly proportional to the mass that is included in the puff. In the EXTRAN code, puffs are released at regular intervals of length dt where dt is determined by the distance between the release point and the air intake, the wind speed, and the atmospheric stability. The mass in a puff released at time t is the mass entering the atmosphere in the period between t and t + dt.

If the toxic substance is a liquefied gas and both flashing and evaporation are occurring, two puffs will be released simultaneously. One of these puffs will have the mass of the liquid that has flashed, and the other will have the mass that has evaporated. Formulae for calculating the masses flashed to liquid and masses evaporated are given in Stage (1996). Otherwise only one puff will be released, and the mass in the puff will be determined using the formula for the mass that has evaporated.

Diffusion Coefficients

Equation (B.2) shows that the decrease in concentrations in puffs as they move downwind is due only to increases in the magnitudes of the diffusion coefficients. Relationships describing the increase in these coefficients in flat terrain under normal atmospheric conditions are readily available in the literature. The coefficients increase with increasing distance and generally decrease as the atmosphere becomes more stable.

These standard relationships do not adequately describe the growth of diffusion coefficients in the wakes of structures. The effect of wakes is to increase the rate of diffusion, but the effect is limited to the vicinity of the structure. As a result, composite diffusion coefficients that include both normal diffusion and wake effects are used in EXTRAN. These coefficients are computed using

$$\sigma_c=\left(\sigma_n^2+\sigma_1^2+\sigma_2^2\right)^{1/2} \tag{B.4}$$

where

σ_c	=	the composite diffusion coefficient
σ_n	=	a normal diffusion coefficient

σ_1 = a meander diffusion coefficient
σ_2 = a wake diffusion coefficient.

Normal diffusion coefficients are computed with the "Eimutis and Konicek" (1972) relationships used in the NRC PAVAN (Bander 1982) and XOQDOQ (Sagendorf, et al. 1982) codes. In these relationships the diffusion coefficients are functions of distance and atmospheric stability. The diffusion coefficients σ_1 and σ_2 are computed using equations derived by Ramsdell following an analysis of data from building–wake diffusion experiments (Ramsdell 1995). Derivations of the equations are presented in Ramsdell (1988, 1990a,b, 1995).
The puff diffusion equation was derived for point-source releases. The point source equations are reasonable as long as the distance between the release point and the receptor is large. In some EXTRAN applications the point source assumption may lead to unrealistically high concentrations at the source. Consequently, an adjustment is made to the diffusion coefficients to account for the size of the source. The diffusion coefficients are given initial values that result in concentrations at the center of the puff that are no greater than the concentration the pure vapor would have at the atmospheric conditions. These dimensions are related to the density of the vapor and the area of the pool. If a wake is a factor, the adjustment is made to the wake diffusion coefficients. Otherwise, the adjustment is made to the normal coefficients.

Transport

The transport of material is completely defined during model input. Puffs are assumed to move with the wind directly from the release point to the air intake. The time required for material to arrive at the intake is determined by the wind speed and the growth of the puffs. It is somewhat less than the time estimated by x/U where x is the distance to the intake and U is the wind speed.

5.0 Value-Impact Assessment For Proposed Changes To Regulatory Guide 1.78

5.1 Description of Regulatory Action and Alternatives

This value-impact assessment (VIA) provides an evaluation of the benefits (values) and costs (impacts) associated with the proposed revisions to Regulatory Guide 1.78. The proposed revisions have the potential to affect the values and impacts associated with nuclear power plant operations. The purpose of this chapter is to provide the information needed for the NRC staff and Commission to determine whether the proposed revisions to Regulatory Guide 1.78 are justified.

Values and impacts are expressed in terms of the effects on various "attributes" associated with the proposed revisions. The potential value attributes of the proposed revisions include reductions in public health risks from accidents and routine operations at nuclear power plants, changes in nuclear power plant worker risks from accidents, and reductions in offsite and onsite property damage costs from a lower likelihood of accidents. Impact attributes include the increased costs to the industry of operating and maintaining nuclear power plants as well as the costs of developing, implementing, and periodic monitoring of implementation by the NRC. In some cases, other attributes are affected, including increases in routine occupational exposures, impacts on other government agencies, etc. To determine if the proposed revisions are justified, the values and impacts associated with the proposed revisions to Regulatory Guide 1.78 are compared to the no-action alternative of making no changes to Regulatory Guide 1.78. All changes in values and impacts associated with the proposed revisions to Regulatory Guide 1.78 are measured against the no-action alternative baseline, which for the purposes of this analysis are considered as "zeroes."

5.2 Identification of Attributes

Attributes are standardized categories of values and impacts associated with the implementation of the proposed regulatory action. Table 5.1 provides a checklist of attributes taken from NUREG/BR-0058, Rev. 2, *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission* (NRC 1995) and NUREG/BR-0184, *Regulatory Analysis Technical Evaluation Handbook* (NRC 1997). Their relevancy to the proposed revision of Regulatory Guide 1.78 is also discussed in the table. The table describes the basis for dismissing some standardized attributes from further consideration. Only the attributes that are affected by the revisions to Regulatory Guide 1.78 are discussed further. Detailed discussions of the attributes affected by the proposed revision are provided in the next section.

The values and impacts associated with the revision of Regulatory Guide 1.78 have been addressed in a primarily qualitative manner. The results are summarized in Table 5.2. The risk and safety benefits appear small based on a semi-quantitative evaluation. The effects on onsite and offsite property were determined to be small. The industry implementation costs are estimated to be \$2.8 million. The industry operation costs are estimated to be small and a potential for cost savings could result if there is a decrease in the requirements for control room habitability systems as a result of increased toxicity limits. In addition, there is a potential for a larger cost savings due to fewer plant shutdowns and increased plant capacity that could result from the higher toxicity limits for some chemicals. These cost savings are difficult to estimate but could be substantial. NRC implementation costs are estimated at \$400,000. NRC operation costs are small. The proposed revision also represents an improvement of knowledge as the revision incorporates more precise toxicity limits and a more comprehensive list of hazardous chemicals. An increase in regulatory efficiency was not quantified but is an important attribute for this proposed regulatory action.

Table 5.1. Identification of Affected Decision Attributes[a]

Attribute	Affected?	Explanation
Public Health (Accident)	YES	Addressed in this VIA.
Public Health (Routine)	NO	Routine releases are not in the scope of the existing or proposed revision to Regulatory Guide 1.78.
Occupational Health (Accident)	YES	Addressed in this VIA.
Occupational Health (Routine)	NO	Routine exposures to radiation are not in the scope of the existing or proposed revision to Regulatory Guide 1.78.
Offsite Property	YES	Addressed in this VIA.
Onsite Property	YES	Addressed in this VIA.
Industry Implementation	YES	Addressed in this VIA.
Industry Operation	YES	Addressed in this VIA.
NRC Implementation	YES	Addressed in this VIA.
NRC Operation	YES	Addressed in this VIA.
Other Government	NO	No actions from federal government agencies other than the NRC or Agreement States were identified as being required by the existing or proposed revision to Regulatory Guide 1.78. No changes to offsite emergency capabilities or offsite services identified.
General Public	NO	No "out-of-pocket" expenses to be paid by the general public were identified as resulting from the existing or proposed revision to Regulatory Guide 1.78.
Improvements in Knowledge	YES	Addressed in this VIA.
Regulatory Efficiency	YES	Addressed in this VIA.
Antitrust Considerations	NO	No potential violations of antitrust laws identified.
Safeguards and Security Considerations	NO	Neither the existing nor the proposed revision to Regulatory Guide 1.78 affects, or is affected by, safeguards and security considerations at nuclear power plants.
Environmental Considerations	NO	The existing and proposed revisions to Regulatory Guide 1.78 were judged to be covered within existing generic and site-specific environmental documentation.
Other Considerations	NO	No other attributes were identified.

(a) Attributes are described in NUREG/BR-0058, Rev. 2, *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission*, and NUREG/BR-0184, *Regulatory Analysis Technical Evaluation Handbook*.

5.3 Quantification of Attributes

Each of the affected attributes identified in the proceeding section is discussed either quantitatively or qualitatively in the following subsections.

5.3.1 Public Health (Accident)

Implementation of the proposed revisions to Regulatory Guide 1.78 could potentially change the frequencies or consequences of core damage accidents (risk is the product of core damage frequency and consequences) at nuclear power plants. This attribute measures the impacts on (or changes in) public risks from accidents that could result from implementation of the proposed revisions. Based on the discussion provided below, it is believed that no appreciable change will result from this revision.

Table 5.2. Summary of Value-Impact Assessment Results

Affected Attribute	Assessment of Value or Impact
Public Health (accident)	Small effect; could be an overall increase or decrease depending on revised toxicity limits.
Occupational Health (accident)	Same as "Public Health" attribute.
Offsite Property	Same as "Public Health" attribute.
Onsite Property	Same as "Public Health" attribute.
Industry Implementation	Approximately $2.8 million.
Industry Operation	Potential cost savings due to fewer shutdowns and less plant downtime.
NRC Implementation	Approximately $420,000.
NRC Operation	Small; not quantified.
Improvements in Knowledge	Not quantified; favors implementation of revised Regulatory Guide 1.78.
Regulatory Efficiency	Not quantified; favors implementation of revised Regulatory Guide 1.78.

The changes in the public risk as a result of the proposed revision to Regulatory Guide 1.78 are believed to be small. A release of hazardous chemical impacting control room habitability will not by itself result in a severe reactor accident. The low likelihood of simultaneous occurrence of a hazardous chemical release and core damage accident initiator (such as a loss of coolant accident or loss of offsite power) indicates that public health impacts are small.

Two examples were developed to illustrate that the effects on public risks are small. The first example is for a transportation accident that releases a hazardous chemical. The frequency of a transportation accident on a nearby highway was calculated using the traffic accident rate referenced in the current regulatory guide. This was 1.69E-06 accidents/mile. Of these accidents, 18% were postulated to result in a spill of a hazardous chemical. For this example, it was assumed that there are 10 miles of highway in the vicinity of a nuclear power plant and 10 shipments of this chemical are transported per year. The overall frequency of a significant spill is the product of these values, or about 3.0E-05/yr.

To result in an effect on a nuclear power plant control room operator, the hazardous chemical would have to be transported from the accident scene to the control room air intake. Since atmospheric transport is the only credible transport mechanism, the wind would have to be blowing in the direction from the accident scene to the control room. In addition, the weather would need to be relatively calm or the release chemicals would be dispersed quickly and not reach concentrations that could affect an operator's ability to perform required actions. As discussed above, the transportation accident itself would not lead to core damage. Therefore, this scenario would also require simultaneous occurrence of an internally-induced core damage initiating event followed by failure of automatic safety systems. These factors would reduce the frequency of this affected core damage sequence by at least two orders of magnitude and most likely more. Assuming a conditional probability of 0.05 for adverse weather conditions, the magnitude of the affected CDF is on the order of 1.5E-06/reactor-yr (RY). The adverse weather probability is based on use of site-specific relative concentrations, or /Q values, that are exceeded only 5% of the time on an overall basis, regardless of wind direction. This is consistent with guidance given in Regulatory Guide 1.146, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*. Weather conditions that are more frequent (i.e., have a higher probability of occurrence) result in greater dispersion and lower relative concentrations (i.e., smaller /Q value) of the toxic chemical at the control room intake. This conservatively ignores the probability that the wind is blowing in the direction from the accident towards the control room intake. The affected CDF would be even smaller than the value given above when simultaneous occurrence of core damage initiating events are considered and failure probabilities of automatic safety systems are included in the potential core damage sequences. The changes in public risk from transportation accident induced core damage brought about by the proposed revisions to the regulatory guide would therefore be small.

The second example is for a hazardous chemical storage tank on a nuclear power plant site. In this scenario, an onsite storage tank of a hazardous chemical is postulated to rupture and release its contents. The frequency of such an event was estimated to be 1E-06/yr for double-walled storage tanks and 1E-04/yr for single-walled storage tanks and pressure vessels (see the *Handbook of Chemical Hazard Analysis Procedures*, FEMA/DOT/EPA 1988). The *Handbook* also recommends using a spill size equivalent to a 1-inch hole 90% of the time and the entire tank contents 10% of the time. Combining these leads to a significant release frequency on the order of 1E-04 to 1E-05/yr. As with the transportation accident scenario, weather factors would have to be suitable to transport the released chemical to the control room intake in concentrations that could affect operators and an internal initiating event would need to simultaneously occur. Consequently, the affected CDF from a storage tank rupture scenario would be small.

The proposed changes to the regulatory guide may have a mixed effect on public health. The proposed list of hazardous chemicals is much more comprehensive than that in the original regulatory guide. If additional chemicals are recognized as hazards by specific reactors, the public health risk will be lowered. Note that many of the proposed toxicity limits are higher than those originally in Regulatory Guide 1.78. A comparison of Regulatory Guide 1.78 Table C-1 and Section 2 indicates that the proposed toxicity limits are higher for 24 chemicals and lower for only 3 chemicals (ethyl ether, ethylene dichloride, and hydrogen sulfide). Incorporating the new toxicity limits may result in a relaxation of control room habitability requirements and a small increase in public risk relative to current practices. However, the proposed revisions have a superior technical basis to the toxicity limits in the original Regulatory Guide. Significant research has been completed over the 25 yrs since the original Regulatory Guide was published. A comprehensive listing of IDLH values was not available 25 yrs ago. Also, even tough the proposed toxicity limits are higher than those in the original Regulatory Guide, it is not intended to expose the operators to the concentrations for 30 minutes, part of the definition of IDLH. Rather, it is still intended that operators don appropriate protective equipment within 2 minutes after toxic gas concentrations are detected. As a result, control room operators are not likely to be overcome or incapacitated even if toxic gases or aerosols reach the control room at IDLH concentrations. Furthermore, with respect to timing, a hazardous chemical spill is most likely to occur at some distance from the control room. It takes time for the released material to reach the control room intake and additional time for the concentration of toxic gases to build to a dangerous level. Since detection limits for the toxic gases would be set lower than the IDLH values, operators would have additional time to don protective equipment before a dangerous concentration builds in the control room. Consequently, operators would not be exposed to IDLH concentrations during the 2 minutes it takes to don protective equipment. When all this is taken into consideration, the proposed revisions to the toxicity limits are believed to provide adequate protection to control room operators and by extension, to the public. The increased risk associated with higher toxicity limits, if any, would be small.

5.3.2 Occupational Health (Accident)

The occupational health (accident) attribute measures the change in risk to plant workers that would result from changes in accident frequencies and consequences brought about by the proposed revisions to the regulatory guide. Based upon the above discussion of public health, changes to a plant's overall core damage frequency that result from the revisions to Regulatory Guide 1.78 are small. The radiological consequences of core damage accidents are not affected by the revisions. Therefore, the occupational health radiological impacts from the proposed regulatory action are small.

The control room habitability systems also serve an important role in protecting control room personnel from toxic chemicals. Consideration of the additional chemicals in the proposed regulatory action may result in decreased occupational health risk. Incorporating higher toxicity limits for many of the chemicals may result in relaxation of requirements and a slightly higher occupational risk. As with public health risks, this would at least partially offset the reduced occupational risks associated with enhanced protection of control room operators. Occupational health impacts for the proposed regulatory action do not appear to be significant.

5.3.3 Offsite Property

This attribute measures the monetary effect on offsite property and is typically calculated as the product of the change in core damage frequency and the property consequences as a result of a core damage accident (e.g., interdiction, cleanup, and evacuation costs). Based upon the above discussion of public health, the change in core damage frequency that would result from the revisions to Regulatory Guide 1.78 is small and therefore the impacts of the proposed revision to Regulatory Guide 1.78 on offsite property are small.

5.3.4 Onsite Property

This attribute measures the monetary effect on onsite property, including replacement power, decontamination, and refurbishment costs. As with offsite property, this attribute is typically calculated as the product of the change in core damage frequency and the onsite property consequences as a result of a core damage accident. Based upon the above discussion of public health, the change in core damage frequency is small. Therefore, the impacts of the proposed revision to Regulatory Guide 1.78 on onsite property are small.

5.3.5 Industry Implementation

This attribute measures the expected economic effects on licensees to implement the changes required by the proposed regulatory guide revision. Examples include administrative, equipment, labor, and materials costs as well as replacement power costs where the proposed regulatory action plant shutdowns or outage extensions. In this case, implementation costs would consist of labor costs to update the plant's Safety Analysis Report (SAR) where necessary.

The proposed revision to Regulatory Guide 1.78 adds a substantial number of hazardous chemicals to be considered in evaluating control room habitability. However, Table C-1 in Regulatory Guide 1.78 was clearly described as not all-inclusive. If the original hazardous chemical survey was comprehensive, little cost impact is expected. Since the proposed toxicity limits for many chemicals seem to typically be higher than those in Table C-1 of Regulatory Guide 1.78, little cost impact will result from new control room habitability requirements. In fact, a decrease in requirements could result. It is difficult to quantify industry implementation costs. For illustrative purposes, the following case is quantified:

1. Reactor review of potential impacts from revised listing of chemicals and toxicity limits:
   $5,000 per reactor times 111 reactors equals $555,000

   Basis: Labor requirements to review the revised Regulatory Guide, evaluate the impacts on the plant's licensing basis, and document the results of the evaluations were estimated at about 2 man-wks/plant. Each plant would be required to perform this activity. The industry labor rate used in this calculation was $62.50/staff-hr. The total number of plants was taken from Appendix B of NUREG/BR-0184 (NRC 1997).

2. 50% require no additional action; 50% require SAR update:
   $40,000 per reactor times 56 reactors equals $2,240,000

   Basis: Eight of the 16 plants listed in Table 3.2 were judged to require an update of their SAR. The other 8 plants were judged not to require a SAR update because they had either screened out all toxic chemical shipments on the basis of distance from transport routes or frequent shipment screening criteria. If this is 16 plant sample is representative of the entire population of nuclear power plants, 50% of 111 plants, or about 56 plants, will require a SAR update. Sciacca (1989) estimated labor requirements for a complicated technical specification change to be 16 staff-wks of technical, legal, and management effort. This was assumed to be approximately the same amount of resources needed for a complicated update of a SAR. This was judged to be a complicated update because it requires application of computer codes. The industry labor rate used here was $62.50/staff-hr.

3. 0% of these require additional personal protection or detection requirements:
   $0

   Basis: Based on the review of plant SARs and the general increase in toxicity limits associated with the revisions to Regulatory Guide 1.78, it was judged that no plants would require additional protection for control room operators from external sources of toxic chemicals.

The total industry implementation costs are therefore estimated at about $2.8 million.

5.3.6 Industry Operation

This attribute measures the economic impacts on the licensees of routine or recurring activities that result from the new requirements. As discussed above, minimal new requirements are assumed and there may be a potential for a decrease in the requirements for control room habitability systems as a result of increased toxicity limits. It is possible, although unlikely, that a re-analysis could be used to justify relaxation of technical specifications, surveillance and maintenance programs, and other requirements associated with operation of chemical detection systems, operator training, etc., that support control room habitability programs. Increases in control room toxic chemical limits could result in using less sensitive detectors, requiring lower air exchange rates, no isolation valves, smaller filters, and smaller air ducts. Smaller and less complex systems generally require fewer resources to inspect and maintain. However, the cost savings on existing control rooms is likely to be small because the ventilation and chemical detection systems are already in place.

The greatest cost savings potential results from reducing plant shutdowns from spurious actuation of chemical detection systems, including malfunctions of toxic chemical detection systems that lead to actuation of the control room emergency ventilation system. A preliminary review of Licensee Event Reports (LERs) indicated there were numerous occurrences of control room emergency ventilation system actuations but few of them actually lead to plant shutdown. Most LERs indicated that the plants entered a Technical Specification action statement and were able to correct the problems before plant shutdown was required. The most common component malfunctions were radiation monitors on the control room intake supply system, which are not in the scope of Regulatory Guide 1.78. Chlorine gas detectors were the next most frequently mentioned components.

These cost savings are difficult to estimate but could be substantial. To illustrate this, assume that increasing the allowable toxic chemical concentrations will increase plant capacity by one day per year for the entire population of nuclear power plants. Assuming replacement power costs are $480,000/day (NRC 1997) and the average remaining lifetimes of the plants is about 20 yr (approximated from information in Appendix B of NRC 1997), this savings could be about $10 million over the next 20 yr. This conservative estimate would more than offset the increased industry costs to implement the revisions to Regulatory Guide 1.78.

5.3.7 NRC Implementation

NRC implementation is an attribute that measures the economic impacts of the NRC to place the proposed revision to Regulatory Guide 1.78 into action. NRC implementations costs consist of the costs to issue revised Regulatory Guide 1.78 and the costs associated with reviewing the required initial licensee analyses described in the Industry Implementation section.

The *Regulatory Analysis Technical Evaluation Handbook* (NRC 1997) provides some approximate costs for NRC Implementation. For a non-controversial amendment to an existing rule or regulation, one professional NRC staff person-year at a cost of $122,000 is estimated to be required. A cost of $122,000 is assumed required to complete and issue the revision of Regulatory Guide 1.78.

As discussed in the Industry Implementation section, 50% of the plants or about 56 plants are estimated to require SAR updates that must be reviewed and approved by the NRC. It is estimated that 2 NRC staff-wks of labor are required to review and approve each plant's submittal. Therefore, about 112 staff-wks of NRC labor are needed. At a NRC labor rate of $67.50/staff-hr (NRC 1997), the total NRC costs to review and approve these analyses are estimated at about $300,000. The total NRC implementation cost is therefore about $420,000.

5.3.8 NRC Operation

NRC operation is an attribute that measures the economic effects on the NRC of routine or recurring activities (e.g., additional inspection and enforcement activities) necessary to monitor licensee implementation of the proposed revisions to the regulatory guide.

Currently, the NRC monitors implementation of the existing Regulatory Guide. Periodic reviews and inspections and other recurring activities by NRC staff are anticipated to change little with respect to the current efforts to monitor implementation of the Regulatory Guide. Therefore, the incremental costs would be small with respect to the costs of current activities so they were not quantified.

5.3.9 Improvements in Knowledge

This attribute accounts for the potential value of new information on the safety of licensee activities. The recommendation to replace the chemicals and limits in Regulatory Guide 1.78 with the more recent IDLH values represents an improvement in knowledge. The more recent NIOSH IDLH values represent many years of testing and toxicity modeling that were not available when the current version of Regulatory Guide 1.78 was issued. The IDLH values have a sound technical basis and the list of hazardous chemicals for which IDLH values exist is more comprehensive than reflected in the Regulatory Guide. Furthermore, improvements to the meteorological and control room ventilation flow models represent improvements in the ability to estimate toxic chemical concentrations in control rooms and improvements in the accuracy of the results. Consequently, this attribute favors the proposed revisions to Regulatory Guide 1.78.

5.3.10 Regulatory Efficiency

This attribute attempts to measure regulatory and compliance improvements. The revision of Regulatory Guide 1.78 to include a comprehensive list of chemicals and toxicity limits generated by NIOSH will result in more consistent and comprehensive control room habitability evaluations. Improvements in atmospheric dispersion and control room ventilation flow models, although not expected to enhance regulatory efficiency, increase confidence in the results. Implementation of the revisions is also anticipated to reduce licensee burden by incorporating new data that is more appropriate and more accurate than the original basis for Regulatory Guide 1.78. In addition, clarification that the definition of "frequent shipments" includes all hazardous chemical shipments will increase regulatory efficiency by reducing each licensee's need to interpret the old guidance and the NRCs need to review and approve the possible varying interpretations. Therefore, this attribute favors the proposed revisions to the regulatory guide.

6.0 Recommended Changes to Regulatory Guide 1.78

6.1 Use of IDLH in Regulatory Guide 1.78

We reviewed the IDLH concentrations for the purpose of using them to replace the toxicity limits and expand the number of chemicals in Regulatory Guide 1.78. We found that the IDLH concentrations represent reasonable limits to provide adequate time to don protective apparel and determined that they would provide an adequate margin of safety for protecting the operators. Therefore, we recommend that the IDLH values replace the chemical toxicity limits listed in Regulatory Guide 1.78. IDLH values of most chemicals not listed in the Regulatory Guide 1.78 are also appropriate to use as toxicity limits if this list requires expanding.

6.1.1 Table C-1

We recommend that the NIOSH Pocket Guide (NIOSH, 1997) be referenced in the revised Regulatory Guide 1.78. This document is widely used in industry and is a readily available resource. One option is to replaceTable C-1 in Regulatory Guide 1.78 with Appendix A of this report. Alternatively, NRC may wish to continue to provide a list of "example" chemicals with their toxicity limits (Table C-1). In this case, Table C-1 would not necessarily need to be extensively revised. However, selection of the chemicals listed could include those used in nuclear power plants and some of the more common chemicals transported in large quantities. In addition, any chemical not listed in the "Pocket Guide" or any for which a value other than the IDLH is being used as an exposure limit should be included (could include chlorine and Halon).

6.2 Recommended Transport Accident Revisions to Regulatory Guide 1.78

The recent accident rate data used to derive the definitions of frequent shipments in Regulatory Guide 1.78 were examined to determine if an update to the Regulatory Guide is warranted. It was observed that the accident rates given in the recent studies are relatively close to each other and to the accident rates used in Regulatory Guide 1.78. The spread between the highest and lowest accident rates is small. A general downward trend in accident rates for motor vehicle, rail, and water transportation was also observed over time. Based on this review, it is recommended that the screening criteria based on distance from the control room and frequency of hazardous chemical shipments within 5 miles of the control room be retained in Regulatory Guide 1.78. The definitions of frequent accidents given in Regulatory Guide 1.78 are recommended to be retained in their present form. It is also recommended that clarification be added to the Regulatory Guide to indicate that the frequent shipment criteria refer to total shipments irrespective of the nature of the chemicals.

6.2.1 Table C-2

Table C-2, which provides an example of the allowable weights of hazardous chemicals as a function of distance, would need to be revised to reflect application of the recommended meteorological and ventilation flow models to be incorporated in the revised regulatory guide. In addition, it is recommended that the last sentence from footnote (4) on page 1.78-2 be deleted, as there is no need to retain the reference to the "Guide for Emergency Services for Hazardous Materials."

If the computer codes (see section 4) are used in the revision of Regulatory Guide 1.78, Table C-2 would need to be revised to reflect distance/weight relationships calculated by the codes. Appendix A could probably be deleted as the codes would have to be implemented to adjust the distance/weight relationships for specific chemical toxicities, control room airflow rates, and Pasquil stability. Appendix B would have to be revised to incorporate the recommendation to change from the hand calculation approach in the current Regulatory Guide to the computer codes described below.

6.3 Computer Codes

It is recommended that the current Appendix B be replaced in its entirety by a brief description of the meteorological and control room ventilation flow models (EXTRAN and CHEM code models), which are components of the Control Room Habitability software package, HABIT. Minor revisions to Regulatory Positions C.5 and C.6 are also recommended as outlined below.

Regulatory Position C.5. Chemical Release Amounts

The EXTRAN and CHEM portions of the HABIT computer codes (Stage, 1995 and Ramsdell, 1991) may be used to estimate the rates of release, atmospheric dispersion, and subsequent control room concentrations of toxic chemicals. If another computer program is used, it should consider physical processes similar to those considered in CHEM and EXTRAN.

Two types of industrial accidents should be considered for each source of hazardous chemicals: maximum concentration chemical accidents and maximum concentration-duration chemical accidents.

a. For a maximum concentration accident the quantity of the chemical to be considered is the instantaneous release of the total contents of one of the following (1) the largest storage container falling within the guidelines of Table C-2 and located at a nearby facility, (2) the largest shipping container (or for multiple containers of equal size, the failure of only one container unless the failure of that container could lead to successive failures) falling within the guidelines of Table C-2 and frequently transported near the site, or (3) the largest container stored onsite (normally the total release from this container unless the containers are interconnected so that a single failure could cause a release from several containers.)

   For chemicals that are not gases at 100°F and normal atmospheric pressure but are liquids with vapor pressures in excess of 10 torr, consideration should be given to the rate of flashing and boiloff to determine the rate of release to the atmosphere and the appropriate time duration of the release. In situations where liquid pools may form on the ground or other surfaces, evaporation from such pools should also be considered.

b. For a maximum concentration-duration accident, the continuous release of hazardous chemicals from the largest safety relief valve in a stationary, mobile, or onsite source falling within the guidelines of Table C-2 should be considered.

Regulatory Position C.6. Atmospheric Dispersion

The atmospheric diffusion model to be used in the evaluation should be the same as or similar to the model presented in Chapter 6 of NUREG/CR-6210, *Computer Codes for Evaluation of Control Room Habitability (HABIT)* (Stage 1995, Ramsdell and Stage 1998) and presented in Appendix B of this guide. The model in the appendix allows for dispersion in the vertical direction when the distance between the release point and the control room is small. The model assumes uniform mixing between the ground and the elevation of the fresh air inlet (a 15-m elevation from ground level is assumed).

The value of the atmospheric dilution factor between the release point and the control room that is used in the analysis should be the value that is exceeded only 5% of the time. Techniques for determining this value may be found in Ramsdell (1995, 1997).

When the boiloff or a slow leak is analyzed, the effects of density on vertical diffusion may be considered if adequately substantiated by reference to data from experiments. Density effects of heavier-than-air gases should not be considered for releases of a violent nature or for release material that becomes entrained in the turbulent air near buildings.

In evaluating dispersion, formulas should be used that give a good representation of data for low wind cases (Ramsdell, 1994).

Additional credit due to building wake or other dispersive phenomena may be allowed, depending on the properties of the released gas, the method of release, and the intervening topology or structures.

Appendix B:

It is recommended that this Appendix be replaced in its entirety to reflect improvements made meteorological and ventilation flow models since publication of Regulatory Guide 1.78 in 1974. The entire revised Appendix B was presented in Chapter 4 and will not be repeated here.

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Appendix A. Revised IDLH Values Established by NIOSH

	Chemical Name	CAS Number†	IDLH Values
1	Acetaldehyde	75-07-0	2000 ppm
2	Acetic acid	64-19-7	50 ppm
3	Acetic anhydride	108-24-7	200 ppm
4	Acetone	67-64-1	2500 ppm*
5	Acetonitrile	75-05-8	500 ppm
6	2-Acetylaminofluorene	53-96-3	Ca
7	Acetylene tetrabromide	79-27-6	8 ppm
8	Acrolein	107-02-8	2 ppm
9	Acrylamide	79-06-1	60 mg/m^3
10	Acrylonitrile	107-13-1	85 ppm
11	Aldrin	309-00-2	25 mg/m^3
12	Allyl alcohol	107-18-6	20 ppm
13	Allyl chloride	107-05-1	250 ppm
14	Allyl glycidyl ether	106-92-3	50 ppm
15	4-Aminodiphenyl	92-67-1	Ca
16	2-Aminopyridine	504-29-0	5 ppm
17	Ammonia	7664-41-7	300 ppm
18	Ammonium sulfamate	7773-06-0	1500 mg/m^3
19	n-Amyl acetate	628-63-7	1000 ppm
20	sec-Amyl acetate	626-38-0	1000 ppm
21	Aniline and homologs	62-53-3	100 ppm
22	Anisidine (o-, p-isomers)	o: 90-04-0; p:104-94-9	50 mg/m^3
23	Antimony and compounds	7440-36-0	50 mg Sb/m^3
24	ANTU (alpha-naphthyl-thiourea)	86-88-4	100 mg/m^3
25	Arsenic (inorganic compounds)	7740-38-2	5 mg As/m^3
26	Arsine	7784-42-1	3 ppm
27	Asbestos	1332-21-4	Ca
28	Azinphos-methyl	86-50-0	10 mg/m^3
29	Barium compounds (Ba(NO3)2)	10022-31-8	50 mg Ba/m^3
30	Barium compounds (BaCl2)	10361-37-2	50 mg Ba/m^3
31	Benzene	71-43-2	500 ppm
32	Benzidine	92-87-5	Ca
33	Benzoyl peroxide	94-36-0	1500 mg/m^3

34	Benzyl chloride	100-44-7	10 ppm
35	Beryllium (and compounds)	7440-41-7	4 mg Be/m^3
36	Boronoxide	1303-86-2	2000 mg/m^3
37	Boron trifluoride	7637-07-2	25 ppm
38	Bromine	7726-95-6	3 ppm
39	Bromoform	75-25-2	850 ppm
40	1,3-Butadiene	106-99-0	2000 ppm*
41	2-Butanone	78-93-3	3000 ppm
42	2-Butoxyethanol	111-76-2	700 ppm
43	n-Butyl acetate	123-86-4	1700 ppm *
44	sec-Butyl acetate	105-46-4	1700 ppm *
45	tert-Butyl acetate	540-88-5	1500 ppm*
46	n-Butyl alcohol	71-36-3	1400 ppm*
47	sec-Butyl alcohol	78-92-2	2000 ppm
48	tert-Butyl alcohol	75-65-0	1600 ppm
49	Butylamine	109-73-9	300 ppm
50	tert-Butyl chromate	1189-85-1	15 mg Cr(VI) /m^3
51	n-Butyl glycidyl ether	2426-08-6	250 ppm
52	Butyl mercaptan	109-79-5	500 ppm
53	p-tert-Butyltoluene	98-51-1	100 ppm
54	Cadmium dust	7440-43-9	9 mg Cd/m^3
55	Cadmium fume	1306-19-0	9 mg Cd/m^3
56	Calcium arsenate	7778-44-1	5 mg As/m^3
57	Calcium oxide	1305-78-8	25 mg/m^3
58	Camphor (synthetic)	76-22-2	200 mg/m^3
59	Carbaryl (Sevin®)	63-25-2	100 mg/m^3
60	Carbon black	1333-86-4	1750 mg/m^3
61	Carbon dioxide	124-38-9	40000 ppm
62	Carbon disulfide	75-15-0	500 ppm
63	Carbon monoxide	630-08-0	1200 ppm
64	Carbon tetrachloride	56-23-5	200 ppm
65	Chlordane	57-74-9	100 mg/m^3
66	Chlorinated camphene	8001-35-2	200 mg/m^3
67	Chlorinated diphenyl oxide	55720-99-5	5 mg/m^3
68	Chlorine	7782-50-5	10 ppm
69	Chlorine dioxide	10049-04-4	5 ppm
70	Chlorine trifluoride	7790-91-2	20 ppm
71	Chloroacetaldehyde	107-20-0	45 ppm

72	alpha-Chloroacetophenone	532-27-4	15 mg/m^3
73	Chlorobenzene	108-90-7	1000 ppm
74	o-Chlorobenzylidine malononitrile	2698-41-1	2 mg/m^3
75	Chlorobromomethane	74-97-5	2000 ppm
76	Chlorodiphenyl (42% Cl)	53469-21-9	5 mg/m^3
77	Chlorodiphenyl (54% Cl)	11097-69-1	5 mg/m^3
78	Chloroform	67-66-3	500 ppm
79	bis-Chloromethyl ether	542-88-1	Ca
80	Chloromethyl methyl ether	107-30-2	Ca
81	1-Chloro-1-nitropropane	600-25-9	100 ppm
82	Chloropicrin	76-06-2	2 ppm
83	beta-Chloroprene	126-99-8	300 ppm
84	Chromic acid and chromates	7738-94-5	15 mg Cr(VI)/m^3
85	Chromium metal	7440-47-3	250 mg Cr/m^3
86	Chromium (II) compounds	varies	250 mg Cr(II)/m^3
87	Chromium (III) compounds	varies	25 mg Cr(III)/m^3
88	Coal tar pitch volatiles	65996-93-2	80 mg/m^3
89	Cobalt metal, dust, and fume	7440-48-4	20 mg Co/m^3
90	Copper dusts and mists	7440-50-8	100 mg Cu/m^3
91	Copper fume (Cu)	7440-50-8	100 mg Cu/m^3
92	Copper fume (CuO)	1317-38-0	100 mg Cu/m^3
93	Cotton dust (raw)	none	500 mg/m^3
94	Crag® herbicide	136-78-7	500 mg/m^3
95	Cresol (all isomers)	1319-77-3	250 ppm
96	Crotonaldehyde (trans-isomer)	123-73-9	50 ppm
97	Cumene	98-82-8	900 ppm*
98	Cyanides (KCN)	151-50-8	25 mg/m^3(as CN)
99	Cyanides (NaCN)	143-33-9	25 mg/m^3 (as CN)
100	Cyclohexane	110-82-7	1300 ppm *
101	Cyclohexanol	108-93-0	400 ppm
102	Cyclohexanone	108-94-1	700 ppm
103	Cyclohexene	110-83-8	2000 ppm
104	Cyclopentadiene	542-92-7	750 ppm
105	2,4-D (2-4-dichlorophenoxyacetic acid)	94-75-7	100 mg/m^3
106	DDT (dichlorodiphenyltrichloroethane)	50-29-3	500 mg/m^3
107	Decaborane	17702-41-9	15 mg/m^3
108	Demeton	8065-48-3	10 mg/m^3
109	Diacetone alcohol	123-42-2	1800 ppm *

110	Diazomethane	334-88-3	2 ppm
111	Diborane	19287-45-7	15 ppm
112	1,2-Dibromo-3-chloropropane	96-12-8	Ca
113	Dibutyl phosphate	107-66-4	30 ppm
114	Dibutylphthalate	84-74-2	4000 mg/m^3
115	0-Dichlorobenzene	95-50-1	200 ppm
116	p-Dichlorobenzene	106-46-7	150 ppm
117	3,3'-Dichlorobenzidine	91-94-1	Ca
118	Dichlorodifluoromethane	75-71-8	15000 ppm
119	1,3-Dichloro-5,5- dimethylhydantoin	118-52-5	5 mg/m^3
120	1,1-Dichloroethane	75-34-3	3000 ppm
121	1,2-Dichloroethylene	540-59-0	1000 ppm
122	Dichloroethyl ether	111-44-4	100 ppm
123	Dichloromonofluoromethane	75-43-4	5000 ppm
124	1,1-Dichloro-1-nitroethane	594-72-9	25 ppm
125	Dichlorotetrafluoroethane	76-14-2	15000 ppm
126	Dichlorvos	62-73-7	100 mg/m^3
127	Dieldrin	60-57-1	50 mg/m^3
128	Diethylamine	109-89-7	200 ppm
129	2-Diethylaminoethanol	100-37-8	100 ppm
130	Difluorodibromomethane (Halon 1202)	75-61-6	2000 ppm
131	Diglycidyl ether	2238-07-5	10 ppm
132	Diisobutyl ketone	108-83-8	500 ppm
133	Diisopropylamine	108-18-9	200 ppm
134	Dimethyl acetamide	127-19-5	300 ppm
135	Dimethylamine	124-40-3	500 ppm
136	4-Dimethylaminoazobenzene	60-11-7	Ca
137	Dimethylaniline	121-69-7	100 ppm
138	Dimethyl-1, 2-dibromo-2, 2-dichlorethyl phosphate	300-76-5	200 mg/m^3
139	Dimethylformamide	68-12-2	500 ppm
140	1,1-Dimethylhydrazine	57-14-7	15 ppm
141	Dimethylphthalate	131-11-3	2000 mg/m^3
142	Dimethyl sulfate	77-78-1	7 ppm
143	Dinitrobenzene (all isomers)	100-25-4	50 mg/m^3
144	Dinitro-o-cresol	534-52-1	5 mg/m^3
145	Dinitrotoluene	25321-14-6	50 mg/m^3
146	Di-sec octyl phthalate	117-81-7	5000 mg/m^3
147	Dioxane	123-91-1	500 ppm

148	Diphenyl	92-52-4	100 mg/m^3
149	Dipropylene glycol methyl ether	34590-94-8	600 ppm
150	Endrin	72-20-8	2 mg/m^3
151	Epichlorohydrin	106-89-8	75 ppm
152	EPN (ethyl p-nitrophenyl thionobenzene phosphonate)	2104-64-5	5 mg/m^3
153	Ethanolamine	141-43-5	30 ppm
154	2-Ethoxyethanol	110-80-5	500 ppm
155	2-Ethoxyethyl acetate	111-15-9	500 ppm
156	Ethyl acetate	141-78-6	2000 ppm*
157	Ethyl acrylate	140-88-5	300 pm
158	Ethylamine	75-04-7	600 ppm
159	Ethyl benzene	100-41-4	800 ppm*
160	Ethyl bromide	74-96-4	2000 ppm
161	Ethyl butyl ketone	106-35-4	1000 ppm
162	Ethyl chloride	75-00-3	3800 ppm *
163	Ethylene chlorohydrin	107-07-3	7 ppm
164	Ethylenediamine	107-15-3	1000 ppm
165	Ethylene dibromide	106-93-4	100 ppm
166	Ethylene dichloride	107-06-2	50 ppm
167	Ethylene glycol dinitrate	628-96-6	75 mg/m^3
168	Ethyleneimine	151-56-4	100 ppm
169	Ethylene oxide	75-21-8	800 ppm
170	Ethyl ether	60-29-7	1900 ppm*
171	Ethyl formate	109-94-4	1500 ppm
172	Ethyl mercaptan	75-08-1	500 ppm
173	N-Ethylmorpholine	100-74-3	100 ppm
174	Ethyl silicate	78-10-4	700 ppm
175	Ferbam	14484-64-1	800 mg/m^3
176	Ferrovanadium dust	12604-58-9	500 mg/m^3
177	Fluorides (NaF)	7681-49-4	250 mg F/m^3
178	Fluorides (Na3AlF6)	15096-52-3	250 mg F/m^3
179	Fluorine	7782-41-4	25 ppm
180	Fluorotrichloromethane	75-69-4	2000 ppm
181	Formaldehyde	50-00-0	20 ppm
182	Formic acid	64-18-6	30 ppm
183	Furfural	98-01-1	100 ppm

184	Furfuryl alcohol	98-00-0	75 ppm
185	Glycidol	556-52-5	150 ppm
186	Graphite	7782-42-5	1250 mg/m^3
187	Hafnium and compounds	7440-58-6	50 mg Hf/m^3
188	Halon 1211	353-59-3	none (20000 ppm)**
189	Halon 1301 (Trifluorobromomethane)	75-63-8	40000 ppm
190	Heptachlor	76-44-8	35 mg/m^3
191	n-Heptane	142-82-5	750 ppm
192	Hexachloroethane	67-72-1	300 ppm
193	Hexachloronaphthalene	1335-87-1	2 mg/m^3
194	n-Hexane	110-54-3	1100 ppm*
195	2-Hexanone	591-78-6	1600 ppm
196	Hexone	108-10-1	500 ppm
197	sec-Hexyl acetate	108-84-9	500 ppm
198	Hydrazine	302-01-2	50 ppm
199	Hydrogen bromide	10035-10-6	30 ppm
200	Hydrogen chloride	7647-01-0	50 ppm
201	Hydrogen cyanide	74-90-8	50 ppm
202	Hydrogen fluoride	7664-39-3	30 ppm
203	Hydrogen peroxide	7722-84-1	75 ppm
204	Hydrogen selenide	7783-07-5	1 ppm
205	Hydrogen sulfide	7783-06-4	100 ppm
206	Hydroquinone	123-31-9	50 mg/m^3
207	Iodine	7553-56-2	2 ppm
208	Iron oxide dust and fume	1309-37-1	2500 mg Fe/m^3
209	Isoamyl acetate	123-92-2	1000 ppm
210	Isoamyl alcohol (primary)	123-51-3	500 ppm
211	Isoamyl alcohol (secondary)	528-75-4	500 ppm
212	Isobutyl acetate	110-19-0	1300 ppm*
213	Isobutyl alcohol	78-83-1	1600 ppm
214	Isophorone	78-59-1	200 ppm
215	Isopropyl acetate	108-21-4	1800 ppm
216	Isopropyl alcohol	67-63-0	2000 ppm*
217	Isopropylamine	75-31-0	750 ppm
218	Isopropyl ether	108-20-3	1400 ppm*
219	Isopropyl glycidyl ether	4016-14-2	400 ppm

220	Ketene	463-51-4	5 ppm
221	Lead	7439-92-1	100 mg Pb/m^3
222	Lindane	58-89-9	50 mg/m^3
223	Lithium hydride	7580-67-8	0.5 mg/m^3
224	L.P.G. (Liquified petroleum gas)	68476-85-7	2000 ppm *
225	Magnesium oxide fume	1309-48-4	750 mg/m^3
226	Malathion	121-75-5	250 mg/m^3
227	Maleic anhydride	108-31-6	10 mg/m^3
228	Manganese compounds	7439-96-5	500 mg Mn/m^3
229	Mercury vapor and compounds	7439-97-6	10 mg Hg/m^3
230	Mercury (organo) alkyl compounds	varies	2 mg Hg/m^3
231	Mesityl oxide	141-79-7	1400 ppm *
232	Methoxychlor	72-43-5	5000 mg/m^3
233	Methyl acetate	79-20-9	3100 ppm
234	Methyl acetylene	74-99-7	1700 ppm*
235	Methyl acetylene-propadiene mixture	59355-75-8	3400 ppm*
236	Methyl acrylate	96-33-3	250 ppm
237	Methylal	109-87-5	2200 ppm*
238	Methyl alcohol	67-56-1	6000 ppm
239	Methylamine	74-89-5	100 ppm
240	Methyl (n-amyl) ketone	110-43-0	800 ppm
241	Methyl bromide	74-83-9	250 ppm
242	Methyl Cellosolve®	109-86-4	200 ppm
243	Methyl Cellosolve® acetate	110-49-6	200 ppm
244	Methyl chloride	74-87-3	2000 ppm
245	Methyl chloroform	71-55-6	700 ppm
246	Methylcyclohexane	108-87-2	1200 ppm*
247	Methylcyclohexanol	25639-42-3	500 ppm
248	o-Methylcyclohexanone	583-60-8	600 ppm
249	Methylene bisphenyl isocyanate	101-68-8	75 mg/m^3
250	Methylene chloride	75-09-2	2300 ppm
251	Methyl formate	107-31-3	4500 ppm
252	5-Methyl-3-heptanone	541-85-5	100 ppm
253	Methyl hydrazine	60-34-4	20 ppm
254	Methyl iodide	74-88-4	100 ppm
255	Methyl isobutyl carbinol	108-11-2	400 ppm
256	Methyl isocyanate	624-83-9	3 ppm

257	Methyl mercaptan	74-93-1	150 ppm
258	Methyl methacrylate	80-62-6	1000 ppm
259	alpha-Methyl styrene	98-83-9	700 ppm
260	Mica (containing <1% quartz)	12001-26-2	1500 mg/m^3
261	Molybdenum (soluble compounds)	7439-93-7	1000 mg Mo/m^3
262	Molybdenum (insoluble compounds)	7439-93-7	5000 mg Mo/m^3
263	Monomethyl aniline	100-61-8	100 ppm
264	Morpholine	110-91-8	1400 ppm*
265	Naphtha (coal tar)	8030-30-6	1000 ppm*
266	Naphthalene	91-20-3	250 ppm
267	alpha-Naphthylamine	134-32-7	Ca
268	beta-Naphthylamine	91-59-8	Ca
269	Nickel Carbonyl	13463-39-3	2 ppm
270	Nickel metal and compounds	7440-02-0	10 mg Ni/m^3
271	Nicotine	54-11-5	5 mg/m^3
272	Nitric acid	7697-37-2	25 ppm
273	Nitric oxide	10102-43-9	100 ppm
274	p-Nitroaniline	100-01-6	300 mg/m^3
275	Nitrobenzene	98-95-3	200 ppm
276	4-Nitrobiphenyl	92-93-3	Ca
277	p-Nitrochlorobenzene	100-00-5	100 mg/m^3
278	Nitroethane	79-24-3	1000 ppm
279	Nitrogen dioxide	10102-44-0	20 ppm
280	Nitrogen trifluoride	7783-54-2	1000 ppm
281	Nitroglycerine	55-63-0	75 mg/m^3
282	Nitromethane	75-52-5	750 ppm
283	1-Nitropropane	108-03-2	1000 ppm
284	2-Nitropropane	79-46-9	100 ppm
285	N-Nitrosodimethylamine	62-75-9	Ca
286	p-Nitrotoluene	88-72-2;99-08-1;99-99-0	200 ppm
287	Octachloronaphthalene	2234-13-1	unknown
288	Octane	111-65-9	1000 ppm*
289	Oil mist (mineral)	8012-95-1	2500 mg/m^3
290	Osmium tetroxide	20816-12-0	1 mg Os/m^3
291	Oxalic acid	144-62-7	500 mg/m^3
292	Oxygen difluoride	7783-41-7	0.5 ppm
293	Ozone	10028-15-6	5 ppm

294	Paraquat	1910-42-5	1 mg/m^3
295	Parathion	56-38-2	10 mg/m^3
296	Pentaborane	19624-22-7	1 ppm
297	Pentachloronaphthalene	1321-64-8	unknown
298	Pentachlorophenol	87-86-5	2.5 mg/m^3
299	n-Pentane	109-66-0	1500 ppm*
300	2-Pentanone	107-87-9	1500 ppm
301	Perchloromethyl mercaptan	594-42-3	10 ppm
302	Perchloryl fluoride	7616-94-6	100 ppm
303	Petroleum distillates (naphtha)	8002-05-9	1100 ppm*
304	Phenol	108-95-2	250 ppm
305	p-Phenylene diamine	106-50-3	25 mg/m^3
306	Phenyl ether (vapor)	101-84-8	100 ppm
307	Phenyl ether-biphenyl mixture (vapor)	8004-13-5	10 ppm
308	Phenyl glycidyl ether	122-60-1	100 ppm
309	Phenylhydrazine	100-63-0	15 ppm
310	Phosdrin®	7786-34-7	4 ppm
311	Phosgene	75-44-5	2 ppm
312	Phosphine	7803-51-2	50 ppm
313	Phosphoric acid	7664-38-2	1000 mg/m^3
314	Phosphorus (yellow)	7723-14-0	5 mg/m^3
315	Phosphorus pentachloride	10026-13-8	70 mg/m^3
316	Phosphorus pentasulfide	1314-80-3	250 mg/m^3
317	Phosphorus trichloride	7719-12-2	25 ppm
318	Phthalic anhydride	85-44-9	60 mg/m^3
319	Picricacid	88-89-1	75 mg/m^3
320	Pindone	83-26-1	100 mg/m^3
321	Platinum (soluble salts)	varies	4 mg Pt/m^3
322	Portland cement	65997-15-1	5000 mg/m^3
323	Propane	74-98-6	2100 ppm*
324	beta-Propiolactone	57-57-8	Ca
325	n-Propyl acetate	109-60-4	1700 ppm
326	n-Propyl alcohol	71-23-8	800 ppm
327	Propylene dichloride	78-87-5	400 ppm
328	Propylene imine	75-55-8	100 ppm
329	Propylene oxide	75-56-9	400 ppm
330	n-Propyl nitrate	627-13-4	500 ppm
331	Pyrethrum	8003-34-7	5000 mg/m^3
332	Pyridine	110-86-1	1000 ppm

333	Quinone	106-51-4	100 mg/m3
334	Rhodium (metal fume & insoluble)	7440-16-6	100 mg Rh/m3
335	Rhodium (soluble compounds)	7440-16-6	2 mg Rh/m3
336	Ronnel	299-84-3	300 mg/m3
337	Rotenone	83-79-4	2500 mg/m3
338	Selenium compounds	7782-49-2	1 mg Se/m3
339	Selenium hexafluoride	7783-79-1	2 ppm
340	Silica, amorphous	7631-86-9	3000 mg/m3
341	Silica, crystalline dust (cristobalite,tridymite)	14808-60-7	25 mg/m3
342	Silica, crystalline dust (quartz, tripoli)	14808-60-7	50 mg/m3
343	Silver (metal dust and soluble compounds)	7440-22-4	10 mg Ag/m3
344	Soapstone (with <1% quartz)	none	3000 mg/m3
345	Sodium fluoroacetate	62-74-8	2.5 mg/m3
346	Sodium hydroxide	1310-73-2	10 mg/m3
347	Stibine	7803-52-3	5 ppm
348	Stoddard solvent	8052-41-3	20000 mg/m3
349	Strychnine	57-24-9	3 mg/m3
350	Styrene	100-42-5	700 ppm
351	Sulfur dioxide	7446-09-5	100 ppm*
352	Sulfuric acid	7664-93-9	15 mg/m3
353	Sulfur monochloride	10025-67-9	5 ppm
354	Sulfur pentafluoride	5714-22-7	1 ppm
355	Sulfuryl fluoride	2699-79-8	200 ppm
356	2,4,5-T (2,4,5 Trichlorophenoxyacetic acid)	93-76-5	250 mg/m3
357	Talc (with no asbestos and <1% quartz)	14807-96-6	1000 mg/m3
358	Tantalum (metal and oxide dust)	7440-25-7	2500 mg Ta/m3
359	TEDP (tetraethyl dithionopyrophosphate)	3689-24-5	10 mg/m3
360	Tellurium and compounds	13494-80-9	25 mg Te/m3
361	Tellurium hexafluoride	7783-80-4	1 ppm
362	TEPP (tetraethyl pyrophosphate)	107-49-3	5 mg/m3
363	Terphenyls	26140-60-3	500 mg/m3
364	1,1,2,2-Tetrachloro-1,2- difluoroethane	76-12-0	2000 ppm
365	1,1,1,2-Tetrachloro-2,2- difluoroethane	76-11-9	2000 ppm

366	1,1,2,2-Tetrachloroethane	79-34-5	100 ppm
367	Tetrachloroethylene	127-18-4	150 ppm
368	Tetrachloronaphthalene	1335-88-2	unknown
369	Tetraethyl lead	78-00-2	40 mg Pb/m^3
370	Tetrahydrofuran	109-99-9	2000 ppm*
371	Tetramethyl lead	75-74-1	40 mg Pb/m^3
372	Tetramethyl succinonitrile	3333-52-6	.5 ppm
373	Tetranitromethane	509-14-8	4 ppm
374	Tetryl	479-45-8	750 mg/m^3
375	Thallium (soluble compounds)	7440-28-0	15 mg Tl/m^3
376	Thiram	137-26-8	100 mg/m^3
377	Tin (inorganic compounds except oxides)	7440-31-5	100 mg Sn/m^3
378	Tin (organic compounds)	7440-31-5	25 mg Sn/m^3
379	Titanium dioxide	13463-67-7	5000 mg/m^3
380	Toluene	108-88-3	500 ppm
381	Toluene-2,4-diisocyanate	584-84-9	2.5 ppm
382	o-Toluidine	95-53-4	50 ppm
383	Tributyl phosphate	126-73-8	30 ppm
384	1,1,2-Trichloroethane	79-00-5	100 ppm
385	Trichloroethylene	79-01-6	1000 ppm
386	Trichloronaphthalene	1321-65-9	(unknown)
387	1,2,3-Trichloropropane	96-18-4	100 ppm
388	1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	2000 ppm
389	Triethylamine	121-44-8	200 ppm
390	2,4,6-Trinitrotoluene	118-96-7	500 mg/m^3
391	Triorthocresyl phosphate	78-30-8	40 mg/m^3
392	Triphenyl phosphate	115-86-6	1000 mg/m^3
393	Turpentine	8006-64-2	800 ppm
394	Uranium (insoluble compounds)	7440-61-1	10 mg U/m^3
395	Uranium (soluble compounds)	7440-61-1	10 mg U/m^3
396	Vanadium pentoxide (dust)	1314-62-1	35 mg V/m^3
397	Vanadium pentoxide (fume)	1314-62-1	35 mg V/m^3
398	Vinyl chloride	75-01-4	Ca
399	Vinyl toluene	25013-15-4	400 ppm
400	Warfarin	81-81-2	100 mg/m^3

401	Xylenes (o-, m-, and p- isomers)	1330-20-7	900 ppm
402	Xylidine	1300-73-8	50 ppm
403	Yttrium compounds	7440-65-5	500 mg Y/m^3
404	Zinc chloride fume	7646-85-7	50 mg/m^3
405	Zinc oxide fume	1314-13-2	500 mg/m^3
406	Zirconium compounds	7440-67-7	50 mg Zr/m^3

†CAS - Chemical Abstract Service registy number

Ca - Carginogen, no IDLH established.

* IDLH based on 10% of the LEL

** Toxicity limit based on Nureg/Cr-5669

Appendix B. AIHA Odor Detection Thresholds and NIOSH IDLH Values

Chemical Name	CAS Number†	Odor Threshold ppm	IDLH Values ppm
Acetaldehyde	75-07-0	0.067	2000
Acetic acid	64-19-7	0.074	50
Acetic anhydride	108-24-7	<0.14	200
Acetone	67-64-1	62	2500
Acetonitrile	75-05-8	1160	500
Acrolein	107-02-8	1.8	2
Acrylonitrile	107-13-1	1.6	85
Allyl alcohol	107-18-6	1.7	20
Ammonia	7664-41-7	17	300
Aniline and homologs	62-53-3	2.4	100
Benzene	71-43-2	61	500
Benzyl chloride	100-44-7	0.041	10
1,3-Butadiene	106-99-0	0.45	2000
2-Butanone	78-93-3	16	3000
2-Butoxyethanol	111-76-2	0.1	700
n-Butyl acetate	123-86-4	0.31	1700
n-Butyl alcohol	71-36-3	1.2	1400
sec-Butyl alcohol	78-92-2	3.2	2000
tert-Butyl alcohol	75-65-0	960	1600
Butylamine	109-73-9	0.08	300
Butyl mercaptan	109-79-5	0.001	500
Carbon tetrachloride	56-23-5	252	200
Chlorine	7782-50-5	0.08	10
Chlorobenzene	108-90-7	1.3	1000
Chloroform	67-66-3	192	500
Cresol (all isomers)	1319-77-3	0.0006	250
Crotonaldehyde (trans-isomer)	123-73-9	0.11	50
Cumene	98-82-8	0.032	900
Cyclohexane	110-82-7	780	1300
Cyclohexanol	108-93-0	0.16	400
Cyclohexanone	108-94-1	3.5	700
Diacetone alcohol	123-42-2	0.27	1800
0-Dichlorobenzene	95-50-1	0.7	200
p-Dichlorobenzene	106-46-7	0.12	150
Diethylamine	109-89-7	0.053	200
2-Diethylaminoethanol	100-37-8	0.11	100
Diisobutyl ketone	108-83-8	2.8	500
Diisopropylamine	108-18-9	0.13	200
1,1-Dimethylhydrazine	57-14-7	9.2	15
Dioxane	123-91-1	12	500
2-Ethoxyethanol	110-80-5	2.7	500
2-Ethoxyethyl acetate	111-15-9	0.06	500
Ethyl acetate	141-78-6	18	2000
Ethyl acrylate	140-88-5	0.00024	300
Ethylamine	75-04-7	0.27	600
Ethylene dichloride	107-06-2	26	50
Ethylene oxide	75-21-8	420	800

Ethyl formate	109-94-4	0.66	1500
Ethyl mercaptan	75-08-1	0.00035	500
N-Ethylmorpholine	100-74-3	0.085	100
Ethyl silicate	78-10-4	3.6	700
Furfuryl alcohol	98-00-0	8	75
n-Heptane	142-82-5	230	750
Hydrazine	302-01-2	3.7	50
Hydrogen sulfide	7783-06-4	0.0094	100
Isoamyl acetate	123-92-2	0.22	1000
Isobutyl acetate	110-19-0	1.1	1300
Isobutyl alcohol	78-83-1	3.6	1600
Isophorone	78-59-1	0.19	200
Isopropyl acetate	108-21-4	4.1	1800
Isopropyl alcohol	67-63-0	43	2000
Isopropylamine	75-31-0	0.21	750
Isopropyl ether	108-20-3	0.017	1400
Mesityl oxide	141-79-7	0.17	1400
Methyl acetate	79-20-9	180	3100
Methyl alcohol	67-56-1	160	6000
Methylamine	74-89-5	4.7	100
Methyl chloroform	71-55-6	390	700
Methylene chloride	75-09-2	160	2300
Methyl formate	107-31-3	2000	4500
Methyl mercaptan	74-93-1	0.00054	150
Methyl methacrylate	80-62-6	0.049	1000
Morpholine	110-91-8	0.011	1400
Naphthalene	91-20-3	0.038	250
Nitrobenzene	98-95-3	0.37	200
1-Nitropropane	79-46-9	140	1000
Octane	108-03-2	150	1000
2-Pentanone	107-87-9	7.7	1500
Phenol	108-95-2	0.06	250
Phosphine	7803-51-2	0.14	50
n-Propyl acetate	109-60-4	0.18	1700
n-Propyl alcohol	71-23-8	5.3	800
Propylene dichloride	78-87-5	0.26	400
Propylene oxide	75-56-9	45	400
Pyridine	110-86-1	0.66	1000
Styrene	100-42-5	0.14	700
Sulfur dioxide	7446-09-5	2.7	100
1,1,2,2-Tetrachloroethane	79-34-5	7.3	100
Tetrachloroethylene	127-18-4	47	150
Tetrahydrofuran	109-99-9	31	2000
Toluene	108-88-3	1.6	500
1,1,2-Trichloroethane	79-00-5	390	100

Trichloroethylene	79-01-6	82	1000
Triethylamine	121-44-8	0.25	200
Xylene	1330-20-7	20	900

†CAS - Chemical Abstract Service registy number

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG/CR-6624

2. TITLE AND SUBTITLE

Recommendations for Revision of Regulatory Guide 1.78

3. DATE REPORT PUBLISHED

MONTH	YEAR
November	1999

4. FIN OR GRANT NUMBER

W6308

5. AUTHOR(S)

L.B. Sasser, P.M. Daling, P. Pelto, M. Yurconic

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

September 1998-September 1999

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Pacific Northwest National Laboratory
P.O. Box 999
Richland, WA 99352

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Division of Systems Analysis and Regulatory Efectiveness
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES

S. Basu, NRC Project Manager

11. ABSTRACT *(200 words or less)*

To ensure safe operation of commercial nuclear power plants, control room operators must be protected from dangers arising from possible exposure to hazardous chemicals that may be discharged as a result of equipment failure, operator errors, or events external to plant operation. Conditions must exist where accidental exposure to such materials still allows the operators to operate the plant safely. Regulatory Guide 1.78 provides guidance in assessing the control room habitability of the control room during and after a postulated external release of hazardous chemicals from mobile or stationary sources, offsite or onsite. This report provides recommendations for revising the Regulatory Guide 1.78 in two areas, namely, control room ventilation flow modeling and toxicity limit. Additionally, the report provides a value and impact analysis associated with the revision of Regulatory Guide 1.78.

In the area of ventilation flow modeling, the report recommends the use of the HABIT code, in particular, the EXTRAN module of the code. EXTRAN represents an improvement in atmospheric dispersion modeling. In the area of toxicity limits, the report recommends the use of National Institute for Occupational Safety and Health (NIOSH) Immediately Dangerous to Life and Health (IDLH) concentration values. The IDLH values, based on a 30-minute exposure level, is defined as one that is likely to cause death or immediate delayed permanent adverse health effects if no protection is afforded within 30 minutes. Control room operators are expected to use protective measures within 2 minutes after the detection of hazardous chemicals so that they will not be subjected to prolonged exposure at the IDLH concentration levels. Thus, the IDLH limits represent reasonable values to provide adequate margin of safety in protecting control room operators.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Regulatory Guide 1.78, Regulatory Guide 1.95, control room habitability, hazardous chemical release, toxic chemical release, chlorine, toxicity limits, immediately dangerous to life and health (IDLH) odor threshold, control room ventilation flow, air dispersion modeling, Gaussian plume model, meteorology, frequent shipment criterion, transportation accident statistics, value/impact assessment, regulatory efficiency

13. AVAILABILITY STATEMENT

unlimited

14. SECURITY CLASSIFICATION

(This Page) unclassified

(This Report) unclassified

15. NUMBER OF PAGES

16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FIRST CLASS MAIL
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PERMIT NO. G-67

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