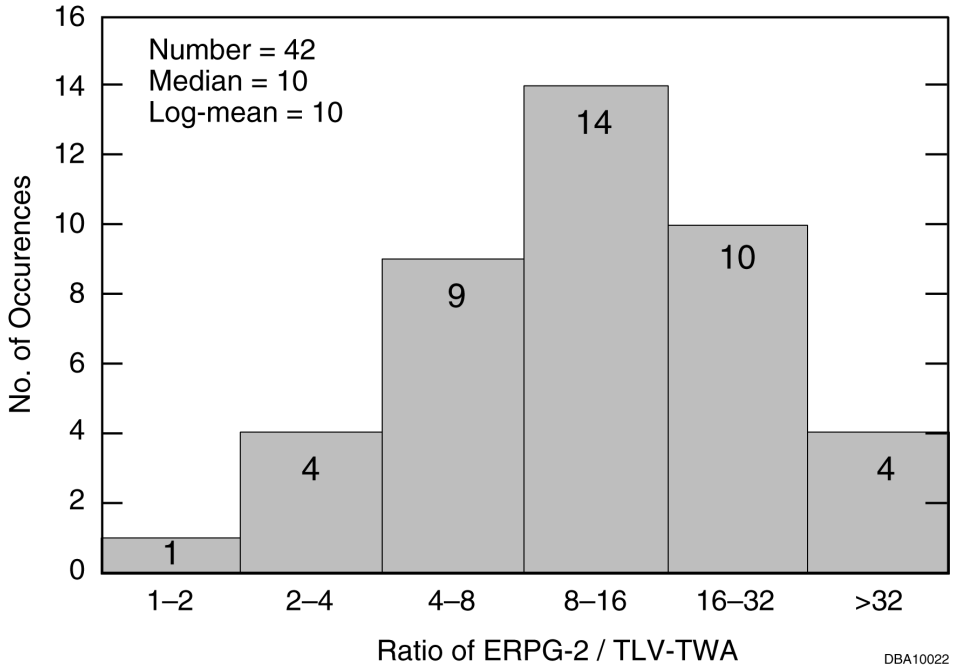
Section 4
Health Criteria

Over the past 15 years, various health criteria have been used to develop Initial Isolation Zones and PADs. Early efforts employed occupational exposure guidelines such as threshold limit values (TLVs) established by the American Conference of Governmental Industrial Hygienists (ACGIH). In more recent work (e.g., the 1990 version of the ERG), Emergency Response Planning Guidelines (ERPGs) developed by the AIHA were identified as the best available health criteria for evaluating the health significance of accidental releases. This preference was based on a number of factors, including the high quality of documentation, the consensus approach upon which the values are derived, and the consideration of exposure to the general population.

In 1990, only a limited number of ERPGs were published. Therefore, DOT sought the advice of a panel of expert toxicologists on alternative health criteria to use and on the selection order for the alternative criteria. The alternative criteria recommended by the panel included adjusted occupational exposure guidelines, other emergency exposure guidelines, and acute inhalation toxicity data. The selection order hierarchy recommended was similar to the scheme recommended by Organization Resources Counselors, Inc. (1989).

In 1995, as part of a continuing effort to improve the ERG, an analysis of the various health criteria used to develop Initial Isolation and Protective Action Distances was performed. The analysis indicated that certain health criteria were stratified when compared with ERPG-2 values. For example, as demonstrated in Figure 4.1, use of ACGIH 8-h time-weighted average TLVs (TLVs-TWA) or ACGIH ceiling TLVs (TLVs-C) resulted in significant stratification. This stratification had a significant influence on the PADs calculated by using these health criteria. As a result, efforts were undertaken to further identify and minimize sources of stratification. These efforts, which are described below, included: (1) reviewing published studies on health criteria used to evaluate accidental releases, (2) performing an independent analysis of the ERPG values, and (3) convening an independent panel of expert toxicologists to recommend uses for health criteria and ways to minimize stratification.

For the 2000ERG analysis, we left the basic framework developed for the 1996 version of the ERG unchanged. The limited changes included incorporating several new ERPGs that became available between 1996 and 1999. In addition, we studied several new materials that had been added to the TIH list to determine appropriate health criteria. We also performed an extensive literature search to determine if any new acute toxicity information was published for the materials on the TIH list in the past several years that would be relevant to our analysis. Except for the ERPG values noted above, however, no new studies relevant to our analysis were identified.



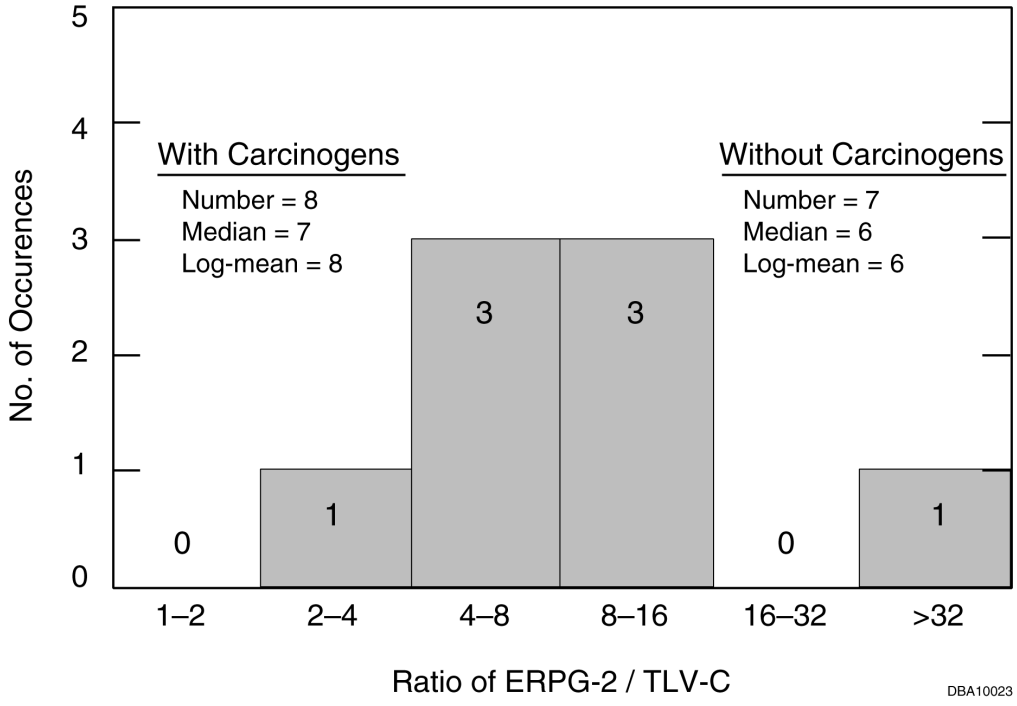


Figure 4.1 Histograms Comparing the Frequencies of ERPG-2 and TLV-TWA (both values were available for 22 chemicals) and Frequencies of ERPG-2 and TLV-C (values for 8 chemicals and a subset of 7 chemicals with the carcinogen removed)

The remainder of this chapter describes the framework developed as part of the analysis done for the 1996 version of ERG. With minor changes, this material is taken from Dunn et al. (1996).

4.1 Review of Past Development Efforts

4.1.1 Published Studies

A number of published studies compare alternative health criteria for use in evaluating accidental releases. These studies have helped to resolve several questions on the relationship between ERPGs and alternative values, which include National Institute for Occupational Safety and Health (NIOSH) immediately dangerous to life and health (IDLH) levels, National Research Council emergency exposure guidance levels (EEGLs), and occupational health guidelines.

Craig et al. (1995) calculated the ratios of ERPG-2 values to other health criteria and examined the statistical relationship between them. The mean, coefficient of variation, and coefficient of determination of these ratios were calculated. The analysis included ERPG data for 35 chemicals. None of the existing values adequately estimated ERPG-3 values. For example, National Research Council 30-min EEGLs substantially underestimated ERPG-3 values (mean ratio = 0.55), while NIOSH IDLHs overestimated ERPG-2 values (mean ratio = 2.48).

A good correlation was observed between ERPG-2 values and National Research Council 60-min EEGLs and EPA levels of concern (LOCs) (mean ratios of 0.99 and 0.82, respectively). Similarly, good correlations were observed between ERPG-2 and Occupational Safety and Health Administration (OSHA) permissible exposure limit ceiling (PEL) values and 5 times the ACGIH 8-hour TLVs (mean ratios = 1.09 and 1.05, respectively). A poor correlation was observed between ERPG-2 and ACGIH TLV-C values (mean ratio = 0.2). Data were not presented for the ratio of ERPG-2 and TLV values. However, on the basis of the good correlation with 5 times the 8-h TLVs, the correlation between ERPG-2 and unadjusted 8-h TLVs is probably very poor.

The study by Craig et al. (1995) confirms the stratification observed when unadjusted ACGIH TLV-C values, unadjusted 8-h TLV values, or 3 times the 8-h TLV values are used as surrogates for ERPG-2 values. Also, on the basis of the good correlation between the EPA LOC and ERPG-2, and since many EPA LOC values were derived by dividing the IDLH by 10 and many IDLHs were derived by dividing an LC_{50} value by 10, a relationship between the ERPG-2 and $LC_{50}/100$ is inferred.

Woudenberg and Van Der Torn (1992) performed a number of nonparametric and parametric comparisons of various exposure limits including ERPGs (3, 2, and 1), IDLHs, ACGIH short-term exposure limits (STELs), 50% decrease in mean respiratory rate (RD_{50}) values, Health and Safety Executive (HSE) specified levels of toxicity (SLOTs), and National Research Council EEGLs. Woudenberg and Van Der Torn also

calculated ratios of ERPG-3 to ERPG-2. At the time these analyses were performed, ERPG values were available for only 25 chemicals.

For ERPG-2, the nonparameteric comparison procedure identified a cluster with only EEGLs. This trend was confirmed by using parametric procedures. The ratio of mean EEGL to mean ERPG-2 was 1, with a range of 0.1 to 3.3 (N = 7). For ERPG-3, the nonparametric procedure identified a cluster with IDLHs. When the limits were scaled to a common time period, the RD_{50} was included in this cluster. The mean ERPG-3/IDLH ratio was 0.92, with a range of 0.125 to 5 (N = 16). The mean RD_{50}/ERPG-3 ratio was 2, with a range of 0.1 to 7.8 (N = 12). In the above ratios, the values are not scaled to a common time period. The ratio ERPG-2/ERPG-3 was 0.2, with a range of 0.01 to 0.4, indicating a fivefold difference between ERPG-2 and ERPG-3.

Two additional analyses were performed as part of 1996 ERG study to further improve the values used in the Guidebook. Data from 65 ERPGs were used in the analyses (N = 65). The relationship between the ratio of the key LC_{50} value and the ERPG-3 was analyzed. The key LC_{50} values were selected from the ERPG documentation, except where noted. With the exception of one chemical, dimethylamine, the LC_{50} values were for 30-min to 4-h exposure durations. Non-1-h values were adjusted to 1 h. In this study, the ranking order described in Table 4.1 (see Section 4.2) was used. The ratio of mean LC_{50} to mean ERPG-3 was 25.7, with a median of 17 and range of 3 to 168. The ratio of ERPG-3 and ERPG-2 was also analyzed. The ratio of mean ERPG-3 to mean ERPG-2 was 6.6, with a median of 5 and range of 1 to 50.

For both ratios, the median values are slightly lower than the mean values, indicating that a few high values are influencing the means. For such data, the median values, which minimize the influence of extreme values, are the best estimate of central tendency. Considering the median value, the 1-h $LC_{50}/20$ value (i.e., $0.05 \times LC_{50}$) is a reasonable approximation for the ERPG-3 value. Since ERPG-3 values are based on protection from life-threatening health effects, the relationship between LC_{50} and ERPG-3 has biological relevance. The product of the ratio of LC_{50}/ERPG-3 and ERPG-3/ERPG-2 is calculated as $17 \times 5 = 85$. Therefore, 1-h $LC_{50}/100$ values appear to be a reasonable and slightly conservative approximation for ERPG-2 values. Note that this relationship is empirical, since ERPG-2 values are based on a variety of serious health effects rather than lethality.

4.1.2 Expert Panel Review

On May 4, 1995, an independent panel of expert toxicologists convened to make recommendations on the use of health criteria for the 1996 version of the ERG. The panel made a number of recommendations for improving the consistency of criteria and for reducing stratification. They are presented below.

- Avoid using occupational health guidelines based on cancer since their use results in significant stratification.

- Avoid using occupational health guidelines based on effects other than irritation since their use introduces a similar bias.

- Using acute inhalation toxicity data (e.g., LC_{50} values) in place of occupational health guidelines probably improves the consistency of the health criteria. However, the inconsistent use of these data has a high potential of introducing bias. To increase consistency, a scheme that considers species, exposure duration differences, and data sources should be developed and uniformly applied to data on individual chemicals.

In addition, the panel recommended identifying new potential sources of information for developing the health criteria. For example, additional acute toxicity data may be found in the documentation of the AIHA ERPGs. These documents site proprietary data not included in the open literature. Also, the panel recommended making more use of ERPG values by using existing ERPGs for closely related analogs that have limited toxicity data and no ERPGs.

The recommendations from the expert panel, and information gained from the studies and analyses described above, were incorporated into an updated procedure for developing the health criteria used to calculate Initial Isolation and Protective Action Distances.

4.2 Overview of the Procedure Used to Develop Health Criteria

Modeling considerations indicated a need for three values for each chemical. These values were a 1-h life-threatening value for determining the Initial Isolation Distances, and 1-h and 15-min protective action values for determining PADs. The procedure used to derive these values is described below.

4.2.1 Use of ERPGs

When published or approved ERPGs were available for the chemical of interest, ERPG-3 and ERPG-2 were used as the 1-h life-threatening and 1-h protective action criteria, respectively. ERPG-2 $\times$ 2 was used to estimate 15-min protective criteria. Use of the twofold factor is explained in Section 4.2.2 below. If ERPGs were available for a closely related structural analog, ERPG-3 and ERPG-2 values for the structural analog were used for the chemical of interest, as described above.

4.2.2 Use of Acute Inhalation Lethality Data in Animals

When ERPGs were not available, health criteria were derived by using median lethal concentration (LC_{50}) data and lowest reported lethal concentration (LC_{LO}) data from acute inhalation studies on animals. When such data were not available for a chemical of interest, we used corresponding data for a structural analog. For example, for certain isocyanates for which there were no acute lethality data, data for methyl or butyl

isocyanate could be used. Similarly, data for boron trichloride could be used for boron tribromide.

Several factors were considered in selecting and using the LC_{50} and LC_{LO} data. These factors included species, time, data source, and structure activity considerations. These factors are discussed below and the resulting ranking of studies appears in Table 4.1.

4.2.2.1 Species Considerations

Data from studies using rats and mice were preferred for several reasons. Studies conducted with these species tend to use standardized protocols. Also, there is a wealth of comparative lethality data on rats and mice and much less comparative data on other species. Data on primates are rare, so using these data would limit the ability to compare responses across chemicals. However, acute lethal responses in this species might more closely simulate human responses. Therefore, when such data were available, they were generally included after the data for rats and mice but before data for other species, as presented in Table 4.1. The amount of comparative data on rabbits is limited. Results on this species are not as representative as data on primates, and so they appear lower in the ranking scheme.

Table 4.1 Order of Acute Lethality Data for Estimating Health Criteria

Rank	Data	Rank	Data
1	1-h LC_{50} in rats	14	2- to 4-h LC_{50} in dogs
2	2- to 4-h LC_{50} in rats	15	30 min LC_{50} in dogs
3	30-min LC_{50} in rats	16	6- to 8-h LC_{50} in dogs
4	1-h LC_{50} in mice	17	1-h LC_{50} in guinea pigs
5	2- to 4-h LC_{50} in mice	18	2- to 4-h LC_{50} in guinea pigs
6	30-min LC_{50} in mice	19	30 min LC_{50} in guinea pigs
7	6- to 8-h LC_{50} in rats	20	6- to 8-h LC_{50} in guinea pigs
8	6- to 8-h LC_{50} in mice	21	1-h LC_{50} in rabbits
9	1-h LC_{50} in primates	22	2- to 4-h LC_{50} rabbits
10	2- to 4-h LC_{50} in primates	23	30-min LC_{50} in rabbits
11	30-min LC_{50} in primates	24	6- to 8-h LC_{50} in rabbits
12	6- to 8-h LC_{50} in primates	25	1-h LC_{LO} in rats[a]
13	1-h LC_{50} in dogs	26	2- to 4-h LC_{LO} in rats, etc. [a]

[a] Rank 25 through 50 for LC_{LO} data follow the same order as Rank 1 through 24 for LC_{50} data shown.

4.2.2.2 Exposure Duration Considerations

Data from 1-h exposures were preferred, since data from this duration require no adjustments. The most commonly reported acute lethality studies are for 1-h and 4-h exposure durations. Therefore, use of data from studies of this duration provides a

measure of consistency in estimating health criteria. There is also a tendency for 1-h and 4-h LC_{50} values to have been calculated by using standard protocols. For exposures less than 30 min long, concerns over chamber equilibration time (T_{99}) increased. For exposures more than 4 h long, concerns that effects other than acute lethal effects might influence the study results increased. Limited confidence was placed on data reported as LC_{LO}. In these studies, no information was available concerning the slope of the dose response curve. Also, in some studies that used LC_{LO} values, 100% mortality was observed.

Data from non-1-h exposures were adjusted to predict results for 1-h exposures. To develop an approach for making the adjustments, various reports published by investigators who have examined the relationship between exposure duration and acute mortality response were reviewed (Doe and Milburn 1983; Haber 1924; Klimisch et al. 1987; Ten Berge et al. 1986).

In the simplest case, where the inhaled substance accumulates in the body and is not rapidly destroyed or excreted, the dose accumulated is directly proportional to the concentration *c* and the exposure time *t*, and uptake is linear. This concept, known as Habers's rule or law, would result in the following relationship:

$$W = c\,t, \tag{4.1}$$

where *W* is a constant dose specific for any given effect. This relationship is applicable for many reactive gases or highly lipid-soluble vapors over a limited range of concentrations and time.

However, many other relationships are possible. For example, for chemicals that are excreted as fast as they are inhaled and for which accumulation does not occur until a certain threshold concentration is reached, the following generalized dose-response equation applies:

$$W = (c - a)\,t^{b}, \tag{4.2}$$

where *a* is the threshold concentration and *b* is derived from experimental data.

For a significant percentage of chemicals, the following relationship has been observed:

$$LC_{50}(T_1) = LC_{50}(T_o)\left(\frac{T_1}{T_o}\right)^{1/n}, \tag{4.3}$$

where

T_1 = actual exposure time,

T_o = experimental exposure time, and

n = constant.

Klimisch et al. (1987), citing Doe and Milburn (1983), found that for many chemicals, n centers around a value of 0.5. Ten Berge et al. (1986) determined that for 18 of 20 chemicals studied, n values were greater than 0.3.

For deriving the health criteria, acute lethality data for exposure durations T_o longer than 1 h were normalized by using the following quadratic dose-response function:

$$LC_{50}(1\ hr) = LC_{50}(T_o)\left(\frac{1\ hr}{T_o}\right)^{0.5}. \tag{4.4}$$

This approach predicts lower LC_{50}/LC_{LO} values than does Habers's rule. Acute lethality data for exposure durations T_o of less than 1 h were predicted by using a linear dose-response function (i.e., Habers's rule):

$$LC_{50}(1\,hr) = LC_{50}(T_o)\left(\frac{1\ hr}{T_o}\right). \tag{4.5}$$

4.2.2.3 Data Source Considerations

The source of the data is critical. Information from main-stream, peer-reviewed toxicology and industrial hygiene journals is preferable to information from auxiliary, non-peer-reviewed sources. The publication date may also be important. Many studies conducted before 1950 did not include analytical verification of concentrations. Information from foreign journals tends to contain more transposition errors, especially as cited in the NIOSH Registry of Toxic Effects of Chemical Substances.

4.2.2.4 Adjustment Factors

As described in Section 4.1, the 1-h LC_{50} or adjusted 1-h $LC_{50}/100$ is a reasonable estimate of ERPG-2. Also, a fivefold factor is a reasonable central tendency adjustment factor between ERPG-2 and ERPG-3. Therefore, 1-h or adjusted 1-h LC_{50} or LC_{LO} values were divided by 100 to estimate 1-h protective health criteria, and this value was multiplied by 5 to estimate the 1-h life-threatening health criteria.

Members of the AIHA ERPG Committee indicate that when 1-h ERPGs are extrapolated to values of shorter duration, there is concern that the potential effects of peak, high-level exposures should be minimized. A default value of 2 was suggested for these purposes. Therefore, to estimate 15-min protective health criteria from 1-h values, a factor of 2 was employed in estimating the 15-min criteria from the 1-h criteria.

4.2.3 Use of Alternative Health Criteria

For a few select chemicals, National Research Council EEGLs, Emergency Exposure Levels (EELs) published in the *AIHA Journal*, ACGIH 8-h TLVs, or ACGIH TLV-C values were used to develop health criteria. For one chemical, data on oral LD_{50} in animals were used to estimate an LC_{50} value and to derive health criteria. Standard assumptions of animal inhalation rate and body weight were used.

4.2.4 Summary

By building on past efforts, an updated procedure was developed to provide health criteria for use in determining Initial Isolation and Protective Action Distances. The new procedure incorporated additional ERPG values published since 1992 and expanded the use of existing ERPGs by applying them to structural analogs that otherwise had limited or no available acute toxicity data. A strategy was developed to reduce the stratification of PADs according to health criteria. The strategy involved minimizing the use of occupational health criteria through increased use of acute lethality data and more consistent selection and use of acute lethality data.

The updated procedure was used to develop health criteria for 163 chemicals. A summary of the basis for health criteria appears in Table 4.2. Documentation of the health criteria for individual chemicals is presented in Appendix B. For 56 chemicals (34% of them), ERPGs or ERPGs for a structurally similar chemical formed the basis of the health criteria. For 90 chemicals (55%), LC_{50} values or LC_{50} values for a structurally similar chemical were used to develop the health criteria. For 11 chemicals (7%), LC_{50} or LC_{LO} values for a structurally similar chemical formed the basis of the health criteria. Alternative health-based values, including National Research Council EEGLs, AIHA EELs, and ACGIH TLVs were used to develop criteria for only 5 chemicals (3%). For 1 chemical, oral toxicity data were used to estimate an inhalation LC_{50} and to derive the health criteria.

The increased use of ERPGs and LC_{50} values and decreased reliance on alternative health-based values (e.g., TLVs) as a basis for the health criteria was consistent with the opinions of the expert panel. Use of the updated approach reduced the stratifications found as a result of previous efforts.

4.3 Comparison to Other Procedures

A number of other procedures have been developed for deriving health criteria used in evaluating accidental releases of chemicals. These include procedures developed by the EPA for deriving LOCs to evaluate releases of extremely hazardous substances (EPA 1991) and other procedures developed by the EPA for performing consequence analyses to comply with requirements of Section 112 R of the Clean Air Act (EPA 1996).

In the EPA LOC procedure, the NIOSH/OSHA IDLH/10 is the preferred value for deriving the LOC. Since IDLHs were developed during the Standards Completion

Table 4.2 Summary of the Basis for Health Criteria Used to Prepare 2000ERG

Basis of Health Criteria	No. of Chemicals	Percentage
ERPG for chemical of concern	37	23
ERPG for structurally similar chemical	19	12
Subtotal for ERPGs	56	34
LC_{50} for chemical of concern	81	50
LC_{50} for structurally similar chemical	9	6
Subtotal for LC_{50}s	90	55
LC_{LO} for chemical of concern	10	6
LC_{LO} for structurally similar chemical	1	<1
Subtotal for LC_{LO}s	11	7
AIHA EEL	3	2
National Research Council EEGL	1	<1
ACGIH TLV for structurally similar chemical	1	<1
Subtotal for alternative health-based values	5	3
Oral toxicity data	1	<1
Total	163	100

Program for the purpose of selecting respirators in the event of an emergency in the work place, the tenfold uncertainty factor is intended to account for the greater sensitivity of the general population versus the worker population. When IDLHs are unavailable, estimated IDLHs based on $LC_{50}/100$, LC_{LO}, $LD_{50}/100$, or $LD_{LO}/100$ are used. As a third choice, ACGIH TLVs (8-h TLV-TWA, STEL, and TLV-C values) and National Research Council EEGLs are also used to derive a number of LOCs. AIHA ERPGs were cited as alternative criteria to use to develop LOCs. However, because only 15 draft ERPGs were available at the time the LOC guidance was developed, ERPGs did not form the basis for any LOC.

In the procedure described by NIOSH to develop IDLHs, human data are preferred. However, since reliable human data are rarely available, many of the IDLHs are based on adjusting the results of acute inhalation lethality data in animals to a 30-min exposure duration by using the calculation LC_{50} (30 min) = LC_{50} (T) × $(T/0.5)^{1/3}$, then dividing by 10. Therefore, many LOCs are based on adjusted LC_{50} or LC_{LO} data divided by 100.

Several similarities exist between the procedure used by the EPA to develop LOCs and the procedure used by DOT to develop health criteria for deriving Isolation and Protection Action Distances. Many LOC and DOT 1-h protective levels are based on adjusted LC_{50} or LC_{LO} values divided by 100. Also, various alternative values such as

National Research Council EEGLs and ACGIH TLVs are considered as "last resort" criteria.

There are also several important differences in these two procedures. In the DOT approach, AIHA ERPGs are the preferred choice for deriving health criteria. We believe this to be a sounder approach, since ERPG values are considered by many authorities to be the best available criteria for evaluating accidental releases. Also, in the DOT procedure, when it was necessary to use acute lethality data in animals, a critical review of the available data was performed, which included a scheme for selecting the best study when multiple studies were available. In the DOT approach, when LC_{LO} data were employed, use of a hundredfold instead of a tenfold uncertainty factor was maintained. This recommendation was based on the concept that a significant number of LC_{LO} values represent concentrations that produced a significant percentage of mortality, including 100% mortality.

In the approach described in the guidance document for off-site consequence analysis (EPA 1996), ERPGs are recommended as the preferred values, followed by LOC values. Since ERPGs are recommended as first priority in the DOT scheme, followed by the time-adjusted $LC_{50}/100$, and many LOCs are based on $LC_{50}/100$, the two approaches are quite similar. However, as described above, there are differences in the methods used to select the acute lethality data.

4.4 Future Modifications

Through efforts of the AIHA ERPG Committee, ERPGs for additional chemicals will be provided in the future. The committee plans to publish approximately 10 new ERPGs per year. Not all of the chemicals on the ERPG list appear in the Table of Initial Isolation and Protective Action Distances, since many of the ERPG chemicals do not meet the specific toxicity and physical criteria for listing in the Table. However, when new ERPGs are available for chemicals on the DOT table, the values will be incorporated into the development of Isolation and Protective Action Distances in future additions of the ERG.

A National Advisory Committee for Acute Exposure Guidance Levels (AEGLs) was approved in 1995. Its first meeting was held on June 19–21, 1996. The committee is composed of scientists representing federal, state, and local agencies and organizations from the private sector with an interest in emergency planning, prevention, and response programs for acutely toxic chemicals. The purpose of the committee is to develop AEGLs that will meet the needs of various organizations (EPA, DOT, DOD, DOE, NIOSH, OSHA, Agency for Toxic Substances Disease Registry, industry). The National Research Council framework will be used to develop the AEGLs. Several draft AEGLs were available at the time of the 2000ERG work; however, no final values are available. When final consensus AEGL values are available, they will be incorporated into future ERG development.

4.5 Glossary for Chapter 4

ACGIH 8-hour TLV: American Conference of Governmental Industrial Hygienists 8-hour threshold limit value (ACGIH 1995). The time-weighted average concentration to which nearly all workers may be repeatedly exposed, day after day, without adverse effect.

ACGIH TLV STEL: American Conference of Governmental Industrial Hygienists short-term exposure limit (ACGIH 1995). The concentration to which workers can be exposed continuously for a short period of time without suffering from (1) irritation, (2) chronic or irreversible tissue damage, or (3) narcosis of sufficient degree to increase the likelihood of accidental injury, impair self-rescue, or materially reduce work efficiency, provided that the daily TLV-TWA is not exceeded.

ACGIH TLV Ceiling: American Conference of Governmental Industrial Hygienists threshold limit value ceiling (ACGIH 1995). The concentration that should not be exceeded during any part of the working exposure.

AIHA EEL: Emergency Exposure Level published in the *American Industrial Hygiene Association Journal* (Frawley et al. 1964). The concentrations of contaminant that can be tolerated without adversely affecting health but not necessarily without acute discomfort or other evidence of irritation or intoxication. The level is intended to provide guidance in managing single, brief exposures to airborne contaminants in the working environment.

AIHA ERPGs: American Industrial Hygiene Association Emergency Response Planning Guidelines (AIHA 1999).

ERPG-3: The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 h without experiencing or developing life-threatening health effects.

ERPG-2: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 h without experiencing or developing irreversible or other serious health effects, or symptoms that could impair an individual's ability to take protective action.

ERPG-1: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 h without experiencing other than mild, transient adverse health effects or perceiving a clearly defined objectionable odor.

EPA LOC: U.S. Environmental Protection Agency level of concern (EPA 1991). The concentration of an extremely hazardous substance in the air above which there may be serious irreversible health effects or death as a result of a single exposure for a relatively short period of time.

HSE SLOT: Health and Safety Executive (England) specified level of toxicity (Turner and Fairhurst 1989).

LC_{50}: median (50%) lethal concentration; lethal concentration to 50% of the exposed population.

LC_{LO}: lowest reported lethal concentration.

NIOSH IDLH: National Institute for Occupational Safety and Health immediately dangerous to life and health level (NIOSH 1994). The maximum concentration from which, in the event of respirator failure, one could escape within 30 min without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects.

NRC EEGL: National Research Council emergency exposure guidance level (National Research Council, 1984–1987). A concentration of a substance in air (as gas, vapor, or aerosol) that will permit continued performance of specific tasks during rare emergency conditions lasting for periods of 1 to 24 h.

OSHA PEL Ceiling: Occupational Safety and Health Administration permissible exposure limit ceiling (OSHA 1989). Concentration that should not be exceeded during any part of the workday.

RD_{50}: 50% decrease in mean respiratory rate.