Introduction to Physical Agents Recommendations of the ACGIH

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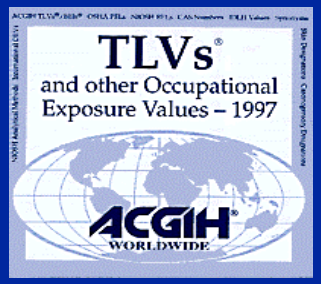
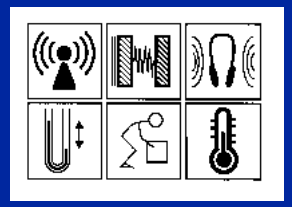
OUTLINE

- Acoustic Radiation, Infrasound, Noise, and Ultrasound
- Vibration
- Ergonomics
- Ionizing Radiation
- Lasers and Non-coherent Optical Radiation
- Non-ionizing Radiation and Fields (0 - 300 GHz)
- Thermal (Heat and Cold Stress)
- Physical agents Under Study



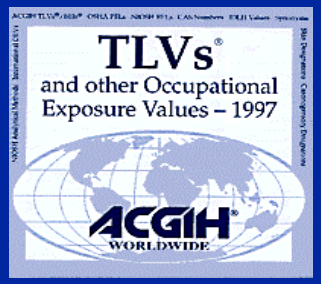
The ACGIH



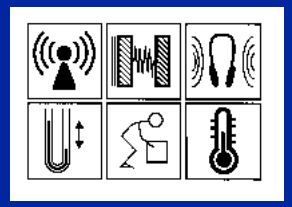
- The American Conference of Governmental Industrial Hygienists (ACGIH), is a professional organization of personnel from governmental agencies and educational institutions which is devoted to the development of administrative and technical aspects of worker health protection, and establishes recommended Threshold Limit Values (TLVs ®) concerning chemical substances and physical agents to which employees may be exposed during the course of their employment.

Introduction to the Physical Agents

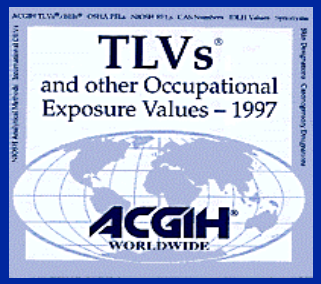
- Threshold Limit Values for Physical Agents are for *occupational exposures*. The physical agent TLVs® refer to levels of exposure and conditions which it is believed that all healthy workers may be repeatedly exposed, day after day, without adverse health effects.
- TLVs® are based on available information from industrial experience, from experimental human and animal studies, and when possible, from a combination of the three.



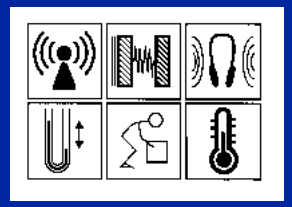
Important Caveat



- **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, 1) in the evaluation and control of the physical agents in the community or 2) as proof or disproof of an existing physical disability.**
- **ACGIH disclaims any liability with respect to the use of TLVs®.**



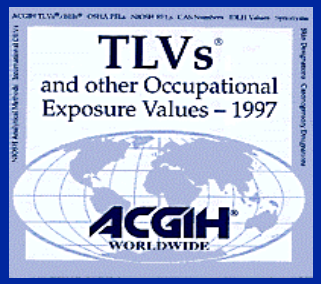
Definitions



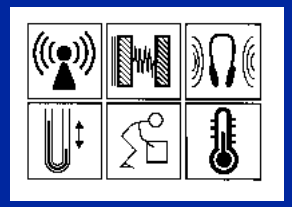
- Threshold Limit Value - Time Weighted Average (TLV-TWA). The time-weighted average exposure for an 8-hour workday and 40-hour workweek.
- Threshold Limit Value - Ceiling (TLV-C). Exposure limit that should not be exceeded even instantaneously.

Infrasound

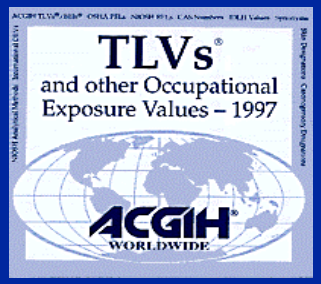
- Infrasound: at certain high levels of sounds, particularly at the lower frequencies, exposed persons may suffer adverse effects that do not involve the hearing organs. These can include annoyance and body discomfort, as well as nausea and other effects.
- Notice of Intended Change (NIC) published, December 1998 - limits are now proposed.



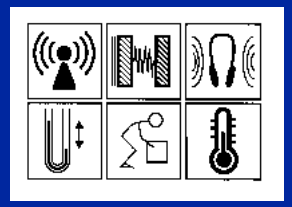
Physics of Sound (1)



- The perception of sound begins when vibration or turbulence causes pressure changes in the air (or in some other medium). These pressure changes produce longitudinal waves that propagate away from the vibrating or turbulent source to the receiver (i.e., human ear) in the form of alternating compression and rarefaction of molecules. The receiver in turn translates these waves into what is known as sound. The effects of sound on the receiver depend on three physical parameters of sound: *amplitude*, *frequency*, and *duration*.



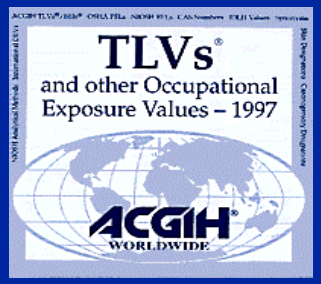
Physics of Sound (2)



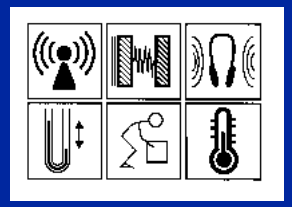
- Sound pressure level (SPL), expressed in decibels (dB), is a measure of the *amplitude* of the pressure change that produces sound. This amplitude is perceived by the listener as loudness. In sound measuring instruments, weighting networks are used to modify the sound pressure level. The A-weighted network is commonly used in measuring noise to evaluate its effect on people. Exposure limits are expressed in decibels, A-weighted network (dBA). When used without a weighted network suffix, the expression "dB" usually implies "dB SPL" (i.e., no network).

Physics of Sound (3)

- Each wave of compression and rarefaction of molecules described above represents a complete cycle. The frequency, in Hertz (Hz), represents the number of cycles occurring in one second, and determines the pitch perceived by the listener. Humans with normal hearing can hear a frequency range of about 20 to 20,000 Hz. An ordinary sound generally contains a mixture of frequencies.



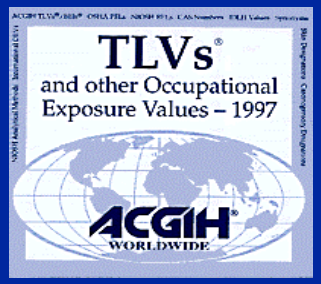
Physics of Sound (4)



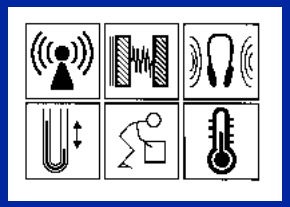
- *Duration* refers to the pattern of sound levels over time. Industrial noise can be arbitrarily classified as continuous, varying, intermittent and impulsive. Lacking quantitative definitions, continuous, varying and intermittent noises together denote a continuum of relatively constant sound levels to noticeably different sound levels occurring within an exposure period (usually an 8-hour workday). For simplicity, when compared with impulsive noise, the term "continuous noise" would normally include continuous, varying and intermittent noises. Impulsive noise is distinguished from continuous noise by a steep rise in sound pressure level to a high peak, followed by a rapid decay, and can be either reverberant (impact noise) or nonreverberant (impulse noise). In many workplaces, the exposures are often a mixture of continuous and impulsive sounds

Concept of Exchange Rate

- An increment of decibels that requires the halving of exposure time, or a decrement of decibels that requires the doubling of exposure time. For examples, a 3-dB exchange rate requires that noise exposure time be halved for each 3-dB increase in noise level; likewise, a 5-dB exchange rate requires that exposure time be halved for each 5-dB increase.

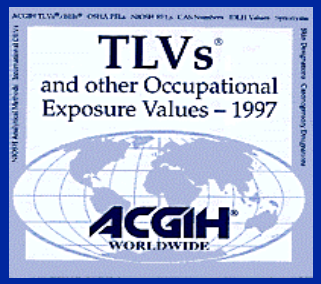


TLVs for Noise

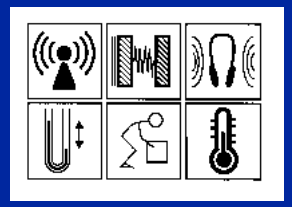


Duration per day (hrs)	Sound Level dBA
24	80
16	82
8	85
4	88
2	91
1	94
0.5	97
0.25	100

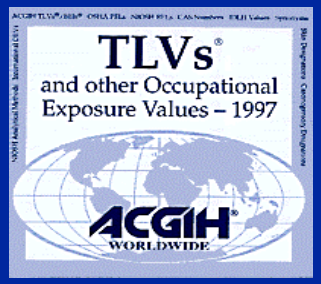
TLV uses a 3 dB exchange rate.



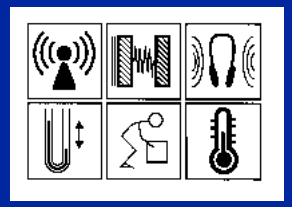
Continuous or Intermittent Noise



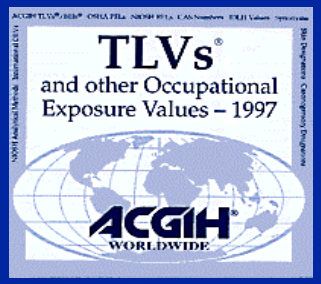
- Daily noise dose (D) is a descriptor for noise exposure, in percent, expressed by the following relationship:
- $D = [C_1/T_1 + C_2/T_2 + ... + C_n/T_n] \times 100$
- C_n = total time of exposure at a specified noise level
- T_n = total time of exposure permitted at that noise level
- If the sum of the fractions is greater than 100%, then the mixed exposure should be considered to exceed the TLV.
- All on-the-job noises exposures of 80 dBA or greater should be used in the above calculation.



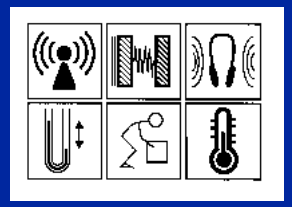
Impact Noise



- No exposure of an unexposed ear in excess of a C-weighted peak sound pressure level of 140 dB should be permitted.
- If instrumentation is not available to measure a C-weighted peak, an unweighted peak measurement below 140 dB may be used to imply that the C-weighted peak is below 140 dB.



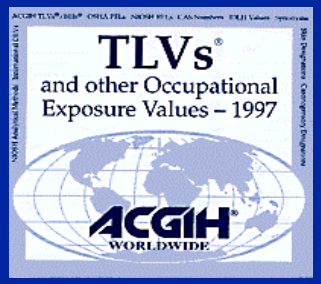
Elements of a Hearing Conservation Program



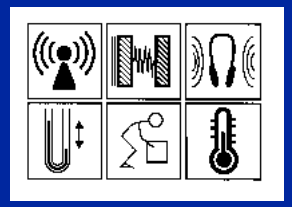
- A hearing conservation program is required workers are exposed to noise at or above the TLV levels
- identification of work areas with a noise hazard
- regular monitoring of noise levels and maintaining of records on noise assessments
- implementation of noise control measures as far as practicable
- provision of proper hearing protectors to workers
- health education of workers on the importance and necessity of using hearing protectors
- annual medical examination, including audiometric tests for the detection of early hearing impairment

NIC for Fetal Exposure

- There is evidence to suggest that noise exposures in excess of a C-weighted, 8 hour TWA of 155 dBC to the abdomen of pregnant workers, beyond the fifth month of pregnancy, may cause hearing loss in the fetus.



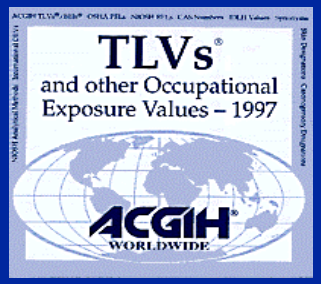
Ultrasound



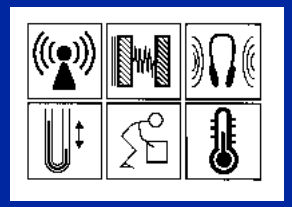
- Ultrasound is acoustic energy which is not audible to humans (10 - 100 kHz).
- TLVs are based on human coupling with water or some other medium.
- Limits can be raised by 30 dB (1000 x) if there is no possibility that the ultrasound can couple with the body through water or some other substrate.

Ultrasound (2)

- Limits are given for head in air or head in water.
- Limits do not apply if the ultrasound source is directly touching the body, in which case a vibrational analysis must be done.
- Ceiling value of 105 dB relative to 20 μPa from 10 to 20 kHz for a head in air, 110 dB for 25 kHz, and 115 dB from 31.5 to 100 kHz.
- Ceiling value of 167 dB relative to 1 μPa from 10 to 20 kHz for a head in water, 172 dB for 25 kHz, and 177 dB from 31.5 to 100 kHz.



Vibration



- Vibration-induced white finger (VWF) is the most common condition among the operators of hand-held vibrating tools. Vibration can cause changes in tendons, muscles, bones and joints, and can affect the nervous system. Collectively, these effects are known as Hand-Arm Vibration Syndrome (HAVS). The symptoms of VWF are aggravated when the hands are exposed to cold.

Vibration (2)

- Workers affected by HAVS commonly report:
- attacks of whitening (blanching) of one or more fingers when exposed to cold
- tingling and loss of sensation in the fingers
- loss of light touch
- pain and cold sensations between periodic white finger attacks
- loss of grip strength
- bone cysts in fingers and wrists
- The development of HAVS is gradual and increases in severity over time. It may take a few months to several years for the symptoms of HAVS to become noticeable.

Vibration (3)

The Stockholm Workshop classification scale for cold-induced vascular (blood flow) symptoms in fingers with hand-arm vibration syndrome

Stage	Grade	Description
0	none	No attacks
1	Mild	Occasional attacks affecting only the tips of one or more fingers
2	Moderate	Occasional attacks affecting finger tips and middle of the finger and rarely also the finger parts close to the palm
3	Severe	Frequent attacks affecting most fingers
4	Very Severe	Same symptoms as in stage 3 with degenerate skin changes in the finger

Source: Gemne, G., et al. *Scandinavian Journal of Work, Environment and Health*. Vol.. 13, no. 4 (1987). p. 275-278.

Vibration (4)

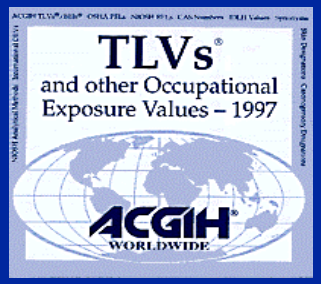
- The TLVs for Hand-Arm (segmental) Vibration Syndrome (HAVS) represent component acceleration levels in m/s^2 and durations of exposure that nearly all workers may be exposed repeatedly without progressing beyond Stage 1 of the Stockholm Workshop Classification System.

Vibration (5)

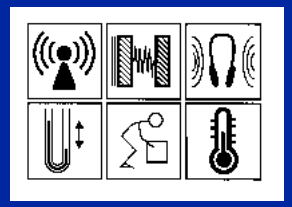
- Whole-body vibration can cause fatigue, insomnia, headache and "shakiness" shortly after or during exposure. The symptoms are similar to those that many people experience after a long car or boat trip. After daily exposure over a number of years, whole-body vibration can affect the entire body and result in a number of health disorders. Sea, air or land vehicles cause motion sickness when the vibration exposure occurs in the 0.1 to 0.6 Hz frequency range. Studies of bus and truck drivers found that occupational exposure to whole-body vibration could have contributed to a number of circulatory, bowel, respiratory, muscular and back disorders. The combined effects of body posture, postural fatigue, dietary habits and whole-body vibration are the possible causes for these disorders.

Vibration (6)

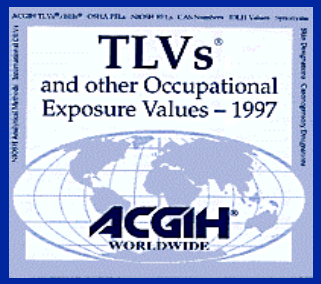
- Studies show that whole-body vibration can increase heart rate, oxygen uptake and respiratory rate, and can produce changes in blood and urine. East European researchers have noted that exposure to whole-body vibration can produce an overall ill feeling which they call "vibration sickness."
- Many studies have reported decreased performance in workers exposed to whole-body vibration.
- The TLV is given in terms of a mechanically induced whole-body vibration acceleration vector in units of m/s^2. Allowable exposure durations as a function of this vector are graphed.



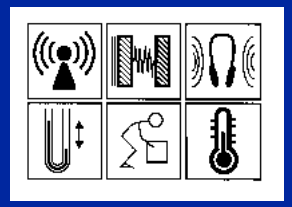
Ergonomics



- Statement on Work-Related Musculoskeletal Disorders encourages the use of an ergonomics health and safety management program.
- This program should recognize the problem, isolate causative factors, include workers as fully informed active participants, and provide competent health care for workers who have developed musculoskeletal disorders.

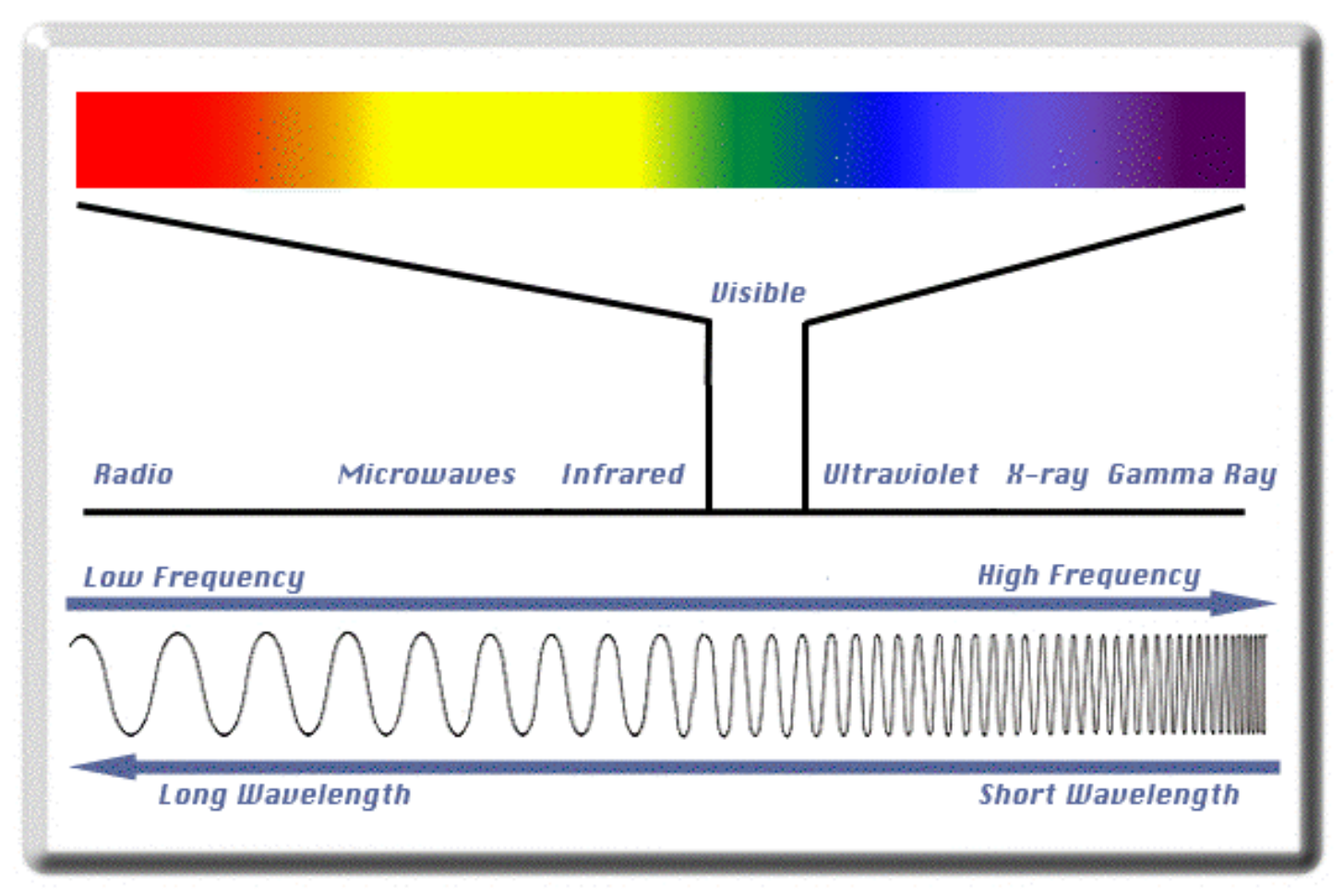


Ionizing Radiation



- The Physical Agents TLV Committee accepts the exposure guidance of the International Commission on Radiological Protection (ICRP) for all particulate and electromagnetic radiation with energy greater than 12.4 eV, approximately corresponding to wavelengths less than 100 nanometers (i.e. the end of the UV spectrum).

The Electromagnetic Spectrum



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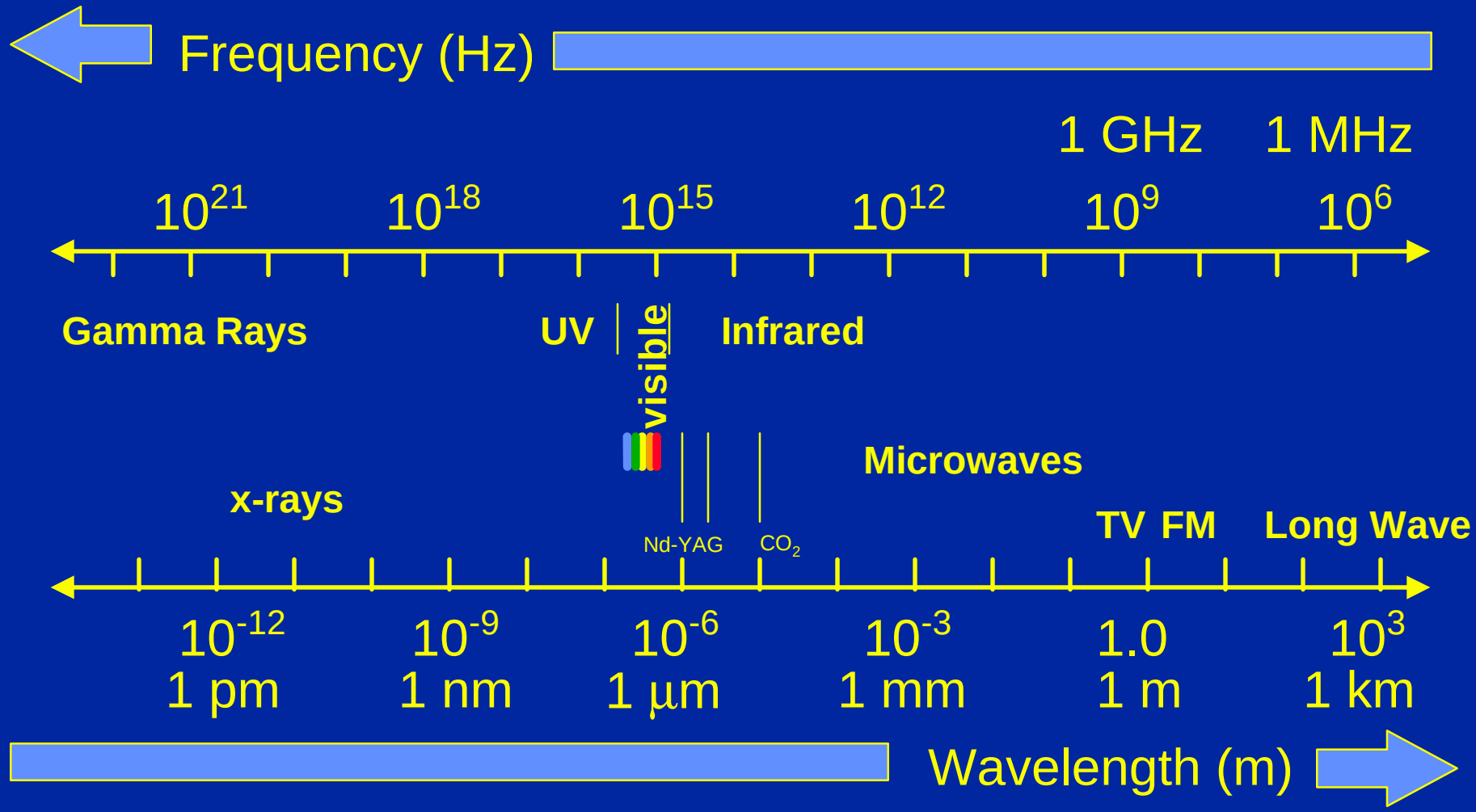
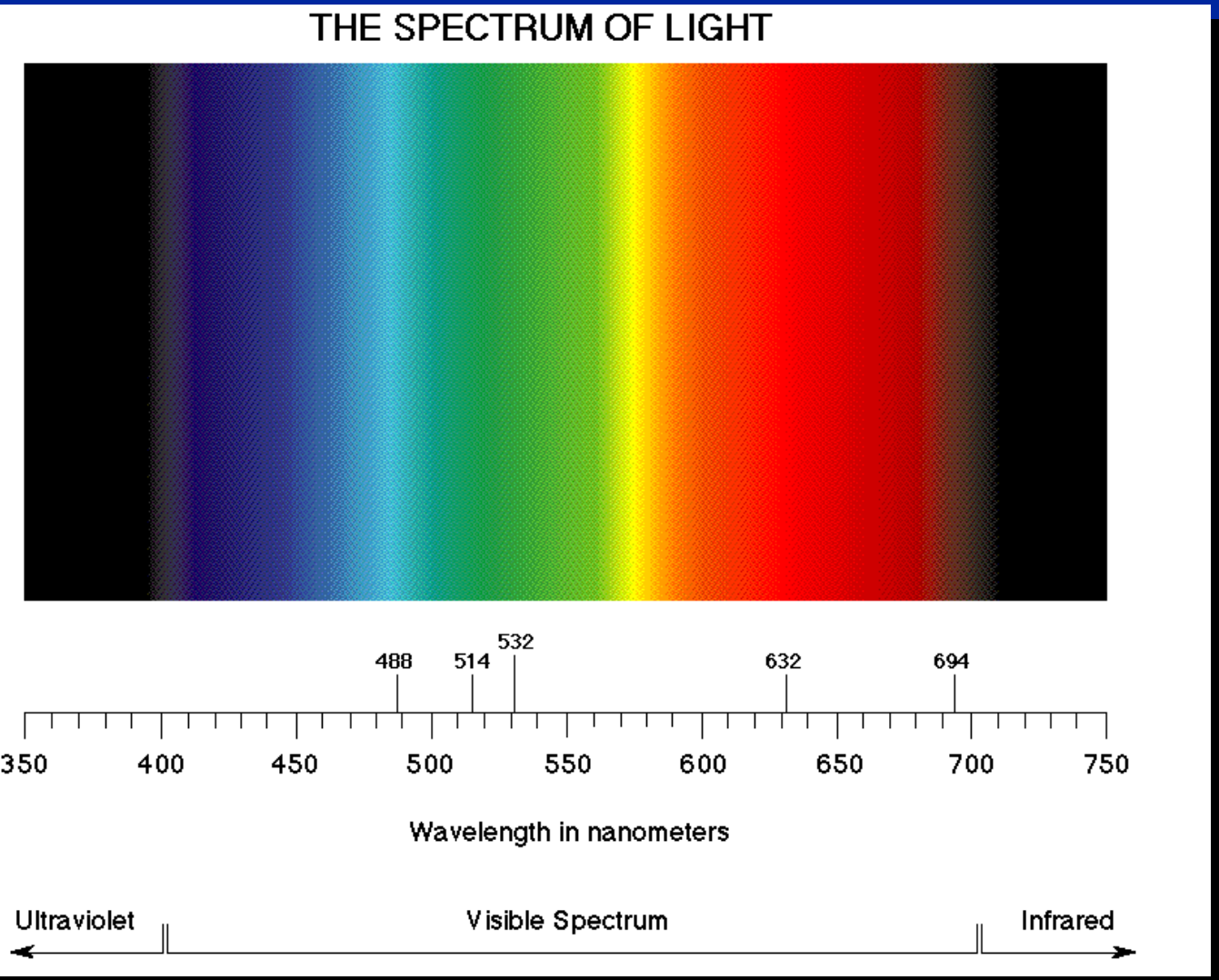


Lasers and Non-Coherent Optical Radiation

- Ultraviolet Radiation has wavelengths for 100 to 400 nm.
- Visible light is 400 to approximately 760 nm
- Infrared is from approximately 760 nm to 1 mm (frequency of 300 GHz).
- Lasers operate in all three of the above.

Optical Radiation Spectrum



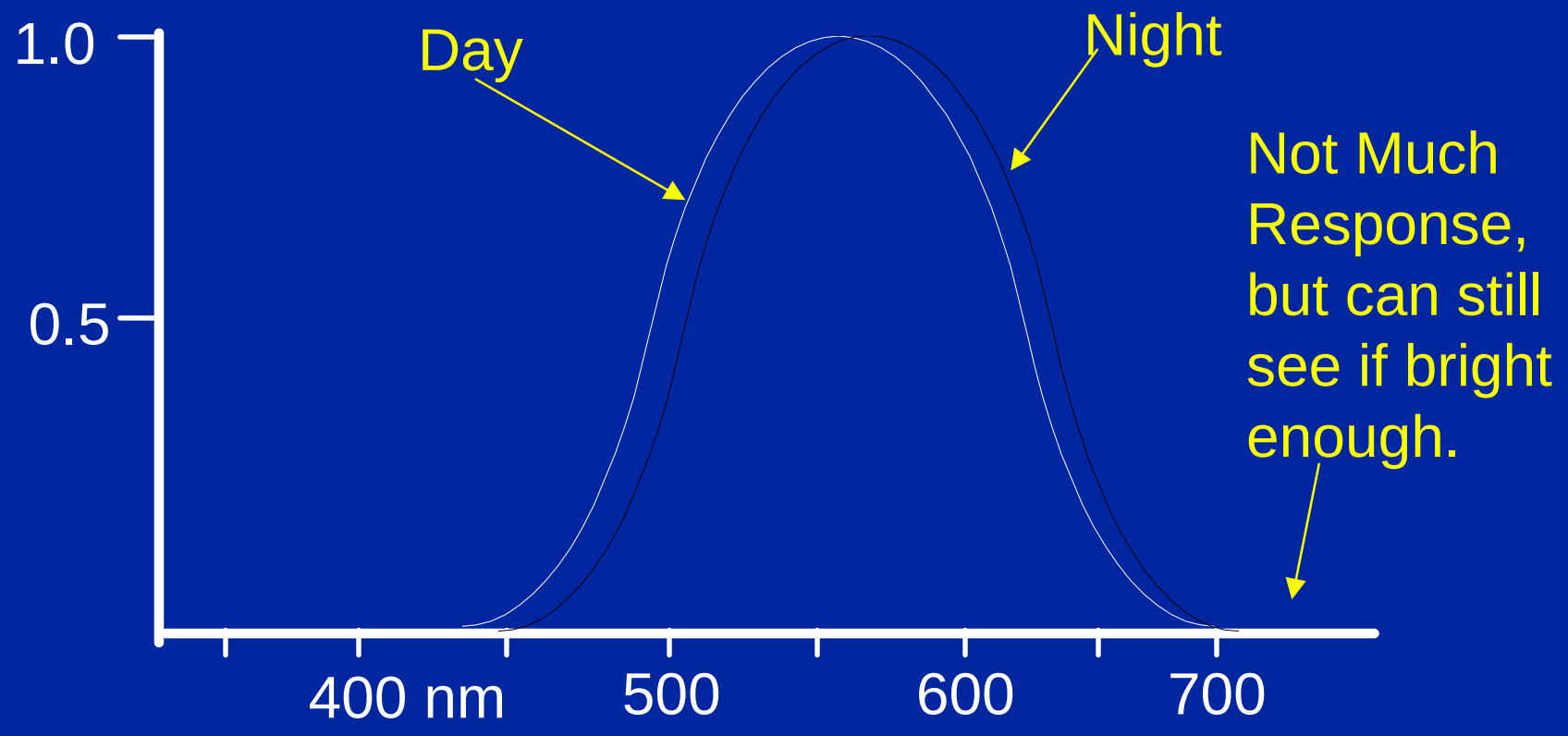
Optical Sources: Units

Units:

- Common Unit for Measurement of the Color or Wavelength for an optical source
  - nm - 1×10^{-9} m (1 billionth of a meter, or a milli-micrometer)
  - µm - 1×10^{-6} m (1 millionth of a meter, a micron)
- Examples:
  - Green Light is approximately 500 nm
  - Nd-YAG laser is 1064 nm or 1.064 µm (infrared)

Human Eye Response

- The Human Eye does not have an equal response over all optical wavelengths:



Ultraviolet Radiation

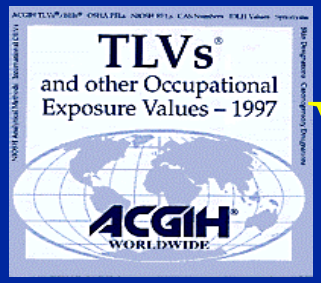
- For a broadband source (180 - 315 nm), use 'effectiveness factors' to account for both eye/skin sensitivity at various wavelengths (based on maximum biological effect at 270 nm):
- Step 1. Calculate the effective irradiance of a broadband source
- $E_{eff} = \Sigma E_{\lambda} S_{\lambda} \Delta\lambda$, where:
- E_{eff} = effective irradiance (W/cm^2) relative to 270 nm
- E_{λ} = spectral irradiance ($W/cm^2 \cdot nm$)
- S_{λ} = relative spectral effectiveness (unitless), $\Delta\lambda$ = bandwidth (nm)

Ultraviolet Radiation (2)

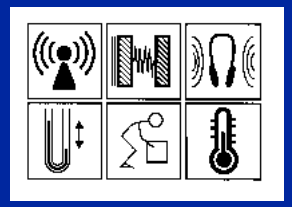
- Step 2. Calculate the permissible exposure time:

- $t = 0.003\ (J/cm^2) / E_{eff}\ (W/cm^2)$

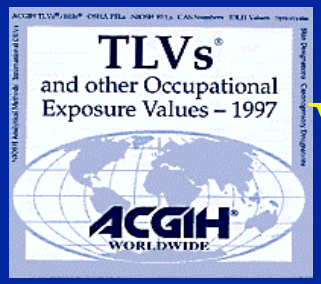
- **UV standard is protective against acute effects such as**
- **erythema and photokeratitis, not necessarily skin cancers!**
- For exposures to the unprotected eye in the UV-A spectral region (313 - 400 nm) an irradiance of 1 mW/cm^2 for times> 10^3 seconds, or a radiant exposure of 1 J/cm^2 for times $< 10^3$ seconds are permitted.



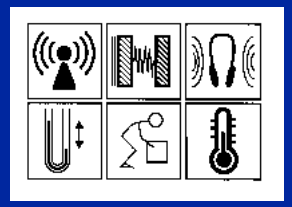
Visible Light and Infrared Radiation



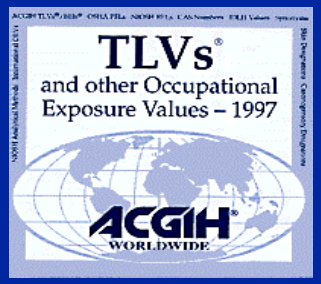
- All visible wavelengths from the sun are transmitted by the atmosphere.
- Welding arcs are sources of broadband visible emission, including blue light, photoflood, metal halide and sunlamps may produce intense visible output rich in blue light.
- Infrared from incandescent sources such as blackbody sources in industry (furnaces and ovens).



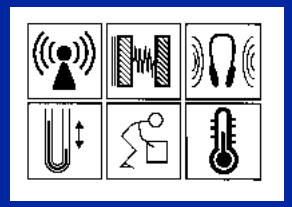
Visible Light and Infrared Radiation (2)



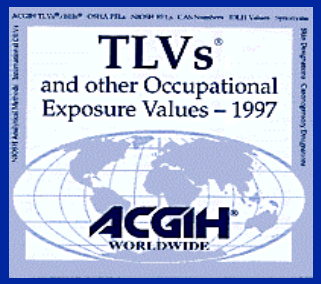
- Intense daylight causes colorblindness, night-vision impairment, and retinal degeneration.
- Chronic “blue light” (400 - 700 nm) exposures cause photochemical injuries, visible and near infrared (400 - 1400 nm) may cause retinal thermal injuries.
- Exposure standards are for protection against thermal, photochemical, and delayed effect of cataractogenesis.
- Formulas in ACGIH TLV Booklet difficult to apply in real life situations.



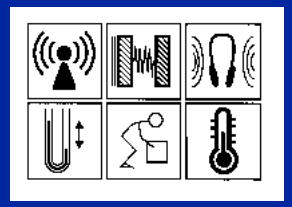
Laser Examples



- Gas Lasers
  - HeNe, Ar, Kr, N, CO_2
  - Laser Light Shows
- Solid State Lasers
  - Nd:YAG, Diodes(GaAs, InGaAs, GaP, InGaP), Ti:Sapphire, Ruby
  - Military Applications
- Chemical Lasers



Common Commercial Laser Applications



- Communications (Fiber Optics)
- Medical Procedures (Surgery, Diagnosis)
- Laser Light Shows
- Material Characterization
- CD Players
- Metal Cutting, Welding
- Paint Removal
- UPC Scanners

Common Military Applications of Lasers

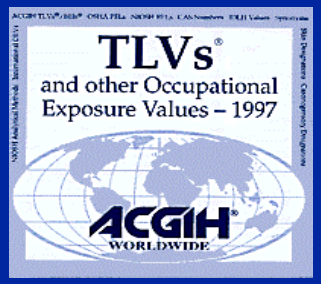
- Rangefinders
- Laser Target Designators
- Illuminators
- LIDAR (Light Detection and Ranging)
- Wind Shear Meters
- Other (High Energy Lasers)

Laser TLVs

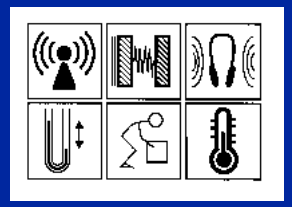
- TLVs are from 30,000 seconds to 10^{-9} seconds are identical to the maximum permissible exposure limits (MPEs) found in ANSI Standard Z136.1 *National Standard for Safe Use of Lasers - 1993.*
- NIC for 1999 includes TLVs for sub nano-second pulses from 10^{-9} to 10^{-14} seconds.

Non-ionizing Radiation and Fields 0 - 300 GHz

- Static Electric and Magnetic Fields
- Sub-Radiofrequency Electric and Magnetic Fields (1 Hz - 30 kHz)
- Radiofrequency and Microwave Radiation (30 kHz - 300 GHz)



Static Electric and Magnetic Fields



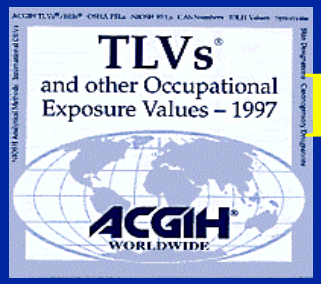
- Maximum ceiling limit for the electric field of 25 kV/m.
- TWA magnetic field daily whole-body exposure: 60 mT (600 Gauss)
- TWA magnetic field daily exposure of limbs: 600 mT (6000 Gauss)
- Ceiling value for whole-body exposure: 2 T (20,000 Gauss)
- Ceiling value for limb exposure: 5 T (50,000 Gauss)
- Ceiling value for exposure of persons wearing cardiac pacemakers of other implanted medical devices is 0.5 mT (5 gauss).

Sub-Radiofrequency Electric Fields (1 Hz - 30 kHz)

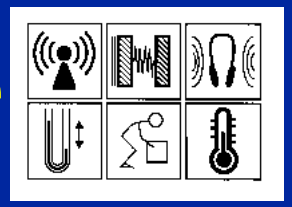
- $0\ \text{Hz} \leq f \leq 100\ \text{Hz}$ $\quad E_{TLV} = 25\ \text{kV/m}$
- $100\ \text{Hz} \leq f \leq 4000\ \text{Hz}$ $\quad E_{TLV} = 2.5 \times 10^6/f$
- $4000\ \text{Hz} \leq f \leq 30\ \text{kHz}$ $\quad E_{TLV} = 625\ \text{V/m}$
- Ceiling value for exposure of persons wearing cardiac pacemakers or other implanted medical electronic devices is 1 kV/m at power frequencies (50/60 Hz).

Sub-Radiofrequency Magnetic Fields (1 Hz - 30 kHz)

- Ceiling values for the ELF Range (1 Hz $\leq$ f $\leq$ 300 Hz), B_{TLV} in mT = 60/f (with f in Hz). Partial body exposures can be increased by a factor of 10 for the hands and feet and by a factor of 5 for the arms and legs.
- Ceiling values for Whole-body and Partial-body Exposures, VF and VLF Range (300 Hz $\leq$ f $\leq$ 30 kHz), B_{TLV} = 0.2 mT (160 A/m). Similar to IEEE C95.1 where they overlap above 3 kHz.
- Ceiling value for exposure of persons wearing cardiac pace-makers or other implanted medical electronic devices is 0.1 mT at power frequencies (50/60 Hz).



Radiofrequency and Microwave Radiation



- TLVs are identical to the controlled area limits found in *ANSI/IEEE C95.1 - 1991 Standards for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz.*
- ACGIH covers region from 30 kHz to 300 GHz
- Personnel should not needlessly be exposed to higher levels, approaching the TLV, when simple measures will prevent it - is this ALARA?

Thermal - Cold Stress

- The cold stress TLV s are intended to protect workers from the severest effects of cold stress (hypothermia) and cold injury.
- TLV objective is to prevent core or rectal temperature from falling below 36°C (96.8°F) and to prevent cold injury to body extremities. Below 27°C (80.6°F) voluntary motion stops, and at 20°C (68°F) cardiac standstill occurs. 18°C (64.4°F) was the lowest accidental hypothermia victim to survive.
- TLV consists of tables of temperature and wind velocity with suggested work and break times.

Thermal - Cold Stress (2)

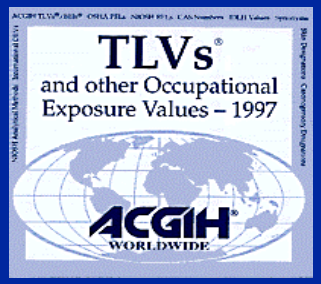
- Factors Increasing Risk:
- Illness
- Fatigue
- Age
- Alcohol
- Wetness
- Inadequate Clothing
- Medications

Thermal - Cold Stress (3)

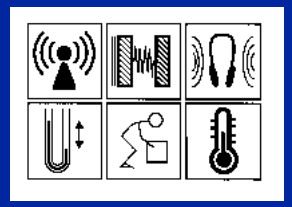
- Harmful effects include frost bite, trench or immersion foot, general hypothermia, and vascular abnormalities.
- Control measures include, heating (warming devices and shelters), minimizing length of exposure and air velocity, clothing, surface insulation, warm liquids, the “buddy system”, and worker education.

Thermal - Heat Stress

- Concept of Wet Bulb Globe Temperature Index (WBGT) - simple way to correlate deep body temperature with environmental factors
- Outdoors with solar load:
- WBGT = 0.7 NWB + 0.2GT + 0.1DB
- Indoors or outdoors with no solar load:
- WBGT = 0.7 NWB + 0.3GT; where:
- NWB = Natural Wet-Bulb Temperature
- DB = Dry Bulb Temperature
- GT = Globe Temperature



Thermal - Heat Stress (2)



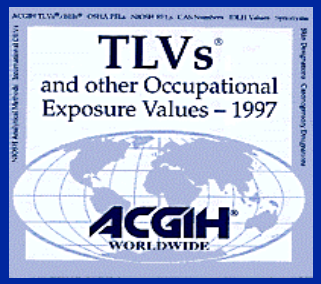
- TLV gives table of work / rest regimes as a function of WBGT for light, moderate, and heavy work loads.
- For example, a worker doing heavy work at 30°C (86°F) WBGT should work only 15 minutes each hour, and rest the remaining time.
- Workers should never work if their core body temperature exceeds 38°C (100.4°F).

Thermal - Heat Stress (3)

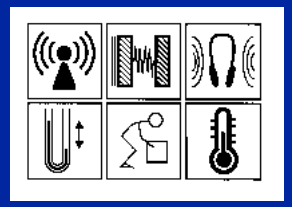
- Heat disorders include heat rash, heat cramps, heat exhaustion, and most severely, heat stroke. Heat cramps and heat exhaustion can usually be treated by resting in a cool place and replacing water and salt. Heat stroke, on the other hand, is a serious health problem which is caused by the body's failure to regulate core temperature and requires *immediate* medical attention.
- Special attention to females in the first trimester - there is an increased risk of malformation of the unborn fetus if the core temperature exceeds 39°C (102.2^{o}F) for extended periods. In addition, core temperatures above 38°C (100.4^{o}F) may be associated with temporary infertility in males and females.

Thermal - Heat Stress (4)

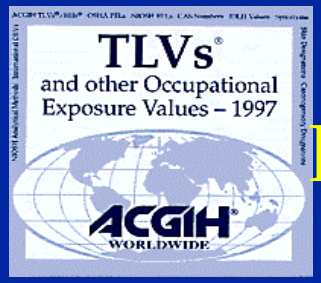
- Mitigation includes:
- Water and salt augmentation (1 g salt to 1 liter of water)
- wearing loose clothing allowing maximum cooling
- air conditioned rest areas
- acclimatization and fitness - TLV assumes employees are acclimated and physically fit



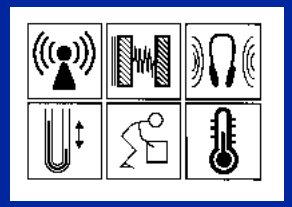
Physical Agents Under Study



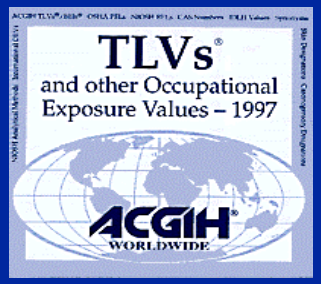
- The Physical Agents TLV Committee solicits information, especially data, which may assist in its deliberations regarding physical agents, especially those under study. Comments and suggestions, accompanied by substantive supporting data, should be forwarded to the technical affairs office at ACGIH headquarters. In addition, the Committee solicits recommendations for additional agents and issues of concerns to the Industrial Hygiene and Occupational Health communities.



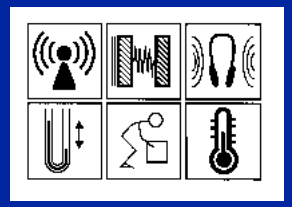
Physical Agents Under Study -1999



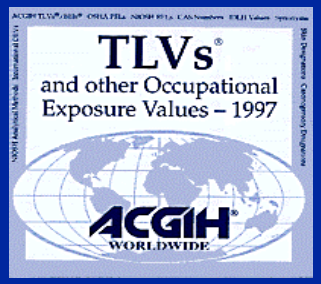
- *Carcinogenicity of physical agents - known and suspected*
- *Cold Stress*
- *Combined effects with chemical substances (e.g., noise and chemical exposure interaction)*
- *Electromagnetic pulses, ultra-wide-band communications and RF*
- *Extremely low frequency (ELF) magnetic fields*
- *Impulse noise, including blast over-pressure*
- *Induced and contact currents*
- *Ionizing radiation*
- *Ergonomics - Hand-Arm Vibration and Musculoskeletal Disorders*
- *Lighting levels and safety performance during night work*
- *Noise effects on pregnancy and the fetus and other reproductive hazards*
- *Pressure Variations*



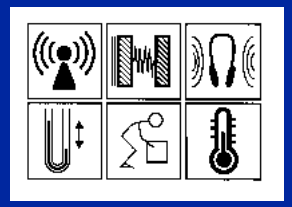
Further Reading



- *1998 TLVs and BEIs Threshold Limit Values for Chemical Substances and Physical Agents*, ACGIH, Cincinnati, OH.
- *ANSI Z136.1 - 1993 National Standard for Safe Use of Lasers*, ANSI, New York, NY.
- Sliney and Wolbarsht, *Safety with Lasers and Other Optical Sources*, Plenum Press, New York, NY (1985).
- *ANSI/IEEE C95.1 - 1991 Standards for Safety Levels with Respect to Human Exposure to Radiofrequency Electromagnetic Fields, 3 kHz to 300 GHz*, IEEE, Piscataway, NJ.



Do You Want to Know More?



- Demystifying the Physical Agents TLVs®: The Basics and Beyond - 2 day course - should be presented again in 1999
- Registration information can be found at: http://www.acgih.org/events/
- You can download this presentation as a Adobe Acrobat file at: **http://www.pnl.gov/health/health_prot/p_agents.html**