

# 2019

## TLVs<sup>®</sup> and BEIs<sup>®</sup>

*Based on the Documentation of the*

**Threshold Limit  
Values**

**for Chemical Substances  
and Physical Agents**

**&**

**Biological Exposure  
Indices**



**ACGIH<sup>®</sup>**

*Defining the Science of  
Occupational and Environmental Health<sup>®</sup>*

*Signature Publications*

## POLICY STATEMENT ON THE USES OF TLVs® AND BEIs®

The Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®) are developed as guidelines to assist in the control of health hazards. These recommendations or guidelines are intended for use in the practice of industrial hygiene, to be interpreted and applied only by a person trained in this discipline. They are not developed for use as legal standards and ACGIH® does not advocate their use as such. However, it is recognized that in certain circumstances individuals or organizations may wish to make use of these recommendations or guidelines as a supplement to their occupational safety and health program. ACGIH® will not oppose their use in this manner, if the use of TLVs® and BEIs® in these instances will contribute to the overall improvement in worker protection. However, the user must recognize the constraints and limitations subject to their proper use and bear the responsibility for such use.

The Introductions to the TLV®/BEI® Book and the TLV®/BEI® *Documentation* provide the philosophical and practical bases for the uses and limitations of the TLVs® and BEIs®. To extend those uses of the TLVs® and BEIs® to include other applications, such as use without the judgment of an industrial hygienist, application to a different population, development of new exposure/recovery time models, or new effect endpoints, stretches the reliability and even viability of the database for the TLV® or BEI® as evidenced by the individual *Documentation*.

It is not appropriate for individuals or organizations to impose on the TLVs® or the BEIs® their concepts of what the TLVs® or BEIs® should be or how they should be applied or to transfer regulatory standards requirements to the TLVs® or BEIs®.

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*Approved by the ACGIH® Board of Directors on March 1, 1988.*

### Special Note to User

The values listed in this book are intended for use in the practice of industrial hygiene as guidelines or recommendations to assist in the control of potential workplace health hazards and for no other use. These values are *not* fine lines between safe and dangerous concentrations and *should not* be used by anyone untrained in the discipline of industrial hygiene. **It is imperative that the user of this book read the Introduction to each section and be familiar with the *Documentation* of the TLVs® and BEIs® before applying the recommendations contained herein.** ACGIH® disclaims liability with respect to the use of the TLVs® and BEIs®.

# 2019

## TLVs<sup>®</sup> and BEIs<sup>®</sup>

*Based on the Documentation of the*

### Threshold Limit Values

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and Physical Agents

# &

### Biological Exposure Indices



*Signature Publications*

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ACGIH® is a 501(c)(3) charitable scientific organization that advances occupational and environmental health. The organization has contributed substantially to the development and improvement of worker health protection. The organization is a professional society, not a government agency.

The *Documentation of the Threshold Limit Values and Biological Exposure Indices* is the source publication for the TLVs® and BEIs® issued by ACGIH®. That publication gives the pertinent scientific information and data with reference to literature sources that were used to base each TLV® or BEI®. For better understanding of the TLVs® and BEIs®, it is essential that the *Documentation* be consulted when the TLVs® or BEIs® are being used. For further information, contact The Science Group, ACGIH®. The most up-to-date list of substances and agents under study by the committees is available at [www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list).

**Comments, suggestions, and requests for interpretations or technical information should be directed to The Science Group at the address below or to the following e-mail address: [science@acgih.org](mailto:science@acgih.org). To place an order, visit our website at [www.acgih.org/store](http://www.acgih.org/store), contact Customer Service at the address or phone number below, or use the following e-mail address: [customerservice@acgih.org](mailto:customerservice@acgih.org).**

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TLVs® and BEIs®. Make a tax deductible donation to  
the FOHS Sustainable TLV®/BEI® Fund today!*

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**In the event significant errata are required, they will be listed on the ACGIH® website at [www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations).**

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## STATEMENT OF POSITION REGARDING THE TLVs® AND BEIs®

The American Conference of Governmental Industrial Hygienists (ACGIH®) is a private, not-for-profit, nongovernmental corporation whose members are industrial hygienists or other occupational health and safety professionals dedicated to promoting health and safety within the workplace. ACGIH® is a scientific association. ACGIH® is not a standards-setting body. As a scientific organization, it has established committees that review the existing published, peer-reviewed scientific literature. ACGIH® publishes guidelines known as Threshold Limit Values (TLVs®) and Biological Exposure Indices (BEIs®) for use by industrial hygienists in making decisions regarding safe levels of exposure to various chemical and physical agents found in the workplace. In using these guidelines, industrial hygienists are cautioned that the TLVs® and BEIs® are only one of multiple factors to be considered in evaluating specific workplace situations and conditions.

Each year, ACGIH® publishes its TLVs® and BEIs® in a book. In the introduction to the book, ACGIH® states that the TLVs® and BEIs® are guidelines to be used by professionals trained in the practice of industrial hygiene. The TLVs® and BEIs® are not designed to be used as standards. Nevertheless, ACGIH® is aware that in certain instances the TLVs® and the BEIs® are used as standards by national, state, or local governments.

Governmental bodies establish public health standards based on statutory and legal frameworks that include definitions and criteria concerning the approach to be used in assessing and managing risk. In most instances, governmental bodies that set workplace health and safety standards are required to evaluate health effects, economic and technical feasibility, and the availability of acceptable methods to determine compliance.

ACGIH® TLVs® and BEIs® are not consensus standards. Voluntary consensus standards are developed or adopted by voluntary consensus standards bodies. The consensus standards process involves canvassing the opinions, views, and positions of all interested parties and then developing a consensus position that is acceptable to these parties. While the process used to develop a TLV® or BEI® includes public notice and requests for all available and relevant scientific data, the TLV® or BEI® does not represent a consensus position that addresses all issues raised by all interested parties (e.g., issues of technical or economic feasibility). The TLVs® and BEIs® represent a scientific opinion based on a review of existing peer-reviewed scientific literature by committees of experts in public health and related sciences.

ACGIH® TLVs® and BEIs® are health-based values. ACGIH® TLVs® and BEIs® are established by committees that review existing published and peer-reviewed literature in various scientific disciplines (e.g., industrial hygiene, toxicology, occupational medicine, and epidemiology). Based on the available information, ACGIH® formulates a conclusion on the level of exposure that the typical worker can experience without adverse health effects. The TLVs® and BEIs® represent conditions under which ACGIH® believes that nearly all workers may be repeatedly exposed without adverse health effects. They are not

fine lines between safe and dangerous exposures, nor are they a relative index of toxicology. The TLVs<sup>®</sup> and BEIs<sup>®</sup> are not quantitative estimates of risk at different exposure levels or by different routes of exposure.

Since ACGIH<sup>®</sup> TLVs<sup>®</sup> and BEIs<sup>®</sup> are based solely on health factors, there is no consideration given to economic or technical feasibility. Regulatory agencies should not assume that it is economically or technically feasible for an industry or employer to meet TLVs<sup>®</sup> or BEIs<sup>®</sup>. Similarly, although there are usually valid methods to measure workplace exposures at the TLVs<sup>®</sup> and BEIs<sup>®</sup>, there can be instances where such reliable test methods have not yet been validated. Obviously, such a situation can create major enforcement difficulties if a TLV<sup>®</sup> or BEI<sup>®</sup> was adopted as a standard.

ACGIH<sup>®</sup> does not believe that TLVs<sup>®</sup> and BEIs<sup>®</sup> should be adopted as standards without full compliance with applicable regulatory procedures, including an analysis of other factors necessary to make appropriate risk management decisions. However, ACGIH<sup>®</sup> does believe that regulatory bodies should consider TLVs<sup>®</sup> or BEIs<sup>®</sup> as valuable input into the risk characterization process (hazard identification, dose-response relationships, and exposure assessment). Regulatory bodies should view TLVs<sup>®</sup> and BEIs<sup>®</sup> as an expression of scientific opinion.

ACGIH<sup>®</sup> is proud of the scientists and the many members who volunteer their time to work on the TLV<sup>®</sup> and BEI<sup>®</sup> Committees. These experts develop written *Documentation* that includes an expression of scientific opinion and a description of the basis, rationale, and limitations of the conclusions reached by ACGIH<sup>®</sup>. The *Documentation* provides a comprehensive list and analysis of all the major published peer-reviewed studies that ACGIH<sup>®</sup> relied upon in formulating its scientific opinion. Regulatory agencies dealing with hazards addressed by a TLV<sup>®</sup> or BEI<sup>®</sup> should obtain a copy of the full written *Documentation* for the TLV<sup>®</sup> or BEI<sup>®</sup>. Any use of a TLV<sup>®</sup> or BEI<sup>®</sup> in a regulatory context should include a careful evaluation of the information in the written *Documentation* and consideration of all other factors as required by the statutes which govern the regulatory process of the governmental body involved.



- *ACGIH® is a not-for-profit scientific association.*
- *ACGIH® proposes guidelines known as TLVs® and BEIs® for use by industrial hygienists in making decisions regarding safe levels of exposure to various hazards found in the workplace.*
- *ACGIH® is not a standard-setting body.*
- *Regulatory bodies should view TLVs® and BEIs® as an expression of scientific opinion.*
- *TLVs® and BEIs® are not consensus standards.*
- *ACGIH® TLVs® and BEIs® are based solely on health factors; there is no consideration given to economic or technical feasibility. Regulatory agencies should not assume that it is economically or technically feasible to meet established TLVs® or BEIs®.*
- *ACGIH® believes that TLVs® and BEIs® should NOT be adopted as standards without an analysis of other factors necessary to make appropriate risk management decisions.*
- *TLVs® and BEIs® can provide valuable input into the risk characterization process. Regulatory agencies dealing with hazards addressed by a TLV® or BEI® should review the full written Documentation for the numerical TLV® or BEI®.*

*ACGIH® is publishing this Statement in order to assist ACGIH® members, government regulators, and industry groups in understanding the basis and limitations of the TLVs® and BEIs® when used in a regulatory context. This Statement was adopted by the ACGIH® Board of Directors on March 1, 2002.*

## TLV®/BEI® DEVELOPMENT PROCESS: AN OVERVIEW

Provided below is an overview of the ACGIH® TLV®/BEI® Development Process. Additional information is available on the ACGIH® website ([www.acgih.org](http://www.acgih.org)). Please also refer to the attached Process Flowchart (Figure 1).

1. **Under Study:** When a substance or agent is selected for the development or revision of a TLV® or BEI®, the appropriate committee places it on its Under Study list. Each committee determines its own selection of chemical substances or physical agents for its Under Study list. A variety of factors is used in this selection process, including prevalence, use, number of workers exposed, availability of scientific data, existence/absence of a TLV® or BEI®, age of TLV® or BEI®, input from the public, etc. The public may offer input to any TLV® or BEI® Committee by e-mail to [science@acgih.org](mailto:science@acgih.org).

The Under Study lists serve as notification and invitation to interested parties to submit substantive data and comments to assist the committees in their deliberations. Each committee considers only those comments and data that address issues of health and exposure, but not economic or technical feasibility. Comments must be accompanied by copies of substantiating data, preferably in the form of peer-reviewed literature. Should the data be from unpublished studies, ACGIH® requires written authorization from the owner of the studies granting ACGIH® permission to (1) use, (2) cite within the *Documentation*, and (3) upon request from a third party, release the information. All three permissions must be stated/covered in the written authorization. (See endnote for a sample permission statement.) Electronic submission of all information to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org) is preferred and greatly increases the ease and efficiency with which the committee can consider the comments or data.

The Under Study list is published each year by February 1 on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)), in the *Annual Reports of the Committees on TLVs® and BEIs®*, and later in the annual *TLVs® and BEIs®* book. In addition, the Under Study list is updated by July 31 into a two-tier list.

- Tier 1 entries indicate which chemical substances and physical agents **may** move forward as an NIC or NIE in the upcoming year, based on their status in the development process.
- Tier 2 consists of those chemical substances and physical agents that **will not** move forward, but will either remain on, or be removed from, the Under Study list for the next year.

This updated list will remain in two-tiers for the balance of the year. All updates to the Under Study lists and publication of the two-tier lists are posted on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)).

2. **Draft Documentation:** One or more members of the appropriate committee are assigned the task of collecting information and data from the scientific literature, reviewing results of unpublished studies submitted for review,

and developing a draft TLV<sup>®</sup> or BEI<sup>®</sup> *Documentation*. The draft *Documentation* is a critical evaluation of the scientific literature relevant to recommending a TLV<sup>®</sup> or BEI<sup>®</sup>; however, it is not an exhaustive critical review of all studies but only those pertinent to identifying the critical effect and setting the TLV<sup>®</sup>. Particular emphasis is given to papers that address minimal or no adverse health effect levels in exposed animals or workers that deal with the reversibility of such effects, or in the case of a BEI<sup>®</sup>, that assess chemical uptake and provide applicable determinant(s) as an index of uptake. Human data, when available, are given special emphasis. This draft *Documentation*, with its proposed TLV<sup>®</sup> or BEI<sup>®</sup>, is then reviewed and critiqued by additional committee members, and eventually by the full committee. This often results in several revisions to the draft *Documentation* before the full committee accepts the proposed draft TLV<sup>®</sup> or BEI<sup>®</sup> and draft *Documentation*. The draft *Documentation* is not available to the public during this stage of the development process and is not released until it is at the Notice of Intended Changes (NIC) stage. Authorship of the *Documentation* is not disclosed.

### 3. Notice of Intended Changes (NIC):

**[Notice of Intent to Establish (NIE):** *The Physical Agents section of the TLVs<sup>®</sup> and BEIs<sup>®</sup> book also uses the term Notice of Intent to Establish (NIE) in addition to NIC. An NIE follows the same development process as an NIC. For purposes of this process overview, only the term NIC is used.]*

When the full committee accepts the draft *Documentation* and its proposed TLV<sup>®</sup> or BEI<sup>®</sup>, the *Documentation* and proposed values are then recommended to the ACGIH<sup>®</sup> Board of Directors for ratification as an NIC. If ratified, each proposed TLV<sup>®</sup> or BEI<sup>®</sup> is published as an NIC in the *Annual Reports of the Committees on TLVs<sup>®</sup> and BEIs<sup>®</sup>*, which is published in the ACGIH<sup>®</sup> member newsletter, *Today! Online* and is also available online for purchase at [www.acgih.org/store](http://www.acgih.org/store). At the same time, the draft *Documentation* is made available through ACGIH<sup>®</sup> Customer Service or online at [www.acgih.org/store](http://www.acgih.org/store). All information contained in the *Annual Reports of the Committees on TLVs<sup>®</sup> and BEIs<sup>®</sup>* is integrated into the annual *TLVs<sup>®</sup> and BEIs<sup>®</sup>* book, which is usually available to the general public in February or March of each year. Following the NIC ratification by the ACGIH<sup>®</sup> Board of Directors, interested parties, including ACGIH<sup>®</sup> members, are invited to provide data and substantive comments, preferably in the form of peer-reviewed literature, on the proposed TLVs<sup>®</sup> or BEIs<sup>®</sup> contained in the NIC. Should the data be from unpublished studies, ACGIH<sup>®</sup> requires written authorization from the owner of the studies granting ACGIH<sup>®</sup> permission to (1) use, (2) cite within the *Documentation*, and (3) upon request from a third party, release the information. All three permissions must be stated/covered in the written authorization. (See endnote for a sample permission statement.) The most effective and helpful comments are those that address specific points within the draft *Documentation*. Changes or updates are made to the draft *Documentation* as necessary. If the committee finds or receives

substantive data that change its scientific opinion regarding TLV® or BEI® values or notations, the committee may revise the proposal(s) and recommend to the ACGIH® Board of Directors that it be retained on the NIC.

**Important Notice:** The comment period for an NIC or NIE draft *Documentation* and its respective TLV(s)®, notation(s), or BEI(s)®, will be limited to a firm 4-month period, running from February 1 to May 31 of each year. ACGIH® has structured the comment period to ensure all comments are received by ACGIH® in time for full consideration by the appropriate committee before its fall meeting. Because of the time required to properly review, evaluate, and consider comments during the fall meetings, any comments received after the deadline of May 31 will not be considered in that year's committee deliberations regarding the outcome for possible adoption of an NIC or NIE. As general practice, ACGIH® reviews all submissions regarding chemical substances and physical agents on the Under Study list, as well as NICs or NIEs, or currently adopted BEI(s)® or TLV(s)®. All comments received after May 31 will be fully considered in the following year. Draft *Documentation* will be available for review during the comment period.

*When submitting comments, ACGIH® requires that the submission be limited to 10 pages in length, including an executive summary. The submission may include appendices of citable material not included as part of the 10-page limit. It would be very beneficial to structure comments as follows:*

- A. **Executive Summary** – Provide an executive summary with a limit of 250 words.
- B. **List of Recommendations/Actions** – Identify, in a vertical list, specific recommendations/actions that are being requested.
- C. **Rationale** – Provide specific rationale to justify each recommendation/action requested.
- D. **Citable Material** – Provide citable material to substantiate the rationale.

The above procedure will help ACGIH® to more efficiently and productively review comments.

4. **TLV®/BEI® and Adopted *Documentation*:** If the committee neither finds nor receives any substantive data that change its scientific opinion regarding an NIC TLV® or BEI® (or notation), the committee may then approve its recommendation to the ACGIH® Board of Directors for adoption. Once approved by the committee and subsequently ratified by the Board, the TLV® or BEI® is published as adopted in the *Annual Reports of the Committees on TLVs® and BEIs®* and in the annual *TLVs® and BEIs®* book, and the draft TLV® or BEI® *Documentation* is finalized for formal publication.
5. **Withdraw from Consideration:** At any point in the process, the committee may determine not to proceed with the development of a TLV® or BEI® and withdraw it from further consideration. Substances or physical agents that have been withdrawn from consideration may be reconsidered by placement on the Under Study list (step 1 above).

**Summary:** There are *several important points* to consider throughout the above process:

- i. The appropriate method for an interested party to contribute to the TLV<sup>®</sup> and BEI<sup>®</sup> process is through the submission of literature that is peer-reviewed and public. ACGIH<sup>®</sup> strongly encourages interested parties to publish their studies, and not to rely on unpublished studies as their input to the TLV<sup>®</sup> and BEI<sup>®</sup> process. Also, the best time to submit comments to ACGIH<sup>®</sup> is in the early stages of the TLV<sup>®</sup>/BEI<sup>®</sup> Development Process, preferably while the substance or agent is on the Under Study list.
- ii. An additional venue for presentation of new data is an ACGIH<sup>®</sup>-sponsored symposium or workshop that provides a platform for public discussion and scientific interpretation. ACGIH<sup>®</sup> encourages input from external parties for suggestions on symposia topics, including suggestions about sponsors, speakers and format. ACGIH<sup>®</sup> employs several criteria to determine the appropriateness of a symposium. A key criterion is that the symposium must be the most efficient format to present the committee with information that will assist in the scientific judgment used for writing the *Documentation* and in setting the respective TLVs<sup>®</sup> or BEIs<sup>®</sup>. A symposium topic should be suggested while the substance/agent is under study, as symposia require considerable time, commitment, and resources to develop. Symposium topic suggestions submitted while a substance is on the NIC will be considered, but this is usually too late in the decision-making process. A symposium topic will not be favorably considered if its purpose is to provide a forum merely for voicing opinions about existing data. Rather, there must be on-going research, scientific uncertainty about currently available data, or another scientific reason for the symposium. Symposium topic suggestions should be sent to the ACGIH<sup>®</sup> Science Group ([science@acgih.org](mailto:science@acgih.org)).
- iii. ACGIH<sup>®</sup> periodically receives requests from external parties to make a presentation to a committee about specific substances or issues. It is *strictly by exception* that such requests are granted. While there are various reasons for this position, the underlying fact is that the committee focuses on data that have been peer-reviewed and published and not on data presented in a private forum. A committee may grant a request when the data is significantly new, has received peer review, is the best vehicle for receipt of the information, and is essential to the committee's deliberations. The presentation is not a forum to merely voice opinions about existing data. In order for a committee to evaluate such a request, the external party must submit a request in writing that, at a minimum, addresses the following elements: (a) a detailed description of the presentation; (b) a clear demonstration of why the information is important to the committee's deliberations; and (c) a clear demonstration of why a meeting is the necessary method of delivery. This request must be sent to the ACGIH<sup>®</sup> Science Group ([science@acgih.org](mailto:science@acgih.org)).

Also, the committee may initiate contact with outside experts (a) to meet with the committee to discuss specific issues or to obtain addi-

tional knowledge on the subject, and (b) to provide written input or review of a *Documentation*. This is only done on an as needed basis, and not as a routine practice.

- iv. ACGIH® does *not* commit to deferring consideration of a new or revised TLV® or BEI® pending the outcome of proposed or ongoing research.

**Important dates to consider throughout each calendar year of the TLV®/BEI® Development Process:**

**First Quarter:**

- The *Annual Reports of the Committees on TLVs® and BEIs®* and the *TLVs® and BEIs®* book are published.

**Year Round:**

- Public comments are accepted. See Note below.
- Committees meet.

**Note:** It is recommended that comments be submitted as early as practical, and preferably no later than May 31st to allow sufficient time for their proper consideration/review. This is particularly important for an NIC TLV®/BEI®.

**Important Notice:** The comment period for an NIC or NIE draft *Documentation* and its respective TLV(s)®, notation(s), or BEI(s)® will be limited to a firm 4-month period, running from February 1 to May 31 of each year. (See Important Notice, step 3 above.)

**Third Quarter:**

- Two-tier Under Study list published on website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)).

**Fourth Quarter: \***

- TLV®/BEI® Committees vote on proposed TLVs®/BEIs® for NIC or final adoption.
- ACGIH® Board of Directors ratifies TLV®/BEI® Committee recommendations.

\*These actions typically occur early in the fourth quarter, but may occur during other periods of the quarter or year.

[Name], [author or sponsor of the study\*\*] grants permission to ACGIH® to use and cite the documents listed below, and to fully disclose them to parties outside of ACGIH® upon request. Permission to disclose the documents includes permission to make copies as needed.

*Example:* Joseph D. Doe, PhD, co-author of the study, grants permission to ACGIH® to use and cite the document listed below, and to fully disclose this document to parties outside of ACGIH®. Permission to disclose the document includes permission to make copies as needed.

“Effects of Quartz Status on Pharmacokinetics of Intratracheally Instilled Cristobalite in Rats, March 21, 2003.”

\*\*This statement must be signed by an individual authorized to give this permission, and should include contact information such as title and address.

Last Revised April 2012

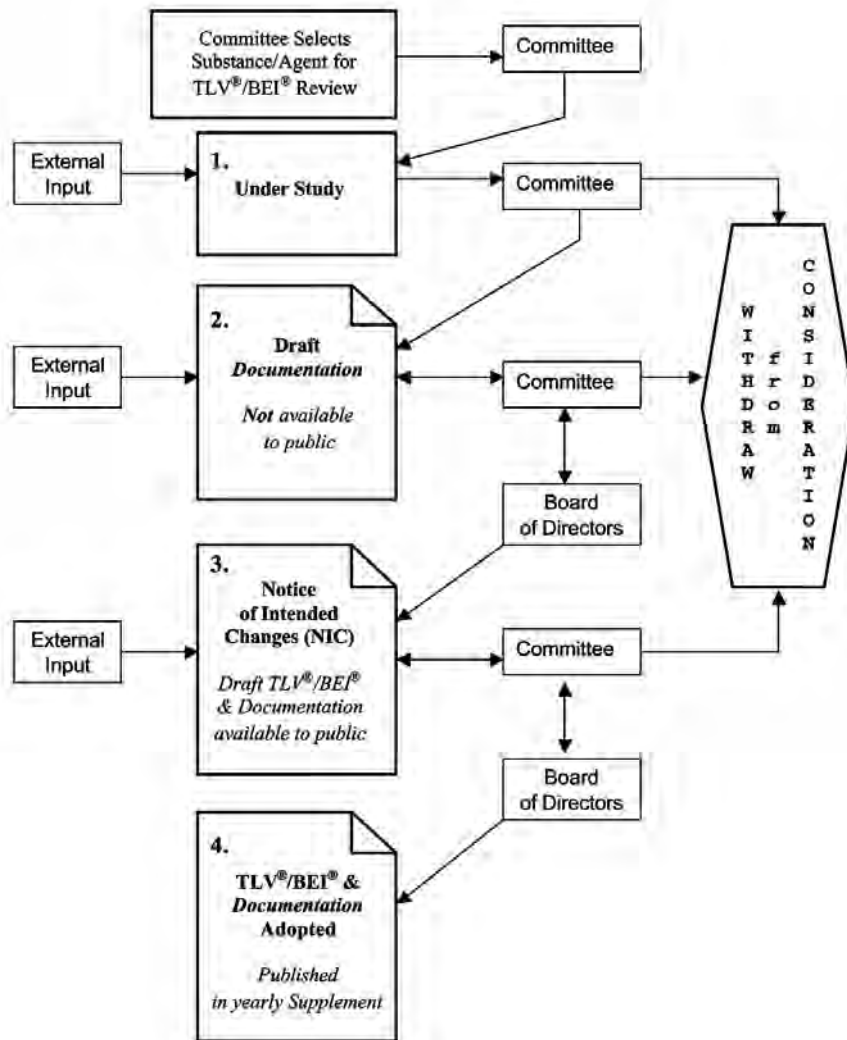


FIGURE 1. The TLV®/BEI® Development Process Flow Chart.

## ONLINE TLV® AND BEI® RESOURCES

In an effort to make the threshold limit values (TLVs®) and biological exposures indices (BEIs®) guideline establishment process more transparent, and to assist ACGIH® members, government regulators, and industry groups in understanding the basis and limitations of the TLVs® and BEIs®, ACGIH® has an online TLV®/BEI® Resources Section on its website at [www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/overview](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/overview).

The TLV®/BEI® Resources Section is divided into eight categories, each containing clear and concise information. The categories are:

- **Conflict of Interest Policy** — applies to the Board of Directors, Committee Chairs, and Committee members (including consultant members), and safeguards the integrity and credibility of ACGIH® programs and activities. The Policy, as well as ACGIH®'s oversight and review, each play an important part in the protection of ACGIH®'s programs and activities from inappropriate influences ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/conflict-of-interest-policy](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/conflict-of-interest-policy)).
- **Notice of Intended Changes (NIC)** — a listing of the proposed actions of the TLV®-CS, TLV®-PA, and BEI® Committees. This Notice provides an opportunity for public comment. Values remain on the NIC for approximately one year after they have been ratified by ACGIH®'s Board of Directors. The proposals should be considered trial values during the period they are on the NIC. If the Committee neither finds nor receives any substantive data that change its scientific opinion regarding an NIC TLV® or BEI®, the Committee may then approve its recommendation to the ACGIH® Board of Directors for adoption. If the Committee finds or receives substantive data that change its scientific opinion regarding an NIC TLV® or BEI®, the Committee may change its recommendation to the ACGIH® Board of Directors for the matter to be either retained on or withdrawn from the NIC (Note: In the Physical Agents section of this book, the term Notice of Intent to Establish (NIE) is used in addition to NIC. For the purpose of this process overview, only the term NIC is used.) ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/notice-of-intended-changes](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/notice-of-intended-changes)).
- **TLV®/BEI® Policy Statement** — states what the TLVs® and BEIs® are and how they are intended to be used. While the TLVs® and BEIs® do contribute to the overall improvement in worker protection, the user must recognize the constraints and limitations subject to their proper use and bear the responsibility for such use ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-policy-statement](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-policy-statement)).
- **TLV®/BEI® Position Statement** — expresses ACGIH®'s position on the TLVs® and BEIs® process. ACGIH® is proud of the positive impact that the TLVs® and BEIs® have had on workers worldwide, and stands behind the hard work of its Committees to make the process more transparent and accessible. This section is presented in its entirety on pages v through vii ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-position-statement](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-position-statement)).



- **TLV®/BEI® Development Process** — gives an overview of the process the Committees go through when establishing a TLV® or BEI®. This section is presented in its entirety on pages viii through xiii ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process)).
- **Committee Operations Manuals** — portable data files (PDF) of the Threshold Limit Values for Chemical Substances, the Threshold Limit Values for Physical Agents, and the Biological Exposure Indices Committees' Operations Manuals. Each Manual covers such areas as the Committee's mission, membership in the Committee, Committee make-up, internal and external communications with the Committee, flow of information, procedures for development of symposia and workshops, etc. ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-committee-operations-manuals](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-committee-operations-manuals)).
- **TLV®/BEI® Process Presentations** — stand-alone PowerPoint presentations from the annual American Industrial Hygiene Conference and Exposition (AIHce) are offered. These forums are open to all AIHce registrants and focus on the process used by ACGIH® and its TLV®, BEI®, and Bioaerosols Committees. These presentations are posted on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-process-presentations](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-process-presentations)).
- **Under Study List** — contains substances, agents, and issues that are being considered by the Committees. Each Committee solicits data, comments, and suggestions that may assist in their deliberations about substances, agents, and issues on the Under Study list ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)). Further, each Committee solicits recommendations for additional chemical substances, physical agents, and issues of concern to the industrial hygiene and occupational health communities.

## REVISIONS OR ADDITIONS FOR 2019

*All pertinent endnotes, abbreviations, and definitions relating to the materials in this publication appear on the inside back cover.*

### Introduction to the Chemical Substances

- The Threshold Limit Value–Surface Limit (TLV–SL) definition that appeared on the 2018 NIC is adopted.

### Chemical Substances Section

- Proposed TLVs<sup>®</sup> that appeared on the 2018 NIC are adopted for the following substances:

Cobalt and inorganic compounds	Methyl vinyl ketone
Cyanazine	Monomethylformamide
Dicyclopentadiene, including Cyclopentadiene	o-Phthalaldehyde
Dimethylphenol, all isomers	Propylene glycol ethyl ether
Fluorine	Sulfoxaflor
Indium tin oxide	Tetramethyl succinonitrile
Methyltetrahydrophthalic anhydride isomers	Thiacloprid
	Tin and inorganic compounds, excluding Tin hydride and Indium tin oxide

- The following substances that appeared on the 2018 NIC for the proposed addition of the Inhalable fraction and vapor (IFV) endnote only are adopted:

Chlordane	Nitrapyrin
o-Chlorobenzylidene malononitrile	5-Nitro-o-toluidine
Dinitrobenzene, all isomers	Pentachloronaphthalene
Dinitro-o-cresol	Sulfometuron methyl
EPN	2,4,6-Trinitrotoluene
4,4-Methylene bis(2-chloroaniline)	

- The following substances that appeared on the 2018 NIC for the proposed withdrawal of the Inhalable fraction and vapor (IFV) endnote only are adopted:

Isobutyl nitrite	1,1,2,2-Tetrabromoethane
------------------	--------------------------

- The following substance that appeared on the 2018 NIC for the proposed withdrawal of the inhalable fraction and vapor (IFV) endnote and addition of the inhalable particulate matter (I) endnote only is adopted:

Temephos

- The following substance that appeared on the 2018 NIC for the proposed withdrawal of the (V) endnote only is adopted:

m-Xylene  $\alpha,\alpha'$ -diamine

(Note: The (V) endnote withdrawn refers to the former vapor and aerosol endnote.)

- The adopted *Documentation* and TLV<sup>®</sup> for the following substance are withdrawn:  
Cyclopentadiene
- The following substances and proposed TLVs<sup>®</sup> new to this section are placed on the NIC:
 

4-tert-Butylbenzoic acid	Resin acids
Hexamethylenetetramine	Thiodicarb
Hexazinone	Titanium tetrachloride
Isoflurane	
- Revisions to adopted TLVs<sup>®</sup> are proposed for the following substances and placed on the NIC:
 

Acrylamide	Formamide
Antimony trioxide	Methyl isobutyl carbinol
Cyclohexene	Sulfur pentafluoride
Di(2-ethylhexyl) phthalate	
- The adopted *Documentation* and TLV<sup>®</sup> for the following substance are proposed to be withdrawn and are placed on the NIC:  
Rosin core solder thermal decomposition products (colophony)
- The following substances are retained on the NIC without revised TLV<sup>®</sup> recommendations or notations:
 

Cumene	Trimetacresyl phosphate
Iodoform	Triparacresyl phosphate
Styrene oxide	
- The following substance is retained on the NIC with revised TLV<sup>®</sup> recommendations or notations:  
Styrene
- The following substances have been withdrawn from the NIC:
 

Iodine and Iodides	Sodium sulfate
--------------------	----------------
- *Documentation* was updated for the following substance without change to the recommended TLV<sup>®</sup>. See the 2019 *Supplement to the Documentation of the TLVs<sup>®</sup> and BEIs<sup>®</sup>*, 7th ed.:  
Phosphine

### Definitions and Notations Section

- The Ototoxicant (OTO) notation that appeared on the 2018 NIC is adopted.

### Introduction to the Biological Exposure Indices

- The Introduction to the *Documentation of the Biological Exposure Indices* that appeared on the 2018 NIC is adopted.



# 2019

## Threshold Limit Values for Chemical Substances in the Work Environment



Adopted by ACGIH®  
with Intended Changes

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# INTRODUCTION TO THE CHEMICAL SUBSTANCES

TLV®-CS

## General Information

The TLVs® are guidelines to be used by professional industrial hygienists. The values presented in this book are intended for use only as guidelines or recommendations to assist in the evaluation and control of potential workplace health hazards and for no other use (e.g., neither for evaluating or controlling community air pollution; nor for estimating the toxic potential of continuous, uninterrupted exposures or other extended work periods; nor for proving or disproving an existing disease or physical condition in an individual). Further, these values are not fine lines between safe and dangerous conditions and should not be used by anyone who is not trained in the discipline of industrial hygiene. TLVs® are not regulatory or consensus standards.

*Editor's note:* The approximate year that the current *Documentation* was last substantially reviewed and, where necessary, updated may be found following the CAS number for each of the adopted entries in the alphabetical listing, e.g., Chromium [7440-47-3] and inorganic compounds (2017). The reader is advised to refer to the “TLV® Chronology” section in each *Documentation* for a brief history of the TLV® recommendations and notations.

## Definition of the TLVs®

Threshold Limit Values (TLVs®) refer to airborne concentrations of chemical substances and represent conditions under which it is believed that *nearly all* workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects.

Those who use the TLVs® **MUST** consult the latest *Documentation* to ensure that they understand the basis for the TLV® and the information used in its development. The amount and quality of the information that is available for each chemical substance varies over time.

Chemical substances with equivalent TLVs® (i.e., same numerical values) cannot be assumed to have similar toxicologic effects or similar biologic potency. In this book, there are columns listing the TLVs® for each chemical substance (that is, airborne concentrations in parts per million [ppm] or milligrams per cubic meter [ $\text{mg}/\text{m}^3$ ]) and critical effects produced by the chemical substance. These critical effects form the basis of the TLV®.

ACGIH® recognizes that there will be considerable variation in the level of biological response to a particular chemical substance, regardless of the airborne concentration. Indeed, TLVs® do not represent a fine line between a healthy versus an unhealthy work environment or the point at which material impairment of health will occur. TLVs® will not adequately protect all workers. Some individuals may experience discomfort or even more serious adverse health effects when exposed to a chemical substance at the TLV® or even at concentrations below the TLV®. There are numerous possible reasons for increased susceptibility to a chemical substance, including age, gender, genetic factors (predisposition), lifestyle choices (e.g., diet, smoking, abuse of alcohol and other drugs), medications, and pre-existing medical conditions (e.g., aggravation of asthma or cardiovascular disease). Some individuals may

become more responsive to one or more chemical substances following previous exposures (e.g., sensitized workers). Susceptibility to the effects of chemical substances may be altered during different periods of fetal development and throughout an individual's reproductive lifetime. Some changes in susceptibility may also occur at different work levels (e.g., light versus heavy work) or at exercise — situations in which there is increased cardiopulmonary demand. Additionally, variations in temperature (e.g., extreme heat or cold) and relative humidity may alter an individual's response to a toxicant. The *Documentation* for any given TLV® must be reviewed, keeping in mind that other factors may modify biological responses.

Although TLVs® refer to airborne levels of chemical exposure, dermal exposures may possibly occur in the workplace (see “Skin” on page 73 of the **Definitions and Notations** section).

Four categories of TLVs® are specified: time-weighted average (TWA); short-term exposure limit (STEL); ceiling (C); and surface limit (SL). For most substances, a TWA alone or with a STEL is relevant. For some substances (e.g., irritant gases), only the TLV–STEL or TLV–C is applicable. If any of these TLV® types are exceeded, a potential hazard from that substance is presumed to exist.

**Threshold Limit Value–Time-Weighted Average (TLV–TWA):** The TWA concentration for a conventional 8-hour workday and a 40-hour workweek, to which it is believed that nearly all workers may be repeatedly exposed, day after day, for a working lifetime without adverse effect. Although calculating the average concentration for a workweek, rather than a workday, may be appropriate in some instances, ACGIH® does not offer guidance regarding such exposures.

**Threshold Limit Value–Short-Term Exposure Limit (TLV–STEL):** A 15-minute TWA exposure that should not be exceeded at any time during a workday, even if the 8-hour TWA is within the TLV–TWA. The TLV–STEL is the concentration to which it is believed that nearly all workers can be exposed continuously for a short period of time without suffering from 1) irritation, 2) chronic or irreversible tissue damage, 3) dose-rate-dependent toxic effects, or 4) narcosis of sufficient degree to increase the likelihood of accidental injury, impaired self-rescue, or materially reduced work efficiency. The TLV–STEL will not necessarily protect against these effects if the daily TLV–TWA is exceeded. The TLV–STEL usually supplements the TLV–TWA where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature; however, the TLV–STEL may be a separate, independent exposure guideline. Exposures above the TLV–TWA up to the TLV–STEL (15-min TWA) should be less than 15 minutes, should occur no more than four times per day, and there should be at least 60 minutes between successive exposures in this range. An averaging period other than 15 minutes may be recommended when this is warranted by observed biological effects.

**\*Threshold Limit Value–Surface Limit (TLV–SL):** The concentration on workplace equipment and facility surfaces that is not likely to result in adverse effects following direct or indirect contact. The TLV–SL is intended to supplement airborne TLVs®, especially those with Skin, DSEN and RSEN notations, to provide quantitative criteria for establishing acceptable surface concentrations expressed as mg/100 cm<sup>2</sup>. For systemic effects, consistent with the use of the Skin notation, the TLV–SL will often correspond to the dose permitted by the



TLV–TWA over an 8-hour period, unless chemical-specific data are available linking adverse effects with surface sample results. For certain dermal sensitizers, the surface limit may be established using potency estimates from animal studies, such as the effective concentration causing a 3-fold increase in lymphocyte proliferation (EC3) and applying an appropriate adjustment factor (Naumann and Arnold, 2019). For other sensitizers, including some respiratory sensitizers that cause induction of sensitization via dermal exposure, professional judgment may be required to supplement available surface and airborne monitoring results.

**Threshold Limit Value–Ceiling (TLV–C):** The concentration that should not be exceeded during any part of the working exposure. If instantaneous measurements are not available, sampling should be conducted for the minimum period of time sufficient to detect exposures at or above the ceiling value. ACGIH® believes that TLVs® based on physical irritation should be considered no less binding than those based on physical impairment. There is increasing evidence that physical irritation may initiate, promote, or accelerate adverse health effects through interaction with other chemical or biologic agents or through other mechanisms.

## Peak Exposures

The TLV® Committee recommends consideration of a TLV–STEL if there are supporting data. For many substances with a TLV–TWA, there is no TLV–STEL. Nevertheless, short-term peak exposures above the TLV–TWA should be controlled, even where the 8-hour TLV–TWA is within recommended limits. Limiting short-term high exposures is intended to prevent rapidly occurring acute adverse health effects resulting from transient peak exposures during a workshift. Since these adverse effects may occur at some multiple of the 8-hour TWA, even if they have not yet been documented, it is prudent to limit peak exposures. Therefore, the following default short-term exposure limits apply to those TLV–TWAs that do not have a TLV–STEL:

*Transient increases in workers' exposure levels may exceed 3 times the value of the TLV–TWA level for no more than 15 minutes at a time, on no more than 4 occasions spaced 1 hour apart during a workday, and under no circumstances should they exceed 5 times the value of the TLV–TWA level when measured as a 15-min TWA. In addition, the 8-hour TWA is not to be exceeded for an 8-hour work period.*

This guidance on limiting peak exposures above the value of the TLV–TWA is analogous to that for the TLV–STEL, and both represent 15-minute exposure limits. The consistency in approach is intended to encourage minimizing process variability and ensuring worker protection. Good design and industrial hygiene practice ensures that processes are controlled within acceptable ranges. Historically, guidance on peak exposures (formerly excursion limits) has been based purely on statistical considerations: if log-normally distributed, short-term exposure values for a well-controlled process have a geometric standard deviation of 2.0, then 5% of all values will exceed 3.13 times the geometric

mean. Processes that display greater variability are not under good control, and efforts should be made to restore control. Higher exposure levels also increase the possibility that acute health effects may occur, which were probably not factored into the TLV–TWA if it was based on prevention of chronic effects. The maximum peak exposure factor of 5 also reflects this concern about undesirable health effects. Limiting peak exposures reduces the probability of exceeding the TLV–TWA. When initial samples indicate peak exposures beyond these recommendations, more careful assessment is needed, especially when dealing with unusual work schedules.

The so-called “3 by 5 Rule”, as described above, should be considered a rule of thumb, and a pragmatic precautionary approach. It is recognized that the geometric standard deviations of some common workplace exposures may exceed 2.0. If such distributions are known, and it can be shown that workers are not at increased risk of adverse health effects, recommended peak exposure guidelines may be modified based on workplace-specific and compound-specific health effects data. For example, consideration should be given to dose-rate effects and elimination half-times for the particular substance and for similar compounds. Special consideration should also be given to unusual work schedules and whether the peak exposure factors should be applied to the TLV–TWA (e.g., if concerns for acute health effects predominate) or the adjusted TWA (e.g., if the concern is with exceeding the adjusted TWA). The practicing hygienist must use judgment in applying this guidance on peak exposures. When a TLV–STEL or a TLV–C is available, this value takes precedence over the above guidance for peak exposures.

### ***TWA and STEL versus Ceiling (C)***

A substance may have certain toxicological properties that require the use of a TLV–C rather than a TLV–STEL or peak exposure guidance above a TLV–TWA. The amount by which the TLVs® may be exceeded for short periods without injury to health depends upon a number of factors such as the nature of the contaminant, whether very high concentrations — even for short periods — produce acute poisoning, whether the effects are cumulative, the frequency with which high concentrations occur, and the duration of such periods. All factors must be taken into consideration in arriving at a decision as to whether a hazardous condition exists.

Although the TWA concentration provides the most satisfactory, practical way of monitoring airborne agents for compliance with the TLVs®, there are certain substances for which it is inappropriate. In the latter group are substances that are predominantly fast-acting and whose TLV® is more appropriately based on the concentration associated with this particular response. Substances with this type of response are best controlled by a TLV–C that should not be exceeded. It is implicit in these definitions that the manner of sampling to determine noncompliance with the TLVs® for each group must differ. Consequently, a single, brief sample that is applicable to a TLV–C is not appropriate to the TLV–TWA; here, a sufficient number of samples are needed to permit determination that the TLV–C is not exceeded at any time during a complete cycle of operation or throughout the workshift.

Whereas the TLV–C places a definite boundary that exposure concentra-

tions should not be permitted to exceed, the TLV–TWA requires an explicit limit to the number and duration of peak exposures which are acceptable above the recommended TLV–TWAs.

### **Mixtures**

Special consideration should also be given to the application of the TLVs<sup>®</sup> in assessing the health hazards that may be associated with exposure to a mixture of two or more substances. A brief discussion of basic considerations involved in developing TLVs<sup>®</sup> for mixtures and methods for their development, amplified by specific examples, is given in Appendix E.

## **Deviations in Work Conditions and Work Schedules**

### ***Application of TLVs<sup>®</sup> to Unusual Ambient Conditions***

When workers are exposed to air contaminants at temperatures and pressures substantially different than those at 25°C and 760 torr, care should be taken in comparing sampling results to the applicable TLVs<sup>®</sup>. For aerosols, the TWA exposure concentration (calculated using sample volumes not adjusted to conditions at 25°C and 760 torr) should be compared directly to the applicable TLVs<sup>®</sup> published in the *TLVs<sup>®</sup> and BEIs<sup>®</sup>* book. For gases and vapors, there are a number of options for comparing air-sampling results to the TLV<sup>®</sup>, and these are discussed in detail by Stephenson and Lillquist (2001). One method that is simple in its conceptual approach is 1) to determine the exposure concentration, expressed in terms of mass per volume, at the sampling site using the sample volume not adjusted to conditions at 25°C and 760 torr, 2) if required, to convert the TLV<sup>®</sup> to mg/m<sup>3</sup> (or other mass per volume measure) using a molar volume of 24.4 L/mole, and 3) to compare the exposure concentration to the TLV<sup>®</sup>, both in units of mass per volume.

A number of assumptions are made when comparing sampling results obtained under unusual atmospheric conditions to the TLVs<sup>®</sup>. One such assumption is that the volume of air inspired by the worker per workday is not appreciably different under moderate conditions of temperature and pressure as compared to those at 25°C and 760 torr (Stephenson and Lillquist, 2001). An additional assumption for gases and vapors is that absorbed dose is correlated to the partial pressure of the inhaled compound. Sampling results obtained under unusual conditions cannot easily be compared to the published TLVs<sup>®</sup>, and extreme care should be exercised if workers are exposed to very high or low ambient pressures.

### ***Unusual Work Schedules***

Application of TLVs<sup>®</sup> to work schedules markedly different from the conventional 8-hour day, 40-hour workweek requires particular judgment to provide protection for these workers equal to that provided to workers on conventional workshifts. Short workweeks can allow workers to have more than one job, perhaps with similar exposures, and may result in overexposure, even if neither job by itself entails overexposure.

Numerous mathematical models to adjust for unusual work schedules have been described. In terms of toxicologic principles, their general objective is to

identify a dose that ensures that the daily peak body burden or weekly peak body burden does not exceed that which occurs during a normal 8-hour/day, 5-day/week shift. A comprehensive review of the approaches to adjusting occupational exposure limits for unusual work schedules is provided in *Patty's Industrial Hygiene* (Paustenbach, 2000). Other selected readings on this topic include Lapare et al. (2003), Brodeur et al. (2001), Caldwell et al. (2001), Eide (2000), Verma (2000), Roach (1978), and Hickey and Reist (1977).

Another model that addresses unusual work schedules is the Brief and Scala model (1986), which is explained in detail in *Patty's Industrial Hygiene* (Paustenbach, 2000). This model reduces the TLV® proportionately for both increased exposure time and reduced recovery (i.e., non-exposure) time, and is generally intended to apply to work schedules longer than 8 hours/day or 40 hours/week. The model should not be used to justify very high exposures as “allowable” where the exposure periods are short (e.g., exposure to 8 times the TLV–TWA for 1 hour and zero exposure during the remainder of the shift). In this respect, the general limitations on peak exposures above the TLV–TWA and TLV–STELs should be applied to avoid inappropriate use of the model with very short exposure periods or shifts.

The Brief and Scala model is easier to use than some of the more complex models based on pharmacokinetic actions. The application of such models usually requires knowledge of the biological half-life of each substance, and some models require additional data. Another model developed by the University of Montreal and the Institute de Recherche en Sante et en Securite du Travail (IRSST) uses the Haber method to calculate adjusted exposure limits (Brodeur et al., 2001). This method generates values close to those obtained from physiologically based pharmacokinetic (PBPK) models.

Because adjusted TLVs® do not have the benefit of historical use and long-time observation, medical supervision during initial use of adjusted TLVs® is advised. Unnecessary exposure of workers should be avoided, even if a model shows such exposures to be “allowable.” Mathematical models should not be used to justify higher-than-necessary exposures.

## TLV® Units

TLVs® are expressed in ppm, mg/m<sup>3</sup> or mg/100 cm<sup>2</sup>. An inhaled chemical substance may exist as a gas, vapor, or aerosol.

- A gas is a chemical substance whose molecules are moving freely within a space in which they are confined (e.g., cylinder/tank) at 25°C and 760 torr. Gases assume no shape or volume.
- A vapor is the gaseous phase of a chemical substance that exists as a liquid or a solid at 25°C and 760 torr. The amount of vapor given off by a chemical substance is expressed as the vapor pressure and is a function of temperature and pressure.
- An aerosol is a suspension of solid particles or liquid droplets in a gaseous medium. Other terms used to describe an aerosol include dust, mist, fume, fog, fiber, smoke, and smog. Aerosols may be characterized by their aerodynamic behavior and the site(s) of deposition in the human respiratory tract.

TLVs® for aerosols are usually established in terms of mass of the chemical

substance in air by volume. These TLVs<sup>®</sup> are expressed in mg/m<sup>3</sup>.

TLVs<sup>®</sup> for gases and vapors are established in terms of parts of vapor or gas per million parts of contaminated air by volume (ppm), but may also be expressed in mg/m<sup>3</sup>. For convenience to the user, these TLVs<sup>®</sup> also reference molecular weights. Where 24.45 = molar volume of air in liters at 25°C and 760 torr, the conversion equations for gases and vapors [ppm ↔ mg/m<sup>3</sup>] are as follows:

$$\text{TLV in ppm} = \frac{(\text{TLV in mg/m}^3) (24.45)}{(\text{gram molecular weight of substance})}$$

OR

$$\text{TLV in mg/m}^3 = \frac{(\text{TLV in ppm}) (\text{gram molecular weight of substance})}{24.45}$$

When converting values for volatile forms of inorganic compounds (e.g., as Fe, as Ni), the molecular weight of the element should be used, not that of the entire compound.

In making conversions for substances with variable molecular weights, appropriate molecular weights should be estimated or assumed (see the TLV<sup>®</sup> *Documentation*).

### User Information

Each TLV<sup>®</sup> is supported by a comprehensive *Documentation*. It is imperative to consult the latest *Documentation* when applying the TLV<sup>®</sup>.

Additional copies of the *TLVs<sup>®</sup> and BEIs<sup>®</sup>* book and the multi-volume *Documentation of the Threshold Limit Values and Biological Exposure Indices*, upon which this book is based, are available from ACGIH<sup>®</sup>. *Documentation* of individual TLVs<sup>®</sup> is also available. Consult the ACGIH<sup>®</sup> website ([www.acgih.org/store](http://www.acgih.org/store)) for additional information and availability concerning these publications.

**ACGIH<sup>®</sup> disclaims liability with respect to the use of TLVs<sup>®</sup>.**

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**All pertinent notes relating to the material in the Chemical Substances section of this book appear in the appendices for this section or on the inside back cover.**

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
Acetaldehyde [75-07-0] (2013)	—	C 25 ppm	A2	44.05	Eye & URT irr
Acetamide [60-35-5] (2016)	1 ppm (IFV)	—	A3	59.07	Liver cancer & dam
Acetic acid [64-19-7] (2003)	10 ppm	15 ppm	—	60.00	URT & eye irr; pulm func
Acetic anhydride [108-24-7] (2010)	1 ppm	3 ppm	A4	102.09	Eye & URT irr
Acetone [67-64-1] (2014)	250 ppm	500 ppm	A4; BEI	58.05	URT & eye irr; CNS impair
Acetone cyanohydrin [75-86-5], as CN (1991)	—	C 5 mg/m <sup>3</sup>	Skin	85.10	URT irr; headache; hypoxia/cyanosis
Acetonitrile [75-05-8] (1996)	20 ppm	—	Skin; A4	41.05	LRT irr
Acetophenone [98-86-2] (2008)	10 ppm	—	—	120.15	URT irr; CNS impair; pregnancy loss
Acetylene [74-86-2]	See Appendix F: Minimal Oxygen Content (D, EX)			26.04	Asphyxia
Acetylsalicylic acid (Aspirin) [50-78-2] (1977)	5 mg/m <sup>3</sup>	—	—	180.15	Skin & eye irr
Acrolein [107-02-8] (1995)	—	C 0.1 ppm	Skin; A4	56.06	Eye & URT irr; pulm edema; pulm emphysema
‡ Acrylamide [79-06-1] (2004)	0.03 mg/m <sup>3</sup> (IFV)	—	Skin; ( ); (A3)	71.08	(CNS impair)
Acrylic acid [79-10-7] (1986)	2 ppm	—	Skin; A4	72.06	URT irr
Acrylonitrile [107-13-1] (2015)	2 ppm	—	Skin; A3	53.05	CNS impair; LRT irr
Adipic acid [124-04-9] (1990)	5 mg/m <sup>3</sup>	—	—	146.14	URT irr; ANS impair



Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Adiponitrile [111-69-3] (1990)	2 ppm	—	Skin	108.10	URT & LRT irr
Alachlor [15972-60-8] (2006)	1 mg/m <sup>3</sup> (IFV)	—	DSEN; A3	269.80	Hemosiderosis (liver, spleen, kidney)
Aldicarb [116-06-3] (2017)	0.005 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	190.26	Cholinesterase inhib
Aldrin [309-00-2] (2006)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A3	364.93	CNS impair; liver & kidney dam
Allyl alcohol [107-18-6] (1996)	0.5 ppm	—	Skin; A4	58.08	Eye & URT irr
Allyl bromide [106-95-6] (2011)	0.1 ppm	0.2 ppm	Skin; A4	120.99	Eye & URT irr
Allyl chloride [107-05-1] (2010)	1 ppm	2 ppm	Skin; A3	76.50	Eye & URT irr; liver & kidney dam
Allyl glycidyl ether [106-92-3] (1995)	1 ppm	—	A4	114.14	URT, eye, & skin irr; dermatitis
Allyl methacrylate [96-05-9] (2017)	1 ppm	—	Skin	126.15	Liver dam
Allyl propyl disulfide [2179-59-1] (2001)	0.5 ppm	—	DSEN	148.16	URT & eye irr
Aluminum metal [7429-90-5] and insoluble compounds (2007)	1 mg/m <sup>3</sup> (R)	—	A4	26.98 Varies	Pneumoconiosis; LRT irr; neurotoxicity
4-Aminodiphenyl [92-67-1] (1968)	— (L)	—	Skin; A1	169.23	Bladder & liver cancer
2-Aminopyridine [504-29-0] (1966)	0.5 ppm	—	—	94.12	Headache; nausea; CNS impair; dizziness
Amitrole [61-82-5] (1983)	0.2 mg/m <sup>3</sup>	—	A3	84.08	Thyroid eff



Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
Ammonia [7664-41-7] (1970)	25 ppm	35 ppm	—	17.03	Eye dam; URT irr
Ammonium chloride, fume [12125-02-9] (1970)	10 mg/m <sup>3</sup>	20 mg/m <sup>3</sup>	—	53.50	Eye & URT irr
Ammonium perfluorooctanoate [3825-26-1] (1992)	0.01 mg/m <sup>3</sup>	—	Skin; A3	431.00	Liver dam
Ammonium sulfamate [7773-06-0] (1956)	10 mg/m <sup>3</sup>	—	—	114.13	—
tert-Amyl methyl ether [994-05-8] (1999)	20 ppm	—	—	102.20	CNS impair; embryo/fetal dam
Aniline [62-53-3] (1979)	2 ppm	—	Skin; A3; BEI	93.12	MeHb-emia
Anisidine (1979)					
ortho isomer [90-04-0]	0.5 mg/m <sup>3</sup>	—	Skin; A3; BEI <sub>M</sub>	123.15	MeHb-emia
para isomer [104-94-9]	0.5 mg/m <sup>3</sup>	—	Skin; A4; BEI <sub>M</sub>	123.15	MeHb-emia
Antimony [7440-36-0] and compounds, as Sb (1979)	0.5 mg/m <sup>3</sup>	—	—	121.75	Skin & URT irr
Antimony hydride [7803-52-3] (1990)	0.1 ppm	—	—	124.78	Hemolysis; kidney dam; LRT irr
‡ (Antimony trioxide [1309-64-4], production (1977))	(— <sup>(L)</sup> )	—	A2	291.50	(Lung cancer; pneumoconiosis)
ANTU [86-88-4] (1990)	0.3 mg/m <sup>3</sup>	—	A4; Skin	202.27	Thyroid eff; nausea
Argon [7440-37-1]	See Appendix F: Minimal Oxygen Content <sup>(D)</sup>			39.95	Asphyxia
Arsenic [7440-38-2] and inorganic compounds, as As (1990)	0.01 mg/m <sup>3</sup>	—	A1; BEI	74.92 Varies	Lung cancer



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
<a href="#">Arsine</a> [7784-42-1] (2006)	0.005 ppm	—	—	77.95	PNS & vascular system impair; kidney & liver impair
<a href="#">Asbestos</a> [1332-21-4], all forms (1994)	0.1 f/cc <sup>(F)</sup>	—	A1	—	Pneumoconiosis; lung cancer; mesothelioma
<a href="#">Asphalt (Bitumen) fumes</a> [8052-42-4], as benzene-soluble aerosol (1999)	0.5 mg/m <sup>3</sup> <sup>(I)</sup>	—	A4; BEI <sub>P</sub>	—	URT & eye irr
<a href="#">Atrazine</a> [1912-24-9] (and related symmetrical triazines) (2013)	2 mg/m <sup>3</sup> <sup>(I)</sup>	—	A3	215.69	Hematologic, repro, & developmental eff
<a href="#">Azinphos-methyl</a> [86-50-0] (1999)	0.2 mg/m <sup>3</sup> <sup>(IFV)</sup>	—	Skin; DSEN; A4; BEI <sub>C</sub>	317.34	Cholinesterase inhib
<a href="#">Barium</a> [7440-39-3] and soluble compounds, as Ba (1990)	0.5 mg/m <sup>3</sup>	—	A4	137.30	Eye, skin, & GI irr; muscular stimulation
<a href="#">Barium sulfate</a> [7727-43-7] (2013)	5 mg/m <sup>3</sup> <sup>(I, E)</sup>	—	—	233.43	Pneumoconiosis
<a href="#">Bendiocarb</a> [22781-23-3] (2017)	0.1 mg/m <sup>3</sup> <sup>(IFV)</sup>	—	Skin; A4; BEI <sub>C</sub>	223.20	Cholinesterase inhib
<a href="#">Benomyl</a> [17804-35-2] (2007)	1 mg/m <sup>3</sup> <sup>(I)</sup>	—	DSEN; A3	290.32	URT irr; male repro, testicular, & embryo/fetal dam
<a href="#">Benz[a]anthracene</a> [56-55-3] (1990)	— <sup>(L)</sup>	—	A2; BEI <sub>P</sub>	228.30	Skin cancer
<a href="#">Benzene</a> [71-43-2] (1996)	0.5 ppm	2.5 ppm	Skin; A1; BEI	78.11	Leukemia

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
<a href="#">Benzidine</a> [92-87-5] (1979)	— (L)	—	Skin; A1	184.23	Bladder cancer
<a href="#">Benzo[b]fluoranthene</a> [205-99-2] (1990)	— (L)	—	A2; BEI <sub>P</sub>	252.30	Cancer
<a href="#">Benzo[a]pyrene</a> [50-32-8] (1990)	— (L)	—	A2; BEI <sub>P</sub>	252.30	Cancer
<a href="#">Benzotrichloride</a> [98-07-7] (1994)	—	C 0.1 ppm	Skin; A2	195.50	Eye, skin, & URT irr
<a href="#">Benzoyl chloride</a> [98-88-4] (1992)	—	C 0.5 ppm	A4	140.57	URT & eye irr
<a href="#">Benzoyl peroxide</a> [94-36-0] (1990)	5 mg/m <sup>3</sup>	—	A4	242.22	URT & skin irr
<a href="#">Benzyl acetate</a> [140-11-4] (1990)	10 ppm	—	A4	150.18	URT irr
<a href="#">Benzyl chloride</a> [100-44-7] (1990)	1 ppm	—	A3	126.58	Eye, skin, & URT irr
<a href="#">Beryllium</a> [7440-41-7] and compounds, as Be (2008) Soluble compounds Soluble and insoluble compounds	0.00005 mg/m <sup>3</sup> (1)	—	A1 Skin; DSEN RSEN	9.01	Beryllium sens; chronic beryllium disease (berylliosis)
<a href="#">Biphenyl</a> [92-52-4] (1979)	0.2 ppm	—	—	154.20	Pulm func
<a href="#">Bismuth telluride</a> [1304-82-1] (1970) Undoped, as Bi <sub>2</sub> Te <sub>3</sub> Se-doped, as Bi <sub>2</sub> Te <sub>3</sub>	10 mg/m <sup>3</sup> 5 mg/m <sup>3</sup>	— —	A4 A4	800.83	Lung dam
<a href="#">Borate compounds, inorganic</a> [1303-96-4; 1330-43-4; 10043-35-3; 12179-04-3] (2004)	2 mg/m <sup>3</sup> (1)	6 mg/m <sup>3</sup> (1)	A4	Varies	URT irr



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV <sup>®</sup> Basis
	TWA	STEL	Notations		
Boron oxide [1303-86-2] (1985)	10 mg/m <sup>3</sup>	—	—	69.64	Eye & URT irr
Boron tribromide [10294-33-4] (2015)	—	C 0.7 ppm	—	250.57	Resp tract irr; pneumonitis
Boron trichloride [10294-34-5] (2015)	—	C 0.7 ppm	—	117.20	Resp tract irr; pneumonitis
Boron trifluoride [7637-07-2] (2015)	0.1 ppm	C 0.7 ppm	—	67.82	Resp tract irr; pneumonitis
Boron trifluoride ethers [109-63-7; 353-42-4], as BF <sub>3</sub> (2017)	0.1 ppm	C 0.7 ppm	—	Varies	Resp tract irr; pneumonitis
Bromacil [314-40-9] (1976)	10 mg/m <sup>3</sup>	—	A3	261.11	Thyroid eff
Bromine [7726-95-6] (1991)	0.1 ppm	0.2 ppm	—	159.81	URT & LRT irr; lung dam
Bromine pentafluoride [7789-30-2] (1979)	0.1 ppm	—	—	174.92	Eye, skin, & URT irr
Bromoform [75-25-2] (2008)	0.5 ppm	—	A3	252.73	Liver dam; URT & eye irr
1-Bromopropane [106-94-5] (2013)	0.1 ppm	—	A3	122.99	CNS impair; peripheral neuropathy; hematological eff; developmental & repro toxicity (male & female)
1,3-Butadiene [106-99-0] (1994)	2 ppm	—	A2	54.09	Cancer
Butane, isomers [75-28-5; 106-97-8] (2012)	—	1000 ppm (EX)	—	58.12	CNS impair
n-Butanol [71-36-3] (1998)	20 ppm	—	—	74.12	Eye & URT irr

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
<a href="#">sec-Butanol</a> [78-92-2] (2001)	100 ppm	—	—	74.12	URT irr; CNS impair
<a href="#">tert-Butanol</a> [75-65-0] (1992)	100 ppm	—	A4	74.12	CNS impair
<a href="#">Butenes, all isomers</a> [106-98-9; 107-01-7; 590-18-1; 624-64-6; 25167-67-3]	250 ppm	—	—	56.11	Body weight eff
<a href="#">Isobutene</a> [115-11-7] (2007)	250 ppm	—	A4	—	URT irr; body weight eff
<a href="#">2-Butoxyethanol</a> [111-76-2] (1996)	20 ppm	—	A3; BEI	118.17	Eye & URT irr
<a href="#">2-Butoxyethyl acetate</a> [112-07-2] (2000)	20 ppm	—	A3	160.20	Hemolysis
<a href="#">Butyl acetates, all isomers</a> [105-46-4; 110-19-0; 123-86-4; 540-88-5] (2015)	50 ppm	150 ppm	—	116.16	Eye & URT irr
<a href="#">n-Butyl acrylate</a> [141-32-2] (1996)	2 ppm	—	DSEN; A4	128.17	Irr
<a href="#">n-Butylamine</a> [109-73-9] (1985)	—	C 5 ppm	Skin	73.14	Headache; URT & eye irr
<a href="#">Butylated hydroxytoluene</a> [128-37-0] (2001)	2 mg/m <sup>3</sup> (IFV)	—	A4	220.34	URT irr
<a href="#">tert-Butyl chromate, as CrO<sub>3</sub></a> [1189-85-1] (1960)	—	C 0.1 mg/m <sup>3</sup>	Skin	230.22	LRT & skin irr
<a href="#">n-Butyl glycidyl ether</a> [2426-08-6] (2002)	3 ppm	—	Skin; DSEN	130.21	Reproduction; sens
<a href="#">tert-Butyl hydroperoxide</a> [75-91-2] (2017)	0.1 ppm	—	Skin	90.12	Eye & URT irr; mutagenic & repro eff
<a href="#">n-Butyl lactate</a> [138-22-7] (1973)	5 ppm	—	—	146.19	Headache; URT irr



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
<a href="#">n-Butyl mercaptan</a> [109-79-5] (1968)	0.5 ppm	—	—	90.19	URT irr
<a href="#">o-sec-Butylphenol</a> [89-72-5] (1977)	5 ppm	—	Skin	150.22	URT, eye, & skin irr
<a href="#">p-tert-Butyltoluene</a> [98-51-1] (1990)	1 ppm	—	—	148.18	Eye & URT irr; nausea
<a href="#">Cadmium</a> [7440-43-9] and <a href="#">compounds</a> , as Cd (1990)	0.01 mg/m <sup>3</sup> 0.002 mg/m <sup>3</sup> (R)	— —	A2; BEI A2; BEI	112.40 Varies	Kidney dam
<a href="#">Cadusafos</a> [95465-99-9] (2016)	0.001 mg/m <sup>3</sup> (IFV)	—	Skin; A4	270.40	Cholinesterase inhib
<a href="#">Calcium cyanamide</a> [156-62-7] (1973)	0.5 mg/m <sup>3</sup>	—	A4	80.11	Eye & URT irr
<a href="#">Calcium hydroxide</a> [1305-62-0] (1979)	5 mg/m <sup>3</sup>	—	—	74.10	Eye, URT, & skin irr
<a href="#">Calcium oxide</a> [1305-78-8] (1990)	2 mg/m <sup>3</sup>	—	—	56.08	URT irr
<a href="#">Calcium silicate, naturally occurring as Wollastonite</a> [13983-17-0] (2015)	1 mg/m <sup>3</sup> (I, E)	—	A4	—	Pneumonconiosis; pulm func
<a href="#">Calcium sulfate</a> [7778-18-9; 10034-76-1; 10101-41-4; 13397-24-5] (2005)	10 mg/m <sup>3</sup> (I)	—	—	136.14	Nasal symptoms
<a href="#">Camphor, synthetic</a> [76-22-2] (1990)	2 ppm	3 ppm	A4	152.23	Eye & URT irr; anosmia
<a href="#">Caprolactam</a> [105-60-2] (1997)	5 mg/m <sup>3</sup> (IFV)	—	A5	113.16	URT irr

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
<a href="#">Captafol</a> [2425-06-1] (2016)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; DSEN; RSEN; A3	349.10	Liver & kidney dam; dermal sens
<a href="#">Captan</a> [133-06-2] (1999)	5 mg/m <sup>3</sup> (I)	—	DSEN; A3	300.60	Skin irr
<a href="#">Carbaryl</a> [63-25-2] (2007)	0.5 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	201.20	Cholinesterase inhib; male repro & embryo dam
<a href="#">Carbofuran</a> [1563-66-2] (2001)	0.1 mg/m <sup>3</sup> (IFV)	—	A4; BEI <sub>C</sub>	221.30	Cholinesterase inhib
<a href="#">Carbon black</a> [1333-86-4] (2010)	3 mg/m <sup>3</sup> (I)	—	A3	—	Bronchitis
<a href="#">Carbon dioxide</a> [124-38-9] (1983)	5000 ppm	30,000 ppm	—	44.01	Asphyxia
<a href="#">Carbon disulfide</a> [75-15-0] (2005)	1 ppm	—	Skin; A4; BEI	76.14	PNS impair
<a href="#">Carbon monoxide</a> [630-08-0] (1989)	25 ppm	—	BEI	28.01	COHb-emia
<a href="#">Carbon tetrabromide</a> [558-13-4] (1972)	0.1 ppm	0.3 ppm	—	331.65	Liver dam; eye, URT, & skin irr
<a href="#">Carbon tetrachloride</a> [56-23-5] (1990)	5 ppm	10 ppm	Skin; A2	153.84	Liver dam
<a href="#">Carbonyl fluoride</a> [353-50-4] (1990)	2 ppm	5 ppm	—	66.01	LRT irr; bone dam
<a href="#">Carbonyl sulfide</a> [463-58-1] (2011)	5 ppm	—	—	60.08	CNS impair
<a href="#">Carfentrazone-ethyl</a> [128639-02-1] (2017)	1 mg/m <sup>3</sup> (I)	—	A4	412.20	Liver dam; porphyrin eff
<a href="#">Catechol</a> [120-80-9] (1985)	5 ppm	—	Skin; A3	110.11	Eye & URT irr; dermatitis



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Cellulose [9004-34-6] (1985)	10 mg/m <sup>3</sup>	—	—	NA	URT irr
Cesium hydroxide [21351-79-1] (1990)	2 mg/m <sup>3</sup>	—	—	149.92	URT, skin, & eye irr
* Chlordane [57-74-9] (1985)	0.5 mg/m <sup>3</sup> (IFV)	—	Skin; A3	409.80	Liver dam
Chlorinated camphene [8001-35-2] (1990)	0.5 mg/m <sup>3</sup>	1 mg/m <sup>3</sup>	Skin; A3	414.00	CNS convul; liver dam
Chlorinated diphenyl oxide [31242-93-0] (1979)	0.5 mg/m <sup>3</sup>	—	—	377.00	Chloracne; liver dam
Chlorine [7782-50-5] (2017)	0.1 ppm	0.4 ppm	A4	70.91	Resp tract irr; airway hyper-reactivity; pulm edema
Chlorine dioxide [10049-04-4] (2017)	—	C 0.1 ppm	—	67.46	Resp tract irr; pulm edema
Chlorine trifluoride [7790-91-2] (1979)	—	C 0.1 ppm	—	92.46	Eye & URT irr; lung dam
Chloroacetaldehyde [107-20-0] (1990)	—	C 1 ppm	—	78.50	URT & eye irr
Chloroacetone [78-95-5] (1986)	—	C 1 ppm	Skin	92.53	Eye & URT irr
2-Chloroacetophenone [532-27-4] (1990)	0.05 ppm	—	A4	154.59	Eye, URT, & skin irr
Chloroacetyl chloride [79-04-9] (1988)	0.05 ppm	0.15 ppm	Skin	112.95	URT irr
Chlorobenzene [108-90-7] (1988)	10 ppm	—	A3; BEI	112.56	Liver dam
* o-Chlorobenzylidene malononitrile [2698-41-1] (1990)	—	C 0.05 ppm (IFV)	Skin; A4	188.62	URT irr; skin sens



Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
Chlorobromomethane [74-97-5] (2008)	200 ppm	—	—	129.39	CNS impair; liver dam
Chlorodifluoromethane [75-45-6] (1990)	1000 ppm	—	A4	86.47	CNS impair; asphyxia; card sens
Chlorodiphenyl (42% chlorine) [53469-21-9] (1979)	1 mg/m <sup>3</sup>	—	Skin	266.50	Liver dam; eye irr; chloracne
Chlorodiphenyl (54% chlorine) [11097-69-1] (1990)	0.5 mg/m <sup>3</sup>	—	Skin; A3	328.40	URT irr; liver dam; chloracne
Chloroform [67-66-3] (1990)	10 ppm	—	A3	119.38	Liver & embryo/fetal dam; CNS impair
bis(Chloromethyl) ether [542-88-1] (1979)	0.001 ppm	—	A1	114.96	Lung cancer
Chloromethyl methyl ether [107-30-2] (1979)	— (L)	—	A2	80.50	Lung cancer
1-Chloro-1-nitropropane [600-25-9] (2016)	2 ppm	—	—	123.54	Eye & URT irr; pulm edema
Chloropentafluoroethane [76-15-3] (1978)	1000 ppm	—	—	154.47	Card sens
Chloropicrin [76-06-2] (1990)	0.1 ppm	—	A4	164.39	Eye irr; pulm edema
β-Chloroprene [126-99-8] (2016)	1 ppm	—	Skin; A2	88.54	Lung cancer; URT & eye irr
1-Chloro-2-propanol [127-00-4] and 2-Chloro-1-propanol [78-89-7] (1999)	1 ppm	—	Skin; A4	94.54	Liver dam
2-Chloropropionic acid [598-78-7] (1988)	0.1 ppm	—	Skin	108.53	Male repro dam
o-Chlorostyrene [2039-87-4] (1972)	50 ppm	75 ppm	—	138.60	CNS impair; peripheral neuropathy



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
<a href="#">o-Chlorotoluene</a> [95-49-8] (1971)	50 ppm	—	—	126.59	URT, eye, & skin irr
<a href="#">Chlorpyrifos</a> [2921-88-2] (2000)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	350.57	Cholinesterase inhib
<a href="#">Chromium</a> , [7440-47-3] and inorganic compounds (2017)					
Metallic chromium, as Cr(0)	0.5 mg/m <sup>3</sup> (I)	—	—	Varies	Resp tract irr
Trivalent chromium compounds, as Cr(III)	0.003 mg/m <sup>3</sup> (I)	—	A4	Varies	Resp tract irr; asthma
Water-soluble compounds			DSEN; RSEN		
Hexavalent chromium compounds, as Cr(VI)	0.0002 mg/m <sup>3</sup> (I)	0.0005 mg/m <sup>3</sup> (I)	A1	Varies	Lung & sinonasal cancer; resp tract irr; asthma
Water-soluble compounds			Skin; DSEN; RSEN		
Chromyl chloride [14977-61-8], as Cr(VI)	0.0001 ppm (IFV)	0.00025 ppm (IFV)	Skin; DSEN; RSEN; A1	Varies	Lung & sinonasal cancer; resp tract irr; asthma
Chromite ore processing	See Hexavalent and Trivalent Chromium compounds				
<a href="#">Chrysene</a> [218-01-9] (1990)	— (L)	—	A3; BEI <sub>P</sub>	228.30	Cancer
<a href="#">Citral</a> [5392-40-5] (2009)	5 ppm (IFV)	—	Skin; DSEN; A4	152.24	Body weight eff; URT irr; eye dam
<a href="#">Clopidol</a> [2971-90-6] (2012)	3 mg/m <sup>3</sup> (IFV)	—	A4	192.06	Mutagenic eff
<a href="#">Coal dust</a> (1995)					
Anthracite [8029-10-5]	0.4 mg/m <sup>3</sup> (R)	—	A4	—	Lung dam; pulm fibrosis
Bituminous or Lignite [308062-82-0]	0.9 mg/m <sup>3</sup> (R)	—	A4	—	Lung dam; pulm fibrosis

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Coal tar pitch volatiles [65996-93-2], as benzene soluble aerosol (1984)	0.2 mg/m <sup>3</sup>	—	A1; BEI <sub>P</sub>	—	Cancer
* Cobalt [7440-48-4] and inorganic compounds, as Co (2018)	0.02 mg/m <sup>3</sup> (I)	—	DSEN;RSEN; A3; BEI	58.93 Varies	Pulm func changes
Cobalt carbonyl [10210-68-1], as Co (1980)	0.1 mg/m <sup>3</sup>	—	—	341.94	Pulm edema; spleen dam
Cobalt hydrocarbonyl [16842-03-8], as Co (1980)	0.1 mg/m <sup>3</sup>	—	—	171.98	Pulm edema; lung dam
Copper [7440-50-8] (1990) Fume, as Cu Dusts and mists, as Cu	0.2 mg/m <sup>3</sup> 1 mg/m <sup>3</sup>	— —	— —	63.55	Irr; GI; metal fume fever
Cotton dust, raw, untreated (2009)	0.1 mg/m <sup>3</sup> (T)	—	A4	—	Byssinosis; bronchitis; pulm func
Coumaphos [56-72-4] (2005)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	362.80	Cholinesterase inhib
Cresol, all isomers [95-48-7; 106-44-5; 108-39-4; 1319-77-3] (2009)	20 mg/m <sup>3</sup> (IFV)	—	Skin; A4	108.14	URT irr
Crotonaldehyde [4170-30-3] (1995)	—	C 0.3 ppm	Skin; A3	70.09	Eye & URT irr
Crufomate [299-86-5] (1971)	5 mg/m <sup>3</sup>	—	A4; BEI <sub>C</sub>	291.71	Cholinesterase inhib
‡ Cumene [98-82-8] (1997)	(50 ppm)	—	(—)	120.19	(Eye, skin, & URT irr; CNS impair)
Cyanamide [420-04-2] (1974)	2 mg/m <sup>3</sup>	—	—	42.04	Skin & eye irr

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
* Cyanazine [21725-46-2] (2018)	0.1 mg/m <sup>3</sup> (1)	—	A3	240.70	Body weight, CNS & teratogenic eff
Cyanoacrylates, Ethyl [7085-85-0] and Methyl [137-05-3] (2017)	0.2 ppm	1 ppm	DSEN; RSEN	125.4 (Ethyl) 112.11 (Methyl)	Eye & URT irr; asthma
Cyanogen [460-19-5] (2015)	—	C 5 ppm	—	52.04	Eye & URT irr
Cyanogen bromide [506-68-3] (2014)	—	C 0.3 ppm	—	105.92	Eye & resp tract irr; pulm edema
Cyanogen chloride [506-77-4] (2013)	—	C 0.3 ppm	—	61.48	Pulm edema; eye, skin, & URT irr
Cyclohexane [110-82-7] (1964)	100 ppm	—	—	84.16	CNS impair
Cyclohexanol [108-93-0] (1979)	50 ppm	—	Skin	100.16	Eye irr; CNS impair
Cyclohexanone [108-94-1] (1990)	20 ppm	50 ppm	Skin; A3	98.14	Eye & URT irr
‡ Cyclohexene [110-83-8] (1964)	(300 ppm)	—	—	82.14	(URT & eye irr)
Cyclohexylamine [108-91-8] (1990)	10 ppm	—	A4	99.17	URT & eye irr
Cyclonite [121-82-4] (1994)	0.5 mg/m <sup>3</sup>	—	Skin; A4	222.26	Liver dam
Cyclopentane [287-92-3] (1978)	600 ppm	—	—	70.13	URT, eye, & skin irr; CNS impair
Cyhexatin [13121-70-5] (1990)	5 mg/m <sup>3</sup>	—	A4	385.16	URT irr; body weight eff; kidney dam
2,4-D [94-75-7] (2016)	10 mg/m <sup>3</sup> (1)	—	A4	221.04	Thyroid eff; kidney tubular dam

Substance [CAS No.] ( <i>Documentation date</i> )	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
DDT [50-29-3] (1979)	1 mg/m <sup>3</sup>	—	A3	354.50	Liver dam
Decaborane [17702-41-9] (1979)	0.05 ppm	0.15 ppm	Skin	122.31	CNS convul; cognitive decrement
Demeton [8065-48-3] (1998)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; BEI <sub>C</sub>	258.34	Cholinesterase inhib
Demeton-S-methyl [919-86-8] (1998)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; DSEN; A4; BEI <sub>C</sub>	230.30	Cholinesterase inhib
Diacetone alcohol [123-42-2] (1979)	50 ppm	—	—	116.16	URT & eye irr
Diacetyl [431-03-8] (2011)	0.01 ppm	0.02 ppm	A4	86.10	Lung dam (Bronchiolitis obliterans-like illness)
Diazinon [333-41-5] (2000)	0.01 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	304.36	Cholinesterase inhib
Diazomethane [334-88-3] (1970)	0.2 ppm	—	A2	42.04	URT & eye irr
Diborane [19287-45-7] (1990)	0.1 ppm	—	—	27.69	URT irr; headache
2-N-Dibutylaminoethanol [102-81-8] (1980)	0.5 ppm	—	Skin; BEI <sub>C</sub>	173.29	Eye & URT irr
Dibutyl phenyl phosphate [2528-36-1] (1987)	0.3 ppm	—	Skin; BEI <sub>C</sub>	286.26	Cholinesterase inhib; URT irr
Dibutyl phosphate [107-66-4] (2008)	5 mg/m <sup>3</sup> (IFV)	—	Skin	210.21	Bladder, eye, & URT irr
Dibutyl phthalate [84-74-2] (1990)	5 mg/m <sup>3</sup>	—	—	278.34	Testicular dam; eye & URT irr
Dichloroacetic acid [79-43-6] (2002)	0.5 ppm	—	Skin; A3	128.95	URT & eye irr; testicular dam

Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Dichloroacetylene [7572-29-4] (1992)	—	C 0.1 ppm	A3	94.93	Nausea; PNS impair
o-Dichlorobenzene [95-50-1] (1990)	25 ppm	50 ppm	A4	147.01	URT & eye irr; liver dam
p-Dichlorobenzene [106-46-7] (1990)	10 ppm	—	A3	147.01	Eye irr; kidney dam
3,3'-Dichlorobenzidine [91-94-1] (1990)	— (L)	—	Skin; A3	253.13	Bladder cancer; eye irr
1,4-Dichloro-2-butene [764-41-0] (1990)	0.005 ppm	—	Skin; A2	124.99	URT & eye irr
Dichlorodifluoromethane [75-71-8] (1979)	1000 ppm	—	A4	120.91	Card sens
1,3-Dichloro-5,5-dimethylhydantoin [118-52-5] (1979)	0.2 mg/m <sup>3</sup>	0.4 mg/m <sup>3</sup>	—	197.03	URT irr
1,1-Dichloroethane [75-34-3] (1990)	100 ppm	—	A4	98.97	URT & eye irr; liver & kidney dam
1,2-Dichloroethylene, all isomers [156-59-2; 156-60-5; 540-59-0] (1990)	200 ppm	—	—	96.95	CNS impair; eye irr
Dichloroethyl ether [111-44-4] (1985)	5 ppm	10 ppm	Skin; A4	143.02	URT & eye irr; nausea
Dichlorofluoromethane [75-43-4] (1977)	10 ppm	—	—	102.92	Liver dam
Dichloromethane [75-09-2] (1997)	50 ppm	—	A3; BEI	84.93	COHb-emia; CNS impair
1,1-Dichloro-1-nitroethane [594-72-9] (1978)	2 ppm	—	—	143.96	URT irr
1,3-Dichloropropene [542-75-6] (2003)	1 ppm	—	Skin; A3	110.98	Kidney dam

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
2,2-Dichloropropionic acid [75-99-0] (1997)	5 mg/m <sup>3</sup> (I)	—	A4	143.00	Eye & URT irr
Dichlorotetrafluoroethane [76-14-2] (1979)	1000 ppm	—	A4	170.93	Pulm func
Dichlorvos [62-73-7] (1998)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; DSEN; A4; BEI <sub>C</sub>	220.98	Cholinesterase inhib
Dicrotophos [141-66-2] (1998)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	237.21	Cholinesterase inhib
* Dicyclopentadiene [77-73-6], including Cyclopentadiene (2018)	0.5 ppm	1 ppm	—	132.21	URT, LRT, & eye irr; CNS eff
Dicyclopentadienyl iron, as Fe [102-54-5] (1990)	10 mg/m <sup>3</sup>	—	—	186.03	Liver dam
Dieldrin [60-57-1] (2009)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A3	380.93	Liver dam; repro eff; CNS impair
Diesel fuel [68334-30-5; 68476-30-2; 68476-31-3; 68476-34-6], as total hydrocarbons (2007)	100 mg/m <sup>3</sup> (IFV)	—	Skin; A3	Varies	Dermatitis
Diethanolamine [111-42-2] (2008)	1 mg/m <sup>3</sup> (IFV)	—	Skin; A3	105.14	Liver & kidney dam
Diethylamine [109-89-7] (2012)	5 ppm	15 ppm	Skin; A4	73.14	URT, eye, & skin irr
2-Diethylaminoethanol [100-37-8] (1991)	2 ppm	—	Skin	117.19	URT irr; CNS convul
Diethylene glycol monobutyl ether [112-34-5] (2012)	10 ppm (IFV)	—	—	162.23	Hematologic, liver & kidney eff
Diethylenetriamine [111-40-0] (1985)	1 ppm	—	Skin	103.17	URT & eye irr

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
‡ Di(2-ethylhexyl)phthalate [117-81-7] (1996)	(5 mg/m <sup>3</sup> )	—	( ); A3	390.54	(LRT irr)
N,N-Diethylhydroxylamine [3710-84-7] (2012)	2 ppm	—	—	89.14	URT irr
Diethyl ketone [96-22-0] (1995)	200 ppm	300 ppm	—	86.13	URT irr; CNS impair
Diethyl phthalate [84-66-2] (1996)	5 mg/m <sup>3</sup>	—	A4	222.23	URT irr
Difluorodibromomethane [75-61-6] (1962)	100 ppm	—	—	209.83	URT irr; CNS impair; liver dam
Diglycidyl ether [2238-07-5] (2006)	0.01 ppm	—	A4	130.14	Eye & skin irr; male repro dam
Diisobutyl ketone [108-83-8] (1979)	25 ppm	—	—	142.23	URT & eye irr
Diisopropylamine [108-18-9] (1979)	5 ppm	—	Skin	101.19	URT irr; eye dam
Dimethylacetamide [127-19-5] (2017)	10 ppm	—	Skin; A3; BEI	87.12	Liver, embryo & fetal dam; repro, renal & teratogenic eff
Dimethylamine [124-40-3] (2013)	5 ppm	15 ppm	DSEN; A4	45.08	URT & GI irr
bis(2-Dimethylaminoethyl) ether [3033-62-3] (1997)	0.05 ppm	0.15 ppm	Skin	160.26	URT, eye, & skin irr
Dimethylaniline [121-69-7] (1990)	5 ppm	10 ppm	Skin; A4; BEI <sub>M</sub>	121.18	MeHb-emia
Dimethyl carbamoyl chloride [79-44-7] (2017)	0.005 ppm	—	Skin; A2	107.54	Nasal cancer; URT irr
Dimethyl disulfide [624-92-0] (2006)	0.5 ppm	—	Skin	94.20	URT irr; CNS impair



Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
Dimethylethoxysilane [14857-34-2] (1991)	0.5 ppm	1.5 ppm	—	104.20	URT & eye irr; headache
Dimethylformamide [68-12-2] (2017)	5 ppm	—	Skin; A3; BEI	73.10	Liver dam; eye & URT irr
1,1-Dimethylhydrazine [57-14-7] (1993)	0.01 ppm	—	Skin; A3	60.12	URT irr; nasal cancer
* Dimethylphenol, all isomers [95-65-8; 95-87-4; 105-67-9; 108-68-9; 526-75-0; 576-26-1; 1300-71-6] (2018)	1 ppm (IFV)	—	DSEN; A3	Varies	Hematologic & body weight eff
Dimethyl phthalate [131-11-3] (2005)	5 mg/m <sup>3</sup>	—	—	194.19	Eye & URT irr
Dimethyl sulfate [77-78-1] (1985)	0.1 ppm	—	Skin; A3	126.10	Eye & skin irr
Dimethyl sulfide [75-18-3] (2001)	10 ppm	—	—	62.14	URT irr
* Dinitrobenzene, all isomers [99-65-0; 100-25-4; 528-29-0; 25154-54-5] (1979)	0.15 ppm (IFV)	—	Skin; BEI <sub>M</sub>	168.11	MeHb-emia; eye dam
* Dinitro-o-cresol [534-52-1] (1979)	0.2 mg/m <sup>3</sup> (IFV)	—	Skin	198.13	Basal metabolism
3,5-Dinitro-o-toluamide [148-01-6] (2006)	1 mg/m <sup>3</sup>	—	A4	225.16	Liver dam
Dinitrotoluene [25321-14-6] (1993)	0.2 mg/m <sup>3</sup>	—	Skin; A3; BEI <sub>M</sub>	182.15	Card impair; repro eff
1,4-Dioxane [123-91-1] (1996)	20 ppm	—	Skin; A3	88.10	Liver dam

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Dioxathion [78-34-2] (2001)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	456.54	Cholinesterase inhib
1,3-Dioxolane [646-06-0] (1997)	20 ppm	—	—	74.08	Hematologic eff
Diphenylamine [122-39-4] (1990)	10 mg/m <sup>3</sup>	—	A4	169.24	Liver & kidney dam; hematologic eff
Dipropyl ketone [123-19-3] (1978)	50 ppm	—	—	114.80	URT irr
Diquat [85-00-7; 2764-72-9; 6385-62-2], as the cation (1990)	0.5 mg/m <sup>3</sup> (I) 0.1 mg/m <sup>3</sup> (R)	— —	Skin; A4 Skin; A4	Varies	LRT irr; cataract LRT irr; cataract
Disulfiram [97-77-8] (1979)	2 mg/m <sup>3</sup>	—	A4	296.54	Vasodilation; nausea
Disulfoton [298-04-4] (2000)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	274.38	Cholinesterase inhib
Diuron [330-54-1] (1974)	10 mg/m <sup>3</sup>	—	A4	233.10	URT irr
Divinylbenzene [1321-74-0] (1990)	10 ppm	—	—	130.19	URT irr
Dodecyl mercaptan [112-55-0] (2001)	0.1 ppm	—	DSEN	202.40	URT irr
Endosulfan [115-29-7] (2008)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A4	406.95	LRT irr; liver & kidney dam
Endrin [72-20-8] (1979)	0.1 mg/m <sup>3</sup>	—	Skin; A4	380.93	Liver dam; CNS impair; headache
Enflurane [13838-16-9] (1979)	75 ppm	—	A4	184.50	CNS impair; card impair
Epichlorohydrin [106-89-8] (1994)	0.5 ppm	—	Skin; A3	92.53	URT irr; male repro
* EPN [2104-64-5] (2000)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	323.31	Cholinesterase inhib

Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Ethane [74-84-0]	See Appendix F: Minimal Oxygen Content (D, EX)			30.07	Asphyxia
Ethanol [64-17-5] (2008)	—	1000 ppm	A3	46.07	URT irr
Ethanolamine [141-43-5] (1985)	3 ppm	6 ppm	—	61.08	Eye & skin irr
Ethion [563-12-2] (2000)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	384.48	Cholinesterase inhib
2-Ethoxyethanol [110-80-5] (1981)	5 ppm	—	Skin; BEI	90.12	Male repro & embryo/fetal dam
2-Ethoxyethyl acetate [111-15-9] (1981)	5 ppm	—	Skin; BEI	132.16	Male repro dam
Ethyl acetate [141-78-6] (1979)	400 ppm	—	—	88.10	URT & eye irr
Ethyl acrylate [140-88-5] (1986)	5 ppm	15 ppm	A4	100.11	URT, eye, & GI irr; CNS impair; skin sens
Ethylamine [75-04-7] (2012)	5 ppm	15 ppm	Skin	45.08	URT irr
Ethyl amyl ketone [541-85-5] (2006)	10 ppm	—	—	128.21	Neurotoxicity
Ethylbenzene [100-41-4] (2010)	20 ppm	—	A3; BEI	106.16	URT irr; kidney dam (nephropathy); cochlear impair
Ethyl bromide [74-96-4] (1990)	5 ppm	—	Skin; A3	108.98	Liver dam; CNS impair
Ethyl tert-butyl ether [637-92-3] (2012)	25 ppm	—	A4	102.18	URT & LRT irr; CNS impair
Ethyl butyl ketone [106-35-4] (1995)	50 ppm	75 ppm	—	114.19	CNS impair; eye & skin irr

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Ethyl chloride [75-00-3] (1992)	100 ppm	—	Skin; A3	64.52	Liver dam
Ethylene [74-85-1] (2001)	200 ppm	—	A4	28.05	Asphyxia
Ethylene chlorohydrin [107-07-3] (1985)	—	C 1 ppm	Skin; A4	80.52	CNS impair; liver & kidney dam
Ethylenediamine [107-15-3] (1990)	10 ppm	—	Skin; A4	60.10	—
Ethylene dibromide [106-93-4] (1980)	—	—	Skin; A3	187.88	—
Ethylene dichloride [107-06-2] (1977)	10 ppm	—	A4	98.96	Liver dam; nausea
Ethylene glycol [107-21-1] (2016)	25 ppm <sup>(V)</sup>	50 ppm <sup>(V)</sup> 10 mg/m <sup>3</sup> (I, H)	A4	62.07	URT irr
Ethylene glycol dinitrate [628-96-6] (1980)	0.05 ppm	—	Skin	152.06	Vasodilation; headache
Ethylene oxide [75-21-8] (1990)	1 ppm	—	A2; BEI	44.05	Cancer; CNS impair
Ethyleneimine [151-56-4] (2008)	0.05 ppm	0.1 ppm	Skin; A3	43.08	URT irr; liver & kidney dam
Ethyl ether [60-29-7] (1966)	400 ppm	500 ppm	—	74.12	CNS impair; URT irr
Ethyl formate [109-94-4] (2011)	—	100 ppm	A4	74.08	URT irr
2-Ethylhexanoic acid [149-57-5] (2006)	5 mg/m <sup>3</sup> (IFV)	—	—	144.24	Teratogenic eff
Ethylidene norbornene [16219-75-3] (2013)	2 ppm	4 ppm	—	120.19	URT & eye irr
Ethyl isocyanate [109-90-0] (2013)	0.02 ppm	0.06 ppm	Skin; DSEN	71.10	URT & eye irr

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Ethyl mercaptan [75-08-1] (2003)	0.5 ppm	—	—	62.13	URT irr; CNS impair
N-Ethylmorpholine [100-74-3] (1985)	5 ppm	—	Skin	115.18	URT irr; eye dam
Ethyl silicate [78-10-4] (1979)	10 ppm	—	—	208.30	URT & eye irr; kidney dam
Fenamiphos [22224-92-6] (2005)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	303.40	Cholinesterase inhib
Fensulfothion [115-90-2] (2004)	0.01 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	308.35	Cholinesterase inhib
Fenthion [55-38-9] (2005)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	278.34	Cholinesterase inhib
Ferbam [14484-64-1] (2008)	5 mg/m <sup>3</sup> (I)	—	A4	416.50	CNS impair; body weight eff; spleen dam
Ferrovandium dust [12604-58-9] (1990)	1 mg/m <sup>3</sup>	3 mg/m <sup>3</sup>	—	—	Eye, URT, & LRT irr
Flour dust (2001)	0.5 mg/m <sup>3</sup> (I)	—	RSEN	—	Asthma; URT irr; bronchitis
Fludioxonil [131341-86-1] (2017)	1 mg/m <sup>3</sup> (I)	—	A3	248.20	Liver & kidney dam
Fluorides, as F (1979)	2.5 mg/m <sup>3</sup>	—	A4; BEI	Varies	Bone dam; fluorosis
* Fluorine [7782-41-4], as F (2018)	0.1 ppm	C 0.5 ppm	—	38.00	Fluorosis; eye irr
Folpet [133-07-3] (2016)	1 mg/m <sup>3</sup> (I)	—	DSEN; A3	296.60	Liver dam; body weight eff
Fonofos [944-22-9] (2005)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	246.32	Cholinesterase inhib

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Formaldehyde [50-00-0] (2016)	0.1 ppm	0.3 ppm	DSEN; RSEN; A1	30.03	URT & eye irr; URT cancer
‡ Formamide [75-12-7] (1985)	(10 ppm)	—	Skin; ( )	45.04	(Eye & skin irr; kidney & liver dam)
Formic acid [64-18-6] (1965)	5 ppm	10 ppm	—	46.02	URT, eye, & skin irr
Furfural [98-01-1] (2016)	0.2 ppm	—	Skin; A3; BEI	96.08	URT & eye irr
Furfuryl alcohol [98-00-0] (2016)	0.2 ppm	—	Skin; A3	98.10	URT & eye irr
Gallium arsenide [1303-00-0] (2004)	0.0003 mg/m <sup>3</sup> (R)	—	A3	144.64	LRT irr
Gasoline [86290-81-5] (1990)	300 ppm	500 ppm	A3	Varies	URT & eye irr; CNS impair
Germanium tetrahydride [7782-65-2] (1970)	0.2 ppm	—	—	76.63	Hematologic eff
Glutaraldehyde [111-30-8], activated or unactivated (1998)	—	C 0.05 ppm	DSEN; RSEN; A4	100.11	URT, skin, & eye irr; CNS impair
Glycidol [556-52-5] (1993)	2 ppm	—	A3	74.08	URT, eye, & skin irr
Glyoxal [107-22-2] (1999)	0.1 mg/m <sup>3</sup> (IFV)	—	DSEN; A4	58.04	URT irr; larynx metaplasia
Grain dust (oat, wheat, barley) (1985)	4 mg/m <sup>3</sup>	—	—	NA	Bronchitis; URT irr; pulm func
Graphite (all forms except graphite fibers) [7782-42-5] (1988)	2 mg/m <sup>3</sup> (R)	—	—	—	Pneumoconiosis
Hafnium [7440-58-6] and compounds, as Hf (1990)	0.5 mg/m <sup>3</sup>	—	—	178.49	URT & eye irr; liver dam

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
<a href="#">Halothane</a> [151-67-7] (1979)	50 ppm	—	A4	197.39	Liver dam; CNS impair; vasodilation
<a href="#">Hard metals containing Cobalt</a> [7440-48-4] and <a href="#">Tungsten carbide</a> [12070-12-1], as Co (2015)	0.005 mg/m <sup>3</sup> (T)	—	RSEN; A2	—	Pneumonitis
<a href="#">Helium</a> [7440-59-7]	See Appendix F: Minimal Oxygen Content (D)			4.00	Asphyxia
<a href="#">Heptachlor</a> [76-44-8] and <a href="#">Heptachlor epoxide</a> [1024-57-3] (1990)	0.05 mg/m <sup>3</sup>	—	Skin; A3	373.32 389.40	Liver dam
<a href="#">Heptane, isomers</a> [108-08-7; 142-82-5; 565-59-3; 589-34-4; 590-35-2; 591-76-4] (1979)	400 ppm	500 ppm	—	100.20	CNS impair; URT irr
<a href="#">Hexachlorobenzene</a> [118-74-1] (1994)	0.002 mg/m <sup>3</sup>	—	Skin; A3	284.78	Porphyrin eff; skin dam; CNS impair
<a href="#">Hexachlorobutadiene</a> [87-68-3] (1979)	0.02 ppm	—	Skin; A3	260.76	Kidney dam
<a href="#">Hexachlorocyclopentadiene</a> [77-47-4] (1990)	0.01 ppm	—	A4	272.75	URT irr
<a href="#">Hexachloroethane</a> [67-72-1] (1990)	1 ppm	—	Skin; A3	236.74	Liver & kidney dam
<a href="#">Hexachloronaphthalene</a> [1335-87-1] (1965)	0.2 mg/m <sup>3</sup>	—	Skin	334.74	Liver dam; chloracne
<a href="#">Hexafluoroacetone</a> [684-16-2] (1986)	0.1 ppm	—	Skin	166.02	Testicular & kidney dam
<a href="#">Hexafluoropropylene</a> [116-15-4] (2009)	0.1 ppm	—	—	150.02	Kidney dam
<a href="#">Hexahydrophthalic anhydride, all isomers</a> [85-42-7; 13149-00-3; 14166-21-3] (2002)	—	C 0.005 mg/m <sup>3</sup> (IFV)	RSEN	154.17	Sens



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Hexamethylene diisocyanate [822-06-0] (1985)	0.005 ppm	—	BEI	168.22	URT irr; resp sens
Hexamethyl phosphoramide [680-31-9] (1990)	—	—	Skin; A3	179.20	URT cancer
n-Hexane [110-54-3] (1996)	50 ppm	—	Skin; BEI	86.18	CNS impair; peripheral neuropathy; eye irr
Hexane isomers, other than n-Hexane [75-83-2; 79-29-8; 96-14-0; 107-83-5] (1979)	500 ppm	1000 ppm	—	86.17	CNS impair; URT & eye irr
1,6-Hexanediamine [124-09-4] (1990)	0.5 ppm	—	—	116.21	URT & skin irr
1-Hexene [592-41-6] (1999)	50 ppm	—	—	84.16	CNS impair
sec-Hexyl acetate [108-84-9] (1963)	50 ppm	—	—	144.21	Eye & URT irr
Hexylene glycol [107-41-5] (2016)	25 ppm <sup>(V)</sup>	50 ppm <sup>(V)</sup> 10 mg/m <sup>3</sup> (I, H)	—	118.18	Eye & URT irr
Hydrazine [302-01-2] (1988)	0.01 ppm	—	Skin; A3	32.05	URT cancer
Hydrogen [1333-74-0]	See Appendix F: Minimal Oxygen Content <sup>(D, EX)</sup>			1.01	Asphyxia
Hydrogenated terphenyls (nonirradiated) [61788-32-7] (1990)	0.5 ppm	—	—	241.00	Liver dam
Hydrogen bromide [10035-10-6] (2001)	—	C 2 ppm	—	80.92	URT irr



Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
Hydrogen chloride [7647-01-0] (2000)	—	C 2 ppm	A4	36.47	URT irr
Hydrogen cyanide and cyanide salts, as CN (1991)					URT irr; headache; nausea; thyroid eff
Hydrogen cyanide [74-90-8]	—	C 4.7 ppm	Skin	27.03	
Cyanide salts [143-33-9; 151-50-8; 592-01-8]	—	C 5 mg/m <sup>3</sup>	Skin	Varies	
Hydrogen fluoride [7664-39-3], as F (2004)	0.5 ppm	C 2 ppm	Skin; BEI	20.01	URT, LRT, skin, & eye irr; fluorosis
Hydrogen peroxide [7722-84-1] (1990)	1 ppm	—	A3	34.02	Eye, URT, & skin irr
Hydrogen selenide [7783-07-5], as Se (1990)	0.05 ppm	—	—	80.98	URT & eye irr; nausea
Hydrogen sulfide [7783-06-4] (2009)	1 ppm	5 ppm	—	34.08	URT irr; CNS impair
Hydroquinone [123-31-9] (2007)	1 mg/m <sup>3</sup>	—	DSEN; A3	110.11	Eye irr; eye dam
2-Hydroxypropyl acrylate [999-61-1] (1997)	0.5 ppm	—	Skin; DSEN	130.14	Eye & URT irr
Indene [95-13-6] (2007)	5 ppm	—	—	116.15	Liver dam
Indium [7440-74-6] and compounds, as In (1990)	0.1 mg/m <sup>3</sup>	—	—	114.82	Pulm edema; pneumonitis; dental erosion; malaise
* Indium tin oxide [50926-11-9], as In (2018)	0.0001 mg/m <sup>3</sup> (R)	—	DSEN; A3	Varies	Pulm func; pulm fibrosis

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
<a href="#">Iodine and Iodides</a> (2007)					
Iodine [7553-56-2]	0.01 ppm (IFV)	0.1 ppm (V)	A4	253.80	Hypothyroidism; URT irr
Iodides	0.01 ppm (IFV)	—	A4	Varies	Hypothyroidism; URT irr
‡ <a href="#">Iodoform</a> [75-47-8] (1979)	(0.6 ppm)	—	—	393.73	(CNS impair)
<a href="#">Iron oxide (Fe<sub>2</sub>O<sub>3</sub>)</a> [1309-37-1] (2005)	5 mg/m <sup>3</sup> (R)	—	A4	159.70	Pneumoconiosis
<a href="#">Iron pentacarbonyl</a> [13463-40-6], as Fe (1979)	0.1 ppm	0.2 ppm	—	195.90	Pulm edema; CNS impair
<a href="#">Iron salts, soluble</a> , as Fe (1990)	1 mg/m <sup>3</sup>	—	—	Varies	URT & skin irr
<a href="#">Isoamyl alcohol</a> [123-51-3] (1990)	100 ppm	125 ppm	—	88.15	Eye & URT irr
<a href="#">Isobutanol</a> [78-83-1] (1973)	50 ppm	—	—	74.12	Skin & eye irr
* <a href="#">Isobutyl nitrite</a> [542-56-3] (2000)	—	C 1 ppm	A3; BEI <sub>M</sub>	103.12	MeHb-emia; Vasodilation
<a href="#">Isooctyl alcohol</a> [26952-21-6] (1990)	50 ppm	—	Skin	130.23	URT irr
<a href="#">Isophorone</a> [78-59-1] (1992)	—	C 5 ppm	A3	138.21	Eye & URT irr; CNS impair; malaise; fatigue
<a href="#">Isophorone diisocyanate</a> [4098-71-9] (1985)	0.005 ppm	—	—	222.30	Resp sens
<a href="#">2-Isopropoxyethanol</a> [109-59-1] (1990)	25 ppm	—	Skin	104.15	Hematologic eff
<a href="#">Isopropylamine</a> [75-31-0] (1962)	5 ppm	10 ppm	—	59.08	URT irr; eye dam

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
<a href="#">N-Isopropylaniline</a> [768-52-5] (1990)	2 ppm	—	Skin; BEI <sub>M</sub>	135.21	MeHb-emia
<a href="#">Isopropyl ether</a> [108-20-3] (1979)	250 ppm	310 ppm	—	102.17	Eye & URT irr
<a href="#">Isopropyl glycidyl ether</a> [4016-14-2] (1979)	50 ppm	75 ppm	—	116.18	URT & eye irr; dermatitis
<a href="#">Kaolin</a> [1332-58-7] (1990)	2 mg/m <sup>3</sup> (E, R)	—	A4	—	Pneumoconiosis
<a href="#">Kerosene</a> [8008-20-6; 64742-81-0]/ <a href="#">Jet fuels</a> , as total hydrocarbon vapor (2003)	200 mg/m <sup>3</sup> (P)	—	Skin; A3	Varies	Skin & URT irr; CNS impair
<a href="#">Ketene</a> [463-51-4] (1962)	0.5 ppm	1.5 ppm	—	42.04	URT irr; pulm edema
<a href="#">Lead</a> [7439-92-1] and <a href="#">inorganic compounds</a> , as Pb (1991)	0.05 mg/m <sup>3</sup>	—	A3; BEI	207.20 Varies	CNS & PNS impair; hematologic eff
<a href="#">Lead chromate</a> [7758-97-6], as Cr(VI) (2017)	0.0002 mg/m <sup>3</sup> (I)	0.0005 mg/m <sup>3</sup> (I)	DSEN; RSEN; A1; BEI	323.22	Lung & sinonasal cancer; resp tract irr; asthma
<a href="#">Lindane</a> [58-89-9] (1990)	0.5 mg/m <sup>3</sup>	—	Skin; A3	290.85	Liver dam; CNS impair
<a href="#">Lithium hydride</a> [7580-67-8] (2014)	—	C 0.05 mg/m <sup>3</sup> (I)	—	7.95	Eye & resp tract irr
<a href="#">L.P.G. (Liquefied petroleum gas)</a> [68476-85-7]	See Appendix F: Minimal Oxygen Content (D, EX)			—	Asphyxia
<a href="#">Magnesium oxide</a> [1309-48-4] (2000)	10 mg/m <sup>3</sup> (I)	—	A4	40.32	URT; metal fume fever
<a href="#">Malathion</a> [121-75-5] (2000)	1 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	330.36	Cholinesterase inhib



Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV <sup>®</sup> Basis
Maleic anhydride [108-31-6] (2010)	0.01 mg/m <sup>3</sup> (IFV)	—	DSEN; RSEN; A4	98.06	Resp sens
Manganese [7439-96-5], elemental and inorganic compounds, as Mn (2012)	0.02 mg/m <sup>3</sup> (R) 0.1 mg/m <sup>3</sup> (I)	—	A4	54.94 Varies	CNS impair
Manganese cyclopentadienyl tricarbonyl [12079-65-1], as Mn (1992)	0.1 mg/m <sup>3</sup>	—	Skin	204.10	Skin irr; CNS impair
Mercury [7439-97-6], alkyl compounds, as Hg (1992)	0.01 mg/m <sup>3</sup>	0.03 mg/m <sup>3</sup>	Skin	Varies	CNS & PNS impair; kidney dam
Mercury [7439-97-6], all forms except alkyl, as Hg (1991)				200.59	
Aryl compounds	0.1 mg/m <sup>3</sup>	—	Skin	Varies	CNS impair; kidney dam
Elemental and inorganic forms	0.025 mg/m <sup>3</sup>	—	Skin; A4; BEI	Varies	CNS impair; kidney dam
Mesityl oxide [141-79-7] (1992)	15 ppm	25 ppm	—	98.14	Eye & URT irr; CNS impair
Methacrylic acid [79-41-4] (1992)	20 ppm	—	—	86.09	Skin & eye irr
Methane [74-82-8]	See Appendix F: Minimal Oxygen Content (D, EX)			16.04	Asphyxia
Methanol [67-56-1] (2008)	200 ppm	250 ppm	Skin; BEI	32.04	Headache; eye dam; dizziness; nausea
Methomyl [16752-77-5] (2013)	0.2 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	162.20	Cholinesterase inhib; male repro dam; hematologic eff
Methoxychlor [72-43-5] (1992)	10 mg/m <sup>3</sup>	—	A4	345.65	Liver dam; CNS impair
2-Methoxyethanol [109-86-4] (2005)	0.1 ppm	—	Skin; BEI	76.09	Hematologic & repro eff

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
2-Methoxyethyl acetate [110-49-6] (2005)	0.1 ppm	—	Skin; BEI	118.13	Hematologic & repro eff
(2-Methoxymethylethoxy)propanol [34590-94-8] (1979)	100 ppm	150 ppm	Skin	148.20	Eye & URT irr; CNS impair
4-Methoxyphenol [150-76-5] (1992)	5 mg/m <sup>3</sup>	—	—	124.15	Eye irr; skin dam
1-Methoxy-2-propanol [107-98-2] (2012)	50 ppm	100 ppm	A4	90.12	Eye & URT irr
Methyl acetate [79-20-9] (2012)	200 ppm	250 ppm	—	74.08	Headache; dizziness; nausea; eye dam (degeneration of ganglion cells in the retina)
Methylacetylene [74-99-7] (1956)	1000 ppm (EX)	—	—	40.07	CNS impair
Methylacetylene-propadiene mixture [59355-75-8] (1964)	1000 ppm (EX)	1250 ppm (EX)	—	40.07	CNS impair
Methyl acrylate [96-33-3] (1997)	2 ppm	—	Skin; DSEN; A4	86.09	Eye, skin, & URT irr; eye dam
Methylacrylonitrile [126-98-7] (2010)	1 ppm	—	Skin; A4	67.09	CNS impair; eye & skin irr
Methylal [109-87-5] (1970)	1000 ppm	—	—	76.10	Eye irr; CNS impair
Methylamine [74-89-5] (2012)	5 ppm	15 ppm	—	31.06	Eye, skin, & URT irr
Methyl n-amyl ketone [110-43-0] (1978)	50 ppm	—	—	114.18	Eye & skin irr
N-Methylaniline [100-61-8] (1992)	0.5 ppm	—	Skin; BEI <sub>M</sub>	107.15	MeHb-emia; CNS impair



Substance [CAS No.] ( <i>Documentation date</i> )	ADOPTED VALUES			MW	TLV <sup>®</sup> Basis
	TWA	STEL	Notations		
Methyl bromide [74-83-9] (1994)	1 ppm	—	Skin; A4	94.95	URT & skin irr
Methyl tert-butyl ether [1634-04-4] (1999)	50 ppm	—	A3	88.17	URT irr; kidney dam
Methyl n-butyl ketone [591-78-6] (1995)	5 ppm	10 ppm	Skin; BEI	100.16	Peripheral neuropathy; testicular dam
Methyl chloride [74-87-3] (1992)	50 ppm	100 ppm	Skin; A4	50.49	CNS impair; liver, kidney, & testicular dam; teratogenic eff
Methyl chloroform [71-55-6] (1992)	350 ppm	450 ppm	A4; BEI	133.42	CNS impair; liver dam
Methylcyclohexane [108-87-2] (1962)	400 ppm	—	—	98.19	URT irr; CNS impair; liver & kidney dam
Methylcyclohexanol [25639-42-3] (2005)	50 ppm	—	—	114.19	URT & eye irr
o-Methylcyclohexanone [583-60-8] (1970)	50 ppm	75 ppm	Skin	112.17	URT & eye irr; CNS impair
2-Methylcyclopentadienyl manganese tricarbonyl [12108-13-3], as Mn (1970)	0.2 mg/m <sup>3</sup>	—	Skin	218.10	CNS impair; lung, liver, & kidney dam
Methyl demeton [8022-00-2] (2006)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; BEI <sub>C</sub>	230.30	Cholinesterase inhib
Methylene bisphenyl isocyanate [101-68-8] (1985)	0.005 ppm	—	—	250.26	Resp sens
* 4,4'-Methylene bis(2-chloroaniline) [101-14-4] (1991)	0.01 ppm (IFV)	—	Skin; A2; BEI	267.17	Bladder cancer; MeHb-emia
Methylene bis(4-cyclohexylisocyanate) [5124-30-1] (1985)	0.005 ppm	—	—	262.35	Resp sens; LRT irr

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
4,4'-Methylenedianiline [101-77-9] (1992)	0.1 ppm	—	Skin; A3	198.26	Liver dam
Methyl ethyl ketone [78-93-3] (1992)	200 ppm	300 ppm	BEI	72.10	URT irr; CNS & PNS impair
Methyl ethyl ketone peroxide [1338-23-4] (1992)	—	C 0.2 ppm	—	176.24	Eye & skin irr; liver & kidney dam
Methyl formate [107-31-3] (2014)	50 ppm	100 ppm	Skin	60.05	CNS impair; URT irr; eye dam
Methylhydrazine [60-34-4] (1991)	0.01 ppm	—	Skin; A3	46.07	URT & eye irr; lung cancer; liver dam
Methyl iodide [74-88-4] (1978)	2 ppm	—	Skin	141.95	Eye dam; CNS impair
Methyl isoamyl ketone [110-12-3] (2012)	20 ppm	50 ppm	—	114.20	CNS impair; URT irr
‡ Methyl isobutyl carbinol [108-11-2] (1966)	(25 ppm)	40 ppm	(Skin)	102.18	(URT & eye irr; CNS impair)
Methyl isobutyl ketone [108-10-1] (2009)	20 ppm	75 ppm	A3; BEI	100.16	URT irr; dizziness; headache
Methyl isocyanate [624-83-9] (2013)	0.02 ppm	0.06 ppm	Skin; DSEN	57.05	URT & eye irr
Methyl isopropyl ketone [563-80-4] (2010)	20 ppm	—	—	86.14	Embryo/fetal dam; neonatal toxicity
Methyl mercaptan [74-93-1] (2003)	0.5 ppm	—	—	48.11	Liver dam
Methyl methacrylate [80-62-6] (1992)	50 ppm	100 ppm	DSEN; A4	100.13	URT & eye irr; body weight eff; pulm edema



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
1-Methylnaphthalene [90-12-0] and 2-Methylnaphthalene [91-57-6] (2006)	0.5 ppm	—	Skin; A4	142.20	LRT irr; lung dam
Methyl parathion [298-00-0] (2008)	0.02 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	263.20	Cholinesterase inhib
Methyl propyl ketone [107-87-9] (2006)	—	150 ppm	—	86.17	Pulm func; eye irr
Methyl silicate [681-84-5] (1978)	1 ppm	—	—	152.22	URT irr; eye dam
α-Methylstyrene [98-83-9] (2009)	10 ppm	—	A3	118.18	URT irr; kidney & female repro dam
* Methyltetrahydrophthalic anhydride isomers [3425-89-6; 5333-84-6; 11070-44-3; 19438-63-2; 19438-64-3; 26590-20-5; 42498-58-8] (2018)	0.07 ppb SL 0.7 mg/100 cm <sup>2</sup>	0.3 ppb	Skin; DSEN; RSEN	166.70	Resp sens
* Methyl vinyl ketone [78-94-4] (2018)	—	C 0.01 ppm	—	70.10	Upper resp dam; leukopenia
Metribuzin [21087-64-9] (1981)	5 mg/m <sup>3</sup>	—	A4	214.28	Liver dam; hematologic eff
Mevinphos [7786-34-7] (1998)	0.01 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	224.16	Cholinesterase inhib
Mica [12001-26-2] (1962)	3 mg/m <sup>3</sup> (R)	—	—	—	Pneumoconiosis
Mineral oil, excluding metal working fluids (2009)				Varies	URT irr
Pure, highly and severely refined	5 mg/m <sup>3</sup> (I)	—	A4		
Poorly and mildly refined	— (L)	—	A2		



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
<b>Molybdenum</b> [7439-98-7], as Mo (1999)				95.95	LRT irr
Soluble compounds	0.5 mg/m <sup>3</sup> (R)	—	A3		
Metal and insoluble compounds	10 mg/m <sup>3</sup> (I)	—	—		
	3 mg/m <sup>3</sup> (R)	—	—		
<b>Monochloroacetic acid</b> [79-11-8] (2005)	0.5 ppm (IFV)	—	Skin; A4	94.50	URT irr
<b>Monocrotophos</b> [6923-22-4] (2002)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	223.16	Cholinesterase inhib
* <b>Monomethylformamide</b> [123-39-7] (2018)	1 ppm	—	Skin	59.07	Embryo/fetal & liver dam; teratogenic eff
<b>Morpholine</b> [110-91-8] (1992)	20 ppm	—	Skin; A4	87.12	Eye dam; URT irr
<b>Naled</b> [300-76-5] (2002)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; DSEN; A4; BEI <sub>C</sub>	380.79	Cholinesterase inhib
<b>Naphthalene</b> [91-20-3] (2013)	10 ppm	—	Skin; A3; BEI	128.19	URT irr; cataracts; hemolytic anemia
<b>β-Naphthylamine</b> [91-59-8] (1979)	— (L)	—	A1	143.18	Bladder cancer
<b>Natural gas</b> [8006-14-2]	See Appendix F: Minimal Oxygen Content (D, EX)			—	Asphyxia
<b>Natural rubber latex</b> [9006-04-6], as inhalable allergenic proteins (2007)	0.0001 mg/m <sup>3</sup> (I)	—	Skin; DSEN; RSEN	Varies	Resp sens
<b>Neon</b> [7440-01-9]	See Appendix F: Minimal Oxygen Content (D)			20.18	Asphyxia

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
<b>Nickel</b> [7440-02-0] and inorganic compounds including Nickel subsulfide, as Ni (1996)					
Elemental [7440-02-0]	1.5 mg/m <sup>3</sup> (I)	—	A5	58.71	Dermatitis; pneumoconiosis
Soluble inorganic compounds (NOS)	0.1 mg/m <sup>3</sup> (I)	—	A4	Varies	Lung dam; nasal cancer
Insoluble inorganic compounds (NOS)	0.2 mg/m <sup>3</sup> (I)	—	A1	Varies	Lung cancer
Nickel subsulfide [12035-72-2], as Ni	0.1 mg/m <sup>3</sup> (I)	—	A1	240.19	Lung cancer
<b>Nickel carbonyl</b> [13463-39-3], as Ni (2013)	—	C 0.05 ppm	A3	170.73	Lung irr
<b>Nicotine</b> [54-11-5] (1992)	0.5 mg/m <sup>3</sup>	—	Skin	162.23	GI dam; CNS impair; card impair
* <b>Nitrapyrin</b> [1929-82-4] (1992)	10 mg/m <sup>3</sup> (IFV)	20 mg/m <sup>3</sup> (IFV)	A4	230.93	Liver dam
<b>Nitric acid</b> [7697-37-2] (1992)	2 ppm	4 ppm	—	63.02	URT & eye irr; dental erosion
<b>Nitric oxide</b> [10102-43-9] (1992)	25 ppm	—	BEI <sub>M</sub>	30.01	Hypoxia/cyanosis; nitrosyl-Hb form; URT irr
<b>p-Nitroaniline</b> [100-01-6] (1992)	3 mg/m <sup>3</sup>	—	Skin; A4; BEI <sub>M</sub>	138.12	MeHb-emia; liver dam; eye irr
<b>Nitrobenzene</b> [98-95-3] (1992)	1 ppm	—	Skin; A3; BEI <sub>M</sub>	123.11	MeHb-emia
<b>p-Nitrochlorobenzene</b> [100-00-5] (1985)	0.1 ppm	—	Skin; A3; BEI <sub>M</sub>	157.56	MeHb-emia
<b>4-Nitrodiphenyl</b> [92-93-3] (1992)	— (L)	—	Skin; A2	199.20	Bladder cancer
<b>Nitroethane</b> [79-24-3] (1979)	100 ppm	—	—	75.07	URT irr; CNS impair; liver dam

Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Nitrogen [7727-37-9]	See Appendix F: Minimal Oxygen Content <sup>(D)</sup>			14.01	Asphyxia
Nitrogen dioxide [10102-44-0] (2011)	0.2 ppm	—	A4	46.01	LRT irr
Nitrogen trifluoride [7783-54-2] (1992)	10 ppm	—	BEI <sub>M</sub>	71.00	MeHb-emia; liver & kidney dam
Nitroglycerin [55-63-0] (1980)	0.05 ppm	—	Skin	227.09	Vasodilation
Nitromethane [75-52-5] (1997)	20 ppm	—	A3	61.04	Thyroid eff; URT irr; lung dam
1-Nitropropane [108-03-2] (1992)	25 ppm	—	A4	89.09	URT & eye irr; liver dam
2-Nitropropane [79-46-9] (1992)	10 ppm	—	A3	89.09	Liver dam; liver cancer
N-Nitrosodimethylamine [62-75-9] (1992)	— (L)	—	Skin; A3	74.08	Liver & kidney cancer; liver dam
Nitrotoluene, isomers [88-72-2; 99-08-1; 99-99-0] (1992)	2 ppm	—	Skin; BEI <sub>M</sub>	137.13	MeHb-emia
* 5-Nitro-o-toluidine [99-55-8] (2006)	1 mg/m <sup>3</sup> (IFV)	—	A3	152.16	Liver dam
Nitrous oxide [10024-97-2] (1986)	50 ppm	—	A4	44.02	CNS impair; hematologic eff; embryo/fetal dam
Nonane [111-84-2] (2011)	200 ppm	—	—	128.26	CNS impair
Octachloronaphthalene [2234-13-1] (1970)	0.1 mg/m <sup>3</sup>	0.3 mg/m <sup>3</sup>	Skin	403.74	Liver dam
Octane [111-65-9], all isomers (1979)	300 ppm	—	—	114.22	URT irr

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ADOPTED VALUES					
Substance [CAS No.] (Documentation date)	TWA	STEL	Notations	MW	TLV <sup>®</sup> Basis
Osmium tetroxide [20816-12-0], as Os (1979)	0.0002 ppm	0.0006 ppm	—	254.20	Eye, URT, & skin irr
Oxalic acid, anhydrous [144-62-7] and dihydrate [6153-56-6] (2014)	1 mg/m <sup>3</sup>	2 mg/m <sup>3</sup>	—	90.04 (anhy) 126.00 (dihy)	URT, eye, & skin irr
p,p'-Oxybis(benzenesulfonyl hydrazide) [80-51-3] (1997)	0.1 mg/m <sup>3</sup> (I)	—	—	358.40	Teratogenic eff
Oxygen difluoride [7783-41-7] (1983)	—	C 0.05 ppm	—	54.00	Headache; pulm edema; URT irr
Ozone [10028-15-6] (1995)				48.00	Pulm func
Heavy work	0.05 ppm	—	A4		
Moderate work	0.08 ppm	—	A4		
Light work	0.10 ppm	—	A4		
Heavy, moderate, or light workloads (≤ 2 hours)	0.20 ppm	—	A4		
Paraffin wax fume [8002-74-2] (1972)	2 mg/m <sup>3</sup>	—	—	—	URT irr; nausea
Paraquat [4685-14-7], as the cation (2017)	0.05 mg/m <sup>3</sup> (I)	—	Skin; A4	257.18	Lung dam; URT irr
Parathion [56-38-2] (2000)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI	291.27	Cholinesterase inhib
Particles (insoluble or poorly soluble) not otherwise specified		See Appendix B			
Pentaborane [19624-22-7] (1970)	0.005 ppm	0.015 ppm	—	63.17	CNS convul & impair
* Pentachloronaphthalene [1321-64-8] (1970)	0.5 mg/m <sup>3</sup> (IFV)	—	Skin	300.40	Liver dam; chloracne

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Pentachloronitrobenzene [82-68-8] (1988)	0.5 mg/m <sup>3</sup>	—	A4	295.36	Liver dam
Pentachlorophenol [87-86-5] (2013)	0.5 mg/m <sup>3</sup> (IFV)	1 mg/m <sup>3</sup> (IFV)	Skin; A3; BEI	266.35	URT & eye irr; CNS & card impair
Pentaerythritol [115-77-5] (2012)	10 mg/m <sup>3</sup>	—	—	136.15	GI irr
Pentane, all isomers [78-78-4; 109-66-0; 463-82-1] (2013)	1000 ppm	—	—	72.15	Narcosis; resp tract irr
2,4-Pentanedione [123-54-6] (2010)	25 ppm	—	Skin	100.12	Neurotoxicity; CNS impair
Pentyl acetate, all isomers [123-92-2; 620-11-1; 624-41-9; 625-16-1; 626-38-0; 628-63-7] (1997)	50 ppm	100 ppm	—	130.20	URT irr
Peracetic acid [79-21-0] (2013)	—	0.4 ppm (IFV)	A4	76.05	URT, eye, & skin irr
Perchloromethyl mercaptan [594-42-3] (1988)	0.1 ppm	—	—	185.87	Eye & URT irr
Perchloryl fluoride [7616-94-6] (1962)	3 ppm	6 ppm	—	102.46	LRT & URT irr; MeHb-emia; fluorosis
Perfluorobutyl ethylene [19430-93-4] (2001)	100 ppm	—	—	246.10	Hematologic eff
Perfluoroisobutylene [382-21-8] (1989)	—	C 0.01 ppm	—	200.04	URT irr; hematologic eff
Persulfates, as persulfate [7727-21-1; 7727-54-0; 7775-27-1] (1993)	0.1 mg/m <sup>3</sup>	—	—	Varies	Skin irr
Phenol [108-95-2] (1992)	5 ppm	—	Skin; A4; BEI	94.11	URT irr; lung dam; CNS impair
Phenothiazine [92-84-2] (1968)	5 mg/m <sup>3</sup>	—	Skin	199.26	Eye photosens; skin irr



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
<a href="#">N-Phenyl-β-naphthylamine</a> [135-88-6] (1992)	— (L)	—	A4	219.29	Cancer
<a href="#">m-Phenylenediamine</a> [108-45-2] (1988)	0.1 mg/m <sup>3</sup>	—	A4	108.05	Liver dam; skin irr
<a href="#">o-Phenylenediamine</a> [95-54-5] (1988)	0.1 mg/m <sup>3</sup>	—	A3	108.05	Anemia
<a href="#">p-Phenylenediamine</a> [106-50-3] (1988)	0.1 mg/m <sup>3</sup>	—	A4	108.05	URT irr; skin sens
<a href="#">Phenyl ether</a> [101-84-8] (1979)	1 ppm (V)	2 ppm (V)	—	170.20	URT & eye irr; nausea
<a href="#">Phenyl glycidyl ether</a> [122-60-1] (1992)	0.1 ppm	—	Skin; DSEN; A3	150.17	Testicular dam
<a href="#">Phenylhydrazine</a> [100-63-0] (1988)	0.1 ppm	—	Skin; A3	108.14	Anemia; URT & skin irr
<a href="#">Phenyl isocyanate</a> [103-71-9] (2014)	0.005 ppm	0.015 ppm	Skin; DSEN; RSEN	119.10	URT irr
<a href="#">Phenyl mercaptan</a> [108-98-5] (2001)	0.1 ppm	—	Skin	110.18	CNS impair; eye & skin irr
<a href="#">Phenylphosphine</a> [638-21-1] (1992)	—	C 0.05 ppm	—	110.10	Dermatitis; hematologic eff; testicular dam
<a href="#">Phorate</a> [298-02-2] (2002)	0.05 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	260.40	Cholinesterase inhib
<a href="#">Phosgene</a> [75-44-5] (1992)	0.1 ppm	—	—	98.92	URT irr; pulm edema; pulm emphysema
<a href="#">Phosphine</a> [7803-51-2] (2018)	0.05 ppm	C 0.15 ppm	A4	34.00	Resp tract irr; pulm edema
<a href="#">Phosphoric acid</a> [7664-38-2] (1992)	1 mg/m <sup>3</sup>	3 mg/m <sup>3</sup>	—	98.00	URT, eye, & skin irr

Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Phosphorus (yellow) [12185-10-3] (1992)	0.1 mg/m <sup>3</sup>	—	—	123.92	LRT, URT, & GI irr; liver dam
Phosphorus oxychloride [10025-87-3] (1979)	0.1 ppm	—	—	153.35	URT irr
Phosphorus pentachloride [10026-13-8] (1985)	0.1 ppm	—	—	208.24	URT & eye irr
Phosphorus pentasulfide [1314-80-3] (1992)	1 mg/m <sup>3</sup>	3 mg/m <sup>3</sup>	—	222.29	URT irr
Phosphorus trichloride [7719-12-2] (1992)	0.2 ppm	0.5 ppm	—	137.35	URT, eye, & skin irr
* o-Phthalaldehyde [643-79-8] (2018)	SL 25 µg/100 cm <sup>2</sup>	C 0.1 ppb <sup>(V)</sup>	Skin; DSEN; RSEN	134.10	Eye, skin & resp tract irr; resp sens; anaphylaxis
Phthalic anhydride [85-44-9] (2016)	0.002 mg/m <sup>3</sup> (IFV)	0.005 mg/m <sup>3</sup> (IFV)	Skin; DSEN; RSEN; A4	148.12	Resp sens; asthma
m-Phthalodinitrile [626-17-5] (2008)	5 mg/m <sup>3</sup> (IFV)	—	—	128.14	Eye & URT irr
o-Phthalodinitrile [91-15-6] (2011)	1 mg/m <sup>3</sup> (IFV)	—	—	128.13	CNS convul; body weight eff
Picloram [1918-02-1] (1992)	10 mg/m <sup>3</sup>	—	A4	241.48	Liver & kidney dam
Picric acid [88-89-1] (1992)	0.1 mg/m <sup>3</sup>	—	—	229.11	Skin sens; dermatitis; eye irr
Pindone [83-26-1] (1992)	0.1 mg/m <sup>3</sup>	—	—	230.25	Coagulation
Piperazine and salts [110-85-0], as piperazine (2011)	0.03 ppm (IFV)	—	DSEN; RSEN; A4	86.14	Resp sens; asthma

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
<a href="#">Platinum</a> [7440-06-4], and soluble salts (1979)					
Metal	1 mg/m <sup>3</sup>	—	—	195.09	Asthma; URT irr
Soluble salts, as Pt	0.002 mg/m <sup>3</sup>	—	—	Varies	Asthma; URT irr
<a href="#">Polyvinyl chloride</a> [9002-86-2] (2007)	1 mg/m <sup>3</sup> (R)	—	A4	Varies	Pneumoconiosis; LRT irr; pulm func changes
<a href="#">Portland cement</a> [65997-15-1] (2009)	1 mg/m <sup>3</sup> (E, R)	—	A4	—	Pulm func; resp symptoms; asthma
<a href="#">Potassium hydroxide</a> [1310-58-3] (1992)	—	C 2 mg/m <sup>3</sup>	—	56.10	URT, eye, & skin irr
<a href="#">Propane</a> [74-98-6]	See Appendix F: Minimal Oxygen Content (D, EX)			44.10	Asphyxia
<a href="#">Propane sultone</a> [1120-71-4] (1976)	— (L)	—	A3	122.14	Cancer
<a href="#">n-Propanol</a> (n-Propyl alcohol) [71-23-8] (2006)	100 ppm	—	A4	60.09	Eye & URT irr
<a href="#">2-Propanol</a> [67-63-0] (2001)	200 ppm	400 ppm	A4; BEI	60.09	Eye & URT irr; CNS impair
<a href="#">Propargyl alcohol</a> [107-19-7] (1992)	1 ppm	—	Skin	56.06	Eye irr; liver & kidney dam
<a href="#">β-Propiolactone</a> [57-57-8] (1992)	0.5 ppm	—	A3	72.06	Skin cancer; URT irr
<a href="#">Propionaldehyde</a> [123-38-6] (1998)	20 ppm	—	—	58.10	URT irr
<a href="#">Propionic acid</a> [79-09-4] (1977)	10 ppm	—	—	74.08	Eye, skin, & URT irr
<a href="#">Propoxur</a> [114-26-1] (2015)	0.5 mg/m <sup>3</sup> (IFV)	—	A3; BEI <sub>C</sub>	209.24	Cholinesterase inhib
<a href="#">Propyl acetate isomers</a> [108-21-4; 109-60-4] (2017)	100 ppm	150 ppm	—	102.13	URT & eye irr; CNS impair



Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Propylene [115-07-1] (2005)	500 ppm	—	A4	42.08	Asphyxia; URT irr
Propylene dichloride [78-87-5] (2005)	10 ppm	—	DSEN; A4	112.99	URT irr; body weight eff
Propylene glycol dinitrate [6423-43-4] (1980)	0.05 ppm	—	Skin; BEI <sub>M</sub>	166.09	Headache; CNS impair
* Propylene glycol ethyl ether [1569-02-4] (2018)	50 ppm	200 ppm	Skin	104.17	CNS impair; eye & URT irr
Propylene oxide [75-56-9] (2000)	2 ppm	—	DSEN; A3	58.08	Eye & URT irr
Propyleneimine [75-55-8] (2008)	0.2 ppm	0.4 ppm	Skin; A3	57.09	URT irr; kidney dam
n-Propyl nitrate [627-13-4] (1962)	25 ppm	40 ppm	BEI <sub>M</sub>	105.09	Nausea; headache
Pyrethrum [8003-34-7] (1992)	5 mg/m <sup>3</sup>	—	A4	345 (avg.)	Liver dam; LRT irr
Pyridine [110-86-1] (1992)	1 ppm	—	A3	79.10	Skin irr; liver & kidney dam
Quinone [106-51-4] (1970)	0.1 ppm	—	—	108.09	Eye irr; skin dam
Resorcinol [108-46-3] (1992)	10 ppm	20 ppm	A4	110.11	Eye & skin irr
Rhodium [7440-16-6], as Rh (1981)				102.91	
Metal and Insoluble compounds	1 mg/m <sup>3</sup>	—	A4	Varies	Metal = URT irr; Insoluble = LRT irr
Soluble compounds	0.01 mg/m <sup>3</sup>	—	A4	Varies	Asthma
Ronnel [299-84-3] (2005)	5 mg/m <sup>3</sup> (IFV)	—	A4; BEI <sub>C</sub>	321.57	Cholinesterase inhib

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
‡ (Rosin core solder thermal decomposition products (colophony) [8050-09-7] (1992))	(— <sup>(L)</sup> )	(—)	(DSEN; RSEN)	(NA)	(Skin sens; dermatitis; asthma)
Rotenone (commercial) [83-79-4] (1992)	5 mg/m <sup>3</sup>	—	A4	391.41	URT & eye irr; CNS impair
Selenium [7782-49-2] and compounds, as Se (1992)	0.2 mg/m <sup>3</sup>	—	—	78.96	Eye & URT irr
Selenium hexafluoride [7783-79-1], as Se (1992)	0.05 ppm	—	—	192.96	Pulm edema
Sesone [136-78-7] (1992)	10 mg/m <sup>3</sup>	—	A4	309.13	GI irr
Silica, crystalline — $\alpha$ -quartz [1317-95-9; 14808-60-7] and cristobalite [14464-46-1] (2009)	0.025 mg/m <sup>3</sup> (R)	—	A2	60.09	Pulm fibrosis; lung cancer
Silicon carbide [409-21-2] (2002)				40.10	
Nonfibrous	10 mg/m <sup>3</sup> (I, E) 3 mg/m <sup>3</sup> (R, E)	—	—		URT irr URT irr
Fibrous (including whiskers)	0.1 f/cc (F)	—	A2		Mesothelioma; cancer
Silicon tetrahydride [7803-62-5] (2014)	5 ppm	—	—	32.12	URT irr
Silver [7440-22-4], and compounds (1992)					Argyria
Metal, dust and fume	0.1 mg/m <sup>3</sup>	—	—	107.87	
Soluble compounds, as Ag	0.01 mg/m <sup>3</sup>	—	—	Varies	
Simazine [122-34-9] (2015)	0.5 mg/m <sup>3</sup> (I)	—	A3	201.60	Hematologic eff

Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Sodium azide [26628-22-8] (1992) as Sodium azide as Hydrazoic acid vapor	— —	C 0.29 mg/m <sup>3</sup> C 0.11 ppm	A4 A4	65.02	Card impair; lung dam
Sodium bisulfite [7631-90-5] (1992)	5 mg/m <sup>3</sup>	—	A4	104.07	Skin, eye, & URT irr
Sodium fluoroacetate [62-74-8] (1992)	0.05 mg/m <sup>3</sup>	—	Skin	100.02	CNS impair; card impair; nausea
Sodium hydroxide [1310-73-2] (1992)	—	C 2 mg/m <sup>3</sup>	—	40.01	URT, eye, & skin irr
Sodium metabisulfite [7681-57-4] (1992)	5 mg/m <sup>3</sup>	—	A4	190.13	URT irr
Starch [9005-25-8] (1992)	10 mg/m <sup>3</sup>	—	A4	—	Dermatitis
Stearates <sup>(J)</sup> [57-11-4; 557-04-0; 557-05-1; 822-16-2] (2016)	10 mg/m <sup>3</sup> <sup>(I)</sup> 3 mg/m <sup>3</sup> <sup>(R)</sup>	—	A4	Varies	LRT irr
Stoddard solvent [8052-41-3] (1980)	100 ppm	—	—	140.00	Eye, skin, & kidney dam; nausea; CNS impair
Strychnine [57-24-9] (1992)	0.15 mg/m <sup>3</sup>	—	—	334.40	CNS impair
‡ (Styrene, monomer [100-42-5] (1996))	(20 ppm)	(40 ppm)	( ); (A4); BEI	104.16	(CNS impair; URT irr; peripheral neuropathy)
Subtilisins [1395-21-7; 9014-01-1], as 100% crystalline active pure enzyme (1972)	—	C 0.00006 mg/m <sup>3</sup>	—	—	Asthma; skin, URT, & LRT irr

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Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
Sucrose [57-50-1] (1992)	10 mg/m <sup>3</sup>	—	A4	342.30	Dental erosion
* Sulfometuron methyl [74222-97-2] (1991)	5 mg/m <sup>3</sup> (IFV)	—	A4	364.38	Hematologic eff
Sulfotepp [3689-24-5] (1993)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	322.30	Cholinesterase inhib
* Sulfoxaflor [946578-00-3] (2018)	0.1 mg/m <sup>3</sup> (I)	—	A3	277.30	Liver & Testicular dam
Sulfur dioxide [7446-09-5] (2008)	—	0.25 ppm	A4	64.07	Pulm func; LRT irr
Sulfur hexafluoride [2551-62-4] (1985)	1000 ppm	—	—	146.07	Asphyxia
Sulfur monochloride [10025-67-9] (1986)	—	C 1 ppm	—	135.03	Eye, skin, & URT irr
‡ Sulfur pentafluoride [5714-22-7] (1962)	—	(C 0.01 ppm)	—	254.11	(URT irr; lung dam)
Sulfur tetrafluoride [7783-60-0] (1992)	—	C 0.1 ppm	—	108.07	Eye & URT irr; lung dam
Sulfuric acid [7664-93-9] (2000)	0.2 mg/m <sup>3</sup> (T)	—	A2 (M)	98.08	Pulm func
Sulfuryl fluoride [2699-79-8] (1992)	5 ppm	10 ppm	—	102.07	CNS impair
Sulprofos [35400-43-2] (2008)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	322.43	Cholinesterase inhib

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
<b>Synthetic vitreous fibers</b> (1999)					
Continuous filament glass fibers	1 f/cc (F)	—	A4	—	URT irr
Continuous filament glass fibers	5 mg/m <sup>3</sup> (I)	—	A4	—	URT irr
Glass wool fibers	1 f/cc (F)	—	A3	—	Skin & mucous membrane irr
Rock wool fibers	1 f/cc (F)	—	A3	—	Skin & mucous membrane irr
Slag wool fibers	1 f/cc (F)	—	A3	—	Skin & mucous membrane irr
Special purpose glass fibers	1 f/cc (F)	—	A3	—	Skin & mucous membrane irr
Refractory ceramic fibers	0.2 f/cc (F)	—	A2	—	Pulm fibrosis; pulm func
<b>2,4,5-T</b> [93-76-5] (1992)	10 mg/m <sup>3</sup>	—	A4	255.49	PNS impair
<b>Talc</b> [14807-96-6] (2009)					
Containing no asbestos fibers	2 mg/m <sup>3</sup> (E, R)	—	A4	—	Pulm fibrosis; pulm func
Containing asbestos fibers	Use Asbestos TLV® (K)	—	A1	—	
<b>Tellurium</b> [13494-80-9] and compounds (NOS), as Te, excluding hydrogen telluride (1992)	0.1 mg/m <sup>3</sup>	—	—	127.60	Halitosis
<b>Tellurium hexafluoride</b> [7783-80-4], as Te (1992)	0.02 ppm	—	—	241.61	LRT irr
* <b>Temephos</b> [3383-96-8] (2002)	1 mg/m <sup>3</sup> (I)	—	Skin; A4; BEI <sub>C</sub>	466.46	Cholinesterase inhib
<b>Terbufos</b> [13071-79-9] (1999)	0.01 mg/m <sup>3</sup> (IFV)	—	Skin; A4; BEI <sub>C</sub>	288.45	Cholinesterase inhib
<b>Terephthalic acid</b> [100-21-0] (1990)	10 mg/m <sup>3</sup>	—	—	166.13	—

TLV®

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				TLV® Basis
	TWA	STEL	Notations	MW	
Terphenyls (o-, m-, p- isomers) [26140-60-3] (1977)	—	C 5 mg/m <sup>3</sup>	—	230.31	URT & eye irr
* 1,1,2,2-Tetrabromoethane [79-27-6] (2005)	0.1 ppm	—	—	345.70	Eye & URT irr; pulm edema; liver dam
1,1,1,2-Tetrachloro-2,2-difluoroethane [76-11-9] (2007)	100 ppm	—	—	203.83	Liver & kidney dam; CNS impair
1,1,2,2-Tetrachloro-1,2-difluoroethane [76-12-0] (2007)	50 ppm	—	—	203.83	Liver & kidney dam; CNS impair
1,1,2,2-Tetrachloroethane [79-34-5] (1995)	1 ppm	—	Skin; A3	167.86	Liver dam
Tetrachloroethylene [127-18-4] (1990)	25 ppm	100 ppm	A3; BEI	165.80	CNS impair
Tetrachloronaphthalene [1335-88-2] (1992)	2 mg/m <sup>3</sup>	—	—	265.96	Liver dam
Tetraethyl lead [78-00-2], as Pb (1992)	0.1 mg/m <sup>3</sup>	—	Skin; A4	323.45	CNS impair
Tetraethyl pyrophosphate [107-49-3] (2006)	0.01 mg/m <sup>3</sup> (IFV)	—	Skin; BEI <sub>C</sub>	290.20	Cholinesterase inhib
Tetrafluoroethylene [116-14-3] (1997)	2 ppm	—	A3	100.20	Kidney & liver dam; liver & kidney cancer
Tetrahydrofuran [109-99-9] (2002)	50 ppm	100 ppm	Skin; A3	72.10	URT irr; CNS impair; kidney dam
Tetrakis (hydroxymethyl) phosphonium salts (2002)					Liver dam
Tetrakis (hydroxymethyl) phosphonium chloride [124-64-1]	2 mg/m <sup>3</sup>	—	DSEN; A4	190.56	
Tetrakis (hydroxymethyl) phosphonium sulfate [55566-30-8]	2 mg/m <sup>3</sup>	—	DSEN; A4	406.26	

Substance [CAS No.] (Documentation date)	ADOPTED VALUES				
	TWA	STEL	Notations	MW	TLV® Basis
<a href="#">Tetramethyl lead</a> [75-74-1], as Pb (1992)	0.15 mg/m <sup>3</sup>	—	Skin	267.33	CNS impair
* <a href="#">Tetramethyl succinonitrile</a> [3333-52-6] (2018)	0.5 mg/m <sup>3</sup> (IFV)	—	Skin	136.20	Hypoglycemia; convul
<a href="#">Tetranitromethane</a> [509-14-8] (1992)	0.005 ppm	—	A3	196.04	Eye & URT irr; URT cancer
<a href="#">Tetryl</a> [479-45-8] (1984)	1.5 mg/m <sup>3</sup>	—	—	287.15	URT irr
<a href="#">Thallium</a> [7440-28-0] and <a href="#">compounds</a> , as Tl (2009)	0.02 mg/m <sup>3</sup> (I)	—	Skin	204.37 Varies	GI dam; peripheral neuropathy
* <a href="#">Thiacloprid</a> [111988-49-9] (2018)	0.2 mg/m <sup>3</sup> (I)	—	Skin; A3	252.72	Liver dam; thyroid & CNS eff; cancer
<a href="#">4,4'-Thiobis(6-tert-butyl-m-cresol)</a> [96-69-5] (2010)	1 mg/m <sup>3</sup> (I)	—	A4	358.52	URT irr
<a href="#">Thioglycolic acid</a> [68-11-1] and <a href="#">salts</a> (2017)	1 ppm	—	Skin; DSEN	92.12	Eye & resp irr
<a href="#">Thionyl chloride</a> [7719-09-7] (2009)	—	C 0.2 ppm	—	118.98	URT irr
<a href="#">Thiram</a> [137-26-8] (2007)	0.05 mg/m <sup>3</sup> (IFV)	—	DSEN; A4	240.44	Body weight & hematologic eff
* <a href="#">Tin</a> [7440-31-5] and <a href="#">inorganic compounds</a> [18282-10-5; 21651-19-4], <a href="#">excluding Tin hydride and Indium tin oxide</a> , as Sn (2018)	2 mg/m <sup>3</sup> (I)	—	—	118.69 Varies	Pneumoconiosis
<a href="#">Tin</a> [7440-31-5], <a href="#">organic compounds</a> , as Sn (1995)	0.1 mg/m <sup>3</sup>	0.2 mg/m <sup>3</sup>	Skin; A4	Varies	Eye & URT irr; headache; nausea; CNS & immune eff
<a href="#">Titanium dioxide</a> [13463-67-7] (1992)	10 mg/m <sup>3</sup>	—	A4	79.90	LRT irr



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
<a href="#">o-Tolidine</a> [119-93-7] (1992)	—	—	Skin; A3	212.28	Eye, bladder, & kidney irr; bladder cancer; MeHb-emia
<a href="#">Toluene</a> [108-88-3] (2006)	20 ppm	—	A4; BEI	92.13	Visual impair; female repro; pregnancy loss
<a href="#">Toluene diisocyanate, 2,4- or 2,6- (or as a mixture)</a> [584-84-9; 91-08-7] (2015)	0.001 ppm (IFV)	0.005 ppm (IFV)	Skin; DSEN; RSEN; A3	174.15	Asthma; pulm func; eye irr
<a href="#">m-Toluidine</a> [108-44-1] (1984)	2 ppm	—	Skin; A4; BEI <sub>M</sub>	107.15	Eye, bladder, & kidney irr; MeHb-emia
<a href="#">o-Toluidine</a> [95-53-4] (1984)	2 ppm	—	Skin; A3; BEI <sub>M</sub>	107.15	MeHb-emia; skin, eye, kidney & bladder irr
<a href="#">p-Toluidine</a> [106-49-0] (1984)	2 ppm	—	Skin; A3; BEI <sub>M</sub>	107.15	MeHb-emia
<a href="#">Tributyl phosphate</a> [126-73-8] (2012)	5 mg/m <sup>3</sup> (IFV)	—	A3; BEI <sub>C</sub>	266.31	Bladder, eye, & URT irr
<a href="#">Trichloroacetic acid</a> [76-03-9] (2013)	0.5 ppm	—	A3	163.39	Eye & URT irr
<a href="#">1,2,4-Trichlorobenzene</a> [120-82-1] (1975)	—	C 5 ppm	—	181.46	Eye & URT irr
<a href="#">1,1,2-Trichloroethane</a> [79-00-5] (1992)	10 ppm	—	Skin; A3	133.41	CNS impair; liver dam
<a href="#">Trichloroethylene</a> [79-01-6] (2006)	10 ppm	25 ppm	A2; BEI	131.40	CNS impair; cognitive decrements; renal toxicity
<a href="#">Trichlorofluoromethane</a> [75-69-4] (1992)	—	C 1000 ppm	A4	137.38	Card sens
<a href="#">Trichloronaphthalene</a> [1321-65-9] (1970)	5 mg/m <sup>3</sup>	—	Skin	231.51	Liver dam; chloracne



Substance [CAS No.] (Documentation date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
1,2,3-Trichloropropane [96-18-4] (2014)	0.005 ppm	—	A2	147.43	Cancer
1,1,2-Trichloro-1,2,2-trifluoroethane [76-13-1] (1992)	1000 ppm	1250 ppm	A4	187.40	CNS impair
Trichlorphon [52-68-6] (2003)	1 mg/m <sup>3</sup> (I)	—	A4; BEI <sub>C</sub>	257.60	Cholinesterase inhib
Triethanolamine [102-71-6] (1990)	5 mg/m <sup>3</sup>	—	—	149.22	Eye & skin irr
Triethylamine [121-44-8] (2014)	0.5 ppm	1 ppm	Skin; A4	101.19	Visual impair; URT irr
Trifluorobromomethane [75-63-8] (1979)	1000 ppm	—	—	148.92	CNS & card impair
1,3,5-Triglycidyl-s-triazinetriene [2451-62-9] (1994)	0.05 mg/m <sup>3</sup>	—	—	297.25	Male repro dam
Trimellitic anhydride [552-30-7] (2007)	0.0005 mg/m <sup>3</sup> (IFV)	0.002 mg/m <sup>3</sup> (IFV)	Skin; DSEN; RSEN	192.12	Resp sens
Trimethylamine [75-50-3] (2012)	5 ppm	15 ppm	—	59.11	URT, eye, & skin irr
Trimethylbenzene (mixed isomers) [25551-13-7] (1970)	25 ppm	—	—	120.19	CNS impair; asthma; hematologic eff
Trimethyl phosphite [121-45-9] (1980)	2 ppm	—	—	124.08	Eye irr; cholinesterase inhib
* 2,4,6-Trinitrotoluene [118-96-7] (1984)	0.1 mg/m <sup>3</sup> (IFV)	—	Skin; BEI <sub>M</sub>	227.13	MeHb-emia; liver dam; cataract
Triorthocresyl phosphate [78-30-8] (2015)	0.02 mg/m <sup>3</sup> (IFV)	—	Skin; BEI <sub>C</sub>	368.37	Neurotoxicity; cholinesterase inhib
Triphenyl phosphate [115-86-6] (1992)	3 mg/m <sup>3</sup>	—	A4	326.28	Cholinesterase inhib
Tungsten [7440-33-7] and compounds, in the absence of Cobalt, as W (2016)	3 mg/m <sup>3</sup> (R)	—	—	183.84 Varies	Lung dam

Substance [CAS No.] (Doc. date)	ADOPTED VALUES			MW	TLV <sup>®</sup> Basis
	TWA	STEL	Notations		
Turpentine [8006-64-2] and selected monoterpenes [80-56-8; 127-91-3; 13466-78-9] (2001)	20 ppm	—	DSEN; A4	136.00 Varies	Lung irr
Uranium (natural) [7440-61-1] (1992) Soluble and insoluble compounds, as U	0.2 mg/m <sup>3</sup>	0.6 mg/m <sup>3</sup>	A1; BEI	238.03 Varies	Kidney dam
n-Valeraldehyde [110-62-3] (1984)	50 ppm	—	—	86.13	Eye, skin, & URT irr
Vanadium pentoxide [1314-62-1], as V (2008)	0.05 mg/m <sup>3</sup> <sup>(1)</sup>	—	A3	181.88	URT & LRT irr
Vinyl acetate [108-05-4] (2017)	10 ppm	15 ppm	A3	86.09	URT & eye irr
Vinyl bromide [593-60-2] (1996)	0.5 ppm	—	A2	106.96	Liver cancer
Vinyl chloride [75-01-4] (1997)	1 ppm	—	A1	62.50	Lung cancer; liver dam
4-Vinyl cyclohexene [100-40-3] (1994)	0.1 ppm	—	A3	108.18	Female & male repro dam
Vinyl cyclohexene dioxide [106-87-6] (1994)	0.1 ppm	—	Skin; A3	140.18	Female & male repro dam
Vinyl fluoride [75-02-5] (1996)	1 ppm	—	A2	46.05	Liver cancer; liver dam
N-Vinyl-2-pyrrolidone [88-12-0] (2000)	0.05 ppm	—	A3	111.16	Liver dam
Vinylidene chloride [75-35-4] (1992)	5 ppm	—	A4	96.95	Liver & kidney dam
Vinylidene fluoride [75-38-7] (1996)	500 ppm	—	A4	64.04	Liver dam

<b>ADOPTED VALUES</b>					
<b>Substance [CAS No.] (Documentation date)</b>	<b>TWA</b>	<b>STEL</b>	<b>Notations</b>	<b>MW</b>	<b>TLV® Basis</b>
<a href="#">Vinyltoluene</a> [25013-15-4] (1992)	50 ppm	100 ppm	A4	118.18	URT & eye irr
<a href="#">Warfarin</a> [81-81-2] (2015)	0.01 mg/m <sup>3</sup> (I)	—	Skin	308.32	Bleeding; teratogenic
<a href="#">Wood dusts</a> (2014)				NA	
Western red cedar	0.5 mg/m <sup>3</sup> (I)	—	DSEN; RSEN; A4		Asthma
All other species	1 mg/m <sup>3</sup> (I)	—	—		Pulm func; URT & LRT irr
<i>Carcinogenicity</i>					
Oak and beech	—	—	A1		
Birch, mahogany, teak, walnut	—	—	A2		
All other wood dusts	—	—	A4		
<a href="#">Xylene</a> [1330-20-7] (all isomers) [95-47-6; 106-42-3; 108-38-3] (1992)	100 ppm	150 ppm	A4; BEI	106.16	URT & eye irr; CNS impair
* <a href="#">m-Xylene α,α'-diamine</a> [1477-55-0] (1992)	—	C 0.018 ppm	Skin	136.20	Eye, skin, & GI irr
<a href="#">Xylidine (mixed isomers)</a> [1300-73-8] (1999)	0.5 ppm (IFV)	—	Skin; A3; BEI <sub>M</sub>	121.18	Liver dam; MeHb-emia
<a href="#">Yttrium</a> [7440-65-5] and compounds, as Y (1986)	1 mg/m <sup>3</sup>	—	—	88.91	Pulm fibrosis
<a href="#">Zinc chloride fume</a> [7646-85-7] (1992)	1 mg/m <sup>3</sup>	2 mg/m <sup>3</sup>	—	136.29	LRT & URT irr
<a href="#">Zinc oxide</a> [1314-13-2] (2001)	2 mg/m <sup>3</sup> (R)	10 mg/m <sup>3</sup> (R)	—	81.37	Metal fume fever
<a href="#">Zirconium</a> [7440-67-7] and compounds, as Zr (1992)	5 mg/m <sup>3</sup>	10 mg/m <sup>3</sup>	A4	91.22	Resp irr

## 2019 NOTICE OF INTENDED CHANGES

These substances, with their corresponding values and notations, comprise those for which 1) a limit is proposed for the first time, 2) a change in the Adopted value is proposed, 3) retention as an NIC is proposed, or 4) withdrawal of the *Documentation* and adopted TLV® is proposed. In each case, the proposals should be considered trial values during the period they are on the NIC. These proposals were ratified by the ACGIH® Board of Directors and will remain on the NIC for approximately one year following this ratification. If the Committee neither finds nor receives any substantive data that change its scientific opinion regarding an NIC TLV®, the Committee may then approve its recommendation to the ACGIH® Board of Directors for adoption. If the Committee finds or receives substantive data that change its scientific opinion regarding an NIC TLV®, the Committee may change its recommendation to the ACGIH® Board of Directors for the matter to be either retained on or withdrawn from the NIC.

*Documentation* is available for each of these substances and their proposed values.

This notice provides an opportunity for comment on these proposals. Comments or suggestions should be accompanied by substantiating evidence in the form of peer-reviewed literature and forwarded in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org). Please refer to the ACGIH® TLV®/BEI® Development Process on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process)) for a detailed discussion covering this procedure, methods for input to ACGIH®, and deadline date for receiving comments.

2019 NOTICE OF INTENDED CHANGES					
Substance [CAS No.]	TWA	STEL	Notations	MW	TLV® Basis
† <a href="#">Acrylamide</a> [79-06-1]	0.03 mg/m <sup>3</sup> (IFV)	—	Skin; DSEN; A2	71.08	CNS eff; cancer
† <a href="#">Antimony trioxide</a> [1309-64-4]	0.02 mg/m <sup>3</sup> (I)	—	A2	291.50	Pneumonitis
† <a href="#">4-tert-Butylbenzoic acid</a> [98-73-7]	0.1 mg/m <sup>3</sup> (I)	—	Skin	178.20	Testicular dam; CNS & male repro eff
<a href="#">Cumene</a> [98-82-8]	1 ppm	—	A3	120.19	Liver dam; resp tract inflammation
† <a href="#">Cyclohexene</a> [110-83-8]	20 ppm	—	—	84.169	Liver eff

**2019 NOTICE OF INTENDED CHANGES**

<b>Substance [CAS No.]</b>	<b>TWA</b>	<b>STEL</b>	<b>Notations</b>	<b>MW</b>	<b>TLV® Basis</b>
† Di(2-ethylhexyl) phthalate [117-81-7]	0.03 ppm	—	Skin; A3	390.54	Male repro system dam; teratogenic eff
† Formamide [75-12-7]	1 ppm	—	Skin; A3	45.04	Hematological eff; liver cancer
† Hexamethylenetetramine [100-97-0]	1 mg/m <sup>3</sup> (1)	—	DSEN; A4	140.20	Dermal sens
† Hexazinone [51235-04-2]	3 mg/m <sup>3</sup> (1)	—	A4	252.30	Hematological & liver eff
† Iodine [7553-56-2] and Iodides, as I	WITHDRAWN FROM NOTICE OF INTENDED CHANGES				
Iodoform [75-47-8]	0.2 ppm (IFV)	—	—	393.78	CNS & card system impair; liver & kidney dam
† Isoflurane [26675-46-7]	5 ppm	—	A4	184.49	Male repro system dam
† Methyl isobutyl carbinol [108-11-2]	20 ppm	40 ppm	—	102.18	Dizziness; headache; eye & URT irr
† Resin acids, as total Resin acids [8050-09-7]	0.001 mg/m <sup>3</sup> (1)	—	DSEN; RSEN		Asthma; resp & eye irr; dermal & skin sens
† Rosin core solder thermal decomposition products (colophony) [8050-09-7]	WITHDRAW ADOPTED TLV® AND DOCUMENTATION; SEE RESIN ACIDS				
† Sodium sulfate [7727-73-3; 7757-82-6]	WITHDRAWN FROM NOTICE OF INTENDED CHANGES				
† Styrene [100-42-5]	10 ppm	20 ppm	OTO; A3	104.16	URT irr; CNS impair; peripheral neuropathy; ototoxicity (hearing loss); visual disorders

**TLV®**

## 2019 NOTICE OF INTENDED CHANGES

Substance [CAS No.]	TWA	STEL	Notations	MW	TLV® Basis
Styrene oxide [96-09-3]	1 ppm	—	Skin; DSEN; A3	120.15	URT irr; blood changes
† Sulfur pentafluoride [5714-22-7]	—	C 0.001 ppm	—	254.11	Pulm edema
† Thiodicarb [59669-26-0]	0.1 mg/m <sup>3</sup> (IFV)	—	DSEN; A3	354.50	Acetylcholinesterase inhib
† Titanium tetrachloride, as HCl [7550-45-0]	—	C 0.5 ppm	—	189.70	Upper resp tract irr & corrosion
Trimetacresyl phosphate [563-04-2]	0.05 mg/m <sup>3</sup> (IFV)	—	—	368.36	Adrenal gland & female repro system dam
Triparacresyl phosphate [78-32-0]	0.05 mg/m <sup>3</sup> (IFV)	—	—	368.36	Adrenal gland & female repro system dam

## CHEMICAL SUBSTANCES AND OTHER ISSUES UNDER STUDY


 TLV®-CS

The TLV® Chemical Substances Committee solicits information, especially data, which may assist in its deliberations regarding the following substances and issues. Comments and suggestions, accompanied by substantiating evidence in the form of peer-reviewed literature, should be forwarded in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org). In addition, the Committee solicits recommendations for additional substances and issues of concern to the industrial hygiene and occupational health communities. Please refer to the ACGIH® TLV®/BEI® Development Process found on the ACGIH® website for a detailed discussion covering this procedure and methods for input to ACGIH® ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process)).

The Under Study list is published each year by February 1 on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)), in the *Annual Reports of the Committees on TLVs® and BEIs®*, and later in the annual *TLVs® and BEIs®* book. In addition, the Under Study list is updated by July 31 into a two-tier list.

- Tier 1 entries indicate which chemical substances and physical agents **may** move forward as an NIC or NIE in the upcoming year, based on their status in the development process.
- Tier 2 consists of those chemical substances and physical agents that **will not** move forward, but will either remain on, or be removed from, the Under Study list for the next year.

This updated list will remain in two tiers for the balance of the year. ACGIH® will continue this practice of updating the Under Study list by February 1 and establishing the two-tier list by July 31 each year.

The substances and issues listed below are as of January 1, 2019. *After this date, please refer to the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)) for the up-to-date list.*

### Chemical Substances

Alkyl acrylates	Chloromethyl methyl ether
Aluminum sodium dioxide	Cobalt carbonyl
Antimony and compounds	Cobalt hydrocarbonyl
Antimony hydride	Copper
Benzene	Cyromazine
Benzidine	Diazinon
Bifenazate	Dicamba
Buprofezin	3,3'-Dichlorobenzidine
1,3-Butadiene	1,3-Dichloro-5,5-dimethyl hydantoin
n-Butyl isocyanate	1,1-Dichloro-1-nitroethane
Carbon dioxide	1,2-Dichloropropane
Carbon monoxide	Diesel exhaust
Carbon nanotubes	Difluorodibromomethane
Catechol	Diiodomethyl p-tolyl sulfone
Chlorodiphenyl, 42%	1,2-Dimethoxyethane
Chlorodiphenyl, 54%	4,4-Dimethyloxazolidine

TLV®-CS

Enflurane  
 Epichlorohydrin  
 Ethyl acrylate  
 Ethyl benzene  
 Ethyl ether  
 Ethylene glycol dinitrate  
 Fluorides  
 Furan  
 Furfural  
 Furfuryl alcohol  
 Germanium tetrahydride  
 Glyphosate  
 Hafnium and compounds  
 Halothane  
 Hexachloronaphthalene  
 sec-Hexyl acetate  
 Imazosulfuron  
 Imidacloprid  
 Indium and compounds  
 Iodine and Iodides  
 Isopropylamine  
 Ketene  
 Lead and inorganic compounds  
 Lindane  
 Malathion  
 Manganese cyclopentadienyl  
     tricarbonyl  
 2-Methoxymethylethoxy propanol  
 Methyl acrylate  
 Methyl isobutyl carbinol  
 Methyl n-butyl ketone  
 o-Methylcyclohexanone  
 2-Methylcyclopentadienyl  
     manganese tricarbonyl  
 Methylene bisphenyl isocyanate  
 Metribuzin  
 Mica  
 1-Naphthylamine  
 2-Naphthylamine  
 Nickel and inorganic compounds,  
     including Nickel subsulfide  
 Nitric acid  
 Nitroglycerin  
 Octachloronaphthalene  
 Parathion  
 Pentaborane  
 2,3-Pentanedione  
 Perchloryl fluoride  
 Phenothiazine  
 Phosgene  
 Phosphoric acid  
 Phosphorus (red)  
 Phosphorus (white)  
 Phosphorus (yellow)  
 Polycyclic aromatic hydrocarbons  
 Prometon  
 Prometryn  
 Propane sultone  
 n-Propyl nitrate  
 Propylene glycol dinitrate  
 Quinone  
 Sevoflurane  
 Silicic acid  
 Silicon carbide  
 Sodium hypochlorite  
 Sodium sulfate  
 Stoddard solvent  
 Subtilisins  
 Sulfur trioxide  
 Talc  
 Tetrachlorophthalic anhydride  
 Tetrachlorvinphos  
 Tetraethyl lead  
 1,2,3,6-Tetrahydrophthalic  
     anhydride  
 Tetramethyl lead  
 Tin, organic compounds  
 Titanium dioxide  
 Toluene  
 o-Toluidine  
 Trichlorfon  
 Trichloronaphthalene  
 Triclopyr  
 Triclosan  
 Triethanolamine  
 Trifloxystrobin  
 Triflumizole  
 Trimethyl phosphite  
 Trimethylbenzene mixed isomers  
 Uranium and compounds  
 Vinylidene chloride  
 Vinylidene fluoride  
 Xylene



## DEFINITIONS AND NOTATIONS

### Definitions

#### *Documentation*

The source publication that provides the critical evaluation of the pertinent scientific information and data with reference to literature sources upon which each TLV<sup>®</sup> or BEI<sup>®</sup> is based. See the discussion under “TLV<sup>®</sup>/BEI<sup>®</sup> Development Process: An Overview” found at the beginning of this book. The general outline used when preparing the *Documentation* may be found in the Operations Manual of the Threshold Limit Values for Chemical Substances (TLV<sup>®</sup>-CS) Committee, accessible online at: [www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-committee-operations-manuals](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-committee-operations-manuals).

#### *Minimal Oxygen Content*

An oxygen (O<sub>2</sub>)-deficient atmosphere is defined as one with an ambient  $\rho\text{O}_2$  less than 132 torr (NIOSH, 1980). The minimum requirement of 19.5% oxygen at sea level (148 torr O<sub>2</sub>, dry air) provides an adequate amount of oxygen for most work assignments and includes a margin of safety (NIOSH, 1987; McManus, 1999). Studies of pulmonary physiology suggest that the above requirements provide an adequate level of oxygen pressure in the lungs (alveolar  $\rho\text{O}_2$  of 60 torr) (Silverthorn, 2001; Guyton, 1991; NIOSH, 1976).

Some gases and vapors, when present in high concentrations in air, act primarily as simple asphyxiants, without other significant physiologic effects. A simple asphyxiant may not be assigned a TLV<sup>®</sup> because the limiting factor is the available oxygen. Atmospheres deficient in O<sub>2</sub> do not provide adequate warning and most simple asphyxiants are odorless. Account should be taken of this factor in limiting the concentration of the asphyxiant particularly at elevations greater than 5000 feet where the  $\rho\text{O}_2$  of the atmosphere is less than 120 torr. Several simple asphyxiants present an explosion hazard. See page 85 for adopted Appendix F: Minimal Oxygen Content.

#### *Nanomaterials*

Nanomaterials are objects that are 100 nm or smaller in one or more dimension. Substances composed of nanomaterials, even when agglomerated, may have greater or different toxicity than the same substance in fine or sometimes called “bulk” form. When supported by the literature, ACGIH<sup>®</sup> may differentiate TLVs<sup>®</sup> for nanomaterials.

#### *Notation*

A notation is a designation that appears as a component of the TLV<sup>®</sup> in which specific information is listed in the column devoted to Notations.

#### *Notice of Intended Change (NIC)*

The NIC is a list of actions proposed by the TLV<sup>®</sup>-CS Committee for the coming year. This Notice provides an opportunity for public comment. Values remain on the NIC for approximately one year after they have been ratified by

the ACGIH® Board of Directors. The proposals should be considered trial values during the period they are on the NIC. If the Committee neither finds nor receives any substantive data that change its scientific opinion regarding an NIC TLV®, the Committee may then approve its recommendation to the ACGIH® Board of Directors for adoption. If the Committee finds or receives substantive data that change its scientific opinion regarding an NIC TLV®, the Committee may change its recommendation to the ACGIH® Board of Directors for the matter to be either retained on or withdrawn from the NIC. Values appearing in parentheses in the Adopted TLV® section are to be used during the period in which a proposed change for that value or notation appears on the NIC.

### ***Particulate Matter/Particle Size***

For solid and liquid particulate matter, TLVs® are expressed in terms of “total” particulate matter, except where the terms inhalable, thoracic, or respirable particulate matter are used. The intent of ACGIH® is to replace all “total” particulate TLVs® with inhalable, thoracic, or respirable particulate mass TLVs®. Side-by-side sampling using “total” and inhalable, thoracic, or respirable sampling techniques is encouraged to aid in the replacement of current “total” particulate TLVs®. See Appendix C: Particle Size-Selective Sampling Criteria for Airborne Particulate Matter, for the definitions of inhalable, thoracic, and respirable particulate matter.

### ***Particles (insoluble or poorly soluble) Not Otherwise Specified (PNOS)***

There are many insoluble particles of low toxicity for which no TLV® has been established. ACGIH® believes that even biologically inert, insoluble, or poorly soluble particles may have adverse effects and suggests that airborne concentrations should be kept below 3 mg/m<sup>3</sup>, respirable particles, and 10 mg/m<sup>3</sup>, inhalable particles, until such time as a TLV® is set for a particular substance. A description of the rationale for this recommendation and the criteria for substances to which it pertains are provided in Appendix B.

### ***TLV® Basis***

TLVs® are derived from publicly available information summarized in their respective *Documentation*. Although adherence to the TLV® may prevent several adverse health effects, it is not possible to list all of them in this book. The basis on which the values are established will differ from agent to agent (e.g., protection against impairment of health may be a guiding factor for some, whereas reasonable freedom from irritation, narcosis, nuisance, or other forms of stress may form the basis for others). Health impairments considered include those that shorten life expectancy, adversely affect reproductive function or developmental processes, compromise organ or tissue function, or impair the capability for resisting other toxic substances or disease processes.

The TLV® Basis represents the adverse effect(s) upon which the TLV® is based. The TLV® Basis column in this book is intended to provide a field reference for symptoms of overexposure and as a guide for determining whether components of a mixed exposure should be considered as acting independently or additively. Use of the TLV® Basis column is not a substitute for read-

ing the *Documentation*. Each *Documentation* is a critical component for proper use of the TLV(s)<sup>®</sup> and to understand the TLV<sup>®</sup> basis. A complete list of the TLV<sup>®</sup> bases used by the Threshold Limit Values for Chemical Substances Committee may be found in their Operations Manual online at: ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-committee-operations-manuals](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-committee-operations-manuals)).

TLV<sup>®</sup>-CS

#### Abbreviations used:

<i>card</i> – cardiac	<i>impair</i> – impairment
<i>CNS</i> – central nervous system	<i>inhib</i> – inhibition
<i>COHb-emia</i> – carboxyhemoglobinemia	<i>irr</i> – irritation
<i>convul</i> – convulsion	<i>LRT</i> – lower respiratory tract
<i>dam</i> – damage	<i>MeHb-emia</i> – methemoglobinemia
<i>eff</i> – effects	<i>PNS</i> – peripheral nervous system
<i>form</i> – formation	<i>pulm</i> – pulmonary
<i>func</i> – function	<i>repro</i> – reproductive
<i>GI</i> – gastrointestinal	<i>resp</i> – respiratory
<i>Hb</i> – hemoglobin	<i>sens</i> – sensitization
	<i>URT</i> – upper respiratory tract

#### Notations/Endnotes

##### **Biological Exposure Indices (BEIs<sup>®</sup>)**

The notation “BEI” is listed in the “Notations” column when a BEI<sup>®</sup> (or BEIs<sup>®</sup>) is (are) also recommended for the substance. Three subcategories to the “BEI” notation have been added to help the user identify those substances that would use only the BEI<sup>®</sup> for Cholinesterase inhibiting pesticides or Methemoglobin inducers. They are as follows:

BEI<sub>C</sub> = See the BEI<sup>®</sup> for Cholinesterase inhibiting pesticide

BEI<sub>M</sub> = See the BEI<sup>®</sup> for Methemoglobin inducers

BEI<sub>P</sub> = See the BEI<sup>®</sup> for Polycyclic aromatic hydrocarbons (PAHs)

Biological monitoring should be instituted for such substances to evaluate the total exposure from all sources, including dermal, ingestion, or nonoccupational. See the BEI<sup>®</sup> section in this book and the *Documentation* of the TLVs<sup>®</sup> and BEIs<sup>®</sup> for these substances.

##### **Carcinogenicity**

A carcinogen is an agent capable of inducing benign or malignant neoplasms. Evidence of carcinogenicity comes from epidemiology, toxicology, and mechanistic studies. Specific notations (i.e., A1, A2, A3, A4, and A5) are used by ACGIH<sup>®</sup> to define the categories for carcinogenicity and are listed in the Notations column. See Appendix A for these categories and definitions and their relevance to humans in occupational settings.

##### **Inhalable Fraction and Vapor (IFV)**

The Inhalable Fraction and Vapor (IFV) endnote is used when a material exerts sufficient vapor pressure such that it may be present in both particle and

vapor phases, with each contributing a significant portion of the dose at the TLV-TWA concentration. The ratio of the Saturated Vapor Concentration (SVC) to the TLV-TWA is considered when assigning the IFV endnote. The IFV endnote is typically used for substances with an SVC/TLV® ratio between 0.1 and 10.

The industrial hygienist should also consider both particle and vapor phases to assess exposures from spraying operations, from processes involving temperature changes that may affect the physical state of matter, when a significant fraction of the vapor is dissolved into or adsorbed onto particles of another substance, such as water-soluble compounds in high humidity environments (Perez and Soderholm, 1991).

#### \* **Ototoxicant**

The designation “OTO” for hearing disorders in the “Notations” column highlights the potential for a chemical to cause hearing impairment alone or in combination with noise, even below 85 dBA. The OTO notation is reserved for chemicals that have been shown, through evidence from animals or humans, to adversely affect anatomical structure or auditory function, manifested as a permanent audiometric threshold shift and/or difficulties in processing sounds. Some substances appear to act synergistically with noise, whereas others may potentiate noise effects. The OTO notation is intended to focus attention, not only on engineering controls, administrative controls and PPE needed to reduce airborne concentrations, but also on other means of preventing excessive combined exposures with noise to prevent hearing disorders. Specifically, affected employees may need to be enrolled in hearing conservation and medical surveillance programs to more closely monitor auditory capacity, even when noise exposures do not exceed the TLV® for Audible Sound. Please refer to the section on Ototoxicity in the TLV® *Documentation for Audible Sound*.

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#### **Sensitization**

The designations, “DSEN” and/or “RSEN”, in the “Notations” column in the *TLVs® and BEIs®* book refer to the potential for an agent to produce dermal and/or respiratory sensitization. RSEN and DSEN are used in place of the SEN notation when specific evidence of sensitization by that route is confirmed by human or animal data. The DSEN and RSEN notations do not imply that sensitization is the critical effect on which the TLV® is based, nor do they imply that this effect is the sole basis for that agent's TLV®. If sensitization data exist, they are carefully considered when recommending the TLV® for the agent.

TLVs<sup>®</sup> that are based upon sensitization are meant to protect workers from induction of this effect. These TLVs<sup>®</sup> are not intended to protect those workers who have already become sensitized.

In the workplace, respiratory or dermal exposures to sensitizing agents may occur. Similarly, sensitizers may evoke respiratory or dermal reactions. The notation does not distinguish between sensitization involving any of these tissues. The absence of a DSEN or RSEN notation does not signify that the agent lacks the ability to produce sensitization but may reflect the paucity or inconclusiveness of scientific evidence.

Sensitization often occurs via an immunologic mechanism and should not be confused with hyperreactivity, susceptibility, or sensitivity. Initially, there may be little or no response to a sensitizing agent. However, after a person is sensitized, subsequent exposure may cause intense responses, even at low exposure concentrations (well below the TLV<sup>®</sup>). These reactions may be life-threatening and may have an immediate or delayed onset. Workers who have become sensitized to a particular agent may also exhibit cross-reactivity to other agents that have similar chemical structures. A reduction in exposure to the sensitizer and its structural analogs generally reduces the frequency or severity of reactions among sensitized individuals. For some sensitized individuals, complete avoidance of exposure to the sensitizer and structural analogs provides the only means to prevent the specific immune response.

Agents that are potent sensitizers present special problems in the workplace. Respiratory and dermal exposures should be significantly reduced or eliminated through process control measures and personal protective equipment. Education and training (e.g., review of potential health effects, safe handling procedures, emergency information) are also necessary for those who work with known sensitizing agents.

For additional information regarding the sensitization potential of a particular agent, refer to the TLV<sup>®</sup> *Documentation* for the specific agent.

### **Skin**

The designation “Skin” in the “Notations” column refers to the potential significant contribution to the overall exposure by the cutaneous route, including mucous membranes and the eyes, by contact with vapors, liquids, and solids. Where dermal application studies have shown absorption that could cause systemic effects following exposure, a Skin notation would be considered. The Skin notation also alerts the industrial hygienist that overexposure may occur following dermal contact with liquid and aerosols, even when airborne exposures are at or below the TLV<sup>®</sup>.

A Skin notation is not applied to chemicals that may cause dermal irritation. However, it may accompany a sensitizer notation for substances that cause respiratory sensitization following dermal exposure. Although not considered when assigning a Skin notation, the industrial hygienist should be aware that there are several factors that may significantly enhance potential skin absorption of a substance that otherwise has low potential for the cutaneous route of entry. Certain vehicles can act as carriers, and when pretreated on the skin or mixed with a substance can promote the transfer of the substance into the skin. In addition, the existence of some dermatologic conditions

A vertical black rectangular box containing the text "TLV-OS" in white, oriented vertically from bottom to top.

can also significantly affect the entry of substances through the skin or wound.

While relatively limited quantitative data currently exist with regard to skin absorption of gases, vapors, and liquids by workers, ACGIH® recommends that the integration of data from acute dermal studies and repeated-dose dermal studies in animals and humans, along with the ability of the chemical to be absorbed, be used in deciding on the appropriateness of the Skin notation. In general, available data which suggest that the potential for absorption via the hands and forearms during the workday could be significant, especially for chemicals with lower TLVs®, could justify a Skin notation. From acute animal toxicity data, materials having a relatively low dermal LD<sub>50</sub> (i.e., 1000 mg/kg of body weight or less) would be given a Skin notation. When chemicals penetrate the skin easily (i.e., higher octanol–water partition coefficients) and where extrapolations of systemic effects from other routes of exposure suggest dermal absorption may be important in the expressed toxicity, a Skin notation would be considered. A Skin notation is not applied to chemicals that cause irritation or corrosive effects in the absence of systemic toxicity.

Substances having a Skin notation and a low TLV® may present special problems for operations involving high airborne concentrations of the material, particularly under conditions where significant areas of the skin are exposed for a long period. Under these conditions, special precautions to significantly reduce or preclude skin contact may be required.

Biological monitoring should be considered to determine the relative contribution to the total dose from exposure via the dermal route. ACGIH® recommends a number of adopted Biological Exposure Indices (BEIs®) that provide an additional tool when assessing the total worker exposure to selected materials. For additional information, refer to *Dermal Absorption* in the “Introduction to the Biological Exposure Indices,” *Documentation of the Biological Exposure Indices* (2001), and to Leung and Paustenbach (1994). Other selected readings on skin absorption and the skin notation include Sartorelli (2000), Schneider et al. (2000), Wester and Maibach (2000), Kennedy et al. (1993), Fiserova-Bergerova et al. (1990), and Scansetti et al. (1988).

The use of a Skin notation is intended to alert the reader that air sampling alone is insufficient to quantify exposure accurately and that measures to prevent significant cutaneous absorption may be required.

## References and Selected Reading

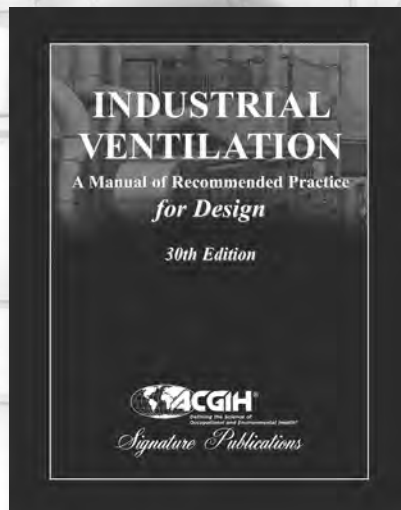
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**All pertinent notes relating to the material in the Chemical Substances section of this book appear in the appendices for this section or on the inside back cover.**

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## ADOPTED APPENDICES

### APPENDIX A: Carcinogenicity

TLV®  
CS

ACGIH® has been aware of the increasing public concern over chemicals or industrial processes that cause or contribute to increased risk of cancer in workers. More sophisticated methods of bioassay, as well as the use of sophisticated mathematical models that extrapolate the levels of risk among workers, have led to differing interpretations as to which chemicals or processes should be categorized as human carcinogens and what the maximum exposure levels should be. The categories for carcinogenicity are:

- A1 — *Confirmed Human Carcinogen*: The agent is carcinogenic to humans based on the weight of evidence from epidemiologic studies.
- A2 — *Suspected Human Carcinogen*: Human data are accepted as adequate in quality but are conflicting or insufficient to classify the agent as a confirmed human carcinogen; OR, the agent is carcinogenic in experimental animals at dose(s), by route(s) of exposure, at site(s), of histologic type(s), or by mechanism(s) considered relevant to worker exposure. The A2 is used primarily when there is limited evidence of carcinogenicity in humans and sufficient evidence of carcinogenicity in experimental animals with relevance to humans.
- A3 — *Confirmed Animal Carcinogen with Unknown Relevance to Humans*: The agent is carcinogenic in experimental animals at a relatively high dose, by route(s) of administration, at site(s), of histologic type(s), or by mechanism(s) that may not be relevant to worker exposure. Available epidemiologic studies do not confirm an increased risk of cancer in exposed humans. Available evidence does not suggest that the agent is likely to cause cancer in humans except under uncommon or unlikely routes or levels of exposure.
- A4 — *Not Classifiable as a Human Carcinogen*: Agents which cause concern that they could be carcinogenic for humans but which cannot be assessed conclusively because of a lack of data. *In vitro* or animal studies do not provide indications of carcinogenicity which are sufficient to classify the agent into one of the other categories.
- A5 — *Not Suspected as a Human Carcinogen*: The agent is not suspected to be a human carcinogen on the basis of properly conducted epidemiologic studies in humans. These studies have sufficiently long follow-up, reliable exposure histories, sufficiently high dose, and adequate statistical power to conclude that exposure to the agent does not convey a significant risk of cancer to humans; OR, the evidence suggesting a lack of carcinogenicity in experimental animals is supported by mechanistic data.

Substances for which no human or experimental animal carcinogenic data have been reported are assigned no carcinogenicity designation.

Exposures to carcinogens must be kept to a minimum. Workers exposed to A1 carcinogens without a TLV® should be properly equipped to eliminate to the fullest extent possible all exposure to the carcinogen. For A1 carcinogens with a TLV® and for A2 and A3 carcinogens, worker exposure by all routes should be carefully controlled to levels as low as possible below the TLV®.

Refer to the “Guidelines for the Classification of Occupational Carcinogenicity” in the Introduction to the Chemical Substances in the *Documentation of the Threshold Limit Values and Biological Exposure Indices* for a complete description and derivation of these designations.

## **APPENDIX B: Particles (insoluble or poorly soluble) Not Otherwise Specified (PNOS)**

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The goal of the TLV<sup>®</sup>-CS Committee is to recommend TLVs<sup>®</sup> for all substances for which there is evidence of health effects at airborne concentrations encountered in the workplace. When a sufficient body of evidence exists for a particular substance, a TLV<sup>®</sup> is established. Thus, by definition the substances covered by this recommendation are those for which little data exist. The recommendation at the end of this Appendix is supplied as a guideline rather than a TLV<sup>®</sup> because it is not possible to meet the standard level of evidence used to assign a TLV<sup>®</sup>. In addition, the PNOS TLV<sup>®</sup> and its predecessors have been misused in the past and applied to any unlisted particles rather than those meeting the criteria listed below. The recommendations in this Appendix apply to particles that:

- Do not have an applicable TLV<sup>®</sup>;
- Are insoluble or poorly soluble in water (or, preferably, in aqueous lung fluid if data are available); and
- Have low toxicity (i.e., are not cytotoxic, genotoxic, or otherwise chemically reactive with lung tissue, and do not emit ionizing radiation, cause immune sensitization, or cause toxic effects other than by inflammation or the mechanism of “lung overload”).

ACGIH<sup>®</sup> believes that even biologically inert, insoluble, or poorly soluble particles may have adverse effects and recommends that airborne concentrations should be kept below 3 mg/m<sup>3</sup>, respirable particles, and 10 mg/m<sup>3</sup>, inhalable particles, until such time as a TLV<sup>®</sup> is set for a particular substance.

## **APPENDIX C: Particle Size-Selective Sampling Criteria for Airborne Particulate Matter**

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For chemical substances present in inhaled air as suspensions of solid particles or droplets, the potential hazard depends on particle size as well as mass concentration because of 1) effects of particle size on the deposition site within the respiratory tract and 2) the tendency for many occupational diseases to be associated with material deposited in particular regions of the respiratory tract.

ACGIH<sup>®</sup> has recommended particle size-selective TLVs<sup>®</sup> for crystalline silica for many years in recognition of the well-established association between silicosis and respirable mass concentrations. The TLV<sup>®</sup>-CS Committee is now re-examining other chemical substances encountered in particle form in occu-



pational environments with the objective of defining: 1) the size-fraction most closely associated for each substance with the health effect of concern and 2) the mass concentration within that size fraction which should represent the TLV®.

The Particle Size-Selective TLVs® (PSS-TLVs) are expressed in three forms:

1. *Inhalable Particulate Matter TLVs®* (IPM-TLVs) for those materials that are hazardous when deposited anywhere in the respiratory tract.
2. *Thoracic Particulate Matter TLVs®* (TPM-TLVs) for those materials that are hazardous when deposited anywhere within the lung airways and the gas-exchange region.
3. *Respirable Particulate Matter TLVs®* (RPM-TLVs) for those materials that are hazardous when deposited in the gas-exchange region.

The three particulate matter fractions described above are defined in quantitative terms in accordance with the following equations (ACGIH®, 1985, 1999; Soderholm, 1989):

- A. IPM fraction consists of those particles that are captured according to the following collection efficiency regardless of sampler orientation with respect to wind direction:

$$\text{IPM}(d_{ae}) = 0.5 [1 + \exp(-0.06 d_{ae})]$$

for  $0 < d_{ae} \leq 100 \mu\text{m}$

where: IPM ( $d_{ae}$ ) = the collection efficiency  
 $d_{ae}$  = aerodynamic diameter of particle in  $\mu\text{m}$

- B. TPM fraction consists of those particles that are captured according to the following collection efficiency:

$$\text{TPM}(d_{ae}) = \text{IPM}(d_{ae}) [1 - F(x)]$$

where: F(x) = cumulative probability function of the standardized normal variable, x

$$x = \frac{\ln(d_{ae}/\Gamma)}{\ln(\Sigma)}$$

ln = natural logarithm  
 $\Gamma = 11.64 \mu\text{m}$   
 $\Sigma = 1.5$

- C. RPM fraction consists of those particles that are captured according to the following collection efficiency:

$$\text{RPM}(d_{ae}) = \text{IPM}(d_{ae}) [1 - F(x)]$$

where F(x) = same as above, but with  $\Gamma = 4.25 \mu\text{m}$  and  $\Sigma = 1.5$

The most significant difference from previous definitions is the increase in the median cut point for a respirable particulate matter sampler from  $3.5 \mu\text{m}$  to  $4.0 \mu\text{m}$ ; this is in accord with the International Organization for Standardization/ European Standardization Committee (ISO/CEN) protocol (ISO, 1995; CEN,

1993). At this time, no change is recommended for the measurement of respirable particles using a 10-mm nylon cyclone at a flow rate of 1.7 liters per minute. Two analyses of available data indicate that the flow rate of 1.7 liters per minute allows the 10-mm nylon cyclone to approximate the particulate matter concentration which would be measured by an ideal respirable particulate sampler as defined herein (Bartley, 1991; Lidén and Kenny, 1993).

Collection efficiencies representative of several sizes of particles in each of the respective mass fractions are shown in Tables 1, 2, and 3. *Documentation* for the respective algorithms representative of the three mass fractions is found in the literature (ACGIH®, 1999; ISO, 1995).

**TABLE 1. Inhalable Fraction**

<b>Particle Aerodynamic Diameter (<math>\mu\text{m}</math>)</b>	<b>Inhalable Particulate Matter (IPM) Fraction Collected (%)</b>
0	100
1	97
2	94
5	87
10	77
20	65
30	58
40	54.5
50	52.5
100	50

**TABLE 2. Thoracic Fraction**

<b>Particle Aerodynamic Diameter (<math>\mu\text{m}</math>)</b>	<b>Thoracic Particulate Matter (TPM) Fraction Collected (%)</b>
0	100
2	94
4	89
6	80.5
8	67
10	50
12	35
14	23
16	15
18	9.5
20	6
25	2

**TABLE 3. Respirable Fraction**

Particle Aerodynamic Diameter (µm)	Respirable Particulate Matter (RPM) Fraction Collected (%)
0	100
1	97
2	91
3	74
4	50
5	30
6	17
7	9
8	5
10	1



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**APPENDIX D: Commercially Important Tree Species  
Suspected of Inducing Sensitization**

Common	Latin
<b>SOFTWOODS</b>	
California redwood	<i>Sequoia sempervirens</i>
Eastern white cedar	<i>Thuja occidentalis</i>
Pine	<i>Pinus</i>
Western red cedar	<i>Thuja plicata</i>
<b>HARDWOODS</b>	
Ash	<i>Fraxinus spp.</i>
Aspen/Poplar/Cottonwood	<i>Populus</i>
Beech	<i>Fagus</i>
Oak	<i>Quercus</i>

Common	Latin
TROPICAL WOODS	
Abirucana	<i>Pouteria</i>
African zebra	<i>Microberlinia</i>
Antiaris	<i>Antiaris africana, Antiaris toxicara</i>
Cabreuva	<i>Myrocarpus fastigiatus</i>
Cedar of Lebanon	<i>Cedra libani</i>
Central American walnut	<i>Juglans olanchana</i>
Cocabolla	<i>Dalbergia retusa</i>
African ebony	<i>Diospyros crassiflora</i>
Fernam bouc	<i>Caesalpinia</i>
Honduras rosewood	<i>Dalbergia stevensonii</i>
Iroko or kambala	<i>Chlorophora excelsa</i>
Kejaat	<i>Pterocarpus angolensis</i>
Kotibe	<i>Nesorgordonia papaverifera</i>
Limba	<i>Terminalia superba</i>
Mahogany (African)	<i>Khaya spp.</i>
Makore	<i>Tieghemella heckelii</i>
Mansonia/Beté	<i>Mansonia altissima</i>
Nara	<i>Pterocarpus indicus</i>
Obeche/African maple/Samba	<i>Triplochiton scleroxylon</i>
Okume	<i>Aucoumea klaineana</i>
Palisander/Brazilian rosewood/ Tulip wood/Jakaranda	<i>Dalbergia nigra</i>
Pau marfim	<i>Balfourodendron riedelianum</i>
Ramin	<i>Gonystylus bancanus</i>
Soapbark dust	<i>Quillaja saponaria</i>
Spindle tree wood	<i>Euonymus europaeus</i>
Tanganyike aningre	

## APPENDIX E: Threshold Limit Values for Mixtures

Most threshold limit values are developed for a single chemical substance. However, the work environment is often composed of multiple chemical exposures both simultaneously and sequentially. It is recommended that multiple exposures that comprise such work environments be examined to assure that workers do not experience harmful effects.

There are several possible modes of chemical mixture interaction. Additivity occurs when the combined biological effect of the components is equal to the sum of each of the agents given alone. Synergy occurs where the combined effect is greater than the sum of each agent. Antagonism occurs when the combined effect is less.

The general ACGIH® mixture formula applies to the additive model. It is utilized when additional protection is needed to account for this combined effect.

**The guidance contained in this Appendix does not  
apply to substances in mixed phases.**

## Application of the Additive Mixture Formula

The “TLV® Basis” column found in the table of Adopted Values lists the adverse effect(s) upon which the TLV® is based. This column is a resource that may help alert the reader to the additive possibilities in a chemical mixture and the need to reduce the combined TLV® of the individual components. Note that the column does not list the deleterious effects of the agent, but rather, lists only the adverse effect(s) upon which the threshold limit was based. The current *Documentation of the TLVs® and BEIs®* should be consulted for toxic effects information, which may be of use when assessing mixture exposures.

When two or more hazardous substances have a similar toxicological effect on the same target organ or system, their combined effect, rather than that of either individually, should be given primary consideration. In the absence of information to the contrary, different substances should be considered as additive where the health effect and target organ or system is the same.

That is, if the sum of

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \dots + \frac{C_n}{T_n}$$

exceeds unity, the threshold limit of the mixture should be considered as being exceeded (where  $C_1$  indicates the observed atmospheric concentration and  $T_1$  is the corresponding threshold limit; see example). It is essential that the atmosphere is analyzed both qualitatively and quantitatively for each component present in order to evaluate the threshold limit of the mixture.

The additive formula applies to simultaneous exposure for hazardous agents with TWA, STEL, and Ceiling values. The threshold limit value time interval base (TWA, STEL, and Ceiling) should be consistent where possible. When agents with the same toxicological effect do not have a corresponding TLV® type, use of mixed threshold limit value types may be warranted. Table E-1 lists possible combinations of threshold limits for the additive mixture formula. Multiple calculations may be necessary.

Where a substance with a STEL or Ceiling limit is mixed with a substance with a TLV–TWA but no STEL, comparison of the short-term limit with the applicable peak exposure may be appropriate. The maximum peak exposure is defined as a value five times the TLV–TWA limit. The amended formula would be:

**TABLE E-1. Possible Combinations of Threshold Limits When Applying the Additive Mixture Formula**

Full Shift or Short Term	Agent A	Agent B
Full Shift	TLV–TWA	TLV–TWA
Full Shift	TLV–TWA	TLV–Ceiling
Short Term	TLV–STEL	TLV–STEL
Short Term	TLV–Ceiling	TLV–Ceiling
Short Term	Peak exposure where there is no STEL (5 times TLV–TWA value)	TLV–Ceiling or TLV–STEL
Short Term	TLV–STEL	TLV–Ceiling



$$\frac{C_1}{T_{1\text{STEL}}} + \frac{C_2}{(T_2)(5)} \leq 1$$

where:  $T_{1\text{STEL}}$  = the TLV–STEL  
 $T_2$  = the TLV–TWA of the agent with no STEL.

The additive model also applies to consecutive exposures of agents that occur during a single workshift. Those substances that have TLV–TWAs (and STELs or peak exposure limits) should generally be handled the same as if they were the same substance, including attention to the recovery periods for STELs and peak exposure limits as indicated in the “Introduction to Chemical Substances.” The formula does not apply to consecutive exposures of TLV–Ceilings.

### Limitations and Special Cases

Exceptions to the above rule may be made when there is a good reason to believe that the chief effects of the different harmful agents are not additive. This can occur when neither the toxicological effect is similar nor the target organ is the same for the components. This can also occur when the mixture interaction causes inhibition of the toxic effect. In such cases, the threshold limit ordinarily is exceeded only when at least one member of the series ( $C_1/T_1$  or  $C_2/T_2$ , etc.) itself has a value exceeding unity.

Another exception occurs when mixtures are suspected to have a synergistic effect. The use of the general additive formula may not provide sufficient protection. Such cases at present must be determined individually. Potentiating effects of exposure to such agents by routes other than that of inhalation are also possible. Potentiation is characteristically exhibited at high concentrations, less probably at low. For situations involving synergistic effects, it may be possible to use a modified additive formula that provides additional protection by incorporating a synergy factor. Such treatment of the TLVs® should be used with caution, as the quantitative information concerning synergistic effects is sparse.

Care must be considered for mixtures containing carcinogens in categories A1, A2, or A3. Regardless of application of the mixture formula, exposure to mixtures containing carcinogens should be avoided or maintained as low as possible. See Appendix A.

The additive formula applies to mixtures with a reasonable number of agents. It is not applicable to complex mixtures with many components (e.g., gasoline, diesel exhaust, thermal decomposition products, fly ash, etc.).

### Example

A worker’s airborne exposure to solvents was monitored for a full shift as well as one short-term exposure. The results are presented in Table E-2.



**TABLE E-2. Example Results**

Agent	Full-Shift Results (TLV-TWA)	Short-Term Results (TLV-STEL)
1) Acetone	80 ppm (250 ppm)	325 ppm (500 ppm)
2) Cyclohexanone	2 ppm (20 ppm)	7.5 ppm (50 ppm)
3) Methyl ethyl ketone	90 ppm (200 ppm)	220 ppm (300 ppm)

TLV®-CS

According to the *Documentation of the TLVs® and BEIs®*, all three substances indicate irritation effects on the respiratory system and thus would be considered additive. Acetone and methyl ethyl ketone exhibit central nervous system effects.

Full-shift analysis would utilize the formula:

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} \leq 1$$

thus,

$$\frac{80}{250} + \frac{2}{20} + \frac{90}{200} = 0.32 + 0.10 + 0.45 = 0.87$$

The full-shift mixture limit is not exceeded.

Short-term analysis would utilize the formula:

$$\frac{C_1}{T_{1\text{STEL}}} + \frac{C_2}{T_{2\text{STEL}}} + \frac{C_3}{T_{3\text{STEL}}} \leq 1$$

thus,

$$\frac{325}{500} + \frac{7.5}{50} + \frac{220}{300} = 0.65 + 0.15 + 0.73 = 1.53$$

The short-term mixture limit is exceeded.

## APPENDIX F: Minimal Oxygen Content

Adequate oxygen delivery to the tissues is necessary for sustaining life and depends on 1) the level of oxygen in inspired air, 2) the presence or absence of lung disease, 3) the level of hemoglobin in the blood, 4) the kinetics of oxygen binding to hemoglobin (oxy-hemoglobin dissociation curve), 5) the cardiac output, and 6) local tissue blood flow. For the purpose of the present discussion, only the effects of decreasing the amount of oxygen in inspired air are considered.

The brain and myocardium are the most sensitive tissues to oxygen deficiency. The initial symptoms of oxygen deficiency are increased ventilation, increased cardiac output, and fatigue. Other symptoms that may develop

include headache, impaired attention and thought processes, decreased coordination, impaired vision, nausea, unconsciousness, seizures, and death. However, there may be no apparent symptoms prior to unconsciousness. The onset and severity of symptoms depend on many factors such as the magnitude of the oxygen deficiency, duration of exposure, work rate, breathing rate, temperature, health status, age, and pulmonary acclimatization. The initial symptoms of increased breathing and increased heart rate become evident when hemoglobin oxygen saturation is reduced below 90%. At hemoglobin oxygen saturations between 80% and 90%, physiological adjustments occur in healthy adults to resist hypoxia, but in compromised individuals, such as emphysema patients, oxygen therapy would be prescribed for hemoglobin oxygen saturations below 90%. As long as the partial pressure of oxygen ( $pO_2$ ) in pulmonary capillaries stays above 60 torr, hemoglobin will be more than 90% saturated and normal levels of oxygen transport will be maintained in healthy adults. The alveolar  $pO_2$  level of 60 torr corresponds to 120 torr  $pO_2$  in the ambient air, due to anatomic dead space, carbon dioxide, and water vapor. For additional information on gas exchange and pulmonary physiology see Silverthorn (2001) and Guyton (1991).

The U.S. National Institute for Occupational Safety and Health (1976) used 60 torr alveolar  $pO_2$  as the physiological limit that establishes an oxygen-deficient atmosphere and has defined an oxygen-deficient atmosphere as one with an ambient  $pO_2$  less than 132 torr (NIOSH, 1979). The minimum requirement of 19.5% oxygen at sea level (148 torr  $pO_2$ , dry air) provides an adequate amount of oxygen for most work assignments and includes a margin of safety (NIOSH, 1987). However, the margin of safety significantly diminishes as the  $O_2$  partial pressure of the atmosphere decreases with increasing altitude, decreases with the passage of low pressure weather events, and decreases with increasing water vapor (McManus, 1999), such that, at 5000 feet, the  $pO_2$  of the atmosphere may approach 120 torr because of water vapor and the passage of fronts and at elevations greater than 8000 feet, the  $pO_2$  of the atmosphere may be expected to be less than 120 torr.

The physiological effects of oxygen deficiency and oxygen partial pressure variation with altitude for dry air containing 20.948% oxygen are given in Table F-1. No physiological effects due to oxygen deficiency are expected in healthy adults at oxygen partial pressures greater than 132 torr or at elevations less than 5000 feet. Some loss of dark adaptation is reported to occur at elevations greater than 5000 feet. At oxygen partial pressures less than 120 torr (equivalent to an elevation of about 7000 feet or about 5000 feet accounting for water vapor and the passage of low pressure weather events) symptoms in unacclimatized workers include increased pulmonary ventilation and cardiac output, incoordination, and impaired attention and thinking. These symptoms are recognized as being incompatible with safe performance of duties.

Accordingly, ACGIH® recommends a minimal ambient oxygen partial pressure of 132 torr, which is protective against inert oxygen-displacing gases and oxygen-consuming processes for altitudes up to 5000 feet. Figure F-1 is a plot of  $pO_2$  with increasing altitude, showing the recommended minimal value of 132 torr. If the partial pressure of oxygen is less than 132 torr or if it is less than the expected value for that altitude, given in Table F-1, then additional work practices are recommended such as thorough evaluation of the confined space to identify the cause of the low oxygen concentration; use of continuous monitors integrated with warning devices; acclimating workers to the altitude of

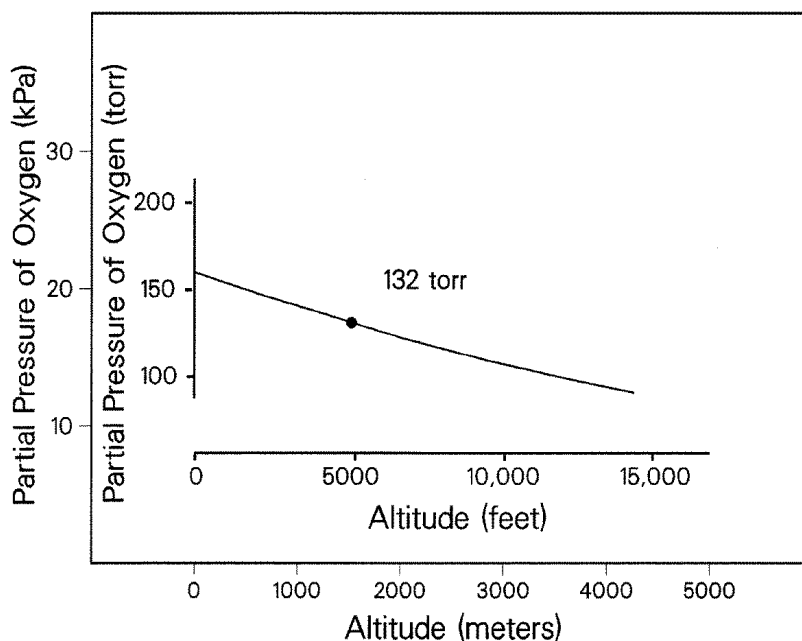


the work, as adaptation to altitude can increase an individual's work capacity by 70%; use of rest-work cycles with reduced work rates and increased rest periods; training, observation, and monitoring of workers; and easy, rapid access to oxygen-supplying respirators that are properly maintained.

Oxygen-displacing gases may have flammable properties or may produce physiological effects, so that their identity and source should be thoroughly investigated. Some gases and vapors, when present in high concentrations in air, act primarily as simple asphyxiants without other significant physiologic effects. A TLV® may not be recommended for each simple asphyxiant because the limiting factor is the available oxygen. Atmospheres deficient in O<sub>2</sub> do not provide adequate warning and most simple asphyxiants are odorless. Account should be taken of this factor in limiting the concentration of the asphyxiant particularly at elevations greater than 5000 feet where the  $\rho_{O_2}$  of the atmosphere may be less than 120 torr.

**References**

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**FIGURE F-1.** Plot of oxygen partial pressure ( $\rho_{O_2}$ ) (expressed in torr and kPa) with increasing altitude (expressed in feet and meters), showing the recommended oxygen partial pressure of 132 torr.

**TABLE F-1. Barometric Pressure, Oxygen Partial Pressure, and Percent Oxygen Concentration Variation with Altitude and Physiological Effect (adapted from McManus, 1999)**

Altitude Feet (meters)	Barometric Pressure torr, Dry Air <sup>A</sup> (kilopascals)	$\rho\text{O}_2$ Equivalent, torr Dry Air at 20.948% $\text{O}_2$ <sup>B</sup> (kilopascals)	% $\text{O}_2$ Equivalent, Dry Air at Sea Level <sup>C</sup> (percent)	Physiological Effect of $\rho\text{O}_2$ Levels <sup>D</sup>
0 (0)	760 (101)	159 (21.2)	20.9	
1000 (305)	731 (97.4)	153 (20.4)	20.1	
2000 (610)	704 (93.8)	147 (19.6)	19.3	
3000 (914)	677 (90.3)	142 (18.9)	18.7	
4000 (1219)	652 (86.9)	137 (18.3)	18.0	
5000 (1524)	627 (83.6)	131 (17.5)	17.2	None in healthy adults
6000 (1829)	603 (80.4)	126 (16.8)	16.6	Loss of dark adaptation can occur at elevations above 5000 feet
7000 (2134)	580 (77.3)	121 (16.1)	16.0	Increased pulmonary ventilation and cardiac output, incoordination, and impaired attention and thinking

8000 (2438)	559 (74.5)	117 (15.6)	15.4	Rapid exposure to altitudes over 8000 feet may cause high altitude sickness (respiratory alkalosis, headache, nausea, and vomiting) in unacclimatized individuals. Rapid ascent increases the risk of high altitude pulmonary edema and cerebral edema
9000 (2743)	537 (71.6)	112 (14.9)	14.7	
10000 (3048)	517 (68.9)	108 (14.4)	14.2	
11000 (3353)	498 (66.4)	104 (13.9)	13.7	Abnormal fatigue on exertion, faulty coordination, impaired judgment, emotional upset
12000 (3658)	479 (63.8)	100 (13.3)	13.2	
13000 (3962)	461 (61.5)	98 (12.9)	12.8	
14000 (4267)	443 (59.1)	93 (12.4)	12.2	Impaired respiration, very poor judgment and coordination, tunnel vision

<sup>A</sup>Calculated from  $P_{re: \text{sea level}} = 760 \times e^{-(\text{altitude in feet}/25970)}$

<sup>B</sup>Calculated from  $\rho O_2 = 0.20948 \times 760 \times e^{-(\text{altitude in feet}/25970)}$

<sup>C</sup>Calculated from:  $P_{\%O_2} = 20.948 \times e^{-(\text{altitude in feet}/25970)}$

<sup>D</sup>The approximate physiological effect in healthy adults is influenced by duration of the oxygen deficiency, work rate, breathing rate, temperature, health status, age and pulmonary acclimatization.

## APPENDIX G: Substances Whose Adopted *Documentation* and TLVs® Were Withdrawn For a Variety of Reasons, Including Insufficient Data, Regrouping, Etc.

[Individual entries will remain for a 10-year period, commencing with the year of withdrawal]

Substance [CRN]	Year Withdrawn	Reason
Acetylene [74-86-2]	2015	See Appendix F: Minimal Oxygen Content
Aliphatic hydrocarbon gases, Alkanes [C <sub>1</sub> -C <sub>4</sub> ]	2013	Methane, Ethane, Propane, Liquefied petroleum gas (LPG) and Natural gas — see Appendix F: Minimal Oxygen Content. Butane and Isobutane — see Butane, all isomers
Argon [7440-37-1]	2014	See Appendix F: Minimal Oxygen Content
n-Butyl acetate [123-86-4]	2016	See Butyl acetates, all isomers
sec-Butyl acetate [105-46-4]	2016	See Butyl acetates, all isomers
tert-Butyl acetate [540-88-5]	2016	See Butyl acetates, all isomers
Calcium chromate [13765-19-0], as Cr	2018	See Chromium and inorganic compounds
Calcium silicate, synthetic nonfibrous [1344-95-2]	2016	Insufficient data
Chromite ore processing (Chromate), as Cr	2018	See Chromium and inorganic compounds
Chromyl chloride [14977-61-8]	2018	See Chromium and inorganic compounds
Cyclopentadiene [542-92-7]	2019	See Dicyclopentadiene, including Cyclopentadiene
Ethyl cyanoacrylate [7085-85-0]	2018	See Cyanoacrylates, Ethyl and Methyl
Glycerin mist [56-81-5]	2013	Insufficient data relevant to human occupational exposure

**APPENDIX G: Substances Whose Adopted *Documentation* and TLVs® Were Withdrawn For a Variety of Reasons, Including Insufficient Data, Regrouping, Etc.**

**[Individual entries will remain for a 10-year period, commencing with the year of withdrawal] (cont.)**

Substance [CRN]	Year Withdrawn	Reason
Helium [7440-59-7]	2014	See Appendix F: Minimal Oxygen Content
Hydrogen [1333-74-0]	2014	See Appendix F: Minimal Oxygen Content
Isobutyl acetate [110-19-0]	2016	See Butyl acetates, all isomers
Isopropyl acetate [108-21-4]	2018	See Propyl acetate isomers
Methyl 2-cyanoacrylate [137-05-3]	2018	See Cyanoacrylates, Ethyl and Methyl
Neon [7440-01-9]	2014	See Appendix F: Minimal Oxygen Content
Nitrogen [7727-37-9]	2014	See Appendix F: Minimal Oxygen Content
Nonane [111-84-2], all isomers	2012	See Nonane
Oil mist, mineral	2010	See Mineral oil, excluding metal working fluids
Piperazine dihydrochloride [142-64-3]	2012	See Piperazine and salts
n-Propyl acetate [109-60-4]	2018	See Propyl acetate isomers
Soapstone	2011	See Talc
Strontium chromate [7789-06-2], as Cr	2018	See Chromium and inorganic compounds

TLV®

**APPENDIX G: Substances Whose Adopted *Documentation* and TLVs® Were Withdrawn For a Variety of Reasons, Including Insufficient Data, Regrouping, Etc.****[Individual entries will remain for a 10-year period, commencing with the year of withdrawal] (cont.)**

<b>Substance [CRN]</b>	<b>Year Withdrawn</b>	<b>Reason</b>
Tantalum [7440-25-7] and Tantalum oxide [1314-61-0] dusts, as Ta	2010	Insufficient data
Zinc chromates [11103-86-9; 13530-65-9; 37300-23-5], as Cr	2018	See Chromium and inorganic compounds



## APPENDIX H: Reciprocal Calculation Method for Certain Refined Hydrocarbon Solvent Vapor Mixtures

TLV®-CS

The reciprocal calculation procedure (RCP) is a method for deriving occupational exposure limits (OELs) for certain refined hydrocarbon solvents based on their bulk composition. Refined hydrocarbon solvents often are found as mixtures created by distillation of petroleum oil over a particular boiling range. These mixtures may consist of up to 200 components consisting of aliphatic (alkane), cycloaliphatic (cycloalkane) and aromatic hydrocarbons ranging from 5 to 15 carbons.

The goal of the TLV-CS Committee is to recommend TLVs® for all substances where there is evidence of health effects at airborne concentrations encountered in the workplace. When a sufficient body of evidence exists for a particular substance or mixture, a TLV® is established. However, hydrocarbon solvents are often complex and variable in composition. The use of the mixture formula, found in Appendix E: Threshold Limit Values for Mixtures, is difficult to apply in such cases because these petroleum mixtures contain a large number of unique compounds, many of which do not have a TLV® recommendation. The RCP does not replace TLVs® but rather calculates a guidance OEL (e.g.,  $GGV_{mixture}$ ) based on the composition of a specific complex mixture.

There are two aspects of the RCP — the methodology and the group guidance values (GGVs). The methodology is based on the special case formula found in pre-2004 versions of the Mixture Appendix in *TLVs® and BEIs® Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*. The RCP formula calculates a unique OEL based on the mass composition of the mixture, the GGVs and where applicable, substance-specific TLVs®.

Group guidance values are categorized based on similar chemical and toxicological concerns. Several entities (both trade groups and regulatory authorities) have adopted group guidance values to utilize with the reciprocal mixture formula (RMF) (Farmer, 1995; UKHSE, 2000; McKee et al., 2005). Two examples of published GGVs are found in Table 1. A mixture-specific time-weighted-average limit ( $GGV-TWA_{mixture}$ ) is calculated based on the mass percent makeup of the designated groups utilizing the reciprocal mixture formula and the GGVs from column B or C and TLV® values for the substances in column D found in Table 1.

ACGIH® considers this method to be applicable for mixtures if the toxic effects of individual constituents are additive (i.e., similar toxicological effect on the same target organ or system). The principal toxicological effects of hydrocarbon solvent constituents are acute central nervous system (CNS) depression (characterised by effects ranging from dizziness and drowsiness to anesthesia), eye, and respiratory tract irritation (McKee et al., 2005; ECETOC, 1997).

### Application

The RCP is a special use application. It applies only to hydrocarbon solvents containing saturated aliphatics (normal, iso-alkanes and cycloalkanes) and aromatics with a carbon number of C<sub>5</sub> to C<sub>15</sub> derived from petroleum and

boiled in the range of 35–329°C. It does not apply to petroleum-derived fuels, lubricating oils, or solvent mixtures for which there exists a unique TLV®. GGVs are not appropriate for compounds that do not have either CNS impairment or irritation effects.

Where the mixture is comprised entirely of compounds with unique TLVs®, the mixture should be handled according to Appendix E. When the mixture contains an appreciable amount of a component for which there is a TLV® and when the use of the TLV® results in a lower  $GGV_{mixture}$ , those specific values should be entered into the RCP (see column *D*, Table 1). When the mixture itself has been assigned a unique TLV®, that value should be utilized rather than the procedures found in this appendix.

Peak exposures above the calculated  $GGV-TWA_{mixture}$  should be handled according to the procedures found in the Introduction to the TLVs® (see *Peak Exposures*).

The reciprocal calculation mixture formula is:

$$GGV_{mixture} = \frac{1}{\frac{F_a}{GGV_a} + \dots + \frac{F_n}{GGV_n}}$$

where:

$GGV_{mixture}$  = the calculated 8-hour TWA–OEL for the mixture

$GGV_a$  = the guidance value (or TLV®) for group (or component) *a*

$F_a$  = the liquid mass fraction of group (or component) *a* in the hydrocarbon mixture (value between 0–1)

$GGV_n$  = the guidance value (or TLV®) for the *n*<sup>th</sup> group (or component)

$F_n$  = the liquid mass fraction of the *n*<sup>th</sup> group (or component) in the hydrocarbon mixture (value between 0–1)

The resulting  $GGV_{mixture}$  should identify the source of GGVs used in the calculation (i.e., column *B* or *C*).

The resulting calculated  $GGV_{mixture}$  value should follow established recommendations regarding rounding. For calculated values < 100 mg/m<sup>3</sup>, round to the nearest 25. For calculated values between 100 and 600 mg/m<sup>3</sup>, round to the nearest 50, and for calculated values > 600 mg/m<sup>3</sup>, round to the nearest 200 mg/m<sup>3</sup>.

### Limitations

1. The reciprocal formula requires that the composition of the mixture be characterized at least to the detail of mass percent of the groups/compounds found in Table 1.
2. Additional care should be utilized for solvent components that have unique toxicological properties and have individual TLVs® significantly less than the GGV to which they would belong. These are marked with an asterisk in Table 1 (e.g., n-hexane). Whenever present in the mixture, these components should be identified and sampled individually to assure exposures are below the TLV®.
3. Care in the use of GGV/RMF should be observed where the mixture in ques-

**TABLE 1. Group Guidance Values**

A	B	C	D
<b>Hydrocarbon Group</b>	<b>McKee et al., 2005 (mg/m<sup>3</sup>)</b>	<b>UK-HSE 40/2000 (mg/m<sup>3</sup>)</b>	<b>ACGIH<sup>®</sup> Unique TLVs<sup>®</sup> and compounds with differing or additional critical effects (<i>italics</i>)*</b>
C5–C6 Alkanes	1500	1800	Pentane, all isomers Hexane isomers <i>n-Hexane peripheral neuropathy*</i>
C7–C8 Alkanes	1500	1200	Heptane, all isomers Octane, all isomers
C5–C6 Cycloalkanes	1500	1800	Cyclopentane Cyclohexane
C7–C8 Cycloalkanes	1500	800	Methyl cyclohexane
C7–C8 Aromatics	200	500	Xylene, all isomers Ethyl benzene <i>Toluene visual impairment, reproductive*</i>
C9–C15 Alkanes	1200	1200	n-Nonane
C9–C15 Cycloalkanes	1200	800	
C9–C15 Aromatics	100	500	Trimethyl benzene, isomers Cumene <i>Naphthalene Hematologic effects*</i> <i>Methylnaphthalene lung damage*</i> <i>Indene liver damage*</i>

\* See limitation #2. These compounds have critical effects (TLV<sup>®</sup> basis) beyond those utilized for the RCP mixture. They are also typically significantly below the recommended GGv for their hydrocarbon group. Whenever present in the mixture in appreciable amounts, these components need to be identified and monitored individually to assure the individual TLV<sup>®</sup> is not exceeded.



tion is known to have significant toxicokinetic interactions of components that are manifested at or below GGV levels.

4. The use of the reciprocal formula should be restricted to applications where the boiling points of the solvents in the mixture are relatively narrow, within a range of less than 45°C (i.e., vapor pressure within approximately one order of magnitude). The procedure should not be used in situations where the liquid composition is significantly different from the vapor composition. If these conditions cannot be met, the reciprocal formula can be utilized by substituting  $F_{(n)}$  in the equation with the vapor mass fraction for each group ( $n$ ) in the hydrocarbon mixture, based on situation-specific airborne concentration measurements.
5. The group guidance values apply only to vapors and do not apply to mists or aerosols. The GGV/RMF procedure does not apply to mixtures containing olefins or other unsaturated compounds or carcinogenic polycyclic aromatic hydrocarbons (PAHs).
6. The GGV/RCP procedure does not apply to benzene. Benzene is not typically found in the liquid phase of refined hydrocarbon solvents above 0.01% v/v but in any case should be monitored separately to assure that airborne concentrations are not being exceeded (McKee et al., 2005; Hollins et al., 2013).

### Example

A solvent containing the following mass composition is matched with the appropriate group guidance value:

Component	Percent by weight	Group Guidance Value (mg/m <sup>3</sup> )
C7–C8 alkanes cycloalkanes	45%	1500
C9–C10 alkanes cycloalkanes	40%	1200
C7–C8 aromatics	9%	200
Toluene	6%	75

Based on Column B, Table 1 (McKee et al., 2005), the  $GGV_{\text{mixture}}$  would be:

$$GGV_{\text{mixture}} = \frac{1}{\frac{.45}{1500} + \frac{.40}{1200} + \frac{.09}{200} + \frac{.06}{75}} = \frac{1}{.001884} = 531 \text{ (rounded to 550 mg/m}^3\text{)}$$

Toluene (part of the aromatic C7, 8 fraction) is added as a TLV® rather than a GGV since it makes a difference in the resulting  $GGV_{\text{mixture}}$ .

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# 2019 Biological Exposure Indices

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BEIS®

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## INTRODUCTION TO THE BIOLOGICAL EXPOSURE INDICES

Biological monitoring provides an important means to assess exposure and health risk to workers. It entails measurement of a chemical determinant in the biological media of those exposed and is an indicator of the uptake of a substance. Biological Exposure Indices (BEIs<sup>®</sup>) are guidance values for evaluating biological monitoring results. BEIs<sup>®</sup> generally represent the levels of determinants that are most likely to be observed in specimens collected from healthy workers who have been exposed to chemicals to the same extent as workers with inhalation exposure at the Threshold Limit Value–Time Weighted Average (TLV–TWA). However, there are BEIs<sup>®</sup> for chemicals for which the TLVs<sup>®</sup> are based on protection against nonsystemic effects (e.g., irritation or respiratory impairment) where biological monitoring is desirable because of the potential for significant absorption via an additional route of entry (usually the skin). There are also BEIs<sup>®</sup> that better predict health effects than air levels and finally, BEIs<sup>®</sup> that are based on the levels in the environmentally exposed population. The BEI<sup>®</sup> generally indicates a concentration below which nearly all workers should not experience adverse health effects. The BEI<sup>®</sup> determinant can be the chemical itself; one or more metabolites; or a characteristic, reversible biochemical change induced by the chemical. The specimens used for BEIs<sup>®</sup> are urine, blood, or exhaled air. The BEIs<sup>®</sup> are not intended for use as a measure of adverse effects or for diagnosis of occupational illness.

Biological monitoring can assist the occupational health professional (occupational and industrial hygienists, occupational physicians and nurses, etc.) to determine absorption via the skin or gastrointestinal system, in addition to that by inhalation; assess body burden; reconstruct past exposure; detect nonoccupational exposures among workers; test the efficacy of personal protective equipment and engineering controls; and monitor work practices.

Biological monitoring serves as a complement to exposure assessment by air sampling and medical surveillance. The existence of a BEI<sup>®</sup> does not indicate a need to conduct biological monitoring. Conducting, designing, and interpreting biological monitoring protocols and the application of the BEI<sup>®</sup> require professional experience in occupational health and reference to the current edition of the *Documentation of the Threshold Limit Values and Biological Exposure Indices* (ACGIH<sup>®</sup>).

*Editor's note:* The approximate year that the current *Documentation* was last substantially reviewed and, where necessary, updated may be found following the CAS number for each of the adopted entries in the alphabetical listing, e.g., Acetone [67-64-1] (2014). The reader is advised to refer to the “BEI<sup>®</sup> Chronology” section in each *Documentation* for a brief history of the BEI<sup>®</sup> recommendations and notations.

### **Documentation**

It is essential that the user consult the specific BEI<sup>®</sup> *Documentation* before designing biological monitoring protocols and interpreting BEIs<sup>®</sup> for a specific agent. The *Documentation* for each compound contains the explicit information that is only discussed in general in this Introduction. In addition, each BEI<sup>®</sup> *Documentation* now provides a chronology that traces all BEI<sup>®</sup> recommended

actions for the chemical substance in question.

BEIs® are developed by Committee consensus through an analysis and evaluation process. The detailed scientific criteria and justification for each BEI® can be found in the *Documentation of the Threshold Limit Values and Biological Exposure Indices*. The principal material evaluated by the BEI® Committee includes peer-reviewed published data taken from the workplace (i.e., field studies), data from controlled exposure studies, and from appropriate toxicokinetic modeling when available. The results of animal research are also considered when relevant. The *Documentation* provides essential background information and the scientific reasoning used in establishing each BEI®. Information given includes the analytical methods, possible potential for confounding exposures, specimen collection recommendations, limitations, as well as other essential information, specific for each compound and analyte.

In recommending a BEI®, ACGIH® considers whether published data are of reasonable quality and may also consider unpublished data if a complete copy of the data/report is provided to ACGIH®. However, unpublished data are never used as the primary basis for a BEI®, although it may provide a secondary support. There are numerous instances when analytical techniques are available for the measurement of a biological determinant, but published information is unavailable or inadequate to determine a BEI®. The data needed to establish a BEI® include comprehensive assessment of total exposure and/or health effects. Therefore, occupational health professionals are encouraged to accumulate and report biological monitoring data together with exposure and health data.

### Relationship of BEIs® to TLVs®

BEI® determinants are an index of an individual's uptake of a chemical by all routes. In some cases they correspond to the TLV® as a "safe" level without reported health effects. In other cases they may reflect the highest 5% of levels seen in the general population. In addition, some BEIs® are without a numerical value and/or provide only qualitative estimates of exposure. These indices are useful to confirm that an exposure to a specific agent is occurring. The basis of each BEI® is provided in the *Documentation*. Air monitoring to determine the TLV® indicates the potential inhalation exposure of an individual or group. The internal dose for individuals within a workgroup may be different for a variety of reasons, some of which are indicated below:

- Exposure by routes other than inhalation, usually dermal, is often a major reason why there is less than perfect concordance between air sampling and biological monitoring. This is often the strongest argument for doing biological monitoring.
- Physiological makeup and health status of the worker, such as body build, diet (water and fat intake), metabolism, body fluid composition, age, gender, pregnancy, medication, and disease state.
- Occupational exposure factors, such as the work-rate intensity and duration, temperature and humidity, co-exposure to other chemicals, and other work factors.
- Nonoccupational exposure factors, such as community and home air pollution, water and food components, personal hygiene, smoking, alcohol and drug intake, exposure to household products, or exposure

- to chemicals from hobbies or from another workplace.
- Methodological factors, which include specimen contamination or deterioration during collection and storage and bias of the selected analytical method.
- Location of the air monitoring device in relation to the worker's breathing zone.
- Particle size distribution and bioavailability.
- Variable effectiveness of personal protective devices.

It is important that the reader consult the *Documentation* of the TLVs® and BEIs® to understand the importance of each of these factors for each particular agent.

## Specimen Collection

Because the concentration of some determinants can change rapidly, the specimen collection time (sampling time) is very important and must be observed and recorded carefully. The sampling time is specified in the BEI® and is determined by the duration of retention of the determinant, modified in some cases by practicality (for example, if the peak level is expected several hours after the end of a shift). Substances and determinants that accumulate may not require a specific sampling time. An explanation of the BEI® sampling time is as follows:

Sampling Time	Recommended Collection
1. Prior to shift	16 hours after exposure ceases, but before any exposure on sampling day
2. Prior to last shift	Prior to last shift of a workweek
3. Increase during shift	Requires pre- and post-shift sample collection
4. During shift	Anytime after two hours of exposure
5. End of shift	As soon as possible after exposure ceases
6. End of the workweek	After four or five consecutive working days with exposure
7. Discretionary/Not Critical	At any time*

\*These determinants have long half-lives and their levels may take weeks, months or years after a worker first begins their job to approach steady state and be comparable to the BEI®. Health professionals should note that if sequential samples taken early in a worker's exposure career show a marked increase, an overexposure situation might be developing and must be addressed despite the values being below the BEI®.

## Urine Specimen Acceptability

Urine specimens that are highly dilute or highly concentrated are generally not suitable for biomonitoring. The World Health Organization has adopted guidelines (without reference) for acceptable limits on urine specimens as follows:

Creatinine concentration: > 0.3 g/L and < 3.0 g/L  
or  
Specific gravity: > 1.010 and < 1.030

Specimens falling outside either of these ranges should be discarded and another specimen should be collected when possible.

Some BEIs<sup>®</sup> for determinants whose concentration is dependent on urine output are expressed relative to creatinine concentration. For other determinants such as those excreted by diffusion into the renal tubules, correction for urine output is not appropriate. In general, the best correction method is chemical-specific, but research data sufficient to identify the best method may not be available. When the field data are only available as adjusted for creatinine, the BEI<sup>®</sup> will continue to be expressed relative to creatinine; in other circumstances, no correction is recommended, and the BEI<sup>®</sup> will be expressed as concentration in urine (e.g., µg/L).

The logo consists of the letters "BEI" in a white, sans-serif font, with a registered trademark symbol (®) to the upper right, all contained within a solid black rectangular box.

## Notations

“**B**” = Background

The determinant may be present in biological specimens collected from subjects who have not been occupationally exposed, at a concentration that could affect interpretation of the result. A “**B**” notation is assigned to a determinant when the observed 95th percentile value of a random sample, from national population studies, such as the NHANES surveys, is more than 20% of the BEI<sup>®</sup>. When general population data are not available to make this assessment, the BEI<sup>®</sup> Committee may assign a “**B**” notation based on its interpretation of the available data in the scientific literature. In this case, the rationale for the notation is provided in the *Documentation* for the particular Index. Such background concentrations are incorporated in the BEI<sup>®</sup> value.

“**Nq**” = Nonquantitative

Biological monitoring should be considered for this compound based on the review; however, a specific BEI<sup>®</sup> could not be determined due to insufficient data.

“**Ns**” = Nonspecific

The determinant is nonspecific, since it is also observed after exposure to other chemicals.

“**Sq**” = Semi-quantitative

The biological determinant is an indicator of exposure to the chemical, but the quantitative interpretation of the measurement is ambiguous. These determinants should be used as a screening test if a quantitative test is not practical or as a confirmatory test if the quantitative test is not specific and the origin of the determinant is in question.

“**Pop**” = Population based

“**Pop**” indices are assigned when there are insufficient data to establish a numerical BEI<sup>®</sup> but where there are sufficient data on background levels in the general population. “**Pop**” values can be based on the 95th percentile of large studies of the general population, like the NHANES surveys by the CDC, or they can be based on nonoccupationally exposed populations from the scientific literature.

“**Pop**” values are not health-based and are intended to give the health professional guidance regarding exposures that are likely to be occupational and not from the general environment. A measurement at or above a “**Pop**” level will have a high probability of resulting from an occupational exposure.

### Quality Assurance

Each aspect of biological monitoring should be conducted within an effective quality assurance (QA) program. The appropriate specimen must be collected at the proper time, without contamination or loss, utilizing a suitable container. Donor identification, time of exposure, source of exposure, and the sampling time must be recorded. The analytical method used by the laboratory must have the accuracy, sensitivity, and specificity needed to produce results consistent with the BEI<sup>®</sup>. Appropriate quality control specimens should be included in the analysis, and the laboratory must follow routine quality control rules. Whenever possible, the laboratory should participate in an external proficiency program.

The occupational health professional may also provide known challenge samples to the laboratory along with worker specimens (e.g., blanks, purchased specimens containing the determinant, or split specimens). These challenges will enable the occupational health professional to assess the ability to process, analyze, and report results properly, and to have confidence in their ability to estimate exposure.

The most effective means for controlling laboratory quality is through an external QA/QC program.

### Application of BEIs<sup>®</sup>

BEIs<sup>®</sup> are intended as guidelines to be used in the evaluation of potential health hazards in the practice of occupational hygiene. BEIs<sup>®</sup> do not indicate a sharp distinction between hazardous and nonhazardous exposures. For example, it is possible for an individual's determinant concentration to exceed the BEI<sup>®</sup> without incurring an increased health risk. If measurements in specimens obtained from a worker on different occasions exceed the BEI<sup>®</sup>, the cause of the excessive value should be investigated and action taken to reduce the exposure. An investigation is also warranted if measurements in specimens obtained from a group of workers at the same workplace and work-shift exceed the BEI<sup>®</sup>. It is desirable that relevant information on related operations in the workplace be recorded.

Due to the variable nature of concentrations in biological specimens, administrative action should not be normally based on a single result, but on measurements of multiple samplings, or an analysis of a repeat specimen.

However, it may be appropriate to remove the worker from exposure following a single high result if there is reason to believe that significant exposure may have occurred.

BEIs<sup>®</sup> apply to 8-hour exposures, 5 days per week. Although modified work schedules are sometimes used in various occupations, the BEI<sup>®</sup> Committee does not recommend that any adjustment or correction factor be applied to the BEIs<sup>®</sup> (i.e., the BEIs<sup>®</sup> should be used as listed, regardless of the work schedule).

Use of the BEI<sup>®</sup> should be applied by a knowledgeable occupational health professional. Toxicokinetic and toxicodynamic information is taken into account when establishing the BEI<sup>®</sup>; thus, some knowledge of the metabolism, distribution, accumulation, excretion, and effect(s) is helpful in using the BEI<sup>®</sup> effectively. ACGIH<sup>®</sup> may be contacted for technical assistance on any BEI<sup>®</sup> issue. The BEI<sup>®</sup> is a guideline for the control of potential health hazards to the worker and should not be used for other purposes. The values are inappropriate to use for the general population or for nonoccupational exposures. The BEI<sup>®</sup> values are neither rigid lines between safe and dangerous concentrations nor are they an index of toxicity.



BEIs<sup>®</sup>

*Note:*

It is essential to consult the BEI<sup>®</sup> *Documentation* before designing biological monitoring protocols and interpreting BEIs<sup>®</sup>. In addition, each BEI<sup>®</sup> *Documentation* now provides a chronology that traces all BEI<sup>®</sup> actions for the chemical substance in question.

**ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS**

<b>Chemical [CAS No.] (Documentation date)</b>	<b>Determinant</b>	<b>Sampling Time</b>	<b>BEI®</b>	<b>Notation</b>
<b>ACETONE</b> [67-64-1] (2014)	Acetone in urine	End of shift	25 mg/L	Ns
<b>ANILINE</b> [62-53-3] (2003)	Aniline in urine★	End of shift	—	Nq
	Aniline released from hemoglobin in blood	End of shift	—	Nq
	p-Aminophenol in urine★	End of shift	50 mg/L	B, Ns, Sq
<b>ARSENIC, ELEMENTAL</b> [7440-38-2] <b>AND SOLUBLE INORGANIC COMPOUNDS</b> (excludes gallium arsenide and arsine) (1998)	Inorganic arsenic plus methylated metabolites in urine	End of workweek	35 µg As/L	B
<b>BENZENE</b> [71-43-2] (1999)	S-Phenylmercapturic acid in urine	End of shift	25 µg/g creatinine	B
	t,t-Muconic acid in urine	End of shift	500 µg/g creatinine	B
<b>1,3-BUTADIENE</b> [106-99-0] (2005)	1,2 Dihydroxy-4-(N-acetylcysteinyl)-butane in urine	End of shift	2.5 mg/L	B, Sq
	Mixture of N-1- and N-2-(hydroxybutenyl)valine hemoglobin (Hb) adducts in blood	Not critical	2.5 pmol/g Hb	Sq

**BEI®**

## ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (Documentation date)	Determinant	Sampling Time	BEI®	Notation
<b>2-BUTOXYETHANOL</b> [111-76-2] (2006)	Butoxyacetic acid (BAA) in urine★	End of shift	200 mg/g creatinine	—
<b>CADMIUM</b> [7440-43-9] <b>AND INORGANIC COMPOUNDS</b> (2015)	Cadmium in urine	Not critical	5 µg/g creatinine	B
	Cadmium in blood	Not critical	5 µg/L	B
<b>CARBON DISULFIDE</b> [75-15-0] (2008)	2-Thiothiazolidine-4-carboxylic acid (TTCA) in urine	End of shift	0.5 mg/g creatinine	B, Ns
<b>CARBON MONOXIDE</b> [630-08-0] (2015)	Carboxyhemoglobin in blood	End of shift	3.5% of hemoglobin	B, Ns
	Carbon monoxide in end-exhaled air	End of shift	20 ppm	B, Ns
<b>CHLOROBENZENE</b> [108-90-7] (2006)	4-Chlorocatechol in urine★	End of shift at end of workweek	100 mg/g creatinine	Ns
	p-Chlorophenol in urine★	End of shift at end of workweek	20 mg/g creatinine	Ns



**ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS**

**Chemical [CAS No.] (Documentation date)**

<i>Determinant</i>	<i>Sampling Time</i>	<i>BEI®</i>	<i>Notation</i>
<b>CHOLINESTERASE INHIBITING PESTICIDES (2017)</b>			
Acetylcholinesterase activity in red blood cells and Butyrylcholinesterase activity in serum or plasma	End of shift	70% of individual's baseline activity**	Ns
	End of shift	60% of individual's baseline activity**	Ns
** The average of two baseline respective cholinesterase activity determinations three days apart, with no exposures to enzyme inhibiting pesticides for at least 30 days, is recommended for each worker prior to exposure to cholinesterase inhibitors because of large inter-individual differences in published baseline values. To be established at least once a year. Removal from workplace exposures is recommended until the cholinesterase activity returns to within 20% of baseline.			
<b>CHROMIUM(VI), Water-soluble fume (2003)</b>			
Total chromium in urine	End of shift at end of workweek	25 µg/L	—
Total chromium in urine	Increase during shift	10 µg/L	—
<b>COBALT [7440-48-4] AND INORGANIC COMPOUNDS, including Cobalt oxides but not combined with Tungsten carbide (2014)</b>			
Cobalt in urine	End of shift at end of workweek	15 µg/L	Ns
Cobalt with Tungsten carbide Cobalt in urine	End of shift at end of workweek	—	Ns, Nq
<b>CYCLOHEXANOL [108-93-0] (2003)</b>			
1,2-Cyclohexanediol in urine★	End of shift at end of workweek	—	Nq, Ns
Cyclohexanol in urine★	End of shift	—	Nq, Ns



## ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (Documentation date)

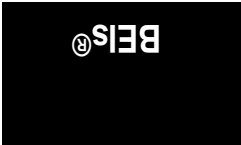
<i>Determinant</i>	<i>Sampling Time</i>	<i>BEI®</i>	<i>Notation</i>
<b>CYCLOHEXANONE</b> [108-94-1] (2003) 1,2-Cyclohexanediol in urine★ Cyclohexanol in urine★	End of shift at end of workweek End of shift	80 mg/L 8 mg/L	Ns, Sq Ns, Sq
<b>DICHLOROMETHANE</b> [75-09-2] (2004) Dichloromethane in urine	End of shift	0.3 mg/L	Sq
<b>N,N-DIMETHYLACETAMIDE</b> [127-19-5] (1993) N-Methylacetamide in urine	End of shift at end of workweek	30 mg/g creatinine	—
<b>N,N-DIMETHYLFORMAMIDE</b> [68-12-2] (2016) Total N-Methylformamide in urine** N-Acetyl-S-(N-methylcarbamoyl) cysteine in urine	End of shift End of shift at end of workweek	30 mg/L 30 mg/L	— —
** Total N-Methylformamide represents the sum of N-Methylformamide and N-(Hydroxymethyl)-N-Methylformamide			
<b>2-ETHOXYETHANOL</b> (EGEE) [110-80-5] AND <b>2-ETHOXYETHYL ACETATE</b> (EGEEA) [111-15-9] (1992) 2-Ethoxyacetic acid in urine	End of shift at end of workweek	100 mg/g creatinine	—
<b>ETHYLBENZENE</b> [100-41-4] (2013) Sum of mandelic acid and phenylglyoxylic acid in urine	End of shift	0.15 g/g creatinine	Ns

**ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS**

**Chemical [CAS No.] (Documentation date)**

<i>Determinant</i>	<i>Sampling Time</i>	<i>BEI®</i>	<i>Notation</i>
* <b>ETHYLENE OXIDE</b> [75-21-8] (2018)			
N-(2-hydroxyethyl)valine (HEV) hemoglobin adducts	Not critical	5000 pmol HEV/g globin**	Ns
S-(2-hydroxyethyl)mercapturic acid (HEMA) in urine	End of shift	5 µg HEMA/g creatinine	Pop, Ns
** Applies to workers having representative Ethylene oxide exposure during the previous 120 days.			
* <b>N-ETHYL-2-PYRROLIDONE</b> [2687-91-4] (2018)			
5-Hydroxy-N-ethyl-2-pyrrolidone (5-HNEP) in urine**	End of shift	—	Nq
<b>FLUORIDES</b> (2011)			
Fluoride in urine	Prior to shift	2 mg/L	B, Ns
Fluoride in urine	End of shift	3 mg/L	B, Ns
<b>FURFURAL</b> [98-01-1] (2006)			
Furoic acid in urine*	End of shift	200 mg/L	Ns
<b>1,6-HEXAMETHYLENE DIISOCYANATE</b> [822-06-0] (2014)			
1,6-Hexamethylene diamine in urine*	End of shift	15 µg/g creatinine	Ns
* <b>n-HEXANE</b> [110-54-3] (2018)			
2,5-Hexanedione in urine**	End of shift	0.5 mg/L	—
<b>LEAD AND INORGANIC COMPOUNDS</b> [7439-92-1] (2016)			
Lead in blood	Not critical	200 µg/L	—

Note: Persons applying this BEI® are encouraged to counsel female workers of child-bearing age about the risk of delivering a child with a PbB over the current CDC reference value. (CDC: Guidelines for the identification and management of lead exposure in pregnant and lactating women, 2010.)



## ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (Documentation date)	Determinant	Sampling Time	BEI®	Notation
MERCURY, ELEMENTAL [7439-97-6] (2012)	Mercury in urine	Prior to shift	20 µg/g creatinine	—
METHANOL [67-56-1] (2004)	Methanol in urine	End of shift	15 mg/L	B, Ns
METHEMOGLOBIN INDUCERS (2005)	Methemoglobin in blood	During or end of shift	1.5% of hemoglobin	B, Ns, Sq
2-METHOXYETHANOL [109-86-4] AND 2-METHOXYETHYL ACETATE [110-49-6] (2009)	2-Methoxyacetic acid in urine	End of shift at end of workweek	1 mg/g creatinine	—
‡ (METHYL n-BUTYL KETONE [591-78-6] (2002)) (2,5-Hexanedione in urine★★)		(End of shift at end of workweek)	(0.4 mg/L)	(—)
METHYL CHLOROFORM [71-55-6] (1987)	Methyl chloroform in end-exhaled air	Prior to last shift of workweek	40 ppm	—
	Trichloroacetic acid in urine	End of workweek	10 mg/L	Ns, Sq
	Total trichloroethanol in urine	End of shift at end of workweek	30 mg/L	Ns, Sq
	Total trichloroethanol in blood	End of shift at end of workweek	1 mg/L	Ns
4,4'-METHYLENE BIS(2-CHLOROANILINE) (MBOCA) (2012) [101-14-4]	Total MBOCA in urine★	End of shift	—	Nq

**ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS**

<b>Chemical [CAS No.] (Documentation date)</b>	<b>Determinant</b>	<b>Sampling Time</b>	<b>BEI®</b>	<b>Notation</b>
<b>METHYL ETHYL KETONE</b> [78-93-3] (2012)	Methyl ethyl ketone in urine	End of shift	2 mg/L	Ns
<b>METHYL ISOBUTYL KETONE</b> [108-10-1] (2009)	Methyl isobutyl ketone in urine	End of shift	1 mg/L	—
<b>N-METHYL-2-PYRROLIDONE</b> [872-50-4] (2006)	5-Hydroxy-N-methyl-2-pyrrolidone in urine	End of shift	100 mg/L	—
<b>NAPHTHALENE</b> [91-20-3] (2012)	1-Naphthol★ + 2-Naphthol★	End of shift	—	Nq, Ns
<b>NITROBENZENE</b> [98-95-3] (2013)	Methemoglobin in blood	See Methemoglobin Inducers BEI®	—	—
‡ <b>PARATHION</b> [56-38-2] (1992)	Total p-Nitrophenol in urine (Cholinesterase activity in red cells)	End of shift (Discretionary)	0.5 mg/g creatinine (70% of individual's baseline)	Ns (B, Ns, Sq)
<b>PENTACHLOROPHENOL</b> [87-86-5] (2013)	Pentachlorophenol in urine★	Prior to last shift of workweek	—	Nq
<b>PHENOL</b> [108-95-2] (2005)	Phenol in urine★	End of shift	250 mg/g creatinine	B, Ns

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## ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (Documentation date)

<i>Determinant</i>	<i>Sampling Time</i>	<i>BEI®</i>	<i>Notation</i>
<b>POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) (2016)</b>			
1-Hydroxypyrene in urine★	End of shift at end of workweek	2.5 µg/L**	B
3-Hydroxybenzo(a)pyrene in urine★	End of shift at end of workweek	—	Nq
** Adjusted for the Pyrene to Benzo(a)pyrene ratio of the PAH mixture to which workers are exposed			
<b>2-PROPANOL [67-63-0] (2005)</b>			
Acetone in urine	End of shift at end of workweek	40 mg/L	B, Ns
<b>STYRENE [100-42-5] (2014)</b>			
Mandelic acid plus phenylglyoxylic acid in urine	End of shift	400 mg/g creatinine	Ns
Styrene in urine	End of shift	40 µg/L	—
<b>TETRACHLOROETHYLENE [127-18-4] (2008)</b>			
Tetrachloroethylene in end-exhaled air	Prior to shift	3 ppm	—
Tetrachloroethylene in blood	Prior to shift	0.5 mg/L	—
<b>TETRAHYDROFURAN [109-99-9] (2006)</b>			
Tetrahydrofuran in urine	End of shift	2 mg/L	—
<b>TOLUENE [108-88-3] (2009)</b>			
Toluene in blood	Prior to last shift of workweek	0.02 mg/L	—
Toluene in urine	End of shift	0.03 mg/L	—
o-Cresol in urine★	End of shift	0.3 mg/g creatinine	B

**ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS**

**Chemical [CAS No.] (Documentation date)**

<i>Determinant</i>	<i>Sampling Time</i>	<i>BEI®</i>	<i>Notation</i>
<b>TOLUENE DIISOCYANATE-2,4-</b> [584-84-9] <b>or 2,6-</b> [91-08-7] or as a mixture of isomers (2015)			
Toluene diamine in urine★, **	End of shift	5 µg/g creatinine	Ns
** Sum of 2,4- and 2,6- isomers			
<b>TRICHLOROETHYLENE</b> [79-01-6] (2007)			
Trichloroacetic acid in urine	End of shift at end of workweek	15 mg/L	Ns
Trichloroethanol in blood★★	End of shift at end of workweek	0.5 mg/L	Ns
Trichloroethylene in blood	End of shift at end of workweek	—	Sq
Trichloroethylene in end-exhaled air	End of shift at end of workweek	—	Sq
<b>URANIUM</b> [7440-61-1] (2009)			
Uranium in urine	End of shift	200 µg/L	—
<b>XYLENES</b> [95-47-6; 106-42-3; 108-38-3; 1330-20-7] (technical or commercial grade) (2011)			
Methylhippuric acids in urine	End of shift	1.5 g/g creatinine	—

★ With hydrolysis

★★ Without hydrolysis; n-Hexane, Methyl n-butyl ketone and Trichloroethylene

**BEI®**

## 2019 NOTICE OF INTENDED CHANGES

These substances, with their corresponding indices, comprise those for which (1) a BEI® is proposed for the first time, (2) a change in the Adopted index is proposed, (3) retention as an NIC is proposed, or (4) withdrawal of the *Documentation* and adopted BEI® is proposed. In each case, the proposals should be considered trial indices during the period they are on the NIC. These proposals were ratified by the ACGIH® Board of Directors and will remain on the NIC for approximately one year following this ratification. If the Committee neither finds nor receives any substantive data that change its scientific opinion regarding an NIC BEI®, the Committee may then approve its recommendation to the ACGIH® Board of Directors for adoption. If the Committee finds or receives substantive data that change its scientific opinion regarding an NIC BEI®, the Committee may change its recommendation to the ACGIH® Board of Directors for the matter to be either retained on or withdrawn from the NIC.

*Documentation* is available for each of these substances and their proposed values.

This notice provides an opportunity for comment on these proposals. Comments or suggestions should be accompanied by substantiating evidence in the form of peer-reviewed literature and forwarded in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org). Please refer to the ACGIH® TLV®/BEI® Development Process on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process)) for a detailed discussion covering this procedure, methods for input to ACGIH®, and deadline date for receiving comments.

### 2019 NOTICE OF INTENDED CHANGES

Chemical [CAS No.]

<i>Determinant</i>	<i>Sampling Time</i>	<i>BEI®</i>	<i>Notation</i>
METHYL n-BUTYL KETONE [591-78-6]	WITHDRAW ADOPTED BEI® AND <i>DOCUMENTATION</i>		
† PARATHION [56-38-2]			
Total p-Nitrophenol in urine	End of shift	0.5 mg/g creatinine	Ns
Acetylcholinesterase activity in red blood cells	End of shift	70% of individual's baseline activity**	Ns

\*\* The average of two baseline respective acetylcholinesterase activity determinations 3 days apart, with no exposures to enzyme inhibiting pesticides for at least 30 days, is recommended for each worker prior to exposure to parathion because of large inter-individual differences in published baseline values. To be established at least once a year. Removal from workplace exposures is recommended until the acetylcholinesterase activity returns to within 20% of baseline.

† = 2019 Revision or Addition to the Notice of Intended Changes



## CHEMICAL SUBSTANCES AND OTHER ISSUES UNDER STUDY

The BEI<sup>®</sup> Committee solicits information, especially data, which may assist it in its deliberations regarding the following substances and issues. Comments and suggestions, accompanied by substantiating evidence in the form of peer-reviewed literature, should be forwarded in electronic format to the ACGIH<sup>®</sup> Science Group at [science@acgih.org](mailto:science@acgih.org). In addition, the Committee solicits recommendations for additional substances and issues of concern to the industrial hygiene and occupational health communities. Please refer to the ACGIH<sup>®</sup> TLV<sup>®</sup>/BEI<sup>®</sup> Development Process found on the ACGIH<sup>®</sup> website for a detailed discussion covering this procedure and methods for input to ACGIH<sup>®</sup> ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process)).

The Under Study list is published each year by February 1 on the ACGIH<sup>®</sup> website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)), in the *Annual Reports of the Committees on TLVs<sup>®</sup> and BEIs<sup>®</sup>*, and later in the annual *TLVs<sup>®</sup> and BEIs<sup>®</sup>* book. In addition, the Under Study list is updated by July 31 into a two-tier list.

- Tier 1 entries indicate which chemical substances and physical agents **may** move forward as an NIC or NIE in the upcoming year, based on their status in the development process.
- Tier 2 consists of those chemical substances and physical agents that **will not** move forward, but will either remain on, or be removed from, the Under Study list for the next year.

This updated list will remain in two tiers for the balance of the year. ACGIH<sup>®</sup> will continue this practice of updating the Under Study list by February 1 and establishing the two-tier list by July 31 each year.

The substances and issues listed below are as of January 1, 2019. *After this date, please refer to the ACGIH<sup>®</sup> website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)) for the up-to-date list.*

### Chemical Substances

Acrylamide	Indium
Adipates	Iodine
Aniline	Methemoglobin inducers
Arsenic	Methyl n-butyl ketone
Benzene	Methyl chloroform
Bisphenol A	Methylcyclohexane
Chromium	Methyl isobutyl carbinol
Cyclohexane	Nickel
3,3'-Dichlorobenzidine	Parathion
Di(2-ethylhexyl)phthalate	Phthalates (see Di(2-ethylhexyl) phthalate)
Ethylene glycol	Styrene
Furfural	Styrene oxide
Heptane	

## Other Issues Under Study

1. Sq Notation
2. Introduction to the *Documentation* of the BEIs®

## Feasibility Assessments

For the substances listed below, the BEI® Committee has determined that developing a BEI® is not currently feasible owing to inadequate scientific data. However, the Committee believes that these substances may pose important risks to the health of workers, and therefore, it encourages the submission of new data. Field or experimental studies on the relationship between biological indicators and either health risk or environmental exposure are needed for these agents. A brief summary of the current negative feasibility assessment, including data needs, for each of the listed substances is available from the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org).

BEI®

Substance	Date of Feasibility Assessment
Acrylonitrile	March 1994
Alachlor	September 2009
Aluminum	September 2007
Antimony	November 1996
Beryllium	November 2010
1-Bromopropane	April 2017
Chlorpyrifos	October 1996
1,4-Dichlorobenzene	March 1994
2,4-Dichlorophenoxy- acetic acid	March 1994
Diethanolamine	September 2013
2-Ethyl hexanoic acid	September 2001
Hydrazines	March 1994
Inorganic borates	October 1995
Manganese	October 2017
Methyl tert-butyl ether	October 1993
Methyl n-butyl ketone	October 2017
Methyl formate	September 2005
$\alpha$ -Methylstyrene	November 2010
Nickel	November 1996
Nitrobenzene	September 2013
Perfluorooctanoic acid	April 2007
Selenium	October 1995
Thallium	November 2010
Trimethylbenzene	August 1999
Vanadium pentoxide	September 2009
Vinyl chloride	August 2002

# 2019

## Threshold Limit Values for Physical Agents in the Work Environment

Adopted by ACGIH®  
with Intended Changes

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## \* INTRODUCTION TO THE PHYSICAL AGENTS

This section presents Threshold Limit Values (TLVs®) for occupational exposure to physical agents of acoustic, electromagnetic, ergonomic, mechanical, and thermal nature. As with other TLVs®, those for physical agents provide guidance on the levels of exposure and conditions under which it is believed that nearly all healthy workers may be repeatedly exposed, day after day, without adverse health effects.

The target organs and health effects of these physical agents vary greatly with their nature; thus, TLVs® are not single numbers, but rather integrations of the measured parameters of the agent, its effects on workers, or both. Due to the many types of physical agents, a variety of scientific disciplines, detection techniques, and instrumentation are applied. Therefore, it is especially important that the Physical Agents TLVs® be applied only by individuals adequately trained and experienced in the corresponding measurement and evaluation techniques. Given the unavoidable complexity of some of these TLVs®, the most current *Documentation* of the Physical Agents TLVs® must be consulted when they are applied.

Because of wide variations in individual susceptibility, exposure of an individual at, or even below, the TLV® may result in annoyance, aggravation of a pre-existing condition, or physiological effects. Certain individuals may also be more susceptible or otherwise unusually responsive to some physical agents at the workplace because of a variety of factors such as age, sex, genetic factors (predisposition), personal behaviors (e.g., smoking, diet, exercise, abuse of alcohol or other drugs, extracurricular activities – hobbies), medications, medical conditions (e.g., cardiovascular disease). Some workers may become more susceptible to adverse effects from a physical agent following previous exposures. Concurrent exposures to other physical agents may increase susceptibility. Changes in susceptibility may also occur at different work levels (e.g., light versus heavy work). Maternal and fetal susceptibility to the effects of some physical agents may be altered during different periods of fetal development. Such workers may not be adequately protected from adverse health effects from exposures to certain physical agents at or below the TLVs®. An occupational physician should evaluate the extent to which such workers require additional protection.

TLVs® are based on available information from industrial experience, from experimental human and animal studies, and when possible, from a combination of the three, as cited in their *Documentation*.

**Like all TLVs®, these limits are intended for use in the practice of occupational hygiene and should be interpreted and applied only by a person trained in this discipline. They are not intended for use, or for modification for use, 1) in the evaluation or control of the levels of physical agents in the community or 2) as proof or disproof of an existing physical disability.**

These values are reviewed annually by ACGIH® for revision or additions, as further information becomes available. ACGIH® regularly examines the data related to mutagenicity, cancer, adverse reproductive effects, and other health effects of physical agents. Comments, accompanied by substantive

documentation, are solicited and should be forwarded in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org).

ACGIH® disclaims liability with respect to the use of TLVs®.

## Notice of Intended Changes

Each year, proposed actions for the forthcoming year are issued in the form of a “Notice of Intended Changes” (NIC). These physical agents, with their corresponding values, comprise those for which 1) a limit is proposed for the first time (i.e., NIE), 2) a change in the Adopted Values is proposed, 3) retention as an NIC is proposed, or 4) withdrawal of the *Documentation* and adopted TLV® is proposed. In each case, the proposals should be considered trial values during the period they are on the NIC/NIE. These proposals are ratified by the ACGIH® Board of Directors and will remain as NICs/NIEs for approximately one year following this ratification. If the Committee neither finds nor receives any substantive data that change its scientific opinion regarding physical agent TLVs® on the NIC/NIE, the Committee may approve its recommendation to the ACGIH® Board of Directors for adoption. If the Committee finds or receives substantive data that change its scientific opinion regarding a TLV® on the NIC/NIE, the Committee may change its recommendation to the ACGIH® Board of Directors for the matter to be either retained on or withdrawn from the NIC.

*Documentation* is available for each of these physical agents and their proposed values.

This notice provides an opportunity for comment on these proposals. Comments or suggestions should be accompanied by substantiating evidence in the form of peer-reviewed literature and forwarded in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org). Please refer to the ACGIH® TLV®/BEI® Development Process on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process)) for a detailed discussion covering this procedure, methods for input to ACGIH®, and deadline date for receiving comments.

## Definitions

TLV® categories used in this section include the following:

- a) *Threshold Limit Value–Time-Weighted Average (TLV–TWA)*. The time-weighted average exposure for an 8-hour workday and 40-hour workweek.
- b) *Threshold Limit Value–Ceiling (TLV–C)*. Exposure limit that should not be exceeded even instantaneously.

## Physical and Chemical Factors

Combinations of such physical factors as heat, ultraviolet and ionizing radiation, humidity, abnormal pressure (altitude), and the like, as well as the interaction of physical factors with chemical substances in the workplace, may place added stress on the body so that the effects from exposure at a TLV®

may be altered. This stress may act adversely to increase the toxic response to a foreign substance. Although most TLVs® have built-in uncertainty factors to guard against adverse health effects when there are moderate deviations from normal environments, the uncertainty factors for most exposures are not of such a magnitude as to compensate for gross deviations. In such instances, informed professional judgment must be exercised in the proper adjustment of the TLVs®.

### **Unusual Work Schedules**

Work schedules markedly different from the traditional 8-hour day, 40-hour workweek require careful judgment in the application of the TLVs®. Non-traditional workshifts may result in overexposure and/or limited opportunity to recover prior to re-exposure. Some workers have more than one job, which may result in overexposure, even if neither job by itself entails overexposure. Extrapolation of the TLVs® to account for potential overexposure and/or insufficient recovery due to unusual work schedules should be approached with great caution.

## ACOUSTIC

### INFRASOUND AND LOW-FREQUENCY SOUND

These limits represent sound exposures to which it is believed nearly all workers may be repeatedly exposed without adverse effects that do not involve hearing.

Except for impulsive sound with durations of less than 2 seconds, one-third octave band<sup>(1)</sup> levels for frequencies between 1 and 80 Hz should not exceed a sound pressure level (SPL) ceiling limit of 145 dB. In addition, the overall unweighted SPL should not exceed a ceiling limit of 150 dB.

There are no time limits for these exposures. However, application of the TLVs<sup>®</sup> for Noise and Ultrasound, recommended to prevent noise-induced hearing loss, may provide a reduced acceptable level with time. This reduction will depend upon the amount of attenuation allowed for hearing protection.

An alternative but slightly more constrictive criterion, where the peak SPL measured with the linear or unweighted frequency response of a Sound Level Meter does not exceed 145 dB for nonimpulsive events, may be used. When using this criterion, the measurement instrument should conform to ANSI Standard S1.4 and the linear or unweighted response should extend down to at least 2 Hz.

*Note: Low frequency sounds in the chest resonance range from about 50 Hz to 60 Hz can cause whole-body vibration. Such an effect may cause annoyance and discomfort. The SPL of such sound may need to be reduced to a level where the problem disappears.*

TLV<sup>®</sup>-PA

#### Reference

1. American National Standards Institute: Specification for Octave-Band and Fractional-Octave Band Analog and Digital Filters S1.11-1986 (R1998). ANSI, New York (1998).



## AUDIBLE SOUND

These TLVs® refer to sound pressure levels of noise (i.e., unwanted audible sound between the frequencies of 20 and 20,000 Hz) and durations of exposure that represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech. The values should be used as guides in the control of noise exposure and, due to individual susceptibility, should not be regarded as fine lines between safe and dangerous levels.

It should be recognized that the application of the TLVs® for noise will not protect all workers from the adverse auditory effects of noise exposure, and also may not protect against a range of non-auditory effects. The TLVs® should protect the median of the population against noise-induced hearing loss  $\geq 2$  decibels (dB) after 40 years of occupational exposure for the average hearing threshold level across the critical audiometric frequencies of 0.5, 1, 2, and 3 kHz. A hearing conservation program, including key program elements (exposure monitoring, implementation of noise controls, worker training, use of hearing protection devices, recordkeeping, program evaluation, and audiometric testing) is necessary when workers are exposed to noise at or above the TLV® levels.

### Continuous or Intermittent Noise

The noise level should be determined by a sound level meter, integrating sound level meter, or dosimeter conforming, as a minimum, to the requirements of the American National Standards Institute (ANSI) Sound Level Meter – Part 1: Specifications, S1.4-1 Type 2 (ANSI, 2007), ANSI S1.25 – Specification for Personal Noise Dosimeters (ANSI, 2007), or IEC 61672-1 (IEC, 2013). The measurement device should be set to use the A-weighted network (i.e., dBA) with slow meter response. The duration of exposure should not exceed that shown in Table 1. These values apply to total duration of exposure per day regardless of whether this is one continuous exposure or a number of short-term exposures.

When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered rather than the individual effect of each. If the sum of the following fractions,

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \Lambda \frac{C_n}{T_n}$$

exceeds unity, then the combined exposure should be considered to exceed the TLV®. C indicates the total duration of exposure at a specific noise level, and T indicates the total duration of exposure permitted at that level. All on-the-job noise exposures of 80–140 dBA should be used in the above calculations.

This formula should be used for sounds with limited variability ( $\pm 2.5$  dB or less) as measured with sound level meters (ANSI, 2016a, b). For more variable sound pressure levels and when brief, impulsive or impact sounds are present, a dosimeter or an integrating sound level meter must be used. The limit is exceeded when the dose is more than 100% as indicated on a dosimeter set with a 3 dB time-intensity exchange rate and an 8-hour criteria level of 85 dBA. The TLV® is exceeded on an integrating sound level meter when the average noise level over a given duration exceeds the values given in Table 1.

**TABLE 1 . Threshold Limit Values for Audible Sound<sup>A</sup>**

	<b>Duration per Day</b>	<b>Sound Pressure Level dBA<sup>B</sup></b>
Hours	24	80
	16	82
	8	85
	4	88
	2	91
	1	94
Minutes	30	97
	15	100
	7.50 <sup>C</sup>	103
	3.75 <sup>C</sup>	106
	1.88 <sup>C</sup>	109
	0.94 <sup>C</sup>	112
Seconds <sup>C</sup>	28.12	115
	14.06	118
	7.03	121
	3.52	124
	1.76	127
	0.88	130
	0.44	133
	0.22	136
	0.11	139
	0.08	140

<sup>A</sup> No exposure to continuous, intermittent, or impact noise (e.g., audible sound between the frequencies of 20 and 20,000 Hz) is permitted in excess of a peak C-weighted level of 140 decibels (dB).

<sup>B</sup> Noise levels in dB are measured on a sound level meter, conforming, as a minimum, to the requirements of the American National Standards Institute Sound Level Meters – Part 1: Specifications, S1.4 (ANSI, 2007) Type 2, and set to use the A-weighted network with slow meter response.

<sup>C</sup> Limited by engineering control of the noise source if feasible. Administrative control is permissible if engineering control is infeasible.

TLV<sup>®</sup>-PA

### Impulsive or Impact Noise

Impact and impulse noise involves brief noise excursions that last < 1 sec. Impact noise results from colliding objects, causing them to “ring.” Impulsive noise results from explosions or formation of shock waves. Together, they comprise what is generically called impulse noise. Use of the instrumentation specified by ANSI S1.4-1 (2014), ANSI S1.25 (2007), or IEC 61672-1 (2013) ensures that impulse noise is integrated into the measured noise level. The only measurement requirements for impulse noise level are that the metering equipment should have a measurement range between 80 and 140 dBA and a pulse range response of at least 63 dB. No exposures of an unprotected ear in excess of a C-weighted peak sound pressure level of 140 dB are permitted. If instrumentation is not available to measure a C-weighted peak, a Z-weighted (IEC, 2013) or unweighted peak measurement below 140 dB may be used to imply that the C-weighted peak is below 140 dB.

**Notes:**

1. For audible sound impulses above a C-weighted peak of 140 dB, hearing protection should be worn. The MIL-STD-1474E (U.S. DOD, 2015) provides guidance for those situations in which single protection (plugs or muffs) or double protection (both muffs and plugs) should be worn. Additional guidance on appropriate attenuated exposure levels is provided by the European Committee for Standardization (2004).
2. Exposure to certain chemicals may also result in hearing loss and the exacerbation of the effects of noise (EU OSHA, 2009; Johnson and Morata, 2010; Choi and Kim, 2014). In settings where there may be exposures to noise and to Carbon monoxide, Hydrogen cyanide, Lead, and solvent mixtures, or exposures to Ethylbenzene, Styrene, Toluene, or Xylene in the absence of noise, periodic audiograms are advised and should be carefully reviewed, with the potential confounding effect of noise in mind (Nies, 2012). Other substances under investigation for ototoxic effects include Arsenic, Carbon disulfide, Chlorobenzene, Mercury, Nitriles, n-Hexane, pesticides, and Trichloroethylene.
3. There is evidence to suggest that noise exposure in excess of a C-weighted, 8-hour TWA of 115 dBC or a peak exposure of 155 dBC to the abdomen of pregnant workers beyond the fifth month of pregnancy may cause hearing loss in the fetus.
4. The sum of the fractions of any one day may exceed unity, provided that the sum of the fractions over a seven-day period is five or less and no daily fraction is more than three.
5. Table 1 is based on daily exposures in which there will be time away from the workplace in effective quiet, i.e., < 70 dBA. This time away from the workplace will allow any temporary shifts in worker's hearing thresholds to recover. When the worker is restricted for periods of greater than 24 hours to employer-controlled spaces or areas that serve as both workplace and living quarters, the average noise exposure over any 24-hour period should not exceed 80 dBA.
6. There is evidence to suggest that chronic exposures to occupational noise < 85 dBA – i.e., below that sufficient for a substantially elevated risk of noise-induced hearing loss – may be associated with an increased risk of elevated blood pressure, hypertension, and ischemic heart disease among manufacturing and production workers. The TLV® may not be protective against these effects.
7. There is evidence to suggest that noise exposures > 85 dBA may be associated with an increased risk of occupational injury through distraction, stress, fatigue, performance degradation, or other mechanisms among manufacturing and production workers. The TLV® may be protective against these effects, though it is possible that acute injury risk is more highly associated with brief excursions rather than an 8-hour average level; if true, this suggests a different risk scenario than those presented for noise-induced hearing loss and cardiovascular disease.
8. While auditory effects of noise are determined largely by signal intensity and frequency, non-auditory effects (e.g., cardiovascular effects and

injury risk) may also be influenced by predictability of signal, perceived control, time of day, rise-time, and even information content.

## References

- American National Standards Institute (ANSI): Specification for Personal Noise Dosimeters. ANSI S1.25-1991 (R2007). ANSI, New York (2007).
- American National Standards Institute (ANSI): Sound Level Meters – Part 1: Specifications. ANSI S1.4-1 (2014). ANSI, New York (2014).
- American National Standards Institute (ANSI): Measurement of Occupational Noise Exposure. ANSI/ASA S12.19-1996 (R2016). ANSI, New York (2016a).
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## ULTRASOUND

These TLVs<sup>®</sup> represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect on their ability to hear and understand normal speech. Previous TLVs<sup>®</sup> for the frequencies 10 kilohertz (kHz) to 20 kHz, et to prevent subjective effects, are referenced in a cautionary note to Table 1. The 8-hour TWA values are an extension of the TLV<sup>®</sup> for Noise, which is an 8-hour TWA of 85 dBA. The ceiling values may be verified by using a sound level meter with slow detection and 1/3 octave bands. The TWA values may be verified by using an integrating sound level meter with 1/3 octave bands. All instrumentation should have adequate frequency response and should meet the specifications of ANSI S1.4-1983 (R1997)<sup>(1)</sup> and IEC 804.<sup>(2)</sup>

**TABLE 1. TLVs<sup>®</sup> for Ultrasound**

Mid-Frequency of Third-Octave Band (kHz)	One-third Octave-Band Level <sup>(3)</sup>		
	Measured in Air in dB re: 20 µPa; Head in Air		Measured in Water in dB re: 1 µPa; Head in Water
	Ceiling Values	8-Hour TWA	Ceiling Values
10	105 <sup>A</sup>	88 <sup>A</sup>	167
12.5	105 <sup>A</sup>	89 <sup>A</sup>	167
16	105 <sup>A</sup>	92 <sup>A</sup>	167
20	105 <sup>A</sup>	94 <sup>A</sup>	167
25	110 <sup>B</sup>	—	172
31.5	115 <sup>B</sup>	—	177
40	115 <sup>B</sup>	—	177
50	115 <sup>B</sup>	—	177
63	115 <sup>B</sup>	—	177
80	115 <sup>B</sup>	—	177
100	115 <sup>B</sup>	—	177

**TLV<sup>®</sup>-PA**

<sup>A</sup> Subjective annoyance and discomfort may occur in some individuals at levels between 75 and 105 dB for the frequencies from 10 kHz to 20 kHz especially if they are tonal in nature. Hearing protection or engineering controls may be needed to prevent subjective effects. Tonal sounds in frequencies below 10 kHz might also need to be reduced to 80 dB.

<sup>B</sup> These values assume that human coupling with water or other substrate exists. These thresholds may be raised by 30 dB when there is no possibility that the ultrasound can couple with the body by touching water or some other medium. [When the ultrasound source directly contacts the body, the values in the table do not apply. The vibration level at the mastoid bone must be used.] Acceleration Values 15 dB above the reference of 1 g rms should be avoided by reduction of exposure or isolation of the body from the coupling source (g = acceleration due to the force of gravity, 9.80665 meters/second<sup>2</sup>; rms = root-mean-square).

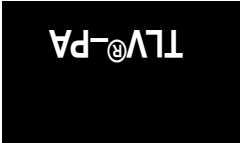
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1. American National Standards Institute: Specification for Sound Level Meters. ANSI S1.4-1983 (R1997). ANSI, New York (1997).
2. International Electrotechnical Commission: Integrating-Averaging Sound Level Meters. IEC 804. IEC, New York (1985).
3. American National Standards Institute: Specification for Octave-Band and Fractional-Octave-Band Analog and Digital Filters S1.11-1986 (R1998). ANSI, New York (1998).

### ELECTROMAGNETIC RADIATION SPECTRUM AND RELATED TLVs®

Non-ionizing Radiation												Ionizing Radiation	
Region*	Sub-Radiofrequency		Radiofrequency	Microwave	Infrared			Light	Ultraviolet			X-ray	
Waveband	ELF				IR-C	IR-B	IR-A		UV-A	UV-B	UV-C		
Wavelength	1000 km	10 km	1 m	1 mm	3 μm	1.4 μm	760 nm	400 nm	315 nm	280 nm	180 nm	100 nm	
Frequency	300 Hz	30 kHz	300 MHz	300 GHz									
Applicable TLV®	Sub-Radiofrequency		Radiofrequency and Microwave			Light and Near Infrared			Ultraviolet				Ionizing Radiation
						Lasers							

\*The boundaries between regions are set by convention and should not be regarded as absolute dividing lines.



## ELECTROMAGNETIC FIELDS 0–300 GHz

### STATIC MAGNETIC FIELDS

These TLVs<sup>®</sup> refer to static magnetic field flux densities to which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects. These values should be used as guides in the control of exposure to static magnetic fields and should not be regarded as fine lines between safe and dangerous levels.

Routine occupational exposures should not exceed 2 tesla (T) in the general workplace environment, but can have ceiling values of 8 T for workers with special training and operating in a controlled workplace environment. Special training involves making workers aware of transient sensory effects that can result from rapid motion in static magnetic fields with flux densities greater than 2 T. A controlled workplace environment is one in which forces exerted by static magnetic fields on metallic objects do not create potentially hazardous projectiles. Exposure of the limbs of workers in the general workplace environment should not exceed 20 T. Workers with implanted ferromagnetic or electronic medical devices should not be exposed to static magnetic fields exceeding 0.5 mT.

These TLVs<sup>®</sup> are summarized in Table 1.

TLV<sup>®</sup>-PA

**TABLE 1. TLVs<sup>®</sup> for Static Magnetic Fields**

Exposure	Ceiling Value
Whole body (general workplace)	2 T
Whole body (special worker training and controlled workplace environment)	8 T
Limbs	20 T
Medical device wearers	0.5 mT



## SUB-RADIOFREQUENCY (30 kHz and below) MAGNETIC FIELDS

These TLVs® refer to the amplitude of the magnetic flux density (B) of sub-radiofrequency (sub-RF) magnetic fields in the frequency range of 30 kilohertz (kHz) and below to which it is believed that nearly all workers may be exposed repeatedly without adverse health effects. The magnetic field strengths in these TLVs® are root-mean-square (rms) values. These values should be used as guides in the control of exposure to sub-radiofrequency magnetic fields and should not be regarded as fine lines between safe and dangerous levels.

Occupational exposures in the extremely-low-frequency (ELF) range from 1 to 300 hertz (Hz) should not exceed the ceiling value given by the equation:

$$B_{\text{TLV}} = \frac{60}{f}$$

where: f = the frequency in Hz

$B_{\text{TLV}}$  = the magnetic flux density in millitesla (mT).

For frequencies in the range of 300 Hz to 30 kHz (which includes the voice frequency [VF] band from 300 Hz to 3 kHz and the very-low-frequency [VLF] band from 3 to 30 kHz), occupational exposures should not exceed the ceiling value of 0.2 mT.

These ceiling values for frequencies of 300 Hz to 30 kHz are intended for both partial-body and whole-body exposures. For frequencies below 300 Hz, the TLV® for exposure of the extremities can be increased by a factor of 10 for the hands and feet and by a factor of 5 for the arms and legs.

The magnetic flux density of 60 mT/f at 60 Hz corresponds to a maximum permissible flux density of 1 mT. At 30 kHz, the TLV® is 0.2 mT, which corresponds to a magnetic field intensity of 160 amperes per meter (A/m).<sup>1</sup>

Contact currents from touching ungrounded objects that have acquired an induced electrical charge in a strong sub-RF magnetic field should not exceed the following point contact levels to avoid startle responses or severe electrical shocks:

- A.** 1.0 milliamperere (mA) at frequencies from 1 Hz to 2.5 kHz;
- B.** 0.4 f mA at frequencies from 2.5 to 30 kHz, where f is the frequency expressed in kHz.

<sup>1</sup> Magnetic fields are expressed in units of amperes/m. In health and safety studies, a more common dosimetric quantity is the magnetic flux density in units of Tesla (T) or Gauss (G). 1 T = 10,000 G. The two quantities are related by the magnetic permeability of the medium. In air, 1 A/m corresponds to a flux density of 1.3 μT.

**Notes:**

1. These TLVs<sup>®</sup> are based on an assessment of available data from laboratory research and human exposure studies. Modifications of the TLVs<sup>®</sup> will be made if warranted by new information. At this time, there is insufficient information on human responses and possible health effects of magnetic fields in the frequency range of 1 Hz to 30 kHz to permit the establishment of a TLV<sup>®</sup> for time-weighted average exposures.
2. For workers wearing cardiac pacemakers, the TLV<sup>®</sup> may not protect against electromagnetic interference with pacemaker function. Some models of cardiac pacemakers have been shown to be susceptible to interference by power-frequency (50/60 Hz) magnetic flux densities as low as 0.1 mT. It is recommended that, lacking specific information on electromagnetic interference from the manufacturer, the exposure of persons wearing cardiac pacemakers or similar medical electronic devices be maintained at or below 0.1 mT at power frequencies.
3. Fields in excess of the TLV<sup>®</sup> are likely to be present only in close proximity to high powered electrical equipment; in most occupational environments sub-RF fields are likely to be far below the TLV<sup>®</sup>. There should consequently be little need for detailed field surveys in general occupational spaces, although such surveys may help to address workers' concerns. If field surveys are undertaken, however, they should use appropriate equipment that has been calibrated and suitable for the anticipated measurements. In particular, unless they are designed for such measurements, magnetic field meters can be significantly in error when used to measure nonsinusoidal waveforms or fields at frequencies other than 50/60 Hz.

TLV<sup>®</sup>-PA**TABLE 1. TLVs<sup>®</sup> for Sub-Radiofrequency(30 kHz and below) Magnetic Fields**

Frequency Range	TLV <sup>®</sup>
1 to 300 Hz	Whole-body exposure: $\frac{60}{f^*}$ ceiling value in mT
1 to 300 Hz	Arms and legs: $\frac{300}{f^*}$ ceiling value in mT
1 to 300 Hz	Hands and feet: $\frac{600}{f^*}$ ceiling value in mT
* where: f = frequency in Hz	
300 Hz to 30 kHz	Whole-body and partial-body ceiling value: 0.2 mT
1 Hz to 2.5 kHz	Point contact current limit: 1.0 mA
2.5 to 30 kHz	Point contact current limit: 0.4 f mA
where: f = frequency in kHz	

## SUB-RADIOFREQUENCY (30 kHz and below) AND STATIC ELECTRIC FIELDS

These TLVs<sup>®</sup> refer to the maximum workplace field strengths of sub-radiofrequency electric fields (30 kHz and below) and static electric fields that represent conditions under which it is believed that nearly all workers may be exposed repeatedly without special protection without adverse health effects. The electric field intensities in these TLVs<sup>®</sup> are root-mean-square (rms) values. The values should be used as guides in the control of exposure and should not be regarded as a fine line between safe and dangerous levels. The electric field strengths stated in these TLVs<sup>®</sup> refer to the field levels present in air, away from the surfaces of conductors (where spark discharges and contact currents may pose significant hazards).

Occupational exposures should not exceed a field strength of 25 kilovolts per meter (kV/m) at frequencies from 0 Hz to 220 Hz. For frequencies in the range of 220 Hz to 3 kilohertz (kHz), the ceiling value is given by:

$$E_{\text{TLV}} = 5.525 \times 10^6 / f$$

where:

$f$  = the frequency in Hz

$E_{\text{TLV}}$  = the rms electric field strength in V/m

A rms value of 1842 V/m is the ceiling value for frequencies from 3 to 30 kHz. These ceiling values are intended for both partial-body and whole-body exposures.

### Notes:

1. These TLVs<sup>®</sup> are based on limiting field-induced effects at the body surface and induced currents within the body to levels below those that are believed to be hazardous. These are direct effects.
2. Indirect effects associated with touching charged objects within the electric field can be the limiting phenomena that determine safe practice. A noticeable and potentially annoying spark discharge can be experienced beneath power lines when the ground level field strength is at or below 5 kV/m (EPRI, 2005). Mitigation of such effects requires compliance with safe work practices and electrical safety codes beyond the scope of this TLV<sup>®</sup>.
3. Certain biological effects have been reported in laboratory studies at electric field strengths below those permitted in the TLV<sup>®</sup>; however, there is no convincing evidence at the present time that occupational exposure to such field levels leads to adverse health effects.

Modifications of the TLVs<sup>®</sup> will be made if warranted by new information. At this time, there is insufficient information on human responses and possible health effects of electric fields in the frequency range of 0 to 30 kHz to permit the establishment of a TLV<sup>®</sup> for time-weighted average exposures.

## Reference

Electrical Power Research Institute (EPRI): AC Transmission Line Reference Book — 200 kV and Above, 3rd Edition. EPRI, Palo Alto, CA (2005).

## RADIOFREQUENCY/MICROWAVE RADIATION

These TLVs<sup>®</sup> refer to radiofrequency (RF) radiation in the frequency range of 30 kilohertz (kHz) to 300 gigahertz (GHz). This includes microwave radiation (300 MHz–300 GHz), which is a region of the RF spectrum. These TLVs<sup>®</sup> represent conditions under which it is believed nearly all workers may be repeatedly exposed without adverse health effects.

The TLVs<sup>®</sup> were designed to limit electrostimulation of nerve and muscle tissue at frequencies from 0.03 to 0.1 MHz, and tissue heating above 0.1 MHz. The TLVs<sup>®</sup> are given in terms of root-mean-square (rms) electric (E), and magnetic (H) field strengths, the equivalent plane-wave free-space power densities (S), and induced currents (I) in the body.

The TLVs<sup>®</sup> are summarized in Table 1 as a function of frequency, f, in megahertz (MHz). Table 2 summarizes the major dosimetric quantities in different frequency ranges specified in the TLV<sup>®</sup>, and major hazard mechanisms and typical exposure scenarios that would be of concern.

- A.** For exposures to electric and magnetic free fields, TLVs<sup>®</sup> in Table 1, Part A refer to exposure values obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). In the case of partial body exposure, the TLVs<sup>®</sup> can be relaxed. In nonuniform fields, spatial peak values of field strength may exceed the TLVs<sup>®</sup> if the spatially averaged specific absorption rate (SAR) value remains within the specified limits.
- B.** Access should be restricted to limit the rms RF body current and potential for RF electrostimulation (“shock,” below 0.1 MHz) or perceptible heating (at or above 0.1 MHz) as follows (see Table 1, Part B):
1. For freestanding individuals (no contact with metallic objects), RF current induced in the human body, as measured through either foot, should not exceed the following values, where f is the frequency in MHz:
    - $I = 1000 f \text{ mA}$  for  $(0.03 < f < 0.1 \text{ MHz})$  averaged over 0.2 s;  
where mA = milliamperes
    - $I = 100 \text{ mA}$  for  $(0.1 < f < 100 \text{ MHz})$  averaged over 6 min
  2. For conditions of possible contact with metallic bodies, the maximum RF current that can be passed into the body as measured with a contact current meter should not exceed the following values:
    - $I = 1000 f \text{ mA}$  for  $(0.03 < f < 0.1 \text{ MHz})$  (where f is the frequency in MHz) averaged over 0.2 s
    - $I = 100 \text{ mA}$  for  $(0.1 < f < 100 \text{ MHz})$  averaged over 6 min

**TABLE 1. Radiofrequency and Microwave TLVs<sup>®</sup>**

<b>Part A—Electromagnetic Fields<sup>A</sup> (f = frequency in MHz)</b>				
<b>Frequency</b>	<b>Power Density, S (W/m<sup>2</sup>)</b>	<b>Electric Field Strength, E (V/m)</b>	<b>Magnetic Field Strength, H (A/m)</b>	<b>Averaging Time E<sup>2</sup>, H<sup>2</sup>, or S (min)</b>
30 kHz–100 kHz		1842	163	6
100 kHz–1 MHz		1842	16.3/f	6
1 MHz–30 MHz		1842/f	16.3/f	6
30 MHz–100 MHz		61.4	16.3/f	6
100 MHz–300 MHz	10	61.4	0.163	6
300 MHz–3 GHz	f/30			6
3 GHz–30 GHz	100			34000/f <sup>1.079</sup>
30 GHz–300 GHz	100			68/f <sup>0.476</sup>

<sup>A</sup>The exposure values in terms of electric and magnetic field strengths are obtained by spatially averaging over an area equivalent to the vertical cross-section of the human body (projected area). At frequencies between 100 MHz and 300 MHz, the TLV<sup>®</sup> is defined in the near field of the source in terms of electric and magnetic field, and in the far field in terms of the power density of the wave. At frequencies above 30 GHz, the power density TLV<sup>®</sup> is the limit of exposure averaged over any contiguous 0.01 m<sup>2</sup> of body surface. However, above 30 GHz the maximum power density is 1000 W/m<sup>2</sup> in any one square centimeter.

**Part B—Maximum Induced and Contact Radiofrequency Currents (mA)<sup>B</sup>**

<b>Frequency</b>	<b>Through Both Feet</b>	<b>Through Either Foot</b>	<b>Grasping<sup>B1</sup></b>	<b>Averaging Time</b>
30 kHz–100 kHz	2000 f	1000 f	1000 f	0.2 s <sup>C</sup>
100 kHz–100 MHz	200	100	100	6 min <sup>D</sup>

<sup>B</sup> It should be noted that the current limits given above may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object.

The ceiling value for induced and contact currents is 500 mA for no more than 15 s per 6 min period.

<sup>B1</sup> Maximum touch current is limited to 50% of the maximum grasping current.

<sup>C</sup> I is averaged over a 0.2 s period.

<sup>D</sup> I is averaged over a 6-minute period (e.g., for either foot or hand contact, i.e.,  $I t < 60,000 \text{ mA}^2\text{-min}$ ). In this table, f is the frequency in Hz.

3. For touch contact with conductive objects, the maximum RF current should not exceed more than one-half of the maximum RF current for grasping contact. The means of compliance with these current limits can be determined by the user of the TLVs<sup>®</sup> as appropriate. The use of protective gloves, the avoidance of touch contact with conductive objects, the prohibition of metallic objects, or training of personnel may be sufficient to ensure compliance with these TLVs<sup>®</sup>. Evaluation of the magnitude of the induced currents will normally require a direct measurement. However, induced and contact current measurements are not required if the spatially averaged electric field strength does not exceed the TLV<sup>®</sup> given in Table 1, Part A at frequencies between 0.1 and 100 MHz, as shown graphically in Figure 2.
- C. For source frequencies greater than 100 MHz, Table 1, Part A provides an equivalent plane-wave power density,  $S$  (in  $W/m^2$ ), which can be calculated from field strength measurement data as follows:

$$S = \frac{E^2}{377}$$

where:  $E^2$  is in volts squared ( $V^2$ ) per meter squared ( $m^2$ ); and

$$S = 377 H^2$$

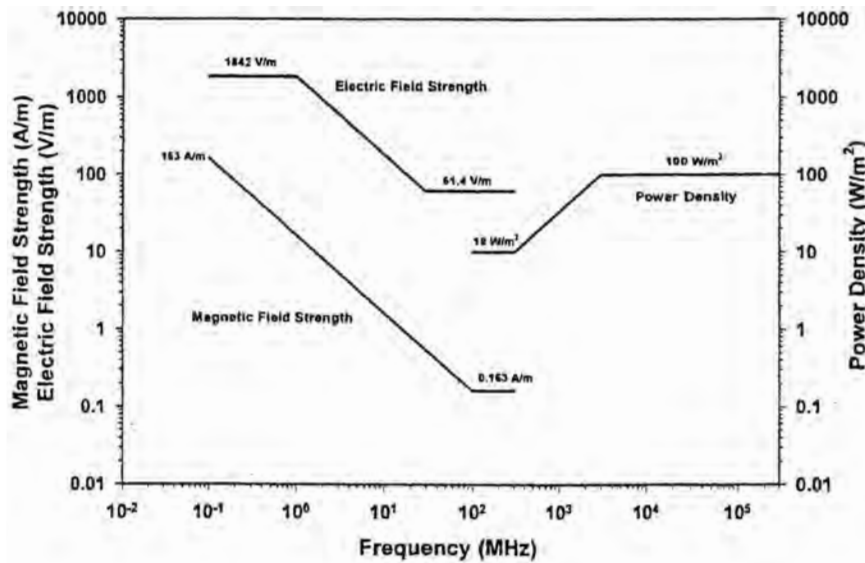
where:  $H^2$  is in amperes squared ( $A^2$ ) per meter squared ( $m^2$ ).

- D. For exposures to pulsed fields of pulse duration less than 100 milliseconds (ms) at frequencies in the range 0.1 MHz to 300 GHz, the total incident energy density during any 100 ms period within the averaging time (see Table 1, Part A) shall not exceed 20% of the total specific energy absorption (SA) permitted during the entire averaging time for a continuous field, i.e.,  $0.2 \times 144 = 28.8$  J/kg. For pulse durations greater than 100 ms, normal time-averaging calculations apply.

The TLV<sup>®</sup> values in Table 1 should be used as guides in the evaluation and control of exposure to radiofrequency and microwave radiation and should not be regarded as fine lines between safe and dangerous levels. The values of  $E$ ,  $H$  and  $S$  given in Table 1, Part A are shown graphically as a function of frequency in Figure 1. Figure 2 depicts the maximum permissible current values given in Table 1, Part B through one foot or touch current as a function of the maximum permissible electric field strength TLV<sup>®</sup> over the frequency range 0.1 to 100 MHz.

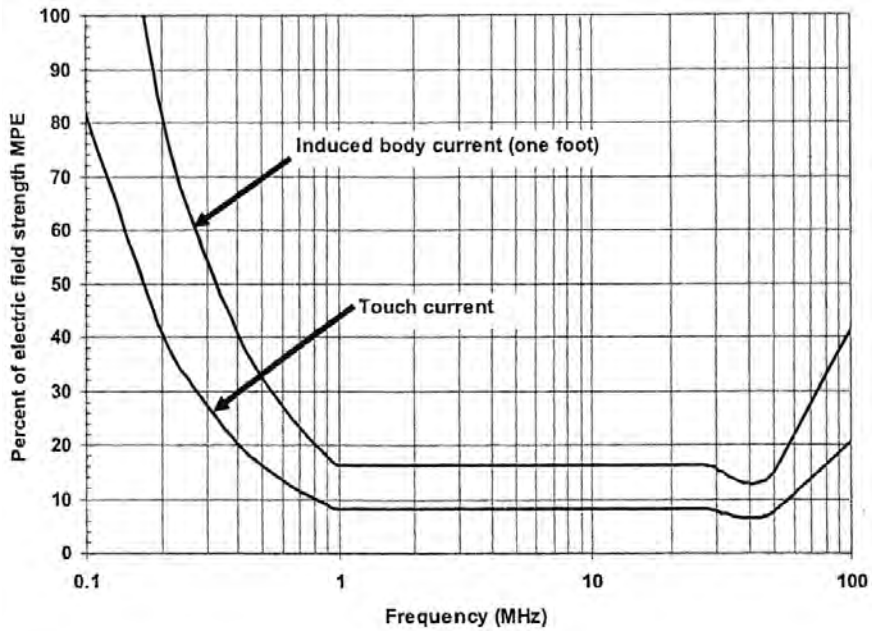
#### Notes:

1. It is believed that workers may be exposed repeatedly to fields up to these TLVs<sup>®</sup> without adverse health effects. Nevertheless, personnel should not needlessly be exposed to higher levels of RF radiation, approaching the TLVs<sup>®</sup>, when simple measures can prevent it.
2. For mixed or broadband fields at a number of frequencies for which there are different values of the TLV<sup>®</sup>, the fraction of the TLV<sup>®</sup> (in terms of  $E^2$ ,



**FIGURE 1.** Threshold Limit Values (TLVs<sup>®</sup>) for Radiofrequency/Microwave Radiation in the workplace (for whole-body specific absorption rate [SAR] < 0.4 W/kg). (From IEEE Std. C95.1 – 2005a. Copyright © IEEE. All Rights Reserved).

**TLV<sup>®</sup>-PA**



**FIGURE 2.** Percent of electric field strength TLVs<sup>®</sup> below which induced and contact current limits are *not* required from 0.1 to 100 MHz. (From IEEE Std. C95.1 – 2005a. Copyright © IEEE. All Rights Reserved).



**TABLE 2. Major Frequency Ranges Covered by the TLV®**

<b>Part A – Frequency Range</b>				
	<b>30 kHz– 100 kHz</b>	<b>100 kHz– 100 MHz</b>	<b>100 MHz– 300 MHz*</b>	<b>300 MHz– 300 GHz</b>
Electric Field	X	X	X	
Magnetic Field	X	X	X	
Power Density			X	X
Contact Current	X	X†		
<b>Part B – Hazard Mechanism</b>				
	<b>Electrical stimulation</b>	<b>Thermal</b>	<b>Thermal</b>	
<b>Typical cause of injury</b>	Contact current (current introduced into body from touching a charged conductor)	Contact current / possible RF heating of deeper tissues	RF heating of tissues	
<b>Typical injury</b>	Electric shock (sometimes burns)	Burns (can be deep in tissue)	Excessive whole body heating/heat stress	
<b>Example sources with potential overexposure</b>	AM radio transmission tower	RF heat sealers and FM transmitting antennae	High-powered broadcasting transmitting antennae (e.g., TV)	Industrial microwave heating equipment, high-powered transmitting antennae



\*Power density measurements should be made in the far field of the source; otherwise, measurements should be made of electric and magnetic field as appropriate.

† Measure contact current if the electric field is greater than the % of E-TLV® for that frequency (see Figure 2).

- H<sup>2</sup>, or S) incurred within each frequency interval should be determined and the sum of all such fractions should not exceed unity.
3. The TLVs® refer to values averaged over any 6-minute (0.1-h) period for frequencies less than 3 GHz, and over shorter periods for higher frequencies down to 10 seconds at 300 GHz, as indicated in Table 1, Part A.
  4. At frequencies between 0.1 and 3 GHz, the TLVs® for electromagnetic field strengths may be exceeded if:
    - a) the exposure conditions can be shown by appropriate techniques to produce SARs below 0.4 W/kg, as averaged over the whole body;
    - b) the induced currents in the body conform with the TLVs® in Table 1, Part B; and
    - c) spatial peak SAR values do not exceed 10 W/kg, as averaged over any cubic volume with 10 g of tissue, except for the hands, wrists, feet,

ankles, and pinnae, where the spatial peak SAR exposure should not exceed 20 W/kg averaged over any cubic volume of tissue containing 10 g. The SARs are to be averaged over 6 minutes.

5. Above 3 GHz, relaxation of the TLV<sup>®</sup> conditions may be permissible under partial body exposure conditions.
6. The measurement of RF field should follow the recommendations given in IEEE C95.3-2002 (IEEE, 2002) and Report No. 119 of the National Council on Radiation Protection and Measurements (NCRP, 1993).

### References

Institute of Electrical and Electronic Engineers (IEEE): IEEE Recommended Practice for Measurements and Computations of Radiofrequency Electromagnetic Fields with Respect to Human Exposure to Such Fields, 100 kHz–300 GHz. IEEE C95.3-2002. IEEE, New York (2002).

Institute of Electrical and Electronic Engineers (IEEE): IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz. IEEE C95.1-2005. IEEE, New York (2005a).

National Council on Radiation Protection and Measurements (NCRP): A Practical Guide to the Determination of Human Exposures to Radiofrequency Fields. Report No 119. NCRP, Bethesda, MD (1993).

## OPTICAL RADIATION

### LIGHT AND NEAR-INFRARED RADIATION

These TLVs<sup>®</sup> refer to values for incoherent (non-laser) visible and near-infrared radiation (LNIR) in the wavelength region of 305 to 3000 nm that nearly all workers may be exposed without adverse health effects. The values are based on the best available information from experimental studies. They should be used only as guides in the control of exposures to light and should not be regarded as fine lines between safe and dangerous levels. For purposes of specifying these TLVs<sup>®</sup>, the optical radiation spectrum is divided into the regions shown in the figure “The Electromagnetic Radiation Spectrum and Related TLVs<sup>®</sup>” found at the beginning of the section on Electromagnetic Fields 0–300 GHz.

#### Recommended Values

The TLVs<sup>®</sup> for occupational exposure of the eyes to broadband light and near-infrared radiation apply to exposures in any 8-hour workday. Table 1 provides examples of sources and the applicable TLV<sup>®</sup>. Figure 1 is a guide to the application of the TLVs<sup>®</sup> for visible and near-infrared sources.

The LNIR TLVs<sup>®</sup> are divided into four potential health effects and spectral regions as follows:

**Section 1.** *To protect against retinal photo-chemical injury from chronic blue-light ( $305 < \lambda < 700$  nm) exposure:* Determine the effective radiance of the light source ( $L_B$ ) in  $W \cdot cm^{-2} \cdot sr^{-1}$  by integrating the spectral radiance ( $L_\lambda$ ) in  $W \cdot cm^{-2} \cdot sr^{-1} \cdot nm^{-1}$  weighted by the blue-light hazard function  $B(\lambda)$  using Equation 1 or a light meter with a  $B(\lambda)$  filter.  $B(\lambda)$  is shown in Figure 2 and values are provided in Table 2.

$$L_B [W \cdot cm^{-2} \cdot sr^{-1}] = \sum_{305}^{700} L_\lambda \cdot B(\lambda) \cdot \Delta\lambda \quad (1)$$

Some meters provide a total energy emitted in units of  $J \cdot cm^{-2} \cdot sr^{-1}$  over the sampling period, which is the time integral of  $L_B$  over the sampling period.  $L_B$  is the total energy divided by the sample period.

For viewing durations ( $t$ ) less than  $10^4$  s (167 mins or  $\sim 2.8$  hrs) in a day, an acceptable exposure is present when:

$$L_B [W \cdot cm^{-2} \cdot sr^{-1}] \leq 100 \cdot t^{-1} \quad (2a)$$

Alternatively, when  $L_B$  exceeds  $0.01 W \cdot cm^{-2} \cdot sr^{-1}$ , the maximum acceptable exposure duration  $t_{max}$  in seconds is:

$$t_{max} [s] = 100(L_B)^{-1} \quad (2b)$$



**TABLE 1. Example Sources of Non-Laser Optical Radiation and Applicable TLVs®**

<i>Source Type*</i>	<b>Arc Sources</b>	<b>Discharge Lamps</b>	<b>Fluorescent Lamps and LEDs</b>	<b>Thermal Sources</b>	<b>Germicidal Lamps</b>
	Arc welding; Arc lamps; Xenon-arc searchlights		White-light and “black-light” fluorescent lamps; Visible or UV-A LEDs	Hot and molten metals; Gas welding; Incandescent lamps; IR LEDs	Low-pressure mercury discharge lamps; UV-B and UV-C lamps and LEDs
Ultraviolet <i>See UV TLV®</i>	◆◆	◆	◆		◆◆
Blue-Light <i>See LNIR Section 1</i>	◆◆	◆◆	◆		
IR Cornea/Lens <i>See LNIR Section 2</i>	◆	◆		◆◆	
Infrared Retina <i>See LNIR Section 3</i>	f	f		◆	
Retinal Thermal <i>See LNIR Section 4</i>	M				

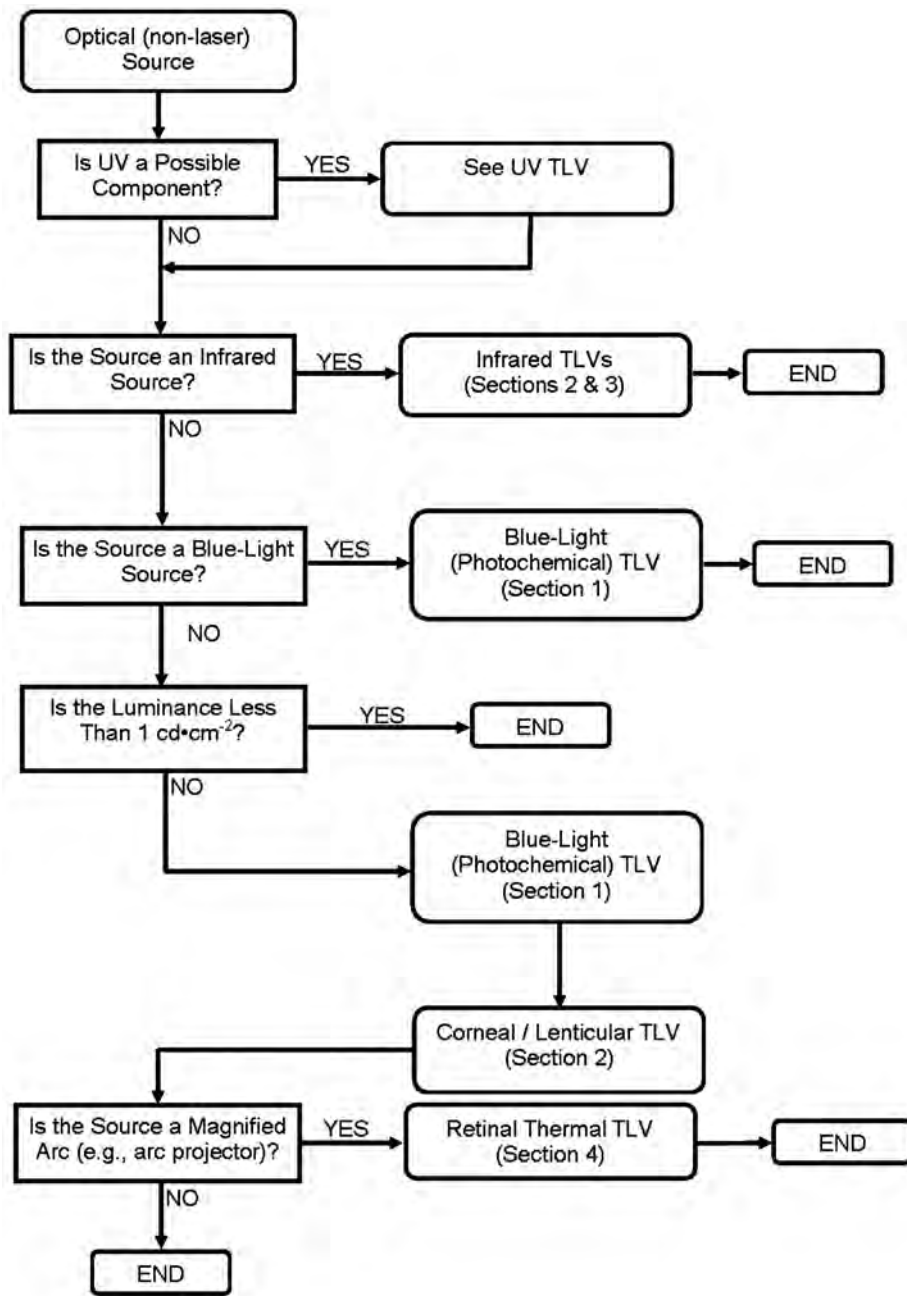
◆◆ – Likely

◆ – Possible

f – Applicable when filtered lamp blocks visible emission

M – Only if magnified source size (e.g., searchlight or projection optics)

\*A special type of diode emitter, the super-luminescent diode (SLD), although not a laser, should be assessed with the laser TLV®.



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FIGURE 1. Evaluation scheme for visible and near-infrared radiation.

For viewing durations greater than  $10^4$  s (167 mins) in a day, an acceptable exposure is present when:

$$L_B [W \cdot cm^{-2} \cdot sr^{-1}] \leq 10^{-2} \quad (2c)$$

*Note for blue-light hazard:* The  $L_B$  limits are greater than the maximum permissible exposure limits for 440 nm laser radiation (see Laser TLV®) because of the need for caution related to narrow-band spectral effects of lasers.

**SPECIAL CASE FOR SMALL-SOURCE ANGLES:** For a light source subtending an angle less than 0.011 radian, the above limits are relaxed. Determine the effective irradiance ( $E_B$ ) by integrating the spectral irradiance ( $E_\lambda$ ) weighted by the blue-light hazard function  $B(\lambda)$ :

$$E_B [W \cdot cm^{-2}] = \sum_{305}^{700} E_\lambda \cdot B(\lambda) \cdot \Delta\lambda \quad (3)$$

For durations less than 100 s (1 min, 40 s) in a day, an acceptable exposure is present when:

$$E_B [W \cdot cm^{-2}] = 0.01 \cdot t^{-1} \quad (4a)$$

Alternatively, for a source where the blue-light weighted irradiance  $E_B$  exceeds  $10^{-4} W \cdot cm^{-2}$ , the maximum acceptable exposure duration,  $t_{max}$ , in seconds is:

$$t_{max} [s] = 0.01 \cdot (E_B)^{-1} \quad (4b)$$

For viewing durations greater than  $10^2$  s (1 min, 40 s) in a day, an acceptable exposure is present when:

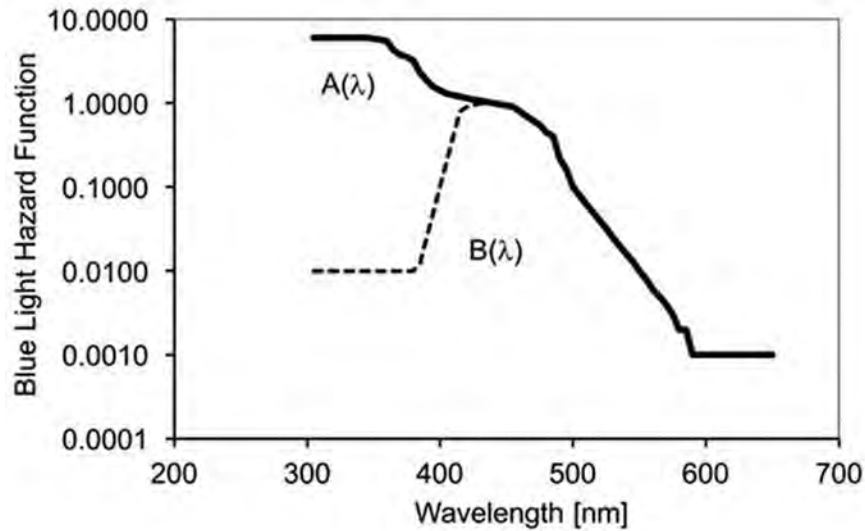
$$E_B [W \cdot cm^{-2}] \leq 10^{-4} \quad (4c)$$

**SPECIAL CASE:** To protect the worker having a lens removed (cataract surgery) against retinal photochemical injury from chronic exposure: Unless an ultraviolet (UV)-absorbing intraocular lens has been surgically inserted into the eye, the Aphakic Hazard Function,  $A(\lambda)$ , should be used for  $L_B$  and  $E_B$ , as shown in Equations 5a and 5b.

$$L_B [W \cdot cm^{-2} \cdot sr^{-1}] = \sum_{305}^{700} L_\lambda \cdot A(\lambda) \cdot \Delta\lambda \quad (5a)$$

$$E_B [W \cdot cm^{-2}] = \sum_{305}^{700} E_\lambda \cdot A(\lambda) \cdot \Delta\lambda \quad (5b)$$

The value for  $L_B$  is used in Equation 2 and the value for  $E_B$  is used in Equation 4.



**FIGURE 2.** Blue-light (retinal photochemical) hazard function for normal eyes [B( $\lambda$ )] and the aphakic hazard function [A( $\lambda$ )].

**Section 2.** *To protect against thermal injury to the cornea and lens from infrared (IR) radiation:* To avoid thermal injury of the cornea and possible delayed effects on the lens of the eye (cataractogenesis), the total infrared irradiance in hot environments is calculated as:

$$E_{IR-only} [W \cdot cm^{-2}] = \sum_{770}^{3000} E_{\lambda} \cdot \Delta\lambda \quad (6)$$

For exposure durations ( $t$ ) less than  $10^3$  sec (17 mins), an acceptable exposure is present when:

$$E_{IR-only} [W \cdot cm^{-2}] \leq 1.8 \cdot t^{-0.75} \quad (7a)$$

For exposure durations greater than  $10^3$  sec (17 mins), an acceptable exposure is present when:

$$E_{IR-only} [W \cdot cm^{-2}] \leq 0.01 \quad (7b)$$

**Section 3.** *To protect against retinal thermal injury from near-infrared (NIR) radiation:* For a near-infrared source associated with an infrared heat lamp or any NIR source where a strong visual stimulus is absent (luminance less than  $10^{-2}$  cd  $\cdot$  cm $^{-2}$ ), the total effective radiance ( $L_{NIR}$ ) as viewed by the eye is the integrated spectral radiance ( $L_{\lambda}$ ) weighted by the thermal hazard function,  $R(\lambda)$ .

$$L_{NIR} [W \cdot cm^{-2} \cdot sr^{-1}] = \sum_{770}^{1400} L_{\lambda} \cdot R(\lambda) \cdot \Delta\lambda \quad (8)$$

**TABLE 2. Retinal and UVR Hazard Spectral Weighting Functions**

Wavelength (nm)	Aphakic Hazard Function A( $\lambda$ )	Blue-Light Hazard Function B( $\lambda$ )	Retinal Thermal Hazard Function R( $\lambda$ )
305–335	6.000	0.01	—
340	5.880	0.01	—
345	5.710	0.01	—
350	5.460	0.01	—
355	5.220	0.01	—
360	4.620	0.01	—
365	4.290	0.01	—
370	3.750	0.01	—
375	3.560	0.01	—
380	3.190	0.01	0.01
385	2.310	0.0125	0.0125
390	1.880	0.025	0.025
395	1.580	0.050	0.050
400	1.430	0.100	0.100
405	1.300	0.200	0.200
410	1.250	0.400	0.400
415	1.200	0.800	0.800
420	1.150	0.900	0.900
425	1.110	0.950	0.950
430	1.070	0.980	0.980
435	1.030	1.000	1.00
440	1.000	1.000	1.00
445	0.970	0.970	1.00
450	0.940	0.940	1.00
455	0.900	0.900	1.00
460	0.800	0.800	1.00
465	0.700	0.700	1.00
470	0.620	0.620	1.00
475	0.550	0.550	1.00
480	0.450	0.450	1.00
485	0.400	0.400	1.00
490	0.220	0.220	1.00
495	0.160	0.160	1.00
500	0.100	0.100	1.00
505	0.079	0.079	1.00
510	0.063	0.063	1.00
515	0.050	0.050	1.00
520	0.040	0.040	1.00
525	0.032	0.031	1.00
530	0.025	0.025	1.00
535	0.020	0.020	1.00
540	0.016	0.016	1.00
545	0.013	0.013	1.00
550	0.010	0.010	1.00
555	0.008	0.008	1.0
560	0.006	0.006	1.0
565	0.005	0.005	1.0
570	0.004	0.004	1.0
575	0.003	0.003	1.0

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**TABLE 2 (cont.). Retinal and UVR Hazard Spectral Weighting Functions**

Wavelength (nm)	Aphakic Hazard Function A( $\lambda$ )	Blue-Light Hazard Function B( $\lambda$ )	Retinal Thermal Hazard Function R( $\lambda$ )
580	0.002	0.002	1.0
585	0.002	0.002	1.0
590	0.001	0.001	1.0
595	0.001	0.001	1.0
600–700	0.001	0.001	1.0
700–1050	—	—	$10^{\{(700-\lambda)/500\}}$
1050–1150	—	—	0.2
1150–1200	—	—	$0.2 \times 10^{\{0.02(1150-\lambda)\}}$
1200–1400	—	—	0.02

Limits for IR only exposures are based on a 7-mm pupil diameter (since the aversion response may not exist due to an absence of light) and a detector field-of-view of 0.011 rad. For exposures less than 810 s, an acceptable exposure is present when:

$$L_{NIR} [W \cdot cm^{-2} \cdot sr^{-1}] < 3.2 \cdot \alpha^{-1} \cdot t^{-0.25} \quad (9a) \blacklozenge$$

For exposures greater than 810 s in a day, an acceptable exposure is present when:

$$L_{NIR} [W \cdot cm^{-2} \cdot sr^{-1}] \leq 0.6 \cdot \alpha^{-1} \quad (9b) \blacklozenge$$

**Section 4.** *To protect against retinal thermal injury from a visible light source:* Determine the effective radiance of the lamp ( $L_R$ ) in  $W \cdot cm^{-2} \cdot sr^{-1}$  [ $sr$  = steradian] by integrating the spectral radiance ( $L_\lambda$ ) in  $W \cdot cm^{-2} \cdot sr^{-1} \cdot nm$  weighted by the thermal hazard function  $R(\lambda)$ , using Equation 10 or a light meter with an  $R(\lambda)$  filter.  $R(\lambda)$  is shown in Figure 3.

$$L_R [W \cdot cm^{-2} \cdot sr^{-1}] = \sum_{380}^{1400} L_\lambda \cdot R(\lambda) \cdot \Delta\lambda \quad (10)$$

Some meters provide a total time-integrated radiance emitted in units of  $J \cdot cm^{-2} \cdot sr^{-1}$  over the sampling period, which is the time integral of  $L_R$  over the sampling period. Therefore, an alternative expression of the retinal thermal injury TLV<sup>®</sup> is a dose limit (called  $DL_R$  in this TLV<sup>®</sup>).

Determine the angular subtense ( $\alpha$ ) of the source in radians (rad). For circular lamps,  $\alpha$  is the lamp diameter divided by the viewing distance. If the lamp is oblong,  $\alpha$  is estimated from the mean of the shortest and longest dimension that can be viewed divided by the viewing distance; that is according to Equation 11.

$$\alpha [rad] = \frac{(l + w)}{2r} \quad (11)$$

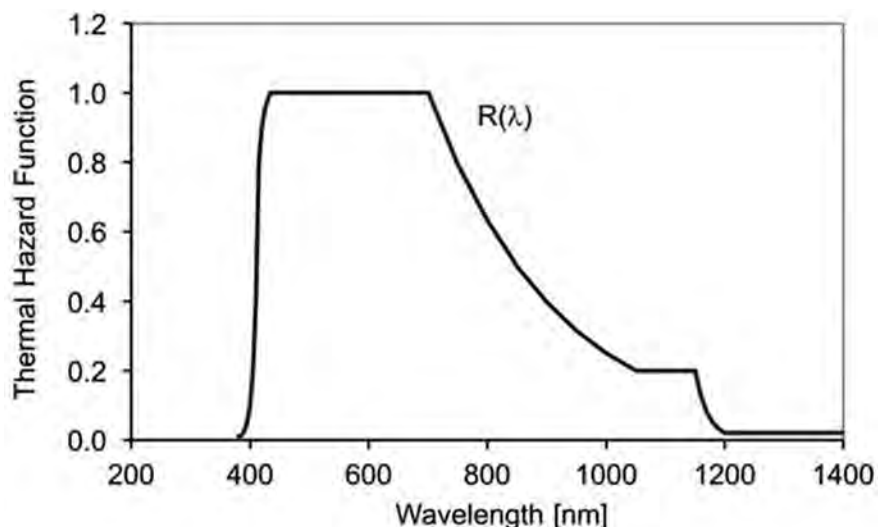


FIGURE 3. Retinal thermal hazard function  $[R(\lambda)]$ .

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For instance, at a viewing distance  $r = 100$  cm from a 0.8 cm diameter tubular flash lamp of length  $l = 5$  cm, the viewing angle  $\alpha$  is 0.029 rad.

Large sources are those with an angular subtense ( $\alpha$ ) greater than 0.1 rad. For large sources, Equations 12a through 12c define the TLV® for protection against retinal thermal injury depending on the exposure duration ( $t$ ) in seconds [s]. These limits also serve as a useful screening step.

For viewing durations ( $t$ ) from 1  $\mu$ s ( $10^{-6}$  s) through 0.00063 s, an acceptable exposure is present when Equation 12a is true. For pulse durations less than 1  $\mu$ s, the TLV® is the same as that for 1  $\mu$ s. Since the retinal thermal hazard TLVs® for pulsed sources assume a 7-mm, dark-adapted pupil, this exposure limit may be modified for daylight conditions.

$$L_R [W \cdot cm^{-2} \cdot sr^{-1}] \leq 640 \cdot t^{-0.25} \quad (12a) \blacklozenge$$

OR

$$DL_R [J \cdot cm^{-2} \cdot sr^{-1}] \leq 640 \cdot t^{0.75}$$

For viewing durations between 0.63 ms (0.00063 s) and 0.25 s, an acceptable exposure is present when Equation 12b is true.

$$L_R [W \cdot cm^{-2} \cdot sr^{-1}] \leq 16 \cdot t^{-0.75} \quad (12b) \blacklozenge$$

OR

$$DL_R [J \cdot cm^{-2} \cdot sr^{-1}] \leq 16 \cdot t^{1/4}$$

For viewing durations greater than 0.25 s, an acceptable exposure is present when Equation 12c is true. This is a rate-limited, rather than dose-limited, threshold.

$$L_R [W \cdot cm^{-2} \cdot sr^{-1}] \leq 45 \quad (12c) \blacklozenge$$

Small sources have an angular subtense ( $\alpha$ ) less than 0.1 rad, but are limited to no less than 1.7 mrad. For small sources, the retinal thermal injury risk depends on both the exposure duration ( $t$ ) and  $\alpha$ . The interaction is a maximum value for  $\alpha$  ( $\alpha_{\max}$ ) as a function of viewing duration ( $t$  [s]).

For viewing durations from 1  $\mu$ s ( $10^{-6}$  s) through 0.00063 s, an acceptable exposure is present when Equation 12a above is true. For pulse durations less than 1  $\mu$ s, the TLV<sup>®</sup> is the same as that for 1  $\mu$ s. Since the retinal thermal hazard TLVs<sup>®</sup> for pulsed sources assume a 7-mm, dark-adapted pupil, this exposure limit may be modified for daylight conditions.

For viewing durations from 0.00063 to 0.25 s, an acceptable exposure is present when Equation 13a is true.

$$\text{With } \alpha < \alpha_{\max} = 0.2 \cdot t^{0.5} \text{ rad,}$$

$$L_R [W \cdot cm^{-2} \cdot sr^{-1}] \leq 3.2 \cdot \alpha^{-1} \cdot t^{-0.25} \quad (13a) \blacklozenge$$

OR

$$DL_R [J \cdot cm^{-2} \cdot sr^{-1}] \leq 3.2 \cdot \alpha^{-1} \cdot t^{0.75}$$

For viewing durations greater than 0.25 s, an acceptable exposure is present when Equation 13b is true. This is a rate-limited exposure and a dose limit does not apply.

$$\text{With } \alpha < \alpha_{\max} = 0.1 \text{ rad,}$$

$$L_R [W \cdot cm^{-2} \cdot sr^{-1}] \leq 4.5 \cdot \alpha^{-1} \quad (13b) \blacklozenge$$

*Note:* There may be special individual circumstances where the pupil remains dilated (tonic) and exposures extend beyond 0.25 s. Under these conditions, Equation 13c is the limiting exposure.

$$\text{With } \alpha < \alpha_{\max} = 0.1 \text{ rad,}$$

$$L_R [W \cdot cm^{-2} \cdot sr^{-1}] \leq 3.2 \cdot \alpha^{-1} \cdot t^{-0.25} \quad (13c) \blacklozenge$$

◆ Equations 9, 12, and 13 are empirical and are not dimensionally correct. To obtain the correct value in the units given on the left side of the equation,  $\alpha$  must be in radians and  $t$  in seconds. To make the equations dimensionally correct, one would have to insert unity dimensional correction factors in the right-hand numerator in each equation.

## ULTRAVIOLET RADIATION

These TLVs® refer to incoherent ultraviolet (UV) radiation with wavelengths between 180 and 400 nm and represent conditions under which it is believed that nearly all healthy workers may be repeatedly exposed without acute adverse health effects such as erythema and photokeratitis. Some UV sources covered by this TLV® are welding and carbon arcs, gas and vapor discharges, fluorescent, incandescent and germicidal lamps, and solar radiation. Coherent UV radiation from lasers is covered in the TLV® for Lasers. The TLV® values apply to continuous sources for exposure durations equal to or greater than 0.1 second. The sources may subtend an angle less than 80 degrees at the detector and for those sources that subtend a greater angle need to be measured over an angle of 80 degrees.

The values do not apply to UV radiation exposure of photosensitive individuals or of individuals concomitantly exposed to photo-sensitizing agents (see Note 3). The values for the eye do not apply to aphakes (persons who have had the lens of the eye removed in cataract surgery), for which case, see Light and Near-Infrared Radiation TLVs®.

The TLVs® should be used as guides in the control of exposure to UV sources and should not be regarded as fine lines between safe and dangerous levels.

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### Threshold Limit Values

The TLVs® for occupational exposure to UV radiation incident upon the skin or the eye follow. The flow chart in Figure 1 provides a map of the UV TLV®.

#### ***Broadband UV Sources (180 to 400 nm) — Corneal Hazard***

The first step in evaluating broadband UV sources is to determine the effective irradiance ( $E_{\text{eff}}$ ). To determine  $E_{\text{eff}}$  for a broadband source weighted against the peak of the spectral effectiveness curve (270 nm), Equation 1 should be used.

$$E_{\text{eff}} = \sum_{180}^{400} E_{\lambda} \cdot S(\lambda) \cdot \Delta\lambda \quad (1)$$

- where:
- $E_{\text{eff}}$  = effective irradiance relative to a monochromatic source at 270 nm [W/cm<sup>2</sup>]
  - $E_{\lambda}$  = spectral irradiance at a center wavelength [W/(cm<sup>2</sup> • nm)]
  - $S(\lambda)$  = relative spectral effectiveness at the center wavelength [unitless]
  - $\Delta\lambda$  = bandwidth around the center wavelength [nm]

More practically,  $E_{\text{eff}}$  can be measured directly with a UV radiometer having a built-in spectral response that mimics the relative spectral effectiveness values in Table 1 and Figure 2.

The daily exposure ( $t_{\text{exp}}$ ) based on  $E_{\text{eff}}$  is dose limited to  $0.003 \text{ J/cm}^2$ . That is,

$$0.003[\text{J}/\text{cm}^2] \geq E_{\text{eff}}[\text{W}/\text{cm}^2] \cdot t_{\text{exp}}[\text{s}] \quad (2)$$

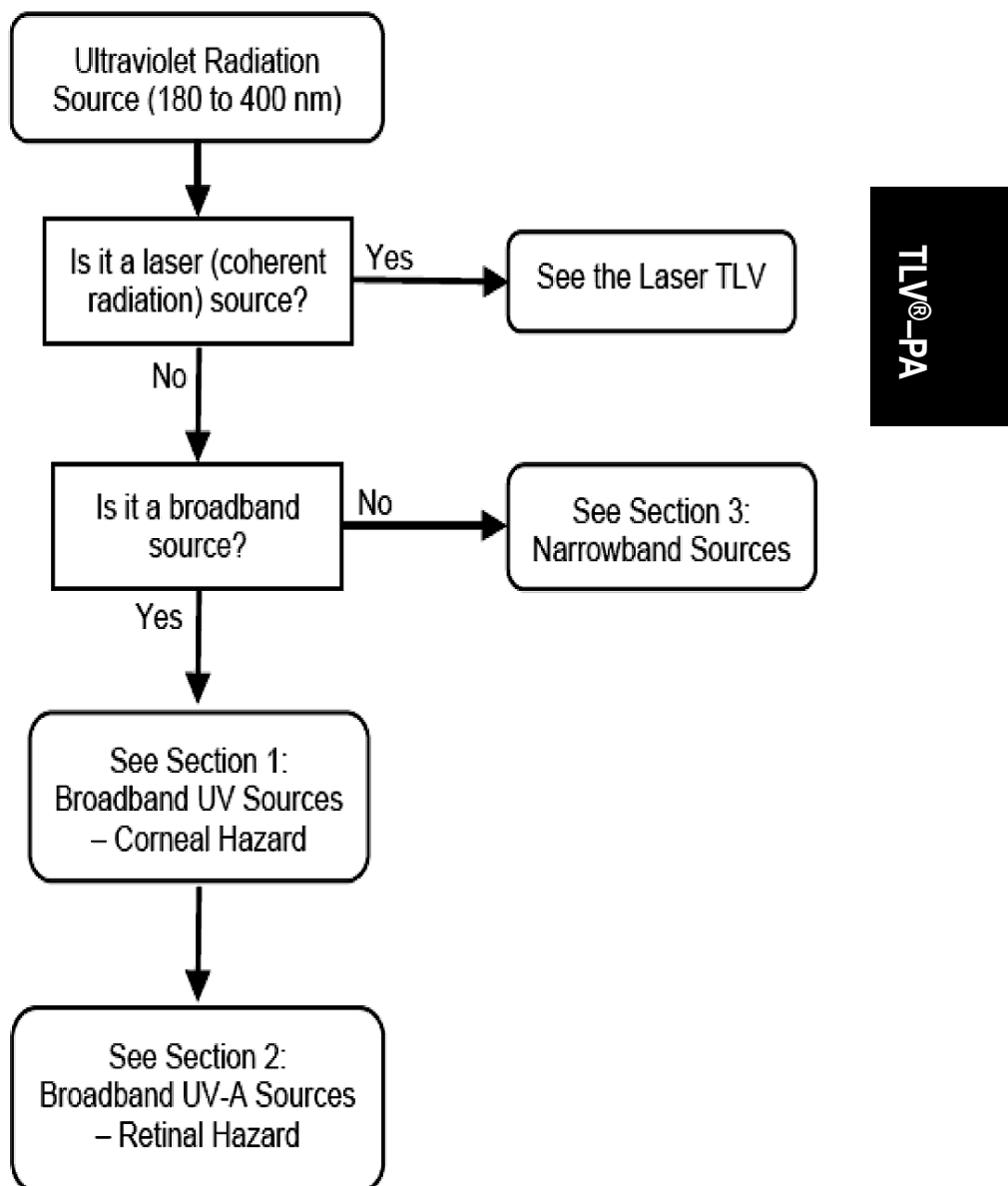


FIGURE 1. Flow chart for UV TLV®.

**TABLE 1. Ultraviolet Radiation TLV<sup>®</sup> and Relative Spectral Effectiveness**

Wavelength <sup>A</sup> (nm)	TLV <sup>®</sup> (J/m <sup>2</sup> ) <sup>B</sup>	TLV <sup>®</sup> (mJ/cm <sup>2</sup> ) <sup>B</sup>	Relative Spectral Effectiveness, S( $\lambda$ )
180	2500	250	0.012
190	1600	160	0.019
200	1000	100	0.030
205	590	59	0.051
210	400	40	0.075
215	320	32	0.095
220	250	25	0.120
225	200	20	0.150
230	160	16	0.190
235	130	13	0.240
240	100	10	0.300
245	83	8.3	0.360
250	70	7.0	0.430
254 <sup>C</sup>	60	6.0	0.500
255	58	5.8	0.520
260	46	4.6	0.650
265	37	3.7	0.810
270	30	3.0	1.00
275	31	3.1	0.960
280 <sup>C</sup>	34	3.4	0.880
285	39	3.9	0.770
290	47	4.7	0.640
295	56	5.6	0.540
297 <sup>C</sup>	65	6.5	0.460
300	100	10	0.300
303 <sup>C</sup>	250	25	0.120
305	500	50	0.060
308	1200	120	0.026
310	2000	200	0.015
313 <sup>C</sup>	5000	500	0.006
315	$1.0 \times 10^4$	$1.0 \times 10^3$	0.003
316	$1.3 \times 10^4$	$1.3 \times 10^3$	0.0024
317	$1.5 \times 10^4$	$1.5 \times 10^3$	0.0020
318	$1.9 \times 10^4$	$1.9 \times 10^3$	0.0016
319	$2.5 \times 10^4$	$2.5 \times 10^3$	0.0012
320	$2.9 \times 10^4$	$2.9 \times 10^3$	0.0010
322	$4.5 \times 10^4$	$4.5 \times 10^3$	0.00067
323	$5.6 \times 10^4$	$5.6 \times 10^3$	0.00054
325	$6.0 \times 10^4$	$6.0 \times 10^3$	0.00050
328	$6.8 \times 10^4$	$6.8 \times 10^3$	0.00044
330	$7.3 \times 10^4$	$7.3 \times 10^3$	0.00041
333	$8.1 \times 10^4$	$8.1 \times 10^3$	0.00037
335	$8.8 \times 10^4$	$8.8 \times 10^3$	0.00034
340	$1.1 \times 10^5$	$1.1 \times 10^4$	0.00028
345	$1.3 \times 10^5$	$1.3 \times 10^4$	0.00024
350	$1.5 \times 10^5$	$1.5 \times 10^4$	0.00020

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**TABLE 1 (cont.). Ultraviolet Radiation TLV<sup>®</sup> and Relative Spectral Effectiveness**

Wavelength <sup>A</sup> (nm)	TLV <sup>®</sup> (J/m <sup>2</sup> ) <sup>B</sup>	TLV <sup>®</sup> (mJ/cm <sup>2</sup> ) <sup>B</sup>	Relative Spectral Effectiveness, S(λ)
355	1.9 × 10 <sup>5</sup>	1.9 × 10 <sup>4</sup>	0.00016
360	2.3 × 10 <sup>5</sup>	2.3 × 10 <sup>4</sup>	0.00013
365 <sup>C</sup>	2.7 × 10 <sup>5</sup>	2.7 × 10 <sup>4</sup>	0.00011
370	3.2 × 10 <sup>5</sup>	3.2 × 10 <sup>4</sup>	0.000093
375	3.9 × 10 <sup>5</sup>	3.9 × 10 <sup>4</sup>	0.000077
380	4.7 × 10 <sup>5</sup>	4.7 × 10 <sup>4</sup>	0.000064
385	5.7 × 10 <sup>5</sup>	5.7 × 10 <sup>4</sup>	0.000053
390	6.8 × 10 <sup>5</sup>	6.8 × 10 <sup>4</sup>	0.000044
395	8.3 × 10 <sup>5</sup>	8.3 × 10 <sup>4</sup>	0.000036
400	1.0 × 10 <sup>6</sup>	1.0 × 10 <sup>5</sup>	0.000030

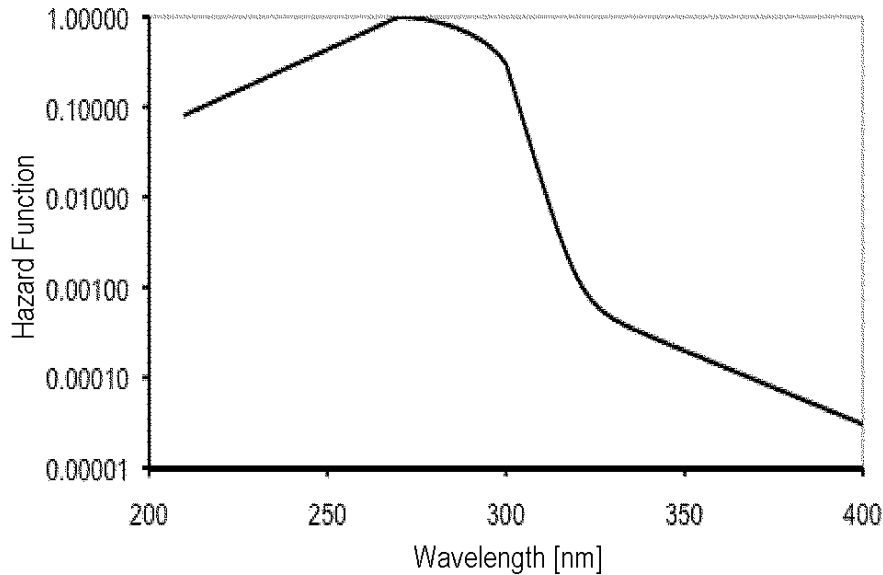
<sup>A</sup> Wavelengths chosen are representative; other values should be interpolated at intermediate wavelengths.

<sup>B</sup> 1 mJ/cm<sup>2</sup> = 10 J/m<sup>2</sup>

<sup>C</sup> Emission lines of a mercury discharge spectrum.

Table 2 gives TLV<sup>®</sup> values for the effective irradiance for different daily exposure durations. In general, the maximum exposure time ( $t_{max}$ ) [s] for a broadband UV source can be determined from Equation 3.

$$t_{max} [s] = \frac{0.003 [J/cm^2]}{E_{eff} [W/cm^2]} \tag{3}$$



**FIGURE 2.** Hazard function (relative spectral effectiveness, S(λ)) for UV.

**TABLE 2. Exposure Durations for Given Actinic UV Radiation Effective Irradiances**

<b>Duration of Exposure Per Day</b>	<b>Effective Irradiance, <math>E_{\text{eff}}</math> (mW/cm<sup>2</sup>)</b>
8 hours	0.0001
4 hours	0.0002
2 hours	0.0004
1 hour	0.0008
30 minutes	0.0017
15 minutes	0.0033
10 minutes	0.005
5 minutes	0.01
1 minute	0.05
30 seconds	0.1
10 seconds	0.3
1 second	3
0.5 second	6
0.1 second	30

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**Broadband UV-A Sources (315 to 400 nm) — Lens and Retinal Hazard**

The irradiance,  $E_{\text{UV-A}}$  [mW/cm<sup>2</sup>], can be measured with an unfiltered meter that is sensitive to UV-A radiation. For daily exposure periods ( $t_{\text{exp}}$ ) less than 1000 s (17 min), the exposure is dose limited to 1000 mJ/cm<sup>2</sup> as described in Equation 4.

$$1000 \text{ [mJ/cm}^2\text{]} \geq E_{\text{UV-A}} \text{ [mW/cm}^2\text{]} \cdot t_{\text{exp}} \text{ [s]} \quad (4)$$

For daily exposure periods greater than 1000 s (17 min), the exposure is rate limited to 1.0 mW/cm<sup>2</sup> as described in Equation 5.

$$1.0 \text{ [mW/cm}^2\text{]} \geq E_{\text{UV-A}} \text{ [mW/cm}^2\text{]} \quad (5)$$

**Narrowband Sources**

Narrowband sources are comprised of one wavelength or a narrow band of wavelengths (e.g., within 5–10 nm). Locate the center wavelength ( $\lambda$ ) in Table 1, and find the TLV <sub>$\lambda$</sub>  as an 8-hour dose limit in J/m<sup>2</sup> or mJ/cm<sup>2</sup>. The narrowband TLV® is protective for both corneal and retinal exposures.

The dose limit may be adjusted proportionately for work periods of longer or shorter duration. The TLV® dose limit of a daily exposure period ( $t_{\text{exp}}$ ) for a narrowband source can be expressed as Equation 6 using the Spectral Sensitivity ( $S_{\lambda}$ ) from Table 1 and unfiltered irradiance ( $E_{\lambda}$ ) [W/m<sup>2</sup> or mW/cm<sup>2</sup>].



$$30 [J/m^2] \geq E_\lambda [W/m^2] \cdot S(\lambda) \cdot t_{exp}[s] \quad (6a)$$

$$3.0 [mJ/cm^2] \geq E_\lambda [mW/cm^2] \cdot S(\lambda) \cdot t_{exp}[s] \quad (6b)$$

The maximum exposure time ( $t_{max}$ ) [s] for a narrowband source can be determined from Equation 7 using the  $TLV_\lambda$  and the unfiltered irradiance ( $E_\lambda$ ) [ $W/m^2$  or  $mW/cm^2$ ]. (Note: The energy and surface area units must match.)

$$t_{max} [s] = \frac{TLV_\lambda}{E_\lambda} \quad (7)$$

**Notes:**

1. The probability of developing skin cancer depends on a variety of factors such as skin pigmentation, a history of blistering sunburns, and the accumulated UV dose. It also depends on genetic susceptibility and factors such as skin and eye color. Individuals who have a familial history of melanoma, or numerous nevi over their body, for example, may be at higher risk of developing malignant melanoma. The risks for developing melanoma and non-melanoma cancers may differ from each other and depend on the UV exposure history.
2. Outdoor workers in latitudes within 40 degrees of the equator can be exposed outdoors to levels above the TLVs<sup>®</sup> in as little as five minutes around noontime during the summer.
3. Exposure to ultraviolet radiation concurrently with topical or systemic exposure to a variety of chemicals, including some prescription drugs, can result in skin erythema at sub-TLV<sup>®</sup> exposures. Hypersensitivity should be suspected if workers present skin reactions when exposed to sub-TLV<sup>®</sup> doses or when exposed to levels (generally UV-A) that did not cause a noticeable erythema in the same individual in the past. Among the hundreds of agents that can cause hypersensitivity to UV radiation are certain plants and chemicals such as some antibiotics (e.g., tetracycline and sulphathiazole), some antidepressants (e.g., imipramine and sinequan), as well as some diuretics, cosmetics, antipsychotic drugs, coal tar distillates, some dyes, or lime oil.
4. Ozone is produced in air by sources emitting UV radiation at wavelengths below 250 nm. Refer to the latest version of the Chemical Substances TLV<sup>®</sup> for ozone.

## ‡ LASERS

These TLVs<sup>®</sup> are for exposure to laser radiation under conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects. The TLVs<sup>®</sup> should be used as guides in the control of exposures and should not be regarded as fine lines between safe and dangerous levels. They are based on the best available information from experimental studies. In practice, hazards to the eye and skin can be controlled by application of control measures appropriate to the classification of the laser.

### Classification of Lasers

Most lasers have a label affixed to them by the manufacturer that describes their hazard class. Normally, it is not necessary to determine laser irradiances or radiant exposures for comparison with the TLVs<sup>®</sup>. The potential for hazardous exposures can be minimized by the application of control measures that are appropriate to the hazard class of the laser. Control measures are applicable to all classes of lasers except for Class 1. Such measures, and other laser safety information, may be found in the ACGIH<sup>®</sup> publication, *A Guide for Control of Laser Hazards*, and the ANSI Z136 series published by the Laser Institute of America.

TLV<sup>®</sup>-PA

### Limiting Apertures

For comparison with the TLVs<sup>®</sup> in this section, laser beam irradiance or radiant exposure is averaged over the limiting aperture appropriate to the spectral region and exposure duration. If the laser beam diameter is less than that of the limiting aperture, the effective laser beam irradiance or radiant exposure may be calculated by dividing the laser beam power or energy by the area of the limiting aperture. Limiting apertures are listed in Table 1.

### Source Size and Correction Factor $C_E$

The following considerations apply only at wavelengths in the retinal hazard region, 400–1400 nanometers (nm). Normally, a laser is a small source, which approximates a “point” source and subtends an angle less than  $\alpha_{\min}$ , which is 1.5 mrad for all values of  $t$ . However, any source that subtends an angle,  $\alpha$ , greater than  $\alpha_{\min}$ , and is measured from the viewer’s eye, is treated as an “intermediate source” ( $\alpha_{\min} < \alpha \leq \alpha_{\max}$ ) or a “large, extended source” ( $\alpha > \alpha_{\max}$ ). For exposure duration “ $t$ ”, the angle  $\alpha_{\max}$  is defined as:

$$\begin{aligned}\alpha_{\max} &= 5 \text{ mrad for } t \leq \text{to } 0.625 \text{ ms} \\ \alpha_{\max} &= 200 \cdot t^{0.5} \text{ mrad for } 0.625 \text{ ms} < t < 0.25 \text{ s} \\ \alpha_{\max} &= 100 \text{ mrad for } t \geq 0.25 \text{ s, and} \\ \alpha_{\min} &= 1.5 \text{ mrad}\end{aligned}$$

Figure 1 illustrates the time dependence of  $\alpha_{\max}$ . If the source is oblong, alpha is determined from the arithmetic average of the longest and shortest viewable dimensions.

**TABLE 1. Limiting Apertures Applicable to Laser TLVs®**

Spectral Region	Duration	Eye	Skin
180 nm to 400 nm	1 ns to 0.25 s	1 mm	3.5 mm
180 nm to 400 nm	0.25 s to 30 ks	3.5 mm	3.5 mm
400 nm to 1400 nm	$10^{-4}$ ns to 0.25 s	7 mm	3.5 mm
400 nm to 1400 nm	0.25 s to 30 ks	7 mm	3.5 mm
1400 nm to 0.1 mm	$10^{-5}$ ns to 0.25 s	1 mm	3.5 mm
1400 nm to 0.1 mm	0.25 s to 30 ks	3.5 mm	3.5 mm
0.1 mm to 1.0 mm	$10^{-5}$ ns to 30 ks	11 mm	11 mm

For intermediate and large sources, the TLVs® in Table 2 are modified by a correction factor CE, as detailed in the Notes for Table 2.

### Correction Factors A, B, C ( $C_A$ , $C_B$ , $C_C$ )

The TLVs® for ocular exposures in Table 2 are to be used as given for all wavelength ranges. The TLVs® for wavelengths between 700 and 1049 nm are to be increased by the factor  $C_A$  (to account for reduced absorption of melanin) as given in Figure 2. For certain exposure times at wavelengths between 400 and 600 nm, a correction factor  $C_B$  (to account for reduced photochemical sensitivity for retinal injury) is applied. The correction factor  $C_C$  is applied from 1150 to 1400 nm to account for pre-retinal absorption of the ocular media.

The TLVs® for skin exposure are given in Table 4. The TLVs® are to be increased by a factor  $C_A$ , as shown in Figure 2, for wavelengths between 700 nm and 1400 nm. To aid in the determination for exposure durations requiring calculations of fractional powers, Figures 3a, 3b, 4a, and 4b may be used.

### Repetitively Pulsed Exposures

Scanned, continuous-wave (CW) lasers or repetitively pulsed lasers can both produce repetitively pulsed exposure conditions. The TLV® for intrabeam viewing, which is applicable to wavelengths between 400 and 1400 nm and a single-pulse exposure (of exposure duration  $t > t_{\min}$ ), is modified in this instance by a correction factor determined by the number of pulses in the exposure. First, calculate the number of pulses ( $n$ ) in an expected exposure situation; this is the pulse repetition frequency (PRF in Hz) multiplied by the duration of the exposure. Normally, realistic exposures may range from 0.25 second (s) for a bright visible source to 10 s for an infrared source. The corrected TLV® on a per-pulse basis is:

$$\text{TLV} = (C_p)(\text{TLV for Single-pulse}) \quad (1)$$

where  $C_p = 1.0$  for  $t < t_{\min}$  (i.e.,  $5 \mu\text{s}$  for 400–1050 nm and  $13 \mu\text{s}$  for 1050–1400 nm) and for  $t > t_{\min}$ ,  $C_p = 1.0$  for  $\alpha < 5.0$  milliradians (mrad), which applies to all cases of intrabeam viewing. However, for larger, intermediate extended sources where  $\alpha > 5$  mrad,  $C_p = n^{-0.25}$  for the following numbers of pulses: for  $n < 40$

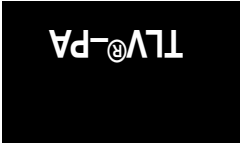
pulses, otherwise,  $C_p = 0.4$  whenever  $\alpha < \alpha_{\max}$ ; for  $\alpha_{\max} \leq \alpha < 0.1$  radians and  $n < 625$ ,  $C_p = n^{-0.25}$ , and for greater  $n$ ,  $C_p = 0.2$ . For  $\alpha > 0.1$  radian,  $C_p = 1.0$ . This approach applies only to thermal injury conditions, i.e., all exposures at wavelengths  $> 700$  nm and for many exposures at shorter wavelengths. For wavelengths  $\leq 700$  nm, the corrected TLV<sup>®</sup> from Equation 1 applies if the average irradiance does not exceed the TLV<sup>®</sup> for continuous exposure. The average irradiance (i.e., the total accumulated exposure for  $nt$  s) shall not exceed the radiant exposure given in Table 2 for exposure durations of 10 s to  $T_1$ . Some thermal additivity can occur for larger image sizes, and for pulse-repetition frequencies (PRFs) between 150 Hz and 250 Hz where  $\alpha > 5$  mrad and the pulse duration is between 1 ms and 100 ms, the single-pulse TLV<sup>®</sup> applied should be reduced by a further correction factor,  $C_p = 0.5$ . It is recommended that the user of the TLVs<sup>®</sup> for laser radiation consult *A Guide for Control of Laser Hazards*, 4th Edition, 1990, published by ACGIH<sup>®</sup>, for additional information.

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**TABLE 2. TLVs<sup>®</sup> for Direct Ocular Exposures (Intrabeam “Point Source” Viewing) from a Laser Beam**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV <sup>®</sup>
UVC	180 nm to 280 nm*	$10^{-9}$ to $3 \times 10^4$	3 mJ/cm <sup>2</sup>
UVB	280 nm to 302 nm	“	3 mJ/cm <sup>2</sup>
	303 nm	“	4 mJ/cm <sup>2</sup>
	304 nm	“	6 mJ/cm <sup>2</sup>
	305 nm	“	10 mJ/cm <sup>2</sup>
	306 nm	“	16 mJ/cm <sup>2</sup>
	307 nm	“	25 mJ/cm <sup>2</sup>
	308 nm	“	40 mJ/cm <sup>2</sup>
	309 nm	“	63 mJ/cm <sup>2</sup>
	310 nm	“	100 mJ/cm <sup>2</sup>
	311 nm	“	160 mJ/cm <sup>2</sup>
	312 nm	“	250 mJ/cm <sup>2</sup>
	313 nm	“	400 mJ/cm <sup>2</sup>
	314 nm	“	630 mJ/cm <sup>2</sup>
UVA	315 nm to 400 nm	$10^{-9}$ to 10	$0.56 t^{1/4}$ J/cm <sup>2</sup>
	315 nm to 400 nm	10 to $10^3$	1.0 J/cm <sup>2</sup>
	315 nm to 400 nm	$10^3$ to $3 \times 10^4$	1.0 mW/cm <sup>2</sup>

**Not to exceed (NTE)  $0.56 t^{1/4}$  J/cm<sup>2</sup> for  $t \leq 10$  s**





**TABLE 2 (continued). TLVs<sup>®</sup> for Direct Ocular Exposures (Intrabeam “Point Source” Viewing) from a Laser Beam**

<b>Spectral Region</b>	<b>Wavelength</b>	<b>Exposure, (t) Seconds</b>	<b>TLV<sup>®</sup></b>
Light	400 to 700 nm	$10^{-13}$ to $10^{-11}$	$1 \times 10^{-7} \text{ J/cm}^2$
	400 to 700 nm	$10^{-11}$ to $5 \times 10^{-6}$	$2 \times 10^{-7} \text{ J/cm}^2$
	400 to 700 nm	$5 \times 10^{-6}$ to 10	$1.8 t^{3/4} \times 10^{-3} \text{ J/cm}^2$
	400 to 450 nm	10 to 100	$10 \text{ mJ/cm}^2$
	450 to 500 nm	10 to $T_1$	$1 \text{ mW/cm}^2$
	450 to 500 nm	$T_1$ to 100	$10 C_B \text{ mJ/cm}^2$
	400 to 500 nm	100 to $3 \times 10^4$	$0.1 C_B \text{ mW/cm}^2$
	500 to 700 nm	10 to $3 \times 10^4$	$1.0 \text{ mW/cm}^2$
IRA	700 to 1050 nm	$10^{-13}$ to $10^{-11}$	$1.0 \times 10^{-7} \text{ J/cm}^2$
	700 to 1050 nm	$10^{-11}$ to $5 \times 10^{-6}$	$2.0 C_A \times 10^{-7} \text{ J/cm}^2$
	700 to 1050 nm	$5 \times 10^{-6}$ to 10	$1.8 C_A \times t^{0.75} \times 10^{-3} \text{ J/cm}^2$
	700 to 1050 nm	10 to $3 \times 10^4$	$C_A \times 10^{-3} \text{ W/cm}^2$
	1050 to 1400 nm	$10^{-13}$ to $10^{-11}$	$C_C \times 10^{-7} \text{ J/cm}^2$
	1050 to 1400 nm	$10^{-11}$ to $1.3 \times 10^{-5}$	$2 C_C \times 10^{-6} \text{ J/cm}^2$
	1050 to 1400 nm	$1.3 \times 10^{-5}$ to 10	$9.0 C_C t^{0.75} \times 10^{-3} \text{ J/cm}^2$
1050 to 1400 nm	10 to $3 \times 10^4$	$5.0 C_C \times 10^{-3} \text{ W/cm}^2$	

**TABLE 2 (continued). TLVs<sup>®</sup> for Direct Ocular Exposures (Intrabeam “Point Source” Viewing) from a Laser Beam**

<b>Spectral Region</b>	<b>Wavelength</b>	<b>Exposure, (t) Seconds</b>	<b>TLV<sup>®</sup></b>
IRB & IRC	1.401 to 1.5 μm	10 <sup>-13</sup> to 10 <sup>-3</sup>	0.3 J/cm <sup>2</sup>
	1.401 to 1.5 μm	10 <sup>-3</sup> to 4.0	0.56 t <sup>0.25</sup> + 0.2 J/cm <sup>2</sup>
	1.401 to 1.5 μm	4.0 to 10	1.0 J/cm <sup>2</sup>
	1.501 to 1.8 μm	10 <sup>-13</sup> to 10	1.0 J/cm <sup>2</sup>
	1.801 to 2.6 μm	10 <sup>-13</sup> to 10 <sup>-3</sup>	0.1 J/cm <sup>2</sup>
	1.801 to 2.6 μm	10 <sup>-3</sup> to 10	0.56 t <sup>1/4</sup> J/cm <sup>2</sup>
	2.601 to 10 <sup>3</sup> μm	10 <sup>-13</sup> to 10 <sup>-7</sup>	10 mJ/cm <sup>2</sup>
	2.601 to 10 <sup>3</sup> μm	10 <sup>-7</sup> to 10	0.56 t <sup>1/4</sup> J/cm <sup>2</sup>
	1.400 to 10 <sup>3</sup> μm	10 to 3 × 10 <sup>4</sup>	100 mW/cm <sup>2</sup>

\*Ozone (O<sub>3</sub>) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV<sup>®</sup> for ozone.

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**Notes for Table 2**

$C_A = \text{Fig. 2}$ ;  $C_B = 1$  for  $\lambda = 400$  to  $\leq 450$  nm;  $C_B = 10^{0.02(\lambda - 450)}$  for  $\lambda = 450$  to  $600$  nm;  $C_C = 1.0$  for wavelengths less than or equal to  $1150$  nm;  $C_C = 10^{[0.018(\lambda - 1150)]}$  for wavelengths greater than  $1150$  nm and less than  $1200$  nm;  $C_C = 8.0 + 10^{[0.04(\lambda - 1250)]}$  from  $1200$  to  $1400$  nm.

$T_1 = 10$  s for  $\lambda = 400$  to  $450$  nm;  $T_1 = 10 \times 10^{[0.02(\lambda - 450)]}$  for  $\lambda = 450$  to  $500$  nm; and  $T_1 = 10$  s for  $\lambda = 500$  to  $700$ . For intermediate or large sources (e.g., laser diode arrays) at wavelengths between  $400$  nm and  $1400$  nm, the intrabeam viewing TLVs<sup>®</sup> can be increased by correction factor  $C_E$  (use Table 3) provided that the angular subtense  $\alpha$  of the source (measured at the viewer’s eye) is greater than  $\alpha_{\min}$ .  $C_E$  depends on  $\alpha$  as follows:

Angular Subtense	Source Size Designation	Correction Factor $C_E$
$\alpha \leq \alpha_{\min}$	Small	$C_E = 1$
$\alpha_{\min} < \alpha \leq \alpha_{\max}$	Intermediate	$C_E = \alpha / \alpha_{\min}$
$\alpha = \alpha_{\max}$	Large	$C_E = \alpha_{\max} / \alpha_{\min} = 3.33$ for $t \leq 0.625$ ms; $C_E = 133 t^{1/2}$ for $0.625$ ms $< t < 0.25$ s $C_E = 66.7$ for $t \geq 0.25$ s

The angle referred to as  $\alpha_{\max}$  corresponds to the angular source size where the TLVs<sup>®</sup> may be expressed as a constant time-integrated radiance or radiance dose (J/(cm<sup>2</sup> sr)) or radiance (W/(cm<sup>2</sup> sr)) and the TLVs<sup>®</sup> for  $\alpha > \alpha_{\max}$  can be written in terms of integrated radiance  $L_{\text{TLV}} \cdot t$  or radiance  $L_{\text{TLV}}$ .

$$L_{\text{TLV}} = (1.7 \times 10^5) \times (\text{TLV}_{\text{pt source}}) \text{ J}/(\text{cm}^2 \text{ sr}) \text{ for } t < 0.625 \text{ } \mu\text{s for } 400 < \lambda < 700 \text{ nm}$$

$$L_{\text{TLV}} = 7.6 t^{1/4} \text{ J}/(\text{cm}^2 \text{ sr}) \text{ for } 0.625 \text{ ms} < t < 0.25 \text{ s for } 400 < \lambda < 700 \text{ nm}$$

$$L_{\text{TLV}} = 4.8 \text{ W}/(\text{cm}^2 \text{ sr}) \text{ for } t > 100 \text{ s for } 400 < \lambda < 700 \text{ nm}$$

Figure 5 illustrates these TLVs<sup>®</sup> for large sources expressed in terms of radiance. The measurement aperture should be placed at a distance of  $100$  mm or greater from the source. For large area irradiation, the reduced TLV<sup>®</sup> for skin exposure applies as noted in the footnote to “IRB & C,” Table 4.



**TABLE 3. TLVs<sup>®</sup> for Extended Source Laser Viewing Conditions**

<b>Spectral Region</b>	<b>Wavelength</b>	<b>Exposure, (t) Seconds</b>	<b>TLV<sup>®</sup></b>
Light	400 to 700 nm	$10^{-13}$ to $10^{-11}$	$C_E \times 10^{-7} \text{ J/cm}^2$
	400 to 700 nm	$10^{-11}$ to $5 \times 10^{-6}$	$2 C_E \times 10^{-7} \text{ J/cm}^2$
	400 to 700 nm	$5 \times 10^{-6}$ to 10	$1.8 C_E t^{-0.75} \times 10^{-3} \text{ J/cm}^2$
	400 to 700 nm	$18 \times 10^{-6}$ to 0.7	$1.8 C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
Dual Limits for 400 to 600 nm visible laser exposure for $t > 0.7$ s			
<i>Photochemical</i>			
For $\alpha \leq 11$ mrad, the MPE is expressed as irradiance and radiant exposure*			
	400 to 600 nm	0.7 to 100	$C_B \times 10^{-2} \text{ J/cm}^2$
	400 to 600 nm	100 to $3 \times 10^4$	$C_B \times 10^{-4} \text{ W/cm}^2$
For $\alpha > 11$ mrad, the MPE is expressed as radiance and integrated radiance*			
	400 to 600 nm	0.7 to $1 \times 10^4$	$100 C_B \text{ J/(cm}^2 \text{ sr)}$
	400 to 600 nm	$1 \times 10^4$ to $3 \times 10^4$	$C_B \times 10^{-2} \text{ W/(cm}^2 \text{ sr)}$
<i>Thermal</i> <span style="float: right;"><i>and</i></span>			
	400 to 700 nm	0.7 to $T_2$	$1.8 C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
	400 to 700 nm	$T_2$ to $3 \times 10^4$	$1.8 C_E T_2^{-0.25} \times 10^{-3} \text{ W/cm}^2$



**TABLE 3 (continued). TLVs<sup>®</sup> for Extended Source Laser Viewing Conditions**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV <sup>®</sup>
IRA	700 to 1050 nm	$10^{-13}$ to $10^{-11}$	$C_E \times 10^{-7} \text{ J/cm}^2$
	700 to 1050 nm	$10^{-11}$ to $5 \times 10^{-6}$	$5 C_A C_E \times 10^{-7} \text{ J/cm}^2$
	700 to 1050 nm	$5 \times 10^{-6}$ to $T_2$	$1.8 C_A C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
	700 to 1050 nm	$T_2$ to $3 \times 10^4$	$1.8 C_A C_E T_2^{-0.25} \times 10^{-3} \text{ W/cm}^2$
	1050 to 1400 nm	$10^{-13}$ to $10^{-11}$	$C_C C_E \times 10^{-7} \text{ J/cm}^2$
	1050 to 1400 nm	$10^{-11}$ to $1.3 \times 10^{-5}$	$2 C_C C_E \times 10^{-6} \text{ J/cm}^2$
	1050 to 1400 nm	$1.3 \times 10^{-5}$ to $T_2$	$9.0 C_C C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
	1050 to 1400 nm	$T_2$ to $3 \times 10^4$	$9.0 C_C C_E T_2^{-0.25} \times 10^{-3} \text{ W/cm}^2$

\* For sources subtending an angle greater than 11 mrad, the limit may also be expressed as an integrated radiance.

$L_p = 100 C_B \text{ J/(cm}^2 \text{ sr)}$  for  $0.7 \text{ s} \leq t < 10^4 \text{ s}$  and  $L_e = C_B \times 10^{-2} \text{ W/(cm}^2 \text{ sr)}$  for  $t \geq 10^4 \text{ s}$  as measured through a limiting cone angle  $\gamma$ .

These correspond to values of  $\text{J/cm}^2$  for  $10 \text{ s} \leq t < 100 \text{ s}$  and  $\text{W/cm}^2$  for  $t \geq 100 \text{ s}$  as measured through a limiting cone angle  $\gamma$ .

$$\gamma = 11 \text{ mrad for } 0.7 \text{ s} \leq t < 100 \text{ s}$$

$$\gamma = 1.1 \times t^{0.5} \text{ mrad for } 100 \text{ s} \leq t < 10^4 \text{ s}$$

$$\gamma = 110 \text{ mrad for } 10^4 \text{ s} \leq t < 3 \times 10^4 \text{ s}$$

$$T_2 = 10 \times 10^{(\alpha - 1.5)/98.5} \text{ for } \alpha \text{ expressed in mrad for } \lambda = 400 \text{ to } 1400 \text{ nm.}$$

For exposure duration “t”, the angle  $\alpha_{\text{max}}$  is defined as:

$$\alpha_{\text{max}} = 5 \text{ mrad for } t \leq \text{to } 0.625 \text{ ms}$$

$$\alpha_{\text{max}} = 200 t^{0.5} \text{ mrad for } 0.625 \text{ ms} < t < 0.25 \text{ s, and}$$

$$\alpha_{\text{max}} = 100 \text{ mrad for } t \geq 0.25 \text{ s}$$

$$\alpha_{\text{min}} = 1.5 \text{ mrad}$$

**Notes for Tables 2 and 3**

“NTE”: To protect the cornea and lens: Change the  $1 \text{ J/cm}^2$  to this set of dual limits for wavelengths between 400 nm and  $1.5 \text{ }\mu\text{m}$ . The lower of the TLVs<sup>®</sup> from Table 2 or Table 3 and the following apply:

<b>Wavelength</b>	<b>Exposure, (t) Seconds</b>	<b>NTE (Second of Dual Limits)†</b>
400 to 1200 nm	$10^{-9}$ to $10^{-7}$	$6 C_A \times 10^{-2} \text{ J/cm}^2$
400 to 1200 nm	$10^{-7}$ to 10	$3.3 C_A t^{1/4} \text{ J/cm}^2$
400 to 1200 nm	10 to $3 \times 10^4$	$0.6 C_A \text{ W/cm}^2$
1200 to 1400 nm	$10^{-9}$ to $10^{-3}$	$10^{0.01(1400-\lambda)} \text{ J/cm}^2$
1200 to 1400 nm	$10^{-3}$ to 4.0	$0.3 \times 10^{0.01(1400-\lambda)} + 0.56 t^{0.25} - 0.1 \text{ J/cm}^2$
1200 to 1400 nm	4.0 to 10	$0.3 \times 10^{0.01(1400-\lambda)} + 0.7 \text{ J/cm}^2$
1200 to 1400 nm	10 to $3 \times 10^4$	$0.03 \times 10^{0.01(1400-\lambda)} + 0.07 \text{ W/cm}^2$

†These dual limits will rarely apply except for exposures of very large angular subtense  $\alpha$  – at least for wavelengths less than 1200 nm.



**TABLE 4. TLVs<sup>®</sup> for Skin Exposure from a Laser Beam**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV <sup>®</sup>
UV <sup>A</sup>	180 nm to 400 nm	10 <sup>-9</sup> to 10 <sup>4</sup>	Same as Table 2
Light & IRA	400 nm to 1400 nm	10 <sup>-9</sup> to 10 <sup>-7</sup>	2 C <sub>A</sub> × 10 <sup>-2</sup> J/cm <sup>2</sup>
	“	10 <sup>-7</sup> to 10	1.1 C <sub>A</sub> <sup>4</sup> √t J/cm <sup>2</sup>
	“	10 to 3 × 10 <sup>4</sup>	0.2 C <sub>A</sub> W/cm <sup>2</sup>
IRB & C <sup>B</sup>	1.401 to 10 <sup>3</sup> μm	10 <sup>-14</sup> to 3 × 10 <sup>4</sup>	Same as Table 2

<sup>A</sup>Ozone (O<sub>3</sub>) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV<sup>®</sup> for ozone.

C<sub>A</sub> = 1.0 for λ = 400 – 700 nm; *see* Figure 2 for λ = 700 to 1400 nm

<sup>B</sup>At wavelengths greater than 1400 nm, for beam cross-sectional areas exceeding 100 cm<sup>2</sup>, the TLV<sup>®</sup> for exposure durations exceeding 10 seconds is:

$$TLV = (10,000/A_s) \text{ mW/cm}^2$$

where A<sub>s</sub> is the irradiated skin area for 100 to 1000 cm<sup>2</sup>, and the TLV<sup>®</sup> is 10 mW/cm<sup>2</sup> for irradiated skin areas exceeding 1000 cm<sup>2</sup> and is 100 mW/cm<sup>2</sup> for irradiated skin areas less than 100 cm<sup>2</sup>.

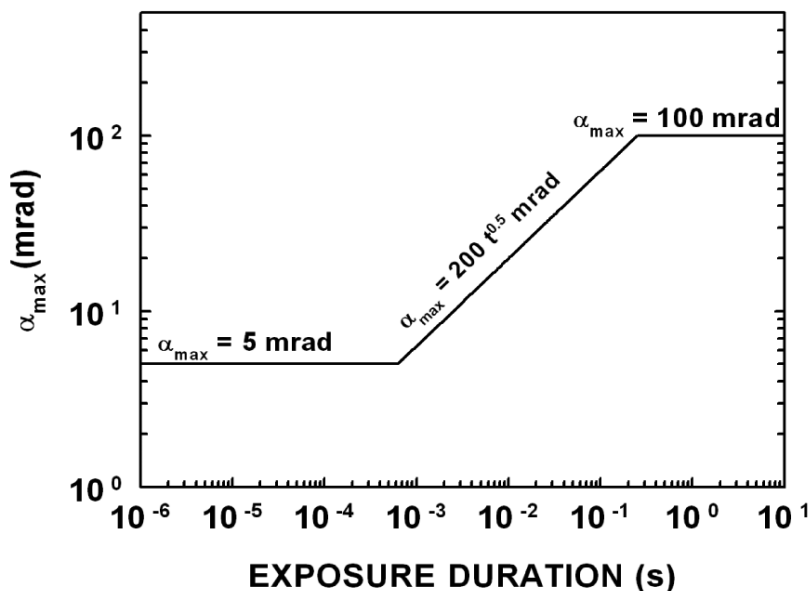


FIGURE 1. Variation of  $\alpha_{max}$  with exposure duration.

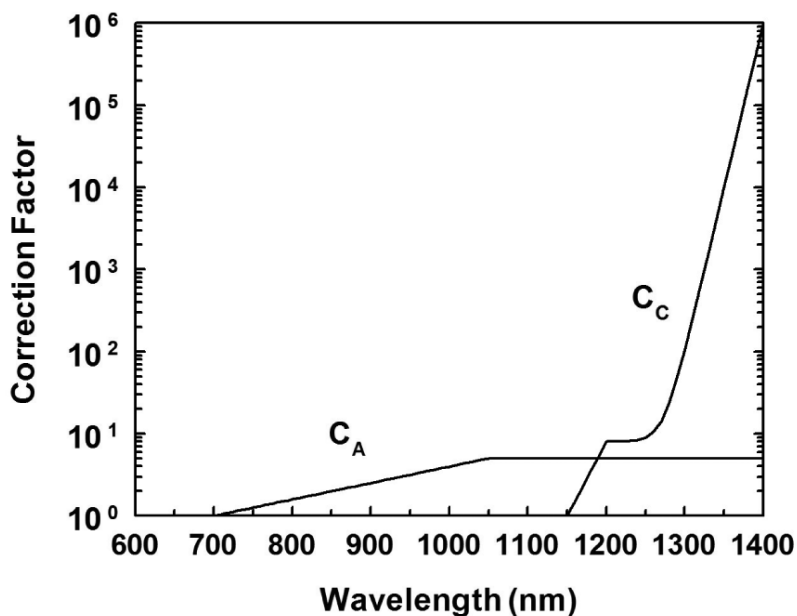


FIGURE 2. TLV<sup>®</sup> correction factors for  $\lambda = 700\text{--}1400\text{ nm}^*$   
 \*For  $\lambda = 700\text{--}1049\text{ nm}$ ,  $C_A = 10^{[0.002(\lambda - 700)]}$ ; for  $\lambda = 1050\text{--}1400\text{ nm}$ ,  $C_A = 5$ ;  
 for  $\lambda \leq 1150\text{ nm}$ ,  $C_C = 1$ ; for  $\lambda = 1150\text{--}1200\text{ nm}$ ,  $C_C = 10^{[0.018(\lambda - 1150)]}$ ; and for  $\lambda = 1200\text{--}1399\text{ nm}$ ,  $C_C = 8 + 10^{[0.04(\lambda - 1250)]}$ .



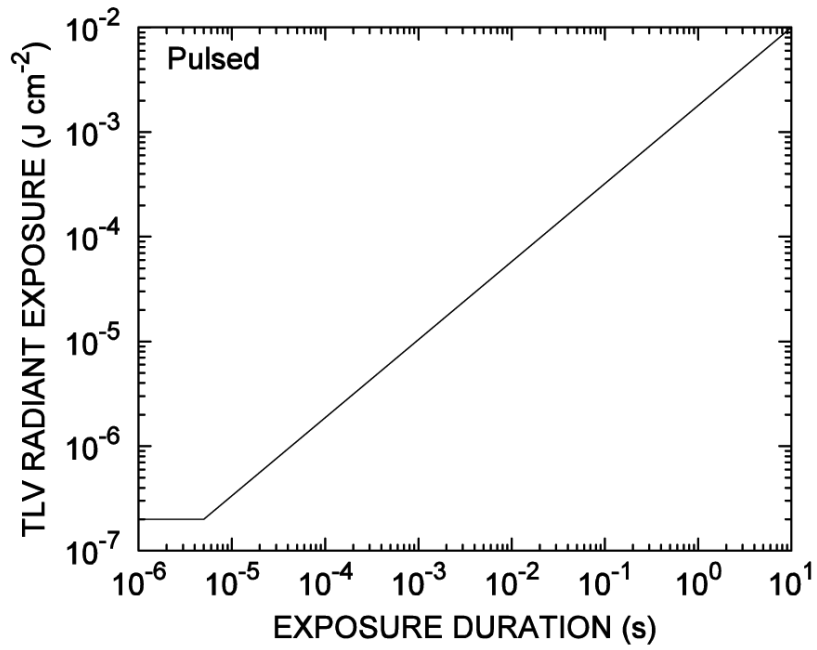


FIGURE 3a. TLV<sup>®</sup> for intrabeam viewing of laser beam (400–700 nm).

TLV<sup>®</sup>-PA

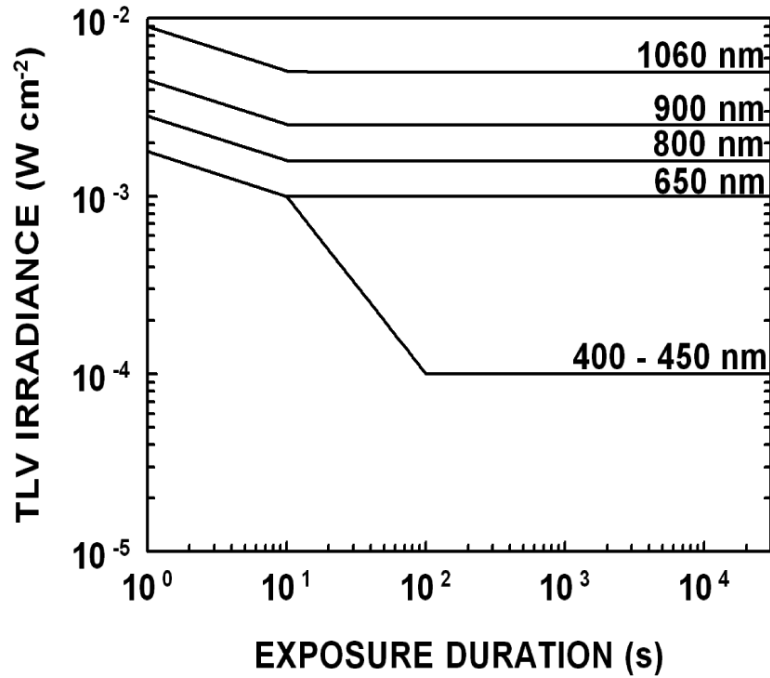


FIGURE 3b. TLV<sup>®</sup> for intrabeam (direct) viewing of CW laser beam (400–1400 nm).

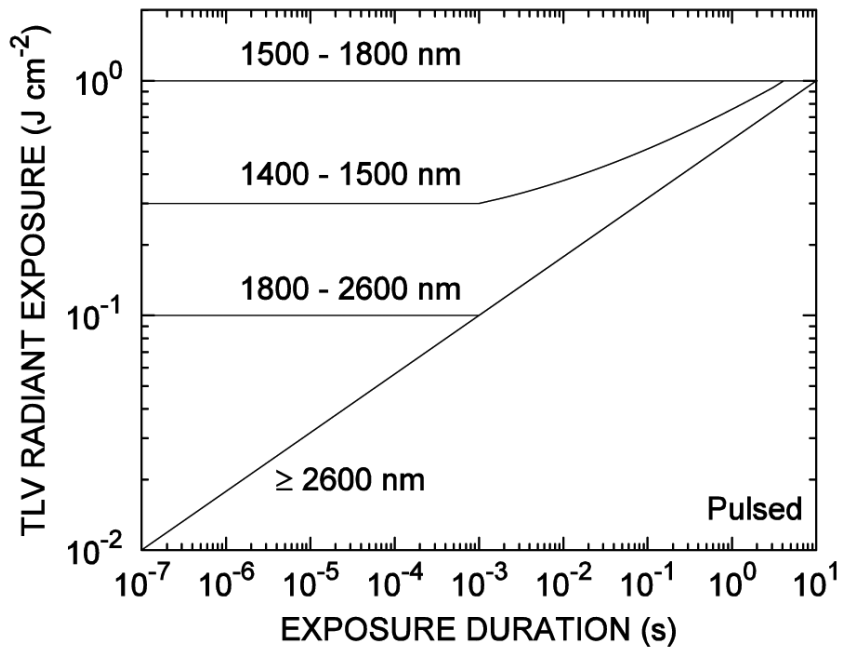


FIGURE 4a. TLV<sup>®</sup> for laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1400 nm).

TLV<sup>®</sup>-PA

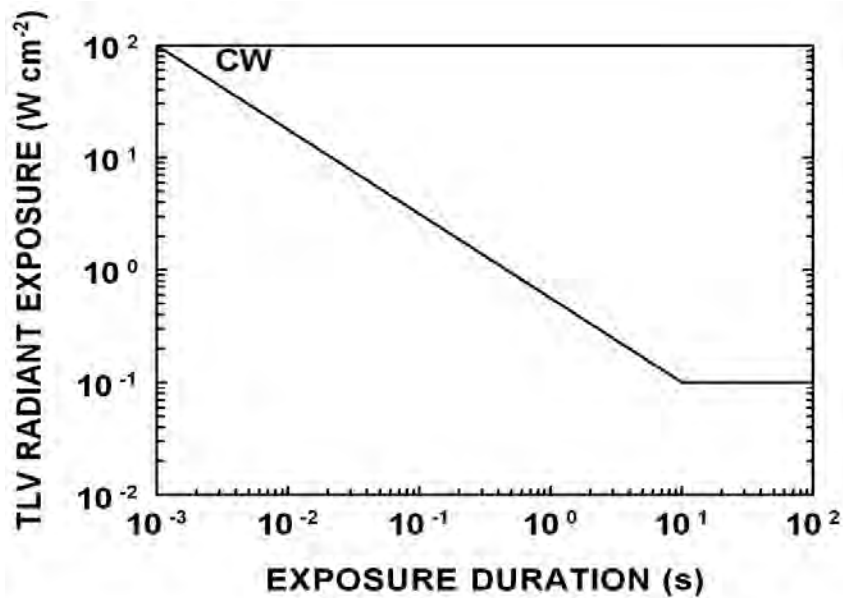


FIGURE 4b. TLV<sup>®</sup> for CW laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1.4  $\mu\text{m}$ ).

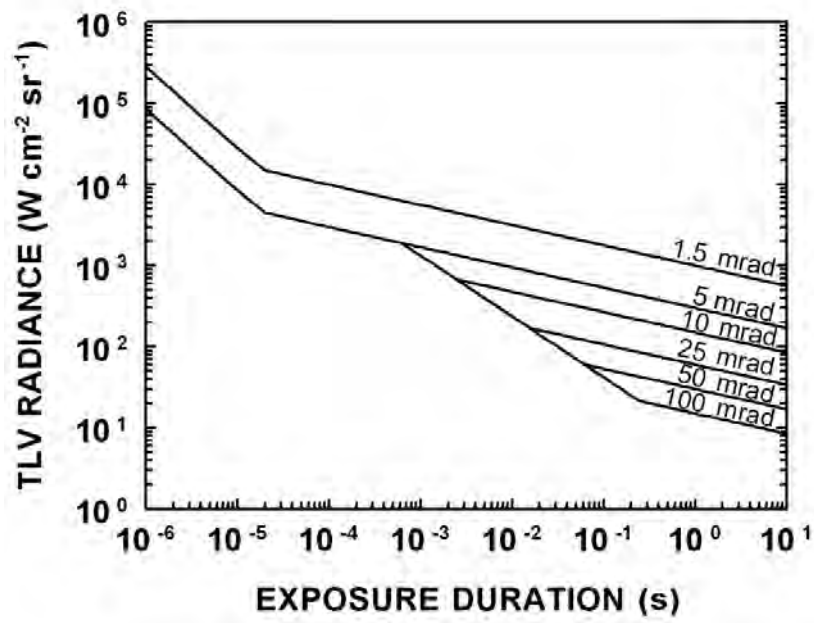


FIGURE 5. TLVs® in terms of radiance for exposures to extended-source lasers in the wavelength range of 400 to 700 nm.

TLV®-PA



## NOTICE OF INTENDED CHANGE—

### † LASERS

The reason for this NIC is revision to the TLVs<sup>®</sup> for direct ocular exposures for all UV and UVC spectral regions; the addition of not to exceed (NTE) dual limits for direct ocular exposures and extended sources laser viewing conditions in the IRA spectral regions; and revision to TLVs<sup>®</sup> for skin exposure for UV and Light and IR regions.

These TLVs<sup>®</sup> are for exposure to laser radiation under conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects. The TLVs<sup>®</sup> should be used as guides in the control of exposures and should not be regarded as fine lines between safe and dangerous levels. They are based on the best available information from experimental studies. In practice, hazards to the eye and skin can be controlled by application of control measures appropriate to the classification of the laser.

#### Classification of Lasers

Most lasers have a label affixed to them by the manufacturer that describes their hazard class. Normally, it is not necessary to determine laser irradiances or radiant exposures for comparison with the TLVs<sup>®</sup>. The potential for hazardous exposures can be minimized by the application of control measures that are appropriate to the hazard class of the laser. Control measures are applicable to all classes of lasers except for Class 1. Such measures, and other laser safety information, may be found in the ACGIH<sup>®</sup> publication, *A Guide for Control of Laser Hazards*, and the ANSI Z136 series published by the Laser Institute of America.

#### Limiting Apertures

For comparison with the TLVs<sup>®</sup> in this section, laser beam irradiance or radiant exposure is averaged over the limiting aperture appropriate to the spectral region and exposure duration. If the laser beam diameter is less than that of the limiting aperture, the effective laser beam irradiance or radiant exposure may be calculated by dividing the laser beam power or energy by the area of the limiting aperture. Limiting apertures are listed in Table 1.

#### Source Size and Correction Factor $C_E$

The following considerations apply only at wavelengths in the retinal hazard region, 400–1400 nanometers (nm). Normally, a laser is a small source, which approximates a “point” source and subtends an angle less than  $\alpha_{\min}$ , which is 1.5 mrad for all values of  $t$ . However, any source that subtends an angle,  $\alpha$ , greater than  $\alpha_{\min}$ , and is measured from the viewer’s eye, is treated as an “intermediate source” ( $\alpha_{\min} < \alpha \leq \alpha_{\max}$ ) or a “large, extended source” ( $\alpha > \alpha_{\max}$ ). For exposure duration “ $t$ ”, the angle  $\alpha_{\max}$  is defined as:

$$\alpha_{\max} = 5 \text{ mrad for } t \leq 0.625 \text{ ms}$$

$$\alpha_{\max} = 200 \cdot t^{0.5} \text{ mrad for } 0.625 \text{ ms} < t < 0.25 \text{ s}$$

$$\alpha_{\max} = 100 \text{ mrad for } t \geq 0.25 \text{ s, and}$$

$$\alpha_{\min} = 1.5 \text{ mrad}$$

**TABLE 1. Limiting Apertures Applicable to Laser TLVs®**

Spectral Region	Duration	Eye	Skin
180 nm to 400 nm	100 fs to 0.25 s	1 mm	3.5 mm
180 nm to 400 nm	0.25 s to 30 ks	3.5 mm	3.5 mm
400 nm to 1400 nm	10 <sup>-4</sup> ns to 0.25 s	7 mm	3.5 mm
400 nm to 1400 nm	0.25 s to 30 ks	7 mm	3.5 mm
1400 nm to 0.1 mm	10 <sup>-5</sup> ns to 0.25 s	1 mm	3.5 mm
1400 nm to 0.1 mm	0.25 s to 30 ks	3.5 mm	3.5 mm
0.1 mm to 1.0 mm	10 <sup>-5</sup> ns to 30 ks	11 mm	11 mm

Figure 1 illustrates the time dependence of  $\alpha_{\max}$ . If the source is oblong, alpha is determined from the arithmetic average of the longest and shortest viewable dimensions.

For intermediate and large sources, the TLVs® in Table 2 are modified by a correction factor  $C_E$ , as detailed in the Notes for Table 2.

### Correction Factors A, B, C ( $C_A$ , $C_B$ , $C_C$ )

The TLVs® for ocular exposures in Table 2 are to be used as given for all wavelength ranges. The TLVs® for wavelengths between 700 and 1049 nm are to be increased by the factor  $C_A$  (to account for reduced absorption of melanin) as given in Figure 2. For certain exposure times at wavelengths between 400 and 600 nm, a correction factor  $C_B$  (to account for reduced photochemical sensitivity for retinal injury) is applied. The correction factor  $C_C$  is applied from 1150 to 1400 nm to account for pre-retinal absorption of the ocular media.

The TLVs® for skin exposure are given in Table 4. The TLVs® are to be increased by a factor  $C_A$ , as shown in Figure 2, for wavelengths between 700 nm and 1400 nm. To aid in the determination for exposure durations requiring calculations of fractional powers, Figures 3a, 3b, 4a, and 4b may be used.

### Repetitively Pulsed Exposures

Scanned, continuous-wave (CW) lasers or repetitively pulsed lasers can both produce repetitively pulsed exposure conditions. The TLV® for intrabeam viewing, which is applicable to wavelengths between 400 and 1400 nm and a single-pulse exposure (of exposure duration  $t > t_{\min}$ ), is modified in this instance by a correction factor determined by the number of pulses in the exposure. First, calculate the number of pulses ( $n$ ) in an expected exposure situation; this is the pulse repetition frequency (PRF in Hz) multiplied by the duration of the exposure. Normally, realistic exposures may range from 0.25 second (s) for a bright visible source to 10 s for an infrared source. The corrected TLV® on a per-pulse basis is:

$$\text{TLV} = (C_P)(\text{TLV for Single-pulse}) \quad (1)$$

where  $C_P = 1.0$  for  $t < t_{\min}$  (i.e., 5  $\mu\text{s}$  for 400–1050 nm and 13  $\mu\text{s}$  for 1050–1400 nm) and for  $t > t_{\min}$ ,  $C_P = 1.0$  for  $\alpha < 5.0$  milliradians (mrad), which applies to all

cases of intrabeam viewing. However, for larger, intermediate extended sources where  $\alpha > 5$  mrad,  $C_p = n^{-0.25}$  for the following numbers of pulses: for  $n < 40$  pulses, otherwise,  $C_p = 0.4$  whenever  $\alpha < \alpha_{\max}$ ; for  $\alpha_{\max} \leq \alpha < 0.1$  radians and  $n < 625$ ,  $C_p = n^{-0.25}$ , and for greater  $n$ ,  $C_p = 0.2$ . For  $\alpha > 0.1$  radian,  $C_p = 1.0$ . This approach applies only to thermal injury conditions, i.e., all exposures at wavelengths  $> 700$  nm and for many exposures at shorter wavelengths. For wavelengths  $\leq 700$  nm, the corrected TLV<sup>®</sup> from Equation 1 applies if the average irradiance does not exceed the TLV<sup>®</sup> for continuous exposure. The average irradiance (i.e., the total accumulated exposure for  $nt$  s) shall not exceed the radiant exposure given in Table 2 for exposure durations of 10 s to  $T_1$ . Some thermal additivity can occur for larger image sizes, and for pulse-repetition frequencies (PRFs) between 150 Hz and 250 Hz where  $\alpha > 5$  mrad and the pulse duration is between 1 ms and 100 ms, the single-pulse TLV<sup>®</sup> applied should be reduced by a further correction factor,  $C_p = 0.5$ .

For ultraviolet wavelengths, the accumulated exposure of repetitive exposures is added up to the total duration of exposure (up to a maximal duration of  $3 \times 10^4$  s). For repetitive-pulse trains, the total accumulated radiant exposure for  $nt$  s of a group of pulses should not exceed the exposure given in Table 2 for exposure durations of 10 s to  $3 \times 10^4$  s with continuous exposures.

It is recommended that the user of the TLVs<sup>®</sup> for laser radiation consult *A Guide for Control of Laser Hazards*, 4th Edition, 1990, published by ACGIH<sup>®</sup>, for additional information on control measures.



**TABLE 2. TLVs® for Direct Ocular Exposures (Intrabeam “Point Source” Viewing) from a Laser Beam**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
All UV	180 nm to 400 nm	$10^{-13}$ to $10^{-11}$	0.3 mJ/cm <sup>2</sup>
	180 nm to 400 nm	$10^{-11}$ to $10^{-9}$	1 mJ/cm <sup>2</sup>
UVC	180 nm to 260 nm	$10^{-9}$ to $3 \times 10^4$	$3 \times 10^{0.033(260 \text{ nm} - \lambda)}$ mJ/cm <sup>2</sup>
	260 nm to 280 nm*	$10^{-9}$ to $3 \times 10^4$	3 mJ/cm <sup>2</sup>
UVB	280 nm to 302 nm	“	3 mJ/cm <sup>2</sup>
	303 nm	“	4 mJ/cm <sup>2</sup>
	304 nm	“	6 mJ/cm <sup>2</sup>
	305 nm	“	10 mJ/cm <sup>2</sup>
	306 nm	“	16 mJ/cm <sup>2</sup>
	307 nm	“	25 mJ/cm <sup>2</sup>
	308 nm	“	40 mJ/cm <sup>2</sup>
	309 nm	“	63 mJ/cm <sup>2</sup>
	310 nm	“	100 mJ/cm <sup>2</sup>
	311 nm	“	160 mJ/cm <sup>2</sup>
	312 nm	“	250 mJ/cm <sup>2</sup>
UVA	313 nm	“	400 mJ/cm <sup>2</sup>
	314 nm	“	630 mJ/cm <sup>2</sup>
	315 nm to 400 nm	$10^{-9}$ to 10	$0.56 t^{1/4}$ J/cm <sup>2</sup>
	315 nm to 400 nm	10 to $10^3$	1.0 J/cm <sup>2</sup>
	315 nm to 400 nm	$10^3$ to $3 \times 10^4$	1.0 mW/cm <sup>2</sup>

Not to exceed (NTE)  
 $0.56 t^{1/4}$  J/cm<sup>2</sup>  
 for  $t \leq 10$  s

**TABLE 2. TLVs<sup>®</sup> for Direct Ocular Exposures (Intrabeam “Point Source” Viewing) from a Laser Beam (Continued)**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV <sup>®</sup>
Light	400 to 700 nm	$10^{-13}$ to $10^{-11}$	$1 \times 10^{-7}$ J/cm <sup>2</sup>
	400 to 700 nm	$10^{11}$ to $5 \times 10^{-6}$	$2 \times 10^{-7}$ J/cm <sup>2</sup>
	400 to 700 nm	$5 \times 10^{-6}$ to 10	$1.8 t^{3/4} \times 10^{-3}$ J/cm <sup>2</sup>
	400 to 450 nm	10 to 100	10 mJ/cm <sup>2</sup>
	450 to 500 nm	10 to T <sub>1</sub>	1 mW/cm <sup>2</sup>
	450 to 500 nm	T <sub>1</sub> to 100	10 C <sub>B</sub> mJ/cm <sup>2</sup>
	400 to 500 nm	100 to $3 \times 10^4$	0.1 C <sub>B</sub> mW/cm <sup>2</sup>
	500 to 700 nm	10 to $3 \times 10^4$	1.0 mW/cm <sup>2</sup>
IRA	700 to 1050 nm	$10^{-13}$ to $10^{-11}$	$1.0 \times 10^{-7}$ J/cm <sup>2</sup>
	700 to 1050 nm	$10^{-11}$ to $5 \times 10^{-6}$	$2.0 C_A \times 10^{-7}$ J/cm <sup>2</sup>
	700 to 1050 nm	$5 \times 10^{-6}$ to 10	$1.8 C_A \times t^{0.75} \times 10^{-3}$ J/cm <sup>2</sup>
	700 to 1050 nm	10 to $3 \times 10^4$	$C_A \times 10^{-3}$ W/cm <sup>2</sup>
	1050 to 1400 nm	$10^{-13}$ to $10^{-11}$	$C_C \times 10^{-7}$ J/cm <sup>2</sup>
	1050 to 1400 nm	$10^{-11}$ to $1.3 \times 10^{-5}$	$2 C_C \times 10^{-6}$ J/cm <sup>2</sup>
	1050 to 1400 nm	$1.3 \times 10^{-5}$ to 10	$9.0 C_C t^{0.75} \times 10^{-3}$ J/cm <sup>2</sup> NTE: 50 J/cm <sup>2</sup>
1050 to 1400 nm	10 to $3 \times 10^4$	$5.0 C_C \times 10^{-3}$ W/cm <sup>2</sup> NTE: 5 W/cm <sup>2</sup>	

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**TABLE 2. TLVs® for Direct Ocular Exposures (Intrabeam “Point Source” Viewing) from a Laser Beam (Continued)**

IRB	1.401 to 1.5 μm	10 <sup>-13</sup> to 10 <sup>-3</sup>	0.3 J/cm <sup>2</sup>
& IRC	1.401 to 1.5 μm	10 <sup>-3</sup> to 4.0	0.56 t <sup>0.25</sup> + 0.2 J/cm <sup>2</sup>
	1.401 to 1.5 μm	4.0 to 10	1.0 J/cm <sup>2</sup>
	1.501 to 1.8 μm	10 <sup>-13</sup> to 10	1.0 J/cm <sup>2</sup>
	1.801 to 2.6 μm	10 <sup>-13</sup> to 10 <sup>-3</sup>	0.1 J/cm <sup>2</sup>
	1.801 to 2.6 μm	10 <sup>-3</sup> to 10	0.56 t <sup>1/4</sup> J/cm <sup>2</sup>
	2.601 to 10 <sup>3</sup> μm	10 <sup>-13</sup> to 10 <sup>-7</sup>	10 mJ/cm <sup>2</sup>
	2.601 to 10 <sup>3</sup> μm	10 <sup>-7</sup> to 10	0.56 t <sup>1/4</sup> J/cm <sup>2</sup>
	1.400 to 10 <sup>3</sup> μm	10 to 3 × 10 <sup>4</sup>	100 mW/cm <sup>2</sup>

\*Ozone (O<sub>3</sub>) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV® for ozone.

**Notes for Table 2**

$C_A$  = Fig. 2;  $C_B = 1$  for  $\lambda = 400$  to  $\leq 450$  nm;  $C_B = 10^{0.02(\lambda - 450)}$  for  $\lambda = 450$  to 600 nm;  $C_C = 1.0$  for wavelengths less than or equal to 1150 nm;  $C_C = 10^{[0.018(\lambda - 1150)]}$  for wavelengths greater than 1150 nm and less than 1200 nm;  $C_C = 8.0 + 10^{[0.04(\lambda - 1250)]}$  from 1200 to 1400 nm.

$T_1 = 10$  s for  $\lambda = 400$  to 450 nm;  $T_1 = 10 \times 10^{[0.02(\lambda - 450)]}$  for  $\lambda = 450$  to 500 nm; and  $T_1 = 10$  s for  $\lambda = 500$  to 700.

For intermediate or large sources (e.g., laser diode arrays) at wavelengths between 400 nm and 1400 nm, the intrabeam viewing TLVs<sup>®</sup> can be increased by correction factor  $C_E$  (use Table 3) provided that the angular subtense  $\alpha$  of the source (measured at the viewer’s eye) is greater than  $\alpha_{min}$ .  $C_E$  depends on  $\alpha$  as follows:

Angular Subtense	Source Size Designation	Correction Factor $C_E$
$\alpha \leq \alpha_{min}$	Small	$C_E = 1$
$\alpha_{min} < \alpha \leq \alpha_{max}$	Intermediate	$C_E = \alpha/\alpha_{min}$
$\alpha = \alpha_{max}$	Large	$C_E = \alpha_{max}/\alpha_{min} = 3.33$ for $t \leq 0.625$ ms; $C_E = 133 t^{1/2}$ for $0.625$ ms $< t < 0.25$ s $C_E = 66.7$ for $t \geq 0.25$ s

The angle referred to as  $\alpha_{max}$  corresponds to the angular source size where the TLVs may be expressed as a constant time-integrated radiance or radiance dose (J/(cm<sup>2</sup> sr)) or radiance (W/(cm<sup>2</sup> sr)) and the TLVs for  $\alpha > \alpha_{max}$  can be written in terms of integrated radiance  $L_{TLV} \cdot t$  or radiance  $L_{TLV}$ .

$$L_{TLV} = (1.7 \times 10^5) \times (TLV_{pt\ source}) \text{ J/(cm}^2 \text{ sr)} \text{ for } t < 0.625 \text{ } \mu\text{s for } 400 < \lambda < 700 \text{ nm}$$

$$L_{TLV} = 7.6 t^{1/4} \text{ J/(cm}^2 \text{ sr)} \text{ for } 0.625 \text{ ms} < t < 0.25 \text{ s for } 400 < \lambda < 700 \text{ nm}$$

$$L_{TLV} = 4.8 \text{ W/(cm}^2 \text{ sr)} \text{ for } t > 100 \text{ s for } 400 < \lambda < 700 \text{ nm}$$

Figure 5 illustrates these TLVs<sup>®</sup> for large sources expressed in terms of radiance. The measurement aperture should be placed at a distance of 100 mm or greater from the source. For large area irradiation, the reduced TLV<sup>®</sup> for skin exposure applies as noted in the footnote to “IRB & C,” Table 4.





**TABLE 3. TLVs® for Extended Source Laser Viewing Conditions**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
Light	400 to 700 nm	$10^{-13}$ to $10^{-11}$	$C_E \times 10^{-7} \text{ J/cm}^2$
	400 to 700 nm	$10^{-11}$ to $5 \times 10^{-6}$	$2 C_E \times 10^{-7} \text{ J/cm}^2$
	400 to 700 nm	$5 \times 10^{-6}$ to 10	$1.8 C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
	400 to 700 nm	$18 \times 10^{-6}$ to 0.7	$1.8 C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
Dual Limits for 400 to 600 nm visible laser exposure for $t > 0.7$ s			
<i>Photochemical</i>			
For $\alpha \leq 11$ mrad, the MPE is expressed as irradiance and radiant exposure*			
	400 to 600 nm	0.7 to 100	$C_B \times 10^{-2} \text{ J/cm}^2$
	400 to 600 nm	100 to $3 \times 10^4$	$C_B \times 10^{-4} \text{ W/cm}^2$
For $\alpha > 11$ mrad, the MPE is expressed as radiance and integrated radiance*			
	400 to 600 nm	0.7 to $1 \times 10^4$	$100 C_B \text{ J/(cm}^2 \text{ sr)}$
	400 to 600 nm	$1 \times 10^4$ to $3 \times 10^4$	$C_B \times 10^{-2} \text{ W/(cm}^2 \text{ sr)}$
<i>Thermal</i>		<i>and</i>	
	400 to 700 nm	0.7 to $T_2$	$1.8 C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
	400 to 700 nm	$T_2$ to $3 \times 10^4$	$1.8 C_E T_2^{-0.25} \times 10^{-3} \text{ W/cm}^2$



**TABLE 3. TLVs<sup>®</sup> for Extended Source Laser Viewing Conditions**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV <sup>®</sup>
IRA	700 to 1050 nm	$10^{-13}$ to $10^{-11}$	$C_E \times 10^{-7} \text{ J/cm}^2$
	700 to 1050 nm	$10^{-11}$ to $5 \times 10^{-6}$	$5 C_A C_E \times 10^{-7} \text{ J/cm}^2$
	700 to 1050 nm	$5 \times 10^{-6}$ to $T_2$	$1.8 C_A C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$
	700 to 1050 nm	$T_2$ to $3 \times 10^4$	$1.8 C_A C_E T_2^{-0.25} \times 10^{-3} \text{ W/cm}^2$
	1050 to 1400 nm	$10^{-13}$ to $10^{-11}$	$C_C C_E \times 10^{-7} \text{ J/cm}^2$
	1050 to 1400 nm	$10^{-11}$ to $1.3 \times 10^{-5}$	$2 C_C C_E \times 10^{-6} \text{ J/cm}^2$
	1050 to 1400 nm	$13 \times 10^{-6}$ to $T_2$	$9.0 C_C C_E t^{0.75} \times 10^{-3} \text{ J/cm}^2$ NTE: 50 J/cm <sup>2</sup>
	1050 to 1400 nm	$T_2$ to $3 \times 10^4$	$9.0 C_C C_E T_2^{-0.25} \times 10^{-3} \text{ W/cm}^2$ NTE: 5 W/cm <sup>2</sup>

\* For sources subtending an angle greater than 11 mrad, the limit may also be expressed as an integrated radiance.

$L_p = 100 C_B \text{ J/(cm}^2 \text{ sr)}$  for  $0.7 \text{ s} \leq t < 10^4 \text{ s}$  and  $L_e = C_B \times 10^{-2} \text{ W/(cm}^2 \text{ sr)}$  for  $t \geq 10^4 \text{ s}$  as measured through a limiting cone angle  $\gamma$ .

These correspond to values of J/cm<sup>2</sup> for  $10 \text{ s} \leq t < 100 \text{ s}$  and W/cm<sup>2</sup> for  $t \geq 100 \text{ s}$  as measured through a limiting cone angle  $\gamma$ .

$$\gamma = 11 \text{ mrad for } 0.7 \text{ s} \leq t < 100 \text{ s}$$

$$\gamma = 1.1 \times t^{0.5} \text{ mrad for } 100 \text{ s} \leq t < 10^4 \text{ s}$$

$$\gamma = 110 \text{ mrad for } 10^4 \text{ s} \leq t < 3 \times 10^4 \text{ s}$$

$T_2 = 10 \times 10^{(\alpha - 1.5)/98.5}$  for  $\alpha$  expressed in mrad for  $\lambda = 400$  to  $1400 \text{ nm}$ .

For exposure duration “t”, the angle  $\alpha_{\text{max}}$  is defined as:

$$\alpha_{\text{max}} = 5 \text{ mrad for } t \leq \text{to } 0.625 \text{ ms}$$

$$\alpha_{\text{max}} = 200 t^{0.5} \text{ mrad for } 0.625 \text{ ms} < t < 0.25 \text{ s, and}$$

$$\alpha_{\text{max}} = 100 \text{ mrad for } t \geq 0.25 \text{ s}$$

$$\alpha_{\text{min}} = 1.5 \text{ mrad}$$





*Notes for Tables 2 and 3*

“NTE”: To protect the cornea and lens, the TLVs<sup>®</sup> for wavelengths between 400 nm and 1.4 μm, in Table 3 should not exceed:

<b>Wavelength</b>	<b>Exposure, (t) Seconds</b>	<b>NTE (Second of Dual Limits)†</b>
400 to 1400 nm	$10^{-13}$ to $10^{-7}$	$6 C_A \times 10^{-2} \text{ J/cm}^2$
400 to 1400 nm	$10^{-7}$ to 10	$3.3 C_A t^{1/4} \text{ J/cm}^2$
400 to 1400 nm	10 to $3 \times 10^4$	$0.6 C_A \text{ W/cm}^2$

†These dual limits will rarely apply except for exposures of very large angular subtense  $\alpha$  – at least for wavelengths less than 1200 nm.

**TABLE 4. TLVs<sup>®</sup> for Skin Exposure from a Laser Beam**

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV <sup>®</sup>
UV <sup>A</sup>	180 nm to 400 nm	$10^{-13}$ to $3 \times 10^4$	Same as Table 2
Light & IRA	400 nm to 1400 nm	$10^{-13}$ to $10^{-11}$	$2 C_A \times 10^{-3} \text{ J/cm}^2$
	“	$10^{-11}$ to $10^{-9}$	$6 C_A \times 10^{-3} \text{ J/cm}^2$
	“	$10^{-9}$ to $10^{-7}$	$2 C_A \times 10^{-2} \text{ J/cm}^2$
	“	$10^{-7}$ to 10	$1.1 C_A \sqrt[4]{t} \text{ J/cm}^2$
	“	10 to $3 \times 10^4$	$0.2 C_A \text{ W/cm}^2$
IRB & C <sup>B</sup>	1.401 to $10^3 \mu\text{m}$	$10^{-13}$ to $3 \times 10^4$	Same as Table 2

<sup>A</sup>Ozone (O<sub>3</sub>) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV<sup>®</sup> for ozone.

$C_A = 1.0$  for  $\lambda = 400 - 700 \text{ nm}$ ; *see* Figure 2 for  $\lambda = 700$  to 1400 nm

<sup>B</sup>At wavelengths greater than 1400 nm, for beam cross-sectional areas exceeding 100 cm<sup>2</sup>, the TLV<sup>®</sup> for exposure durations exceeding 10 seconds is:

$$\text{TLV} = (10,000/A_s) \text{ mW/cm}^2$$

where  $A_s$  is the irradiated skin area for 100 to 1000 cm<sup>2</sup>, and the TLV<sup>®</sup> is 10 mW/cm<sup>2</sup> for irradiated skin areas exceeding 1000 cm<sup>2</sup> and is 100 mW/cm<sup>2</sup> for irradiated skin areas less than 100 cm<sup>2</sup>.

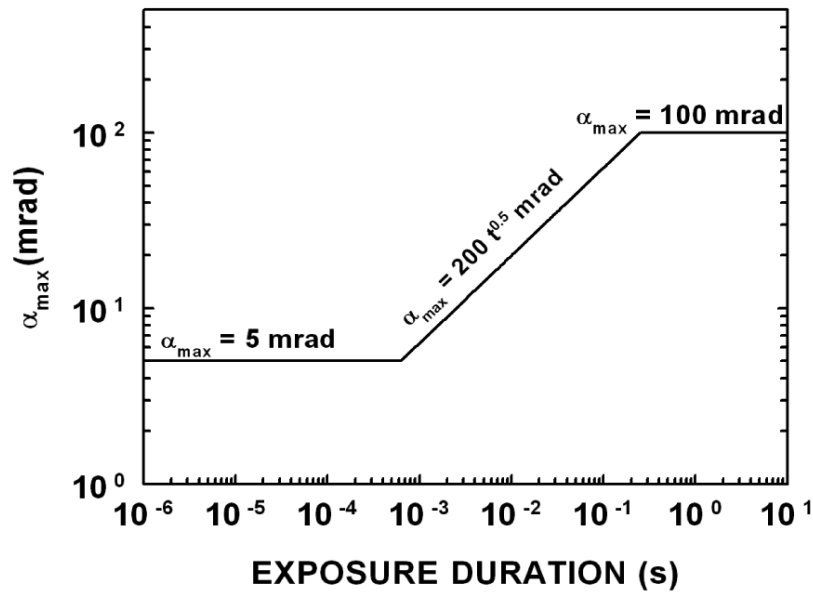


FIGURE 1. Variation of  $\alpha_{\max}$  with exposure duration.

TLV®-PA

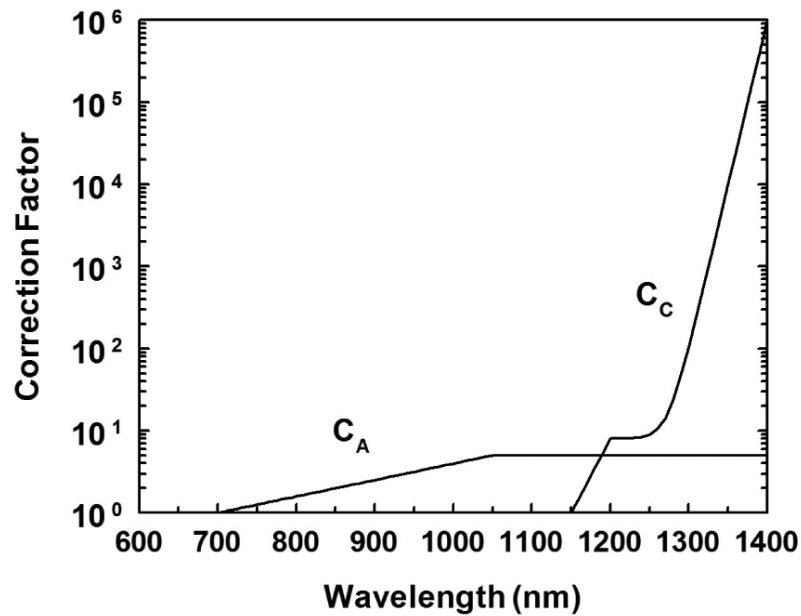


FIGURE 2. TLV® correction factors for  $\lambda = 700\text{--}1400$  nm\*  
 \*For  $\lambda = 700\text{--}1049$  nm,  $C_A = 10^{[0.002(\lambda - 700)]}$ ; for  $\lambda = 1050\text{--}1400$  nm,  $C_A = 5$ ;  
 for  $\lambda \leq 1150$  nm,  $C_C = 1$ ; for  $\lambda = 1150\text{--}1200$  nm,  $C_C = 10^{[0.018(\lambda - 1150)]}$ ; and for  $\lambda = 1200\text{--}1399$  nm,  $C_C = 8 + 10^{[0.04(\lambda - 1250)]}$ .

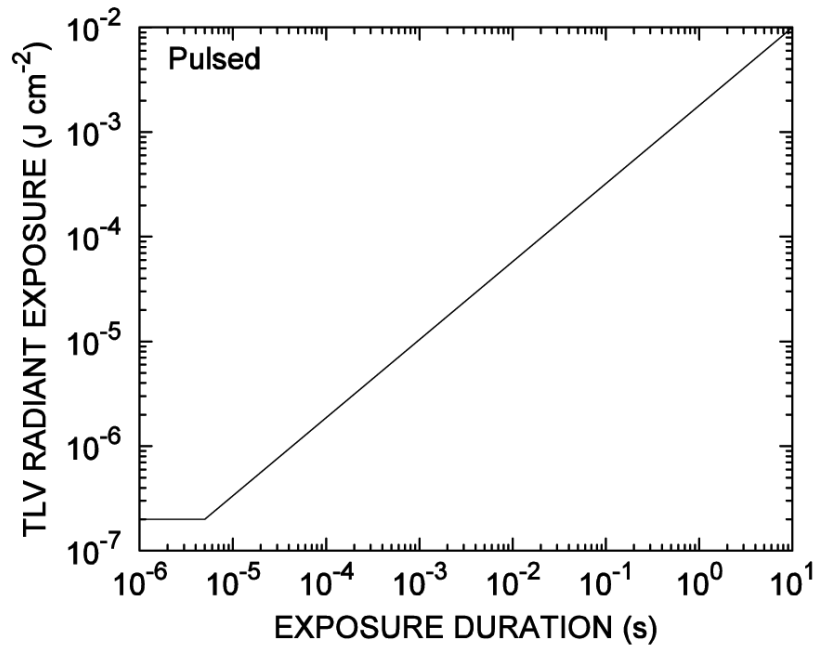


FIGURE 3a. TLV<sup>®</sup> for intrabeam viewing of laser beam (400–700 nm).

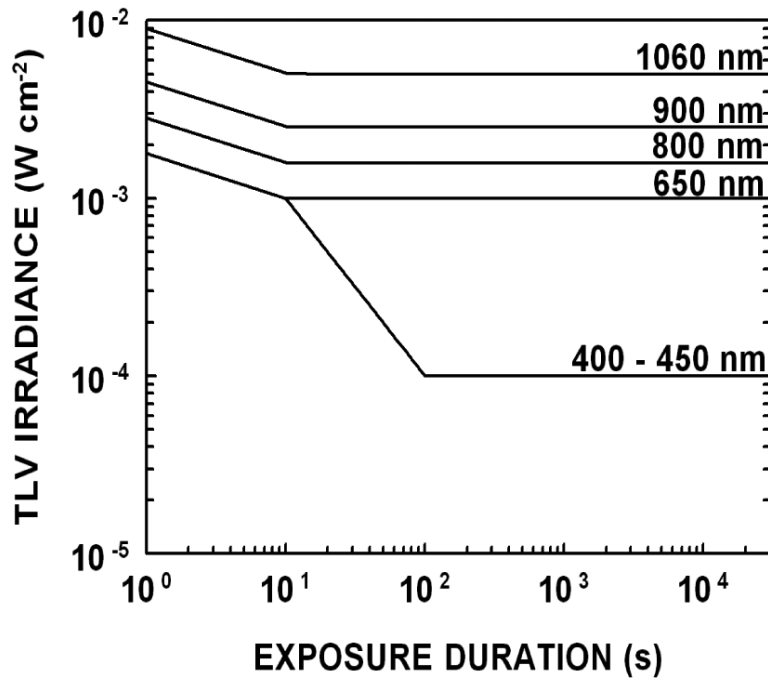


FIGURE 3b. TLV<sup>®</sup> for intrabeam (direct) viewing of CW laser beam (400–1400 nm).



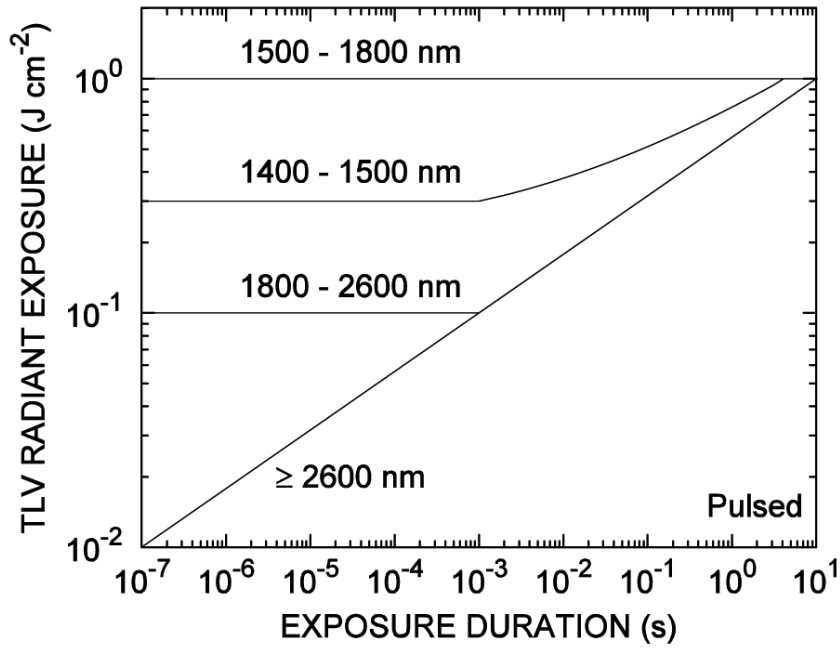


FIGURE 4a. TLV<sup>®</sup> for laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1400 nm).

TLV<sup>®</sup>-PA

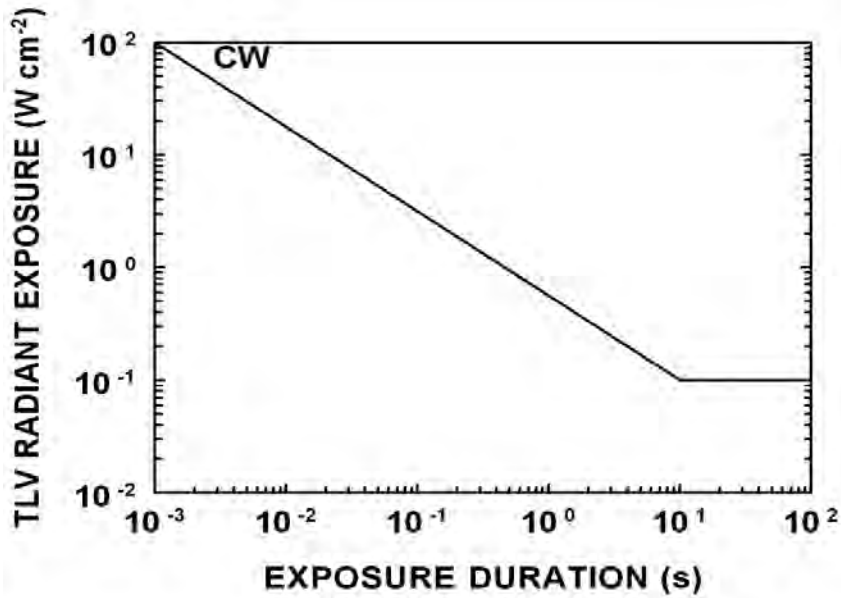


FIGURE 4b. TLV<sup>®</sup> for CW laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1.4  $\mu\text{m}$ ).

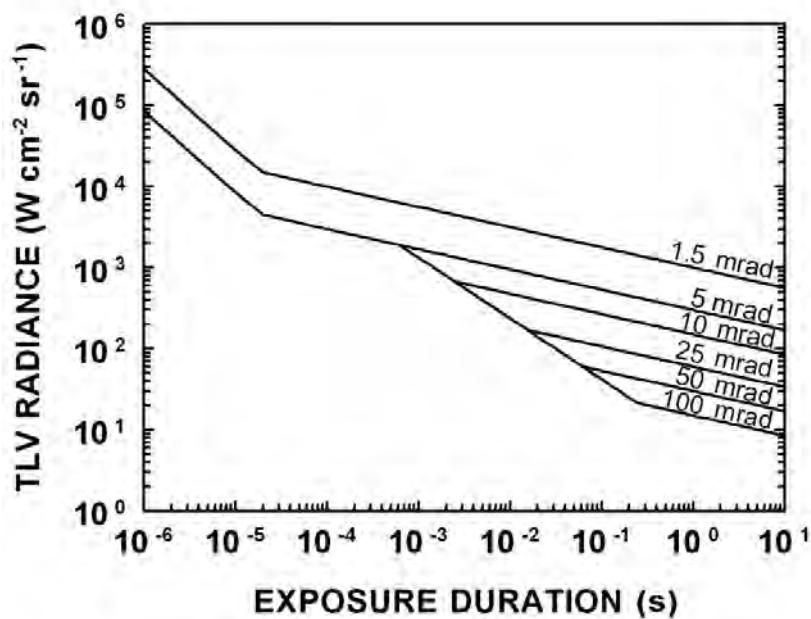


FIGURE 5. TLVs® in terms of radiance for exposures to extended-source lasers in the wavelength range of 400 to 700 nm.



## IONIZING RADIATION

ACGIH® has adopted as a TLV® for occupational exposure to ionizing radiation the guidelines recommended by the International Commission on Radiation Protection (ICRP, 2007) and the National Council on Radiation Protection and Measurements (NCRP, 1993). Ionizing radiation includes particulate radiation ( $\alpha$  particles and  $\beta$  particles emitted from radioactive materials, and neutrons, protons and heavier charged particles produced in nuclear reactors and accelerators) and electromagnetic radiation (gamma rays emitted from radioactive materials and X-rays from electron accelerators and X-ray machines) with energy > 12.4 electron volts (eV) corresponding to wavelengths less than approximately 100 nanometers (nm).

The guiding principles of ionizing radiation protection are:

- **Justification:** No practice involving exposure to ionizing radiation should be adopted unless it produces sufficient benefit to an exposed individual or society to offset the detriment it causes.
- **Optimization:** All radiation exposures must be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.
- **Limitation:** The radiation dose from all occupationally relevant sources should not produce a level of risk of greater than about  $10^{-3}$  per year of inducing fatal cancer during the lifetime of the exposed individual.\*

The TLV® guidelines are the dose limits shown in Table 1. Application of ALARA principles are recommended for all workers to keep radiation exposures as far below the guidelines as practicable.

\* This level of risk is based on the ICRP (2007) and NCRP (1993) estimate of a 5% lifetime risk of fatal cancer for an exposure of one Sv and an annual occupational exposure of 20 mSv averaged over five years.

**TABLE 1. Guidelines for Exposure to Ionizing Radiation<sup>A</sup>**

Type of Exposure	Guideline for Annual Exposure
Effective Dose:	
a) in any single year	50 mSv (millisievert) <sup>B</sup>
b) averaged over 5 years	20 mSv per year
Annual Equivalent Dose <sup>C</sup> to:	
a) lens of the eye	150 mSv
b) skin, hands and feet	500 mSv
Cumulative Effective Dose:	10 mSv × age in years
Embryo/Fetus Monthly Equivalent Dose <sup>C</sup> :	0.5 mSv
Radon and Radon Daughters:	4 Working Level Months (WLM) <sup>D</sup>



- <sup>A</sup> Doses are the effective doses from combined external and internal sources (excluding background radiation from radon, terrestrial, cosmic and internal body sources). The effective dose is that defined by ICRP and NCRP, where the effective dose is  $H_T = \sum w_T \sum w_R D_{T,R}$ , in which  $D_{T,R}$  is the average absorbed dose in each tissue or organ,  $w_T$  is the tissue weighting factor representing the proportionate detriment (stochastic cancer risk), and  $w_R$  is the radiation weighting factor for the types of radiation(s) impinging on the body or, in the case of internal emitters, the radiation emitted by the source(s). The values of  $w_R$  and  $w_T$  to be used are those recommended by ICRP (2007).
- <sup>B</sup> 10 mSv = 1 rem.
- <sup>C</sup> The equivalent dose is the sum of external and internal absorbed doses multiplied by the appropriate radiation weighting factors.
- <sup>D</sup> One WLM =  $3.5 \times 10^{-3}$  Jh/m<sup>3</sup>. The upper value for the individual worker annual dose is 10 mSv, which corresponds to an upper activity reference level of 1500 becquerels per m<sup>3</sup> for radon and radon progeny in equilibrium, where a becquerel is a reciprocal second (ICRP, 1993, 2007).

## References

- International Commission on Radiological Protection (ICRP): ICRP Publication 103, The 2007 Recommendations of the International Commission on Radiological Protection. Ann ICRP Vol 37(2–4) (2007).
- National Council on Radiation Protection and Measurements (NCRP): Limitations of Exposure to Ionizing Radiation, NCRP Report No 116. NCRP, Bethesda, MD (1993).

## **ERGONOMICS**

Ergonomics is the term applied to the field that studies and designs the human-machine interface to prevent illness and injury and to improve work performance. It attempts to ensure that jobs and work tasks are designed to be compatible with the capabilities of the workers. ACGIH® recognizes that some physical agents play an important role in ergonomics. Force and acceleration are addressed, in part, in the Hand-Arm Vibration (HAV) and Whole-Body Vibration (WBV) TLVs®. Thermal factors are addressed, in part, in the TLVs® for Thermal Stress. Force is also an important causal agent in injuries from lifting. Other important ergonomic considerations include work duration, repetition, contact stresses, postures, and psychosocial issues.

### **STATEMENT ON WORK-RELATED MUSCULOSKELETAL DISORDERS**

ACGIH® recognizes work-related musculoskeletal disorders (MSDs) as an important occupational health problem that can be managed using an ergonomics health and safety program. The term musculoskeletal disorders refers to chronic muscle, tendon, and nerve disorders caused by repetitive exertions, rapid motions, high forces, contact stresses, extreme postures, vibration, and/or low temperatures. Other commonly used terms for work-related musculoskeletal disorders include cumulative trauma disorders (CTDs), repetitive motion illnesses (RMIs), and repetitive strain injuries (RSIs).

Some of these disorders fit established diagnostic criteria such as carpal tunnel syndrome or tendinitis. Other musculoskeletal disorders may be manifested by nonspecific pain. Some transient discomfort is a normal consequence of work and is unavoidable, but discomfort that persists from day to day or interferes with activities of work or daily living should not be considered an acceptable outcome of work.

#### **Control Strategies**

The incidence and severity of MSDs are best controlled by an integrated ergonomics program. Major program elements include:

- Recognition of the problem,
- Evaluation of suspected jobs for possible risk factors,
- Identification and evaluation of causative factors,
- Involvement of workers as fully informed active participants, and
- Appropriate health care for workers who have developed musculoskeletal disorders.

General programmatic controls should be implemented when risk of MSDs is recognized. These include:

- Education of workers, supervisors, engineers, and managers;
  - Early reporting of symptoms by workers; and
  - Ongoing surveillance and evaluation of injury, health and medical data.
- Job-specific controls are directed to individual jobs associated with

MSDs. These include engineering controls and administrative controls. Personal protection may be appropriate under some limited circumstances.

Among engineering controls to eliminate or reduce risk factors from the job, the following may be considered:

- Using work methods engineering, e.g., time study, motion analysis, to eliminate unnecessary motions and exertions.
- Using mechanical assists to eliminate or reduce exertions required to hold tools and work objects.
- Selecting or designing tools that reduce force requirements, reduce holding time, and improve postures.
- Providing user-adjustable workstations that reduce reaching and improve postures.
- Implementing quality control and maintenance programs that reduce unnecessary forces and exertions, especially associated with nonvalue-added work.

Administrative controls reduce risk through reduction of exposure time and sharing the exposure among a larger group of workers. Examples include:

- Implementing work standards that permit workers to pause or stretch as necessary but at least once per hour.
- Re-allocating work assignments (e.g., using worker rotation or work enlargement) so that a worker does not spend an entire workshift performing high-demand tasks.

Due to the complex nature of musculoskeletal disorders, there is no “one size fits all” approach to reducing the incidence and severity of cases. The following principles apply to selecting actions:

- Appropriate engineering and administrative controls will vary from industry to industry and company to company.
- Informed professional judgment is required to select the appropriate control measures.
- Work-related MSDs typically require periods of weeks to months for recovery. Control measures should be evaluated accordingly to determine their effectiveness.

### **Nonoccupational Factors**

It is not possible to eliminate all musculoskeletal disorders via engineering and administrative controls. There are individual and organizational factors that may influence the likelihood that an individual will experience musculoskeletal disorders. Some cases may be associated with nonoccupational factors such as:

- Rheumatoid arthritis
- Endocrinological disorders
- Acute trauma
- Obesity
- Pregnancy
- Age
- Gender

- Level of physical condition
- Previous injuries
- Diabetes
- Recreational/leisure activities

The recommended TLV® may not provide protection for people with these conditions and/or exposures. Engineering and administrative actions can help eliminate ergonomic barriers for persons with predisposing conditions and thus help to minimize disability.

### **Chronology of the Statement**

1995: *Proposed* “Lifting Statement”

1996: Adopted with name change to “Musculoskeletal Statement”

2000: Editorial changes

2004: Editorial changes

## HAND ACTIVITY

Although work-related musculoskeletal disorders can occur in a number of body regions (including the shoulders, neck, low back, and lower extremities), the focus of this TLV<sup>®</sup> is on the hand, wrist, and forearm.

The TLV<sup>®</sup> shown in Figure 1 is based on epidemiological, psychophysical, and biomechanical studies and is intended for jobs performed from 4 to 8 hours per day. The TLV<sup>®</sup> specifically considers average Hand Activity Level (HAL) and Normalized Peak Force (NPF) to represent conditions to which it is believed nearly all workers may be repeatedly exposed without adverse health effects.

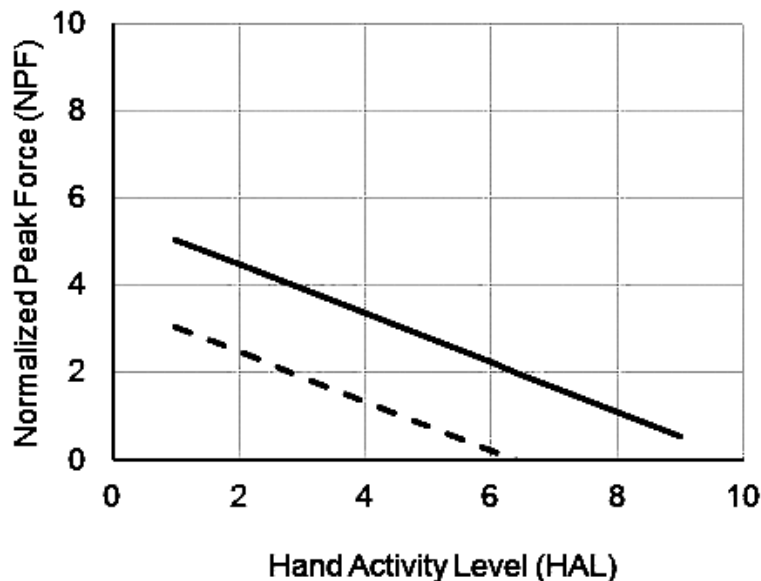
HAL is based on the frequency of hand exertions and the duty cycle (distribution of work and recovery periods). HAL can be determined by trained observers based on exertion frequency, rest pauses and speed of motion using the rating scale shown in Figure 2. Only hand exertions greater than 10% of posture specific strength should be considered. HAL can also be calculated based on empirical studies of expert ratings, hand exertion frequency and duty cycle (exertion time/(exertion + rest time) × 100%). HAL can be calculated as:

$$\text{HAL} = 6.56 \ln D \left[ \frac{F^{1.31}}{1 + 3.18 F^{1.31}} \right]$$

(D = duty cycle [%] and F = hand exertion frequency [exertions/s]) or estimated from Table 1. Calculated HAL values should be rounded to the nearest whole number.

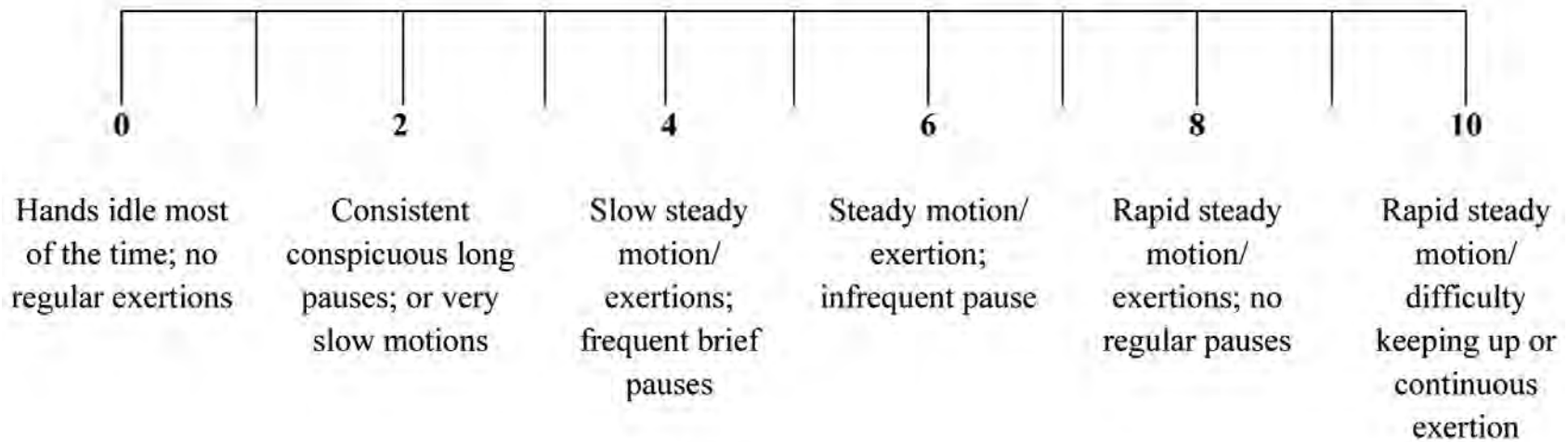
Peak hand force (PF) is a typically high value of hand force, generally taken to be the 90th percentile force exerted by the hand over the task period. Peak hand force is normalized to a scale of 0 to 10, which corresponds

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**FIGURE 1.** The Hand Activity TLV<sup>®</sup> for reduction of work-related musculoskeletal disorders based on hand activity level (HAL) and normalized peak hand force. The top line depicts the TLV<sup>®</sup>. The bottom line is the Action Limit (AL) for which general controls are recommended.

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**FIGURE 2.** Hand Activity Level (HAL) (0–10) can be rated using the above guidelines.

**TABLE 1. Hand Activity Level (HAL) (0–10) is Related to Hand Exertion Frequency and Duty Cycle (percent of work cycle where hand force is greater than 10% of posture specific strength)**

Frequency (exertions/s)	Period (s/exertion)	Duty Cycle (%)				
		0–20	20–40	40–60	60–80	80–100
0.125	8.0	1	1	–	–	–
0.25	4.0	2	2	3	–	–
0.5	2.0	3	4	5	5	5
1.0	1.0	4	5	6	7	7
2.0	0.5	–	6	7	8	8

*Notes:*

1. Round HAL values to the nearest whole number.
2. Use Figure 2 to obtain HAL values outside those listed in the table.

to 0% to 100% of the posture-specific strength for the applicable population (males, females, young, old, office workers, factory workers, etc.):

Normalized Peak Force (NPF) = (Peak force/Posture specific referent strength)  $\times$  10

PF and NPF can be estimated using ratings by a trained observer, rated by workers using a Borg or visual analog scale (see TLV<sup>®</sup> *Documentation* for definition), or measured using instrumentation, e.g., strain gauges or electromyography. In some cases, it can be calculated using biomechanical methods. These methods are intended to measure recurring peak forces. Random force peaks associated with noise that occur less than 10% of the time are disregarded.

Posture is included in the TLV<sup>®</sup> to the extent that it affects strength. For instance, strength is reduced by the use of a pinch posture, wrist deviation, or forearm rotation and consequently normalized peak force will be increased.

The solid line in Figure 1 represents those combinations of force and hand activity level associated with a significantly elevated prevalence of musculoskeletal disorders. Appropriate control measures should be employed so that the force for a given level of hand activity is below the upper solid line in Figure 1. It is not possible to specify a TLV<sup>®</sup> that protects all workers in all situations without profoundly affecting work rates. Therefore, an Action Limit is prescribed above for which general controls, including surveillance and training, are recommended.

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### Process

1. Identify the hand-activity tasks performed during the workday. There may be one or more and they should cumulatively represent four or more hours of work.
2. For each task, select a period of the task that represents an average activity. The selected period should include several complete work cycles. Videotapes may be used for documentation purposes and to facilitate rating of the job.
3. Rate the Hand Activity Level using the scale shown in Figure 2. Independent rating of jobs and discussion of results by three or more people can help produce a more precise rating than individual ratings.
4. Observe the job to identify forceful exertions and corresponding postures. Evaluate postures and forces using observer ratings, worker ratings, biomechanical analysis, or instrumentation. Normalized peak force is the required peak force divided by the representative maximum force for the posture multiplied by 10.
5. For jobs with multiple tasks, time-weighted averaging (TWA) may be used. One method is to determine the TWA of HAL across tasks and use the highest NPF observed among the tasks. A second method is to determine a TWA on the Peak Force Index (PFI) for each task (see Notes). A third method is to determine the TWA for NPF across all tasks and separately a TWA for HAL across all tasks.

### Consideration of Other Factors

Professional judgment should be used to reduce exposures below the Action Limit if one or more of the following factors is present:

- sustained non-neutral postures such as wrist flexion, extension, wrist deviation, or forearm rotation;



- contact stresses;
- low temperatures; or
- vibration

Employ appropriate control measures any time the TLV<sup>®</sup> is exceeded or an elevated incidence of work-related musculoskeletal disorders is detected.

**Notes:**

The actual TLV<sup>®</sup> and Action Limit (AL) are represented by Figure 1. There are alternative methods for expressing the limit values, and some are described here. In all cases, they are limited to the range of HAL between 1 and 9.

**1. Equations for Lines**

$$\text{TLV: NPF} = 5.6 - 0.56 \times \text{HAL}$$

$$\text{Action Limit: NPF} = 3.6 - 0.56 \times \text{HAL}$$

Or, equivalent description of lines:

$$\text{NPF}_{\text{TLV}} = 0.56 (10 - \text{HAL})$$

$$\text{NPF}_{\text{AL}} = \text{NPF}_{\text{TLV}} - 2$$

**2. Peak Force Index (PFI)**

A value greater than 1.0 means that the respective limit is exceeded.

$$\text{PFI}_{\text{TLV}} = \text{NPF} / \text{NPF}_{\text{TLV}}$$

$$\text{PFI}_{\text{AL}} = \text{NPF} / \text{NPF}_{\text{AL}}$$

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## LIFTING

These TLVs® recommend workplace lifting conditions under which it is believed nearly all workers may be repeatedly exposed, day after day, without developing work-related low back and shoulder disorders associated with repetitive lifting tasks. There are individual and organizational risk factors that may influence the likelihood that an individual will experience low back and shoulder disorders.

### Lifting TLVs®

The TLVs® consist of three tables with weight limits, in kilograms (kg), for two-handed, mono-lifting tasks within 30 degrees of the sagittal [neutral] plane. A mono-lifting task is one in which the loads are similar and the starting and destination points are repeated, and this is the only lifting task performed during the day. Other manual material-handling tasks such as carrying, pushing, and pulling are not accounted for in the TLV®, and care must be exercised in applying the TLVs® under these circumstances.

These TLVs® (Tables 1 through 3) are presented for lifting tasks defined by their durations, either less than or greater than 2 hours per day, and by their frequency, expressed in number of lifts per hour, as qualified in the *Notes* to each table.

**In the presence of any factor(s) or working condition(s) listed below, professional judgment should be used to reduce weight limits below those recommended in the TLVs®:**

- High-frequency lifting: > 360 lifts per hour.
- Extended workshifts: lifting performed for longer than 8 hours per day.
- High asymmetry: lifting more than 30 degrees away from the sagittal plane.
- Rapid lifting motions and motions with twisting (e.g., from side to side).
- One-handed lifting.
- Constrained lower body posture, such as lifting while seated or kneeling.
- High heat and humidity (see Heat Stress and Heat Strain TLVs®).
- Lifting unstable objects (e.g., liquids with shifting center of mass or lack of coordination or equal sharing in multi-person lifts).
- Poor hand coupling: lack of handles, cut-outs, or other grasping points.
- Unstable footing (e.g., inability to support the body with both feet while standing).
- During or immediately after exposure to whole-body vibration at or above the TLV® for Whole-Body Vibration (see the current *TLV® Documentation* for Whole-Body Vibration).

### Instructions for Users

1. **Read the *Documentation* for the Lifting TLVs®** so you understand the basis for these TLVs® and their limitations.
2. **Classify task duration** as less than or equal to a cumulative 2 hours per day or greater than a cumulative 2 hours per day. Task duration is the total length of time that a worker performs the task in 1 day.

**TABLE 1. TLVs<sup>®</sup> for Lifting Tasks:**  
**≤ 2 Hours per Day with ≤ 60 Lifts per Hour**  
**OR**  
**> 2 Hours per Day with ≤ 12 Lifts per Hour**

Vertical Zone	Horizontal Zone <sup>A</sup>		
	Close: < 30 cm	Inter- mediate: 30 to 60 cm	Extended: <sup>B</sup> > 60 to 80 cm
Reach limit <sup>C</sup> or 30 cm above shoulder to 8 cm below shoulder height	16 kg	7 kg	No known safe limit for repetitive lifting <sup>D</sup>
Knuckle height <sup>E</sup> to below shoulder	32 kg	16 kg	9 kg
Middle shin to knuckle height <sup>E</sup>	18 kg	14 kg	7 kg
Floor to middle shin height	14 kg	No known safe limit for repetitive lifting <sup>D</sup>	No known safe limit for repetitive lifting <sup>D</sup>

**Footnotes for Tables 1 through 3:**

- A. Distance from midpoint between inner ankle bones and the load.
- B. Lifting tasks should not start or end at a horizontal reach distance more than 80 cm from the midpoint between the inner ankle bones (Figure 1).
- C. Routine lifting tasks should not start or end at heights that are greater than 30 cm above the shoulder or more than 180 cm above floor level (Figure 1).
- D. Routine lifting tasks should not be performed for shaded table entries marked “No known safe limit for repetitive lifting.” While the available evidence does not permit identification of safe weight limits in the shaded regions, professional judgment may be used to determine if infrequent lifts of light weights may be safe.
- E. Anatomical landmark for knuckle height assumes the worker is standing erect with arms hanging at the sides.

**TABLE 2. TLVs<sup>®</sup> for Lifting Tasks**  
**> 2 Hours per Day with > 12 and ≤ 30 Lifts per Hour**  
**OR**  
**≤ 2 Hours per Day with > 60 and ≤ 360 Lifts per Hour**

Vertical Zone	Horizontal Zone <sup>A</sup>		
	Close: < 30 cm	Inter- mediate: 30 to 60 cm	Extended: <sup>B</sup> > 60 to 80 cm
Reach limit <sup>C</sup> or 30 cm above shoulder to 8 cm below shoulder height	14 kg	5 kg	No known safe limit for repetitive lifting <sup>D</sup>
Knuckle height <sup>E</sup> to below shoulder	27 kg	14 kg	7 kg
Middle shin to knuckle height <sup>E</sup>	16 kg	11 kg	5 kg
Floor to middle shin height	9 kg	No known safe limit for repetitive lifting <sup>D</sup>	No known safe limit for repetitive lifting <sup>D</sup>

*See Notes in Table 1.*

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**TABLE 3. TLVs<sup>®</sup> for Lifting Tasks**  
**> 2 Hours per Day with > 30 and ≤ 360 Lifts per Hour**

Vertical Zone	Horizontal Zone <sup>A</sup>		
	Close: < 30 cm	Inter- mediate: 30 to 60 cm	Extended: <sup>B</sup> > 60 to 80 cm
Reach limit <sup>C</sup> from 30 cm above to 8 cm below shoulder height	11 kg	No known safe limit for repetitive lifting <sup>D</sup>	No known safe limit for repetitive lifting <sup>D</sup>
Knuckle height <sup>E</sup> to below shoulder	14 kg	9 kg	5 kg
Middle shin to knuckle height <sup>E</sup>	9 kg	7 kg	2 kg
Floor to middle shin height	No known safe limit for repetitive lifting <sup>D</sup>	No known safe limit for repetitive lifting <sup>D</sup>	No known safe limit for repetitive lifting <sup>D</sup>

*See Notes in Table 1.*

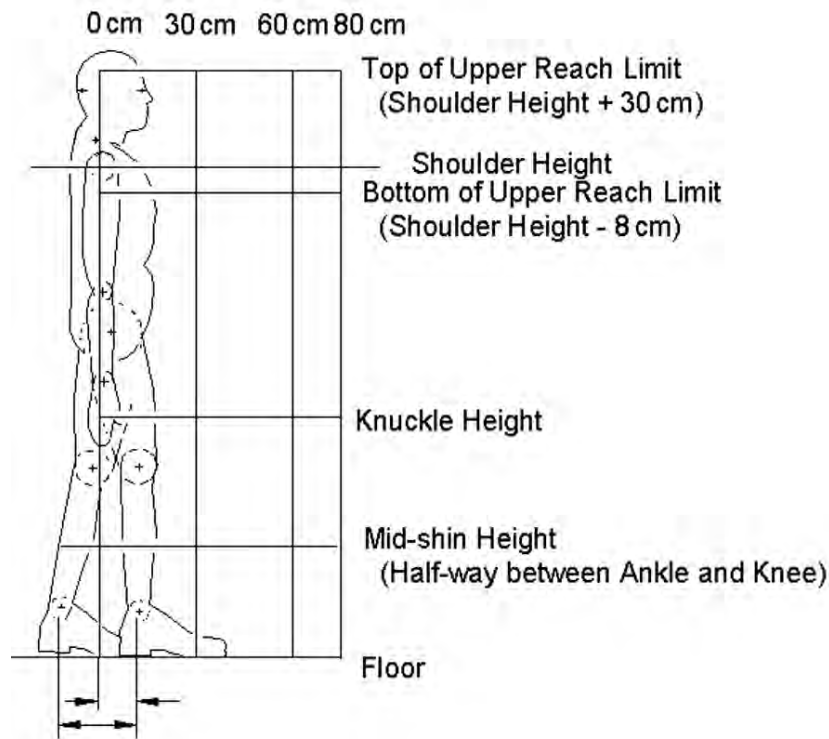


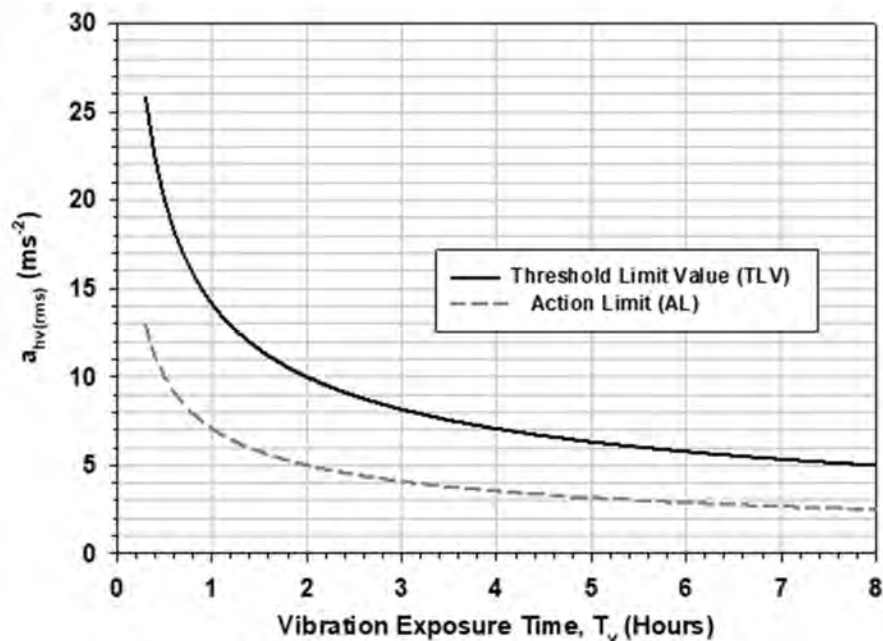
FIGURE 1. Graphic representation of hand location.

3. **Determine the lifting frequency** as the number of lifts a worker performs per hour.
4. **Use the TLV<sup>®</sup> table that corresponds to the duration and lifting frequency of the task.**
5. **Determine the vertical zone** (Figure 1) based on the location of the hands at the start of the lift.
6. **Determine the horizontal zone of the lift** (Figure 1) by measuring the horizontal distance from the midpoint between the inner ankle bones to the midpoint between the hands at the start of the lift.
7. **Determine the TLV<sup>®</sup>** in kilograms for the lifting task, as displayed in the table cell that corresponds to the vertical and horizontal zones in the appropriate table, based upon frequency and duration.
8. **Consider load control at destination.** If the load is placed at the destination in a controlled fashion (i.e., slowly or deliberately placed), repeat Steps 5 through 7 using the destination point instead of the start. The TLV<sup>®</sup> is represented by the lower of the two limits.

## \* HAND-ARM VIBRATION

Exposure to vibration may lead to Hand-Arm Vibration Syndrome (HAVS), a set of upper extremity disorders that include vascular, sensorineural, and musculoskeletal signs and symptoms. The Threshold Limit Value (TLV<sup>®</sup>) for hand-arm vibration illustrated by the upper solid line in Figure 1 and tabulated in Table 1, refers to the daily vibration exposure [8-hour energy equivalent total value **A(8)**] of 5 m/s<sup>2</sup> that represents conditions under which it is believed that most workers may be exposed repeatedly without progressing beyond Stage 1 of the Stockholm Workshop Classification System for Vibration-Induced White Finger (VWF), also known as Raynaud's Phenomenon of Occupational Origin (see Vascular Assessment in Table 2). Vibration mitigation processes or controls should be employed that will maintain worker exposure below the TLV<sup>®</sup> illustrated in Figure 1. It is not possible to specify a TLV<sup>®</sup> that will be protective of all workers for all work situations, i.e., high force exertions, cold environments, and unusual postures. The Action Limit (AL) illustrated by the lower dashed line in Figure 1 and tabulated in Table 1 refers to an **A(8)** of 2.5 m/s<sup>2</sup>. This limit represents conditions under which the risk of developing symptoms is very low for the large majority of workers. Therefore, the area between the AL and TLV<sup>®</sup> corresponds to a caution zone that requires actions to control exposure, such as 1) the use of antivibration tools or gloves; 2) training of workers and supervisors on early symptoms of HAVS and the importance of keeping the worker's hands and body warm and reducing the vibration coupling between the hands and the vibrating tool to minimize vibration exposure, and 3) a conscientiously applied

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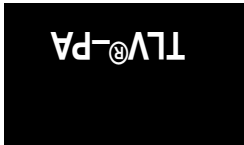
**FIGURE 1.** Threshold Limit Values (TLVs<sup>®</sup>) and Action Limits (ALs) associated with ANSI 2.70 Daily Exposure Limit Values (DELV) and Daily Exposure Action Values (DEAV), respectively.

**TABLE 1. TLV<sup>®</sup> and AL Weighted Acceleration Levels**

Vibration Exposure Time (hrs)	Weighted Acceleration ( $a_{hv(rms)}ms^{-2}$ )	
	TLV <sup>®</sup>	AL
0.25 (15 min)	28.28	14.14
1.0	14.14	7.07
2	10.0	5.0
4	7.07	3.54
6	5.77	2.89
8	5.0	2.5

TLV at Time $T_v$ (hrs):	$a_{hv(TLV)} = 5.0 \left(\frac{8}{T_v}\right)^{\frac{1}{2}}$
AL at Time $T_v$ (hrs):	$a_{hv(AL)} = 2.5 \left(\frac{8}{T_v}\right)^{\frac{1}{2}}$
Time Duration $T_v$ (hrs) to reach TLV:	$T_v = \frac{200}{a_{hv(TLV)}^2}$
Time Duration $T_v$ (hrs) to reach AL:	$T_v = \frac{50}{a_{hv(AL)}^2}$



medical surveillance program. These recommendations have been derived mainly from epidemiological data from forestry, mining, stone and metal-working occupations and should be used as guides in the control of hand–arm vibration exposure. Due to individual susceptibility, they should not be regarded as defining a boundary between safe and unsafe exposure levels.

**Notes:**

1. The TLV<sup>®</sup> curve shown in Figure 1 coincides with the Daily Exposure Limit Values (DELVs) defined in ANSI S2.70 (2006) and the daily exposure limit value standardized to an 8-hour reference period (or 8-hour energy equivalent total value) defined in the European Union Directive 2002/44/EC. The AL curve shown in Figure 1 coincides with the Daily Exposure Action Values (DEAVs) defined in ANSI S2.70 (2006) and the daily exposure action value (or 8-hour energy equivalent vibration total value) defined in the European Union Directive 2002/44/EC.
2. **A(8)** is the vector sum of the 8-hour energy equivalent total value, constructed from the root-mean-square (rms) component accelerations measured in three orthogonal axes.
3. The frequency weighting factors provided in ISO 5349 (2001a, b) and ANSI S2.70 (2006) are considered the best available frequency weightings for the acceleration components for assessing hand–arm vibration exposure (see Figure 2). However, studies suggest that the frequency weighting at frequencies above 16 Hz may not incorporate a sufficient safety factor, and caution must be applied when tools with high-frequency components are used (Pelmear et al., 1989; Wasserman, 1987, 1989a, b; Taylor and Pelmear, 1975; Wasserman and Taylor, 1977; Brammer, 1982; Miwa, 1967; Bovenzi et al., 2011; Dong et al., 2012).
4. Acute exposures corresponding to measured frequency-weighted rms component accelerations either in compliance with or in excess of the TLVs<sup>®</sup> for infrequent periods of time (i.e., intermittency: 1 day per week or several days over a 2-week period) may be less harmful than continuous exposure (Taylor and Pelmear, 1975; Wasserman and Taylor, 1977; Brammer, 1982; Miwa, 1967).
5. Good work practices should be used and should include instructing workers to employ a minimum hand grip force consistent with safe operation of the power tool or process, to keep the body and hands warm and dry, to avoid smoking, and to use antivibration tools. As a general rule, gloves may dampen vibration at high frequencies (beyond 200 Hz) (Taylor and Pelmear, 1975; Wasserman and Taylor, 1977; Brammer, 1982).
6. A vibration measurement transducer, together with its device for attachment to the vibration source, should weigh less than 15 grams and should possess a cross-axis sensitivity of less than 10% (Taylor and Pelmear, 1975; Wasserman and Taylor, 1977; Brammer, 1982; Wasserman et al., 1982a; U.S. NIOSH, 1983, 1989).
7. The measurement by many (mechanically under-damped) piezoelectric accelerometers of repetitive and large displacement impact vibrations, such as those produced by percussive pneumatic tools, is subject to error. The insertion of a suitable, low-pass, mechanical filter between the accelerometer and the source of vibration with a cutoff frequency of at most 1500 Hz (and cross-axis sensitivity of less than 10%) can help eliminate incorrect readings.



**TABLE 2. Stockholm Workshop HAVS Classification System for Cold-Induced Peripheral Vascular and Sensorineural Symptoms**

Vascular Assessment		
Stage	Grade	Description
0	—	No attacks
1	Mild	Occasional attacks affecting only the tips of one or more fingers
2	Moderate	Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers
3	Severe	Frequent attacks affecting ALL phalanges of most fingers
4	Very Severe	As in Stage 3, with trophic skin changes in the finger tips

Note: Separate staging is made for each hand, e.g., 2L(2)/1R(1) = Stage 2 on left hand in 2 fingers; Stage 1 on right hand in 1 finger.

Sensorineural Assessment	
Stage	Symptoms
0SN	Exposed to vibration but no symptoms
1SN	Intermittent numbness, with or without tingling
2SN	Intermittent or persistent numbness, reducing sensory perception
3SN	Intermittent or persistent numbness, reducing tactile discrimination and/or manipulative dexterity

Note: Separate staging is made for each hand.

8. The manufacturer and type number of all apparatus used to measure vibration should be reported, as well as the value **A(8)** (Wasserman, 1987; Wasserman and Taylor, 1977; Brammer, 1978, 1982; Wasserman et al., 1982b).
9. The measurement of vibration should be performed in accordance with the procedures and instrumentation specified by ISO 5349-1 or ANSI S2.70. The procedures are summarized below.
  - a. It is highly recommended that signal processing techniques be applied to generate the spectral content in each axis to identify the frequencies corresponding to major acceleration peaks. The spectra can be generated in either narrow frequency bands of constant bandwidth, or proportional bands no greater than one-third octave.
  - b. A small and lightweight transducer should be mounted so as to accurately record one or more orthogonal components of the source vibration in the frequency range from 5 to 1500 Hz (one-third octave frequency bands 6.3 to 1250 Hz).
  - c. Evaluation of vibration should be made for each applicable direction ( $X_h$ ,  $Y_h$ ,  $Z_h$ ) since vibration is a vector quantity (magnitude and direction).

- d. Each component should be frequency-weighted by a filter network with gain characteristics specified for human-response vibration measuring instrumentation, to account for the change in vibration hazard with frequency (ISO 5349-1, 2001a).

$$a_{hw} = \left( \frac{1}{T} \int_0^T a_{hw}^2(t) dt \right)^{\frac{1}{2}} \quad (1)$$

where:  $a_{hw}$  = The frequency-weighted rms acceleration associated with worker exposure time ( $T$ ) in each respective direction ( $m/s^2$  rms)

- e. The weighted acceleration can also be obtained in the one-third octave frequency domain per Equation 2.

$$a_{hw} = \left( \sum_i [W_{hi} a_{hi}]^2 \right)^{\frac{1}{2}} \quad (2)$$

where:  $a_{hw}$  = The frequency-weighted rms acceleration associated with the exposure time in each respective direction ( $m/s^2$  rms)

$W_{hi}$  = The ISO/ANSI frequency weighting factor for the  $i^{\text{th}}$  one-third octave frequency band (see Figure 2)

$a_{hi}$  = The rms acceleration in the  $i^{\text{th}}$  one-third octave frequency band associated with the exposure time in each respective direction ( $m/s$  rms)

- f. In each direction, the magnitude of the vibration total value,  $a_{hv}$ , during normal operation of the power tool, machine, or work piece should be expressed by the root-sum-of-squares of the rms frequency-weighted component accelerations, in units of meters per second squared ( $m/s^2$ ).

$$a_{hv} = \left( [a_{hwx}^2] + [a_{hwy}^2] + [a_{hwz}^2] \right)^{\frac{1}{2}} \quad (3)$$

- g. Assessment of vibration exposure should be made by determining the 8-hour energy equivalent vibration total value of the frequency weighted rms acceleration components [alternatively termed the vector sum or frequency weighted acceleration sum]. The 8-hour energy equivalent vibration total value is termed the **A(8)**. These computations may be performed by commercially available human-response vibration measuring instruments.

$$A(8) = a_{hv} \left( \frac{T_v}{T_0} \right)^{\frac{1}{2}} \quad (4)$$

where:  $T_v$  = The total time in hours associated with the actual worker exposure (same as  $T$  in Equation 1)

$T_0$  = The reference time duration of 8 hours

- h. The guidelines in ANSI S2.70 (ANSI, 2006) should be used if the vibration exposure is made up of several operations with different vibration magnitudes.

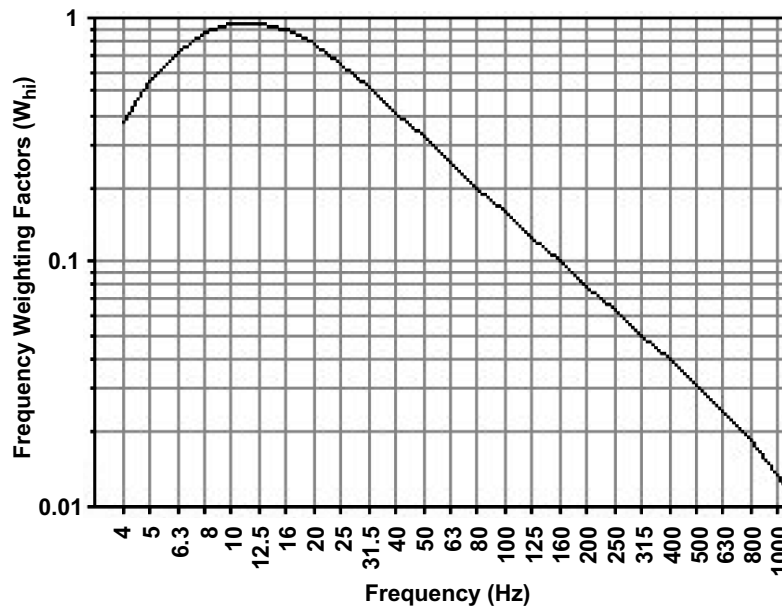
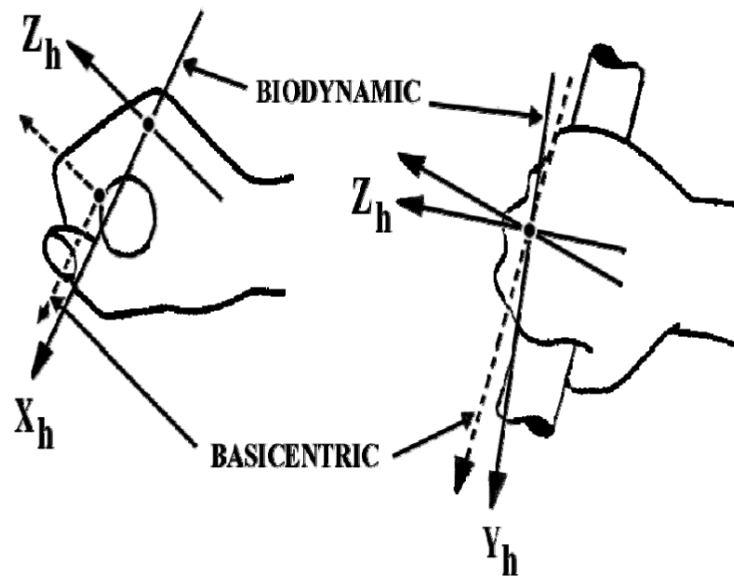


FIGURE 2. ISO Frequency Weighting Factors (ISO 5349-1, 2001a; ANSI S2.70, 2006).

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**FIGURE 3.** Biodynamic and basicentric coordinate systems for the hand, showing the directions of the acceleration components (ISO 5349, 2001a; ANSI S2.70, 2006).

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## UPPER LIMB LOCALIZED FATIGUE

The TLV® in Figure 1 is recommended for workplace tasks that require the use of the upper limbs, to which it is believed that most healthy workers may be exposed, day after day, to maintain their work capacity and normal performance for the duration of the workday without experiencing excessive or persistent upper limb musculoskeletal fatigue. Individual, environmental and other workplace factors may influence the likelihood that fatigue will be experienced as a pain or reduced upper limb motor control. This recommended TLV® may not be protective for persons with pre-existing musculoskeletal disorders.

Localized fatigue is a complex phenomenon based on multiple factors, mechanisms, and outcomes that results from exertion of the body and affects our comfort and the ability of our musculoskeletal system to perform activities of work, daily living and leisure. Fatigue may be experienced as localized discomfort, pain, decreased strength, tremor or other symptoms or signs of reduced motor control. Physical exertions can cause fatigue that is brief, lasting for just a few hours, or fatigue that may persist for 24 hours or more or, in extreme cases, tissue damage that can require several days or weeks for complete recovery. For purposes of this guideline, fatigue refers to discomfort or reduced upper limb function that occurs within 24 hours after sustained or repeated exertions of the hands and arms. Signs or symptoms that persist beyond 24 hours should be investigated as possible work-related musculoskeletal disorders. Fatigue may be a precursor to chronic soft tissue injuries.

A certain amount of localized fatigue, in and of itself, is not detrimental. Fatigue is a fact of life and a normal physiological response and may play an important role in adaptation of musculoskeletal tissues to physical stresses and unaccustomed work, but fatigue should not persist from one workday to the next or interfere with activities of work or daily living. As with any activity, workers may require several days or weeks to mentally and physically adapt to a new job. Abnormal symptoms may be experienced during this period of adaptation.

Localized fatigue that occurs during the workday should be reversibly resolved during the daily breaks from work, allowing for normal work function and typical life activities beyond work.

The recommended limits apply specifically to the upper limb: the hand/wrist, forearm, elbow and shoulder. There are underlying biomechanical and behavioral differences between the upper limb, trunk and lower limbs and care should be exercised in generalizing recommended limits for the upper limb to other body parts.

### Workload Patterns

Work performance is measured as the ability to repeat and/or sustain biomechanical loads to reach for, grasp, hold, and use or manipulate work objects. Loads, used in this context, refers to the exertion of forces and moments to support the weight of the body and work objects or to grasp, hold and manipulate work objects as necessary to meet the job requirements. Rapid body motions may briefly increase or decrease the loads during work due to acceleration and deceleration, but most fatigue computations are based on static or “quasi static” conditions where these dynamic effects are negligible.

Loads can be normalized to strength by dividing the applied forces or moments by the strength of the corresponding joint and posture of an individual or population of interest. Strength refers to the maximum force or moment that can be voluntarily generated by the body segment of interest. Normalized loads are expressed as a fraction between 0 and 1, on a scale of 0 to 10, or as a percentage from 0 to 100%. These normalized loads are also frequently expressed as a Percent of Maximum Voluntary Contraction (%MVC).

Loads may be estimated from observations, perceived exertions estimated by workers, direct measurements, indirect measurements (e.g., electromyography) and biomechanical computations. Worker strength can be measured directly or estimated from population studies or biomechanical models. The best method will depend on the type of work being performed and the characteristics of the workers who perform the job. Procedures for analysis of load patterns are documented in the literature.

The equation for the TLV<sup>®</sup> in Figure 1 is:

$$\%MVC = (100\%) \cdot (-0.143 \ln (DC/100\%) + 0.066)$$

Where %MVC is the percent of maximum strength or effort of the hand, elbow or shoulder and DC is the duty cycle expressed as a percent of the total work cycle. The duty cycle is the percent of time over a work cycle or a certain time period that force is applied.

The TLV<sup>®</sup> can also be expressed as:

$$\%DC = (100\%) \cdot e^{((0.066 - (\%MVC/100\%))/0.143)}$$

The TLV<sup>®</sup> fatigue curve can be used to compute acceptable percent duty cycle for a given force (%MVC) or an acceptable %MVC for a given percent duty cycle. The TLV<sup>®</sup> applies to duty cycles within the range of 0.5% to 90%. The TLV<sup>®</sup> is intended for cyclical work normally performed for 2 or more hours per day. If a worker does multiple tasks that are each 2 hours or more, none of the tasks should exceed the TLV<sup>®</sup>. Static exertions of the hand, elbow or shoulder would not be expected to exceed 20 minutes.

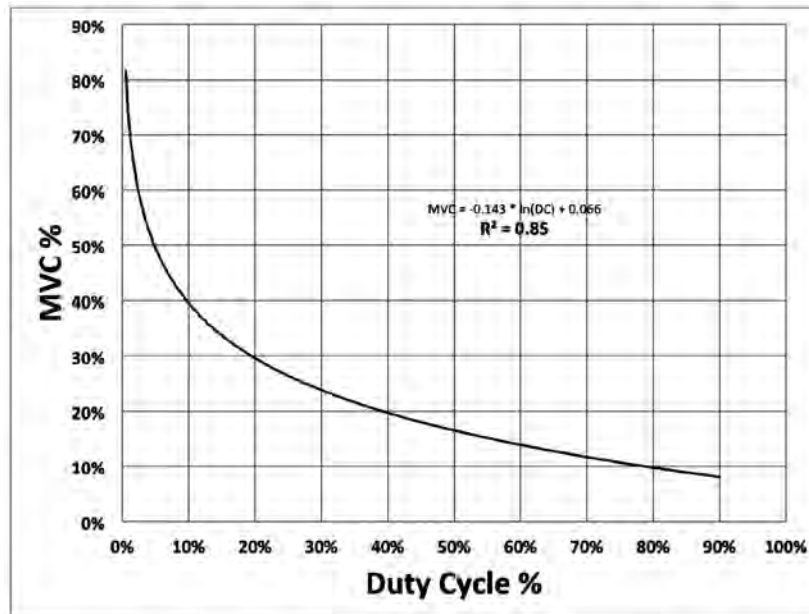


FIGURE 1. Fatigue TLV<sup>®</sup> for MVC (%) versus duty cycle (%).



## ‡ **WHOLE-BODY VIBRATION**

The Threshold Limit Values (TLVs<sup>®</sup>), illustrated by the solid line in Figure 1 and tabulated at the center frequencies of one-third octave bands in Table 1, refer to the weighted root-mean-square (rms) acceleration magnitudes and durations of mechanically induced whole-body vibration (WBV). Operator or occupant exposures shall remain below the TLV<sup>®</sup> curve for the respective exposure duration occurring within a 24-hour period. The Action Levels (ALs) represented by the dashed line in Figure 1, and tabulated at the center frequencies of one-third octave bands in Table 1, also refer to the weighted rms acceleration magnitudes and durations of mechanically induced WBV. It is highly recommended that vibration mitigation activity be undertaken to reduce any operator or occupant exposures that occur within a 24-hour period and fall within the region bounded by the TLV<sup>®</sup> curve and AL curve. It is noted that unknown psychological or physiological influences may affect an individual's susceptibility to health risk. While the TLV<sup>®</sup> and AL curves may be used as a guide in the control of WBV exposure, they should not be regarded as defining a distinct boundary between safe and dangerous levels.

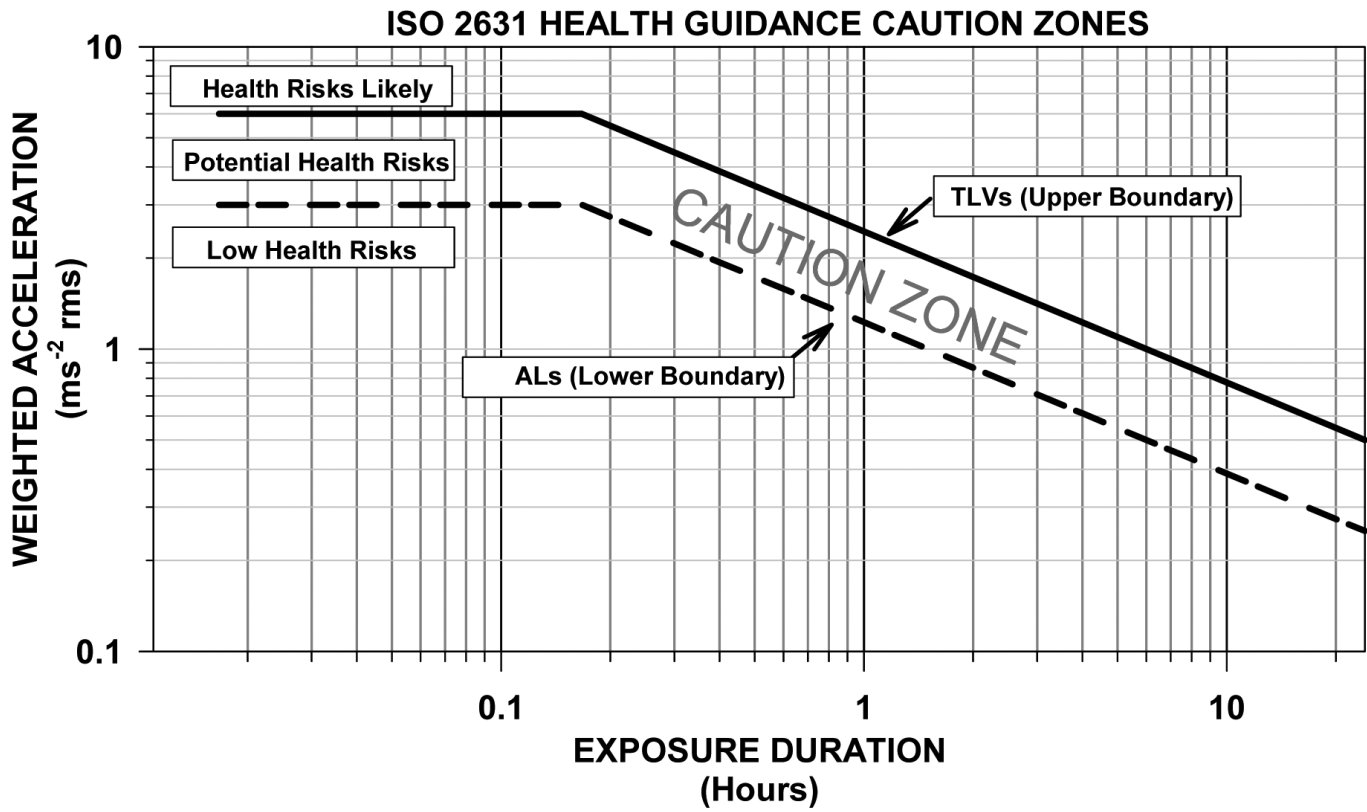
### **Notes:**

1. The TLV<sup>®</sup> curve coincides with the upper boundary of the Health Guidance Caution Zones defined in ISO 2631-1 (ISO, 1997, 2003, 2010). The TLVs<sup>®</sup> refer to the maximum weighted accelerations for a given exposure duration that it is believed a majority of operators and occupants of land, air, and water vehicles may be repeatedly exposed to within a 24-hour period with a low probability of health risks. The AL curve coincides with the lower boundary of the Health Guidance Caution Zones defined in ISO 2631-1 (ISO, 1997, 2003, 2010). With reference to ISO 2631-1, Annex B (ISO, 1997, 2003), operator and occupant exposures falling between the lower boundary (dashed line) and upper boundary (solid line) in Figure 1 within a 24-hour period have been associated with the potential for health risks.
2. Vibration acceleration is a vector with magnitude expressed in units of meters per second squared ( $\text{ms}^{-2}$ ). The gravitational acceleration, "g" =  $9.81 \text{ ms}^{-2}$ . The biodynamic coordinate system used for measuring the accelerations is illustrated in Figure 2. The procedures described in this *Documentation* apply to translational accelerations of the seated upright operator or occupant. Other postures and directions are addressed in ISO 2631-1 (ISO, 1997, 2003).
3. The TLVs<sup>®</sup> and ALs listed in Table 1 are valid for vibration crest factors (ratio of weighted peak acceleration to weighted rms acceleration) of 9 or less (ISO, 1997, 2003). The TLVs<sup>®</sup> and ALs may underestimate the effects of WBV and must be used with caution when the crest factor exceeds 9. See Note 8 for vibration with crest factors beyond 9. The crest factor should be estimated for the WBV exposure to determine if, in addition to the rms method, the Vibration Dose Value (VDV) method may be warranted.



4. The TLV® and AL are not intended for use in fixed buildings (see ISO 2631-2) (ISO, 1992), in off-shore structures, or in large ships.
5. A summary of WBV measurement procedures follows (ISO, 1997, 2003, 2010):
  - a. Three lightweight accelerometers (or triaxial accelerometer), each with a cross-axis sensitivity of less than 10%, are mounted orthogonally in the center of a hard rubber disc, per ISO 10326-1 (ISO, 1992). The total weight of the instrumented rubber disc and cables should not exceed 400 grams.
  - b. At a minimum and for health risk assessment, one instrumented rubber disc should be placed on the top of the operator's or occupant's seat, and at the interface between the buttocks and contacted seat or cushion surface. A second instrumented rubber disc may be placed at the interface between the back and the seat back, particularly if a comfort assessment is desirable (see ISO 2631-1, Section 8.2) (ISO, 1997, 2003).
  - c. At each measurement location (i.e., seat pan, seat back), continuous acceleration measurements should be simultaneously made and recorded along the three orthogonal axes (x, y, z) shown in Figure 2 (seat surface and seat back). The duration of the measurement should insure measurement accuracy and that the vibration is typical of the operator or occupant exposure being assessed (see ISO 2631-1, Section 5.5) (ISO, 1997, 2003).
6. A summary of WBV data processing procedures, including the calculation of the weighted rms acceleration in each axis (x, y, z) for assessing health risk follows:
  - a. It is highly recommended that signal processing techniques be applied to generate the spectral content in each axis to identify the frequencies corresponding to major acceleration peaks. The spectra can be generated in either narrow frequency bands of constant bandwidth, or proportional bands no greater than one-third octave.
  - b. At a minimum for health risk assessment, the acceleration measurements obtained for each axis at the buttocks-seat interface surface should be recorded and processed in accordance with ISO 2631-1 (ISO, 1997, 2003, 2010) for the seated operator or occupant using the basic evaluation method and the frequency weightings and multiplying factors for health risk. This can be done in the time domain or frequency domain using narrow band or one-third octave band data as mentioned above. The frequency weighting curves for health risk are illustrated in Figure 3. The multiplying factors ( $k_i$ ) for health risk are given below for the respective direction. The frequency range is 0.5 to 80 Hz. This yields the overall weighted rms acceleration for each axis (x, y, z). The calculation in the time domain is illustrated in Equation 1 (ISO, 1997, 2003, 2010):

$$a_{wrl} = k_l \left( \frac{1}{T} \int_0^T a_{wl}^2(t) dt \right)^{\frac{1}{2}} \quad (1)$$



**FIGURE 1.** Threshold Limit Values (TLVs®) and Action Levels (ALs) associated with the upper boundary and lower boundary of the ISO 2631-1 Health Guidance Caution Zones, respectively (ISO, 1997, 2003, 2010).

**TABLE 1. TLV<sup>®</sup> and AL Weighted Acceleration Levels**

Duration (Hours)	TLV <sup>®</sup> (ISO Upper Boundary)	AL (ISO Lower Boundary)
0.1667	6.0000	3.0000
0.5000	3.4644	1.7322
1.0000	2.4497	1.2249
2.0000	1.7322	0.8661
4.0000	1.2249	0.6124
8.0000	0.8661	0.4331
24.0000	0.5000	0.2500

TLV<sup>®</sup> at Time  $T$  (hrs):  $TLV^{\otimes} = \frac{2.4497}{\sqrt{T}}$  (ms<sup>-2</sup> rms)

AL at Time  $T$  (hrs):  $AL = \frac{1.2249}{\sqrt{T}}$  (ms<sup>-2</sup> rms)

Time duration  $T$  (hrs) to reach TLV<sup>®</sup> (permissible exposure time):  $T = \frac{(6.0012)}{a_{wl}^2 \text{ or } a_{wl,e}^2 \text{ or } a_p^2}$

Time duration  $T$  (hrs) to reach AL (permissible exposure time):  $T = \frac{(1.5003)}{a_{wl}^2 \text{ or } a_{wl,e}^2 \text{ or } a_p^2}$

*Note: Equations do not apply for exposure durations shorter than 10 minutes.*

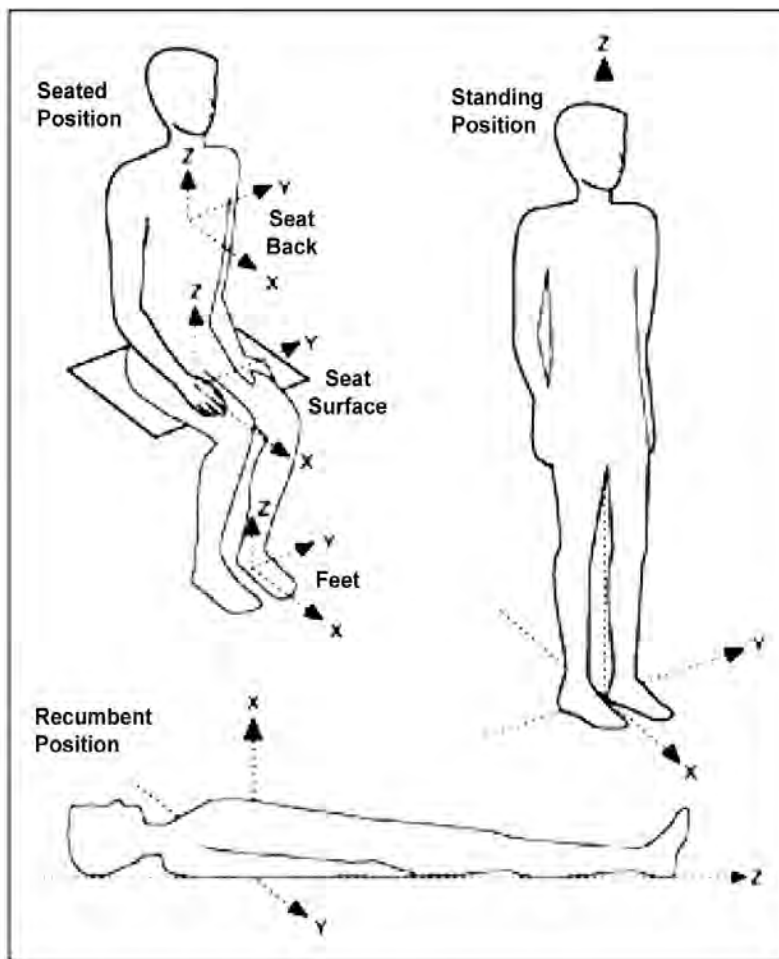
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- where:  $a_{wl}$  = The overall weighted rms acceleration for the  $l$ -axis, ( $l = x, y, \text{ or } z$ ) (ms<sup>-2</sup> rms)  
 $k_l$  = The multiplying factor for direction ( $k = 1.4$  for  $l = x, y$ ;  $k = 1.0$  for  $l = z$ )  
 $a_{wl}(t)$  = The weighted acceleration as a function of time between 0.5 and 80 Hz (ms<sup>-2</sup> rms)  
 $T$  = Duration of the measurement (s)

The calculation in the frequency domain is illustrated in Equation 2:

$$a_{wl} = k_l \left( \sum [W_{li} a_{li}]^2 \right)^{\frac{1}{2}} \quad (2)$$

- where:  $a_{wl}$  = The overall weighted rms acceleration for the  $l$ -axis, ( $l = x, y, \text{ or } z$ ) (ms<sup>-2</sup> rms)  
 $k_l$  = The multiplying factor for direction  $l$  ( $k = 1.4$  for  $l = x, y$ ;  $k = 1.0$  for  $l = z$ )  
 $W_{li}$  = The frequency weighting for the  $l$ -axis at the respective narrow band frequency or 1/3 octave band center frequency,  $i$ , from 0.5 to 80 Hz  
 $a_{li}$  = rms acceleration value for the  $l$ -axis at the respective narrow band frequency or 1/3 octave band center frequency,  $i$ , from 0.5 to 80 Hz



**FIGURE 2.** Biodynamic Coordinate System for the Seated, Standing, Recumbent Positions (Postures) (ISO, 1997, 2003, 2010). The coordinate system adheres to the right-hand rule for the seated and standing human.

If the vibration exposure includes periods with vibration of different magnitudes and durations occurring within contiguous 24 hours, the energy-equivalent weighted acceleration in each direction,  $x$ ,  $y$ , and  $z$ , can be calculated as follows, in accordance with ISO 2631-1 (ISO, 1997, 2003, 2010):

$$a_{wl,e} = \left( \frac{\sum [a_{wlj}^2 \cdot T_j]}{\sum T_j} \right)^{\frac{1}{2}} \quad (3)$$

- where:  $a_{wl,e}$  = The equivalent overall weighted acceleration magnitude in either the  $l = x, y$ , or  $z$  direction ( $\text{ms}^{-2}$  rms)
- $a_{wlj}$  = The overall weighted acceleration magnitude in either the  $l = x, y$ , or  $z$  direction for exposure period  $j$  ( $\text{ms}^{-2}$  rms) (from Equations 1 or 2)
- $T_j$  = The duration for exposure period  $j$  (s)

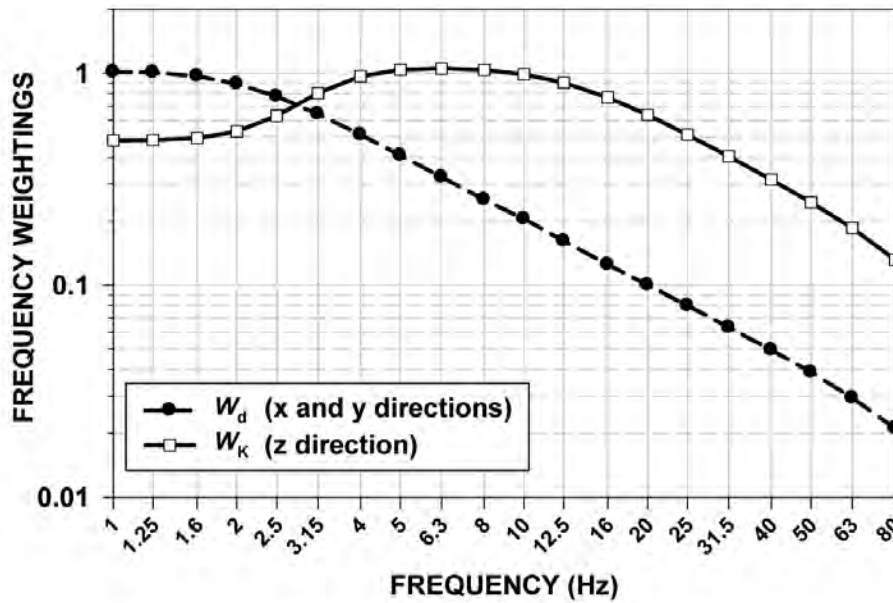


FIGURE 3. ISO 2631-1 Frequency Weightings  $W_d$  (x and y directions) and  $W_K$  (z direction) (ISO, 1997).

- c. If the overall weighted accelerations are similar along the x, y, and z translational axes, as determined by Equations 1, 2, or 3, the combined motion of all three axes could be greater than any one component and could possibly affect operator or occupant health risk. Each of the axis component results determined by Equations 1, 2, or 3 may be used in Equation 4 to calculate the vector sum of the overall weighted accelerations or the vibration total value,  $a_v$ :

$$a_v = \left( [1.4a_{wx}]^2 + [1.4a_{wy}]^2 + [a_{wz}]^2 \right)^{\frac{1}{2}} \quad (4)$$

7. A summary of the analysis procedure is as follows:
- If the overall weighted rms acceleration  $a_{wl}$  or  $a_{wl,e}$  in any axes, or the vibration total value,  $a_v$ , equals or exceeds the values shown in Figure 1 (ISO upper boundary) or Table 1 (ISO upper boundary), for the relevant time period, then the TLV<sup>®</sup> is exceeded for that exposure duration.
  - The axis with an overall weighted rms acceleration that intersects the TLV<sup>®</sup> curve in Figure 1 with the lowest exposure time dominates and determines the permissible exposure duration, unless the vibration total value ( $a_v$ ) is used. It is recommended that the overall weighted accelerations in all three axes be reported, in addition to the vibration total value (if the latter is calculated).
  - It may be desirable to calculate the daily vibration exposure (within a 24-hour period) standardized to an 8-hour reference period as follows:

$$a_{wl}(8) = \left( \frac{1}{T_0} \sum a_{wlj}^2 \cdot T_j \right)^{\frac{1}{2}} \quad (5)$$

- where:  $a_w(8)$  = The daily (8-hour) vibration exposure for the  $l$ -axis (ms<sup>-2</sup> rms)  
 $a_{wjl}$  = The overall weighted rms acceleration for the  $l$ -axis over the time period  $T_j$ , ( $l = x, y, \text{ or } z$ ) (ms<sup>-2</sup> rms) (from Equations 1 or 2)  
 $T_0$  = The reference duration of 8 hours or 28,800 seconds

8. With reference to ISO 2631-1, Section 6.3 (ISO, 1997, 2003), the weighted rms method described above may underestimate the effects of vibration with high crest factors (> 9), such as transient vibration and vibration combined with occasional small shocks. In addition to the rms method described above, the fourth power Vibration Dose Value (VDV) may be calculated in each direction as:

$$VDV = k_l \left( \int_0^T [a_{wl}(t)^4] dt \right)^{\frac{1}{4}} \quad (6)$$

It is noted that, unlike the overall weighted acceleration calculated in accordance with Equations 1 and 2, the VDV is dependent on the duration of the measurement. When using this method, the TLV<sup>®</sup> in any direction shall not exceed a VDV value of 17.0 ms<sup>-1.75</sup> to avoid health risks. It is highly recommended that vibration mitigation activity be undertaken to reduce any VDV falling between 8.5 and 17.0 ms<sup>-1.75</sup>. The VDV method should not be applied to exposures lasting more than 8 hours.

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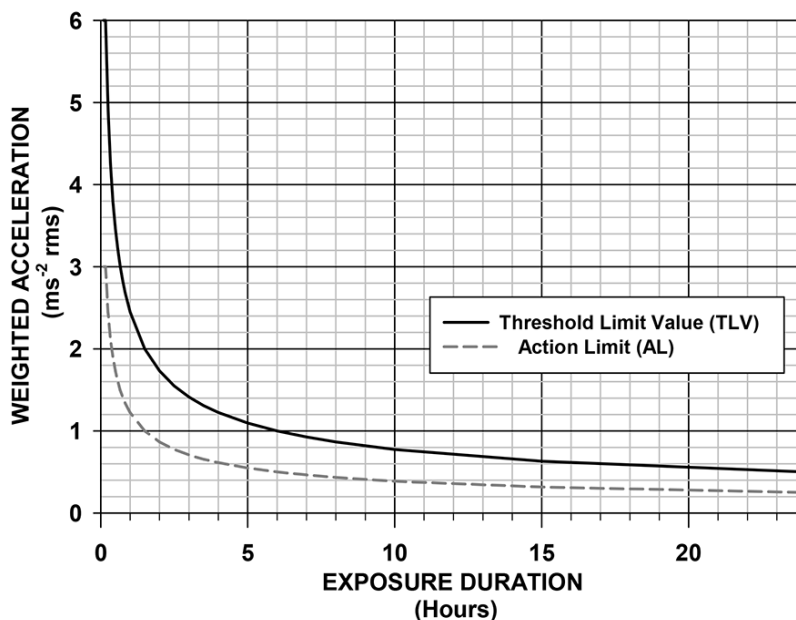
## References

- International Standards Organization (ISO): ISO 10326-1:1992: Mechanical Vibration—Laboratory Method for Evaluating Vehicle Seat Vibration—Part 1: Basic Requirements. Switzerland, Geneva (1992).
- International Standards Organization (ISO): ISO 2631-1:1997: Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 1: General Requirements. Geneva, Switzerland (1997).
- International Standards Organization (ISO): ISO 2631-2:2003: Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 2: Vibration in Buildings (1 Hz to 80 Hz). Geneva, Switzerland (2003).
- International Standards Organization (ISO): ISO 2631-1:1997/Amd.1:2010: Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 1: General Requirements, Amendment 1. ISO, Geneva, Switzerland (2010).

## NOTICE OF INTENDED CHANGE— † WHOLE-BODY VIBRATION

The reason for this NIC is revision to the TLVs<sup>®</sup> including: TLVs<sup>®</sup> reduced by  $R$  (the stress variable) associated with a 10% risk of injury; addition of Note 8 regarding multiple shocks exceeding 1 g; reference to crest factor eliminated; and TLVs<sup>®</sup> and ALs plotted on both linear and natural log axes.

The Threshold Limit Values (TLVs<sup>®</sup>), illustrated by the solid line in Figure 1 and tabulated at the center frequencies of one-third octave bands in Table 1, refer to the weighted root-mean-square (rms) acceleration magnitudes and durations of mechanically induced whole-body vibration (WBV). Operator or occupant exposures shall remain below the TLV<sup>®</sup> curve for the respective exposure duration occurring within a 24-hour period. The Action Levels (ALs) represented by the dashed line in Figure 1, and tabulated at the center frequencies of one-third octave bands in Table 1, also refer to the weighted rms acceleration magnitudes and durations of mechanically induced WBV. It is highly recommended that vibration mitigation activity be undertaken to reduce any operator or occupant exposures that occur within a 24-hour period and fall within the region bounded by the TLV<sup>®</sup> curve and AL curve. It is noted that unknown psychological or physiological influences may affect an individual's susceptibility to health risk. While the TLV<sup>®</sup> and AL curves may be used as a guide in the control of WBV exposure, they should not be regarded as defining a distinct boundary between safe and dangerous levels.



**FIGURE 1.** Threshold Limit Values (TLVs<sup>®</sup>) and Action Limits (ALs) associated with the upper boundary and lower boundary of the ISO 2631-1 Health Guidance Caution Zones, respectively (ISO, 1997, 2010). Note: Values are constant for exposures at and below 10 minutes.

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**TABLE 1. TLV<sup>®</sup> and AL Weighted Acceleration Levels**

Duration (Hours)	TLV <sup>®</sup> (ISO Upper Boundary)	AL (ISO Lower Boundary)
0.17	6.00	3.0000
0.5000	3.46	1.73
1.0000	2.45	1.22
2.0000	1.73	0.87
4.0000	1.22	0.61
8.0000	0.87	0.43
24.0000	0.5000	0.25

$$\text{TLV}^{\text{®}} \text{ at Time } T \text{ (hrs): } TLV = \frac{2.45}{\sqrt{T}} \text{ (ms}^{-2} \text{ rms)}$$

$$\text{AL at Time } T \text{ (hrs): } AL = \frac{1.22}{\sqrt{T}} \text{ (ms}^{-2} \text{ rms)}$$

$$\text{Time duration } T \text{ (hrs) to reach TLV}^{\text{®}} \text{ (permissible exposure time): } T = \frac{(6.0)}{a_w^2 \text{ or } a_{w,e}^2 \text{ or } a_v^2}$$

$$\text{Time duration } T \text{ (hrs) to reach AL (permissible exposure time): } T = \frac{(1.5)}{a_w^2 \text{ or } a_{w,e}^2 \text{ or } a_v^2}$$

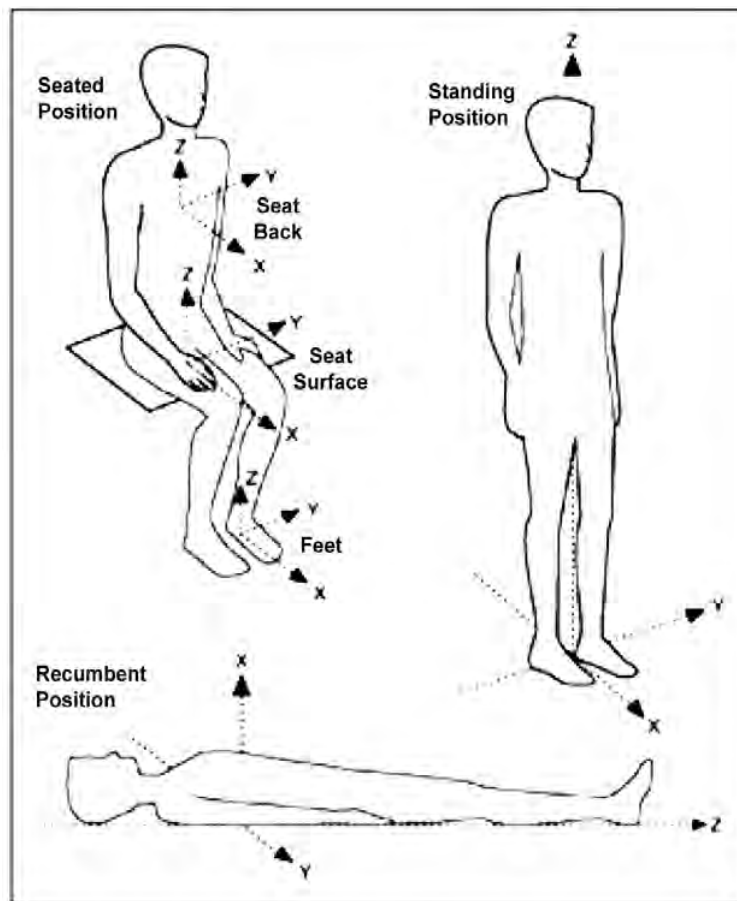
*Note: Equations do not apply for exposure durations shorter than 10 minutes.*

TLV<sup>®</sup>-PA

**Notes:**

1. The TLV<sup>®</sup> curve coincides with the upper boundary of the Health Guidance Caution Zones defined in ISO 2631-1 (ISO, 1997, 2003, 2010). The TLVs<sup>®</sup> refer to the maximum weighted accelerations for a given exposure duration that it is believed a majority of operators and occupants of land, air, and water vehicles may be repeatedly exposed to within a 24-hour period with a low probability of health risks. The AL curve coincides with the lower boundary of the Health Guidance Caution Zones defined in ISO 2631-1 (ISO, 1997, 2003, 2010). With reference to ISO 2631-1, Annex B (ISO, 1997, 2003), operator and occupant exposures falling between the lower boundary (dashed line) and upper boundary (solid line) in Figure 1 within a 24-hour period have been associated with the potential for health risks.
2. Vibration acceleration is a vector with magnitude expressed in units of meters per second squared (ms<sup>-2</sup>). The gravitational acceleration, “g” = 9.81 ms<sup>-2</sup>. The biodynamic coordinate system used for measuring the accelerations is illustrated in Figure 2. The procedures described in this *Documentation* apply to translational accelerations of the seated upright operator or occupant. Other postures and directions are addressed in ISO 2631-1 (ISO, 1997, 2003).
3. The TLVs<sup>®</sup> and ALs associated with the weighted rms acceleration may underestimate the health risk for vibration with occasional or substantial shocks, or transient vibration. ISO 2631-1 provides guidance on alternative methods. These methods include the Vibration Dose Value (VDV). The





**FIGURE 2.** Biodynamic Coordinate System for the Seated, Standing, Recumbent Positions (Postures) (ISO, 1997, 2010). The coordinate system adheres to the right-hand rule for the seated and standing human.

TLV®-PA

ISO 2631-5 provides guidance for assessing vibration with multiple shocks and should be considered for assessing exposures that include shocks or impacts that exceed  $9.81 \text{ m/s}^2$  (1 g peak). The alternative methods should be used in addition to the rms method (see Note 8). The TLV® and AL are not intended for use in fixed buildings (see ISO 2631-2) (ISO, 1992), in off-shore structures, or in large ships.

4. A summary of WBV measurement procedures follows (ISO, 1997, 2003, 2010):
  - a. Three lightweight accelerometers (or triaxial accelerometer), each with a cross-axis sensitivity of less than 10%, are mounted orthogonally in the center of a hard rubber disc, per ISO 10326-1 (ISO, 1992). The total weight of the instrumented rubber disc and cables should not exceed 400 grams.
  - b. At a minimum, and for health risk assessment, one instrumented rubber disc should be placed on the top of the operator's or occupant's seat, and at the interface between the buttocks and contacted seat or cushion surface. A second instrumented rubber disc may be placed at the interface between the back and the seat back, particularly if a comfort assessment is desirable (see ISO 2631-1, Section 8.2) (ISO, 1997, 2003).

- c. At each measurement location (i.e., seat pan, seat back), continuous acceleration measurements should be simultaneously made and recorded along the three orthogonal axes (x, y, z) shown in Figure 2 (seat surface and seat back). The duration of the measurement should insure measurement accuracy and that the vibration is typical of the operator or occupant exposure being assessed (see ISO 2631-1, Section 5.5) (ISO, 1997, 2003).
5. A summary of WBV data processing procedures, including the calculation of the weighted rms acceleration in each axis (x, y, z) for assessing health risk follows:
- It is highly recommended that signal processing techniques be applied to generate the spectral content in each axis to identify the frequencies corresponding to major acceleration peaks. The spectra can be generated in either narrow frequency bands of constant bandwidth, or proportional bands no greater than one-third octave.
  - At a minimum for health risk assessment, the acceleration measurements obtained for each axis at the buttocks-seat interface surface should be recorded and processed in accordance with ISO 2631-1 (ISO, 1997, 2010) for the seated operator or occupant using the basic evaluation method and the frequency weightings and multiplying factors for health risk. This can be done in the time domain or frequency domain using narrow band or one-third octave band data as mentioned above. The frequency weighting curves for health risk are illustrated in Figure 3. The multiplying factors ( $k_j$ ) for health risk are given below for the respective direction. The frequency range is 0.5 to 80 Hz. This yields the overall weighted rms acceleration for each axis (x, y, z). The calculation in the time domain is illustrated in Equation 1 (ISO, 1997, 2010):

TLV®-PA

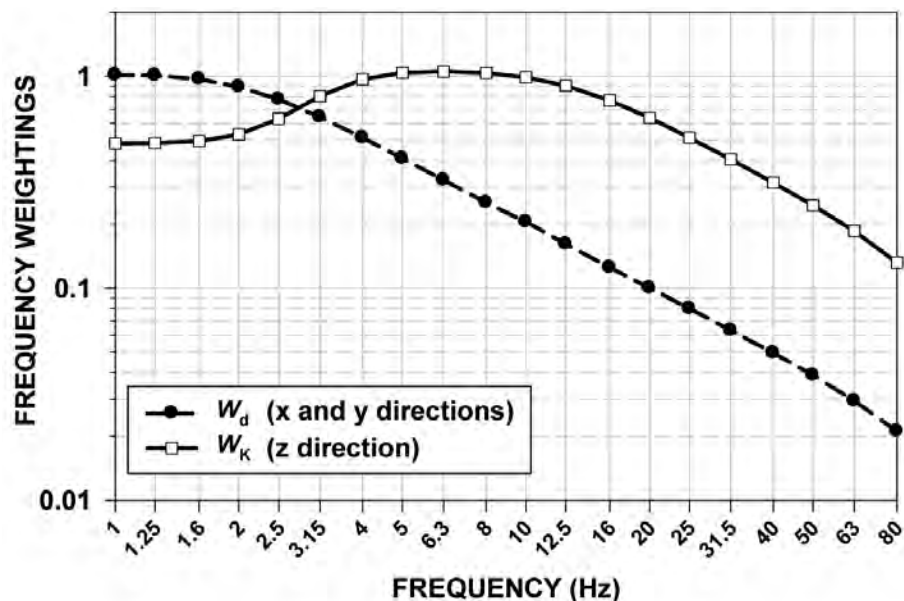


FIGURE 3. ISO 2631-1 Frequency Weightings  $W_d$  (x and y directions) and  $W_K$  (z direction) (ISO, 1997).

$$a_{wl} = k_l \left( \frac{1}{T} \int_0^T a_{wl}^2(t) dt \right)^{\frac{1}{2}} \quad (1)$$

- where:  $a_{wl}$  = The overall weighted rms acceleration for the  $l$ -axis, ( $l = x, y, \text{ or } z$ ) ( $\text{ms}^{-2}$  rms)  
 $k_l$  = The multiplying factor for direction  $l$  ( $k = 1.4$  for  $l = x, y$ ;  $k = 1.0$  for  $l = z$ )  
 $a_{wl}(t)$  = The weighted acceleration as a function of time between 0.5 and 80 Hz ( $\text{ms}^{-2}$  rms)  
 $T$  = Duration of the measurement (s)

The calculation in the frequency domain is illustrated in Equation 2:

$$a_{wl} = k_l \left( \sum [W_{li} a_{li}]^2 \right)^{\frac{1}{2}} \quad (2)$$

- where:  $a_{wl}$  = The overall weighted rms acceleration for the  $l$ -axis, ( $l = x, y, \text{ or } z$ ) ( $\text{ms}^{-2}$  rms)  
 $k_l$  = The multiplying factor for direction  $l$  ( $k = 1.4$  for  $l = x, y$ ;  $k = 1.0$  for  $l = z$ )  
 $W_{li}$  = The frequency weighting for the  $l$ -axis at the respective narrow band frequency or 1/3 octave band center frequency,  $i$ , from 0.5 to 80 Hz  
 $a_{li}$  = rms acceleration value for the  $l$ -axis at the respective narrow band frequency or 1/3 octave band center frequency,  $i$ , from 0.5 to 80 Hz

If the vibration exposure includes periods with vibration of different magnitudes and durations occurring within contiguous 24 hours, the energy-equivalent weighted acceleration in each direction,  $x$ ,  $y$ , and  $z$ , can be calculated as follows, in accordance with ISO 2631-1 (ISO, 1997, 2003, 2010):

$$a_{wl,e} = \left( \frac{\sum [a_{wlj}^2 \cdot T_j]}{\sum T_j} \right)^{\frac{1}{2}} \quad (3)$$

- where:  $a_{wl,e}$  = The equivalent overall weighted acceleration magnitude in either the  $l = x, y, \text{ or } z$  direction ( $\text{ms}^{-2}$  rms)  
 $a_{wlj}$  = The overall weighted acceleration magnitude in either the  $l = x, y, \text{ or } z$  direction for exposure period  $j$  ( $\text{ms}^{-2}$  rms) (from Equations 1 or 2)  
 $T_j$  = The duration for exposure period  $j$  (s)

- c. If the overall weighted accelerations are similar along the  $x$ ,  $y$ , and  $z$  translational axes, as determined by Equations 1, 2, or 3, the combined motion of all three axes could be greater than any one component and could possibly affect operator or occupant health risk. Each of the axis component results determined by Equations 1, 2, or 3 may be used in Equation 4 to calculate the vector sum of the overall weighted accelerations or the vibration total value,  $a_v$ :

$$a_v = \left( [1.4a_{wx}]^2 + [1.4a_{wy}]^2 + [a_{wz}]^2 \right)^{\frac{1}{2}} \quad (4)$$

6. A summary of the analysis procedure is as follows:
- If the overall weighted rms acceleration  $a_{wl}$  or  $a_{wl,e}$  in any axes, or the vibration total value,  $a_v$ , equals or exceeds the values shown in Figure 1 (ISO upper boundary) or Table 1 (ISO upper boundary), for the relevant time period, then the TLV<sup>®</sup> is exceeded for that exposure duration. The axis with an overall weighted rms acceleration that intersects the TLV<sup>®</sup> curve in Figure 1 with the lowest exposure time dominates and determines the permissible exposure duration, unless the vibration total value ( $a_v$ ) is used. It is recommended that the overall weighted accelerations in all three axes be reported, in addition to the vibration total value (if the latter is calculated).
  - It may be desirable to calculate the daily vibration exposure (within a 24-hour period) standardized to an 8-hour reference period as follows:

$$a_{wl}(8) = \left( \frac{1}{T_0} \sum a_{wlj}^2 \cdot T_j \right)^{\frac{1}{2}} \quad (5)$$

- where:  $a_{wl}(8)$  = The daily (8-hour) vibration exposure for the  $l$ -axis (ms<sup>-2</sup> rms)  
 $a_{wlj}$  = The overall weighted rms acceleration for the  $l$ -axis over the time period  $T_j$ , ( $l = x, y, \text{ or } z$ ) (ms<sup>-2</sup> rms) (from Equations 1 or 2)  
 $T_0$  = The reference duration of 8 hours or 28,800 seconds

7. With reference to ISO 2631-1, Section 6.3 (ISO, 1997, 2003), the weighted rms method described above may underestimate the effects of vibration with high crest factors (> 9), such as transient vibration and vibration combined with occasional small shocks. In addition to the rms method described above, the fourth power Vibration Dose Value (VDV) may be calculated in each direction as:

$$VDV = k_l \left( \int_0^T [a_{wl}(t)^4] dt \right)^{\frac{1}{4}} \quad (6)$$

It is noted that, unlike the overall weighted acceleration calculated in accordance with Equations 1 and 2, the VDV is dependent on the duration of the measurement. When using this method, the TLV<sup>®</sup> in any direction is defined by a VDV value of 17.0 ms<sup>-1.75</sup> and shall not be exceeded for the exposure duration. The AL in any direction is defined by a VDV value of 8.5 ms<sup>-1.75</sup>. It is highly recommended that vibration mitigation activity be undertaken to reduce any VDV falling between 8.5 and 17.0 ms<sup>-1.75</sup>. The VDV method should not be applied to exposures lasting more than 6 hours. For exposures lasting more than 6 hours, the TLVs<sup>®</sup> and ALs associated with the rms method should be applied to assess health risk.

8. For vibration exposure with shocks or impacts that exceed 9.81 m/s (1 g peak), the guidelines in ISO 2631-5 should be followed to calculate the stress variable,  $R$ . The TLV<sup>®</sup> is defined by an  $R$  value of 1.6 and should not be exceeded. This  $R$  value corresponds to a relatively low risk of injury. The ISO 2631-5 also provides an alternative method for exposures containing shocks or impacts at or below 9.81 m/s (1 g peak).

### References

- International Standards Organization (ISO): ISO 10326-1:1992: Mechanical Vibration—Laboratory Method for Evaluating Vehicle Seat Vibration—Part 1: Basic Requirements. Geneva, Switzerland (1992).
- International Standards Organization (ISO): ISO 2631-1:1997: Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 1: General Requirements. Geneva, Switzerland (1997).
- International Standards Organization (ISO): ISO 2631-2:2003: Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 2: Vibration in Buildings (1 Hz to 80 Hz). Geneva, Switzerland (2003).
- International Standards Organization (ISO): ISO 2631-1:1997/Amd.1:2010: Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 1: General Requirements, Amendment 1. ISO, Geneva, Switzerland (2010).

## THERMAL STRESS

### COLD STRESS

#### Introduction

The cold stress TLVs<sup>®</sup> are intended to protect workers from the most severe effects of cold stress (hypothermia and frostbite) and to describe exposures to cold working conditions under which it is believed that nearly all workers can be repeatedly exposed without adverse health effects. The TLV<sup>®</sup> objective is to prevent the deep body core temperature from falling below 36°C (96.8°F) and to prevent frostbite to body extremities. Fatal exposures to cold among workers have almost always resulted from accidental exposures involving failure to escape from low environmental air temperatures or from immersion in low temperature water. Preventing cold injuries is best done through a risk management strategy that assesses cold hazards and then develops and implements controls to mitigate the effects of the cold environment. Figure 1 presents a risk management process to use in cold-weather environments. Figure 2 shows the types of cold injuries.

#### Hypothermia Prevention

Hypothermia is defined as a core body temperature below 95°F (35°C). The physiological changes that occur as the temperature goes below this value are presented in Table 1. In an occupational setting, workers should be protected from cold exposure so that the deep core temperature does not fall below 36°C (96.8°F); lower body temperatures can result in reduced mental alertness and rational decision making. As the core body temperature goes below 91.4°F (33°C), workers can become severely debilitated. Hypothermia is a life-threatening condition and must be treated promptly.

Early symptoms of hypothermia include feeling cold, shivering, and exhibiting signs of apathy and social withdrawal. Supervisors and workers should be aware of these early symptoms so that proper preventative measures can be taken at this time. More pronounced hypothermia manifests as confusion or sleepiness, slurred speech, and a change in behavior or appearance. Exposure to cold should be immediately terminated for any workers when severe shivering becomes evident.

Since prolonged exposure to extremely cold air, cold-wet conditions, and cold water immersion can lead to hypothermia, whole-body protection must be provided. Cold, wet, and windy weather poses the greatest risk for developing hypothermia. Figure 3 presents the clothing insulation required as a function of air temperature and work rate. As seen, the amount of insulation increases as the ambient temperature and work rate decrease. In wet weather, it is imperative that the outer layer of clothing be waterproof. In windy weather, a wind-proof outer layer is needed. Table 2 presents different activities and their associated work rate in Metabolic Equivalents (METS). This table can be used in conjunction with Figure 3 to determine the approximate clothing insulation required at different air temperatures.

Cold-water immersion can cause life-threatening hypothermia in a matter of hours if proper protection is not worn. Table 3 presents the amount of time that an average person can be immersed based on the water temperature and depth. This guidance is based on wearing normal personal protection

that is not waterproof. It should also be noted that another type of cold injury—nonfreezing cold injury—can occur when skin is subjected to prolonged immersion or cold-wet exposures in temperatures between 32–60°F (0–15°C).

Risk factors for hypothermia include inactivity, energy depletion, endocrine disorders, age (old and young), burns and skin disorders, trauma, neuropathies, and drug/alcohol use.

Field expedient re-warming methods include removing wet clothes, increasing insulation (with dry clothes, blankets, sleeping bags), and moving to a sheltered area. If able to, patients can also exercise to increase heat production. Other techniques, using external re-warming, should be initiated by trained medical personnel.

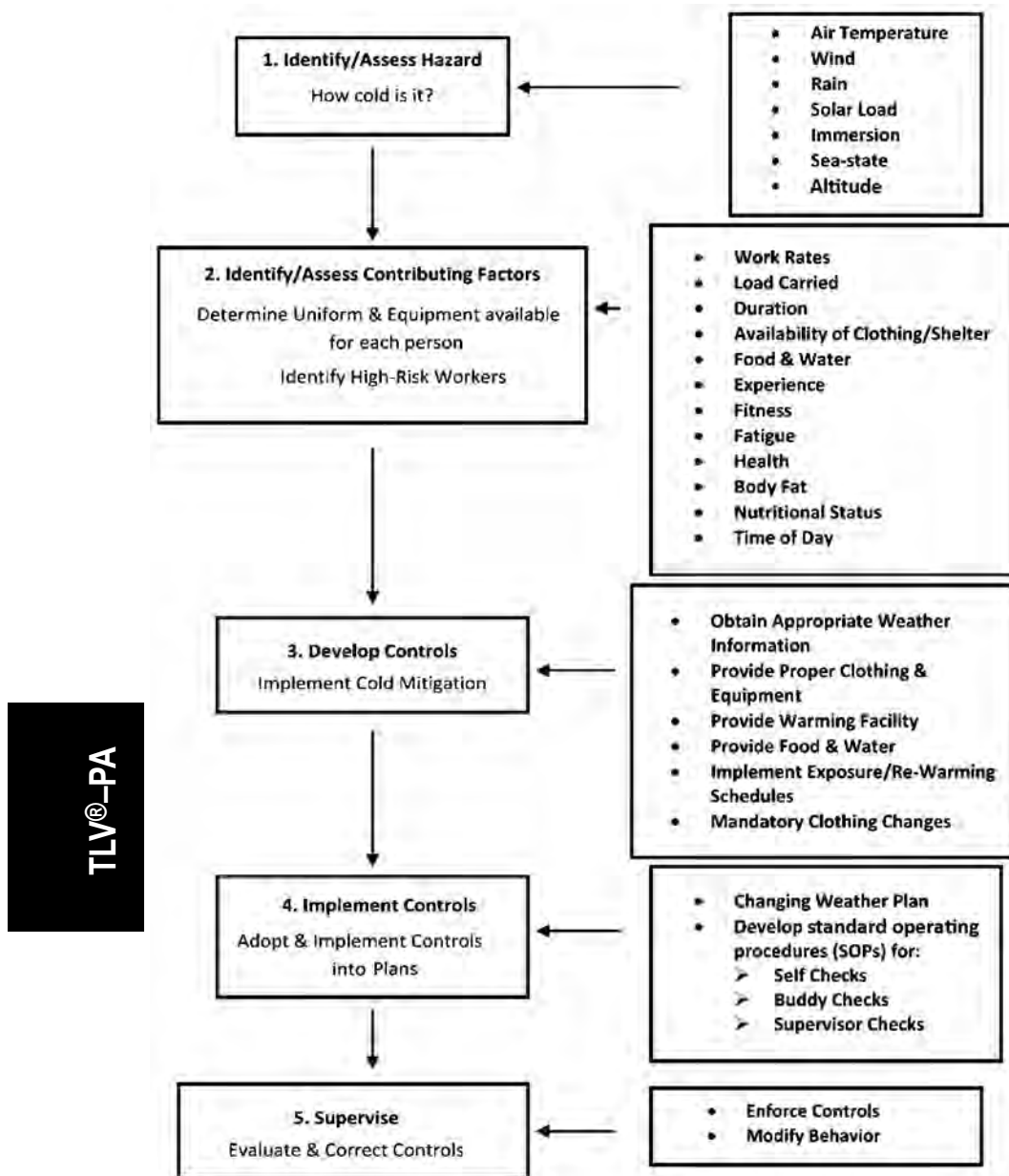
### **Frostbite Prevention**

Frostbite occurs when tissue temperature decreases below 32°F (0°C). Frostbite is most common in exposed skin (nose, ears, cheeks, exposed wrists), but also occurs in the hands and feet because peripheral vasoconstriction significantly lowers tissue temperatures. Wet skin cools faster. Instantaneous frostbite can occur when the skin comes in contact with super-cooled liquids, such as petroleum products, oil, fuel, antifreeze, and alcohol, all of which remain liquid at temperatures of -40°F (-40°C). Contact frostbite can occur by touching cold objects with bare skin (particularly highly conductive metal or stone), which causes rapid heat loss. To prevent contact frostbite, the workers should wear anti-contact gloves.

Usually, the first sign of frostbite is numbness. In the periphery, the initial sense of cooling begins at skin temperatures of 82°F (28°C) and pain appears at ~68°F (20°C), but as skin temperature falls below 50°F (10°C), these sensations are replaced by numbness. Individuals often report feeling a “wooden” sensation in the injured area. After re-warming, pain is significant. The initial sensations are an uncomfortable sense of cold, which may include tingling, burning, aching, sharp pain, and decreased sensation. The skin color may initially appear red; it then becomes waxy white.

Risk factors for frostbite include temperature, wetness, wind chill, constrictive clothing, race, sex, hypoxia, Raynaud’s syndrome, and vasoconstrictor drugs. African American men and women are 2–4 times more likely than Caucasians to suffer from frostbite. Raynaud’s disease is a peripheral vascular disorder more prevalent in women than men.

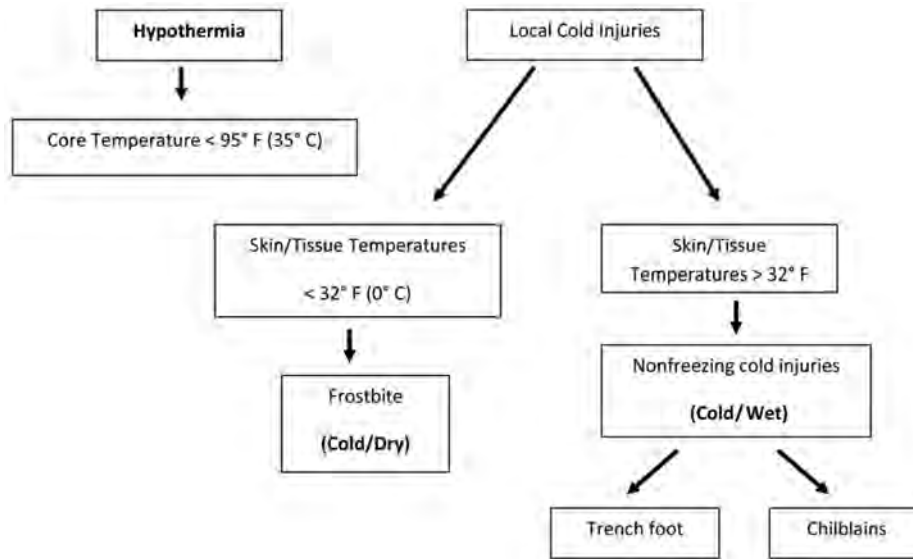
The Wind Chill Temperature (WCT) Index (Tables 4, 5) integrates wind speed and air temperature to provide an estimate of the cooling power of the environment. The WCT standardizes the cooling power of the environment to an equivalent air temperature for calm conditions. WCTs are specific in their correct application, only estimating the danger of cooling for the exposed skin of persons walking at 3 mph. Wind does not cause an exposed object to become cooler than the ambient temperature, but instead wind causes exposed objects to cool toward ambient temperature more rapidly than without wind. Wind speeds obtained from weather reports do not take into account man-made wind. The WCT presents the relative risk of frostbite and the predicted times to freezing (Tables 4, 5) of exposed facial skin. Facial skin was chosen because this area of the body is typically not protected. Frostbite cannot occur if the air temperature is above 32°F (0°C). Wet skin



**FIGURE 1.** Risk Management Process for Evaluating Cold Stress and Strain.

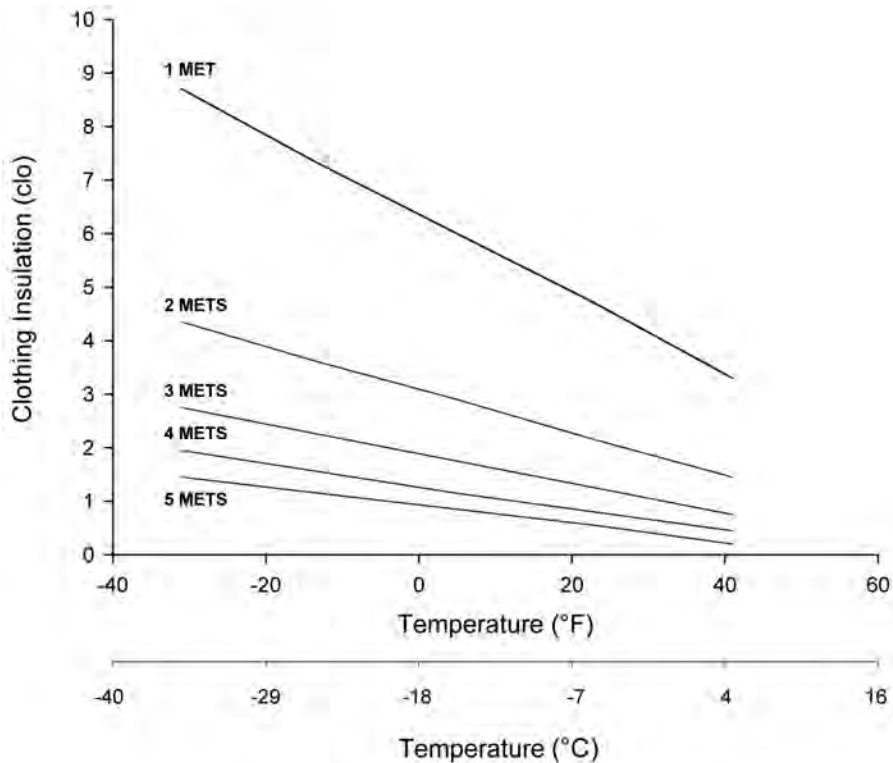
*Source: Department of the Army: Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508). Falls Church, VA (2005).*





**FIGURE 2.** Types of cold injuries.

Source: Department of the Army: *Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508).* Falls Church, VA (2005).



**FIGURE 3.** Approximate amount of clothing insulation needed at different air temperatures and physical activity levels. Wind speed is assumed to be less than 5 mph (2.2 m/s). 1 MET refers to energy expenditure at rest (58.2 W/m<sup>2</sup>). One clo of insulation is the clothing necessary to allow a resting person to be comfortable when the air temperature is 21°C (70°F).

Source: Castellani JW; Young AJ; Ducharme MB; et al.: *Prevention of cold injuries during exercise. Med Sci Sports Exerc 38:2012–2029 (2006).*





**TABLE 1. Core Temperature and Associated Physiological Changes that Occur as Core Temperature Falls. Individuals Respond Differently at Each Level of Core Temperature**

Stage	Core Temperature		Physiological Changes
	°F	°C	
Normothermia	98.6	37.0	
Mild Hypothermia	95.0	35.0	Maximal shivering; increased blood pressure
	93.2	34.0	Amnesia; dysarthria; poor judgment; behavior change
	91.4	33.0	Ataxia; apathy
Moderate Hypothermia	89.6	32.0	Stupor
	87.8	31.0	Shivering ceases; pupils dilate
	85.2	30.0	Cardiac arrhythmias; decreased cardiac output
	85.2	29.0	Unconsciousness
	82.4	28.0	Ventricular fibrillation likely; hypoventilation
Severe Hypothermia	80.6	27.0	Loss of reflexes and voluntary motion
	78.8	26.0	Acid-base disturbances; no response to pain
	77.0	25.0	Reduced cerebral blood flow
	75.2	24.0	Hypotension; bradycardia; pulmonary edema
	73.4	23.0	No corneal reflexes; areflexia
	66.2	19.0	Electroencephalographic silence
	64.4	18.0	Asystole
	59.2	15.2	Lowest infant survival from accidental hypothermia
56.7	13.7	Lowest adult survival from accidental hypothermia	

*Source: Castellani JW; Young AJ; Ducharme MB; et al.: Prevention of cold injuries during exercise. Med Sci Sports Exerc 38:2012–2029 (2006).*

exposed to the wind will cool even faster and if the skin is wet and exposed to wind, the ambient temperature used for the WCT table should be 10°C (50°F) lower than the actual ambient temperature. When cold surfaces below -7°C (19.4°F) are within reach, a warning should be given to each worker by the supervisor to prevent inadvertent contact by bare skin. If the air temperature is -17.5°C (0°F) or less, the hands should be protected by mittens. Machine controls and tools for use in cold conditions should be designed so that they can be handled without removing the mittens.

Manual dexterity is an important attribute in occupational settings. Manual dexterity is the ability to make coordinated hand and finger movements to grasp and manipulate objects. Manual dexterity includes muscular, skeletal, and neurological functions to produce small, precise movements. In cold weather, manual dexterity can decrease 60–80% in gloved workers and, depending on the ambient conditions, can decrease just as much in non-gloved personnel. When hand temperature declines, the manual performance deteriorates. This performance is reduced by 30% when the finger skin temperature decreases from 33°C (91°F) to 10°C (50°F). Special protection of the hands is required to maintain manual dexterity for the prevention of accidents:

1. If fine work is to be performed with bare hands for more than 10–20 minutes in an environment below 16°C (60.8°F), special provisions should be established for keeping the worker's hands warm. For this purpose, warm air jets, radiant heaters (fuel burner or electric radiator), or contact warm plates may be utilized. Metal handles of tools and control bars should be covered by thermal insulating material at temperatures below -1°C (30.2°F).
2. If the air temperature falls below 16°C (60.8°F) for sedentary work, 4°C (39.2°F) for light work, and -7°C (19.4°F) for moderate work and fine manual dexterity is not required, then gloves should be used by the workers.

Dexterity is primarily impacted by peripheral skin and muscle temperatures, with little influence from core temperature.

### Acute Cold-Water Exposure

Sudden immersion into cold water causes a cold shock response. Physiological responses to sudden immersion include gasping, hyperventilating, peripheral vasoconstriction, and increased heart rate and blood pressure. It is during the first few minutes of sudden immersion that drowning is likely to occur as gasping and hyperventilating increase the chances of aspirating water. After the initial responses subside, the core and muscle temperatures begin to fall over time. After ~10 minutes of immersion in water less than 10°C, muscle temperatures will have decreased so that there is reduced skeletal muscle function. Individuals at this point will no longer be able to swim/self-rescue and drowning will likely ensue if a flotation aid is not available. Finally, as an individual remains in the water, core temperature will continue to fall. Generally, the core temperature falls to 35°C in about 1 hour in 5°C water, in 2 hours in 10°C water, and in 3–6 hours in 15°C water. The progression from cold shock to hypothermia can be summed up in the “1-10-1” rule. This states that the cold shock response with increased water aspira-

**TABLE 2. Intensity of Exercise for Selected Outdoor Activities**

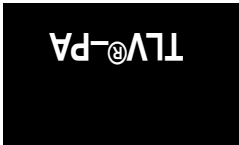
<b>Sedentary 100 Watts (1 MET)</b>	<b>Easy work 250 Watts (2–3 METS)</b>	<b>Moderate work 450 Watts (4–5 METS)</b>	<b>Hard work 600 Watts (6 METS)</b>
<ul style="list-style-type: none"> <li>• Sleeping</li> <li>• Seated, quiet</li> </ul>	<ul style="list-style-type: none"> <li>• Walking (on level surface) at 3–4 km/h</li> <li>• Snowmobiling</li> </ul>	<ul style="list-style-type: none"> <li>• Walking in loose snow/sand at 2.5 mph, no load</li> <li>• Walking on hard surface at 3.5 mph, &lt; 40-lb load</li> <li>• Handling 50-kg bags</li> <li>• Pick and shovel work</li> </ul>	<ul style="list-style-type: none"> <li>• Walking on hard surface at 3.5 mph, 40-lb load</li> <li>• Walking in loose sand at 2.5 mph with load</li> <li>• Snowshoeing</li> </ul>

*Source: Department of the Army: Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508). Falls Church, VA (2005).*

**TABLE 3. Cold-Water Immersion Time Limits (Hours) for Reaching a Core Temperature of 35.5°C at Different Water Temperatures and Immersion Depths. For Immersion Times Greater than 6 Hours, the Risk of Non-Freezing Cold Injury Substantially Increases**

Water Temperature (°F)	Water Temperature (°C)	Knee-Deep	Waist-Deep	Chest-Deep
50–54	10–12	12.8	1.9	1.3
55–59	13–15	15.6	7.5	2.2
60–64	16–18	22.2	10.2	7.9
65–69	18–21	33	13.8	10.5

*Source: Department of the Army: Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508). Falls Church, VA (2005).*



**TABLE 4. Wind Chill Temperature Index. Frostbite Times are for Exposed Facial Skin**

Wind Speed (km/h)	Air Temperature (°C)											
	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
5	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
10	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	-63
15	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	-60	-66
20	1	-5	-12	-18	-24	-30	-37	-43	-49	-56	-62	-68
25	1	-6	-12	-19	-25	-32	-38	-44	-51	-57	-64	-70
30	0	-6	-13	-20	-26	-33	-39	-46	-52	-59	-65	-72
35	0	-7	-14	-20	-27	-33	-40	-47	-53	-60	-66	-73
40	-1	-7	-14	-21	-27	-34	-41	-48	-54	-61	-68	-74
45	-1	-8	-15	-21	-28	-35	-42	-48	-55	-62	-69	-75
50	-1	-8	-15	-22	-29	-35	-42	-49	-56	-63	-69	-76
55	-2	-8	-15	-22	-29	-36	-43	-50	-57	-63	-70	-77
60	-2	-9	-16	-23	-30	-36	-43	-50	-57	-64	-71	-78
65	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79
70	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-80
75	-3	-10	-17	-24	-31	-38	-45	-52	-59	-66	-73	-80
80	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81

**FROSTBITE GUIDE**

Low risk of frostbite for most people

Increasing risk of frostbite for most people in 10 to 30 minutes of exposure

High risk for most people in 5 to 10 minutes of exposure

High risk for most people in 2 to 5 minutes of exposure

High risk for most people in 2 minutes of exposure or less

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*Sources:*

*National Weather Service: Wind Chill Temperature Index. NOAA, National Weather Service, Office of Climate, Water and Weather Services (2001).*

*Castellani JW; Young AJ; Ducharme MB; et al.: Prevention of cold injuries during exercise. Med Sci Sports Exerc 38:2012–2029 (2006).*

tion occurs in the first minute; in 10 minutes the skeletal muscle temperatures decline to a point that muscle function is severely impaired, and in 1 hour, core temperature begins to fall to levels that are dangerous.

**Cold-Weather Clothing**

Cold-weather clothing protects against hypothermia and peripheral cold injuries by reducing heat loss through the insulation provided by the clothing and the trapped air within and between clothing layers. Typical cold-weather clothing consists of multiple layers: an inner layer (light-weight polyester or polypropylene) that is in direct contact with the skin and does not readily absorb moisture, but wicks moisture to the outer layers where it can evaporate; middle layers (polyester fleece or wool) provide the primary insulation; and an outer layer, which is designed to allow moisture transfer to the air, while repelling wind and rain. Sweating can easily exceed the vapor transfer rate of the outer shell layer, causing moisture to accumulate on the inside, even if the outer layer has substantial venting (e.g., zippers in armpits) to allow moisture to escape. The outer layer should typically not be worn during moderate/heavy work (unless it is rainy or very windy), but should be donned during subsequent rest periods.

**TABLE 5. Time in Minutes Until the Occurrence of Cheek Frostbite in the Most Susceptible 5% of Military Personnel**

Wind speed		Air temperature												
m · s <sup>-1</sup>	mph	°C	-12	-15	-18	-21	-23	-26	-29	-32	-34	-37	-40	-43
		°F	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
2	5	>120	>120	>120	>120	31	22	17	14	12	11	9	8	
4	10	>120	>120	>120	28	19	15	12	10	9	7	7	6	
7	15	>120	>120	33	20	15	12	9	8	7	6	5	4	
9	20	>120	>120	23	16	12	9	8	8	6	5	4	4	
11	25	>120	42	19	13	10	8	7	6	5	4	4	3	
13	30	>120	28	16	12	9	7	6	5	4	4	3	3	
16	35	>120	23	14	10	8	6	5	4	4	3	3	2	
18	40	>120	20	13	9	7	6	5	4	3	3	2	2	
20	45	>120	18	12	8	7	5	4	4	3	3	2	2	
22	50	>120	16	11	8	6	5	4	3	3	2	2	2	

Note: Wet skin could significantly decrease the time for frostbite to occur.

**FROSTBITE RISK**

LOW – freezing is possible, but unlikely (WHITE)

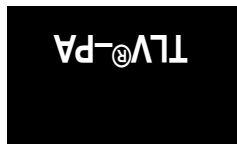
HIGH – freezing could occur in 10–30 minutes (LIGHT GREY)

SEVERE – freezing could occur in 5–10 minutes (DARK GREY)

EXTREME – freezing could occur in < 5 minutes (MEDIUM GREY)

*Sources:*

*Department of the Army: Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508). Falls Church, VA (2005). Xu X; Tikuisis P: Thermoregulatory modeling for cold stress. Compr Physiol 4:1057–81 (2014).*



Imposing a single standard clothing ensemble for an entire group could result in overheating and sweating during work in some, while others would not be kept warm; therefore, people should adjust clothing according to their own needs. A common problem is that people begin working while still wearing clothing layers appropriate for resting conditions, and thus, are “over-dressed” after the work is started. If the combination of environmental conditions, work intensity, and available clothing suggest that body heat content cannot be maintained (e.g., low work intensity in rainy conditions), then supervision of the worker or use of the buddy system should be encouraged. All workers need to be aware that the risk of hypothermia increases if the weather is wet and wet-weather clothing is not available and work intensity is low (e.g., stop digging to rest). Remaining dry, especially for those working in remote regions, is extremely important and dictates that carrying extra clothing that is water-proof and dry clothing to change into is vital. If work is done at normal temperatures or in a hot environment before entering the cold area, the employee should make sure that clothing is not wet as a consequence of sweating. If clothing is wet, the employee should change into dry clothes before entering the cold area. The workers should change socks and any removable felt insoles at regular, daily intervals or use vapor barrier boots. The optimal frequency of change should be determined empirically and will vary individually and according to the type of shoe worn and how much the individual's feet sweat.

If exposed areas of the body cannot be protected sufficiently to prevent sensation of excessive cold or frostbite, protective items should be supplied in auxiliary heated versions.

If the available clothing does not give adequate protection to prevent hypothermia or frostbite, work should be modified or suspended until adequate clothing is made available or until weather conditions improve. Feet are susceptible to peripheral cold injuries. All workers should be provided with appropriately rated footwear for the conditions they are working in. For example, if the environment is wet, footwear should provide protection against water penetration; likewise, if the air temperatures have the potential to be extremely low (less than 0°F (-18°C)), specific boots for this environment need to be provided.

### **Work-Warming Regimen**

If work is performed continuously in the cold at or below a WCT of -7°C (19.4°F), heated warming shelters (tents, cabins, rest rooms, etc.) should be made available nearby. The workers should be encouraged to use these shelters at regular intervals, the frequency depending on the severity of the environmental exposure. Indications for immediate return to the shelter are the onset of heavy shivering; frostnip; or the feeling of excessive fatigue, drowsiness, irritability, or euphoria. When entering the heated shelter, the outer layer of clothing should be removed and the remainder of the clothing loosened to permit sweat evaporation, or a change of dry work clothing should be provided as necessary to prevent workers from returning to their work with wet clothing. Dehydration, or the loss of body fluids, occurs insidiously in the cold environment and can impair work performance. However, dehydration likely does not increase susceptibility to cold injuries. Workers can drink a variety of fluids (milk, juice, sports drinks, tea, coffee). Hot bever-



ages and soups should be provided at the work site as they provide calories and increase morale.

For work at or below  $-12^{\circ}\text{C}$  ( $10.4^{\circ}\text{F}$ ) WCT, the following should apply:

1. The worker should be under constant protective observation (buddy system or supervision).
2. The work rate should not be so high as to cause heavy sweating that will result in wet clothing; if heavy work must be done, rest periods should be taken in heated shelters and opportunity for changing into dry clothing should be provided.
3. New employees should not be required to work full-time in the cold during the first days of employment until they become accustomed to the working conditions and required protective clothing.
4. The weight and bulkiness of clothing should be included in estimating the required work performance and weights to be lifted by the worker.
5. The work should be arranged in such a way that sitting still or standing still for long periods is minimized. Unprotected, metal chair seats should not be used. The worker should be protected from drafts to the greatest extent possible.
6. The worker should be instructed in safety and health procedures. The training program should include, as a minimum, instruction in:
  - a. Proper re-warming procedures and appropriate first aid treatment.
  - b. Proper clothing practices.
  - c. Proper eating and drinking habits.
  - d. Recognition of impending frostbite.
  - e. Recognition of signs and symptoms of impending hypothermia or excessive cooling of the body even when shivering does not occur.
  - f. Safe work practices.

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### Special Workplace Recommendations

Special design requirements for refrigerator rooms include:

1. Air velocity should be minimized as much as possible and should not exceed 1 m/sec (200 fpm) at the job site. This can be achieved by properly designed air distribution systems.
2. Special wind protective clothing should be provided based on existing air velocities to which workers are exposed.

Special caution should be exercised when working with toxic substances and when workers are exposed to vibration. Cold exposure may require reduced exposure limits.

Eye protection for workers employed out-of-doors in a snow- and/or ice-covered terrain should be supplied. Special safety goggles to protect against ultraviolet light and glare (which can produce temporary conjunctivitis and/or temporary loss of vision) and blowing ice crystals should be required when there is an expanse of snow coverage causing a potential eye exposure hazard.

Workplace monitoring is required as follows:

1. Suitable thermometry should be arranged at any workplace where the environmental temperature is below  $16^{\circ}\text{C}$  ( $60.8^{\circ}\text{F}$ ) so that overall compliance with the requirements of the TLV® can be maintained.

2. Whenever the air temperature at a workplace falls below  $-1^{\circ}\text{C}$  ( $30.2^{\circ}\text{F}$ ), the air temperature should be measured and recorded at least every 4 hours.
3. In indoor workplaces, the wind speed should also be recorded at least every 4 hours whenever the rate of air movement exceeds 2 m/sec (5 mph).
4. In outdoor work situations, the wind speed should be measured and recorded together with the air temperature whenever the air temperature is below  $-1^{\circ}\text{C}$  ( $30.2^{\circ}\text{F}$ ).
5. The WCT should be obtained from Table 4 in all cases where air movement measurements are required; it should be recorded with the other data whenever the WCT is below  $-7^{\circ}\text{C}$  ( $19.4^{\circ}\text{F}$ ).

Employees should be excluded from work in cold at  $-1^{\circ}\text{C}$  ( $30.2^{\circ}\text{F}$ ) or below if they are suffering from diseases or taking medication that interferes with normal body temperature regulation or reduces tolerance to work in cold environments. Workers who are routinely exposed to temperatures below  $-24^{\circ}\text{C}$  ( $-11.2^{\circ}\text{F}$ ) with wind speeds  $< 2$  m/sec (5 mph), or air temperatures below  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) with wind speeds above 2 m/sec (5 mph), should be medically certified as suitable for such exposures.

Trauma sustained in freezing or subzero conditions requires special attention because an injured worker is predisposed to cold injury. In addition to providing for first aid treatment, special provisions should be made to prevent hypothermia and freezing of damaged tissues.

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### References

- Castellani JW; Young AJ; Ducharme MB; et al.: Prevention of cold injuries during exercise. *Med Sci Sports Exerc* 38:2012–2029 (2006).
- National Weather Service: Windchill Temperature Index. NOAA, National Weather Service, Office of Climate, Water, and Weather Services (2001).
- US Department of the Army: Prevention and management of cold-weather injuries. Technical Bulletin Medical 508, (TB MED 508). Falls Church, VA (2005).
- Xu X; Tikuisis P: Thermoregulatory modeling for cold stress. *Compr Physiol* 4:1057–1081 (2014).

## HEAT STRESS AND STRAIN

**Warning:** While the TLV<sup>®</sup> is based on the ability of most healthy, acclimatized workers to sustain a heat stress exposure, cases of heat stroke and other exertional heat illnesses may occur below the TLV<sup>®</sup>. A program of heat stress management should include acclimatization, early recognition of symptoms with appropriate first aid, and recognition of personal risk factors. Further, there is evidence of a carry-over effect from a previous day's exposure.

Personal risk factors include, among others, prior heat stroke, repeated heat exhaustion, cardiac or kidney disease, pregnancy, obesity, older age and certain medications. It is recommended that workers with personal risk factors consult a health care provider prior to working in a hot environment.

This TLV<sup>®</sup> has a small margin of safety. Therefore, those working near the TLV<sup>®</sup> should be warned to drink water regularly and be alert for dizziness, lightheadedness, nausea, and headache.

**Goal:** The goal of this TLV<sup>®</sup> is to maintain body core temperature within +1°C of normal (37°C) for the average person. For most individuals, body core temperature will be below 38.3°C. Body core temperature can exceed 38.3°C under certain circumstances with selected populations, environmental and physiologic monitoring, and other controls.

More than any other physical agent, the potential health hazards from work in hot environments depends strongly on physiological factors that lead to a range of susceptibilities depending on the level of acclimatization. Therefore, professional judgment is of particular importance in assessing the level of heat stress and physiological heat strain to adequately provide guidance for protecting nearly all healthy workers with due consideration of individual factors and the type of work. Assessment of both heat stress and heat strain can be used for evaluating the risk to worker safety and health. A decision-making process is suggested in Figure 1. The exposure guidance provided in Figures 1 and 2 and in the associated *Documentation* of the TLV<sup>®</sup> represents conditions under which it is believed that nearly all heat acclimatized, adequately hydrated, unmedicated, healthy workers may be repeatedly exposed without adverse health effects. The Action Limit (AL) is similarly protective of unacclimatized workers and represents conditions for which a heat stress management program should be considered. While not part of the TLV<sup>®</sup>, elements of a heat stress management program are offered. The exposure guidance is not a fine line between safe and dangerous levels.

*Heat Stress* is the net heat load to which a worker may be exposed from the combined contributions of metabolic heat, environmental factors (i.e., air temperature, humidity, air movement, and radiant heat), and clothing requirements. A mild or moderate heat stress may cause discomfort and may adversely affect performance and safety, but it is not harmful to health. As the heat stress approaches human tolerance limits, the risk of heat-related disorders increases.

*Heat Strain* is the overall physiological response resulting from heat stress. The physiological responses are dedicated to dissipating excess heat from the body.

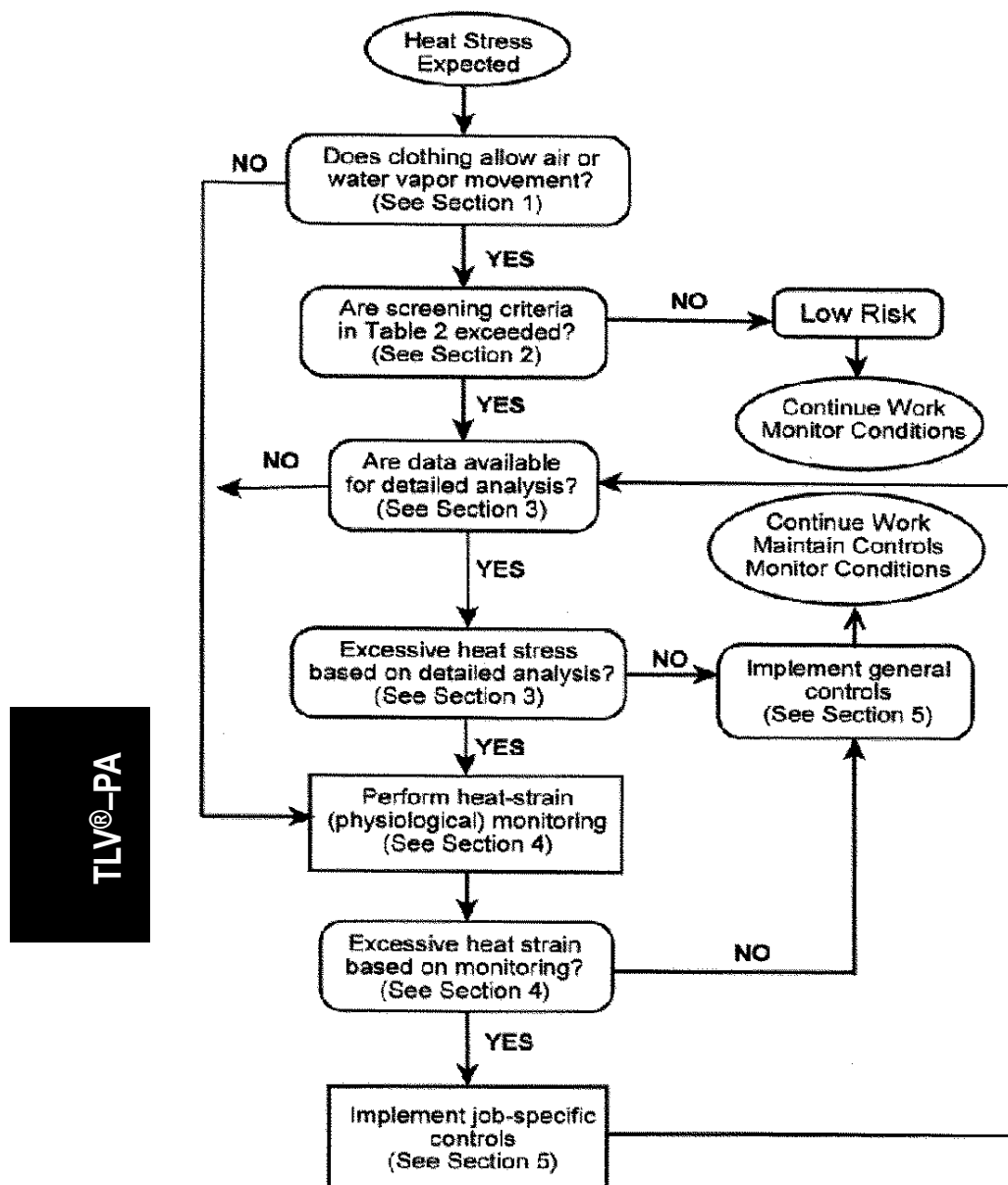
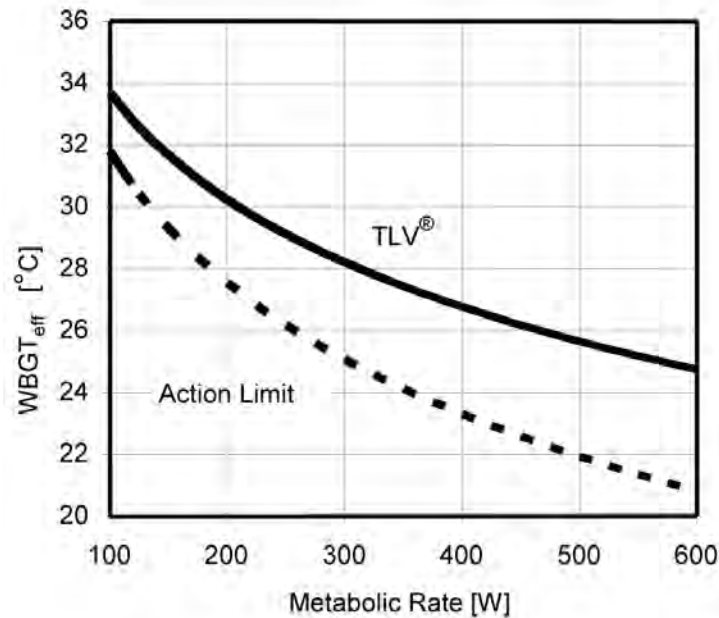


FIGURE 1. Evaluating heat stress and strain.

*Acclimatization* is a gradual physiological adaptation that improves an individual's ability to tolerate heat stress. Acclimatization requires physical activity under heat-stress conditions similar to those anticipated for the work. With a recent history of heat-stress exposures of at least two continuous hours (e.g., 5 of the last 7 days to 10 of 14 days), a worker can be considered acclimatized for the purposes of the TLV®. Its loss begins when the activity under those heat stress conditions is discontinued, and a noticeable loss occurs after four days and may be completely lost in three to four weeks. Because acclimatization is to the level of the heat stress exposure, a person will not be fully acclimatized to a sudden higher level; such as during a heat wave.



**FIGURE 2.** TLV® (solid line) and Action Limit (broken line) for heat stress.  $WBGT_{eff}$  is the measured WBGT plus the Clothing-Adjustment Factor.

The decision process illustrated in Figure 1 should be started if (1) a qualitative exposure assessment indicates the possibility of heat stress, (2) there are reports of discomfort due to heat stress, or (3) professional judgment indicates heat stress conditions.

*Section 1: Clothing.* Ideally, free movement of cool, dry air over the skin's surface maximizes heat removal by both evaporation and convection. Evaporation of sweat from the skin is the predominant heat removal mechanism. Water-vapor-impermeable, air-impermeable, and thermally insulating clothing, as well as encapsulating suits and multiple layers of clothing, severely restrict heat removal. With heat removal hampered by clothing, metabolic heat may produce excessive heat strain even when ambient conditions are considered cool.

Figure 1 requires a decision about clothing and how it might affect heat loss. The WBGT-based heat exposure assessment was developed for a traditional work uniform of a long-sleeve shirt and pants. If the required clothing is adequately described by one of the ensembles in Table 1 or by other available data, then the "YES" branch is selected.

If workers are required to wear clothing not represented by an ensemble in Table 1, then the "NO" branch should be taken. This decision is especially applicable for clothing ensembles that are 1) totally encapsulating suits or 2) multiple layers where no data are available for adjustments. For these kinds of ensembles, Table 2 is not a useful screening method to determine a threshold for heat-stress management actions and some risk must be assumed. Unless a detailed analysis method appropriate to the clothing requirements is available, physiological and signs/symptoms monitoring described in Section 4 and Table 4 should be followed to assess the exposure.

**TABLE 1. Clothing-Adjustment Factors for Some Clothing Ensembles\***

<b>Clothing Type</b>	<b>Addition to WBGT [°C]</b>
Work clothes (long sleeve shirt and pants)	0
Cloth (woven material) coveralls	0
Double-layer woven clothing	3
SMS polypropylene coveralls	0.5
Polyolefin coveralls	1
Limited-use vapor-barrier coveralls	11

\*These values must not be used for completely encapsulating suits, often called Level A. Clothing Adjustment Factors cannot be added for multiple layers. The coveralls assume that only modesty clothing is worn underneath, not a second layer of clothing.

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*Section 2: Screening Threshold Based on Wet-Bulb Globe Temperature (WBGT).* The WBGT offers a useful first order index of the environmental contribution to heat stress. It is influenced by air temperature, radiant heat, air movement, and humidity. As an approximation, it does not fully account for all the interactions between a person and the environment and cannot account for special conditions such as heating from a radiofrequency/microwave source.

WBGT values are calculated using one of the following equations:

With direct exposure to sunlight:

$$\text{WBGT}_{\text{out}} = 0.7 T_{\text{nwb}} + 0.2 T_{\text{g}} + 0.1 T_{\text{db}}$$

Without direct exposure to the sun:

$$\text{WBGT}_{\text{in}} = 0.7 T_{\text{nwb}} + 0.3 T_{\text{g}}$$

where:

$T_{\text{nwb}}$  = natural wet-bulb temperature (sometimes called NWB)

$T_{\text{g}}$  = globe temperature (sometimes called GT)

$T_{\text{db}}$  = dry-bulb (air) temperature (sometimes called DB)

Because WBGT is only an index of the environment, the screening criteria are adjusted for the contributions of work demands and clothing. Table 2 provides WBGT criteria suitable for screening purposes. For clothing ensembles listed in Table 1, Table 2 can be used when the clothing adjustment values are added to the environmental WBGT.

To determine the degree of heat stress exposure, the work pattern and demands must be considered. If the work (and rest) is distributed over more than one location, then a time-weighted average WBGT should be used for comparison to Table 2 limits.

**TABLE 2. Screening Criteria for TLV<sup>®</sup> and Action Limit for Heat Stress Exposure**

Allocation of Work in a Cycle of Work and Recovery	TLV <sup>®</sup> (WBGT values in °C)				Action Limit (WBGT values in °C)			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
75 to 100%	31.0	28.0	—	—	28.0	25.0	—	—
50 to 75%	31.0	29.0	27.5	—	28.5	26.0	24.0	—
25 to 50%	32.0	30.0	29.0	28.0	29.5	27.0	25.5	24.5
0 to 25%	32.5	31.5	30.5	30.0	30.0	29.0	28.0	27.0

*Notes:*

- See Table 3 and the *Documentation* for work demand categories.
- WBGT values are expressed to the nearest 0.5°C.
- The thresholds are computed as a TWA-Metabolic Rate where the metabolic rate for rest is taken as 115 W and work is the representative (mid-range) value of Table 3. The time base is taken as the proportion of work at the upper limit of the percent work range (e.g., 50% for the range of 25 to 50%).
- If work and rest environments are different, hourly time-weighted averages (TWA), WBGT should be calculated and used. TWAs for work rates should also be used when the work demands vary within the hour, but note that the metabolic rate for rest is already factored into the screening limit.
- Values in the table are applied by reference to the “Work-Rest Regimen” section of the *Documentation* and assume 8-hour workdays in a 5-day workweek with conventional breaks as discussed in the *Documentation*. When workdays are extended, consult the “Application of the TLV<sup>®</sup>” section of the *Documentation*.
- Because of the physiological strain associated with Heavy and Very Heavy work among less fit workers regardless of WBGT, criteria values are not provided for continuous work and for up to 25% rest in an hour for Very Heavy work. The screening criteria are not recommended, and a detailed analysis and/or physiological monitoring should be used.
- Table 2 is intended as an initial screening tool to evaluate whether a heat stress situation may exist (according to Figure 1) and thus, the table is more protective than the TLV<sup>®</sup> or Action Limit (Figure 2). Because the values are more protective, they are not intended to prescribe work and recovery periods.

**TABLE 3. Metabolic Rate Categories and the Representative Metabolic Rate with Example Activities**

Category	Metabolic Rate [W] *	Examples
Rest	115	Sitting
Light	180	Sitting with light manual work with hands or hands and arms, and driving. Standing with some light arm work and occasional walking.
Moderate	300	Sustained moderate hand and arm work, moderate arm and leg work, moderate arm and trunk work, or light pushing and pulling. Normal walking.
Heavy	415	Intense arm and trunk work, carrying, shoveling, manual sawing; pushing and pulling heavy loads; and walking at a fast pace.
Very Heavy	520	Very intense activity at fast to maximum pace.

\* The effect of body weight on the estimated metabolic rate can be accounted for by multiplying the estimated rate by the ratio of actual body weight divided by 70 kg (154 lb).

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As metabolic rate increases (i.e., work demands increase), the criteria values in the table decrease to ensure that most workers will not have a core body temperature above 38°C. Correct assessment of work rate is of equal importance to environmental assessment in evaluating heat stress. Table 3 provides broad guidance for selecting the work rate category to be used in Table 2. Often there are natural or prescribed rest breaks within an hour of work, and Table 2 provides the screening criteria for three allocations of work and rest.

Based on metabolic rate category for the work and the approximate proportion of work within an hour, a WBGT criterion can be found in Table 2 for the TLV and for the Action Limit. If the measured time-weighted average WBGT adjusted for clothing is less than the table value for the Action Limit, the “NO” branch in Figure 1 is taken, and there is little risk of excessive exposures to heat stress. If the conditions are above the Action Limit, but below the TLV®, then consider general controls described in Table 5. If there are reports of the symptoms of heat-related disorders such as fatigue, nausea, dizziness, and lightheadedness, then the analysis should be reconsidered.

If the work conditions are above the TLV® screening criteria in Table 2, then a further analysis is required following the “YES” branch.

*Section 3: Detailed Analysis.* Table 2 is intended to be used as a screening step. It is possible that a condition may be above the TLV® or Action Limit criteria



provided in Table 2 and still not represent an exposure above the TLV® or the Action Limit. To make this determination, a detailed analysis is required. Methods are fully described in the *Documentation*, in industrial hygiene and safety books, and in other sources.

Provided that there is adequate information on the heat stress effects of the required clothing, the first level of detailed analysis is a task analysis that includes a time-weighted average of the Effective WBGT (environmental WBGT plus clothing adjustment value) and the metabolic rate. Some clothing adjustment values have been suggested in Table 1. Values for other clothing ensembles appearing in the literature can be used in similar fashion following good professional judgment. The TLV® and Action Limit are shown in Figure 2.

The second level of detailed analysis would follow a rational model of heat stress, such as the International Standards Organization (ISO) Predicted Heat Strain (ISO 7933, 2004; Malchaire et al., 2001). While a rational method (versus the empirically derived WBGT thresholds) is computationally more difficult, it permits a better understanding of the sources of the heat stress and is a means to appreciate the benefits of proposed modifications in the exposure. Guidance to the ISO method and other rational methods is described in the literature.

The screening criteria require the minimal set of data to make a determination. Detailed analyses require more data about the exposures. Following Figure 1, the next question asks about the availability of data for a detailed analysis. If these data are not available, the “NO” branch takes the evaluation to physiological monitoring to assess the degree of heat strain.

If the data for a detailed analysis are available, the next step in Figure 1 is the detailed analysis. If the exposure does not exceed the criteria for the Action Limit (or unacclimatized workers) for the appropriate detailed analysis (e.g., WBGT analysis, another empirical method, or a rational method), then the “NO” branch can be taken. If the Action Limit criteria are exceeded but the criteria for the TLV® (or other limit for acclimatized workers) in the detailed analysis are not exceeded, then consider general controls and continue to monitor the conditions. General controls include training for workers and supervisors, heat stress hygiene practices, and medical surveillance (Table 5). If the exposure exceeds the limits for acclimatized workers in the detailed analysis, the “YES” branch leads to physiological monitoring as the only alternative to demonstrate that adequate protection is provided.

*Section 4: Heat Strain.* The risk and severity of excessive heat strain will vary widely among people, even under identical heat stress conditions. The normal physiological responses to heat stress provide an opportunity to monitor heat strain among workers and to use this information to assess the level of heat strain present in the workforce, to control exposures, and to assess the effectiveness of implemented controls. Table 4 provides guidance for acceptable limits of heat strain.

Following good industrial hygiene sampling practice, which considers likely extremes and the less tolerant workers, the absence of any of these limiting observations indicates acceptable management of the heat stress exposures. With acceptable levels of heat strain, the “NO” branch in Figure 1 is taken. Nevertheless, if the heat strain among workers is considered acceptable at the time, consideration of the general controls is recommended. In addition,

**TABLE 4. Guidelines for Limiting Heat Strain**

Monitoring heat strain and signs and symptoms of heat-related disorders is sound industrial hygiene practice, especially when clothing may significantly reduce heat loss. For surveillance purposes, a pattern of workers exceeding the heat strain limits is indicative of a need to control the exposures. On an individual basis, the limits represent a time to cease an exposure and allow for recovery.

One or more of the following measures may mark excessive heat strain, and an individual's exposure to heat stress should be discontinued when any of the following occur:

- Sustained (several minutes) heart rate is in excess of 180 bpm (beats per minute) minus the individual's age in years (e.g., 180 – age) for individuals with assessed normal cardiac performance; or
- Body core temperature is greater than 38.5°C (101.3°F) for medically selected and acclimatized personnel; or greater than 38°C (100.4°F) in unselected, unacclimatized workers; or
- Recovery heart rate at one minute after a peak work effort is greater than 120 bpm; or
- There are symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.

An individual may be at greater risk of heat-related disorders if:

- Profuse sweating is sustained over hours; or
- Weight loss over a shift is greater than 1.5% of body weight; or
- 24-hour urinary sodium excretion is less than 50 mmoles

**EMERGENCY RESPONSE:** If a worker appears to be disoriented or confused, suffers inexplicable irritability, malaise, or chills, the worker should be removed for rest in a cool location with rapidly circulating air and kept under skilled observation. Absent medical advice to the contrary, treat this as an emergency with immediate transport to a hospital. An emergency response plan is necessary.

— **NEVER ignore anyone's signs or symptoms of heat-related disorders** —

TLV®-PA

periodic physiological monitoring should be continued to ensure acceptable levels of heat strain.

If limiting heat strain is found during the physiological assessments, then the "YES" branch is taken. This means that suitable job-specific controls should be implemented to a sufficient extent to control heat strain. The job-specific controls include engineering controls, administrative controls, and personal protection.

After implementation of the job-specific controls, it is necessary to assess their effectiveness and to adjust them as needed.

*Section 5: Heat Stress Management and Controls.* The elements of a heat stress management program including general and job-specific controls should be considered in the light of local conditions and the judgment of the industrial hygienist. The recommendation to initiate a heat stress management program is marked by 1) heat stress levels that exceed the Action Limit or 2) work in clothing ensembles that limit heat loss. In either case, general controls should be considered (Table 5).

Heat stress hygiene practices are particularly important because they reduce the risk that an individual may suffer a heat-related disorder. The key elements are fluid replacement, self-determination of exposures, health status monitoring, maintenance of a healthy lifestyle, and adjustment of expectations based on acclimatization state. The hygiene practices require the full cooperation of supervision and workers.

In addition to general controls, appropriate job-specific controls are often required to provide adequate protection. During the consideration of job-specific controls, Table 2 and Figure 2, along with Tables 1 and 3, provide a framework to appreciate the interactions among acclimatization state, metabolic rate, work-rest cycles, and clothing. Among administrative controls, Table 4 provides acceptable physiological and signs/symptoms limits. The mix of job-specific controls can be selected and implemented only after a review of the demands and constraints of any particular situation. Once implemented, their effectiveness must be confirmed and the controls maintained.

The prime objective of heat stress management is the prevention of heat stroke, which is life-threatening and the most serious of the heat-related disorders. The heat stroke victim is often manic, disoriented, confused, delirious, or unconscious. The victim's body core temperature is greater than 40°C (104°F). If signs of heat stroke appear, aggressive cooling should be started immediately, and emergency care and hospitalization are essential. The prompt treatment of other heat-related disorders generally results in full recovery, but medical advice should be sought for treatment and return-to-work protocols. It is worth noting that the possibility of accidents and injury increases with the level of heat stress.

Prolonged increases in deep body temperatures and chronic exposures to high levels of heat stress are associated with other disorders such as temporary infertility (male and female), elevated heart rate, sleep disturbance, fatigue, and irritability. During the first trimester of pregnancy, a sustained core temperature greater than 39°C may endanger the fetus.

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**TABLE 5. Elements to Consider in Establishing a Heat Stress Management Program**

Monitor heat stress (e.g., WBGT Screening Criteria in Table 2) and heat strain (Table 4) to confirm adequate control

**General Controls**

- Provide accurate verbal and written instructions, annual training programs, and other information about heat stress and strain
- Encourage drinking small volumes (approximately 1 cup) of cool, palatable water (or other acceptable fluid replacement drink) about every 20 minutes
- Encourage employees to report symptoms of heat-related disorders to a supervisor
- Encourage self-limitation of exposures when a supervisor is not present
- Encourage co-worker observation to detect signs and symptoms of heat strain in others
- Counsel and monitor those who take medications that may compromise normal cardiovascular, blood pressure, body temperature regulation, renal, or sweat gland functions; and those who abuse or are recovering from the abuse of alcohol or other intoxicants
- Encourage healthy lifestyles, ideal body weight and electrolyte balance
- Adjust expectations of those returning to work after absence from hot exposure situations and encourage consumption of salty foods (with approval of physician if on a salt-restricted diet)
- Consider pre-placement medical screening to identify those susceptible to systemic heat injury
- Monitor the heat stress conditions and reports of heat-related disorders

**Job-Specific Controls**

- Consider engineering controls that reduce the metabolic rate, provide general air movement, reduce process heat and water vapor release, and shield radiant heat sources, among others
- Consider administrative controls that set acceptable exposure times, allow sufficient recovery, and limit physiological strain
- Consider personal protection that is demonstrated effective for the specific work practices and conditions at the location

— **NEVER ignore anyone's signs or symptoms of heat-related disorders** —

## 2019 PHYSICAL AGENTS AND OTHER ISSUES UNDER STUDY

The TLV® Physical Agents Committee solicits information, especially data, which may assist it in its deliberations regarding the following agents and issues. Comments and suggestions, accompanied by substantiating evidence in the form of peer-reviewed literature, should be forwarded in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org). In addition, ACGIH® solicits recommendations for additional agents and issues of concern to the industrial hygiene and occupational health communities. Please refer to the ACGIH® TLV®/BEI® Development Process found on the ACGIH® website for a detailed discussion covering this procedure and methods for input to ACGIH® ([www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process](http://www.acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development-process)).

The Under Study list is published each year by February 1 on the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)), in the *Annual Reports of the Committees on TLVs® and BEIs®*, and later in the annual *TLVs® and BEIs®* book. In addition, the Under Study list is updated by July 31 into a two-tier list.

- Tier 1 entries indicate which chemical substances and physical agents **may** move forward as an NIC or NIE in the upcoming year, based on their status in the development process.
- Tier 2 consists of those chemical substances and physical agents that **will not** move forward, but will either remain on or be removed from, the Under Study list for the next year.

This updated list will remain in two-tiers for the balance of the year. ACGIH® will continue this practice of updating the Under Study list by February 1 and establishing the two-tier list by July 31 each year.

The substances and issues listed below are as of January 1, 2019. *After this date, please refer to the ACGIH® website* ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)) *for the up-to-date list.*

### Physical Agents

1. Acoustic
  - Audible sound
  - Infrasound and Low-frequency sound
2. Optical Radiation
  - Lasers
  - Light and Near-infrared radiation
  - Ultraviolet radiation
3. Ergonomics
  - Lifting
  - Hand–arm vibration
  - Whole-body vibration
4. Thermal Stress
  - Cold stress
  - Heat stress and strain

**Other Issues Under Study**

1. Fatigue and its management in the workplace
2. Head supported mass and neck loading
3. Hypobaric pressure
4. Sensory-induced motion sickness

## \* APPENDIX A: STATEMENT ON THE OCCUPATIONAL HEALTH ASPECTS OF NEW LIGHTING TECHNOLOGIES – CIRCADIAN, NEUROENDOCRINE AND NEUROBEHAVIORAL EFFECTS OF LIGHT

Over the past decade a revolution in indoor lighting has been underway, fueled partly by new technologies of compact fluorescent lamps (CFLs) and solid-state, light-emitting-diode (LED) lamps, and partly by efforts to reduce the consumption of electrical energy. Do these changes in the work environment pose any real health concerns? The ACGIH® TLVs® for Light and Near Infrared Radiation for evaluating optical radiation have existed for decades and lamp-safety standards refer to these TLVs®. These are designed chiefly to avoid retinal injuries from exposure to very intense light sources (e.g., welding arcs). In most workplace settings, there is little to no chance that workers will be exposed to general lighting sources (GLS) used for visual purposes that exceed current TLVs®.

However, the new lighting technologies, in particular LED and CFL lighting that are now widely used in workplaces for energy conservation, have significantly different spectral output than traditional incandescent light bulbs. There is considerable evidence that the body is highly sensitive to the blue light that forms a considerable fraction of the output of these sources. Some of the new lamps have sufficiently different spectra (color spectra) that concerns have been raised about potential health effects (AMA, 2016; CIE, 2006; IESNA, 2008). This Statement addresses possible health and safety issues that are associated with artificial lighting at levels that would be used for visual purposes.

Light is a potent stimulus for regulating circadian, hormonal, and behavioral systems in humans. Research over the past 12 years has shown that the biological and behavioral effects of light are particularly influenced by a distinct photoreceptor in the eye, the melanopsin containing intrinsically photosensitive retinal ganglion cells (ipRGCs), in addition to the conventional rods and cones (Lucas et al., 2014; CIE, 2009; IESNA, 2008). Published action spectra show that ipRGCs are most sensitive to blue-appearing light with a strong sensitivity in the 450–520 nm spectral band for circadian, neuroendocrine and neurobehavioral regulation in humans (480 nm is widely cited when a single peak is provided). However, the relatively recent discovery of a new photopigment (melanopsin) in the retina located in a previously unknown photoreceptor (Berson et al., 2002; Hattar et al., 2002), referred to as the “intrinsically photoreceptive retinal ganglion cell” (ipRGC), has raised new questions regarding light and health (CIE, 2006). The ipRGC responds strongly to short-wavelength (blue) light and plays a key role in neurobiological and neurobehavioral effects that fall under the general umbrella of “circadian” effects (Lucas et al., 2014; Brainard and Hanifin, 2004). The circadian (24-h) rhythm affects many physiological processes in the body other than just the sleep/wake cycle. Most organ systems undergo circadian cycles regulated by the neuroendocrine system. These include circadian rhythms, variations in body temperature, heart rate, etc. (Turner et al., 2010). Variations in hormone levels beside melatonin include cortisol and thyroid stimulating hormone (TSH). Thus, the physiological processes that determine mood, performance, alertness and tiredness are affected. The adverse physiological effects of shift work are driven by circadian disruption.

Particular attention has been paid to the potential for “blue light” (460–490 nm) to increase alertness, since the blue-sensitive ipRGCs signal the pineal body (through the suprachiasmatic nucleus) to suppress secretion of melatonin (the “sleep hormone”). Indeed, there have been suggestions to increase alertness in the workplace by increasing the blue light spectrum in office lighting. This is most often described in the lighting literature as increasing the correlated color temperature (CCT) of the lamp spectrum, although this is not the most accurate way to describe the ‘melanopic’ content of light, as different light spectra can have the same CCT (Lucas et al., 2014). In reality, all visible wavelengths provide an alerting stimulus during the day.

Some life scientists have noted that blue light is frequently cited as producing a phototoxic effect at very high retinal exposure levels, but far more than produced by standard commercially available general-service lamps. Although concerns have arisen as to the potential for adverse effects from chronic exposure to new lighting installations with blue-rich emissions in workplace lighting (Behar-Cohen et al., 2011), routine, normal exposure to the newer blue-rich lamps will remain well below the TLVs® for UV, visible and infrared radiation. General lighting service lamps for illumination also meet photobiological safety standards (based on the TLVs®). The IARC classification of shift work as a probable carcinogen has accentuated concerns that lighting in workplaces might play a role in carcinogenesis; however, this hypothesis remains quite controversial (IARC, 2011).

### Conclusions and Recommendations

Given the present state of knowledge, ACGIH® considers that its present TLVs® are sufficiently protective against photochemically induced “blue light hazard.” ACGIH® does not consider it practical or advisable to develop TLVs® to protect against light-induced changes in circadian rhythms or possible related health effects from shift work.

However, employers and occupational safety experts are advised:

1. Shift work involves a range of issues apart from disruption of circadian rhythms, and these are best addressed by measures such as optimal planning of work schedules, rather than exposure limits such as TLVs®. Employers should be aware of recommendations by NIOSH and other occupational health organizations about shift work. For example: <http://www.cdc.gov/niosh/topics/workschedules/>.
2. Adjusting the color palette of computer displays to reduce their short-wavelength content or dimming computer screens for evening work has been shown to affect circadian physiology and cognitive performance (Cajochen et al., 2011; Chang et al., 2015). Tools to adjust the color palette exist. The magnitude, if any, of any health benefit from their use remains unproven.
3. In occupational settings, employee alertness, safety and health are key. The lighting conditions should provide the safest and most alerting environment possible, while maintaining typical visual function. Work environments should therefore incorporate high intensity, blue-enriched (high melanopic) light during both the day, and especially at night given the high risk of sleepiness-related accidents and injuries. In occupational settings



where there are potentially conflicting needs, such as a hospital during the night when patients sleep but staff are awake, the patient bedroom or ward environment should be optimized for sleep with low intensity, blue-depleted (low melanopic) light while the staff environment (nursing station, break rooms) should enhance alertness with high intensity, blue-enriched (high melanopic) light. During the daytime, both groups would benefit from high intensity, blue-enriched (high melanopic) light. These more complex environments need careful consideration of the spectrum, location and use of the light but are likely to be solved through the lighting design process.

4. Worker complaints related to new installations of high-intensity, high-brightness LED lighting fixtures frequently relate to discomfort glare because of poor luminaire design or installation, not the blue-enriched spectrum of the light. Consulting good lighting practice guides may be helpful. For example: *IESNA Lighting Handbook* (IESNA, 2011).

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## NOTICE OF INTENT TO ESTABLISH — † APPENDIX B: PERSONAL PHYSIOLOGIC MONITORING IN THE WORKPLACE

The development of recent technologies opens the possibility of continuously monitoring physiologic responses of workers for the assessment of health and safety factors. Specifically, the use of these systems could provide actionable information that guides the worker on safe and effective performance such as warning about approaching thermal-work strain limits, extremity freezing cold injury risk, hypoxia risks, impending muscle fatigue, injury, etc. (Pancarado et al., 2015). They may also be proposed as dosimeters for health risk exposures based on physiological responses and workload, and perhaps measured in conjunction with environmental sensors. A third major category of proposed use is to detect an injury event and trigger an automatic “911”, assist with geolocation of the individual worker, and provide early medical triage assistance with signs and symptoms.

Workplace health and safety personnel may be called on to assess the value and use of these devices for protecting the health of workers. While there are some very specialized use cases for real time physiological monitoring today, there are few systems that have been fully validated for use (Mijovic et al., 2017). Furthermore, there are systems that are available that may be dangerous because they provide inaccurate information, the technologies interfere with other systems, or the systems themselves provide some risks to the workers.

Physiological monitoring systems involve sensors along with some kind of data collection and transmission strategy and they require software algorithms and models that turn the sensor information into useful and actionable information. The interpretation of the signals is equally important to the quality of the measurements. Raw data such as heart rate, oxygen saturation, or skin temperature are not as useful to a worker or their supervisors as a stoplight system of alerts (e.g., green-amber-red warnings) that can be queried or outputs that recommend data-based work-rest cycles, etc. A number of factors should be evaluated before these devices are adopted for routine worker monitoring.

- Device design issues
  - Usability
  - Accuracy
  - Reliability
  - Safety
- Policy issues
  - Data analysis and interpretation
  - Ownership and control of information
  - Decision on workplace interventions
  - Discrimination
  - Security
  - Training

The device should be evaluated for accuracy against a gold standard across a range of the workplace settings where it would be expected to be used. Reliability should be evaluated across differences in expected users, environments, and settings. Usability should be evaluated by novice users to address design issues and training requirements. Current systems and systems

in development suffer from size, weight, and power issues. Power is a particular problem for many of the continuous monitoring systems with high frequency data capture and transmission, requiring frequent battery replacement or recharge (Nangalia et al., 2010; Pantelopoulos and Bourbakis, 2010). Safety factors should be evaluated if decisions made using information from the device may impact worker safety or health. If medical decisions will be made from this information, the devices will require FDA certification.

Policy issues become important based on how the data are interpreted and the actions taken based on those interpretations. Information may be directly used by the worker to provide recommendations for actions they should take. Or information may be used by the employer for changes in work assignments, work restrictions, or changing work practices. In addition, there are increasing concerns about cybersecurity for seemingly trivial personal physiological data as well, both in terms of privacy and risk of interference with predictive outputs (Clifford and Clifton, 2012).

Questions on who owns the data, where the data are stored, who has access to the data and how long the data are stored are important to employees and employers. Other concerns relate to distinguishing occupational health effects from personal medical data that can be derived from these measurements but are not related to the job; determination of what may be reported to insurers or medical records; and efforts to assess individual work performance and productivity.

Wearable technologies are evolving rapidly into wear-and-forget smart clothing systems and will soon be proposed as ubiquitous implantable systems such as the RFID personal identifier chips that are coming into use. Feasibility of body powered systems that do not require batteries has been demonstrated and these systems are currently in development, drawing power from body heat and movement. Individual systems will increase in usefulness as they “learn” their individual users with adaptive algorithms and as they are networked into the internet of things (IoT), gaining context from other systems in the surrounding environment.

Personal physiological measurements should reliably signal a relevant exposure or health outcome before they are adopted in the workplace. In addition, policy issues such as privacy, ownership, security, training and actions taken should be worked out in advance before workplace adoption. Personal physiological measurement technologies make it possible to move from generalized workplace assessments to personalized health status assessments of the individual worker. However, the measurements must benefit the health and safety of the individual, and personal health data must be firewalled from occupationally related data.

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# 2019

## Biologically Derived Airborne Contaminants

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## INTRODUCTION TO THE BIOLOGICALLY DERIVED AIRBORNE CONTAMINANTS

Biologically derived airborne contaminants include bioaerosols (airborne particles composed of or derived from living organisms) and volatile organic compounds that organisms release. Bioaerosols include microorganisms (i.e., culturable, nonculturable, and dead microorganisms) and fragments, toxins, and particulate waste products from all varieties of living things. Biologically derived contaminants are ubiquitous in nature and may be modified by human activity. Humans are repeatedly exposed, day after day, to a wide variety of such materials.

TLVs<sup>®</sup> exist for certain substances of biological origin, including cellulose; some wood, cotton, flour and grain dusts; nicotine; pyrethrum; starch; subtilisins (proteolytic enzymes); sucrose; vegetable oil mist; and volatile compounds produced by living organisms (e.g., ammonia, carbon dioxide, ethanol, and hydrogen sulfide). However, for the reasons identified below, there are no TLVs<sup>®</sup> against which to compare environmental air concentrations of most materials of biological origin.

ACGIH<sup>®</sup> has developed and separately published guidance on the assessment, control, remediation, and prevention of biologically derived contamination of indoor environments.<sup>(1)</sup> Indoor biological contamination is defined as the presence of a) biologically derived aerosols, gases, and vapors of a kind and concentration likely to cause disease or predispose humans to disease; b) inappropriate concentrations of outdoor bioaerosols, especially in buildings designed to prevent their entry; or c) indoor microbial growth and remnants of biological growth that may become aerosolized and to which humans may be exposed. The term “biological agent” refers to a substance of biological origin that is capable of producing an adverse effect, e.g., an infection or a hypersensitivity, irritant, inflammatory, or other response.

The ACGIH<sup>®</sup>-recommended approach to assessing and controlling bioaerosol exposures relies on visually inspecting buildings, assessing occupant symptoms, evaluating building performance, monitoring potential environmental sources, and applying professional judgment. The published guidance provides background information on the major groups of bioaerosols, including their sources and health effects, and describes methods to collect, analyze, and interpret bioaerosol samples from potential environmental sources. Occasionally, environmental monitoring detects a single or predominating biological contaminant. More commonly, monitoring reveals a mixture of many biologically derived materials, reflecting the diverse and interactive nature of indoor microenvironments. Therefore, environmental sampling for bioaerosols should be conducted only following careful formulation of testable hypotheses about potential bioaerosol sources and mechanisms by which workers may be exposed to bioaerosols from these sources. Even when investigators work from testable hypotheses and well-formulated sampling plans, results from environmental bioaerosol monitoring may be inconclusive and occasionally misleading.

There are no TLVs<sup>®</sup> for interpreting environmental measurements of a) total culturable or countable bioaerosols (e.g., total bacteria or fungi); b) specific culturable or countable bioaerosols (e.g., *Aspergillus fumigatus*); c) infectious agents (e.g., *Legionella pneumophila* or *Mycobacterium tuberculosis*); or d) assayable biological contaminants (e.g., endotoxin, mycotoxin, antigens, or microbial volatile organic compounds) for the following reasons.

**A. Total culturable or countable bioaerosols.** Culturable bioaerosols are those bacteria and fungi that can be grown in laboratory culture. Such results are reported as the number of colony-forming units (CFU). Countable bioaerosols are those pollen grains, fungal spores, bacterial cells, and other material that can be identified and counted by microscope. A general TLV<sup>®</sup> for culturable or countable bioaerosol concentrations is not scientifically supportable because of the following:

1. Culturable microorganisms and countable biological particles do not comprise a single entity, i.e., bioaerosols in occupational settings are generally complex mixtures of many different microbial, animal, and plant particles.
2. Human responses to bioaerosols range from innocuous effects to serious, even fatal, diseases, depending on the specific material involved and workers' susceptibility to it. Therefore, an appropriate exposure limit for one bioaerosol may be entirely inappropriate for another.
3. It is not possible to collect and evaluate all bioaerosol components using a single sampling method. Many reliable methods are available to collect and analyze bioaerosol materials. However, different methods of sample collection and analysis may result in different estimates of culturable and countable bioaerosol concentrations.
4. At present, information relating culturable or countable bioaerosol concentrations to health effects is generally insufficient to describe exposure–response relationships.

**B. Specific culturable or countable bioaerosols other than infectious agents.** Specific TLVs<sup>®</sup> for individual culturable or countable bioaerosols have not been established to prevent hypersensitivity, irritant, or toxic responses. At present, information relating culturable or countable bioaerosol concentrations to health effects consists largely of case reports and qualitative exposure assessments. The data available are generally insufficient to describe exposure–response relationships. Reasons for the absence of good epidemiologic data on such relationships include the following:

1. Most data on concentrations of specific bioaerosols are derived from indicator measurements rather than from measurements of actual effector agents. For example, investigators use the air concentration of culturable fungi to represent exposure to airborne fungal antigens. In addition, most measurements are from either area or source samples. These monitoring approaches are less likely to reflect human exposure accurately than would personal sampling for actual effector agents.
2. Bioaerosol components and concentrations vary widely within and among different occupational and environmental settings. Unfortunately, replicate sampling is uncommon in bioaerosol assessments. Further, the most commonly used air-sampling devices for indoor monitoring are designed to collect “grab” samples over relatively short time intervals. Measurements from single, short-term grab samples may be orders of magnitude higher or lower than long-term average concentrations and are unlikely to represent workplace exposures accurately. Some organisms and sources release aerosols as “concentration bursts,” which may only rarely be detected by limited grab sampling. Nevertheless, such episodic bioaerosol releases may produce significant health effects.



3. In studies of single workplaces, the number of persons affected by exposure to biological agents may be small if contamination is localized, thereby affecting only a fraction of the building occupants. However, data from different studies can seldom be combined to reach meaningful numbers of test subjects because the specific types of biological agents responsible for bioaerosol-related illnesses are diverse and often differ from study to study. These factors contribute to the low statistical power common in evaluations of cause–effect relationships between exposures to specific biological agents and building-related health complaints.

**C. Infectious agents.** Human dose–response data are available for only a few infectious bioaerosols. At present, air-sampling protocols for infectious agents are limited and suitable primarily for research endeavors. In most routine exposure settings, public health measures, such as immunization, active case finding, and medical treatment, remain the primary defenses against infectious bioaerosols. Facilities associated with increased risks for transmission of airborne infectious diseases (e.g., microbiology laboratories, animal-handling facilities, and health-care settings) should employ engineering controls to minimize air concentrations of infectious agents. Further, such facilities should consider the need for administrative controls and personal protective equipment to prevent the exposure of workers to these bioaerosols.

**D. Assayable biological contaminants.** Assayable, biologically derived contaminants (e.g., endotoxin, mycotoxins, antigens, and volatile organic compounds) are microbial, animal, or plant substances that can be detected using chemical, immunological, or biological assays. Evidence does not yet support TLVs® for any of these substances. However, assay methods for certain common airborne antigens and endotoxin are steadily improving, and field validation of these assays is also progressing. Dose–response relationships for some assayable bioaerosols have been observed in experimental studies and occasionally in epidemiologic surveys. Therefore, exposure limits for certain assayable, biologically derived, airborne contaminants may be appropriate in the future. In addition, innovative molecular techniques are becoming available for specific bioaerosols currently detectable only by culture or counting.

ACGIH® actively solicits information, comments, and data in the form of peer-reviewed literature on health effects associated with bioaerosol exposures in occupational and related environments that may help the Bioaerosols Committee evaluate the potential for proposing exposure guidelines for selected biologically derived airborne contaminants. Such information should be sent in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org).

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1. ACGIH®: *Bioaerosols: Assessment and Control*. JM Macher, Ed; HM Ammann, HA Burge, DK Milton, and PR Morey, Asst. Eds. ACGIH®, Cincinnati, OH (1999).

## BIOLOGICALLY DERIVED AGENTS UNDER STUDY

The Bioaerosols Committee solicits information, especially data, which may assist it in the establishment of TLVs® for biologically derived airborne contaminants. Comments and suggestions, accompanied by substantiating evidence in the form of peer-reviewed literature, should be forwarded in electronic format to the ACGIH® Science Group at [science@acgih.org](mailto:science@acgih.org).

The substances and issues listed below are as of January 1, 2019. *After this date, please refer to the ACGIH® website ([www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list](http://www.acgih.org/tlv-bei-guidelines/documentation-publications-and-data/under-study-list)) for the up-to-date list.*

### Agents

gram negative bacterial endotoxin  
(1-3) beta, D-glucan

A black rectangular box containing the white text "BDAC" oriented vertically.

## CAS NUMBER INDEX

50-00-0	Formaldehyde
50-29-3	DDT (Dichlorodiphenyltrichloroethane)
50-32-8	Benzo[a]pyrene
50-78-2	Acetylsalicylic acid (Aspirin)
52-68-6	Trichlorphon
54-11-5	Nicotine
55-38-9	Fenthion
55-63-0	Nitroglycerin
56-23-5	Carbon tetrachloride (Tetrachloromethane)
56-38-2	Parathion
56-55-3	Benz[a]anthracene
56-72-4	Coumaphos
56-81-5	Glycerin mist [see Appendix G]
57-11-4	Stearic acid [see Stearates]
57-14-7	1,1-Dimethylhydrazine
57-24-9	Strychnine
57-50-1	Sucrose
57-57-8	$\beta$ -Propiolactone
57-74-9	Chlordane
58-89-9	Lindane ( $\gamma$ -Hexachlorocyclohexane)
60-29-7	Ethyl ether (Diethyl ether)
60-34-4	Methylhydrazine
60-35-5	Acetamide
60-57-1	Dieldrin
61-82-5	Amitrole (3-Amino-1,2,4-triazole)
62-53-3	Aniline
62-73-7	Dichlorvos
62-74-8	Sodium fluoroacetate
62-75-9	N-Nitrosodimethylamine (N,N-Dimethyl-nitrosoamine)
63-25-2	Carbaryl
64-17-5	Ethanol (Ethyl alcohol)
64-18-6	Formic acid
64-19-7	Acetic acid
67-56-1	Methanol (Methyl alcohol)
67-63-0	2-Propanol (Isopropanol; Isopropyl alcohol)
67-64-1	Acetone
67-66-3	Chloroform (Trichloromethane)
67-72-1	Hexachloroethane
68-11-1	Thioglycolic acid
68-12-2	Dimethylformamide
71-23-8	n-Propanol (n-Propyl alcohol)
71-36-3	n-Butanol (n-Butyl alcohol)
71-43-2	Benzene
71-55-6	Methyl chloroform (1,1,1-Trichloroethane)

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72-20-8	Endrin
72-43-5	Methoxychlor
74-82-8	Methane
74-83-9	Methyl bromide
74-84-0	Ethane
74-85-1	Ethylene
74-86-2	Acetylene [see Appendix G]
74-87-3	Methyl chloride
74-88-4	Methyl iodide
74-89-5	Methylamine
74-90-8	Hydrogen cyanide
74-93-1	Methyl mercaptan (Methanethiol)
74-96-4	Ethyl bromide (Bromoethane)
74-97-5	Chlorobromomethane (Bromochloromethane)
74-98-6	Propane
74-99-7	Methylacetylene (Propyne)
75-00-3	Ethyl chloride (Chloroethane)
75-01-4	Vinyl chloride (Chloroethylene)
75-02-5	Vinyl fluoride
75-04-7	Ethylamine
75-05-8	Acetonitrile
75-07-0	Acetaldehyde
75-08-1	Ethyl mercaptan (Ethanethiol)
75-09-2	Dichloromethane (Methylene chloride)
75-12-7	Formamide
75-15-0	Carbon disulfide
75-18-3	Dimethyl sulfide
75-21-8	Ethylene oxide
75-25-2	Bromoform (Tribromomethane)
75-28-5	Isobutane [see Butane, isomers]
75-31-0	Isopropylamine
75-34-3	1,1-Dichloroethane (Ethylidene chloride)
75-35-4	Vinylidene chloride (1,1-Dichloroethylene)
75-38-7	Vinylidene fluoride (1,1-Difluoroethylene)
75-43-4	Dichlorofluoromethane
75-44-5	Phosgene (Carbonyl chloride)
75-45-6	Chlorodifluoromethane
75-47-8	Iodoform
75-50-3	Trimethylamine
75-52-5	Nitromethane
75-55-8	Propyleneimine (2-Methylaziridine)
75-56-9	Propylene oxide (1,2-Epoxypropane)
75-61-6	Difluorodibromomethane

## CAS NUMBER INDEX

75-63-8	Trifluorobromomethane (Bromotrifluoromethane)
75-65-0	tert-Butanol (tert-Butyl alcohol)
75-69-4	Trichlorofluoromethane (Fluorotrichloromethane)
75-71-8	Dichlorodifluoromethane
75-74-1	Tetramethyl lead
75-83-2	2,2-Dimethyl butane [see Hexane, isomers]
75-86-5	Acetone cyanohydrin
75-91-2	tert-Butyl hydroperoxide
75-99-0	2,2-Dichloropropionic acid
76-03-9	Trichloroacetic acid
76-06-2	Chloropicrin (Nitrotrichloromethane; Trichloronitromethane)
76-11-9	1,1,1,2-Tetrachloro-2,2-difluoroethane
76-12-0	1,1,2,2-Tetrachloro-1,2-difluoroethane
76-13-1	1,1,2-Trichloro-1,2,2-trifluoroethane
76-14-2	Dichlorotetrafluoroethane
76-15-3	Chloropentafluoroethane
76-22-2	Camphor, synthetic
76-44-8	Heptachlor
77-47-4	Hexachlorocyclopentadiene
77-73-6	Dicyclopentadiene
77-78-1	Dimethyl sulfate
78-00-2	Tetraethyl lead
78-10-4	Ethyl silicate (Silicic acid, tetraethyl ester)
78-30-8	Triorthocresyl phosphate
78-32-0	Triparacresyl phosphate
78-34-2	Dioxathion
78-59-1	Isophorone
78-78-4	Isopentane [see Pentane, all isomers]
78-83-1	Isobutanol (Isobutyl alcohol)
78-87-5	Propylene dichloride (1,2-Dichloropropane)
78-89-7	2-Chloro-1-propanol
78-92-2	sec-Butanol (sec-Butyl alcohol)
78-93-3	Methyl ethyl ketone (2-Butanone)
78-94-4	Methyl vinyl ketone (3-Buten-2-one)
78-95-5	Chloroacetone
79-00-5	1,1,2-Trichloroethane
79-01-6	Trichloroethylene
79-04-9	Chloroacetyl chloride
79-06-1	Acrylamide
79-09-4	Propionic acid
79-10-7	Acrylic acid

## CAS NUMBER INDEX

79-11-8	Monochloroacetic acid
79-20-9	Methyl acetate
79-21-0	Peracetic acid
79-24-3	Nitroethane
79-27-6	1,1,2,2-Tetrabromoethane (Acetylene tetrabromide)
79-29-8	2,3-Dimethyl butane [see Hexane, isomers]
79-34-5	1,1,2,2-Tetrachloroethane (Acetylene tetrachloride)
79-41-4	Methacrylic acid
79-43-6	Dichloroacetic acid
79-44-7	Dimethyl carbamoyl chloride
79-46-9	2-Nitropropane
80-51-3	p,p'-Oxybis(benzenesulfonyl hydrazide)
80-56-8	$\alpha$ -Pinene [see Turpentine and selected monoterpenes]
80-62-6	Methyl methacrylate (Methacrylic acid; methyl ester)
81-81-2	Warfarin
82-68-8	Pentachloronitrobenzene
83-26-1	Pindone (2-Pivalyl-1,3-indandione)
83-79-4	Rotenone, commercial
84-66-2	Diethyl phthalate
84-74-2	Dibutyl phthalate
85-00-7	Diquat dibromide [see Diquat]
85-42-7	Hexahydrophthalic anhydride
85-44-9	Phthalic anhydride
86-50-0	Azinphos-methyl
86-88-4	ANTU ( $\alpha$ -Naphthylthiourea)
87-68-3	Hexachlorobutadiene
87-86-5	Pentachlorophenol
88-12-0	N-Vinyl-2-pyrrolidone
88-72-2	o-Nitrotoluene
88-89-1	Picric acid (2,4,6-Trinitrophenol)
89-72-5	o-sec-Butylphenol
90-04-0	o-Anisidine
90-12-0	1-Methyl naphthalene
91-08-7	Toluene-2,6-diisocyanate
91-15-6	o-Phthalodinitrile
91-20-3	Naphthalene
91-57-6	2-Methyl naphthalene
91-59-8	$\beta$ -Naphthylamine
91-94-1	3,3'-Dichlorobenzidine
92-52-4	Biphenyl (Diphenyl)
92-67-1	4-Aminodiphenyl

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92-84-2	Phenothiazine
92-87-5	Benzidine
92-93-3	4-Nitrodiphenyl (4-Nitrobiphenyl)
93-76-5	2,4,5-T (2,4,5-Trichlorophenoxyacetic acid)
94-36-0	Benzoyl peroxide (Dibenzoyl peroxide)
94-75-7	2,4-D (2,4-Dichlorophenoxyacetic acid)
95-13-6	Indene
95-47-6	o-Xylene (1,2-Dimethylbenzene) [see Xylene]
95-48-7	o-Cresol [see Cresol, all isomers]
95-49-8	o-Chlorotoluene
95-50-1	o-Dichlorobenzene (1,2-Dichlorobenzene)
95-53-4	o-Toluidine
95-54-5	o-Phenylenediamine
95-65-8	3,4-Dimethylphenol [see Dimethylphenol, all isomers]
95-87-4	2,5-Dimethylphenol [see Dimethylphenol, all isomers]
96-05-9	Allyl methacrylate
96-09-3	Styrene oxide
96-14-0	3-Methyl pentane [see Hexane, isomers]
96-18-4	1,2,3-Trichloropropane
96-22-0	Diethyl ketone
96-33-3	Methyl acrylate (Acrylic acid methyl ester)
96-69-5	4,4'-Thiobis(6-tert-butyl-m-cresol)
97-77-8	Disulfiram
98-00-0	Furfuryl alcohol
98-01-1	Furfural
98-07-7	Benzotrichloride
98-51-1	p-tert-Butyltoluene
98-73-7	4-tert-Butylbenzoic acid
98-82-8	Cumene
98-83-9	$\alpha$ -Methylstyrene
98-86-2	Acetophenone
98-88-4	Benzoyl chloride
98-95-3	Nitrobenzene
99-08-1	m-Nitrotoluene
99-55-8	5-Nitro-o-toluimide
99-65-0	m-Dinitrobenzene [see Dinitrobenzene, all isomers]
99-99-0	p-Nitrotoluene
100-00-5	p-Nitrochlorobenzene

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100-01-6	p-Nitroaniline
100-21-0	Terephthalic acid
100-25-4	p-Dinitrobenzene [see Dinitrobenzene, all isomers]
100-37-8	2-Diethylaminoethanol
100-40-3	Vinyl cyclohexene
100-41-4	Ethylbenzene
100-42-5	Styrene, monomer (Phenylethylene; Vinyl benzene)
100-44-7	Benzyl chloride
100-61-8	N-Methylaniline (Monomethyl aniline)
100-63-0	Phenylhydrazine
100-74-3	N-Ethylmorpholine
100-97-0	Hexamethylenetetramine
101-14-4	4,4'-Methylene bis(2-chloroaniline)
101-68-8	Methylene bisphenyl isocyanate
101-77-9	4,4'-Methylenedianiline (4,4'- Diaminodiphenyl-methane)
101-84-8	Phenyl ether
102-54-5	Dicyclopentadienyl iron (Ferrocene)
102-71-6	Triethanolamine
102-81-8	2-N-Dibutylaminoethanol
103-71-9	Phenyl isocyanate
104-94-9	p-Anisidine
105-46-4	sec-Butyl acetate [see Appendix G]
105-60-2	Caprolactam
105-67-9	2,4-Dimethylphenol [see Dimethylphenol, all isomers]
106-35-4	Ethyl butyl ketone (3-Heptanone)
106-42-3	p-Xylene (1,4-Dimethylbenzene) [see Xylene]
106-44-5	p-Cresol [see Cresol, all isomers]
106-46-7	p-Dichlorobenzene (1,4-Dichlorobenzene)
106-49-0	p-Toluidine
106-50-3	p-Phenylenediamine
106-51-4	Quinone (p-Benzoquinone)
106-87-6	Vinyl cyclohexene dioxide
106-89-8	Epichlorohydrin (1-Chloro-2, 3-epoxypropane)
106-92-3	Allyl glycidyl ether
106-93-4	Ethylene dibromide (1,2-Dibromoethane)
106-94-5	1-Bromopropane
106-95-6	Allyl bromide
106-97-8	Butane
106-98-9	n-Butene [see Butenes, all isomers]



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106-99-0	1,3-Butadiene
107-01-7	2-Butene (mixture of trans- and cis- isomers) [see Butenes, all isomers]
107-02-8	Acrolein
107-05-1	Allyl chloride
107-06-2	Ethylene dichloride (1,2-Dichloroethane)
107-07-3	Ethylene chlorohydrin (2-Chloroethanol)
107-13-1	Acrylonitrile (Vinyl cyanide)
107-15-3	Ethylenediamine (1,2-Diaminoethane)
107-18-6	Allyl alcohol
107-19-7	Propargyl alcohol
107-20-0	Chloroacetaldehyde
107-21-1	Ethylene glycol
107-22-2	Glyoxal
107-30-2	Chloromethyl methyl ether (Methyl chloromethyl ether; Monochlorodimethyl ether)
107-31-3	Methyl formate (Formic acid methyl ester)
107-41-5	Hexylene glycol
107-49-3	Tetraethyl pyrophosphate
107-66-4	Dibutyl phosphate
107-83-5	2-Methyl pentane [see Hexane, isomers]
107-87-9	Methyl propyl ketone (2-Pentanone)
107-98-2	1-Methoxy-2-propanol (Propylene glycol monomethyl ether)
108-03-2	1-Nitropropane
108-05-4	Vinyl acetate
108-08-7	2,4-Dimethylpentane [see Heptane, isomers]
108-10-1	Methyl isobutyl ketone (Hexone)
108-11-2	Methyl isobutyl carbinol (Methyl amyl alcohol; 4-Methyl-2-pentanol)
108-18-9	Diisopropylamine
108-20-3	Isopropyl ether
108-21-4	Isopropyl acetate [see Appendix G]
108-24-7	Acetic anhydride
108-31-6	Maleic anhydride
108-38-3	m-Xylene (1,3-Dimethylbenzene) [see Xylene]
108-39-4	m-Cresol [see Cresol, all isomers]
108-44-1	m-Toluidine
108-45-2	m-Phenylenediamine
108-46-3	Resorcinol

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108-68-9	3,5-Dimethylphenol [see Dimethylphenol, all isomers]
108-83-8	Diisobutyl ketone (2,6-Dimethyl-4-heptanone)
108-84-9	sec-Hexyl acetate
108-87-2	Methylcyclohexane
108-88-3	Toluene (Toluol)
108-90-7	Chlorobenzene (Monochlorobenzene)
108-91-8	Cyclohexylamine
108-93-0	Cyclohexanol
108-94-1	Cyclohexanone
108-95-2	Phenol
108-98-5	Phenyl mercaptan
109-59-1	2-Isopropoxyethanol (Ethylene glycol isopropyl ether)
109-60-4	n-Propyl acetate [see Appendix G]
109-63-7	Boron trifluoride diethyl ether [see Boron trifluoride ethers]
109-66-0	Pentane
109-73-9	n-Butylamine
109-79-5	Butyl mercaptan (Butanethiol)
109-86-4	2-Methoxyethanol
109-87-5	Methylal (Dimethoxymethane)
109-89-7	Diethylamine
109-90-0	Ethyl isocyanate
109-94-4	Ethyl formate (Formic acid ethyl ester)
109-99-9	Tetrahydrofuran
110-12-3	Methyl isoamyl ketone
110-19-0	Isobutyl acetate [see Appendix G]
110-43-0	Methyl n-amyl ketone (2-Heptanone)
110-49-6	2-Methoxyethyl acetate
110-54-3	n-Hexane
110-62-3	n-Valeraldehyde
110-80-5	2-Ethoxyethanol
110-82-7	Cyclohexane
110-83-8	Cyclohexene
110-85-0	Piperazine and salts
110-86-1	Pyridine
110-91-8	Morpholine
111-15-9	2-Ethoxyethyl acetate
111-30-8	Glutaraldehyde
111-40-0	Diethylenetriamine
111-42-2	Diethanolamine
111-44-4	Dichloroethyl ether
111-65-9	n-Octane
111-69-3	Adiponitrile

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111-76-2	2-Butoxyethanol
111-84-2	Nonane
112-07-2	2-Butoxyethyl acetate
112-34-5	Diethylene glycol monobutyl ether
112-55-0	Dodecyl mercaptan
114-26-1	Propoxur
115-07-1	Propylene
115-11-7	Isobutene
115-29-7	Endosulfan
115-77-5	Pentaerythritol
115-86-6	Triphenyl phosphate
115-90-2	Fensulfothion
116-06-3	Aldicarb
116-14-3	Tetrafluoroethylene
116-15-4	Hexafluoropropylene
117-81-7	Di(2-ethylhexyl)phthalate (Di-sec-octyl phthalate)
118-52-5	1,3-Dichloro-5,5-dimethylhydantoin
118-74-1	Hexachlorobenzene
118-96-7	2,4,6-Trinitrotoluene
119-93-7	o-Tolidine (3,3'-Dimethylbenzidine)
120-80-9	Catechol (Pyrocatechol)
120-82-1	1,2,4-Trichlorobenzene
121-44-8	Triethylamine
121-45-9	Trimethyl phosphite
121-69-7	Dimethylaniline (N,N-Dimethylaniline)
121-75-5	Malathion
121-82-4	Cyclonite
122-34-9	Simazine
122-39-4	Diphenylamine
122-60-1	Phenyl glycidyl ether
123-19-3	Dipropyl ketone
123-31-9	Hydroquinone (Dihydroxybenzene)
123-38-6	Propionaldehyde
123-39-7	Monomethylformamide
123-42-2	Diacetone alcohol (4-Hydroxy-4-methyl-2-pentanone)
123-51-3	Isoamyl alcohol
123-54-6	2,4-Pentanedione
123-86-4	n-Butyl acetate [see Appendix G]
123-91-1	1,4-Dioxane (Diethylene dioxide)
123-92-2	Isopentyl acetate (Isoamyl acetate) [see Pentyl acetate]
124-04-9	Adipic acid
124-09-4	1,6-Hexanediamine
124-38-9	Carbon dioxide

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124-40-3	.....	Dimethylamine
124-64-1	.....	Tetrakis (hydroxymethyl) phosphonium chloride
126-73-8	.....	Tributyl phosphate
126-98-7	.....	Methylacrylonitrile
126-99-8	.....	$\beta$ -Chloroprene (2-Chloro-1,3-butadiene)
127-00-4	.....	1-Chloro-2-propanol
127-18-4	.....	Tetrachloroethylene (Perchloroethylene)
127-19-5	.....	N,N-Dimethylacetamide
127-91-3	.....	$\beta$ -Pinene [see Turpentine]
128-37-0	.....	Butylated hydroxytoluene (2,6-Di-tert-butyl-p-cresol)
131-11-3	.....	Dimethylphthalate
133-06-2	.....	Captan
133-07-3	.....	Folpet
135-88-6	.....	N-Phenyl- $\beta$ -naphthylamine
136-78-7	.....	Sesone (Sodium-2,4-dichlorophenoxyethyl sulfate)
137-05-3	.....	Methyl 2-cyanoacrylate [see Appendix G]
137-26-8	.....	Thiram
138-22-7	.....	n-Butyl lactate
140-11-4	.....	Benzyl acetate
140-88-5	.....	Ethyl acrylate (Acrylic acid ethyl ester)
141-32-2	.....	n-Butyl acrylate (Acrylic acid, n-Butyl ester)
141-43-5	.....	Ethanolamine (2-Aminoethanol)
141-66-2	.....	Dicrotophos
141-78-6	.....	Ethyl acetate
141-79-7	.....	Mesityl oxide
142-64-3	.....	Piperazine dihydrochloride [see Appendix G]
142-82-5	.....	Heptane, isomers (n-Heptane)
143-33-9	.....	Sodium cyanide [see Hydrogen cyanide and cyanide salts, as CN]
144-62-7	.....	Oxalic acid, anhydrous
148-01-6	.....	3,5-Dinitro-o-toluamide (Dinitolmide)
149-57-5	.....	2-Ethylhexanoic acid
150-76-5	.....	4-Methoxyphenol
151-50-8	.....	Potassium cyanide [see Hydrogen cyanide and cyanide salts, as CN]
151-56-4	.....	Ethyleneimine
151-67-7	.....	Halothane
156-59-2	.....	1,2-Dichloroethene, cis- isomer
156-60-5	.....	1,2-Dichloroethene, trans- isomer
156-62-7	.....	Calcium cyanamide
205-99-2	.....	Benzo[b]fluoranthene
218-01-9	.....	Chrysene

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287-92-3	Cyclopentane
298-00-0	Methyl parathion
298-02-2	Phorate
298-04-4	Disulfoton
299-84-3	Ronnel
299-86-5	Crufomate
300-76-5	Naled (Dibrom)
302-01-2	Hydrazine
309-00-2	Aldrin
314-40-9	Bromacil
330-54-1	Diuron
333-41-5	Diazinon
334-88-3	Diazomethane
353-42-4	Boron trifluoride dimethyl ether [see Boron trifluoride ethers]
353-50-4	Carbonyl fluoride
382-21-8	Perfluoroisobutylene
409-21-2	Silicon carbide
420-04-2	Cyanamide
431-03-8	Diacetyl
460-19-5	Cyanogen
463-51-4	Ketene
463-58-1	Carbonyl sulfide
463-82-1	Neopentane
479-45-8	Tetryl (2,4,6-Trinitrophenylmethyl- nitramine)
504-29-0	2-Aminopyridine
506-68-3	Cyanogen bromide
506-77-4	Cyanogen chloride
509-14-8	Tetranitromethane
526-75-0	2,3-Dimethylphenol [see Dimethylphenol, all isomers]
528-29-0	o-Dinitrobenzene [see Dinitrobenzene, all isomers]
532-27-4	2-Chloroacetophenone (Phenacyl chloride)
534-52-1	4,6-Dinitro-o-cresol
540-59-0	1,2-Dichloroethylene, sym- isomer (Acetylene dichloride)
540-84-1	Isooctane (2,2,4-Trimethylpentane) [see Octane, all isomers]
540-88-5	tert-Butyl acetate [see Appendix G]
541-85-5	Ethyl amyl ketone (5-Methyl-3- heptanone)
542-56-3	Isobutyl nitrite

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542-75-6	1,3-Dichloropropene
542-88-1	bis(Chloromethyl) ether
542-92-7	Cyclopentadiene [see Appendix G]
552-30-7	Trimellitic anhydride
556-52-5	Glycidol (2,3-Epoxy-1-propanol)
557-04-0	Magnesium stearates [see Stearates]
557-05-1	Zinc stearates [see Stearates]
558-13-4	Carbon tetrabromide
563-04-2	Trimetacresyl phosphate
563-12-2	Ethion
563-80-4	Methyl isopropyl ketone
565-59-3	2,3-Dimethylpentane [see Heptane, isomers]
576-26-1	2,6-Dimethylphenol [see Dimethylphenol, all isomers]
583-60-8	o-Methylcyclohexanone
584-84-9	Toluene-2,4-diisocyanate (TDI)
589-34-4	3-Methylhexane [see Hexane, isomers]
590-18-1	cis-2-Butene
590-35-2	2,2-Dimethylpentane [see Heptane, isomers]
591-76-4	2-Methylhexane [see Heptane, isomers]
591-78-6	Methyl n-butyl ketone (2-Hexanone)
592-01-8	Calcium cyanide [see Hydrogen cyanide and cyanide salts, as CN]
592-41-6	1-Hexene
593-60-2	Vinyl bromide
594-42-3	Perchloromethyl mercaptan
594-72-9	1,1-Dichloro-1-nitroethane
598-78-7	2-Chloropropionic acid
600-25-9	1-Chloro-1-nitropropane
620-11-1	3-Pentyl acetate [see Pentyl acetate, all isomers]
624-41-9	2-Methylbutyl acetate [see Pentyl acetate, all isomers]
624-64-6	trans-2-Butene
624-83-9	Methyl isocyanate
624-92-0	Dimethyl disulfide
625-16-1	1,1-Dimethylpropyl acetate (tert-Amyl acetate) [see Pentyl acetate, all isomers]
626-17-5	m-Phthalodinitrile
626-38-0	2-Pentyl acetate (sec-Amyl acetate)
627-13-4	n-Propyl nitrate
628-63-7	1-Pentyl acetate (n-Amyl acetate)
628-96-6	Ethylene glycol dinitrate

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630-08-0	Carbon monoxide
637-92-3	Ethyl tert-butyl ether
638-21-1	Phenylphosphine
643-79-8	o-Phthalaldehyde
646-06-0	1,3-Dioxolane
680-31-9	Hexamethyl phosphoramidate
681-84-5	Methyl silicate
684-16-2	Hexafluoroacetone
764-41-0	1,4-Dichloro-2-butene
768-52-5	N-Isopropylaniline
822-06-0	Hexamethylene diisocyanate
822-16-2	Sodium stearates [see Stearates]
919-86-8	Demeton-S-methyl
944-22-9	Fonofos
994-05-8	tert-Amyl methyl ether
999-61-1	2-Hydroxypropyl acrylate
1024-57-3	Heptachlor epoxide
1120-71-4	Propane sultone
1189-85-1	tert-Butyl chromate
1300-71-6	Dimethylphenol (mixed isomers)
1300-73-8	Xylidine, mixed isomers (Dimethylaminobenzene)
1303-00-0	Gallium arsenide
1303-86-2	Boron oxide
1303-96-4	Sodium tetraborate, decahydrate [see Borate compounds, inorganic]
1304-82-1	Bismuth telluride
1305-62-0	Calcium hydroxide
1305-78-8	Calcium oxide
1309-37-1	Iron oxide (Fe <sub>2</sub> O <sub>3</sub> )
1309-48-4	Magnesium oxide
1309-64-4	Antimony trioxide, production
1310-58-3	Potassium hydroxide
1310-73-2	Sodium hydroxide
1314-13-2	Zinc oxide
1314-61-0	Tantalum oxide [see Appendix G]
1314-62-1	Vanadium pentoxide
1314-80-3	Phosphorus pentasulfide
1317-95-9	Silica, crystalline — tripoli
1319-77-3	Cresol, all isomers
1321-64-8	Pentachloronaphthalene
1321-65-9	Trichloronaphthalene
1321-74-0	Divinylbenzene
1330-20-7	Xylene, mixed isomers (Dimethylbenzene)

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1330-43-4 .....	Sodium tetraborate, anhydrous [see Borate compounds, inorganic]
1332-21-4 .....	Asbestos
1332-58-7 .....	Kaolin
1333-74-0 .....	Hydrogen
1333-86-4 .....	Carbon black
1335-87-1 .....	Hexachloronaphthalene
1335-88-2 .....	Tetrachloronaphthalene
1338-23-4 .....	Methyl ethyl ketone peroxide
1344-95-2 .....	Calcium silicate [see Appendix G for Calcium silicate, synthetic nonfibrous]
1395-21-7 .....	Subtilisins (proteolytic enzymes)
1477-55-0 .....	m-Xylene $\alpha,\alpha'$ -diamine
1563-66-2 .....	Carbofuran
1569-02-4 .....	Propylene glycol ethyl ether
1634-04-4 .....	Methyl tert-butyl ether
1910-42-5 .....	Paraquat dichloride [see Paraquat]
1912-24-9 .....	Atrazine
1918-02-1 .....	Picloram
1929-82-4 .....	Nitrapyrin (2-Chloro-6-(trichloromethyl)-pyridine)
2039-87-4 .....	o-Chlorostyrene
2074-50-2 .....	Paraquat dimethyl sulfate [see Paraquat]
2104-64-5 .....	EPN
2179-59-1 .....	Allyl propyl disulfide
2234-13-1 .....	Octachloronaphthalene
2238-07-5 .....	Diglycidyl ether
2425-06-1 .....	Captafol
2426-08-6 .....	n-Butyl glycidyl ether
2451-62-9 .....	1,3,5-Triglycidyl-s-triazinetriene
2528-36-1 .....	Dibutyl phenyl phosphate
2551-62-4 .....	Sulfur hexafluoride
2687-91-4 .....	N-Ethyl-2-pyrrolidone
2698-41-1 .....	o-Chlorobenzylidene malononitrile
2699-79-8 .....	Sulfuryl fluoride
2764-72-9 .....	Diquat
2921-88-2 .....	Chlorpyrifos
2971-90-6 .....	Clopidol
3033-62-3 .....	bis(2-Dimethylaminoethyl)ether
3333-52-6 .....	Tetramethyl succinonitrile
3383-96-8 .....	Temephos
3425-89-6 .....	Methyltetrahydrophthalic anhydride isomer [see Methyltetrahydrophthalic anhydride isomers]
3689-24-5 .....	Sulfotepp
3710-84-7 .....	N,N-Diethylhydroxylamine



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3825-26-1	Ammonium perfluorooctanoate
4016-14-2	Isopropyl glycidyl ether
4098-71-9	Isophorone diisocyanate
4170-30-3	Crotonaldehyde
4685-14-7	Paraquat
5124-30-1	Methylene bis(4-cyclohexylisocyanate)
5333-84-6	Methyltetrahydrophthalic anhydride isomer [see Methyltetrahydrophthalic anhydride isomers]
5392-40-5	Citral
5714-22-7	Sulfur pentafluoride
6153-56-6	Oxalic acid, dihydrate
6385-62-2	Diquat dibromide monohydrate [see Diquat]
6423-43-4	Propylene glycol dinitrate
6923-22-4	Monocrotophos
7085-85-0	Ethyl cyanoacrylate [see Appendix G]
7429-90-5	Aluminum
7439-92-1	Lead
7439-96-5	Manganese
7439-97-6	Mercury
7439-98-7	Molybdenum
7440-01-9	Neon
7440-02-0	Nickel
7440-06-4	Platinum
7440-16-6	Rhodium
7440-22-4	Silver
7440-25-7	Tantalum [see Appendix G]
7440-28-0	Thallium
7440-31-5	Tin
7440-33-7	Tungsten
7440-36-0	Antimony
7440-37-1	Argon
7440-38-2	Arsenic
7440-39-3	Barium
7440-41-7	Beryllium
7440-43-9	Cadmium
7440-47-3	Chromium
7440-48-4	Cobalt
7440-50-8	Copper
7440-58-6	Hafnium
7440-59-7	Helium
7440-61-1	Uranium (natural)
7440-65-5	Yttrium
7440-67-7	Zirconium
7440-74-6	Indium

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7446-09-5	Sulfur dioxide
7550-45-0	Titanium tetrachloride
7553-56-2	Iodine
7572-29-4	Dichloroacetylene
7580-67-8	Lithium hydride
7616-94-6	Perchloryl fluoride
7631-90-5	Sodium bisulfite
7637-07-2	Boron trifluoride
7646-85-7	Zinc chloride
7647-01-0	Hydrogen chloride
7664-38-2	Phosphoric acid
7664-39-3	Hydrogen fluoride
7664-41-7	Ammonia
7664-93-9	Sulfuric acid
7681-57-4	Sodium metabisulfite
7697-37-2	Nitric acid
7719-09-7	Thionyl chloride
7719-12-2	Phosphorus trichloride
7722-84-1	Hydrogen peroxide
7726-95-6	Bromine
7727-21-1	Potassium persulfate [see Persulfates, as persulfate]
7727-37-9	Nitrogen
7727-43-7	Barium sulfate
7727-54-0	Ammonium persulfate [see Persulfates, as persulfate]
7758-97-6	Lead chromate
7773-06-0	Ammonium sulfamate
7775-27-1	Sodium persulfate [see Persulfates, as persulfate]
7778-18-9	Calcium sulfate, the anhydrite
7782-41-4	Fluorine
7782-42-5	Graphite (natural)
7782-49-2	Selenium
7782-50-5	Chlorine
7782-65-2	Germanium tetrahydride
7783-06-4	Hydrogen sulfide
7783-07-5	Hydrogen selenide
7783-41-7	Oxygen difluoride
7783-54-2	Nitrogen trifluoride
7783-60-0	Sulfur tetrafluoride
7783-79-1	Selenium hexafluoride
7783-80-4	Tellurium hexafluoride
7784-42-1	Arsine
7786-34-7	Mevinphos
7789-06-2	Strontium chromate [see Appendix G]

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7789-30-2	Bromine pentafluoride
7790-91-2	Chlorine trifluoride
7803-51-2	Phosphine
7803-52-3	Antimony hydride (Stibine)
7803-62-5	Silicon tetrahydride (Silane)
8001-35-2	Chlorinated camphene (Toxaphene)
8002-74-2	Paraffin wax fume
8003-34-7	Pyrethrum
8006-14-2	Natural gas [see Aliphatic hydrocarbon gases]
8006-64-2	Turpentine
8008-20-6	Kerosene
8022-00-2	Methyl demeton (Demeton-methyl)
8029-10-5	Coal dust, Anthracite
8050-09-7	Colophony [see Rosin core solder thermal decomp products]
8052-41-3	Stoddard solvent
8052-42-4	Asphalt (Bitumen) fume
8065-48-3	Demeton
9002-86-2	Polyvinyl chloride
9004-34-6	Cellulose
9005-25-8	Starch
9006-04-6	Natural rubber latex
9014-01-1	Bacillus subtilis [see Subtilisins, as crystalline active enzyme]
10024-97-2	Nitrous oxide
10025-67-9	Sulfur monochloride
10025-87-3	Phosphorus oxychloride
10026-13-8	Phosphorus pentachloride
10028-15-6	Ozone
10034-76-1	Calcium sulfate, the hemihydrate [see Calcium sulfate]
10035-10-6	Hydrogen bromide
10043-35-3	Boric acid [see Borate compounds, inorganic]
10049-04-4	Chlorine dioxide
10101-41-4	Calcium sulfate, the dihydrate [see Calcium sulfate]
10102-43-9	Nitric oxide
10102-44-0	Nitrogen dioxide
10210-68-1	Cobalt carbonyl
10294-33-4	Boron tribromide
10294-34-5	Boron trichloride
11070-44-3	Methyltetrahydrophthalic anhydride

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	[see Methyltetrahydrophthalic anhydride isomers]
11097-69-1 .....	Chlorodiphenyl (54% chlorine)
11103-86-9 .....	Zinc potassium chromate [see Appendix G]
12001-26-2 .....	Mica
12001-28-4 .....	Crocidolite [see Asbestos, all forms]
12001-29-5 .....	Chrysotile [see Asbestos, all forms]
12035-72-2 .....	Nickel subsulfide [see Nickel and inorganic compounds]
12070-12-1 .....	Tungsten carbide [see Hard metals, containing Cobalt and Tungsten carbide]
12079-65-1 .....	Manganese cyclopentadienyl tricarbonyl
12108-13-3 .....	2-Methylcyclopentadienyl manganese tricarbonyl
12125-02-9 .....	Ammonium chloride fume
12172-73-5 .....	Amosite [see Asbestos, all forms]
12179-04-3 .....	Sodium tetraborate, pentahydrate [see Borate compounds, inorganic]
12185-10-3 .....	Phosphorus (yellow)
12604-58-9 .....	Ferrovandium
13071-79-9 .....	Terbufos
13121-70-5 .....	Cyhexatin (Tricyclohexyltin hydroxide)
13149-00-3 .....	Hexahydrophthalic anhydride, cis- isomer
13397-24-5 .....	Calcium sulfate, gypsum [see Calcium sulfate]
13463-39-3 .....	Nickel carbonyl
13463-40-6 .....	Iron pentacarbonyl
13463-67-7 .....	Titanium dioxide
13466-78-9 .....	$\Delta$ -3-Carene [see Turpentine and selected monoterpenes]
13494-80-9 .....	Tellurium
13530-65-9 .....	Zinc chromate [see Appendix G]
13765-19-0 .....	Calcium chromate [see Appendix G]
13838-16-9 .....	Enflurane
14166-21-3 .....	Hexahydrophthalic anhydride, trans- isomer
14464-46-1 .....	Silica, crystalline — cristobalite
14484-64-1 .....	Ferbam
14807-96-6 .....	Talc (nonasbestos form)
14808-60-7 .....	Silica, crystalline — quartz
14857-34-2 .....	Dimethylethoxysilane
14977-61-8 .....	Chromyl chloride [see Appendix G]
15972-60-8 .....	Alachlor

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16219-75-3	Ethylidene norbornene
16752-77-5	Methomyl
16842-03-8	Cobalt hydrocarbonyl
17702-41-9	Decaborane
17804-35-2	Benomyl
19287-45-7	Diborane
19430-93-4	Perfluorobutyl ethylene
19438-63-2	Methyltetrahydrophthalic anhydride isomer [see Methyltetrahydrophthalic anhydride isomers]
19438-64-3	Methyltetrahydrophthalic anhydride isomer [see Methyltetrahydrophthalic anhydride isomers]
19624-22-7	Pentaborane
19624-22-7	Pentaborane
20816-12-0	Osmium tetroxide
21087-64-9	Metribuzin
21351-79-1	Cesium hydroxide
21651-19-4	Tin oxide
21725-46-2	Cyanazine
22224-92-6	Fenamiphos
22781-23-3	Bendiocarb
25013-15-4	Vinyltoluene (Methyl styrene, all isomers)
25154-54-5	Dinitrobenzene, all isomers
25167-67-3	Butene, mixture of isomers
25321-14-6	Dinitrotoluene
25551-13-7	Trimethylbenzene, mixed isomers
25639-42-3	Methylcyclohexanol
26140-60-3	Terphenyls
26590-20-5	Methyltetrahydrophthalic anhydride isomer [see Methyltetrahydrophthalic anhydride isomers]
26628-22-8	Sodium azide
26675-46-7	Isoflurane
26952-21-6	Isooctyl alcohol
31242-93-0	Chlorinated diphenyl oxide
34590-94-8	(2-Methoxymethylethoxy)propanol
35400-43-2	Sulprofos
37300-23-5	Zinc yellow [see Appendix G]
42498-58-8	Methyltetrahydrophthalic anhydride isomer [see Methyltetrahydrophthalic anhydride isomers]
50926-11-9	Indium tin oxide
51235-04-2	Hexazinone
53469-21-9	Chlorodiphenyl (42% chlorine)

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55566-30-8 .....	Tetrakis (hydroxymethyl) phosphonium sulfate
59355-75-8 .....	Methyl acetylene-propadiene mixture
59669-26-0 .....	Thiodicarb
61788-32-7 .....	Hydrogenated terphenyls
64742-81-0 .....	Hydrogenated kerosene [see Kerosene/Jet fuels as total hydrocarbon vapor]
65996-93-2 .....	Coal tar pitch volatiles
65997-15-1 .....	Portland cement
68334-30-5 .....	Diesel oil
68476-30-2 .....	Fuel oil No. 2 [see Diesel fuel as total hydrocarbons]
68476-31-3 .....	Diesel No. 4 [see Diesel fuel as total hydrocarbons]
68476-34-6 .....	Diesel No. 2 [see Diesel fuel as total hydrocarbons]
68476-85-7 .....	L.P.G. (Liquefied petroleum gas)
74222-97-2 .....	Sulfometuron methyl
86290-81-5 .....	Gasoline
95465-99-9 .....	Cadusafos
111988-49-9 .....	Thiacloprid
128639-02-1 .....	Carfentrazone-ethyl
131341-86-1 .....	Fludioxonil
308062-82-0 .....	Coal dust, Bituminous or Lignite
946578-00-3 .....	Sulfoxaflor

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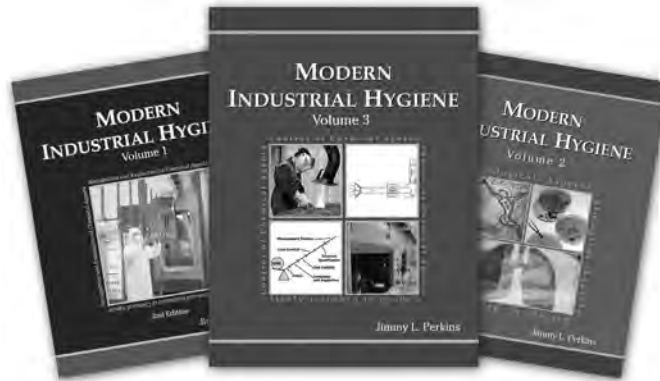
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## NOTES

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## NOTES

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## Endnotes and Abbreviations

- \* 2019 Adoption.
  - ‡ See Notice of Intended Changes (NIC).
  - ( ) Adopted values or notations enclosed are those for which changes are proposed in the NIC.
  - † 2019 Revision or Addition to the Notice of Intended Changes.
  - A Refers to [Appendix A: Carcinogenicity](#).
  - C Ceiling limit; see definition in the “[Introduction to the Chemical Substances](#).”
  - (D) Simple asphyxiant; see discussion covering *Minimal Oxygen Content* found in the “[Definitions and Notations](#)” section following the NIC tables.
  - (E) The value is for particulate matter containing no asbestos and < 1% crystalline silica.
  - (EX) Explosion hazard: the substance is a flammable asphyxiant or excursions above the TLV<sup>®</sup> could approach 10% of the lower explosive limit.
  - (F) Respirable fibers: length > 5 µm; aspect ratio ≥ 3:1, as determined by the membrane filter method at 400–450X magnification (4-mm objective), using phase-contrast illumination.
  - (G) As measured by the vertical elutriator, cotton-dust sampler; see the TLV<sup>®</sup> *Documentation*.
  - (H) Aerosol only.
  - (I) Inhalable particulate matter; see Appendix C, paragraph A.
  - (IFV) Inhalable fraction and vapor; see Notations/Endnotes section, p. 71.
  - (J) Does not include stearates of toxic metals.
  - (K) Should not exceed 2 mg/m<sup>3</sup> respirable particulate matter.
  - (L) Exposure by all routes should be carefully controlled to levels as low as possible.
  - (M) Classification refers to sulfuric acid contained in strong inorganic acid mists.
  - (O) Sampled by method that does not collect vapor.
  - (P) Application restricted to conditions in which there are negligible aerosol exposures.
  - (R) Respirable particulate matter; see [Appendix C](#), paragraph C.
  - (T) Thoracic particulate matter; see Appendix C, paragraph B.
  - (V) Vapor fraction.
- B = Background; see [BEI Intro](#).
- BEI = Substances for which there is a Biological Exposure Index or Indices (see BEI<sup>®</sup> section).
- BEI<sub>C</sub>: see BEI<sup>®</sup> for [Cholinesterase Inhibiting Pesticides](#)
- BEI<sub>M</sub>: see BEI<sup>®</sup> for [Methemoglobin Inducers](#)
- BEI<sub>P</sub>: see BEI<sup>®</sup> for [Polycyclic Aromatic Hydrocarbons \(PAHs\)](#)
- DSEN = Dermal Sensitization; see definition in the “Definitions and Notations” section.
- MW = Molecular weight.
- NOS = Not otherwise specified.
- Nq = Nonquantitative; see BEI Intro.
- Ns = Nonspecific; see BEI Intro.
- RSEN = Respiratory Sensitization; see definition in the “Definitions and Notations” section.
- SEN = Sensitization; see definition in the “Definitions and Notations” section.
- Skin = Danger of cutaneous absorption; see discussion under *Skin* in the “Definitions and Notations” section.
- Sq = Semi-quantitative; see BEI Intro.
- STEL = Short-term exposure limit; see definition in the “Introduction to the Chemical Substances.”
- TWA = 8-hour, time-weighted average; see definition in the “Introduction to the Chemical Substances.”
- ppm = Parts of vapor or gas per million parts of contaminated air by volume at 25°C and 760 torr.
- mg/m<sup>3</sup> = Milligrams of substance per cubic meter of air.

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