Alberta Health

Protective Action Criteria
A Review of Their Derivation, Use, Advantages and Limitations

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About this document:

This technical document was prepared to provide background information for health professionals who may use protective action criteria. The information provided in this report is not intended to be used in place of jurisdiction-specific guidelines for acceptable/safe levels of chemical contaminants in any given media (such as air, water, soil, fish, or wildlife). A plain-language document summarizing this review is available online at: http://open.alberta.ca/publications/9781460131220.

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Executive Summary

Protective action criteria (PACs) are emergency exposure guidelines that are used before or during the unplanned release of a hazardous chemical in the air. The guidelines are intended to protect the general public, including susceptible individuals such as infants, the elderly, and those with illnesses, from health effects resulting from a rare one-time exposure to a chemical. PACs are used prior to emergencies to estimate the toxic severity of potential accident scenarios (hazard analysis or consequence analysis), or during chemical emergencies to identify potential zones of impact (threat zones) and populations that may be at risk.

The main objectives of this report are to provide background information on PACs, present a summary of real-world usage of PACs, and discuss the advantages and limitations associated with these guidelines.

The PAC dataset is a consolidated list of 3 types of emergency exposure guidelines:

- Acute Exposure Guideline Levels (AEGLs); developed by the US Environmental Protection Agency
- Emergency Response Planning Guidelines (ERPGs); developed by the American Industrial Hygiene Association
- Temporary Emergency Exposure Limits (TEELs); developed by the US Department of Energy

AEGLs and ERPGs are the preferred emergency guidelines, in that order, but are only available for a limited number of chemicals. For chemicals without AEGLs or ERPGs, TEELs are temporary guidelines used until AEGLs or ERPGs are developed. The PAC dataset indicates whether a particular value is an AEGL, an ERPG, or a TEEL. PACs are applicable to a 60-minute exposure duration (representing the total time of exposure). Additionally, there are AEGLs for durations of 10 minutes, 30 minutes, 4 hours, and 8 hours.

PACs have 3 health effect levels based on severity of symptoms. Briefly, PAC-1 (which is based on the corresponding AEGL-1, ERPG-1, or TEEL-1 value) is the threshold level for mild, transient health effects; PAC-2 (based on AEGL-2, ERPG-2, or TEEL-2) is the threshold level for irreversible or other serious health effects that could impair the ability to take protective action; and PAC-3 (based on AEGL-3, ERPG-3, or TEEL-3) is the threshold level for life-threatening health effects. Additionally, for TEELs, there is a TEEL-0 value that represents the threshold level for no adverse effects.

The main difference between AEGLs, ERPGs, and TEELs is the method in which they are derived. AEGL and ERPG development is a thorough and rigorous process involving review of all primary source data. Because of this time-consuming process, AEGLs and ERPGs have only been developed for ~270 (final, interim, and proposed) and ~145 substances, respectively. TEEL values, on the other hand, are based on secondary sources of data (existing exposure limits) and require less time to develop. Thus, TEELs are available for a large number of substances (> 3000), though are somewhat less reliable.

The types of groups or individuals using AEGLs, ERPGs, TEELs, and/or the PAC dataset include emergency planning committees, emergency responders, toxicologists, industrial hygienists, and risk assessors. Specific agencies that utilize these guidelines include Environment Canada, Transport Canada, US Environmental Protection Agency, National...

PACs are typically combined with estimates of exposure concentrations (measured directly and/or modeled using atmospheric dispersion modeling programs) to identify areas where a chemical hazard exceeds a specified threshold level. The data can then be used to estimate the severity of a chemical release, identify the potential health impact on the surrounding communities, and assist in decision-making regarding emergency responses. Examples of real-world applications for AEGLs, ERPGs, TEELs, and/or the PAC dataset as a whole were found in reports of past chemical emergencies, hazard analysis (consequence analysis) reports, and environmental impact assessments. Most accounts were related to the specific use of AEGLs and ERPGs, rather than the PAC dataset itself. Additionally, references to the usage of TEEL values were few in number. This is likely because AEGLs and ERPGs are available for commonly used chemicals that are more likely to be involved in a chemical accident, and AEGLs and ERPGs are considered more reliable and scientifically sound than TEELs.

Advantages of PACs include:

- The PAC dataset provides emergency inhalation exposure guidelines for ~3400 substances to assist in the management of chemical emergencies.
- They are intended to be protective for most of the general public including susceptible populations.
- Development of AEGL and ERPG values involves an analysis of all available toxicological data and a rigorous review process. AEGLs and ERPGs are peer-reviewed.
- TEEL values are derived using existing exposure guidelines or toxicity data and can be developed relatively quickly. In the absence of AEGLs or ERPGs, TEELs can be a useful source of information.
- PAC values have been incorporated into several atmospheric dispersion modeling programs.

Limitations of PACs include:

- AEGLs and ERPGs are available for a relatively small number of chemicals. The extensive review process involved in AEGL and ERPG derivation requires a significant amount of time and resources.
- TEEL values are not peer-reviewed and are considered less reliable than AEGLs and ERPGs.
- When using the consolidated PAC dataset, only one exposure duration is available (1 hour), which can lead to some confusion when actual exposure times are shorter or longer. This is particularly important for chemicals that do not have an AEGL (with a range of exposure durations) to refer to.
- Uncertainties in atmospheric modeling may lead to under- or over-estimations of threat zones and potentially cause problems during an emergency (e.g., evacuation areas are too small or too large). Users of the atmospheric modeling software
programs should be properly trained and have a thorough understanding of the capabilities and limitations of the program.

- PACs are not directly applicable to releases of chemical mixtures, as the potential additive, synergistic, or antagonistic effects that may result from exposure to multiple chemicals are not accounted for. Chemicals in combination may behave differently than when alone, and predicting the toxic potential of a mixture is often very difficult. A chemical mixture methodology is available for estimating the potential health impact of exposures involving multiple chemicals.

In summary, PACs are an important source of information for emergency planning and emergency response, providing toxic endpoint values that can be used to determine threat zones and estimate potential health impacts on a surrounding population. AEGLs and ERPGs are the preferred guidelines for use prior to or during a chemical emergency. However, TEELs can also be valuable when a chemical emergency occurs involving a substance with no AEGL or ERPG available.
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Abbreviations

AAQO: Ambient air quality objective
ACGIH: American Conference of Governmental Industrial Hygienists
AEGGL: Acute exposure guideline level
AIHA: American Industrial Hygiene Association
ALOHA: Areal location of hazardous atmospheres
ATSDR: Agency for Toxic Substances and Disease Registry
CAMEO: Computer-aided management of emergency operations
CA-REL: Reference exposure level (California)
CASRAM: Chemical accident statistical risk assessment model
CEGL: Continuous exposure guidance level
CEI: Chemical exposure index
CMM: Chemical mixture methodology
CSEPP: Chemical stockpile emergency preparedness program
DOE: Department of Energy (US)
E2 Regulations: Environmental Emergency Regulations (Canada)
EEGL: Emergency exposure guidance level
ERPG: Emergency response planning guideline
HSDB: Hazardous substances data bank
IDLH: Immediately dangerous to life or health
IMAAC: Interagency Modeling and Atmospheric Assessment Center
LEL: Lower explosive limit
LC50: Lethal concentration in 50% of a sample
LC10: Lethal concentration - lowest
LOAEL: Lowest-observed-adverse-effect level
LOC: Level of concern
MAK: Maximale arbeitsplat-konzentration [Maximum concentrations at the workplace] (Germany)
MRL: Minimal risk level
NAC/AEGL: National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances
NAS: National Academy of Sciences
NHSRC: National Homeland Security Research Center
NIOSH: National Institute for Occupational Safety and Health
NOAEL: No-observed-adverse-effect level
OEHHA: Office of Environmental Health Hazard Assessment (California)
OSHA: Occupational Safety and Health Administration
PAC: Protective action criteria
PAL: Provisional advisory level
PEL: Permissible exposure limit
PHAST: Process hazard analysis software tool
REL: Recommended exposure limit
RfC: Reference concentration
RTECS: Registry of toxic effects of chemical substances
SCAPA: Subcommittee on Consequence Assessment and Protective Actions
STEL: Short-term exposure limit
TC10: Toxic concentration - lowest
TD_{10}:	Toxic dose - lowest
TEEL:	Temporary emergency exposure limit
TERA:	Toxicology Excellence for Risk Assessment
TLV:	Threshold limit value
TWA:	Time-weighted average
USEPA:	United States Environmental Protection Agency
WEEL:	Workplace environmental exposure level
1. Introduction

Protective action criteria (PACs) are emergency inhalation exposure guidelines used in the planning for and response to unplanned releases of a hazardous chemical in the air. PACs are set by the US Department of Energy (DOE) and are defined as the "threshold concentration of a chemical in air at which protective action is required" [1]. The PAC dataset is a consolidated list of 3 types of emergency exposure guidelines: Acute Exposure Guideline Levels (AEGLs, developed by the US Environmental Protection Agency (USEPA)), Emergency Response Planning Guidelines (ERPGs, developed by the American Industrial Hygiene Association (AIHA)), and Temporary Emergency Exposure Limits (TEELs, developed by the DOE) [2].

PACs are used by government agencies and the private sector to evaluate the potential impact of a one-time rare exposure to a chemical. Atmospheric concentrations of the chemical (either measured or modeled) can be used in conjunction with PAC values to identify threat zones. A threat zone is defined as the geographical area where the concentration of a chemical hazard exceeds a specified level of concern (LOC) [3]. The threat zone data can be used to estimate the severity of a chemical release, identify the potential health impact on the surrounding communities, and assist in decision-making regarding emergency responses (e.g., evacuations, shelter-in-place) [1]. This information is used for emergency planning prior to a chemical event (hazard analysis or consequence analysis) or emergency response during a chemical accident.

The objectives of this report are to:

1. Provide background information on PACs (definitions, derivation of PAC values);
2. Present a summary of real-world usage of PACs;
3. Discuss the advantages and limitations associated with PACs

A literature search was conducted for white and grey material (studies, reports, news articles, websites) that discussed the development and usage of AEGLs, ERPGs, TEELs, and PACs. Scientific databases (Scopus, PubMed) and internet search engines (Google) were used for the searches. The search terms included protective action criteria (or PACs), acute exposure guideline level(s) (or AEGLs), emergency response planning guideline(s) (or ERPGs), and temporary emergency exposure limit(s) (or TEELs). The search was generally limited to data published in 2005 or later; however, earlier publications were included if considered particularly relevant.
2. Background Information on the Protective Action Criteria

PACs are made up of 3 types of emergency exposure guidelines: AEGLs, ERPGs, and TEELs. AEGLs and ERPGs are the preferred emergency guidelines, in that order, but are only available for a limited number of chemicals. For chemicals without AEGLs or ERPGs, TEELs are the temporary guidelines to be used until AEGLs or ERPGs are developed. The PAC dataset indicates whether a particular value is an AEGL, an ERPG, or a TEEL [4]. PACs are applicable to an exposure duration of 60-minutes (total exposure time). Additionally, there are AEGLs for durations of 10 minutes, 30 minutes, 4 hours, and 8 hours. The current PAC dataset, last updated in February of 2012 and available online, includes exposure guidelines for ~3400 chemicals [4]. There are currently AEGLs for ~270 chemicals (final (131), interim (130), and proposed (12)), ERPGs for ~145 chemicals, and TEELs for over 3000 chemicals [4,5,6].

For each guideline, there are 3 health effect levels based on severity of symptoms. Briefly, PAC-1 (which is based on the corresponding AEGL-1, ERPG-1, or TEEL-1 value) is the threshold level for mild, transient health effects; PAC-2 (based on AEGL-2, ERPG-2, or TEEL-2) is the threshold level for irreversible or other serious health effects that could impair the ability to take protective action; and PAC-3 (based on AEGL-3, ERPG-3, or TEEL-3) is the threshold level for life-threatening health effects [7]. Additionally, for TEELs, there is a TEEL-0 value that represents the threshold level for no adverse effects.

Specific definitions for each health effect level for AEGLs, ERPGs, and TEELs, as well as summaries of the methods for guideline derivation, are presented in Sections 2.1 to 2.3.

2.1 Acute Exposure Guideline Levels (AEGLs)

2.1.1 Definitions of AEGLs

AEGLs are developed by the National Advisory Committee for Acute Exposure Guideline Levels for Hazardous Substances (NAC/AEGL) of the USEPA. AEGLs are emergency exposure guidelines intended for the general public including susceptible populations (which the NAC/AEGL identifies as infants, children, the elderly, persons with asthma, and those with other illnesses) [8]. Guidelines are derived for 5 exposure durations (total exposure time): 10 minutes, 30 minutes, 60 minutes, 4 hours, and 8 hours.

The 3 health effect tiers for AEGLs are defined as follows:

**AEGL-1**: the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

**AEGL-2**: the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.
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AEGL-3: the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

Regarding susceptible individuals, the NAC/AEGL stated that "these exposure limits are intended to protect most individuals in the general population, including those that might be particularly susceptible to the deleterious effects of the chemicals...It is recognized that certain individuals, subject to unique and idiosyncratic responses, could experience effects at concentrations below the corresponding AEGLs" [9].

2.1.2 Derivation of AEGLs

The methodology for AEGL development is the most comprehensive of the 3 emergency guidelines (AEGLs, ERPGs, TEELs) [9]. It involves both the NAC/AEGL (which includes members from federal and state governments, international governments, academia and other organizations, labour unions, and private industry) and the National Academy of Sciences (NAS). The process includes an in-depth scientific literature search and preparation of a technical support document, followed by a rigorous public and peer review.

AEGL values for each tier are derived using data from key toxicity studies (primary reference sources only) obtained in the literature search [9]. The criteria used for selection of health endpoints for AEGL derivation are summarized in Table 1. Criteria are presented in order of preference for each AEGL tier, and examples of specific health endpoints that have been used to establish AEGL values are also provided. Briefly, the highest concentration from animal or human exposures that does not elicit the effects defined by a specific AEGL tier (the no-observed-adverse-effect level (NOAEL)) is the preferred starting point for derivation of an AEGL value. When a NOAEL is not available, the lowest-observed-adverse-effect level (LOAEL) for a response is the second choice as the starting point. For AEGL-2, when neither a NOAEL nor LOAEL is available, the AEGL-2 value may be calculated as a fraction (typically one-third) of the AEGL-3.

Development of AEGLs typically involves extrapolation methods and use of uncertainty factors and/or modifying factors. For example, exposure-time extrapolations are used in AEGL development when toxicology studies utilize exposure durations that differ from the AEGL exposure durations (10 min, 30 min, 60 min, 4 hr, 8 hr). Additionally, interspecies and intraspecies uncertainty factors are incorporated into AEGLs to account for the differences in biological response between animals and humans, and the variation in response within a human population. Likewise, modifying factors may also be incorporated into AEGLs to account for incomplete information or uncertainties in the overall database. Details on the methodology for selection of values for uncertainty or modifying factors are provided in the Standard Operating Procedures for AEGL development [9].

Table 1: Criteria used for selection of health endpoints for derivation of AEGL-1, AEGL-2, and AEGL-3 values (in order of priority) [9]

<table>
<thead>
<tr>
<th>AEGL Level</th>
<th>Criteria used for selection of health endpoints</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEGL-1</td>
<td>1. Highest experimental exposure without an AEGL-1 effect (NOAEL)</td>
</tr>
<tr>
<td></td>
<td>e.g., sensory irritation, altered pulmonary function, narcosis in humans</td>
</tr>
<tr>
<td>AEGL Level</td>
<td>Criteria used for selection of health endpoints</td>
</tr>
<tr>
<td>------------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>2. Effect level for a response (LOAEL)</td>
</tr>
<tr>
<td></td>
<td>e.g., odour detection, mild sensory irritation, methemoglobin formation (22%), transient changes in pulmonary function</td>
</tr>
<tr>
<td></td>
<td>3. No value established</td>
</tr>
<tr>
<td></td>
<td>(due to insufficient data or because levels that are 'detectable' approach or exceed an AEGL-2 value)</td>
</tr>
<tr>
<td>AEGL-2</td>
<td>1. Highest experimental exposure without an AEGL-2 effect (NOAEL)</td>
</tr>
<tr>
<td></td>
<td>e.g., decreased hematocrit, kidney pathology, behavioral changes</td>
</tr>
<tr>
<td></td>
<td>2. Effect level for a response that was not incapacitating or not irreversible (LOAEL)</td>
</tr>
<tr>
<td></td>
<td>e.g., overt ocular or respiratory irritation, dyspnea, pulmonary function changes, provocation of asthma episodes, respiratory tract pathology, mild narcosis, methemoglobin formation (40%)</td>
</tr>
<tr>
<td></td>
<td>3. A fraction (typically one-third) of the AEGL-3 value</td>
</tr>
<tr>
<td>AEGL-3</td>
<td>1. Highest exposure level that does not cause lethality (NOAEL)</td>
</tr>
<tr>
<td></td>
<td>2. Effect level for a severe response (LOAEL)</td>
</tr>
<tr>
<td></td>
<td>e.g., decreased hematocrit, methemoglobin formation (70-80%), cardiac pathology, severe respiratory pathology</td>
</tr>
</tbody>
</table>

2.2 Emergency Response Planning Guidelines (ERPGs)

2.2.1 Definitions of ERPGs

ERPGs are emergency inhalation exposure guidelines developed by the AIHA [10]. ERPGs are derived for 1-hour exposure durations, and the 3 health severity levels are defined as follows:

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

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

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

The AIHA provided the following statement regarding the target population (i.e., ‘nearly all individuals’) for ERPGs [11]:

"The values derived for ERPGs should not be expected to protect everyone but should be applicable to most individuals in the general population. In all populations there are hypersensitive individuals who will show adverse responses at exposure concentration below levels where most individuals normally would respond. Furthermore, since these values have been derived as planning and emergency response guidelines, not exposure..."
guidelines, they do not contain the safety factors sometimes incorporated into exposure guidelines. Instead, they are estimates, by the committee, of the thresholds above which there would be an unacceptable likelihood of observing the defined effects.”

2.2.2 Derivation of ERPGs

ERPGs are developed in a similar manner to AEGLs; the process includes a comprehensive literature search, preparation of a technical support document, and committee and public reviews [11]. Draft ERPG documents may be prepared by any person, agency, organization, or group desiring a peer-reviewed ERPG for a specific chemical; the documents and ERPG values are then reviewed by the Emergency Response Planning Committee.

Original source toxicity data, preferentially from human and animal acute inhalation studies, are used to derive ERPGs using a weight-of-evidence approach [10]. The highest experimental levels not showing the effects defined by the ERPG tier (the NOAEL) is used for ERPG derivation. For all ERPG tiers, a default uncertainty factor of 10 is applied for interspecies extrapolation, with lesser or greater factors used when the data are sufficient or insufficient, respectively. The AIHA also state that additional uncertainty factors are to be applied when data are insufficient or when there are individuals in the population that are unusually sensitive to a particular chemical; no further details were provided regarding the use of these uncertainty factors [10,11].

The AIHA indicated that the 1-hour exposure duration for ERPGs was chosen based on the availability of toxicity data and the exposure time that would be most relevant for emergency planning [10]. Shorter exposure durations for an ERPG can be established upon request and when justified.

If applicable, ERPG values also include an odour detection symbol for chemicals with an odour that is likely to be detectable near the ERPG-1 value [10]. Also indicated with some ERPG values are lower explosive limit (LEL) warnings to serve as an alert for a potential physical explosion hazard.

2.3 Temporary Emergency Exposure Limits (TEELs)

2.3.1 Definitions of TEELs

TEELs, developed by the DOE Subcommittee on Consequence Assessment and Protective Actions (SCAPA), are emergency exposure guidelines intended for use when no AEGL or ERPG value is available [1]. TEEL values are considered to be protective of the general population including susceptible individuals (identified as infants, children, the elderly, persons with asthma, and those with other illnesses). The 2008 DOE Handbook recommends exposure durations of 15 minutes for TEEL values [1]; however, 60-minute exposure durations are often used [12,13]. The SCAPA group website states that TEELs would be standardized to 1-hour durations in the near future (no date is provided) [14].

There are 4 health severity levels for TEELs [13,15]:

- **TEEL-0**: the threshold concentration below which most people will experience no appreciable risk of health effects.
- **TEEL-1**: the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience
notable discomfort, irritation, or certain asymptomatic nonsensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure.

**TEEL-2**: the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.

**TEEL-3**: the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.

It is interesting to note that the target population in the TEEL-0 definition (‘most people’) differs from that of the other TEEL definitions (‘susceptible individuals’). No further information was given in the DOE Handbook regarding the intended meaning of ‘most people’ in the definition of TEEL-0 [1].

### 2.3.2 Derivation of TEELs

TEELs undergo a less rigorous review process than AEGLs and ERPGs, and are only to be used until AEGLs or ERPGs are developed [1]. The goal of TEEL development is to derive limits in a timely manner while maintaining high quality. To accomplish this, the DOE utilizes secondary data sources as the basis for TEELs. Secondary data sources include existing exposure limits from other agencies (e.g., Permissible Exposure Limits (PELs), Threshold Limit Values (TLVs), Immediately Dangerous to Life or Health concentrations (IDLHs), Recommended Exposure Limit (RELs)), or alternatively, experimentally-derived toxicity parameters (e.g., LC₅₀ (lethal concentration in 50% of a sample), LC₁₅₀ (lethal concentration lowest), TCₕ₀ (toxic concentration lowest), TDₜ₀ (toxic dose lowest). The DOE has developed a hierarchy for selection of toxicity parameters and sources to be used for TEEL development (Table 2). Existing exposure limits are the ideal source of information; for example, the 8-hour time-weighted average PEL is the first choice for derivation of a TEEL-0 value.

The DOE provides the following explanation for their use of occupational guideline levels as general public emergency guidelines [1]:

“Typically, employed persons are healthy adults exposed during working hours so that limits to protect the general public for longer than a typical work shift should be more stringent. TEEL-0 limits, for example, which assume a 15-minute time-weighted average (TWA) concentration, are determined using the 8-hour TWA Permissible Exposure Limit (PEL) value designed for occupational exposure. This value is conservative because the exposure time is short compared with the 8-hour workday.”

The DOE Handbook states that similar considerations are involved in the development of TEEL values for other tiers; however, no further information was provided [1].

For several chemicals, there are no existing exposure limits. In these cases, experimentally-derived toxicity parameters are used as the starting point for development of TEELs. For example, TCₕ₀ and TDₜ₀ are to be used for TEEL-2 development when no other existing exposure guidelines are available (Table 2). The main sources for toxicity data are the Registry of Toxic Effects of Chemical Substances (RTECS), Sax’s Dangerous Properties of Industrial Chemicals, and the Hazardous Substances Data Bank (HSDB), though toxicity data can be obtained from other sources as well. The final TEEL values also incorporate
adjustments for animal-human extrapolations, time extrapolations, and route of exposure extrapolations. A detailed methodology for deriving TEELs from toxicity data is provided in the DOE Handbook [1].

In developing TEELs for chemicals with no exposure limits and absent/insufficient toxicity parameters, toxicity can be estimated based on other structurally similar chemicals for which there are data (Structure-Activity Relationships) [1]. TEELs may also be derived from Health Hazard Ratings (e.g., Sax Hazard Rating) or using TEEL values from other tiers.

Table 2: Hierarchy of selection of toxicity parameters used for TEEL development (in order of priority for each health effect tier) [1]

<table>
<thead>
<tr>
<th>TEEL Tier</th>
<th>Hierarchy of Toxicity Parameters (in order of preference)</th>
<th>Source of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEEL-0</td>
<td>PEL-TWA (Permissible Exposure Limit - TWA)</td>
<td>OSHA</td>
</tr>
<tr>
<td></td>
<td>TLV-TWA (Threshold Limit Value - TWA)</td>
<td>ACGIH</td>
</tr>
<tr>
<td></td>
<td>REL-TWA (Recommended Exposure Limit - TWA)</td>
<td>NIOSH</td>
</tr>
<tr>
<td></td>
<td>WEEL-TWA (Workplace Environmental Exposure Level - TWA)</td>
<td>AIHA</td>
</tr>
<tr>
<td></td>
<td>MAK-TWA (Maximale Arbeitsplatz-Konzentration)</td>
<td>Deutsche Forschungsgemeinschaft (German Research Foundation)</td>
</tr>
<tr>
<td></td>
<td>Other-TWA (TWA from other sources)</td>
<td>Other sources</td>
</tr>
<tr>
<td></td>
<td>CEGL (Continuous Exposure Guidance Level)</td>
<td>National Academy of Sciences</td>
</tr>
<tr>
<td></td>
<td>TLV-TWA x 3 (Threshold Limit Value - TWA multiplied by 3)</td>
<td>ACGIH</td>
</tr>
<tr>
<td>TEEL-1</td>
<td>PEL- STEL (Permissible Exposure Limit - STEL)</td>
<td>OSHA</td>
</tr>
<tr>
<td></td>
<td>TLV- STEL (Threshold Limit Value - STEL)</td>
<td>ACGIH</td>
</tr>
<tr>
<td></td>
<td>REL- STEL (Recommended Exposure Limit - STEL)</td>
<td>NIOSH</td>
</tr>
<tr>
<td></td>
<td>WEEL- STEL (Workplace Environmental Exposure Level - STEL)</td>
<td>AIHA</td>
</tr>
<tr>
<td></td>
<td>Other- STEL (STEL from other sources)</td>
<td>Other sources</td>
</tr>
<tr>
<td></td>
<td>TLV-TWA x 3 (Threshold Limit Value - TWA multiplied by 3)</td>
<td>ACGIH</td>
</tr>
<tr>
<td>TEEL-2</td>
<td>EEGL (Emergency Exposure Guidance Level)</td>
<td>National Academy of Sciences</td>
</tr>
<tr>
<td></td>
<td>LOC (Level of Concern)</td>
<td>USEPA, US Department of Transportation</td>
</tr>
<tr>
<td></td>
<td>PEL-C (Permissible Exposure Limit - ceiling)</td>
<td>OSHA</td>
</tr>
<tr>
<td></td>
<td>TLV-C (Threshold Limit Value - ceiling)</td>
<td>ACGIH</td>
</tr>
<tr>
<td></td>
<td>REL-C (Recommended Exposure Limit - ceiling)</td>
<td>NIOSH</td>
</tr>
<tr>
<td></td>
<td>WEEL-C (Workplace Environmental Exposure Level - ceiling)</td>
<td>AIHA</td>
</tr>
<tr>
<td></td>
<td>TLV-TWA x 5 (Threshold Limit Value - TWA multiplied by 5)</td>
<td>ACGIH</td>
</tr>
<tr>
<td></td>
<td>TClo (Toxic Concentration Lowest)</td>
<td>RTECS, Sax, HSDB, or other sources</td>
</tr>
<tr>
<td></td>
<td>TDlo (Toxic Dose Lowest)</td>
<td>RTECS, Sax, HSDB, or other sources</td>
</tr>
</tbody>
</table>
### 2.4 Comparison of AEGLs, ERPGs, and TEELs

AEGLs, ERPGs, and TEELs all serve the same purpose by providing exposure guideline levels for hazardous chemicals that can be used in emergency situations. However, the guidelines are developed by different agencies and are derived in different ways [12,14]. AEGLs, ERPGs, and TEELs also differ in their exposure durations and in their definitions of health effect levels and target populations. A comparison of the guidelines is presented in Table 3.

With regards to guideline derivation, AEGL and ERPG development is a rigorous and time-consuming process involving review of all primary source data. AEGL values are derived using data from a key toxicology study, while ERPG values are derived using data from multiple studies and a weight-of-evidence approach. Contrarily, TEEL values are derived using secondary sources of data (e.g., existing exposure limits) and require much less time to develop. TEELs are intended to be temporary, only to be used until AEGLs or ERPGs are developed [1].

While AEGLs, ERPGs, and TEELs are all intended to be protective for most individuals in a population, none of the guidelines are designed to be protective of hypersensitive individuals [1]. Hypersensitive individuals are defined as those whose reactions to chemical exposure are unique and idiosyncratic and lie outside the range of distributions expected for the general population including susceptible subpopulations [9]. Examples of hypersensitive individuals include those with severely debilitating pulmonary, hepatic, or renal disorders, the elderly with serious deilities of primary physiologic systems, and those with unique hypersensitivities to specific chemicals or chemical classes.
Table 3: Comparison of AEGLs, ERPGs, and TEELs (modified from [12])

<table>
<thead>
<tr>
<th>Licensing agency</th>
<th>AEGL</th>
<th>ERPG</th>
<th>TEEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chemicals with published values</td>
<td>131 (final)</td>
<td>145</td>
<td>&gt;3000</td>
</tr>
<tr>
<td>130 (interim)</td>
<td>12 (proposed)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure duration</td>
<td>10 min, 30 min, 60 min, 4 hr, 8 hr</td>
<td>60 min</td>
<td>15 min*</td>
</tr>
<tr>
<td>Target population</td>
<td>General population including susceptible individuals</td>
<td>Nearly all individuals</td>
<td>General population including susceptible individuals</td>
</tr>
<tr>
<td>Method of guideline derivation</td>
<td>Key study from primary data sources</td>
<td>Weight-of-evidence approach from primary data sources</td>
<td>Use of secondary data sources (existing exposure limits and toxicity data)</td>
</tr>
<tr>
<td>Peer-reviewed</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

* The DOE Handbook recommends an exposure duration of 15 min for TEELs [1]; ** Other sources indicate a 60-minute exposure duration for TEELs [12,13].
3. Comparisons with Other Air Guideline Levels

In addition to PACs, there are several other guideline levels that exist for airborne chemicals, such as Ambient Air Quality Objectives (AAQOs), Minimal Risk Levels (MRLs), Reference Concentration (RfCs), PELs, RELs, and TLVs, and Workplace Environmental Exposure Levels (WEELs). The definitions and purposes of these guidelines vary, with each having a specified duration of exposure, frequency of exposure, and target population; a comparison of the guidelines is presented in Table 4.

PACs are similar to Provisional advisory levels (PALs) in that they are both used to assist in emergency planning for the general public [16,17]. Both guidelines have 3 health effect levels with similar definitions; however, PACs are intended for acute exposures of 1 hour (or up to 8 hours for chemicals with AEGLs) while PALs are for longer term exposures of 24 hours to 2 years (Table 4a).

The primary difference between PACs and the public health guidelines (e.g., AAQOs, MRLs, RfCs) is related to the frequency of exposure (i.e., acute single exposure vs chronic (continuous/repeated) exposure) (Table 4b). PACs are guidelines for a single acute exposure during a chemical emergency; a 1-hr PAC value refers to a total exposure time of 1 hour as well as an averaging period of 1 hour. Conversely, public health guidelines are for continuous or repeated exposures to ambient pollutants over a lifetime; these guidelines have various averaging periods ranging from 1 hour to 1 year. For example, a 1-hr AAQO value refers to an exposure concentration averaged over 1-hour and assumes the total exposure time to be continuous (lifetime).

The main difference between PACs and occupational exposure guidelines (e.g., IDLHs, PELs, TLVs) is the target population. PACs are guidelines for the general public, while occupational guidelines are intended for healthy adult workers (Table 4c). Additionally, several occupational guidelines (PELs, RELs, TLVs, WEELs) account for both single and repeated exposures to a chemical over a working lifetime, while PACs are for single exposures of 1 hour (or up to 8 hours for AEGLs).

To illustrate the variation in guidance values for a specific chemical, a summary of guideline levels for hydrogen sulfide is presented in Appendix A [18].
4. Usage of Protective Action Criteria

The groups or individuals that typically make use of PACs include [10]:

- Government agencies
- Industrial hygienists
- Fire Protection Specialists
- Air dispersion modelers
- Emergency responders
- Risk assessors and risk managers
- Community action emergency response participants
- Toxicologists
- Transportation safety engineers
- Local emergency planning committees
- Industrial process safety engineers
- State emergency response commissions
- Resources conservation and recovery act managers

Table 4: Comparison of various air guideline levels

<table>
<thead>
<tr>
<th>Guideline</th>
<th>Definition</th>
<th>Exposure Single/ Repeated</th>
<th>Exposure Averaging Time</th>
<th>Developed By</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Emergency Guidelines (for the general public)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protective Action Criteria (PAC) (PAC)</td>
<td>Emergency guidelines intended to protect the general public from rare, unanticipated, short-term chemical exposures. The chemical concentration in air at which protective action is required</td>
<td>Single exposure</td>
<td>1 hr [total exposure time]</td>
<td>AIHA, DOE, USEPA [1,10]</td>
</tr>
<tr>
<td>Provisional Advisory Level (PAL-1, PAL-2, PAL-3)</td>
<td>A tiered set of exposure values used to inform risk-based decision making during a response to environmental release of hazardous chemicals; they are longer term emergency advisory levels for the general public, including sensitive individuals, for contaminated air and water exposures</td>
<td>Repeated exposure</td>
<td>24 hr, 30 day, 90 day, 2 year</td>
<td>NHSRC [16]</td>
</tr>
<tr>
<td>b. Public Health Guidelines (for the general public)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alberta Ambient Air Quality Objective (Alberta AAQO)</td>
<td>Levels intended to protect the environment and human health to an extent technically and economically feasible, as well as socially and politically acceptable</td>
<td>Repeated exposure</td>
<td>1 hr, 24 hr, 8 hr, 3 day, 30 day also used occasionally</td>
<td>Government of Alberta [19]</td>
</tr>
<tr>
<td>Canadian Ambient Air Quality Standard (CAAAQS)</td>
<td>Health-based air quality objectives for pollutant concentrations in outdoor air [beginning in 2015]</td>
<td>Repeated exposure</td>
<td>8 hr, 24 hr, Annual</td>
<td>Environmen t Canada / Health Canada [20]</td>
</tr>
<tr>
<td>National Ambient Air Quality Objective</td>
<td>National goal for outdoor air quality that protects public health, the environment, or aesthetic properties of the environment</td>
<td>Repeated exposure</td>
<td>1 hr, 8 hr, 24 hr, Annual</td>
<td>Environmen t Canada / Health</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Guideline</th>
<th>Definition</th>
<th>Exposure Single/Repeated</th>
<th>Exposure Averaging Time</th>
<th>Developed By</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NAAQO)</td>
<td>Maximum permissible concentrations for criteria pollutants; designed to provide public health protection (including sensitive individuals) and public welfare protection (including decreased visibility and damage to animals, crops, vegetation, and buildings)</td>
<td>Repeated exposure</td>
<td>1 hr, 3 hr, 8 hr, 24 hr, 3 month, Annual</td>
<td>USEPA [22]</td>
</tr>
<tr>
<td>National Ambient Air Quality Standard (NAAQS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimal Risk Level (MRL)</td>
<td>Estimate of daily exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful, noncancerous effects</td>
<td>Repeated exposure</td>
<td>acute (1-14 days), intermediate (&gt;14-364 days), chronic (365+ days)</td>
<td>ATSDR [23]</td>
</tr>
<tr>
<td>Reference Concentration (RfC)</td>
<td>Daily inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime</td>
<td>Repeated exposure</td>
<td>acute (≤24 hr), short-term (&gt;24 hr-30 days), subchronic (30+ days)</td>
<td>USEPA [24]</td>
</tr>
<tr>
<td>Reference Exposure Level (CA-REL)</td>
<td>Concentration of a chemical at or below which adverse noncancer health effects are not anticipated to occur for a specified duration</td>
<td>Repeated exposure</td>
<td>1 hr, 8 hr, Annual</td>
<td>OEHHA (California) [25]</td>
</tr>
<tr>
<td>c. Occupational Exposure Guidelines (for healthy workers)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous Exposure Guidance Level (CEGL)</td>
<td>A ceiling concentration of a chemical in air to which personnel can be exposed for up to 90 days without immediate or delayed adverse effects or degradation of performance</td>
<td>Repeated exposure</td>
<td>90 days</td>
<td>NAS [26]</td>
</tr>
<tr>
<td>Emergency Exposure Guidance Level (EEGL)</td>
<td>Air concentration of a substance that is acceptable for the performance of specific tasks during rare emergencies usually lasting from 1 to 24 hours (i.e., a ceiling guidance level for a single emergency exposure)</td>
<td>Single exposure</td>
<td>1 to 24 hr [total exposure time]</td>
<td>NAS [26]</td>
</tr>
<tr>
<td>Immediately Dangerous to Life or Health (IDLH)</td>
<td>Airborne contaminant exposure that is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment</td>
<td>Single exposure</td>
<td>30 min [total exposure time]</td>
<td>NIOSH [27]</td>
</tr>
<tr>
<td>Permissible Exposure Limit (PEL)</td>
<td>Regulatory limits on the concentration of a substance in the air to protect workers against the health effects of exposure to hazardous substances</td>
<td>Single and repeated exposure</td>
<td>15-30 min (STEL), 8-hr TWA, Ceiling</td>
<td>OSHA [28]</td>
</tr>
<tr>
<td>Recommended Exposure Limit (REL)</td>
<td>Level of hazardous substance in the workplace believed to be protective of worker safety and health over a working lifetime</td>
<td>Single and repeated exposure</td>
<td>15 min (STEL), 10-hr TWA, Ceiling</td>
<td>NIOSH [29]</td>
</tr>
<tr>
<td>Threshold Limit Value (TLV)</td>
<td>Concentration at which it is believed that nearly all workers may be repeatedly exposed</td>
<td>Single and repeated exposure</td>
<td>15 min (STEL), 8-hr TWA, Ceiling</td>
<td>ACGIH [30]</td>
</tr>
<tr>
<td>Guideline</td>
<td>Definition</td>
<td>Exposure Single/Repeated</td>
<td>Exposure Averaging Time</td>
<td>Developed By</td>
</tr>
<tr>
<td>-----------</td>
<td>------------</td>
<td>--------------------------</td>
<td>-------------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Workplace Environmental Exposure Level (WEEL)</td>
<td>Level protecting most workers from adverse health effects related to occupational chemical exposures</td>
<td>Single and repeated exposure</td>
<td>15 min (STEL), 8-hr TWA, Ceiling</td>
<td>AIHA, TERA [31,32]</td>
</tr>
</tbody>
</table>


When responding to or planning for a chemical emergency, field measurements and/or atmospheric modeling are used to estimate the atmospheric concentrations of the chemical in the surrounding area. Atmospheric dispersion models provide computerized estimates of the direction and speed of a chemical plume. The dispersion models take into account several factors that influence the spread of the plume over time, such as rate of chemical release, volatility, wind speed and direction, temperature, and terrain. Field measurements, if they are available, may also be incorporated into the computerized models to improve concentration estimates. Based on the measured and/or modeled concentrations, threat zones can be estimated using PAC values as the toxic LOC.

There are a number of atmospheric modeling software programs that utilize PACs. The most commonly used program is CAMEO/ALOHA (Computer-Aided Management of Emergency Operations / Areal Location of Hazardous Atmospheres), developed by the USEPA and the National Oceanic and Atmospheric Administration [33]. CAMEO is a suite of software used for pre-planning and responding to chemical emergencies. ALOHA is a component of CAMEO that is used for atmospheric dispersion modeling and estimation of threat zones. ALOHA uses the following hierarchy for selection of the toxic LOC: 60-minute AEGL > ERPG > TEEL > IDLH. A typical ALOHA plot is presented in Figure 1, with the 3 threat zones presented as red (AEGL-3), orange (AEGL-2), and yellow (AEGL-1) [34]; the threat zones are then used to develop emergency action plans and determine areas of evacuation and/or sheltering.

ALOHA is designed to be easy to use and to produce results quickly enough to be useful for responders in an emergency situation [35]. It is important to understand that the atmospheric modeling provides only an estimate of the surrounding concentrations and threat zones. Uncertainties in modeled concentrations may lead to under- or over-estimations of threat zones and could potentially cause problems during an emergency (e.g., evacuation areas are too small or too large) [36]. Users of ALOHA, or any other atmospheric dispersion modeling software, should be properly trained and have a thorough understanding of the capabilities and limitations of the program.
Figure 1: An image of ALOHA toxic threat zones, indicating where pollutant concentrations are higher or lower than the chosen levels of concern (LOC). AEGLs are presented and the red (centre) threat zone is the most hazardous (AEGL-3) [34]

Other software tools used for hazard analyses (or consequence analyses) include CAPARS (Computer-Assisted Protective Action Recommendation System), the NARAC (National Atmospheric Release Advisory Center) modeling system, EPIcode, PHAST (Process Hazard Analysis Software Tool), and CASRAM (Chemical Accident Statistical Risk Assessment Model) [37,38]. Consequence analysis tools found in the recent white literature include TORCAT (TOxic Release Consequence Analysis Tool), a CFD FLACS-DDC (Computational Fluid Dynamics FLame Acceleration Simulator - Damage Differential Coupling) model, and a Risk Severity Index tool for industrial sites [39,40,41,42]. Further evaluation of the various software tools used in emergency management was beyond the scope of this review.

Sections 4.1 to 4.3 present specific accounts of real-world usage of AEGLs, ERPGs, TEELs, and/or the PAC dataset as a whole. The lists are not exhaustive, but rather provide several examples of the types of groups or agencies that utilize these emergency guidelines and the situations in which they are used. Application and selection of emergency guideline values tends to vary between agencies and industries, and usage of the guidelines often differs from that of the DOE. For example, many agencies use only AEGLs and ERPGs rather than the PAC dataset. Additionally, some agencies may use a different hierarchy for
selection of toxicological endpoint. For several of the examples presented, the referenced
documents provided very little detail on how and why the specific PAC values are used.

4.1 Agencies Utilizing Protective Action Criteria

4.1.1 Canada

Environment Canada makes use of AEGLs and ERPGs in their Environmental Emergency (E2) Regulations. E2 regulations require "persons who own or manage specified toxic and hazardous substances at or above the specified thresholds to provide required information on the substance(s), their quantities and to prepare and implement environmental emergency plans" [43]. Environment Canada utilizes an evaluation framework methodology to evaluate the properties of chemicals that would be hazardous during an environmental emergency and to calculate the specified thresholds [44]. For substances that are hazardous to human health when inhaled, the specified threshold value is calculated using, in order of priority, AEGL-2 (30 min), IDLH, or ERPG-2 values as the measure of toxicity. When neither of these values is available, lethal concentration limits from animal studies (e.g., LC_{50}, LC_{10}) are used to estimate an IDLH.

AEGL and ERPG values were also used in the '2012 Emergency Response Guidebook’, published jointly by Transport Canada, the US Department of Transportation, and the Secretariat of Communications and Transportation of Mexico [45]. The guidebook offers general guidance for first responders (e.g., firefighters, police, and other emergency services personnel) to an emergency transportation incident involving dangerous goods or hazardous materials. The information provided in the guidebook assists first responders in identifying the hazards of the material(s) involved in the incident, and protecting themselves and the general public during the initial response phase. The guidebook includes tables of estimated initial isolation and protective action distances for large and small spills of various hazardous materials. The initial isolation zone is defined as the area surrounding the incident in which persons may be exposed to dangerous (upwind) and life threatening (downwind) concentrations of material. The protective action zone is defined as the area downwind from the incident in which persons may become incapacitated and unable to take protective action and/or incur serious or irreversible health effects. In determining the initial isolation and protective action distances, the toxicological endpoints used, in order of priority, were AEGL-2 and ERPG-2 values. When AEGL-2 or ERPG-2 values were not available, lethal concentration limits derived from animal studies were used. For each chemical, thousands of hypothetical releases were modeled under various meteorological and release conditions; the 90th percentile initial isolation and protective action distances for each chemical were selected for the tables.

4.1.2 USA

A large number of agencies in the USA utilize AEGLs, ERPGs, TEELs, or PACs for emergency planning and response. The National Oceanic and Atmospheric Administration (Office of Response and Restoration) includes PACs as the toxic LOC for emergency response and in their tools for hazard analysis [46]. The USEPA's Risk Management Program uses ERPG-2 as the first choice for a toxic endpoint for hazardous substances in offsite consequence analyses [47,48]. The toxic endpoint values are then used to estimate consequence distances in worst-case scenario analyses.
The Interagency Modeling and Atmospheric Assessment Center (IMAAC) makes use of PACs to determine threat zones during a chemical emergency [49]. The IMAAC consists of representatives from 7 federal agencies (USEPA, DOE, National Oceanic and Atmospheric Administration, Department of Homeland Security, Department of Defense, National Aeronautics and Space Administration (NASA), and the Nuclear Regulatory Commission), and is often called upon to assist local responders in large-scale chemical emergencies.

The Department of the Army and the Federal Emergency Management Agency adopted AEGLs into their policy for the Chemical Stockpile Emergency Preparedness Program (CSEPP) [50,51]. AEGLs are the toxicity criteria to be used in emergency planning and response by the CSEPP community. Specifically, the guidelines are to be utilized in air dispersion models to identify areas at risk from potential chemical warfare accidents. Other national agencies and programs utilizing PACs include the DOE environmental restoration, waste management, waste transport, and fixed facility programs, the Department of Defense environmental restoration, waste management, and fixed facility programs, the ATSDR health consultation and risk assessment programs, the American Chemistry Council Chemtrec program, the Department of Transportation Emergency Response Guidebook (see Transport Canada above), and OSHA and NIOSH regulations and guidelines for workplace exposure [9]. For example, NIOSH utilizes AEGL-1 and AEGL-2 values in the 'Emergency Response Safety and Health Database' to identify the concentrations at which first responders are required to use personal protective equipment [52].

PACs are also used by local and state governments. For example, the Virginia Department of Environmental Quality uses PAC-1 values for assessments of the potential health impact from air discharges related to soil remediation [53]. Additionally, the Texas Commission on Environmental Quality uses AEGL-1 odour detection values in their guidelines for setting odour-based Effects Screening Levels [54].

Use of PACs was found in documentation for emergency pre-planning in anticipation of a chemical terrorist attack at the Los Angeles airport [55]. AEGL-1, and secondarily AEGL-2 or ERPGs, were used as the exposure guidance levels for the development of clearance goals for airport remediation following a terrorist attack involving chemical warfare agents.

4.1.3 Worldwide

In Australia, accounts of AEGL and ERPG usage were found in state government documents. In Queensland, AEGL-2 and ERPG-2 values are used as the threshold levels for the 'dangerous dose to human health', which is not to be exceeded for foreseeable hazard scenarios [56]. In Victoria, the document titled 'A Best Practice Approach to Shelter-in-Place for Victoria' indicates that AEGLs and ERPGs are used by scientific and health professionals during chemical emergencies to assist with the decision making process [57].

PACs are also used to some extent in Europe; for example, regulation documents indicated that AEGLs and ERPGs are the toxic endpoints used in risk analyses for land-use planning in the European Union [58] and Denmark [59]. In the United Kingdom, values for AEGLs and ERPGs are included in the Incident Management documents for specific chemicals [60,61]; however, no further details were found regarding how the guidelines are used.

In a survey evaluating risk assessment of chemical exposures in emergency response situations across Europe, the most commonly used acute exposure reference values were, in decreasing order, ERPGs, AEGLs, and IDLHs [62]. TEELs and European Acute Exposure...
Threshold Levels (AETLs; analogous to AEGLs) were used less frequently. Typical uses of the acute exposure reference values included land-use planning, emergency planning, evacuation distance estimation, medical planning, and consequence analysis.

The Chemical Events Working Group of the Global Health Security Initiative published an article indicating use of AEGL-3 values, and secondarily PAC-3 values, in their chemical risk screening tool [63]. The tool is used to prioritize public health risk associated with the accidental or deliberate release of chemicals at the local, regional, national, and international levels.

Lastly, use of ERPG values was found in the Chemical Exposure Index (CEI) developed by Dow Chemical [64,65]. The CEI is a method of rating the relative acute health hazard potential of possible chemical release incidents. ERPG-1, ERPG-2, and ERPG-3 values are used the measure of toxicity in the calculations of the CEI and hazard distances for potential incidents.

4.2 Past Chemical Emergency Events

The following list presents examples of actual chemical emergency events where AEGLs, ERPGs, TEELS, or the PAC dataset were used to identify threat zones and the potentially affected population. Accounts of usage of these guidelines in actual emergency events were difficult to find, likely due to limited published documentation of past chemical events. For most incidents, very little information was found and it was not possible to assess the suitability or effectiveness of the usage of PACs for the particular event.

Paulsboro, New Jersey, USA, 2012 [66]
Train derailment led to release of vinyl chloride. Interim AEGLs for vinyl chloride were used to identify red (AEGL-3), orange (AEGL-2), and yellow (AEGL-1) threat zones.

Kilauea, Hawaii, USA, 2008 [67]
Kilauea volcanic eruption led to release of sulfur dioxide. AEGL-1 and AEGL-2 (60-min) were used as the acute health effect endpoints to identify threat zones and the number of people potentially affected.

Port of Montreal, Quebec, Canada, 2007 [68]
Grounding of the Sichem Aneline tanker that was carrying 7700 m³ of benzene. AEGL-2 and ERPG-2 were used to identify threat zones for several potential benzene release scenarios.

Central Taiwan, 2007 [69]
Boiler explosion at a chemical plant resulting in the release of xylene, isopropanol, phosphorus trichloride, and dimethyl formamide. On-site concentrations of contaminants were compared to ERPGs to determine the appropriate emergency action. Xylene and nitrogen dioxide were found to exceed the emission standards but not the evacuation standards; thus, it was suggested that windows be closed in all industrial park plants located downwind from the explosion site. Additionally, leakage simulations of hydrogen chloride (product of phosphorus trichloride and water) were performed using ALOHA, and the results were used to estimate the geographic areas impacted by ERPG-1, ERPG-2, and ERPG-3 concentrations.
Granitville, South Carolina, USA, 2005 [49]
Train accident leading to release of chlorine. ERPGs were used during emergency response to determine red (ERPG-3), orange (ERPG-2), and yellow (ERPG-1) threat zones. Field measurements of chlorine were found to show a strong agreement with modeled concentrations. In follow-up studies of the incident, modeled chlorine concentrations and associated AEGLs were compared to published epidemiologic data of adverse health effects [70]. Modeled estimations of chlorine concentrations and adverse outcomes were in general agreement with epidemiologic findings, confirming the validity of the chlorine dispersion model and AEGL values for this scenario. Contrarily, another report indicated that the use of ALOHA in this emergency lead to an overestimation of plume speed and downwind concentration, which possibly resulted in an over-prediction of the evacuation area [71].

Dalton, Georgia, USA, 2004 [72]
Leakage of allyl alcohol and allyl chloride during a runaway chemical reaction at MFG Chemical Inc. In a follow-up investigation report, AEGL-1/ERPG-1 and AEGL-2/ERPG-2 values were used to estimate threat zones and the number of potentially affected people.

Cincinnati, Ohio, USA, 2004 [67]
Massive fire at Queen City Barrel chemical warehouse led to release of several chemicals in smoke plume. ERPGs (and possibly other guidelines) were used to map acute health impacts.

Table 5: Examples of protective action criteria (PACs) usage in consequence analyses (white literature)

<table>
<thead>
<tr>
<th>PAC</th>
<th>Application</th>
<th>Location</th>
<th>Publication Date</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAC</td>
<td>Consequence analysis for chemical leakage of toxic dust particles from an abandoned mining and metallurgical facility</td>
<td>Greece</td>
<td>2011</td>
<td>[74]</td>
</tr>
<tr>
<td></td>
<td>Consequence analysis at DOE hazard facilities (Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Oak Ridge-Y12, Pantex, Rocky Flats, and West Valley)</td>
<td>USA</td>
<td>2006</td>
<td>[75]</td>
</tr>
<tr>
<td>AEGL</td>
<td>Consequence analysis for leakage simulations of liquefied ammonia</td>
<td>Texas, USA</td>
<td>2012</td>
<td>[76]</td>
</tr>
<tr>
<td></td>
<td>Consequence analysis for leakage simulations of chlorine from a ballistic attack on a chlorine-carrying railway tanker</td>
<td>Missouri and Illinois, USA</td>
<td>2012</td>
<td>[71]</td>
</tr>
<tr>
<td></td>
<td>Consequence analysis and assessment of human vulnerability to leakage simulations of chlorine from a chemical industrial park</td>
<td>China</td>
<td>2010</td>
<td>[77]</td>
</tr>
<tr>
<td></td>
<td>Consequence analysis for leakage simulations of ammonia from an ammonia production plant</td>
<td>Malaysia</td>
<td>2010</td>
<td>[41]</td>
</tr>
<tr>
<td></td>
<td>Consequence analysis and determining toxic effect distances for potential accidents related to hazardous materials transport (ammonia, 1,3-butadiene, ethylene oxide, liquefied petroleum gas, propylene)</td>
<td>India</td>
<td>2011</td>
<td>[78]</td>
</tr>
<tr>
<td>ERPG</td>
<td>Consequence analysis and determining protective action</td>
<td>Illinois, USA</td>
<td>2007</td>
<td>[79]</td>
</tr>
</tbody>
</table>
Table 6: Examples of protective action criteria (PACs) usage in consequence analyses in environmental impact assessments (grey literature)

<table>
<thead>
<tr>
<th>PAC</th>
<th>Application</th>
<th>Location</th>
<th>Publication Date</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAC</td>
<td>In an environmental impact statement for a deep geologic repository for the long-term management of low and intermediate level waste, it was indicated that chemicals released during credible accident scenarios would be less than PAC-1</td>
<td>Ontario  Power Generation (Ontario, Canada)</td>
<td>2013</td>
<td>[85]</td>
</tr>
<tr>
<td>AEGL</td>
<td>In an environmental impact statement for a carbon capture and sequestration project, AEGLs (3 levels) were used to determine threat zones (distances and population densities) for various chemical leakage simulations</td>
<td>US Department of Energy (Louisiana, USA)</td>
<td>2013</td>
<td>[86]</td>
</tr>
<tr>
<td></td>
<td>In an assessment of health impacts related to accidental releases from hazardous waste facilities, the consequence analysis indicated that concentrations (at nearby receptors) resulting from worst-case spill scenarios would be less than AEGL levels</td>
<td>ICF International (for USEPA) (California, USA)</td>
<td>2012</td>
<td>[87]</td>
</tr>
<tr>
<td></td>
<td>In an environmental impact assessment for a national petroleum reserve, it was determined that hazardous air pollutant emissions would not exceed AEGL-1 levels</td>
<td>US Department of the Interior Bureau of Land Management (Alaska, USA)</td>
<td>2012</td>
<td>[88]</td>
</tr>
<tr>
<td>ERPG</td>
<td>In an environmental and social impact assessment for a petrochemical refinery, ERPGs (3 levels) were used for review of hazard consequences and hazard distances for credible chemical release scenarios</td>
<td>Nghi Son Refinery and Petrochemical LLC</td>
<td>2011</td>
<td>[89]</td>
</tr>
<tr>
<td>PAC</td>
<td>Application</td>
<td>Agency</td>
<td>Publication Date</td>
<td>Reference</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
<td>------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>ERPG,</td>
<td>In a hazard assessment report for oil and gas platforms and pipelines, ERPG-3 levels for hydrogen sulfide were used as a level of concern in the consequence analysis for potential release scenarios</td>
<td>(Vietnam)</td>
<td>2009</td>
<td>[90]</td>
</tr>
<tr>
<td>TEEL</td>
<td></td>
<td>US Department of the Interior Minerals Management Service (California, USA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Venoco Inc (California, USA)</td>
<td>2008</td>
<td>[91]</td>
</tr>
<tr>
<td></td>
<td>In an environmental impact report for the development of new oil and gas reserves at a processing facility, it was indicated that hydrogen sulfide concentrations are not to exceed the ERPG-2 level at any location within the facility</td>
<td>Venoco Inc (California, USA)</td>
<td>2008</td>
<td>[91]</td>
</tr>
<tr>
<td></td>
<td>In a hazard and risk assessment for a proposed ammonium nitrate plant, ERPG-2 and ERPG-3 values were used in consequence modeling for toxic release scenarios</td>
<td>Dyno Nobel Asia Pacific LTD (Australia)</td>
<td>2006</td>
<td>[92]</td>
</tr>
<tr>
<td>ERPG,</td>
<td>In a technical basis document for a nuclear storage facility, ERPG-1/TEEL-1 and ERPG-2/TEEL-2 values were used to assess severity of potential accident scenarios for above-ground tanks. Results were combined with a frequency/probability analysis to determine risk categories for various accident scenarios</td>
<td>CH2M HILL Hanford Group, Inc (Washington, USA)</td>
<td>2005</td>
<td>[93]</td>
</tr>
<tr>
<td>TEEL</td>
<td></td>
<td>CH2M HILL Hanford Group, Inc (Washington, USA)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
5. Advantages and Limitations of the Protective Action Criteria

Advantages of PACs include:

- The PAC dataset provides emergency inhalation exposure guidelines for ~3400 substances to assist in the management of chemical emergencies.

- AEGL and ERPG development involves an analysis of all available toxicological data and a rigorous review process. AEGLs and ERPGs are peer-reviewed.

- Intended to be protective for most of the general public, including susceptible populations (identified as infants, children, the elderly, persons with asthma, and those with other illnesses).

- PACs have been incorporated into several atmospheric dispersion modeling programs.

- TEEL values can be developed relatively quickly as they are derived using existing exposure guidelines or toxicity data. In the absence of AEGLs or ERPGs, TEELs can be a useful source of information.

Limitations for PACs include:

- AEGLs and ERPGs are available for a relatively small number of chemicals (~270 AEGLs (final, interim, and proposed) and ~145 ERPGs, compared to over 3000 TEELs). The extensive review process involved in AEGL and ERPG derivation requires a significant amount of time and resources.

- TEEL values are not peer-reviewed and are considered less reliable than AEGLs and ERPGs.

- For chemicals with both AEGLs and ERPGs, the guideline values for a specific tier may vary considerably. For example, for hydrogen sulfide, the values for ERPG-1 (0.1 ppm) and AEGL-1 (60-min; 0.51 ppm) differ by five-fold (Appendix A). Oberg et al. (2010) evaluated discrepancies between AEGL and ERPG values; of 88 substances that had both AEGLs and ERPGs, 34 substances (39%) had values that diverged by more than three-fold [94]. The main reasons for divergence included selection of critical effect, selection of critical studies, definition of health effect tier (particularly for AEGL-1 and ERPG-1), interpretation of data, and use of different modifying factors. These discrepancies may lead to problems with interpretation and communication in risk management, particularly during large-scale releases with multiple parties involved (e.g., one agency uses AEGL values and another agency uses ERPG values).

- When using the consolidated PAC dataset, only one exposure period is available (1 hour). This can lead to some confusion when actual exposure times are shorter or longer. This is particularly important for chemicals that do not have an AEGL (with a range of exposure durations) to refer to. In a survey of European professionals involved in chemical risk assessment and emergency planning, use of acute exposure reference values was considered difficult by 35% of respondents [62]. The problems
associated with use were mainly related to the availability of only a single exposure period, particularly for ERPGs.

- Neither AEGLs, ERPGs, nor TEELs are designed to be protective of hypersensitive individuals (those whose reactions to chemical exposure are unique and idiosyncratic and lie outside the range of distributions expected for the general population including susceptible individuals) [1,9].

- AEGLs have been criticized for the methods in which individuals with asthma are considered in guideline development; Johansson et al. (2012) found that 70% of AEGL technical support documents lack explicit comments or statements relating to individuals with asthma [95].

- Uncertainties in atmospheric modeling may lead to under- or over-estimations of threat zones and potentially cause problems during an emergency (e.g., evacuation areas are too small or too large) [36]. For example, ALOHA results can be unreliable under certain meteorological conditions (e.g., very low wind speeds) and may not be appropriate for certain emergency scenarios [35]. Users of ALOHA, or any other atmospheric dispersion modeling software, should be properly trained and have a thorough understanding of the capabilities and limitations of the program.

- PACs are not directly applicable to releases of chemical mixtures, as the potential additive, synergistic, or antagonistic effects that may result from exposures to multiple chemicals are not accounted for. Chemicals in combination may behave differently than when alone, and predicting the toxic potential of a mixture is often very difficult. A chemical mixture methodology (CMM) has been developed by SCAPA for estimating the potential health impacts of exposures involving multiple chemicals [96,97,98]. This method utilizes the concentration of each chemical, the PAC value, and health code numbers that identify the target organs of the chemicals to estimate the potential health impact of a mixture at a given location. A user guide and CMM workbook (for mixtures of up to 30 chemicals) are available from the DOE-sponsored Emergency Management Issues Special Interest Group [99]. Yu et al. (2010) indicate that the CMM is used by the DOE, its contractors and other private and public sector organizations for emergency response and safety planning [97]. However, specific references to the usage of the CMM for chemical emergencies were difficult to find and it is not known how often this method is used.

Additional notes regarding PACs:

- PACs are applicable only to short-term inhalation exposures of 1 hour (or up to 8 hours for chemicals with AEGLs); they are not intended for other routes of exposure (e.g., drinking water, soil) or longer term exposures. For emergency exposures lasting 24 hours to 2 years, a separate set of emergency guidelines, titled provisional advisory levels (PALS), are available for air and drinking water.

- PACs are used to assess the potential severity of an emergency event, and should not be used as safe limits for repeated exposures, as delineators between safe and unsafe exposure levels, as the basis levels for quantitative risk assessment, or to estimate expected injuries or casualties [100,101].
6. Summary

PACs are emergency exposure guidelines that are used before or during an unplanned release of a hazardous chemical in the air. The guidelines are intended to protect the general public, including susceptible individuals, from health effects resulting from a rare short-term exposure to a chemical. PACs can be used prior to emergencies to estimate the toxic severity of potential accident scenarios (hazard analysis or consequence analysis), or during chemical emergencies to identify threat zones and the populations that may be at risk.

PACs are a consolidated list of 3 types of emergency exposure guidelines: AEGLs, ERPGs, and TEELs. AEGLs and ERPGs are the preferred emergency guidelines, in that order, but are only available for a limited number of chemicals. For chemicals without AEGLs or ERPGs, TEELs are used until AEGLs or ERPGs are developed.

There are 3 health effect levels for PACs: (1) mild, transient effects; (2) irreversible or serious effects that could impair the ability to take protective action; and (3) life-threatening effects. PACs are based on a 60-minute exposure duration, though AEGLs also include guidelines for durations of 10 minutes, 30 minutes, 4 hours, and 8 hours.

The main difference between the 3 emergency guidelines is the methods in which they are derived. AEGL and ERPG development is a thorough and rigorous process involving review of all primary source data. Because of this time-consuming process, AEGLs and ERPGs have only been developed for ~270 (final, interim, and proposed) and ~145 substances, respectively. TEEL values, on the other hand, are based on secondary sources of data (existing exposure limits) and require less time to develop. Thus, TEELs are available for a large number of substances (> 3000), though are somewhat less reliable.

AEGLs, ERPGs, TEELs, and PACs are used by several reputable governing agencies in Canada, the USA, and abroad. Application and selection of guideline values tends to vary between agencies and industries, and usage of the guidelines often differs from that of the DOE. For example, many agencies use only AEGLs and ERPGs rather than the PAC dataset. Additionally, there were few references to the usage of TEEL values. This is likely because AEGLs and ERPGs are available for commonly used chemicals that are more likely to be involved in a chemical accident, and AEGLs and ERPGs are considered more reliable and scientifically sound than TEELs.

In summary, PACs are an important source of information for emergency planning and emergency response, providing toxic endpoint values that can be used to determine threat zones and estimate potential health impacts on a surrounding population. AEGLs and ERPGs are the preferred guidelines for use prior to or during a chemical emergency. However, TEELs can also be valuable when a chemical emergency occurs involving a substance with no AEGL or ERPG available.
7. References


¹ Note: this primary reference has been updated since it was initially retrieved and is now accessible at the following URL: http://energy.gov/ehss/protective-action-criteria-pac-aegls-erpgs-teels-rev-29-chemicals-concern-may-2016.


Appendix: Summary of Guidelines for H$_2$S

To illustrate the variation in guidance values for a specific chemical, a summary of guideline levels for hydrogen sulfide (H$_2$S) is presented below (modified from [18]).

Table 7: Summary of H$_2$S guideline values from various jurisdictions

<table>
<thead>
<tr>
<th>Standard or Guideline</th>
<th>Value (ppm)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>USEPA RfC</td>
<td>0.001</td>
<td><a href="http://www.epa.gov/iris">www.epa.gov/iris</a></td>
</tr>
<tr>
<td>Alberta AAQO (24-hr average)</td>
<td>0.003</td>
<td><a href="http://esrd.alberta.ca/air/objectives-directives-policies-and-standards/documents/5726.pdf">esrd.alberta.ca/air/objectives-directives-policies-and-standards/documents/5726.pdf</a></td>
</tr>
<tr>
<td>OEHHA CA-REL (Chronic; Annual)</td>
<td>0.008</td>
<td><a href="http://oehha.ca.gov/air/allrels.html">oehha.ca.gov/air/allrels.html</a></td>
</tr>
<tr>
<td>Approximate Odour Threshold</td>
<td>0.01</td>
<td><a href="http://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>Alberta AAQO (1-hr average)</td>
<td>0.01</td>
<td><a href="http://esrd.alberta.ca/air/objectives-directives-policies-and-standards/documents/5726.pdf">esrd.alberta.ca/air/objectives-directives-policies-and-standards/documents/5726.pdf</a></td>
</tr>
<tr>
<td>ATSDR Intermediate MRL</td>
<td>0.02</td>
<td><a href="http://www.atsdr.cdc.gov/mrls/mrllist.asp">www.atsdr.cdc.gov/mrls/mrllist.asp</a></td>
</tr>
<tr>
<td>OEHHA CA-REL (Acute; 1-hr)</td>
<td>0.03</td>
<td><a href="http://oehha.ca.gov/air/allrels.html">oehha.ca.gov/air/allrels.html</a></td>
</tr>
<tr>
<td>ATSDR Acute MRL</td>
<td>0.07</td>
<td><a href="http://www.atsdr.cdc.gov/mrls/mrllist.asp">www.atsdr.cdc.gov/mrls/mrllist.asp</a></td>
</tr>
<tr>
<td>AEGL-1 8-hr</td>
<td>0.33</td>
<td><a href="http://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>AEGL-1 4-hr</td>
<td>0.36</td>
<td><a href="http://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>PAC-1 (AEGL-1 1-hr)</td>
<td>0.51</td>
<td><a href="http://www.atlintl.com/doc/teels/teel/Table2.pdf">www.atlintl.com/doc/teels/teel/Table2.pdf</a></td>
</tr>
<tr>
<td>AEGL-1 60-min</td>
<td>0.51</td>
<td><a href="http://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>AEGL-1 30-min</td>
<td>0.6</td>
<td><a href="http://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>AEGL-1 10-min</td>
<td>0.75</td>
<td><a href="http://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>PAL-1 30-day and 90-day</td>
<td>0.85</td>
<td><a href="http://www.ncbi.nlm.nih.gov/pubmed/19827914">www.ncbi.nlm.nih.gov/pubmed/19827914</a></td>
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<tr>
<td>MAK (Germany)</td>
<td>5</td>
<td><a href="http://onlinelibrary.wiley.com/doi/10.1002/9783527666034.oth01/pdf">onlinelibrary.wiley.com/doi/10.1002/9783527666034.oth01/pdf</a></td>
</tr>
<tr>
<td>Standard or Guideline</td>
<td>Value (ppm)</td>
<td>Source</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>NIOSH REL (ceiling; 10-min)</td>
<td>10</td>
<td><a href="https://www.cdc.gov/niosh/npg/default.html">www.cdc.gov/niosh/npg/default.html</a></td>
</tr>
<tr>
<td>AEGL-2 8-hr</td>
<td>17</td>
<td><a href="https://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>OSHA PEL (ceiling; 10-min)</td>
<td>20</td>
<td><a href="https://www.cdc.gov/niosh/npg/default.html">www.cdc.gov/niosh/npg/default.html</a></td>
</tr>
<tr>
<td>AEGL-2 4-hr</td>
<td>20</td>
<td><a href="https://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
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<tr>
<td>PAC-2 (AEGL-2 1-hr)</td>
<td>27</td>
<td><a href="https://www.atlintl.com/doe/teels/teel/Table2.pdf">www.atlintl.com/doe/teels/teel/Table2.pdf</a></td>
</tr>
<tr>
<td>AEGL-2 60-min</td>
<td>27</td>
<td><a href="https://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>AEGL-3 8-hr</td>
<td>31</td>
<td><a href="https://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>AEGL-2 30-min</td>
<td>32</td>
<td><a href="https://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>AEGL-3 4-hr</td>
<td>37</td>
<td><a href="https://www.epa.gov/oppt/aegl/pubs/chemlist.htm">www.epa.gov/oppt/aegl/pubs/chemlist.htm</a></td>
</tr>
<tr>
<td>AEGL-2 10-min</td>
<td>41</td>
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<td>PAC-3 (AEGL-3 1-hr)</td>
<td>50</td>
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