ภาคผนวก ง
กฎหมายที่เกี่ยวข้อง

ภาคผนวก ง1

มาตรฐานตามประกาศกระทรวงทรัพยากรธรรมชาติ และ

สิ่งแวดล้อม เรื่อง กำหนดมาตรฐานควบคุมการปล่อยทิ้งอากาศเสีย

จากโรงไฟฟ้าใหม่ พ.ศ. 2553

ประกาศกระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อม

เรื่อง กำหนดมาตรฐานควบคุมการปล่อยทิ้งอากาศเสียจากโรงไฟฟ้าใหม่

โดยที่เป็นการสมควรปรับปรุงการกำหนดมาตรฐานควบคุมการปล่อยทิ้งอากาศเสียจากโรงไฟฟ้าให้มีความเหมาะสมกับการพัฒนาเทคโนโลยี และสถานการณ์มลพิษในปัจจุบัน

อาศัยอำนาจตามความในมาตรา ๕๕ แห่งพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ อันเป็นพระราชบัญญัติที่มีบทบัญญัติบางประการเกี่ยวกับการจำกัดสิทธิ และเสรีภาพของบุคคล ซึ่งมาตรา ๒๙ ประกอบกับมาตรา ๓๓ มาตรา ๓๘ มาตรา ๔๑ และมาตรา ๔๓ ของรัฐธรรมนูญแห่งราชอาณาจักรไทยบัญญัติให้กระทำได้โดยอาศัยอำนาจตามบทบัญญัติแห่งกฎหมาย รัฐมนตรีว่าการกระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อม โดยคำแนะนำของคณะกรรมการควบคุมมลพิษ และโดยความเห็นชอบของคณะกรรมการสิ่งแวดล้อมแห่งชาติ จึงออกประกาศไว้ ดังต่อไปนี้

ข้อ ๑ ในประกาศนี้

“โรงไฟฟ้าใหม่” หมายความว่า โรงงานผลิตพลังงานไฟฟ้าตามกฎหมายว่าด้วยโรงงานซึ่งใช้ถ่านหิน น้ำมัน ก๊าซธรรมชาติหรือเชื้อเพลิงชีวมวลเป็นเชื้อเพลิง ที่ได้รับอนุญาตให้ประกอบกิจการหลังจากวันที่ประกาศนี้มีผลใช้บังคับ

“เชื้อเพลิงชีวมวล” หมายความว่า เชื้อเพลิงที่ได้มาจากอินทรีย์สารหรือสิ่งมีชีวิต รวมทั้งผลผลิตจากการเกษตร การปศุสัตว์ และการทำป่าไม้ เช่น ไม้ฟืน เศษไม้ แกลบ ฟาง ชานอ้อย ต้นและใบอ้อย ใยปาล์ม กะลาปาล์ม ทะลายปาล์ม กะลามะพร้าว ใยมะพร้าว เศษพืช มูลสัตว์ ก๊าซชีวภาพ กากตะกอนหรือของเสียจากโรงงานแปรรูปผลิตภัณฑ์ทางการเกษตร เป็นต้น

“สภาวะแห้ง” หมายความว่า สภาวะที่ความชื้นของตัวอย่างอากาศเป็นศูนย์

ข้อ ๒ กำหนดมาตรฐานควบคุมการปล่อยทิ้งอากาศเสียจากโรงไฟฟ้าใหม่ และโรงไฟฟ้าตามกฎหมายว่าด้วยการส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติที่ได้รับใบอนุญาตประกอบกิจการโรงงานก่อนและในวันที่ประกาศนี้มีผลใช้บังคับเฉพาะส่วนที่ได้รับอนุญาตให้ขยายโรงงานไว้ ดังต่อไปนี้

ชนิดของเชื้อเพลิง	ฝุ่นละออง (มิลลิกรัมต่อลูกบาศก์เมตร)	ก๊าซซัลเฟอร์ไดออกไซด์ (ส่วนในล้านส่วน)	ก๊าซออกไซด์ของไนโตรเจนซึ่งคำนวณผลในรูปก๊าซไนโตรเจนไดออกไซด์ (ส่วนในล้านส่วน)
๑. โรงไฟฟ้าที่ใช้ถ่านหินเป็นเชื้อเพลิง (๑) ที่มีกำลังการผลิตไฟฟ้าไม่เกิน ๕๐ เมกะวัตต์	ไม่เกิน ๘๐	ไม่เกิน ๓๖๐	ไม่เกิน ๒๐๐
(๒) ที่มีกำลังการผลิตไฟฟ้าเกิน ๕๐ เมกะวัตต์	ไม่เกิน ๘๐	ไม่เกิน ๑๘๐	ไม่เกิน ๒๐๐
๒. โรงไฟฟ้าที่ใช้น้ำมันเป็นเชื้อเพลิง	ไม่เกิน ๑๒๐	ไม่เกิน ๒๖๐	ไม่เกิน ๑๘๐
๓. โรงไฟฟ้าที่ใช้ก๊าซธรรมชาติเป็นเชื้อเพลิง	ไม่เกิน ๖๐	ไม่เกิน ๒๐	ไม่เกิน ๑๒๐
๔. โรงไฟฟ้าที่ใช้เชื้อเพลิงชีวมวลเป็นเชื้อเพลิง	ไม่เกิน ๑๒๐	ไม่เกิน ๖๐	ไม่เกิน ๒๐๐

ข้อ ๓ การคำนวณค่าอากาศเสียแต่ละชนิดที่ปล่อยทิ้งจากปล่องโรงไฟฟ้าตามข้อ ๒ ให้คำนวณผลที่ความดัน ๑ บรรยากาศหรือที่ ๗๖๐ มิลลิเมตรปรอท อุณหภูมิ ๒๕ องศาเซลเซียส ที่สภาวะแห้ง (Dry Basis) โดยมีปริมาตรอากาศส่วนเกินในการเผาไหม้ (Excess Air) ร้อยละ ๕๐ หรือที่ปริมาตรออกซิเจนส่วนเกิน (Excess Oxygen) ในการเผาไหม้ร้อยละ ๗

ข้อ ๔ กรณีโรงไฟฟ้าตามข้อ ๒ ใช้ทั้งถ่านหิน น้ำมัน ก๊าซธรรมชาติหรือเชื้อเพลิงชีวมวลเป็นเชื้อเพลิงร่วมกันตั้งแต่ ๒ ประเภทขึ้นไป ให้คำนวณมาตรฐานควบคุมการปล่อยทิ้งอากาศเสียตามสัดส่วนของเชื้อเพลิงที่ใช้แต่ละประเภทดังต่อไปนี้

ค่ามาตรฐานควบคุมการปล่อยทิ้งอากาศเสีย = AW + BX + CY + DZ

เมื่อ A = ค่ามาตรฐานอากาศเสียที่ปล่อยทิ้งเมื่อใช้ถ่านหินเป็นเชื้อเพลิงอย่างเดียว

B = ค่ามาตรฐานอากาศเสียที่ปล่อยทิ้งเมื่อใช้น้ำมันเป็นเชื้อเพลิงอย่างเดียว

C = ค่ามาตรฐานอากาศเสียที่ปล่อยทิ้งเมื่อใช้ก๊าซธรรมชาติเป็นเชื้อเพลิงอย่างเดียว

D = ค่ามาตรฐานอากาศเสียที่ปล่อยทิ้งเมื่อใช้เชื้อเพลิงชีวมวลเป็นเชื้อเพลิงอย่างเดียว

W = สัดส่วนของความร้อน (Heat Input) ที่ได้จากเชื้อเพลิงประเภทถ่านหิน

X = สัดส่วนของความร้อน (Heat Input) ที่ได้จากเชื้อเพลิงประเภทน้ำมัน

Y = สัดส่วนของความร้อน (Heat Input) ที่ได้จากเชื้อเพลิงประเภทก๊าซธรรมชาติ

Z = สัดส่วนของความร้อน (Heat Input) ที่ได้จากเชื้อเพลิงประเภทเชื้อเพลิงชีวมวล

ข้อ ๕ การตรวจวัดอากาศเสียที่ปล่อยทิ้งจากปล่องโรงไฟฟ้าตามข้อ ๒ ให้ใช้วิธีดังต่อไปนี้

(๑) การตรวจวัดค่าฝุ่นละอองให้ใช้วิธี Determination of Particulate Emissions from Stationary Sources ที่องค์การพิทักษ์สิ่งแวดล้อมแห่งประเทศสหรัฐอเมริกา (United States Environmental Protection Agency) กำหนดไว้หรือวิธีอื่นที่คณะกรรมการควบคุมมลพิษเห็นชอบ

(๒) การตรวจวัดค่าก๊าซซัลเฟอร์ไดออกไซด์ ให้ใช้วิธี Determination of Sulfur Dioxide Emissions from Stationary Sources หรือวิธี Determination of Sulfuric Acid Mist and Sulfur Dioxide Emissions from Stationary Sources ที่องค์การพิทักษ์สิ่งแวดล้อมแห่งประเทศสหรัฐอเมริกา (United States Environmental Protection Agency) กำหนดไว้หรือวิธีอื่นที่คณะกรรมการควบคุมมลพิษเห็นชอบ

(๓) การตรวจวัดค่าก๊าซออกไซด์ของไนโตรเจน ซึ่งคำนวณผลในรูปของก๊าซไนโตรเจนไดออกไซด์ ให้ใช้วิธี Determination of Nitrogen Oxide Emissions from Stationary Sources ที่องค์การพิทักษ์สิ่งแวดล้อมแห่งประเทศสหรัฐอเมริกา (United States Environmental Protection Agency) กำหนดไว้หรือวิธีอื่นที่คณะกรรมการควบคุมมลพิษเห็นชอบ

ข้อ ๖ ประกาศนี้ให้ใช้บังคับตั้งแต่วันถัดจากวันประกาศในราชกิจจานุเบกษาเป็นต้นไป

ประกาศ ณ วันที่ ๒๐ ธันวาคม พ.ศ. ๒๕๕๒

สุวิทย์ คุณกิตติ

รัฐมนตรีว่าการกระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อ

ภาคผนวก ง2

มาตรฐานตามประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ 24 (พ.ศ. 2547) เรื่อง กำหนดมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป ประกาศในราชกิจจานุเบกษา ฉบับประกาศทั่วไป เล่ม 121 ตอนพิเศษ 104 ง วันที่ 22 กันยายน พ.ศ. 2547

ประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ
ฉบับที่ ๒๔ (พ.ศ. ๒๕๔๗)
เรื่อง กำหนดมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป

อาศัยอำนาจตามความในมาตรา ๓๒ และมาตรา ๓๔ แห่งพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ อันเป็นพระราชบัญญัติที่มีบทบัญญัติบางประการเกี่ยวกับการจำกัดสิทธิและเสรีภาพของบุคคล ซึ่งมาตรา ๒๙ ประกอบกับมาตรา ๓๕ มาตรา ๔๘ มาตรา ๕๐ และมาตรา ๕๑ ของรัฐธรรมนูญแห่งราชอาณาจักรไทยบัญญัติให้กระทำได้โดยอาศัยอำนาจตามบทบัญญัติแห่งกฎหมาย คณะกรรมการสิ่งแวดล้อมแห่งชาติ จึงได้มีมติในคราวการประชุมครั้งที่ ๒/๒๕๔๗ เมื่อวันที่ ๒๔ กุมภาพันธ์ ๒๕๔๗ ให้ปรับปรุงแก้ไขมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป ดังต่อไปนี้

ข้อ ๑ ให้ยกเลิกความใน (๔) ของข้อ ๒ แห่งประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๑๐ (พ.ศ. ๒๕๓๘) ออกตามความในพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ เรื่อง กำหนดมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป และให้ใช้ความต่อไปนี้แทน

"(๔) ค่าเฉลี่ยของก๊าซซัลเฟอร์ไดออกไซด์ ในเวลา ๒๔ ชั่วโมง จะต้องไม่เกิน ๐.๑๒ ส่วนในล้านส่วน หรือไม่เกิน ๐.๓๐ มิลลิกรัมต่อลูกบาศก์เมตร และค่ามัชฌิมเลขคณิต (Arithmetic Mean) ในเวลา ๑ ปี จะต้องไม่เกิน ๐.๐๔ ส่วนในล้านส่วน หรือไม่เกิน ๐.๑๐ มิลลิกรัมต่อลูกบาศก์เมตร"

ข้อ ๒ ให้ยกเลิกความใน (๒) และ (๓) ของข้อ ๔ แห่งประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๑๐ (พ.ศ. ๒๕๓๘) ออกตามความในพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ เรื่อง กำหนดมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป และให้ใช้ความต่อไปนี้แทน

“(๒) ค่าเฉลี่ยของฝุ่นละอองขนาดไม่เกิน ๑๐ ไมครอน ในเวลา ๒๔ ชั่วโมง จะต้องไม่เกิน ๐.๑๒ มิลลิกรัมต่อลูกบาศก์เมตร และค่ามัชฌิมเลขคณิต (Arithmetic Mean) ในเวลา ๑ ปี จะต้องไม่เกิน ๐.๐๕ มิลลิกรัมต่อลูกบาศก์เมตร

(๓) ค่าเฉลี่ยของฝุ่นละอองรวมหรือฝุ่นละอองขนาดไม่เกิน ๑๐๐ ไมครอน ในเวลา ๒๔ ชั่วโมง จะต้องไม่เกิน ๐.๓๓ มิลลิกรัมต่อลูกบาศก์เมตร และค่ามัชฌิมเลขคณิต (Arithmetic Mean) ในเวลา ๑ ปี จะต้องไม่เกิน ๐.๑๐ มิลลิกรัมต่อลูกบาศก์เมตร”

ประกาศ ณ วันที่ ๙ สิงหาคม พ.ศ. ๒๕๔๗

(ลงนาม) *จาตุรนต์ ฉายแสง*

(นายจาตุรนต์ ฉายแสง)

รองนายกรัฐมนตรี

ปฏิบัติหน้าที่ประธานคณะกรรมการสิ่งแวดล้อมแห่งชาติ

ราชกิจจานุเบกษา ฉบับประกาศทั่วไป เล่ม ๑๒๑ ตอนพิเศษ ๑๐๔ ง วันที่ ๒๒ กันยายน ๒๕๔๗

ภาคผนวก ง3
มาตรฐานตามประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ 33 (พ.ศ. 2552) เรื่อง กำหนดมาตรฐานค่าก๊าซไนโตรเจนไดออกไซด์ในบรรยากาศโดยทั่วไป ประกาศในราชกิจจานุเบกษา เล่ม 126 ตอนพิเศษ 114ง วันที่ 14 สิงหาคม พ.ศ. 2552

ประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ

ฉบับที่ ๓๓ (พ.ศ. ๒๕๕๒)

เรื่อง กำหนดมาตรฐานค่าก๊าซไนโตรเจนไดออกไซด์ในบรรยากาศโดยทั่วไป

โดยที่เป็นการสมควรกำหนดมาตรฐานค่าก๊าซไนโตรเจนไดออกไซด์ในบรรยากาศโดยทั่วไป เพื่อเป็นเกณฑ์ทั่วไปสำหรับการส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมตามพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕

อาศัยอำนาจตามความในมาตรา ๓๒ (๔) และมาตรา ๓๔ แห่งพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ อันเป็นพระราชบัญญัติที่มีบทบัญญัติบางประการเกี่ยวกับการจำกัดสิทธิและเสรีภาพของบุคคล ซึ่งมาตรา ๒๙ ประกอบกับมาตรา ๓๓ มาตรา ๓๘ มาตรา ๔๑ และมาตรา ๔๓ ของรัฐธรรมนูญแห่งราชอาณาจักรไทย บัญญัติให้กระทำได้โดยอาศัยอำนาจตามบทบัญญัติแห่งกฎหมาย คณะกรรมการสิ่งแวดล้อมแห่งชาติจึงออกประกาศกำหนดมาตรฐานค่าก๊าซไนโตรเจนไดออกไซด์ในบรรยากาศโดยทั่วไปไว้ ดังต่อไปนี้

ข้อ ๑ ในประกาศนี้

"เครื่องวัดระบบเคมีลูมิเนสเซน" (Chemiluminescence) หมายความว่า เครื่องมือวัดค่าก๊าซไนโตรเจนไดออกไซด์โดยใช้ก๊าซโอโซนทำปฏิกิริยากับก๊าซไนตริกออกไซด์ซึ่งถูกเปลี่ยนมาจากก๊าซไนโตรเจนไดออกไซด์แล้ววัดความเข้มของแสงซึ่งเกิดจากปฏิกิริยานั้น ณ ที่ความยาวคลื่นที่สูงกว่า ๖๐๐ นาโนมิเตอร์ (Nanometer)

ข้อ ๒ ให้ยกเลิก

(๑) ความใน (๒) ของข้อ ๒ แห่งประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๑๐ (พ.ศ. ๒๕๓๘) ออกตามความในพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ เรื่อง กำหนดมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป

(๒) ความใน (๑) ของข้อ ๖ แห่งประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๑๐ (พ.ศ. ๒๕๓๘) ออกตามความในพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ เรื่อง กำหนดมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป แก้ไขเพิ่มเติมโดยประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๒๘ (พ.ศ. ๒๕๕๐) เรื่อง กำหนดมาตรฐานคุณภาพอากาศในบรรยากาศโดยทั่วไป

ข้อ ๓ ให้กำหนดมาตรฐานค่าก๊าซไนโตรเจนไดออกไซด์ในบรรยากาศโดยทั่วไปไว้ดังต่อไปนี้

(๑) ค่าเฉลี่ยของก๊าซไนโตรเจนไดออกไซด์ในเวลา ๑ ชั่วโมง จะต้องไม่เกิน ๐.๑๗ ส่วนในล้านส่วนหรือไม่เกิน ๐.๓๒ มิลลิกรัมต่อลูกบาศก์เมตร

(๒) ค่ามัชฌิมเลขคณิต (Arithmetic Mean) ของก๊าซไนโตรเจนไดออกไซด์ในเวลา ๑ ปี จะต้องไม่เกิน ๐.๐๓ ส่วนในล้านส่วน หรือไม่เกิน ๐.๐๕๗ มิลลิกรัมต่อลูกบาศก์เมตร

ข้อ ๔ การคำนวณค่าความเข้มข้นของก๊าซไนโตรเจนไดออกไซด์ในบรรยากาศโดยทั่วไป ให้คำนวณเทียบที่ความดัน ๑ บรรยากาศ และอุณหภูมิ ๒๕ องศาเซลเซียส

ข้อ ๕ การวัดค่าเฉลี่ยของก๊าซไนโตรเจนไดออกไซด์ในเวลา ๑ ชั่วโมง หรือค่ามัชฌิมเลขคณิต (Arithmetic Mean) ในเวลา ๑ ปี ให้ใช้เครื่องวัดระบบเคมีลูมิเนสเซน หรือระบบอื่นที่กรมควบคุมมลพิษให้ความเห็นชอบ

ประกาศ ณ วันที่ ๑๗ มิถุนายน พ.ศ. ๒๕๕๒
อภิสิทธิ์ เวชชาชีวะ
นายกรัฐมนตรี
ประธานกรรมการสิ่งแวดล้อมแห่งชาติ

ภาคผนวก ง4

มาตรฐานตามประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ
ฉบับที่ 21 (พ.ศ. 2544) เรื่อง กำหนดมาตรฐานค่าก๊าซซัลเฟอร์
ไดออกไซด์ ในบรรยากาศโดยทั่วไป 1 ชั่วโมง
ประกาศในราชกิจจานุเบกษา เล่ม 118 ตอนพิเศษ 39ง
วันที่ 30 เมษายน พ.ศ. 2544

ประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ

ฉบับที่ ๒๑ (พ.ศ. ๒๕๔๔)

ออกตามความในพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ

พ.ศ. ๒๕๓๕

เรื่อง กำหนดมาตรฐานค่าก๊าซซัลเฟอร์ไดออกไซด์ในบรรยากาศโดยทั่วไป

ในเวลา ๑ ชั่วโมง

อาศัยอำนาจตามความในมาตรา ๓๒ และมาตรา ๓๔ แห่งพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ คณะกรรมการสิ่งแวดล้อมแห่งชาติ จึงปรับปรุงแก้ไขมาตรฐานค่าก๊าซซัลเฟอร์ไดออกไซด์ในบรรยากาศโดยทั่วไปในเวลา ๑ ชั่วโมง ไว้ดังต่อไปนี้

(๑) ให้ยกเลิกข้อ ๒ แห่งประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๑๒ (พ.ศ. ๒๕๓๘) ออกตามความในพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ เรื่อง กำหนดมาตรฐานค่าก๊าซซัลเฟอร์ไดออกไซด์ในบรรยากาศโดยทั่วไปในเวลา ๑ ชั่วโมง

(๒) ให้ยกเลิกความในข้อ ๓ และข้อ ๕ แห่งประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๑๒ (พ.ศ. ๒๕๓๘) ออกตามความในพระราชบัญญัติส่งเสริมและรักษา คุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ เรื่อง กำหนดมาตรฐานค่าก๊าซซัลเฟอร์ไดออกไซด์ในบรรยากาศโดยทั่วไปในเวลา ๑ ชั่วโมง และให้ใช้ความต่อไปนี้แทน

“ข้อ ๓ ค่าเฉลี่ยความเข้มข้นของก๊าซซัลเฟอร์ไดออกไซด์ในบรรยากาศโดยทั่วไปในเวลา ๑ ชั่วโมง จะต้องไม่เกิน ๐.๓๐ ส่วนในล้านส่วน (ppm) หรือไม่เกิน ๗๘๐ ไมโครกรัมต่อลูกบาศก์เมตร”

“ข้อ ๕ การวัดหาค่าเฉลี่ยความเข้มข้นของก๊าซซัลเฟอร์ไดออกไซด์ในบรรยากาศโดยทั่วไปในเวลา ๑ ชั่วโมง ตามข้อ ๓ ให้ใช้เครื่องวัดระบบ ยูวี ฟลูออเรสเซน หรือระบบอื่นที่กรมควบคุมมลพิษประกาศในราชกิจจานุเบกษา”

ประกาศ ณ วันที่ ๙ เมษายน พ.ศ. ๒๕๔๔

(นายเดช บุญ-หลง)

รองนายกรัฐมนตรี ปฏิบัติหน้าที่

ประธานคณะกรรมการสิ่งแวดล้อมแห่งชาติ

(ประกาศในราชกิจจานุเบกษา เล่ม ๑๑๘ ตอนพิเศษ ๓๙ ง ลงวันที่ ๓๐ เมษายน ๒๕๔๔)

ภาคผนวก ง5

มาตรฐานตามประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ 15 (พ.ศ. 2540) เรื่อง กำหนดมาตรฐานระดับเสียงโดยทั่วไป ประกาศในราชกิจจานุเบกษา เล่ม 114 ตอนที่ 27 ง ลงวันที่ 3 เมษายน 2540

ประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ
ฉบับที่ ๑๕ (พ.ศ. ๒๕๔๐)
เรื่อง กำหนดมาตรฐานระดับเสียงโดยทั่วไป

อาศัยอำนาจตามความในมาตรา ๓๒ (๕) แห่งพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ คณะกรรมการสิ่งแวดล้อมแห่งชาติกำหนดมาตรฐานระดับเสียงโดยทั่วไปไว้ดังต่อไปนี้

ข้อ ๑ ในประกาศนี้

"ระดับเสียงโดยทั่วไป" หมายความว่า ระดับเสียงที่เกิดขึ้นในสิ่งแวดล้อม

"ค่าระดับเสียงสูงสุด" หมายความว่า ค่าระดับเสียงสูงสุดที่เกิดขึ้นในขณะใดขณะหนึ่งระหว่างการตรวจวัดระดับเสียง โดยมีหน่วยเป็นเดซิเบลเอ หรือ dB (A)

"ค่าระดับเสียงเฉลี่ย ๒๔ ชั่วโมง" หมายความว่า ค่าระดับเสียงคงที่ที่มีพลังงานเทียบเท่าระดับเสียงที่เกิดขึ้นจริง ซึ่งมีระดับเสียงเปลี่ยนแปลงตามเวลาในช่วง ๒๔ ชั่วโมง (๒๔ hours A-weighted Equivalent Continuous Sound Level) ซึ่งเรียกโดยย่อว่า Leq ๒๔ hr โดยมีหน่วยเป็นเดซิเบลเอ หรือ dB (A)

"มาตรระดับเสียง" หมายความว่า เครื่องวัดระดับเสียงตามมาตรฐาน IEC ๖๕๑ หรือ IEC ๘๐๔ ของคณะกรรมาธิการระหว่างประเทศว่าด้วยเทคนิคไฟฟ้า (International Electrotechnical Commission, IEC)

ข้อ ๒ ให้กำหนดมาตรฐานระดับเสียงโดยทั่วไป ไว้ดังต่อไปนี้

(๑) ค่าระดับเสียงสูงสุด ไม่เกิน ๑๑๕ เดซิเบลเอ

(๒) ค่าระดับเสียงเฉลี่ย ๒๔ ชั่วโมง ไม่เกิน ๗๐ เดซิเบลเอ

ข้อ ๓ การตรวจวัดระดับเสียงโดยทั่วไป ให้ดำเนินการดังต่อไปนี้

(๑) การตรวจวัดค่าระดับเสียงสูงสุด ให้ใช้มาตรระดับเสียงตรวจวัดระดับเสียงในบริเวณที่มีคนอยู่หรืออาศัยอยู่

(๒) การตรวจวัดค่าระดับเสียงเฉลี่ย ๒๔ ชั่วโมง ให้ใช้มาตรระดับเสียงตรวจวัดระดับเสียงอย่างต่อเนื่องตลอดเวลา ๒๔ ชั่วโมงใดๆ

(๓) การตั้งไมโครโฟนของมาตรระดับเสียงที่บริเวณภายนอกอาคารให้ตั้งสูงจากพื้นไม่น้อยกว่า ๑.๒๐ เมตร โดยในรัศมี ๓.๕๐ เมตร ตามแนวราบรอบไมโครโฟนต้องไม่มีกำแพงหรือสิ่งอื่นใดที่มีคุณสมบัติในการสะท้อนเสียงกีดขวางอยู่

(๔) การตั้งไมโครโฟนของมาตรระดับเสียงที่บริเวณภายในอาคารให้ตั้งสูงจากพื้นไม่น้อยกว่า ๑.๒๐ เมตร โดยในรัศมี ๑.๐๐ เมตร ตามแนวราบรอบไมโครโฟนต้องไม่มีกำแพงสิ่งอื่นใดที่มีคุณสมบัติในการสะท้อนเสียงกีดขวางอยู่และต้องห่างจากช่องหน้าต่างหรือช่องทางที่เปิดออกนอกอาคารอย่างน้อย ๑.๕๐ เมตร

ข้อ ๔ การคำนวณค่าระดับเสียงจะต้องเป็นไปตามวิธีการที่องค์การระหว่างประเทศว่าด้วยมาตรฐาน (International Organization for Standardization, ISO) กำหนด ซึ่งกรมควบคุมมลพิษจะประกาศในราชกิจจานุเบกษา

ประกาศ ณ วันที่ ๑๒ มีนาคม พ.ศ. ๒๕๔๐

พลเอก ชวลิต ยงใจยุทธ

นายกรัฐมนตรี

ประธานคณะกรรมการสิ่งแวดล้อมแห่งชาติ

(ประกาศในราชกิจจานุเบกษา เล่ม ๑๑๔ ตอนที่ ๒๗ ง วันที่ ๓ เมษายน ๒๕๔๐)

ภาคผนวก ง6

มาตรฐานตามประกาศกระทรวงอุตสาหกรรม เรื่องกำหนดค่าระดับเสียงการรบกวน และระดับเสียงที่เกิดจากการประกอบกิจการโรงงาน พ.ศ. 2548 ประกาศในราชกิจจานุเบกษา เล่ม 123 ตอนพิเศษ 11 ง ลงวันที่ 25 มกราคม 2549

ประกาศกระทรวงอุตสาหกรรม

เรื่อง กำหนดค่าระดับเสียงการรบกวนและระดับเสียงที่เกิดจากการประกอบกิจการโรงงาน

พ.ศ. ๒๕๔๘

อาศัยอำนาจตามความในข้อ ๑๗ แห่งกฎกระทรวง ฉบับที่ ๒ (พ.ศ. ๒๕๓๕) ออกตามความในพระราชบัญญัติโรงงาน พ.ศ. ๒๕๓๕ อันเป็นพระราชบัญญัติที่มีบทบัญญัติบางประการเกี่ยวกับการจำกัดสิทธิและเสรีภาพของบุคคล ซึ่งมาตรา ๒๙ ประกอบกับมาตรา ๓๕ มาตรา ๔๘ และมาตรา ๕๐ ของรัฐธรรมนูญแห่งราชอาณาจักรไทย บัญญัติให้กระทำได้โดยอาศัยอำนาจตามบทบัญญัติแห่งกฎหมาย รัฐมนตรีว่าการกระทรวงอุตสาหกรรมจึงได้ออกประกาศไว้ ดังต่อไปนี้

ข้อ ๑ ในประกาศนี้

"เสียงรบกวน" หมายความว่า ระดับเสียงตรวจวัดนอกบริเวณโรงงาน ที่เกิดจากการประกอบกิจการโรงงาน ขณะมีการรบกวน ซึ่งมีระดับเสียงสูงกว่าระดับเสียงพื้นฐาน และมีระดับการรบกวนเกินกว่าค่าที่กำหนดไว้ในประกาศนี้

"ระดับเสียงพื้นฐาน" หมายความว่า ระดับเสียงที่ตรวจวัดในสิ่งแวดล้อมเดิม ขณะยังไม่มีเสียงรบกวนจากการประกอบกิจการโรงงานเป็นระดับเสียงเปอร์เซ็นไทล์ที่ ๙๐ (Percentile Level 90 , L_{90})

"ระดับเสียงเปอร์เซ็นไทล์ที่ ๙๐ (L_{90})" หมายความว่า ระดับเสียงที่ร้อยละ ๙๐ ของเวลาที่ตรวจวัดจะมีระดับเสียงเกินระดับนี้

"ระดับเสียงขณะมีการรบกวน" หมายความว่า ระดับเสียงที่ตรวจวัดหรือคำนวณจากการประกอบกิจการโรงงานขณะเกิดเสียงรบกวน

"ระดับการรบกวน" หมายความว่า ระดับความแตกต่างของระดับเสียงขณะมีการรบกวนกับระดับเสียงพื้นฐาน

"ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง" หมายความว่า ระดับเสียงคงที่นอกบริเวณโรงงานที่มีพลังงานเทียบเท่าระดับเสียงที่เกิดขึ้นจริง ซึ่งมีระดับเสียงเปลี่ยนแปลงตามเวลาในช่วง ๒๔ ชั่วโมง (24 hours A-weighted Equivalent Continuous Sound Level) ซึ่งเรียกโดยย่อว่า Leq 24 hr โดยมีหน่วยเป็นเดซิเบลเอ หรือ dB(A)

"ระดับเสียงสูงสุด" หมายความว่า ระดับเสียงสูงสุดนอกบริเวณโรงงาน ที่เกิดขึ้นในขณะใดขณะหนึ่งระหว่างการตรวจวัดระดับเสียง โดยมีหน่วยเป็นเดซิเบลเอ หรือ dB(A)

"มาตรระดับเสียง" หมายความว่า เครื่องวัดระดับเสียงตามมาตรฐาน IEC 60804 หรือ IEC 61672 ของคณะกรรมาธิการระหว่างประเทศว่าด้วยเทคนิคไฟฟ้า (International Electrotechnical Commission , IEC)

ข้อ ๒ ค่าระดับการรบกวน ที่เกิดจากการประกอบกิจการโรงงาน ไม่เกิน ๑๐ เดซิเบลเอ

ข้อ ๓ ค่าระดับเสียงเฉลี่ย ๒๔ ชั่วโมง ที่เกิดจากการประกอบกิจการโรงงาน ไม่เกิน ๗๐ เดซิเบลเอ

ข้อ ๔ ค่าระดับเสียงสูงสุด ที่เกิดจากการประกอบกิจการโรงงาน ไม่เกิน ๑๑๕ เดซิเบลเอ

ข้อ ๕ วิธีการตรวจวัดระดับเสียงการรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง และระดับเสียงสูงสุดที่เกิดจากการประกอบกิจการโรงงาน ให้เป็นไปตามที่กรมโรงงานอุตสาหกรรมกำหนด

ทั้งนี้ ให้ใช้บังคับตั้งแต่วันถัดจากวันประกาศในราชกิจจานุเบกษาเป็นต้นไป

ประกาศ ณ วันที่ ๒๗ ธันวาคม พ.ศ. ๒๕๔๘

สุริยะ จึงรุ่งเรืองกิจ

รัฐมนตรีว่าการกระทรวงอุตสาหกรรม

ประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ

ฉบับที่ ๒๙ (พ.ศ. ๒๕๕๐)

เรื่อง ค่าระดับเสียงรบกวน

โดยที่เป็นการสมควร ปรับปรุงค่ามาตรฐานระดับเสียงรบกวน ให้เหมาะสมกับกฎเกณฑ์และหลักฐานทางวิทยาศาสตร์ โดยคำนึงถึงความเป็นไปได้ในเชิงเศรษฐกิจสังคมและเทคโนโลยีที่เกี่ยวข้อง อาศัยอำนาจตามความในมาตรา ๓๔ แห่งพระราชบัญญัติส่งเสริมและรักษาคุณภาพสิ่งแวดล้อมแห่งชาติ พ.ศ. ๒๕๓๕ และคำสั่งสำนักนายกรัฐมนตรี ที่ ๗๑/๒๕๕๐ คณะกรรมการสิ่งแวดล้อมแห่งชาติ จึงออกประกาศกำหนดค่าระดับเสียงรบกวน ไว้ดังต่อไปนี้

ข้อ ๑ ให้ยกเลิกประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๑๗ (พ.ศ. ๒๕๔๓) ลงวันที่ ๖ มิถุนายน ๒๕๔๓ เรื่อง ค่าระดับเสียงรบกวน

ข้อ ๒ ให้กำหนดระดับเสียงรบกวนเท่ากับ ๑๐ เดซิเบลเอ

หากระดับการรบกวนที่คำนวณได้มีค่ามากกว่าระดับเสียงรบกวนตามวรรคแรก ให้ถือว่าเป็นเสียงรบกวน

ข้อ ๓ วิธีการตรวจวัดระดับเสียงพื้นฐาน ระดับเสียงขณะไม่มีการรบกวน การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวน การคำนวณค่าระดับการรบกวน และแบบบันทึกการตรวจวัดเสียงรบกวนให้เป็นไปตามที่ คณะกรรมการควบคุมมลพิษประกาศในราชกิจจานุเบกษา

ประกาศ ณ วันที่ ๒๙ มิถุนายน พ.ศ. ๒๕๕๐

โฆสิต ปั้นเปี่ยมรัษฎ์

รองนายกรัฐมนตรี

ประธานกรรมการสิ่งแวดล้อมแห่งชาติ

ประกาศคณะกรรมการควบคุมมลพิษ

เรื่อง วิธีการตรวจวัดระดับเสียงพื้นฐาน ระดับเสียงขณะไม่มีการรบกวน การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวน การคำนวณค่าระดับการรบกวน และแบบบันทึกการตรวจวัดเสียงรบกวน

พ.ศ. ๒๕๖๕

โดยที่เป็นการสมควรปรับปรุงวิธีการตรวจวัดระดับเสียงพื้นฐาน ระดับเสียงขณะไม่มีการรบกวน การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวน การคำนวณค่าระดับการรบกวน และแบบบันทึกการตรวจวัดเสียงรบกวน ให้สอดคล้องกับความก้าวหน้าทางวิทยาศาสตร์และเทคโนโลยี เพื่อประโยชน์ในการตรวจสอบระดับเสียงให้เป็นไปอย่างมีประสิทธิภาพ

อาศัยอำนาจตามความในข้อ ๓ แห่งประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๒๙ (พ.ศ. ๒๕๕๐) เรื่อง ค่าระดับเสียงรบกวน ลงวันที่ ๒๙ มิถุนายน พ.ศ. ๒๕๕๐ คณะกรรมการควบคุมมลพิษ จึงออกประกาศไว้ ดังต่อไปนี้

ข้อ ๑ ให้ยกเลิกประกาศคณะกรรมการควบคุมมลพิษ เรื่อง วิธีการตรวจวัดระดับเสียงพื้นฐานระดับเสียงขณะไม่มีการรบกวน การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวน การคำนวณค่าระดับการรบกวน และแบบบันทึกการตรวจวัดเสียงรบกวน ลงวันที่ ๓๑ สิงหาคม พ.ศ. ๒๕๕๐

ข้อ ๒ วิธีการตรวจวัดระดับเสียงพื้นฐาน ระดับเสียงขณะไม่มีการรบกวน การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวน การคำนวณค่าระดับการรบกวน และแบบบันทึกการตรวจวัดเสียงรบกวนให้เป็นไปตามภาคผนวกท้ายประกาศนี้

ข้อ ๓ ประกาศนี้ให้ใช้บังคับตั้งแต่วันถัดจากวันประกาศในราชกิจจานุเบกษาเป็นต้นไป

ประกาศ ณ วันที่ ๒๑ กันยายน พ.ศ. ๒๕๖๕
จตุพร บุรุษพัฒน์
ปลัดกระทรวงทรัพยากรธรรมชาติและสิ่งแวดล้อม
ประธานกรรมการควบคุมมลพิษ

ภาคผนวก
ท้ายประกาศคณะกรรมการควบคุมมลพิษ
เรื่อง วิธีการตรวจวัดระดับเสียงพื้นฐาน ระดับเสียงขณะไม่มีการรบกวน
การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวน การคำนวณค่าระดับการรบกวน
และแบบบันทึกการตรวจวัดเสียงรบกวน
พ.ศ. ๒๕๖๕

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๑. ในประกาศนี้

"เสียงรบกวน" หมายความว่า ระดับเสียงจากแหล่งกำเนิดในขณะมีการรบกวนที่มีระดับเสียงสูงกว่าระดับเสียงพื้นฐาน โดยมีระดับการรบกวนเกินกว่าระดับเสียงรบกวนที่กำหนดไว้ในประกาศคณะกรรมการสิ่งแวดล้อมแห่งชาติ ฉบับที่ ๒๙ (พ.ศ. ๒๕๕๐) เรื่อง ค่าระดับเสียงรบกวน

"ระดับเสียงพื้นฐาน" (Background sound level) หมายความว่า ระดับเสียงที่ตรวจวัดในสิ่งแวดล้อมในขณะยังไม่เกิดเสียงหรือไม่ได้รับเสียงจากแหล่งกำเนิดที่ประชาชนร้องเรียนหรือแหล่งกำเนิดที่คาดว่าประชาชนจะได้รับการรบกวนเป็นระดับเสียงเปอร์เซ็นไทล์ที่ ๙๐ (Percentile Level 90, L_{A90})

"ระดับเสียงขณะไม่มีการรบกวน" (Residual sound level) หมายความว่า ระดับเสียงที่ตรวจวัดในสิ่งแวดล้อมในขณะยังไม่เกิดเสียงจากแหล่งกำเนิดที่ประชาชนร้องเรียนหรือแหล่งกำเนิดที่คาดว่าประชาชนจะได้รับการรบกวนเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level, L_{Aeq})

"ระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด" (Specific sound level) หมายความว่า ระดับเสียงที่ตรวจวัดในสิ่งแวดล้อมในขณะเกิดเสียงจากแหล่งกำเนิดที่ประชาชนร้องเรียนหรือแหล่งกำเนิดที่คาดว่าประชาชนจะได้รับการรบกวนเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level, L_{Aeq})

"ระดับเสียงขณะมีการรบกวน" (Rating level) หมายความว่า ระดับเสียงที่ได้จากการคำนวณจากระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด และระดับเสียงขณะไม่มีการรบกวน รวมทั้งบวกเพิ่มระดับเสียงในกรณีบริเวณที่ทำการตรวจวัดเสียงของแหล่งกำเนิดเป็นพื้นที่ที่ต้องการความเงียบสงบ หรือเป็นแหล่งกำเนิดที่ก่อให้เกิดเสียงในช่วงเวลาระหว่าง ๒๒.๐๐ – ๐๖.๐๐ นาฬิกา และในกรณีแหล่งกำเนิดเสียงที่ทำให้เกิดเสียงกระแทก เสียงแหลมดัง เสียงที่ก่อให้เกิดความสั่นสะเทือนอย่างใดอย่างหนึ่ง

"เสียงกระแทก" หมายความว่า เสียงที่เกิดจากการตก ตี เคาะ หรือกระทบของวัตถุ หรือลักษณะอื่นใดซึ่งมีระดับเสียงสูงกว่าระดับเสียงทั่วไปในขณะนั้น และเกิดขึ้นในทันทีทันใดและสิ้นสุดลงภายในเวลาน้อยกว่า ๑ วินาที (Impulsive Noise) เช่น การตอกเสาเข็ม การปั๊มขึ้นรูปวัสดุ เป็นต้น

"เสียงแหลมดัง" หมายความว่า เสียงที่เกิดจากการเบียด เสียด สี เจียร หรือขัดวัตถุอย่างใด ๆ ที่เกิดขึ้น ในทันทีทันใด เช่น การใช้สว่านไฟฟ้าเจาะเหล็กหรือปูน การเจียรโลหะ การบีบหรืออัดโลหะโดยเครื่องอัด การขัดขึ้นเงาวัสดุด้วยเครื่องมือกล เป็นต้น

"เสียงที่มีความสั่นสะเทือน" หมายความว่า เสียงเครื่องจักร เครื่องดนตรี เครื่องเสียง หรือเครื่องมืออื่นใดที่มีความสั่นสะเทือนเกิดร่วมด้วย เช่น เสียงเบสที่ผ่านเครื่องขยายเสียง เป็นต้น

“ระดับการรบกวน” หมายความว่า ค่าความแตกต่างระหว่างระดับเสียงขณะมีการรบกวนกับระดับเสียงพื้นฐาน

“มาตรระดับเสียง” หมายความว่า เครื่องวัดระดับเสียงตามมาตรฐาน IEC 61672 class 1 ของคณะกรรมาธิการระหว่างประเทศว่าด้วยเทคนิคไฟฟ้า (International Electrotechnical Commission, IEC)

“เครื่องกำเนิดสัญญาณเสียงอ้างอิง” หมายความว่า เครื่องกำเนิดสัญญาณเสียงตามมาตรฐาน IEC 60942 class 1 ของคณะกรรมาธิการระหว่างประเทศว่าด้วยเทคนิคไฟฟ้า (International Electrotechnical Commission, IEC)

๒. การเตรียมเครื่องมือก่อนทำการตรวจวัด

๒.๑ ให้ใช้มาตรระดับเสียงที่ได้รับการสอบเทียบในช่วงไม่เกิน ๒ ปี เครื่องกำเนิดสัญญาณเสียงอ้างอิงที่ได้รับการสอบเทียบในช่วงไม่เกิน ๑ ปี โดยห้องปฏิบัติการที่ได้รับการรับรองมาตรฐาน มอก. ๑๗๐๒๕ (ISO 17025) หรือมีความสามารถในการสอบกลับได้ในหัวข้อที่ทำการสอบเทียบ

๒.๒ ให้ปรับเทียบมาตรระดับเสียงกับเครื่องกำเนิดสัญญาณเสียงอ้างอิงตามคู่มือการใช้งานที่ผู้ผลิตมาตรระดับเสียงกำหนดไว้ทุกครั้งก่อนที่จะทำการตรวจวัดระดับเสียง และให้ปรับมาตรระดับเสียงให้มีการถ่วงน้ำหนักความถี่แบบ “A” (A Frequency weighting) และการถ่วงน้ำหนักเวลาแบบ “Fast” (Fast Time weighting)

๓. การตั้งไมโครโฟนและมาตรระดับเสียง

การตั้งไมโครโฟนของมาตรระดับเสียงให้เป็นไปตามหลักเกณฑ์ดังต่อไปนี้

๓.๑ เป็นบริเวณที่ประชาชนร้องเรียนหรือที่คาดว่าจะได้รับการรบกวน แต่หากแหล่งกำเนิดเสียงไม่สามารถหยุดกิจกรรมที่เกิดเสียงได้ ให้ตั้งไมโครโฟนของมาตรระดับเสียงในการตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวนบริเวณอื่นที่มีสภาพแวดล้อมใกล้เคียง

๓.๒ การตั้งไมโครโฟนของมาตรระดับเสียงที่บริเวณภายนอกอาคาร ให้ตั้งสูงจากพื้นไม่น้อยกว่า ๑.๒ – ๑.๕ เมตร โดยในรัศมี ๓.๕ เมตร ตามแนวราบรอบไมโครโฟน ต้องไม่มีกำแพงหรือสิ่งอื่นใดที่มีคุณสมบัติในการสะท้อนเสียงกีดขวางอยู่

๓.๓ การตั้งไมโครโฟนของมาตรระดับเสียงที่บริเวณภายในอาคาร ให้ตั้งสูงจากพื้นไม่น้อยกว่า ๑.๒ – ๑.๕ เมตร โดยในรัศมี ๑ เมตร ตามแนวราบรอบไมโครโฟน ต้องไม่มีกำแพงหรือสิ่งอื่นใดที่มีคุณสมบัติในการสะท้อนเสียงกีดขวางอยู่ และต้องห่างจากช่องหน้าต่างหรือช่องทางออกนอกอาคารอย่างน้อย ๑.๕ เมตร

๔. การตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวน

ให้ตรวจวัดเป็นเวลาไม่น้อยกว่า ๕ นาที ขณะไม่มีเสียงจากแหล่งกำเนิดในช่วงเวลาใดเวลาหนึ่งซึ่งสามารถใช้เป็นตัวแทนของระดับเสียงพื้นฐาน และระดับเสียงขณะไม่มีการรบกวน โดยระดับเสียงพื้นฐานให้วัดเป็นระดับเสียงเปอร์เซ็นไทล์ที่ ๙๐ (Percentile Level 90, L_{A90}) ระดับเสียงขณะไม่มีการรบกวนให้วัดเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level, L_{Aeq}) แบ่งออกเป็น ๓ กรณี ดังนี้

๔.๑ แหล่งกำเนิดเสียงยังไม่เกิดหรือยังไม่มีการดำเนินกิจกรรม ให้ตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวน ในวัน เวลา และตำแหน่งที่คาดว่าจะได้รับการรบกวน

๔.๒ แหล่งกำเนิดเสียงมีการดำเนินกิจกรรมไม่ต่อเนื่อง ให้ตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวน ในวัน เวลาและตำแหน่งที่คาดว่าจะได้รับการรบกวน และเป็นตำแหน่งเดียวกันกับตำแหน่งที่จะมีการวัดระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด โดยให้หยุดกิจกรรมของแหล่งกำเนิดเสียงหรือวัดทันทีก่อนหรือหลังการดำเนินกิจกรรม

๔.๓ แหล่งกำเนิดเสียงมีการดำเนินกิจกรรมอย่างต่อเนื่องไม่สามารถหยุดการดำเนินกิจกรรมได้ให้ตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวน ในบริเวณอื่นที่มีสภาพแวดล้อมคล้ายคลึงกับบริเวณที่คาดว่าจะได้รับการรบกวนและไม่ได้รับผลกระทบจากแหล่งกำเนิดเสียง

ทั้งนี้ ระดับเสียงขณะไม่มีการรบกวนที่จะนำไปใช้คำนวณระดับเสียงขณะมีการรบกวนตามข้อ ๕ และระดับเสียงพื้นฐานที่จะนำไปใช้คำนวณค่าระดับการรบกวนตามข้อ ๖ ให้เป็นค่าที่ตรวจวัดเวลาเดียวกัน

๕. การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวน แบ่งออกเป็น ๕ กรณี ดังนี้

๕.๑ กรณีที่เสียงจากแหล่งกำเนิดเกิดขึ้นอย่างต่อเนื่องตั้งแต่ ๑ ชั่วโมงขึ้นไป ให้วัดระดับเสียงขณะเกิดเสียงของแหล่งกำเนิดเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) ๑ ชั่วโมง และนำผลการตรวจวัดมาคำนวณระดับเสียงขณะมีการรบกวน ตามสมการที่ ๑

$$\mathrm{L_{Aeq,Tr}} = [10\log_{10}(10^{0.1LAeq,Ts} - 10^{0.1LAeq,R})] + 10\log_{10}(\frac{T_s}{T_r}) \quad \textbf{สมการที่ ๑}$$

โดย $L_{Aeq,Tr}$ = ระดับเสียงขณะมีการรบกวน (มีหน่วยเป็น เดซิเบลเอ)

$L_{Aeq,Ts}$ = ระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด (มีหน่วยเป็น เดซิเบลเอ)

$L_{Aeq,R}$ = ระดับเสียงขณะไม่มีการรบกวน (มีหน่วยเป็น เดซิเบลเอ)

T_s = ระยะเวลาของช่วงเวลาที่แหล่งกำเนิดเกิดเสียง (มีหน่วยเป็น นาที)

T_r = ระยะเวลาอ้างอิงที่กำหนดขึ้นเพื่อใช้ในการคำนวณระดับเสียงขณะมีการรบกวน โดย

- ถ้าเป็นแหล่งกำเนิดที่ก่อให้เกิดเสียงในช่วงเวลา ๐๖.๐๐ – ๒๒.๐๐ นาฬิกา กำหนดให้มีค่าเท่ากับ ๖๐ นาที
- ถ้าบริเวณที่ทำการตรวจวัดระดับเสียงเป็นพื้นที่ที่ต้องการความเงียบสงบหรือเป็นแหล่งกำเนิดที่ก่อให้เกิดเสียงในช่วงเวลา ๒๒.๐๐ – ๐๖.๐๐ นาฬิกา กำหนดให้มีค่าเท่ากับ ๕ นาที

๕.๒ กรณีที่เสียงจากแหล่งกำเนิดเกิดขึ้นอย่างต่อเนื่องแต่ไม่ถึง ๑ ชั่วโมง ให้วัดระดับเสียงขณะเกิดเสียงของแหล่งกำเนิดตั้งแต่เริ่มต้นจนสิ้นสุดการดำเนินกิจกรรมนั้น ๆ เป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) และนำผลการตรวจวัดมาคำนวณระดับเสียงขณะมีการรบกวนตามสมการที่ ๑

๕.๓ กรณีเสียงจากแหล่งกำเนิดเกิดขึ้นอย่างไม่ต่อเนื่องและเกิดขึ้นมากกว่า ๑ ช่วงเวลา โดยแต่ละช่วงเวลาเกิดขึ้นไม่ถึง ๑ ชั่วโมง ให้วัดระดับเสียงขณะเกิดเสียงของแหล่งกำเนิดเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) ทุกช่วงเวลาที่เกิดขึ้นในเวลา ๑ ชั่วโมง และให้คำนวณระดับเสียงขณะมีการรบกวนตามลำดับ ดังนี้

(ก) คำนวณระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด ตามสมการที่ ๒

$$\mathrm{L_{Aeq,Ts}} = 10\log_{10}\left\{\left(\frac{1}{T_s}\right)\sum T_s 10^{0.1L_{Aeq,Ti}}\right\}$$ **สมการที่ ๒**

โดย $L_{Aeq,Ts}$ = ระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด (มีหน่วยเป็น เดซิเบลเอ)

T_s = $\sum T_i$ (มีหน่วยเป็น นาที)

$L_{Aeq,Ti}$ = ระดับเสียงที่ตรวจวัดได้ในช่วงที่แหล่งกำเนิดเกิดเสียงที่ช่วงเวลา **Ti,** (มีหน่วยเป็น เดซิเบลเอ)

T_i = ระยะเวลาของช่วงเวลาที่แหล่งกำเนิดเกิดเสียงที่ i, (มีหน่วยเป็น นาที)

(ข) นำผลที่ได้จากการคำนวณตามข้อ ๕ (๓) (ก) มาคำนวณเพื่อหาระดับเสียงขณะมีการรบกวนตามสมการที่ ๑

๕.๔ กรณีบริเวณที่จะทำการตรวจวัดเสียงของแหล่งกำเนิดเป็นพื้นที่ที่ต้องการความเงียบสงบ เช่น โรงพยาบาล โรงเรียน ศาสนสถาน ห้องสมุด หรือสถานที่อย่างอื่นที่มีลักษณะทำนองเดียวกัน หรือเป็นแหล่งกำเนิดที่ก่อให้เกิดเสียงในช่วงเวลาระหว่าง ๒๒.๐๐ – ๐๖.๐๐ นาฬิกา ให้วัดระดับเสียงขณะเกิดเสียงของแหล่งกำเนิดเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) ๕ นาที และคำนวณระดับเสียงขณะมีการรบกวนตามสมการที่ ๑ และบวกเพิ่มด้วย ๓ เดซิเบลเอ

๕.๕ กรณีแหล่งกำเนิดเสียงที่ทำให้เกิดเสียงกระแทก เสียงแหลมดัง เสียงที่ก่อให้เกิดความสั่นสะเทือนอย่างใดอย่างหนึ่งแก่ผู้ได้รับผลกระทบจากเสียงนั้น ไม่ว่าเสียงที่เกิดขึ้นจะต่อเนื่องหรือไม่ก็ตาม ให้นำระดับเสียงขณะมีการรบกวนตามข้อ ๕.๑, ๕.๒, ๕.๓ หรือ ๕.๔ แล้วแต่กรณี บวกเพิ่มด้วย ๕ เดซิเบลเอ

๖. วิธีการคำนวณค่าระดับการรบกวน

ให้นำระดับเสียงขณะมีการรบกวนตามข้อ ๕ หักออกด้วยระดับเสียงพื้นฐาน ตามข้อ ๔ ผลลัพธ์เป็นค่าระดับการรบกวน

ผลลัพธ์เป็นตัวเลขทศนิยม ๑ ตำแหน่ง และการปัดเศษทศนิยมให้เป็นไปตามมาตรฐานผลิตภัณฑ์อุตสาหกรรม มอก. ๙๒๙ - ๒๕๓๓ ดังนี้

๖.๑ ถ้าเศษตัวแรกมีค่าน้อยกว่า ๕ ให้ปัดเศษทิ้ง และคงตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้

๖.๒ ถ้าเศษตัวแรกมีค่ามากกว่า ๕ หรือเท่ากับ ๕ แล้วตามด้วยเลขอื่นที่ไม่ใช่ ๐ ทั้งหมด ให้ปัดเศษขึ้น คือ เพิ่มค่าของตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้ขึ้นอีก ๑

๖.๓ ถ้าเศษตัวแรกมีค่าเท่ากับ ๕ โดยไม่มีเลขอื่นต่อท้าย หรือเท่ากับ ๕ แล้วตามด้วย ๐ ทั้งหมด ให้ปฏิบัติดังนี้

(ก) เมื่อตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้เป็นเลขคี่ ให้เพิ่มค่าของตัวเลขนี้ขึ้นอีก ๑

(ข) เมื่อตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้เป็นเลขคู่หรือ ๐ ให้ปัดเศษทิ้ง

๗. แบบบันทึกการตรวจวัดเสียงรบกวน

ให้ผู้ตรวจวัดบันทึก

๗.๑ ชื่อ สกุล ตำแหน่งของผู้ตรวจวัด

๗.๒ ลักษณะเสียงและช่วงเวลาการเกิดเสียงของแหล่งกำเนิด

๗.๓ สถานที่ วัน และเวลาการตรวจวัดเสียง

๗.๔ ผลการตรวจวัดและคำนวณระดับเสียง

๗.๕ สรุปผล

ทั้งนี้ ผู้ตรวจวัดอาจจัดทำแบบบันทึกการตรวจวัดเสียงรบกวนรูปแบบอื่นที่มีเนื้อหาไม่น้อยกว่าที่กำหนดไว้

แบบบันทึกการตรวจวัดเสียงรบกวน

ชื่อสถานประกอบการ/โรงงาน/เจ้าของ	
ลักษณะเสียงของแหล่งกำเนิด ❍ เสียงเกิดขึ้นต่อเนื่องตั้งแต่ ๑ ชั่วโมงขึ้นไป ❍ เสียงเกิดขึ้นต่อเนื่องแต่ไม่ถึง ๑ ชั่วโมง ❍ เสียงเกิดขึ้นไม่ต่อเนื่อง และเกิดขึ้นมากกว่า ๑ ช่วงเวลา แต่ละช่วงเวลาเกิดขึ้นไม่ถึง ๑ ชั่วโมง ❍ มีเสียงกระแทก เสียงแหลมดัง เสียงที่มีความสั่นสะเทือน อย่างใดอย่างหนึ่ง (ระบุ)	
ช่วงเวลา/พื้นที่ที่เกิดเสียง ❍ กลางวัน (๐๖.๐๐-๒๒.๐๐ น.) ❍ กลางคืน (๒๒.๐๐-๐๖.๐๐ น.) ❍ พื้นที่ที่ต้องการความเงียบสงบ (ระบุ)	
เครื่องมือตรวจวัดและปรับเทียบ มาตรระดับเสียง ยี่ห้อ .... รุ่น .... มาตรฐาน IEC .... Class .... หมายเลขเครื่อง .... เครื่องกำเนิดสัญญาณเสียงอ้างอิง ยี่ห้อ .... รุ่น .... มาตรฐาน IEC .... Class .... หมายเลขเครื่อง	
สถานที่ วัน และเวลาการตรวจวัดเสียง **การตรวจวัดระดับเสียงพื้นฐาน และระดับเสียงขณะไม่มีการรบกวน** สถานที่ .... วันที่ .... เวลา ....น. **การตรวจวัดระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด** สถานที่ .... วันที่ .... เวลา ....น. **สภาพแวดล้อมของสถานที่ตรวจวัด**	
ผลการตรวจวัดระดับเสียง ระดับเสียงขณะเกิดเสียงของแหล่งกำเนิด .... เดซิเบลเอ ระดับเสียงขณะไม่มีการรบกวน .... เดซิเบลเอ ระดับเสียงพื้นฐาน .... เดซิเบลเอ	**ผลการคำนวณระดับเสียง** ระดับเสียงขณะมีการรบกวน .... เดซิเบลเอ ค่าระดับการรบกวน .... เดซิเบลเอ
สรุปผล ❍ เป็นเสียงรบกวน (มากกว่า ๑๐ เดซิเบลเอ) ❍ ไม่เป็นเสียงรบกวน	
ความเห็น/ ข้อเสนอแนะ	
(...) ตำแหน่ง .... ผู้ตรวจวัดและบันทึกผล	(...) ตำแหน่ง .... ผู้ตรวจสอบข้อมูล

ภาคผนวก ง7

ประกาศกรมโรงงานอุตสาหกรรม เรื่องวิธีการตรวจวัดระดับเสียงการรบกวน ระดับเสียงเฉลี่ย 24 ชั่วโมง และระดับเสียงสูงสุดที่เกิดจากการประกอบกิจการโรงงาน พ.ศ. 2567 ประกาศในราชกิจจานุเบกษา เล่ม 141 ตอนพิเศษ 50ง วันที่ 21 กุมภาพันธ์ 2567

ประกาศกรมโรงงานอุตสาหกรรม

เรื่อง วิธีการตรวจวัดระดับเสียงการรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง และระดับเสียงสูงสุด ที่เกิดจากการประกอบกิจการโรงงาน

พ.ศ. ๒๕๖๗

โดยที่เป็นการสมควรปรับปรุงวิธีการตรวจวัดและคำนวณระดับเสียงรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง และระดับเสียงสูงสุดที่เกิดจากการประกอบกิจการโรงงาน ให้สอดคล้องกับความก้าวหน้าทางวิทยาศาสตร์และเทคโนโลยีเพื่อประโยชน์ในการตรวจสอบค่าระดับเสียงรบกวนจากการประกอบกิจการโรงงานให้มีความถูกต้องและมีประสิทธิภาพมากยิ่งขึ้น

อาศัยอำนาจตามความในข้อ ๕ แห่งประกาศกระทรวงอุตสาหกรรม เรื่อง กำหนดค่าระดับเสียงการรบกวนและระดับเสียงที่เกิดจากการประกอบกิจการโรงงาน พ.ศ. ๒๕๔๘ อธิบดีกรมโรงงานอุตสาหกรรม จึงออกประกาศไว้ ดังต่อไปนี้

ข้อ ๑ ประกาศนี้ให้ใช้บังคับตั้งแต่วันถัดจากวันประกาศในราชกิจจานุเบกษาเป็นต้นไป

ข้อ ๒ ให้ยกเลิกประกาศกรมโรงงานอุตสาหกรรม เรื่อง กำหนดวิธีการตรวจวัดระดับเสียงการรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง และระดับเสียงสูงสุด ที่เกิดจากการประกอบกิจการโรงงาน พ.ศ. ๒๕๕๓

ข้อ ๓ ในประกาศนี้

“ระดับเสียงขณะไม่มีการรบกวน” หมายความว่า ระดับเสียงที่ตรวจวัดในสิ่งแวดล้อมขณะที่ยังไม่เกิดเสียงหรือไม่ได้รับเสียงที่เกิดจากการประกอบกิจการโรงงานเป็นระดับเสียงเฉลี่ย (L_{Aeq})

“เสียงกระแทก” หมายความว่า เสียงที่เกิดจากการประกอบกิจการโรงงานที่มีลักษณะ ตก ตี เคาะ หรือกระทบของวัตถุหรือลักษณะอื่นใดซึ่งมีระดับเสียงสูงกว่าระดับเสียงทั่วไปในขณะนั้นและเกิดขึ้นในทันทีทันใดและสิ้นสุดลง (Impulsive Noise) เช่น การตอกเสาเข็ม การปั๊มขึ้นรูปวัสดุ เป็นต้น ที่ส่งผลกระทบถึงตำแหน่งบริเวณผู้ร้องเรียนหรือบริเวณที่คาดว่าจะได้รับการรบกวนจากการประกอบกิจการโรงงาน

“เสียงแหลมดัง” หมายความว่า เสียงที่เกิดจากการประกอบกิจการโรงงานที่มีลักษณะ เบียด เสียด สี เจีย หรือขัดวัตถุใด ๆ ที่เกิดขึ้นในทันทีทันใด เช่น การใช้สว่านไฟฟ้าเจาะเหล็กหรือปูน การเจียโลหะ การบีบหรืออัดโลหะโดยเครื่องอัด การขัดขึ้นเงาวัสดุด้วยเครื่องมือกล เป็นต้น ที่ส่งผลกระทบถึงตำแหน่งบริเวณผู้ร้องเรียนหรือบริเวณที่คาดว่าจะได้รับการรบกวนจากการประกอบกิจการโรงงาน

“เสียงที่มีความสั่นสะเทือน” หมายความว่า เสียงจากการประกอบกิจการโรงงานที่มีลักษณะเครื่องจักรหรือเครื่องมืออื่นใดที่มีความสั่นสะเทือนเกิดร่วมด้วย เช่น เสียงเครื่องเจาะหิน เป็นต้น ที่ส่งผลกระทบถึงตำแหน่งบริเวณผู้ร้องเรียนหรือบริเวณที่คาดว่าจะได้รับการรบกวนจากการประกอบกิจการโรงงาน

"เครื่องกำเนิดสัญญาณเสียงอ้างอิง" หมายความว่า เครื่องกำเนิดสัญญาณเสียงตามมาตรฐาน IEC ๖๐๙๔๒ Class ๑ ของคณะกรรมาธิการระหว่างประเทศว่าด้วยเทคนิคไฟฟ้า (International Electrotechnical Commission, IEC)

ข้อ ๔ การเตรียมเครื่องมือก่อนทำการตรวจวัดให้ดำเนินการ ดังต่อไปนี้

๔.๑ ให้ใช้มาตรระดับเสียงที่ได้รับการสอบเทียบในช่วงไม่เกิน ๒ ปี เครื่องกำเนิดสัญญาณเสียงอ้างอิงที่ได้รับการสอบเทียบในช่วงไม่เกิน ๑ ปี โดยการสอบเทียบต้องดำเนินการโดยห้องปฏิบัติการที่ได้รับการรับรองมาตรฐาน มอก. ๑๗๐๒๕ (ISO/IEC 17025) หรือมีความสามารถในการสอบกลับได้ในหัวข้อที่ทำการสอบเทียบ

๔.๒ ให้ปรับเทียบมาตรระดับเสียงกับเครื่องกำเนิดสัญญาณเสียงอ้างอิงตามคู่มือการใช้งานที่ผู้ผลิตมาตรระดับเสียงกำหนดไว้ทุกครั้งเมื่อเปิดเครื่องมาตรระดับเสียงก่อนที่จะทำการตรวจวัดระดับเสียงและให้ปรับมาตรระดับเสียงให้มีการถ่วงน้ำหนักความถี่แบบ "A" (A Frequency weighting) และการถ่วงน้ำหนักเวลาแบบ "Fast" (Fast Time weighting)

ข้อ ๕ การตั้งไมโครโฟนของมาตรระดับเสียงให้เป็นไปตามหลักเกณฑ์ ดังต่อไปนี้

๕.๑ ให้ตั้งในบริเวณที่ประชาชนร้องเรียนหรือที่คาดว่าจะได้รับการรบกวนจากการประกอบกิจการโรงงาน แต่หากเสียงที่เกิดจากการประกอบกิจการโรงงานไม่สามารถหยุดกิจกรรมที่เกิดเสียงรบกวนได้ให้ตั้งไมโครโฟนของมาตรระดับเสียงในการตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวนบริเวณอื่นที่มีสภาพแวดล้อมใกล้เคียง

๕.๒ การตั้งไมโครโฟนของมาตรระดับเสียงที่บริเวณภายนอกอาคารให้ตั้งสูงจากพื้นไม่น้อยกว่า ๑.๒ เมตร แต่ไม่เกิน ๑.๕ เมตร โดยในรัศมี ๓.๕ เมตรตามแนวราบรอบไมโครโฟนต้องไม่มีกำแพงหรือสิ่งอื่นใดที่มีคุณสมบัติในการสะท้อนเสียงกีดขวางอยู่

๕.๓ การตั้งไมโครโฟนของมาตรระดับเสียงที่บริเวณภายในอาคารให้ตั้งสูงจากพื้นไม่น้อยกว่า ๑.๒ แต่ไม่เกิน ๑.๕ เมตรโดยในรัศมี ๑ เมตร ตามแนวราบรอบไมโครโฟนต้องไม่มีกำแพงหรือสิ่งอื่นใดที่มีคุณสมบัติในการสะท้อนเสียงกีดขวางอยู่และต้องห่างจากช่องหน้าต่างหรือช่องทางออกนอกอาคารอย่างน้อย ๑.๕ เมตร

๕.๔ กรณีที่ไม่สามารถตั้งไมโครโฟนของมาตรระดับเสียงตาม ๕.๒ และหรือ ๕.๓ ได้ ให้ตั้งไมโครโฟนในบริเวณที่ใกล้เคียงตามหลักเกณฑ์ใน ๕.๒ และหรือ ๕.๓ มากที่สุด หรือในบริเวณที่กรมโรงงานอุตสาหกรรมเห็นชอบ

ข้อ ๖ การตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวนให้ดำเนินการตรวจวัดเป็นเวลาไม่น้อยกว่า ๕ นาที ทั้งนี้ ตามหลักการและวิธีการ ดังนี้

๖.๑ กรณีเสียงรบกวนจากการประกอบกิจการโรงงานยังไม่เกิดหรือยังไม่มีการดำเนินกิจกรรม ให้ตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวน ในวัน เวลา และตำแหน่งที่คาดว่าจะได้รับการรบกวน

๖.๒ กรณีเสียงรบกวนจากการประกอบกิจการโรงงานที่สามารถหยุดกิจกรรมที่ทำให้เกิดเสียงรบกวนจากการประกอบกิจการโรงงานได้ ให้ตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวนในวันเวลาและตำแหน่งที่คาดว่าจะได้รับการรบกวน โดยให้หยุดกิจกรรมของแหล่งกำเนิดเสียงและตรวจวัดทันทีหลังการดำเนินกิจกรรม

๖.๓ กรณีเสียงรบกวนจากการประกอบกิจการโรงงานที่ไม่สามารถหยุดกิจกรรมที่ทำให้เกิดเสียงรบกวนจากการประกอบกิจการโรงงานได้ ให้ตรวจวัดระดับเสียงพื้นฐานและระดับเสียงขณะไม่มีการรบกวนในบริเวณอื่นที่มีสภาพแวดล้อมคล้ายคลึงกับบริเวณที่คาดว่าจะได้รับการรบกวนและไม่ได้รับผลกระทบจากเสียงรบกวนจากการประกอบกิจการโรงงาน โดยกรณีดังกล่าวให้รวมถึงกรณีร้องเรียนที่ผู้ร้องเรียนมีความประสงค์ไม่ให้แจ้งผู้ประกอบกิจการโรงงานทราบล่วงหน้า

ทั้งนี้ ระดับเสียงขณะไม่มีการรบกวนที่จะนำไปใช้คำนวณระดับเสียงขณะมีการรบกวนตามข้อ ๗ และระดับเสียงพื้นฐานที่จะนำไปใช้คำนวณค่าระดับการรบกวนตามข้อ ๘ ต้องเป็นค่าที่ตรวจวัดเวลาเดียวกัน

ข้อ ๗ การตรวจวัดและคำนวณระดับเสียงขณะมีการรบกวนให้ดำเนินการตามหลักเกณฑ์และวิธีการ ดังนี้

๗.๑ กรณีเสียงรบกวนจากการประกอบกิจการโรงงานเกิดขึ้นตั้งแต่ ๑ ชั่วโมงขึ้นไป ให้วัดระดับเสียงเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) ๑ ชั่วโมง และนำผลการตรวจวัดมาคำนวณระดับเสียงขณะมีการรบกวนตามสมการที่ ๑

$$L_{Aeq,Tr} = [\ 10\log_{10}\ (10^{0.1L_{Aeq,Ts}} - 10^{0.1L_{Aeq,R}})] + \ 10\log_{10}(\frac{T_s}{T_r})$$ **สมการที่ ๑**

โดย $L_{Aeq,Tr}$ = ระดับเสียงขณะมีการรบกวน (หน่วยเป็นเดซิเบลเอ)

$L_{Aeq,Ts}$ = ระดับเสียงที่ตรวจวัดขณะเกิดเสียงรบกวน (หน่วยเป็นเดซิเบลเอ)

$L_{Aeq,R}$ = ระดับเสียงที่ตรวจวัดขณะไม่มีการรบกวน (หน่วยเป็นเดซิเบลเอ)

T_S = ระยะเวลาของช่วงเวลาที่ตรวจวัดเสียงรบกวน (หน่วยเป็นนาที)

T_r = ระยะเวลาอ้างอิงที่กำหนดเพื่อใช้คำนวณระดับเสียงขณะมีการรบกวน โดย

- กรณีเสียงรบกวนในช่วงเวลา ๐๖.๐๐ - ๒๒.๐๐ นาฬิกา กำหนดให้มีค่าเท่ากับ ๖๐ นาที
- กรณีบริเวณที่ทำการตรวจวัดระดับเสียงเป็นพื้นที่ที่ต้องการความเงียบสงบหรือเป็นเสียงรบกวนในช่วงเวลา ๒๒.๐๐ - ๐๖.๐๐ นาฬิกา กำหนดให้มีค่าเท่ากับ ๕ นาที

๗.๒ กรณีเสียงรบกวนจากการประกอบกิจการโรงงานเกิดขึ้นไม่ถึง ๑ ชั่วโมง ให้วัดระดับเสียงขณะเกิดเสียงรบกวนตั้งแต่เริ่มต้นจนสิ้นสุดการดำเนินกิจกรรมนั้น ๆ เป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) และนำผลการตรวจวัดมาคำนวณระดับเสียงขณะมีการรบกวนตามสมการที่ ๑

๗.๓ กรณีเสียงรบกวนจากการประกอบกิจการโรงงานเกิดขึ้นมากกว่า ๑ ช่วงเวลา โดยแต่ละช่วงเวลาเกิดขึ้นไม่ถึง ๑ ชั่วโมง ให้วัดระดับเสียงเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) ทุกช่วงเวลาที่เกิดขึ้นในเวลา ๑ ชั่วโมงและให้คำนวณระดับเสียงขณะมีการรบกวนตามลำดับ ดังนี้

(ก) คำนวณระดับเสียงขณะเกิดเสียงรบกวนจากการประกอบกิจการโรงงาน ตามสมการที่ ๒

$$L_{Aeq,Ts} = 10\log_{10}\left\{\left(\frac{1}{T_s}\right)\sum T_i\, 10^{0.1L_{Aeq.Ti}}\right\}$$ **สมการที่ ๒**

โดย $L_{Aeq,Ts}$ = ระดับเสียงที่ตรวจวัดขณะเกิดเสียงรบกวน (หน่วยเป็น เดซิเบลเอ)

T_s = $\sum T_i$ (หน่วยเป็น นาที)

$L_{Aeq.Ti}$ = ระดับเสียงที่ตรวจวัดได้ในช่วงที่เกิดเสียงรบกวนที่ช่วงเวลา T_i, (หน่วยเป็น เดซิเบลเอ)

Ti = ระยะเวลาของช่วงเวลาที่ตรวจวัดเสียงรบกวนที่ i, (หน่วยเป็น นาที)

(ข) นำผลที่ได้จากการคำนวณตาม ๗.๓ (ก) มาคำนวณเพื่อหาระดับเสียงขณะมีการรบกวนตามสมการที่ ๑

๗.๔ กรณีบริเวณที่จะทำการตรวจวัดเสียงรบกวนจากการประกอบกิจการโรงงานเป็นพื้นที่ที่ต้องการความเงียบสงบ เช่น โรงพยาบาล โรงเรียน ศาสนสถาน ห้องสมุด หรือสถานที่อย่างอื่นที่มีลักษณะทำนองเดียวกันหรือเป็นเสียงรบกวนจากการประกอบกิจการโรงงานที่ก่อให้เกิดเสียงในช่วงเวลาระหว่าง ๒๒.๐๐ - ๐๖.๐๐ นาฬิกา ให้วัดระดับเสียงเป็นระดับเสียงเฉลี่ย (Equivalent A-Weighted Sound Pressure Level) ๕ นาที และคำนวณระดับเสียงขณะมีการรบกวนตามสมการที่ ๑ และบวกเพิ่มด้วย ๓ เดซิเบลเอ

๗.๕ กรณีเสียงรบกวนจากการประกอบกิจการโรงงานที่ทำให้เกิดเสียงกระแทก หรือเสียงแหลมดังหรือเสียงที่ก่อให้เกิดความสั่นสะเทือนอย่างใดอย่างหนึ่งหรือหลายอย่างรวมกันแก่ผู้ได้รับผลกระทบจากเสียงรบกวนนั้นให้นำระดับเสียงขณะมีการรบกวนตาม ๗.๑, ๗.๒, ๗.๓ หรือ ๗.๔ แล้วแต่กรณี บวกเพิ่มด้วย ๕ เดซิเบลเอ

ข้อ ๘ วิธีการคำนวณค่าระดับการรบกวน ให้นำระดับเสียงขณะมีการรบกวนตามข้อ ๗ หักออกด้วยระดับเสียงพื้นฐานตามข้อ ๖

ข้อ ๙ การตรวจวัดระดับเสียงเฉลี่ย ๒๔ ชั่วโมง ให้ใช้มาตรระดับเสียงตรวจวัดระดับเสียงอย่างต่อเนื่องตลอดเวลา ๒๔ ชั่วโมงใด ๆ เป็นค่าระดับเสียงเฉลี่ย ๒๔ ชั่วโมง ($L_{Aeq,24hr}$)

ข้อ ๑๐ การตรวจวัดระดับเสียงสูงสุด ให้ใช้มาตรระดับเสียงตรวจวัดระดับเสียงสูงสุดที่เกิดขึ้นในขณะใดขณะหนึ่งระหว่างการตรวจวัดเสียงรบกวน

ข้อ ๑๑ การตรวจวัดระดับเสียงตามประกาศนี้ ต้องมีการบันทึกข้อมูลโดยอย่างน้อยต้องประกอบด้วยข้อมูล ดังต่อไปนี้

๑๑.๑ ชื่อตัว ชื่อสกุล ตำแหน่งและหน่วยงานของผู้ตรวจวัด

๑๑.๒ ลักษณะเสียงและช่วงเวลาการเกิดเสียง

๑๑.๓ สถานที่วันและเวลาการตรวจวัดเสียง

๑๑.๔ ผลการตรวจวัดระดับเสียงพื้นฐาน ระดับเสียงขณะไม่มีการรบกวน ระดับเสียงขณะมีการรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง หรือระดับเสียงสูงสุด แล้วแต่กรณี

ข้อ ๑๒ การรายงานผลการตรวจวัดเสียงพื้นฐาน ระดับเสียงขณะมีการรบกวน ค่าระดับการรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง และระดับเสียงสูงสุด ให้รายงานเป็นตัวเลขทศนิยม ๑ ตำแหน่ง และการปัดเศษทศนิยมให้เป็นไปตามมาตรฐานผลิตภัณฑ์อุตสาหกรรม มอก. ๙๒๙ - ๒๕๓๓ ดังนี้

๑๒.๑ ถ้าเศษตัวแรกมีค่าน้อยกว่า ๕ ให้ปัดเศษทิ้ง และคงตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้

๑๒.๒ ถ้าเศษตัวแรกมีค่ามากกว่า ๕ หรือเท่ากับ ๕ แล้วตามด้วยเลขอื่นที่ไม่ใช่ศูนย์ทั้งหมดให้ปัดเศษขึ้น คือ เพิ่มค่าของตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้ขึ้นอีก ๑

๑๒.๓ ถ้าเศษตัวแรกมีค่าเท่ากับ ๕ โดยไม่มีเลขอื่นต่อท้ายหรือเท่ากับ ๕ แล้วตามด้วยศูนย์ทั้งหมด ให้ปฏิบัติ ดังนี้

(ก) เมื่อตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้เป็นเลขคี่ ให้เพิ่มค่าของตัวเลขนี้ขึ้นอีก ๑

(ข) เมื่อตัวเลขตัวสุดท้ายในตำแหน่งที่ต้องการคงไว้เป็นเลขคู่หรือศูนย์ให้ปัดเศษทิ้ง

ข้อ ๑๓ การตรวจวัดเสียงตามประกาศกรมโรงงานอุตสาหกรรม เรื่อง กำหนดวิธีการตรวจวัดระดับเสียงการรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง และระดับเสียงสูงสุด ที่เกิดจากการประกอบกิจการโรงงาน พ.ศ. ๒๕๕๓ แต่ยังไม่แล้วเสร็จในวันที่ประกาศนี้มีผลใช้บังคับให้ดำเนินการต่อไปตามประกาศกรมโรงงานอุตสาหกรรม เรื่อง กำหนดวิธีการตรวจวัดระดับเสียงการรบกวน ระดับเสียงเฉลี่ย ๒๔ ชั่วโมง และระดับเสียงสูงสุดที่เกิดจากการประกอบกิจการโรงงาน พ.ศ. ๒๕๕๓ จนแล้วเสร็จ

ประกาศ ณ วันที่ ๒๕ มกราคม พ.ศ. ๒๕๖๗
จุลพงษ์ ทวีศรี
อธิบดีกรมโรงงานอุตสาหกรรม

ภาคผนวก ง8

Guideline for Drinking-water Quality (WHO 2022)

Guidelines for drinking-water quality

Fourth edition incorporating the first and second addenda

World Health Organization

Nitrate and nitrite[1]

Nitrate (NO_3^-) is found naturally in the environment and is an important plant nutrient. It is present at varying concentrations in all plants and is a part of the nitrogen cycle. Nitrite (NO_2^-) is not usually present in significant concentrations except in a reducing environment, because nitrate is the more stable oxidation state. It can be formed by the microbial reduction of nitrate and in vivo by reduction from ingested nitrate. Nitrite can also be formed chemically in distribution pipes by *Nitrosomonas* bacteria during stagnation of nitrate-containing and oxygen-poor drinking-water in galvanized steel pipes, or if chloramination is used to provide a residual disinfectant. An excess of free ammonia entering the distribution system can lead to nitrification and the potential increase of nitrate and nitrite in drinking-water. Nitrate can reach both surface water and groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers and manures), from wastewater disposal and from oxidation of nitrogenous waste products in human and other animal excreta, including septic tanks. Nitrate can also occasionally reach groundwater as a consequence of natural vegetation. Surface water nitrate concentrations can change rapidly owing to surface runoff of fertilizer, uptake by phytoplankton and denitrification by bacteria, but groundwater concentrations generally show relatively slow changes. Nitrate and nitrite can also be produced as a result of nitrification in source water or distribution systems.

In general, the most important source of human exposure to nitrate and nitrite is through vegetables (nitrate and nitrite) and through meat in the diet (nitrite is used as a preservative in many cured meats). In some circumstances, however, drinking-water can make a significant contribution to nitrate and, occasionally, nitrite intake. In the case of bottle-fed infants, drinking-water can be the major external source of exposure to nitrate and nitrite.

Guideline values[2]	*Nitrate*: 50 mg/l as nitrate ion, to be protective against methaemoglobinaemia and thyroid effects in the most sensitive subpopulation, bottle-fed infants, and, consequently, other population subgroups
	Nitrite: 3 mg/l as nitrite ion, to be protective against methaemoglobinaemia induced by nitrite from both endogenous and exogenous sources in bottle-fed infants, the most sensitive subpopulation, and, consequently, the general population
	Combined nitrate plus nitrite: The sum of the ratios of the concentrations of each of nitrate and nitrite to its guideline value should not exceed 1
Occurrence	Nitrate levels vary significantly, but levels in well water are often higher than those in surface water and, unless heavily influenced by surface water, are less likely to fluctuate. Concentrations often approach or exceed 50 mg/l where there are significant sources of contamination. Nitrite levels are normally lower, less than a few milligrams per litre.

[1] As nitrate and nitrite are chemicals of significant concern in some natural waters, the chemical fact sheet on nitrate and nitrite has been expanded.

[2] Conversion factors: 1 mg/l as nitrate = 0.226 mg/l as nitrate-nitrogen; 1 mg/l as nitrite = 0.304 mg/l as nitrite-nitrogen.

Basis of guideline value derivation	*Nitrate (bottle-fed infants)*: In epidemiological studies, no adverse health effects (methaemoglobinaemia or thyroid effects) were reported in infants in areas where drinking-water consistently contained nitrate at concentrations below 50 mg/l
	Nitrite (bottle-fed infants): Based on: 1) no incidence of methaemoglobinaemia at nitrate concentrations below 50 mg/l (as nitrate ion) in drinking-water for bottle-fed infants less than 6 months of age (assuming body weight of 2 kg); 2) converting 50 mg/l as nitrate to corresponding molar concentration for nitrite; 3) multiplying by a factor of 0.1 to account for the estimated conversion rate of nitrate to nitrite in infants where nitrite is formed endogenously from nitrate at a rate of 5–10%; and 4) multiplying by a source allocation factor for drinking-water of 100% or 1, as a bottle-fed infant's primary exposure to nitrite is through consumption of formula reconstituted with drinking-water that contains nitrate or nitrite. As the guideline value is based on the most sensitive subgroup of the population (bottle-fed infants less than 6 months of age), application of an uncertainty factor is not deemed necessary.
	Combined nitrate plus nitrite: To account for the possibility of the simultaneous occurrence of nitrate and nitrite in drinking-water
Limit of detection	MDLs of 0.009 mg/l as nitrate ion and 0.013 mg/l as nitrite ion by IC; MDL of 0.04–4.4 mg/l as nitrate ion by automated cadmium reduction with colorimetry (recommended for the analysis of nitrate at concentrations below 0.4 mg/l)
Treatment performance	*Nitrate*: Effective central treatment technologies involve the physical/chemical and biological removal of nitrate and include ion exchange, reverse osmosis, biological denitrification and electrodialysis, which are capable of removing over 80% of nitrate from water to achieve effluent nitrate concentrations as low as 13 mg/l; conventional treatment processes (coagulation, sedimentation, filtration and chlorination) are not effective
	Nitrite: Treatment usually focuses on nitrate, because nitrite is readily converted to nitrate by many disinfectants
Additional comments	The guideline values for both nitrate and nitrite are based on short-term effects; however, they are also considered protective for any possible long-term effects .
	Methaemoglobinaemia is complicated by the presence of microbial contamination and subsequent gastrointestinal infection, which can increase the risk for bottle-fed infants significantly. Authorities should therefore be all the more vigilant that water to be used for bottle-fed infants is microbiologically safe when nitrate is present at concentrations near or above the guideline value. It is particularly important to ensure that these infants are not currently exhibiting symptoms of gastrointestinal infection (diarrhoea). Also, as excessive boiling of water to ensure microbiological safety can concentrate levels of nitrate in the water, care should be taken to ensure that water is heated only until it reaches a rolling boil. In extreme situations, alternative sources of water (e.g. bottled water) can be used.
	Nitrite is relatively unstable and can be rapidly oxidized to nitrate. Nitrite can occur in the distribution system at higher concentrations when chloramination is used, but the occurrence is almost invariably intermittent. Methaemoglobinaemia is therefore the most important consideration, and the guideline value derived for protection against methaemoglobinaemia would be the most appropriate under these circumstances, allowing for any nitrate that may also be present.

	All water systems that practise chloramination should closely and regularly monitor their systems to verify disinfectant levels, microbiological quality and nitrite levels. If nitrification is detected (e.g. reduced disinfectant residuals and increased nitrite levels), steps can be taken to modify the treatment train or water chemistry in order to minimize nitrite formation. Effective disinfection must never be compromised. Excessively high levels may occur in small supplies; where this is suspected from the risk assessment, testing may be appropriate.
Assessment date	2016
Principal references	Health Canada (2013). *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Nitrate and nitrite* WHO (2016). *Nitrate and nitrite in drinking-water*

Absorption of nitrate ingested from vegetables, meat or water is rapid and in excess of 90%; final excretion is in the urine. In humans, about 25% of ingested nitrate is recirculated in saliva, of which about 20% is converted to nitrite by the action of bacteria in the mouth. There is also endogenous formation of nitrate from nitric oxide and protein breakdown as part of normal metabolism. In normal healthy adults, this endogenous synthesis leads to the excretion of about 62 mg of nitrate ion per day in the urine. Endogenous formation of nitrate or nitrite can be significantly increased in the presence of infections, particularly gastrointestinal infections. When nitrate intake is low, endogenous formation may be the major source of nitrate in the body. Nitrate metabolism is different in humans and rats, as rats may not actively secrete nitrate in their saliva.

Nitrate probably has a role in protecting the gastrointestinal tract against a variety of gastrointestinal pathogens, as nitrous oxide and acidified nitrite have antibacterial properties. It may have other beneficial physiological roles. Hence, there may be a benefit from exogenous nitrate uptake, and there remains a need to balance the potential risks with the potential benefits.

Significant bacterial reduction of nitrate to nitrite does not normally take place in the stomach, except in individuals with low gastric acidity or with gastrointestinal infections. These may include individuals using antacids, particularly those that block acid secretion. In humans, methaemoglobinaemia is a consequence of the reaction of nitrite with haemoglobin in the red blood cells to form methaemoglobin, which binds oxygen tightly and does not release it, thus blocking oxygen transport. Although most absorbed nitrite is oxidized to nitrate in the blood, residual nitrite can react with haemoglobin. High levels of methaemoglobin (>10%) formation in infants can give rise to cyanosis, referred to as blue-baby syndrome. Although clinically significant methaemoglobinaemia can occur as a result of extremely high nitrate intake in adults and children, the most familiar situation is its occurrence in bottle-fed infants. This was considered to be primarily a consequence of high levels of nitrate in water, although there have been cases of methaemoglobinaemia in weaned infants, associated with high nitrate intake from vegetables. Bottle-fed infants are considered to be at greater risk because the intake of water in relation to body weight is high and, in infants, the development of repair enzymes is limited. In clinical epidemiological studies of methaemoglobinaemia and subclinical increases in methaemoglobin levels associated with drinking-water nitrate, 97% of cases occurred at concentrations in excess of 44.3 mg/l, with clinical symptoms associated with the higher concentrations. The affected individuals were almost exclusively under 3 months of age.

Although drinking-water nitrate may be an important risk factor for methaemoglobinaemia in bottle-fed infants, there is compelling evidence that the risk of methaemoglobinaemia is primarily increased in the presence of simultaneous gastrointestinal infections, which increase endogenous nitrite formation, may increase reduction of nitrate to nitrite and may also increase the intake of water in combatting dehydration. Cases have been described in which gastrointestinal infection seems to have been the primary cause of methaemoglobinaemia. Most cases of methaemoglobinaemia reported in the literature are associated with contaminated private wells (predominantly when the drinking-water is anaerobic) that also have a high probability of microbial contamination, which should not occur if it is properly disinfected.

Although numerous epidemiological studies have investigated the relationship between exposure to nitrate or nitrite in drinking-water and cancer occurrence, the weight of evidence does not support an association between cancer and exposure to nitrate or nitrite per se. Nitrite can react with nitrosatable compounds, primarily secondary amines, in the body to form *N*-nitroso compounds. A number of these are considered to be carcinogenic to humans, whereas others, such as *N*-nitrosoproline, are not. Several studies have been carried out on the formation of *N*-nitroso compounds in relation to nitrate intake in humans, but there is large variation in the intake of nitrosatable compounds and in gastric physiology. Higher mean levels of *N*-nitroso compounds, along with high nitrate levels, have been found in the gastric juice of individuals who are achlorhydric (i.e. have very low levels of hydrochloric acid in the stomach). However, other studies have been largely inconclusive, and there appears to be no clear relationship with drinking-water nitrate compared with overall nitrate intake in relation to formation of *N*-nitroso compounds. Moderate consumption of a number of dietary antioxidant components, such as ascorbic acid and green tea, appears to reduce endogenous *N*-nitrosamine formation.

A significant number of epidemiological studies have been carried out on the association of nitrate intake with primarily gastric cancers. Although the epidemiological data are considered to be inadequate to allow definitive conclusions to be drawn regarding all cancers, there is no convincing evidence of a causal association with any cancer site. The weight of evidence indicates that there is unlikely to be a causal association between gastric cancer and nitrate in drinking-water. This is consistent with the conclusion by IARC that ingested nitrate or nitrite under conditions that result in endogenous nitrosation is probably carcinogenic to humans (Group 2A), but not nitrate alone.

There have been suggestions that nitrate in drinking-water could be associated with congenital malformations, but the overall weight of evidence does not support this.

Nitrate appears to competitively inhibit iodine uptake, with the potential for an adverse effect on the thyroid. Current evidence also suggests that exposure to nitrate in drinking-water may alter human thyroid gland function by competitively inhibiting thyroidal iodide uptake, leading to altered thyroid hormone concentrations and functions. Although studies found that exposure to nitrate concentrations above 50 mg/l are weakly associated with altered thyroid function, the evidence is limited, conflicting and based on studies with important methodological limitations. Mode of action data suggest that pregnant women and infants are the most sensitive populations, owing primarily to the importance of adequate thyroid hormones for normal neurodevelopment in the fetus and infant, but also to increased thyroid hormone turnover and low intrathyroidal stores in fetal and early life.

There have been suggestions of an association between nitrate in drinking-water and the incidence of childhood diabetes mellitus. However, subsequent studies have not found a significant relationship, and no mechanism has been identified.

In some studies on rats treated with high doses of nitrite, a dose-related hypertrophy of the zona glomerulosa of the adrenal was seen; one strain of rats appeared to be more sensitive than others. However, this minimal hyperplasia was considered to be due to physiological adaptation to small fluctuations in blood pressure in response to high nitrite doses.

Nitrate is not carcinogenic in laboratory animals. Nitrite has been frequently studied, and there have been suggestions of carcinogenic activity, but only at very high doses. The most recent long-term studies have shown only equivocal evidence of carcinogenicity in the forestomach of female mice, but not in rats or male mice. In view of the lack of evidence for genotoxicity, this led to the conclusion that sodium nitrite was not carcinogenic in mice and rats. In addition, as humans do not possess a forestomach and the doses were high, the significance of these data for humans is very doubtful.

The guideline value for nitrate of 50 mg/l, as nitrate ion, is based on an absence of health effects (methaemoglobinaemia and thyroid effects) in epidemiological studies and is protective for bottle-fed infants and, consequently, other parts of the population. Methaemoglobinaemia is complicated by the presence of microbial contamination and subsequent gastrointestinal infection, which can increase the risk for this group significantly. Authorities should therefore be all the more vigilant that water to be used for bottle-fed infants is microbiologically safe when nitrate is present at concentrations near the guideline value. It is particularly important to ensure that these infants are not currently exhibiting symptoms of significant gastrointestinal infection (diarrhoea). Also, as excessive boiling of water to ensure microbiological safety can concentrate levels of nitrate in the water, care should be taken to ensure that water is heated only until it reaches a rolling boil. In extreme situations, alternative sources of water (e.g. bottled water) can be used.

The guideline for nitrite of 3 mg/l, as nitrite ion, is based on: 1) no incidence of methaemoglobinaemia at nitrate concentrations below 50 mg/l in drinking-water for bottle-fed infants less than 6 months of age (assuming body weight of 2 kg), 2) converting 50 mg/l nitrate to the corresponding molar concentration for nitrite, 3) multiplying by a factor of 0.1 to account for the estimated conversion rate of nitrate to nitrite in infants where nitrite is formed endogenously from nitrate at a rate of 5–10% and 4) multiplying by a source allocation factor for drinking water of 100% or 1, as a bottle-fed infant's primary exposure to nitrite is through consumption of formula reconstituted with nitrate- or nitrite-containing drinking-water. As the health-based value is based on the most sensitive subgroup of the population (bottle-fed infants less than 6 months of age), application of an uncertainty factor is not deemed necessary.

Because of the possibility of the simultaneous occurrence of nitrate and nitrite in drinking-water, the sum of the ratios of the concentration (C) of each to its guideline value (GV) should not exceed 1:

$$\frac{C_{nitrate}}{GV_{nitrate}} + \frac{C_{nitrite}}{GV_{nitrite}} \leq 1$$

The guideline values are based on short-term effects; however, they are also considered protective for long-term effects.

Practical considerations

The most appropriate means of controlling nitrate concentrations, particularly in groundwater, is the prevention of contamination. This may take the form of appropriate management of agricultural practices (e.g. management of fertilizer and manure application and storage of animal manures) and sanitation practices (e.g. the careful siting of pit latrines and septic tanks, sewer leakage control).

Methaemoglobinaemia has most frequently been associated with private wells. It is particularly important to ensure that septic tanks and pit latrines are not sited near a well or where a well is to be dug and to ensure that animal manure is kept at a sufficient distance to ensure that runoff cannot enter the well or the ground near the well. It is particularly important that the household use of manures and fertilizers on small plots near wells should be managed with care to avoid potential contamination. The well should be sufficiently protected to prevent runoff from entering the well. Where there are elevated concentrations of nitrate or where inspection of the well indicated that there are sources of nitrate close by that could be causing contamination, particularly where there are also indications that microbiological quality might also be poor, a number of actions can be taken. As noted above, water should be heated only until the water reaches a rolling boil or disinfected by an appropriate means before consumption. Where alternative supplies are available for bottle-fed infants, these can be used, taking care to ensure that they are microbiologically safe. Steps should then be taken to protect the well and ensure that sources of both nitrate and microbial contamination are removed from the vicinity of the well.

In areas where household wells are common, health authorities may wish to take a number of steps to ensure that nitrate contamination is not or does not become a problem. Such steps could include targeting mothers, particularly expectant mothers, with appropriate information about water safety, assisting with visual inspection of wells to determine whether a problem may exist, providing testing facilities where a problem is suspected, providing guidance on disinfecting water or, where nitrate levels are particularly high, providing bottled water from safe sources or providing advice as to where such water can be obtained.

With regard to piped supplies, where nitrate is present, the first potential approach to treatment of drinking-water supplies, if source substitution is not feasible, is to dilute the contaminated water with a low-nitrate source. Where blending is not feasible, a number of treatment techniques are available for drinking-water. The first is disinfection, which may serve to oxidize nitrite to the less toxic nitrate as well as minimize the pathogenic and non-pathogenic reducing bacterial population in the water. Nitrate removal methods include ion exchange, biological denitrification, reverse osmosis and electrodialysis. However, there are disadvantages associated with all of these approaches, including cost, operational complexities and the need for disposal of resin, brine or reject water. Conventional municipal water treatment processes (coagulation, sedimentation, filtration and chlorination) are not effective for nitrate removal, as nitrate is a stable and highly soluble ion with low potential for co-precipitation and adsorption.

In systems with a water source containing naturally occurring ammonia or that add ammonia for chloramination, free ammonia entering the distribution system can be one of the causative factors of nitrification and the potential increase of nitrate and nitrite in the distribution system. Care should be taken with the use of chloramination for providing a residual disinfectant in the distribution system. It is important to manage this to minimize nitrite formation, either in the main distribution system or in the distribution systems of buildings.

Nitrilotriacetic acid

Nitrilotriacetic acid, or NTA, is used primarily in laundry detergents as a replacement for phosphates and in the treatment of boiler water to prevent accumulation of mineral scale.

Guideline value	0.2 mg/l (200 μg/l)
Occurrence	Concentrations in drinking-water usually do not exceed a few micrograms per litre, although concentrations as high as 35 μg/l have been measured
TDI	10 μg/kg body weight, based on nephritis and nephrosis in a 2-year study in rats and using an uncertainty factor of 1000 (100 for interspecies and intraspecies variation and 10 for carcinogenic potential at high doses)
Limit of detection	0.2 μg/l using GC with a nitrogen-specific detector
Treatment performance	No information found on removal from water
Guideline value derivation	
• allocation to water	50% of TDI
• weight	60 kg adult
• consumption	2 litres/day
Assessment date	1993
Principal reference	WHO (2003) *Nitrilotriacetic acid in drinking-water*

NTA is not metabolized in experimental animals and is rapidly eliminated, although some may be briefly retained in bone. It is of low acute toxicity to experimental animals, but it has been shown to produce kidney tumours in rodents following long-term exposure to doses higher than those required to produce nephrotoxicity. IARC

Reason for not establishing a guideline value	Taste and odour will in most cases be detectable at concentrations below those of health concern, particularly with short-term exposure
Assessment date	2004
Principal reference	WHO (2008) *Petroleum products in drinking-water*

Exposure to the constituents of petroleum products through drinking-water is frequently short term, as the result of an accidental spill or short-term incident. Such incidents may lead to high concentrations of total petroleum hydrocarbons. However, a number of the most soluble aromatic hydrocarbons will be detectable by taste or odour at concentrations below those concentrations of concern for health, particularly for short-term exposure. Substances such as the alkyl benzenes and the alkyl naphthalenes have taste and odour thresholds of a few micrograms per litre. In view of the above, it is not considered appropriate to set a formal health-based guideline value for petroleum products in drinking-water.

In the event of a spill, it may be necessary to carry out a context-specific assessment of the risk to health. The fact that petroleum products are complex mixtures of many individual hydrocarbons is a complicating factor in determining the potential risks to consumers. The traditional approach of evaluating individual chemicals in assessing the risks from drinking-water is therefore largely inappropriate. In order to overcome this difficulty, it is more practical to consider a series of hydrocarbon fractions and to determine appropriate tolerable concentrations for those fractions. The most widely accepted approach is that developed by the Total Petroleum Hydrocarbons Criteria Working Group in the USA, which divided total petroleum hydrocarbons into a series of aliphatic and aromatic fractions based on the number of carbon atoms and the boiling point, to give equivalent carbon numbers.

This pragmatic approach provides a suitable basis for assessing the potential health risks associated with larger-scale contamination of drinking-water by petroleum products. The allocation of 10% of each of the reference doses, equivalent to TDIs, for the various fractions to drinking-water provides a conservative assessment of the risks. Although the approach is based on the analysis of hydrocarbon fractions, most are of low solubility, and the most soluble fractions, consisting largely of lower molecular weight aromatic hydrocarbons, will be present in the greatest concentration.

pH

No health-based guideline value is proposed for pH. Although pH usually has no direct impact on consumers, it is one of the most important operational water quality parameters (see chapter 10).

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	An important operational water quality parameter
Assessment date	1993
Principal reference	WHO (2007) *pH in drinking-water*

has a low acute toxicity. In short-term toxicity studies in rats, impairment of glutathione transferase activity and reduced glutathione concentrations were observed. In in vitro tests, styrene has been shown to be mutagenic in the presence of metabolic activation only. In in vitro as well as in vivo studies, chromosomal aberrations have been observed, mostly at high doses of styrene. The reactive intermediate styrene-7,8-oxide is a direct-acting mutagen. In long-term studies, orally administered styrene increased the incidence of lung tumours in mice at high dose levels but had no carcinogenic effect in rats. Styrene-7,8-oxide was carcinogenic in rats after oral administration. IARC has classified styrene in Group 2B (possibly carcinogenic to humans). The available data suggest that the carcinogenicity of styrene is due to overloading of the detoxification mechanism for styrene-7,8-oxide (e.g. glutathione depletion).

Sulfate

Sulfates occur naturally in numerous minerals and are used commercially, principally in the chemical industry. They are discharged into water in industrial wastes and through atmospheric deposition; however, the highest levels usually occur in groundwater and are from natural sources. In general, the average daily intake of sulfate from drinking-water, air and food is approximately 500 mg, food being the major source. However, in areas with drinking-water supplies containing high levels of sulfate, drinking-water may constitute the principal source of intake.

Reason for not establishing a guideline value	Not of health concern at levels found in drinking-water
Additional comments	May affect acceptability of drinking-water
Assessment date	2003
Principal reference	WHO (2004) *Sulfate in drinking-water*

The existing data do not identify a level of sulfate in drinking-water that is likely to cause adverse human health effects. The data from a liquid diet study with piglets and from tap water studies with human volunteers indicate a laxative effect at concentrations of 1000–1200 mg/l, but no increase in diarrhoea, dehydration or weight loss.

No health-based guideline is proposed for sulfate. However, because of the gastrointestinal effects resulting from ingestion of drinking-water containing high sulfate levels, it is recommended that health authorities be notified of sources of drinking-water that contain sulfate concentrations in excess of 500 mg/l. The presence of sulfate in drinking-water may also cause noticeable taste (see chapter 10) and may contribute to the corrosion of distribution systems.

2,4,5-T

The half-lives for degradation of chlorophenoxy herbicides, including 2,4,5-T (CAS No. 93-76-5), also known as 2,4,5-trichlorophenoxyacetic acid, in the environment are in the order of several days. Chlorophenoxy herbicides are not often found in food.

ภาคผนวก ง9

ข้อกำหนดของ Occupational Safety & Health Administration (OSHA)

PARTICULATES NOT OTHERWISE REGULATED, TOTAL 0500

DEFINITION: total aerosol mass CAS: NONE RTECS: NONE

METHOD: 0500, Issue 2	EVALUATION: FULL	Issue 1: 15 February 1984 Issue 2: 15 August 1994

OSHA: 15 mg/m^3
NIOSH: no REL
ACGIH: 10 mg/m^3, total dust less than 1% quartz

PROPERTIES: contains no asbestos and quartz less than 1%

SYNONYMS: nuisance dusts; particulates not otherwise classified

SAMPLING

SAMPLER:	FILTER (tared 37-mm, 5-µm PVC filter)
FLOW RATE:	1 to 2 L/min
VOL-MIN: -MAX:	7 L @ 15 mg/m^3 133 L @ 15 mg/m^3
SHIPMENT:	routine
SAMPLE STABILITY:	indefinitely
BLANKS:	2 to 10 field blanks per set
BULK SAMPLE:	none required

ACCURACY

RANGE STUDIED:	8 to 28 mg/m^3
BIAS:	0.01%
OVERALL PRECISION ($\hat{S}_{rT}$):	0.056 [1]
ACCURACY:	±11.04%

MEASUREMENT

TECHNIQUE:	GRAVIMETRIC (FILTER WEIGHT)
ANALYTE:	airborne particulate material
BALANCE:	0.001 mg sensitivity; use same balance before and after sample collection
CALIBRATION:	National Institute of Standards and Technology Class S-1.1 weights or ASTM Class 1 weights
RANGE:	0.1 to 2 mg per sample
ESTIMATED LOD:	0.03 mg per sample
PRECISION ($\bar{S}_r$):	0.026 [2]

APPLICABILITY: The working range is 1 to 20 mg/m^3 for a 100-L air sample. This method is nonspecific and determines the total dust concentration to which a worker is exposed. It may be applied, e.g., to gravimetric determination of fibrous glass [3] in addition to the other ACGIH particulates not otherwise regulated [4].

INTERFERENCES: Organic and volatile particulate matter may be removed by dry ashing [3].

OTHER METHODS: This method is similar to the criteria document method for fibrous glass [3] and Method 5000 for carbon black. This method replaces Method S349 [5]. Impingers and direct-reading instruments may be used to collect total dust samples, but these have limitations for personal sampling.

EQUIPMENT:

1. Sampler: 37-mm PVC, 2- to 5-µm pore size membrane or equivalent hydrophobic filter and supporting pad in 37-mm cassette filter holder.
2. Personal sampling pump, 1 to 2 L/min, with flexible connecting tubing.
3. Microbalance, capable of weighing to 0.001 mg.
4. Static neutralizer: e.g., Po-210; replace nine months after the production date.
5. Forceps (preferably nylon).
6. Environmental chamber or room for balance (e.g., 20 °C ± 1 °C and 50% ± 5% RH).

SPECIAL PRECAUTIONS: None.

PREPARATION OF FILTERS BEFORE SAMPLING:

1. Equilibrate the filters in an environmentally controlled weighing area or chamber for at least 2 h. NOTE: An environmentally controlled chamber is desirable, but not required.
2. Number the backup pads with a ballpoint pen and place them, numbered side down, in filter cassette bottom sections.
3. Weigh the filters in an environmentally controlled area or chamber. Record the filter tare weight, W_1 (mg).
   a. Zero the balance before each weighing.
   b. Handle the filter with forceps. Pass the filter over an antistatic radiation source. Repeat this step if filter does not release easily from the forceps or if filter attracts balance pan. Static electricity can cause erroneous weight readings.
4. Assemble the filter in the filter cassettes and close firmly so that leakage around the filter will not occur. Place a plug in each opening of the filter cassette. Place a cellulose shrink band around the filter cassette, allow to dry and mark with the same number as the backup pad.

SAMPLING:

5. Calibrate each personal sampling pump with a representative sampler in line.
6. Sample at 1 to 2 L/min for a total sample volume of 7 to 133 L. Do not exceed a total filter loading of approximately 2 mg total dust. Take two to four replicate samples for each batch of field samples for quality assurance on the sampling procedure.

SAMPLE PREPARATION:

7. Wipe dust from the external surface of the filter cassette with a moist paper towel to minimize contamination. Discard the paper towel.
8. Remove the top and bottom plugs from the filter cassette. Equilibrate for at least 2 h in the balance room.
9. Remove the cassette band, pry open the cassette, and remove the filter gently to avoid loss of dust. NOTE: If the filter adheres to the underside of the cassette top, very gently lift away by using the dull side of a scalpel blade. This must be done carefully or the filter will tear.

CALIBRATION AND QUALITY CONTROL:

10. Zero the microbalance before all weighings. Use the same microbalance for weighing filters before and after sample collection. Maintain and calibrate the balance with National Institute of Standards and Technology Class S-1.1 or ASTM Class 1 weights.
11. The set of replicate samples should be exposed to the same dust environment, either in a laboratory dust chamber [7] or in the field [8]. The quality control samples must be taken with the same

equipment, procedures, and personnel used in the routine field samples. The relative standard deviation calculated from these replicates should be recorded on control charts and action taken when the precision is out of control [7].

MEASUREMENT:

12. Weigh each filter, including field blanks. Record the post-sampling weight, W_2 (mg). Record anything remarkable about a filter (e.g., overload, leakage, wet, torn, etc.)

CALCULATIONS:

13. Calculate the concentration of total particulate, C (mg/m^3), in the air volume sampled, V (L):

$$C = \frac{(W_2 - W_1) - (B_2 - B_1)}{V} \times 10^3, \text{ mg/m}^3,$$

where: W_1 = tare weight of filter before sampling (mg),
W_2 = post-sampling weight of sample-containing filter (mg),
B_1 = mean tare weight of blank filters (mg),
B_2 = mean post-sampling weight of blank filters (mg).

EVALUATION OF METHOD:

Lab testing with blank filters and generated atmospheres of carbon black was done at 8 to 28 mg/m^3 [2,6]. Precision and accuracy data are given on page 0500-1.

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METHOD REVISED BY:

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PARTICULATES NOT OTHERWISE REGULATED, RESPIRABLE 0600

DEFINITION: aerosol collected by sampler with 4-µm median cut point | CAS: None | RTECS: None

METHOD: 0600, Issue 3	EVALUATION: FULL	Issue 1: 15 February 1984 Issue 3: 15 January 1998

OSHA: 5 mg/m³
NIOSH: no REL
ACGIH: 3 mg/m³

PROPERTIES: contains no asbestos and quartz less than 1%; penetrates non-ciliated portions of respiratory system

SYNONYMS: nuisance dusts; particulates not otherwise classified

SAMPLING		MEASUREMENT	
SAMPLER:	CYCLONE + FILTER (10-mm nylon cyclone, Higgins-Dewell [HD] cyclone, or aluminum cyclone + tared 5-µm PVC membrane)	**TECHNIQUE:**	GRAVIMETRIC (FILTER WEIGHT)
FLOW RATE:	nylon cyclone: 1.7 L/min HD cyclone: 2.2 L/min Al cyclone: 2.5 L/min	**ANALYTE:**	mass of respirable dust fraction
VOL-MIN: **-MAX:**	20 L @ 5 mg/m³ 400 L	**BALANCE:**	0.001 mg sensitivity; use same balance before and after sample collection
SHIPMENT:	routine	**CALIBRATION:**	National Institute of Standards and Technology Class S-1.1 or ASTM Class 1 weights
SAMPLE STABILITY:	stable	**RANGE:**	0.1 to 2 mg per sample
BLANKS:	2 to 10 field blanks per set	**ESTIMATED LOD:**	0.03 mg per sample
		PRECISION:	<10 µg with 0.001 mg sensitivity balance; <70 µg with 0.01 mg sensitivity balance [3]

ACCURACY

RANGE STUDIED:	0.5 to 10 mg/m³ (lab and field)
BIAS:	dependent on dust size distribution [1]
OVERALL PRECISION ($\hat{S}_{rT}$):	dependent on size distribution [1,2]
ACCURACY:	dependent on size distribution [1]

APPLICABILITY: The working range is 0.5 to 10 mg/m³ for a 200-L air sample. The method measures the mass concentration of any non-volatile respirable dust. In addition to inert dusts [4], the method has been recommended for respirable coal dust. The method is biased in light of the recently adopted international definition of respirable dust, e.g., ≈ +7% bias for non-diesel, coal mine dust [5].

INTERFERENCES: Larger than respirable particles (over 10 µm) have been found in some cases by microscopic analysis of cyclone filters. Over-sized particles in samples are known to be caused by inverting the cyclone assembly. Heavy dust loadings, fibers, and water-saturated dusts also interfere with the cyclone's size-selective properties. The use of conductive samplers is recommended to minimize particle charge effects.

OTHER METHODS: This method is based on and replaces Sampling Data Sheet #29.02 [6].

EQUIPMENT:

1. Sampler:
   a. Filter: 5.0-µm pore size, polyvinyl chloride filter or equivalent hydrophobic membrane filter supported by a cassette filter holder (preferably conductive).
   b. Cyclone: 10-mm nylon (Mine Safety Appliance Co., Instrument Division, P. O. Box 427, Pittsburgh, PA 15230), Higgins-Dewell (BGI Inc., 58 Guinan St., Waltham, MA 02154) [7], aluminum cyclone (SKC Inc., 863 Valley View Road, Eighty Four, PA 15330), or equivalent.
2. Personal sampling pump, 1.7 L/min ± 5% for nylon cyclone, 2.2 L/min ± 5% for HD cyclone, or 2.5 L/min ± 5% for the Al cyclone with flexible connecting tubing.
   NOTE: Pulsation in the pump flow must be within ± 20% of the mean flow.
3. Balance, analytical, with sensitivity of 0.001 mg.
4. Weights, NIST Class S-1.1, or ASTM Class 1.
5. Static neutralizer, e.g., Po-210; replace nine months after the production date.
6. Forceps (preferably nylon).
7. Environmental chamber or room for balance, e.g., 20 °C ± 1 °C and 50% ± 5% RH.

SPECIAL PRECAUTIONS: None.

PREPARATION OF SAMPLERS BEFORE SAMPLING:

1. Equilibrate the filters in an environmentally controlled weighing area or chamber for at least 2 h.
2. Weigh the filters in an environmentally controlled area or chamber. Record the filter tare weight, W_1 (mg).
   a. Zero the balance before each weighing.
   b. Handle the filter with forceps (nylon forceps if further analyses will be done).
   c. Pass the filter over an anti-static radiation source. Repeat this step if filter does not release easily from the forceps or if filter attracts balance pan. Static electricity can cause erroneous weight readings.
3. Assemble the filters in the filter cassettes and close firmly so that leakage around the filter will not occur. Place a plug in each opening of the filter cassette.
4. Remove the cyclone's grit cap before use and inspect the cyclone interior. If the inside is visibly scored, discard this cyclone since the dust separation characteristics of the cyclone may be altered. Clean the interior of the cyclone to prevent reentrainment of large particles.
5. Assemble the sampler head. Check alignment of filter holder and cyclone in the sampling head to prevent leakage.

SAMPLING:

6. Calibrate each personal sampling pump to the appropriate flow rate with a representative sampler in line.
   NOTE 1: Because of their inlet designs, nylon and aluminum cyclones are calibrated within a large vessel with inlet and outlet ports. The inlet is connected to a calibrator (e.g., a bubble meter). The cyclone outlet is connected to the outlet port within the vessel, and the vessel outlet is attached to the pump. See APPENDIX for alternate calibration procedure. (The calibrator can be connected directly to the HD cyclone.)
   NOTE 2: Even if the flow rate shifts by a known amount between calibration and use, the nominal flow rates are used for concentration calculation because of a self-correction feature of the cyclones.
7. Sample 45 min to 8 h. Do not exceed 2 mg dust loading on the filter. Take 2 to 4 replicate samples for each batch of field samples for quality assurance on the sampling procedure (see Step 10).

NOTE : Do not allow the sampler assembly to be inverted at any time. Turning the cyclone to anything more than a horizontal orientation may deposit oversized material from the cyclone body onto the filter.

SAMPLE PREPARATION:

8. Remove the top and bottom plugs from the filter cassette. Equilibrate for at least 2 h in an environmentally controlled area or chamber.

CALIBRATION AND QUALITY CONTROL:

9. Zero the microbalance before all weighings. Use the same microbalance for weighing filters before and after sample collection. Calibrate the balance with National Institute of Standards and Technology Class S-1.1 or ASTM Class 1 weights.
10. The set of replicate field samples should be exposed to the same dust environment, either in a laboratory dust chamber [8] or in the field [9]. The quality control samples must be taken with the same equipment, procedures, and personnel used in the routine field samples. Calculate precision from these replicates and record relative standard deviation (S_r) on control charts. Take corrective action when the precision is out of control [8].

MEASUREMENT:

11. Weigh each filter, including field blanks. Record this post-sampling weight, W_2 (mg), beside its corresponding tare weight. Record anything remarkable about a filter (e.g., visible particles, overloading, leakage, wet, torn, etc.).

CALCULATIONS:

12. Calculate the concentration of respirable particulate, C (mg/m^3), in the air volume sampled, V (L):

$$C = \frac{(W_2 - W_1) - (B_2 - B_1)}{V} \times 10^3, \text{ mg/m}^3,$$

where: W_1 = tare weight of filter before sampling (mg),
W_2 = post-sampling weight of sample-containing filter (mg),
B_1 = mean tare weight of blank filters (mg),
B_2 = mean post-sampling weight of blank filters (mg),
V = volume as sampled at the nominal flow rate (i.e., 1.7 L/min or 2.2 L/min).

EVALUATION OF METHOD:

1. Bias: In respirable dust measurements, the bias in a sample is calculated relative to the appropriate respirable dust convention. The theory for calculating bias was developed by Bartley and Breuer [10]. For this method, the bias, therefore, depends on the international convention for respirable dust, the cyclones' penetration curves, and the size distribution of the ambient dust. Based on measured penetration curves for non-pulsating flow [1], the bias in this method is shown in Figure 1.

   For dust size distributions in the shaded region, the bias in this method lies within the ± 0.10 criterion established by NIOSH for method validation. Bias larger than ± 0.10 would, therefore, be expected for some workplace aerosols. However, bias within ± 0.20 would be expected for dusts with geometric standard deviations greater than 2.0, which is the case in most workplaces.

Bias can also be caused in a cyclone by the pulsation of the personal sampling pump. Bartley, et al. [12] showed that cyclone samples with pulsating flow can have negative bias as large as −0.22 relative to samples with steady flow. The magnitude of the bias depends on the amplitude of the pulsation at the cyclone aperture and the dust size distribution. For pumps with instantaneous flow rates within 20% of the mean, the pulsation bias magnitude is less than 0.02 for most dust size distributions encountered in the workplace.

Electric charges on the dust and the cyclone will also cause bias. Briant and Moss [13] have found electrostatic biases as large as −50%, and show that cyclones made with graphite-filled nylon eliminate the problem. Use of conductive samplers and filter cassettes (Omega Specialty Instrument Co., 4 Kidder Road, Chelmsford, MA 01824) is recommended.

2. Precision: The figure 0.068 mg quoted above for the precision is based on a study [3] of weighing procedures employed in the past by the Mine Safety and Health Administration (MSHA) in which filters are pre-weighed by the filter manufacturer and post-weighed by MSHA using balances readable to 0.010 mg. MSHA [14] has recently completed a study using a 0.001 mg balance for the post-weighing, indicating imprecision equal to 0.006 mg.

   Imprecision equal to 0.010 mg was used for estimating the LOD and is based on specific suggestions [8] regarding filter weighing using a single 0.001 mg balance. This value is consistent with another study [15] of repeat filter weighings, although the actual attainable precision may depend strongly on the specific environment to which the filters are exposed between the two weighings.

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METHOD REVISED BY:

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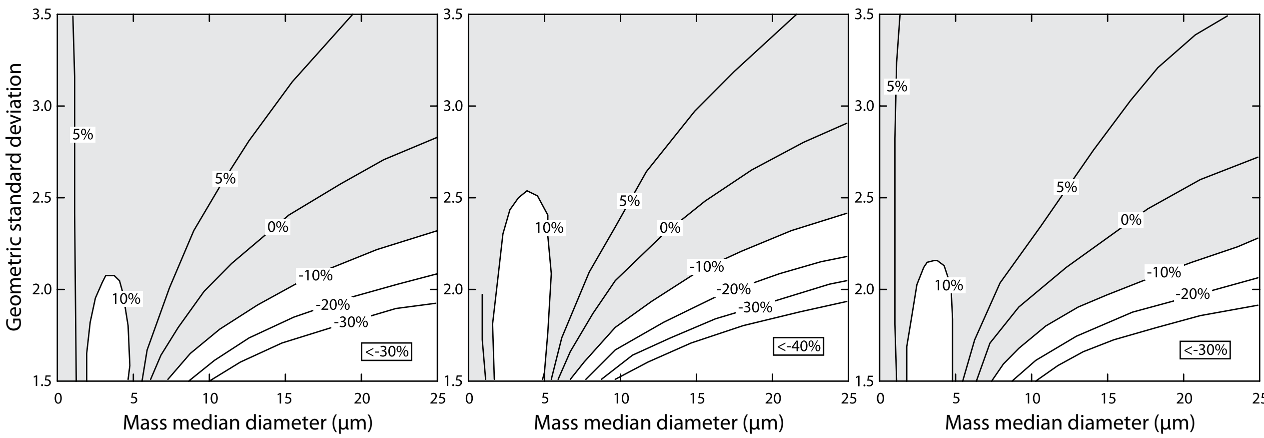

Figure 1. Bias of three cyclone types relative to the international respirable dust sampling convention.

APPENDIX: Jarless Method for Calibration of Cyclone Assemblies

This procedure may be used in the field to calibrate an air sampling pump and a cyclone assembly without using the one-liter "calibration jar".

1. Connect the pump to a pressure gauge or water manometer and a light load (adjustable valve or 5-µm filter) equal to 2" to 5" H_2O with a "TEE" connector and flexible tubing. Connect other end of valve to an electronic bubble meter or standard bubble tube with flexible tubing (See Fig. 2.1).
   NOTE: A light load can be a 5-µm filter and/or an adjustable valve. A heavy load can be several 0.8-µm filters and/or adjustable valve.
2. Adjust the pump to 1.7 L/min, as indicated on the bubble meter/tube, under the light load conditions (2" to 5" H_2O) as indicated on the pressure gauge or manometer.
3. Increase the load until the pressure gauge or water manometer indicates between 25" and 35" H_2O. Check the flow rate of the pump again. The flow rate should remain at 1.7 L/min ± 5%.
4. Replace the pressure gauge or water manometer and the electronic bubble meter or standard bubble tube with the cyclone having a clean filter installed (Fig. 2.2). If the loading caused by the cyclone assembly is between 2" and 5" H_2O, the calibration is complete and the pump and cyclone are ready for sampling.

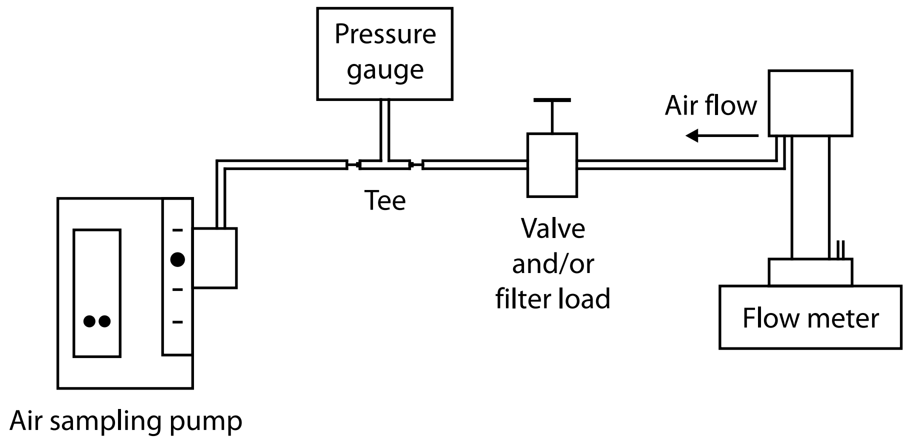

Figure 2.1. Block diagram of pump/load/flow meter set-up.

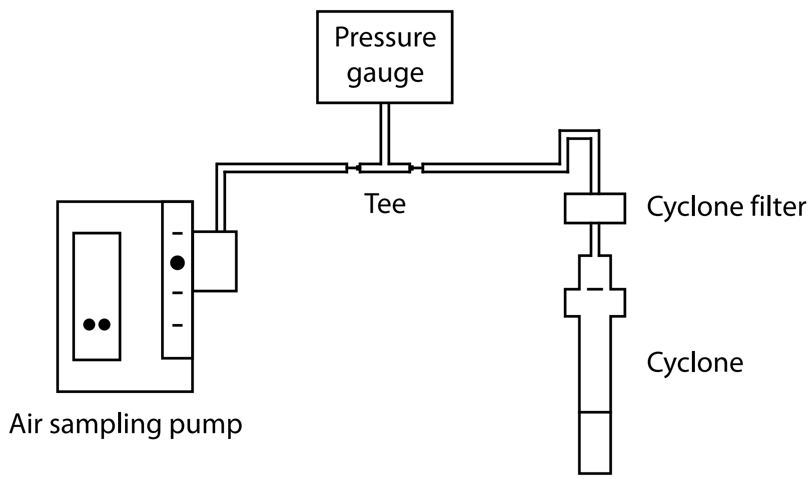

Figure 2.2. Block diagram with cyclone as the test load.

ภาคผนวก ง10

ข้อกำหนดของ American Conference of Governmental Industrial Hygienists; ACGIH (TLV-TWA)

2022

TLVs® and BEIs®

Based on the Documentation of the

Threshold Limit Values

&

Biological Exposure Indices

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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®.

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®.

2022

TLVs® and BEIs®

Based on the Documentation of the

Threshold Limit Values

&

Biological Exposure Indices

ACGIH® est. 1938
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ISBN: 978-1-607261-52-0

Printed in the United States.

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 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. To place an order, visit our website at acgih.org/store, contact Customer Service at the address or phone number below, or use the following e-mail address: customerservice@acgih.org.

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2022

TLVs® and BEIs®

Based on the Documentation of the

Threshold Limit Values
for Chemical Substances and Physical Agents

&

Biological Exposure Indices

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In the event significant errata are required, they will be listed on the ACGIH® website at 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® and BEIs® are not quantitative estimates of risk at different exposure levels or by different routes of exposure.

Since 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 for an industry or employer to meet TLVs® or BEIs®. Similarly, although there are usually valid methods to measure workplace exposures at the TLVs® and BEIs®, 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® or BEI® was adopted as a standard.

ACGIH® does not believe that TLVs® and BEIs® 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® does believe that regulatory bodies should consider TLVs® or BEIs® as valuable input into the risk characterization process (hazard identification, dose-response relationships, and exposure assessment). Regulatory bodies should view TLVs® and BEIs® as an expression of scientific opinion.

ACGIH® is proud of the scientists and the many members who volunteer their time to work on the TLV® and BEI® 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®. The *Documentation* provides a comprehensive list and analysis of all the major published peer-reviewed studies that ACGIH® relied upon in formulating its scientific opinion. Regulatory agencies dealing with hazards addressed by a TLV® or BEI® should obtain a copy of the full written *Documentation* for the TLV® or BEI®. Any use of a TLV® or BEI® 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.

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 (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.

   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 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 (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 (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

- *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.

review, and developing a draft TLV® or BEI® *Documentation*. The draft *Documentation* is a critical evaluation of the scientific literature relevant to recommending a TLV® or BEI®; however, it is not an exhaustive critical review of all studies but only those pertinent to identifying the critical effect and setting the TLV®. 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®, 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® or BEI®, 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® or BEI® 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® and BEIs® 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® or BEI®, the *Documentation* and proposed values are then recommended to the ACGIH® Board of Directors for ratification as an NIC. If ratified, each proposed TLV® or BEI® is published as an NIC in the *Annual Reports of the Committees on TLVs® and BEIs®*, which is published in the ACGIH® newsletter, and is also available online for purchase at acgih.org/store. At the same time, the draft *Documentation* is made available through ACGIH® Customer Service or online at www.acgih.org/ store. All information contained in the *Annual Reports of the Committees on TLVs® and BEIs®* is integrated into the annual *TLVs® and BEIs®* book, which is usually available to the general public in February or March of each year. Following the NIC ratification by the ACGIH® Board of Directors, interested parties, including ACGIH® members, are invited to provide data and substantive comments, preferably in the form of peer-reviewed literature, on the proposed TLVs® or BEIs® contained in the NIC. 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.) 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® and BEI® process is through the submission of literature that is peer-reviewed and public. ACGIH® strongly encourages interested parties to publish their studies, and not to rely on unpublished studies as their input to the TLV® and BEI® process. Also, the best time to submit comments to ACGIH® is in the early stages of the TLV®/BEI® 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®-sponsored symposium or workshop that provides a platform for public discussion and scientific interpretation. ACGIH® encourages input from external parties for suggestions on symposia topics, including suggestions about sponsors, speakers and format. ACGIH® 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® or BEIs®. 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® Science Group (science@acgih.org).

iii. ACGIH® 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® Science Group (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 addition-

al 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 (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.

Endnote: Sample permission statement granting ACGIH® authorization to use, cite, and release unpublished studies:

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 acgih.org/science/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development.

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 (acgih.org/science/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.) (acgih.org/science/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 (acgih.org/science/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 (acgih.org/science/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-position-statement).

[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

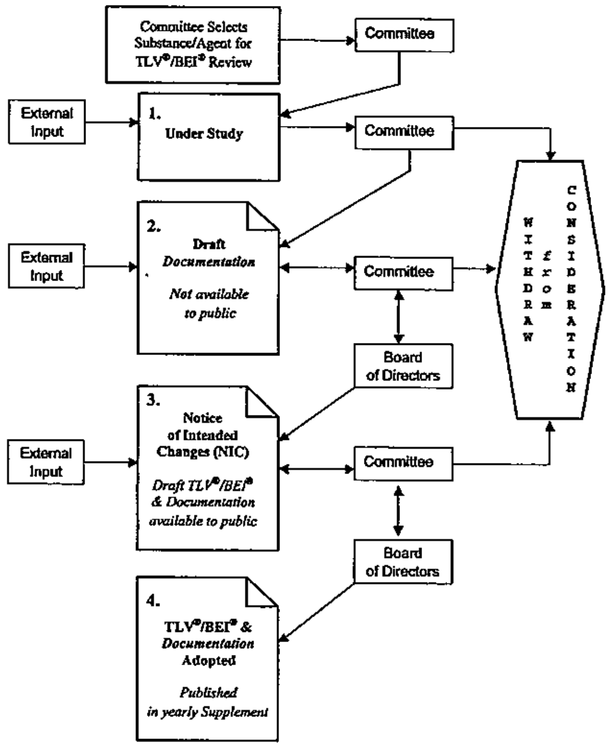

FIGURE 1. The TLV®/BEI® Development Process Flow Chart.

December 20, 2004

- **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 (acgih.org/science/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development).
- **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. (acgih.org/about/volunteer-leadership/committees/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 (acgih.org/science/tlv-bei-guidelines/policies-procedures-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 (acgih.org/science/tlv-bei-guidelines/documentation-publications-and-data/under-study). 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 2022

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

Chemical Substances Section

- Proposed TLVs® that appeared on the 2021 NIC are adopted for the following substances:

Antimony hydride	Iodoform
Benzoic acid and alkali benzoates	Isoflurane
Clothianidin	2-Methyl-2-butene
Cyclopentane	Phosgene
Cyromazine	Prometon
Dipropylene glycol methyl ether	Prometryn
Ethyl benzene	Titanium Dioxide
Imazosulfuron	Trimethyl benzene, isomers
	Xylene

- The following substances and proposed TLVs® new to this section are placed on the NIC:

Benzoquinone	Tetrachlorvinphos
Divinylbenzene-ethyl styrene mixture	
2-Ethylhexanol	
Glycidyl Methacrylate	
Glyphosate	

- Revisions to adopted TLVs® are proposed for the following substances and placed on the NIC:

Benzene	n-Propyl Nitrate
Iodine and Iodides	Propylene glycol dinitrate
Methylnaphthalene, all isomers	Silicon Carbide
Nitric Acid	Vinyltoluene, all isomers
Phenothiazine	

- The following substances are retained on the NIC without revised TLV® recommendations or notations:

Trimetacresyl phosphate
Triparacresyl phosphate

- The following substances are retained on the NIC with revised TLV® recommendations or notations:

Acetamiprid
Di(2-ethylhexyl) phthalate
Ethylene glycol dinitrate

Biologically Derived Airborne Contaminants

- Editorial revisions were made to the Introduction to the Biological Agents section to update the list of mVOCs to those TLVs® that are relevant to the discussion of bioaerosols. This was adopted with minor editorial changes from the NIC last year.

Biological Exposure Indices (BEIs®) Section

- The proposed BEIs® that appeared on the 2021 NIC are adopted for the following substances:

  Cyclohexane

- The following substance and proposed BEI® new to this section is placed on the NIC:

  Acrylamide

- Revisions to the BEIs® for the following are proposed and placed on the NIC:

  2-Ethoxyethanol and 2-Ethoxyethyl Acetate
  Furfural
  Styrene

- Negative Feasibility Assessments were completed for the following substances:

  Diethylhydroxylamine
  Styrene oxide

Physical Agents Section

- The following agents that appeared on the 2021 NIC with proposed changes or revisions are adopted:

  ULTRAVIOLET RADIATION

- Under the *Ergonomics* section, revision to the TLV® for the following is proposed and placed on the NIC:

  UPPER LIMB LOCALIZED FATIGUE

  The reason for this NIC is to add language, including an equation to be applied over the range of the TLV®.

- Under the *Thermal Stress* section, revision to the TLV® for the following is proposed and placed on the NIC:

  HEAT STRESS AND STRAIN

- Under the *Physical Agents* section, the following appendix is adopted: Appendix C: Statement on Fatigue and Its Management in the Workplace.

- Under the *Electromagnetic Fields 0-300* GHz section, editorial revisions were made to the Radiofrequency/Microwave Radiation TLV® to update references reflecting revisions to IEEE and ICNIRP exposure limits.

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2022
Threshold Limit Values for Chemical Substances in the Work Environment

Adopted by ACGIH® with Intended Changes

Contents

INTRODUCTION TO THE CHEMICAL SUBSTANCES

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 [mg/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); surface limit (SL); and ceiling (C). 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^2. 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 is 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 concentrations 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® 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® 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® 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®. 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® published in the *TLVs® and BEIs®* book. For gases and vapors, there are a number of options for comparing air-sampling results to the TLV®, 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® to mg/m³ (or other mass per volume measure) using a molar volume of 24.45 L/mole, and 3) to compare the exposure concentration to the TLV®, 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®. 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®, and extreme care should be exercised if workers are exposed to very high or low ambient pressures.

Unusual Work Schedules

Application of TLVs® 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/m³ or mg/100 cm². 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

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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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substance in air by volume. These TLVs® are expressed in mg/m³.

TLVs® 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/m³. For convenience to the user, these TLVs® 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/m³] 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® *Documentation*).

User Information

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

Additional copies of the *TLVs® and BEIs®* 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®. *Documentation* of individual TLVs® is also available. Consult the ACGIH® website (portal.acgih.org/s/store#/store/browse/cat/a0s4W00000g02f3QAA/tiles) for additional information and availability concerning these publications.

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

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Adiponitrile [111-69-3] (1994)	2 ppm	—	Skin	108.10	URT & LRT irr
Alachlor [15972-60-8] (2014)	1 mg/m^3 (IFV)	—	DSEN; A3	269.80	Hemosiderosis (liver, spleen, kidney)
Aldicarb [116-06-3] (2018)	0.005 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	190.26	Cholinesterase inhib
Aldrin [309-00-2] (2007)	0.05 mg/m^3 (IFV)	—	Skin; A3	364.93	CNS impair; liver & kidney dam
Allyl alcohol [107-18-6] (1999)	0.5 ppm	—	Skin; A4	58.08	Eye & URT irr
Allyl bromide [106-95-6] (2012)	0.1 ppm	0.2 ppm	Skin; A4	120.99	Eye & URT irr
Allyl chloride [107-05-1] (2011)	1 ppm	2 ppm	Skin; A3	76.50	Eye & URT irr; liver & kidney dam
Allyl glycidyl ether [106-92-3] (1997)	1 ppm	—	A4	114.14	URT, eye, & skin irr; dermatitis
Allyl methacrylate [96-05-9] (2018)	1 ppm	—	Skin	126.15	Liver dam
Allyl propyl disulfide [2179-59-1] (2014)	0.5 ppm	—	DSEN	148.16	URT & eye irr
Aluminum metal [7429-90-5] and insoluble compounds (2008)	1 mg/m^3 (R)	—	A4	26.98 Varies	Pneumoconiosis; LRT irr; neurotoxicity
4-Aminodiphenyl [92-67-1] (1987)	— (L)	—	Skin; A1	169.24	Bladder & liver cancer
2-Aminopyridine [504-29-0] (1986)	0.5 ppm	—	—	94.12	Headache; nausea; CNS impair; dizziness
Amitrole [61-82-5] (1995)	0.2 mg/m^3	—	A3	84.08	Thyroid eff

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Acetaldehyde [75-07-0] (2014)	—	C 25 ppm	A2	44.05	Eye & URT irr
Acetamide [60-35-5] (2017)	1 ppm (IFV)	—	A3	59.07	Liver cancer & dam
Acetic acid [64-19-7] (2004)	10 ppm	15 ppm	—	60.05	URT & eye irr; pulm func
Acetic anhydride [108-24-7] (2011)	1 ppm	3 ppm	A4	102.09	Eye & URT irr
Acetone [67-64-1] (2015)	250 ppm	500 ppm	A4; BEI	58.08	URT & eye irr; CNS impair
Acetone cyanohydrin [75-86-5], as CN (1994)	—	C 5 mg/m^3	Skin	85.10	URT irr; headache; hypoxia/cyanosis
Acetonitrile [75-05-8] (2002)	20 ppm	—	Skin; A4	41.05	LRT irr
Acetophenone [98-86-2] (2009)	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] (1980)	5 mg/m^3	—	—	180.15	Skin & eye irr
Acrolein [107-02-8] (1998)	—	C 0.1 ppm	Skin; A4	56.06	Eye & URT irr; pulm edema; pulm emphysema
Acrylamide [79-06-1] (2020)	0.03 mg/m^3 (IFV)	—	Skin; DSEN; A2	71.08	CNS & PNS impair; cancer
Acrylic acid [79-10-7] (1996)	2 ppm	—	Skin; A4	72.06	URT irr
Acrylonitrile [107-13-1] (2016)	2 ppm	—	Skin; A3	53.05	CNS impair; LRT irr
Adipic acid [124-04-9] (1993)	5 mg/m^3	—	—	146.14	Eye, skin, URT irr; ANS impair

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Arsine [7784-42-1] (2007)	0.005 ppm	—	—	77.95	PNS & vascular system impair; kidney & liver impair
Asbestos [1332-21-4], all forms (1998)	0.1 f/cc (F)	—	A1	—	Pneumoconiosis; lung cancer; mesothelioma
Asphalt (Bitumen) fumes [8052-42-4], as benzene-soluble aerosol (2000)	0.5 mg/m^3 (I)	—	A4; BEI_P	—	URT & eye irr
Atrazine [1912-24-9] (and related symmetrical triazines) (2014)	2 mg/m^3 (I)	—	A3	215.69	Hematologic, repro, & developmental eff
Azinphos-methyl [86-50-0] (2014)	0.2 mg/m^3 (IFV)	—	Skin; DSEN; A4; BEI_C	317.34	Cholinesterase inhib
Barium [7440-39-3] and soluble compounds, as Ba (1996)	0.5 mg/m^3	—	A4	137.30	Eye, skin, & GI irr; muscular stimulation
Barium sulfate [7727-43-7] (2014)	5 mg/m^3 (I, E)	—	—	233.43	Pneumoconiosis
Bendiocarb [22781-23-3] (2018)	0.1 mg/m^3 (IFV)	—	Skin; A4; BEI_C	223.20	Cholinesterase inhib
Benomyl [17804-35-2] (2014)	1 mg/m^3 (I)	—	DSEN; A3	290.32	URT irr; male repro, testicular, & embryo/fetal dam
Benz[a]anthracene [56-55-3] (1993)	— (L)	—	A2; BEI_P	228.30	Skin cancer
‡ Benzene [71-43-2] (1997)	(0.5 ppm)	(2.5 ppm)	Skin; A1; BEI	78.11	Leukemia ( )
Benzidine [92-87-5] (1985)	— (L)	—	Skin; A1	184.23	Bladder cancer

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Ammonia [7664-41-7] (1976)	25 ppm	35 ppm	—	17.03	Eye dam; URT irr
Ammonium chloride, fume [12125-02-9] (1976)	10 mg/m^3	20 mg/m^3	—	53.50	Eye & URT irr
Ammonium perfluorooctanoate [3825-26-1] (1994)	0.01 mg/m^3	—	Skin; A3	431.00	Liver dam
Ammonium sulfamate [7773-06-0] (1984)	10 mg/m^3	—	—	114.13	—
tert-Amyl methyl ether [994-05-8] (2002)	20 ppm	—	—	102.20	CNS impair; embryo/fetal dam
Aniline [62-53-3] (1996)	2 ppm	—	Skin; A3; BEI	93.13	MeHb-emia
Anisidine (2002)					
ortho isomer [90-04-0]	0.5 mg/m^3	—	Skin; A3; BEI_M	123.15	MeHb-emia
para isomer [104-94-9]	0.5 mg/m^3	—	Skin; A4; BEI_M	123.15	MeHb-emia
Antimony [7440-36-0] and compounds, as Sb (1995)	0.5 mg/m^3	—	—	121.75	Skin & URT irr
* Antimony hydride [7803-52-3] (2021)	0.005 ppm	—	—	124.78	Hemolysis, hemotologic effects
Antimony trioxide [1309-64-4] (2020)	0.02 mg/m^3 (I)	—	A2	291.50	Pneumonitis
ANTU [86-88-4] (1996)	0.3 mg/m^3	—	A4; Skin	202.27	Thyroid eff; nausea
Argon [7440-37-1]	*See* Appendix F: Minimal Oxygen Content (D)			39.95	Asphyxia
Arsenic [7440-38-2] and inorganic compounds, as As (1992)	0.01 mg/m^3	—	A1; BEI	74.92 Varies	Lung cancer

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Borate compounds, inorganic [1303-96-4; 1330-43-4; 10043-35-3; 12179-04-3] (2005)	2 mg/m^3 (I)	6 mg/m^3 (I)	A4	Varies	URT irr
Boron oxide [1303-86-2] (1985)	10 mg/m^3	—	—	69.64	Eye & URT irr
Boron tribromide [10294-33-4] (2016)	—	C 0.7 ppm	—	250.57	Resp tract irr; pneumonitis
Boron trichloride [10294-34-5] (2016)	—	C 0.7 ppm	—	117.20	Resp tract irr; pneumonitis
Boron trifluoride [7637-07-2] (2016)	0.1 ppm	C 0.7 ppm	—	67.82	Resp tract irr; pneumonitis
Boron trifluoride ethers [109-63-7; 353-42-4], as BF_3 (2018)	0.1 ppm	C 0.7 ppm	—	Varies	Resp tract irr; pneumonitis
Bromacil [314-40-9] (1996)	10 mg/m^3	—	A3	261.11	Thyroid eff
Bromine [7726-95-6] (1994)	0.1 ppm	0.2 ppm	—	159.81	URT & LRT irr; lung dam
Bromine pentafluoride [7789-30-2] (1986)	0.1 ppm	—	—	174.92	Eye, skin, & URT irr
Bromoform [75-25-2] (2009)	0.5 ppm	—	A3	252.73	Liver dam; URT & eye irr
1-Bromopropane [106-94-5] (2014)	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; BEI	54.09	Cancer

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Benzo[b]fluoranthene [205-99-2] (1991)	— (L)	—	A2; BEI$_P$	252.30	Cancer
Benzo[a]pyrene [50-32-8] (1990)	— (L)	—	A2; BEI$_P$	252.30	Cancer
* Benzoic acid and alkali benzoates (2021)					
Benzoic acid [65-85-0]	0.5 mg/m^3 (IFV)	—	Skin; A5	122.12	Eye irr, URT irr, LRT irr; lung dam
Sodium benzoate, as benzoate [532-32-1]	2.5 mg/m^3 (I)	—	Skin; A5	144.10	Kidney changes
Potassium benzoate, as benzoate [582-25-2]	2.5 mg/m^3 (I)	—	Skin; A5	160.21	Kidney changes
Benzotrichloride [98-07-7] (1997)	—	C 0.1 ppm	Skin; A2	195.50	Eye, skin, & URT irr
Benzoyl chloride [98-88-4] (1995)	—	C 0.5 ppm	A4	140.57	URT & eye irr
Benzoyl peroxide [94-36-0] (1996)	5 mg/m^3	—	A4	242.22	URT & skin irr
Benzyl acetate [140-11-4] (1995)	10 ppm	—	A4	150.18	URT irr
Benzyl chloride [100-44-7] (1995)	1 ppm	—	A3	126.58	Eye, skin, & URT irr
Beryllium [7440-41-7] and compounds, as Be (2014)	0.00005 mg/m^3 (I)	—	A1	9.01	Beryllium sens; chronic beryllium disease (berylliosis)
Soluble compounds			Skin; DSEN		
Soluble and insoluble compounds			RSEN		
Biphenyl [92-52-4] (1987)	0.2 ppm	—	—	154.20	Pulm func
Bismuth telluride [1304-82-1] (1996)				800.83	Lung dam
Undoped, as Bi_2Te_3	10 mg/m^3	—	A4		
Se-doped, as Bi_2Te_3	5 mg/m^3	—	A4		

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
n-Butyl glycidyl ether [2426-08-6] (2014)	3 ppm	—	Skin; DSEN	130.21	Reproduction; sens
tert-Butyl hydroperoxide [75-91-2] (2018)	0.1 ppm	—	Skin	90.12	Eye & URT irr; mutagenic & repro eff
n-Butyl lactate [138-22-7] (1976)	5 ppm	—	—	146.19	Headache; URT irr
n-Butyl mercaptan [109-79-5] (1970)	0.5 ppm	—	—	90.19	URT irr
o-sec-Butylphenol [89-72-5] (1980)	5 ppm	—	Skin	150.22	URT, eye, & skin irr
p-tert-Butyltoluene [98-51-1] (1993)	1 ppm	—	—	148.18	Eye & URT irr; nausea
Cadmium [7440-43-9] and compounds, as Cd (1993)	0.01 mg/m^3 0.002 mg/m^3 (R)	— —	A2; BEI A2; BEI	112.40 Varies	Kidney dam
Cadusafos [95465-99-9] (2017)	0.001 mg/m^3 (IFV)	—	Skin; A4; BEI_C	270.40	Cholinesterase inhib
Calcium cyanamide [156-62-7] (1996)	0.5 mg/m^3	—	A4	80.11	Eye & URT irr
Calcium hydroxide [1305-62-0] (1979)	5 mg/m^3	—	—	74.10	Eye, URT, & skin irr
Calcium oxide [1305-78-8] (1990)	2 mg/m^3	—	—	56.08	URT irr
Calcium silicate, naturally occurring as Wollastonite [13983-17-0] (2016)	1 mg/m^3 (I, E)	—	A4	—	Pneumonconiosis; pulm func
Calcium sulfate [7778-18-9; 10034-76-1; 10101-41-4; 13397-24-5] (2006)	10 mg/m^3 (I)	—	—	136.14	Nasal symptoms

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Butane, isomers [75-28-5; 106-97-8] (2017)	—	1000 ppm (EX)	—	58.12	CNS impair
n-Butanol [71-36-3] (2001)	20 ppm	—	—	74.12	Eye & URT irr
sec-Butanol [78-92-2] (2002)	100 ppm	—	—	74.12	URT irr; CNS impair
tert-Butanol [75-65-0] (1995)	100 ppm	—	A4	74.12	CNS impair
Butenes, all isomers [106-98-9; 107-01-7; 590-18-1; 624-64-6; 25167-67-3] Isobutene [115-11-7] (2008)	250 ppm 250 ppm	— —	— A4	56.11 —	Body weight eff URT irr; body weight eff
2-Butoxyethanol [111-76-2] (2003)	20 ppm	—	A3; BEI	118.17	Eye & URT irr
2-Butoxyethyl acetate [112-07-2] (2003)	20 ppm	—	A3	160.20	Hemolysis
Butyl acetates, all isomers [105-46-4; 110-19-0; 123-86-4; 540-88-5] (2016)	50 ppm	150 ppm	—	116.16	Eye & URT irr
n-Butyl acrylate [141-32-2] (2014)	2 ppm	—	DSEN; A4	128.17	Irr
n-Butylamine [109-73-9] (1985)	—	C 5 ppm	Skin	73.14	Headache; URT & eye irr
Butylated hydroxytoluene [128-37-0] (2001)	2 mg/m^3 (IFV)	—	A4	220.34	URT irr
4-tert-Butylbenzoic acid [98-73-7] (2020)	0.1 mg/m^3 (IFV)	—	Skin	178.20	Testicular dam; CNS & male repro eff
tert-Butyl chromate, as CrO_3 [1189-85-1] (1964)	—	C 0.1 mg/m^3	Skin	230.22	LRT & skin irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Carfentrazone-ethyl [128639-02-1] (2018)	1 mg/m^3 (I)	—	A4	412.20	Liver dam; porphyrin eff
Catechol [120-80-9] (1995)	5 ppm	—	Skin; A3	110.11	Eye & URT irr; dermatitis
Cellulose [9004-34-6] (1990)	10 mg/m^3	—	—	NA	URT irr
Cesium hydroxide [21351-79-1] (1990)	2 mg/m^3	—	—	149.92	URT, skin, & eye irr
Chlordane [57-74-9] (2019)	0.5 mg/m^3 (IFV)	—	Skin; A3	409.80	Liver dam
Chlorinated camphene [8001-35-2] (1996)	0.5 mg/m^3	1 mg/m^3	Skin; A3	414.00	CNS convul; liver dam
Chlorinated diphenyl oxide [31242-93-0] (1990)	0.5 mg/m^3	—	—	377.00	Chloracne; liver dam
Chlorine [7782-50-5] (2018)	0.1 ppm	0.4 ppm	A4	70.91	Resp tract irr; airway hyper-reactivity; pulm edema
Chlorine dioxide [10049-04-4] (2018)	—	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] (1989)	—	C 1 ppm	Skin	92.53	Eye & URT irr
2-Chloroacetophenone [532-27-4] (1996)	0.05 ppm	—	A4	154.59	Eye, URT, & skin irr
Chloroacetyl chloride [79-04-9] (1991)	0.05 ppm	0.15 ppm	Skin	112.95	URT irr
Chlorobenzene [108-90-7] (1995)	10 ppm	—	A3; BEI	112.56	Liver dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Camphor, synthetic [76-22-2] (1996)	2 ppm	3 ppm	A4	152.23	Eye & URT irr; anosmia
Caprolactam [105-60-2] (2003)	5 mg/m^3 (IFV)	—	A5	113.16	URT irr
Captafol [2425-06-1] (2017)	0.1 mg/m^3 (IFV)	—	Skin; DSEN; RSEN; A3	349.10	Liver & kidney dam; dermal sens
Captan [133-06-2] (2014)	5 mg/m^3 (I)	—	DSEN; A3	300.60	Skin irr
Carbaryl [63-25-2] (2008)	0.5 mg/m^3 (IFV)	—	Skin; A4; BEI_C	201.20	Cholinesterase inhib; male repro & embryo dam
Carbofuran [1563-66-2] (2004)	0.1 mg/m^3 (IFV)	—	A4; BEI_C	221.30	Cholinesterase inhib
Carbon black [1333-86-4] (2011)	3 mg/m^3 (I)	—	A3	—	Bronchitis
Carbon dioxide [124-38-9] (1986)	5000 ppm	30,000 ppm	—	44.01	Asphyxia
Carbon disulfide [75-15-0] (2006)	1 ppm	—	Skin; A4; BEI	76.14	PNS impair
Carbon monoxide [630-08-0] (1992)	25 ppm	—	BEI	28.01	COHb-emia
Carbon tetrabromide [558-13-4] (1976)	0.1 ppm	0.3 ppm	—	331.65	Liver dam; eye, URT, & skin irr
Carbon tetrachloride [56-23-5] (1996)	5 ppm	10 ppm	Skin; A2	153.84	Liver dam
Carbonyl fluoride [353-50-4] (1990)	2 ppm	5 ppm	—	66.01	LRT irr; bone dam
Carbonyl sulfide [463-58-1] (2012)	5 ppm	—	—	60.08	CNS impair

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
2-Chloropropionic acid [598-78-7] (1991)	0.1 ppm	—	Skin	108.53	Male repro dam
o-Chlorostyrene [2039-87-4] (1976)	50 ppm	75 ppm	—	138.60	CNS impair; peripheral neuropathy
o-Chlorotoluene [95-49-8] (1990)	50 ppm	—	—	126.59	URT, eye, & skin irr
Chlorpyrifos [2921-88-2] (2003)	0.1 mg/m^3 (IFV)	—	Skin; A4; BEI_C	350.57	Cholinesterase inhib
Chromium, [7440-47-3] and inorganic compounds (2018)					
Metallic chromium, as Cr(0)	0.5 mg/m^3 (I)	—	—	Varies	Resp tract irr
Trivalent chromium compounds, as Cr(III) Water-soluble compounds	0.003 mg/m^3 (I)	—	A4 DSEN; RSEN	Varies	Resp tract irr; asthma
Hexavalent chromium compounds, as Cr(VI) Water-soluble compounds	0.0002 mg/m^3 (I)	0.0005 mg/m^3 (I)	A1 Skin; DSEN; RSEN; BEI	Varies	Lung & sinonasal cancer; resp tract irr; asthma
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				
Chrysene [218-01-9] (1996)	— (L)	—	A3; BEI_P	228.30	Cancer
Citral [5392-40-5] (2014)	5 ppm (IFV)	—	Skin; DSEN; A4	152.24	Body weight eff; URT irr; eye dam
Clopidol [2971-90-6] (2013)	3 mg/m^3 (IFV)	—	A4	192.06	Mutagenic eff

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
o-Chlorobenzylidene malononitrile [2698-41-1] (2019)	—	C 0.05 ppm (IFV)	Skin; A4	188.62	URT irr; skin sens
Chlorobromomethane [74-97-5] (2009)	200 ppm	—	—	129.39	CNS impair; liver dam
Chlorodifluoromethane [75-45-6] (1996)	1000 ppm	—	A4	86.47	CNS impair; asphyxia; card sens
Chlorodiphenyl (42% chlorine) [53469-21-9] (1990)	1 mg/m^3	—	Skin	266.50	Liver dam; eye irr; chloracne
Chlorodiphenyl (54% chlorine) [11097-69-1] (1996)	0.5 mg/m^3	—	Skin; A3	328.40	URT irr; liver dam; chloracne
Chloroform [67-66-3] (1995)	10 ppm	—	A3	119.38	Liver & embryo/fetal dam; CNS impair
bis(Chloromethyl) ether [542-88-1] (1987)	0.001 ppm	—	A1	114.96	Lung cancer
Chloromethyl methyl ether [107-30-2] (1983)	— (L)	—	A2	80.50	Lung cancer
1-Chloro-1-nitropropane [600-25-9] (2017)	2 ppm	—	—	123.54	Eye & URT irr; pulm edema
Chloropentafluoroethane [76-15-3] (1981)	1000 ppm	—	—	154.47	Card sens
Chloropicrin [76-06-2] (1996)	0.1 ppm	—	A4	164.39	Eye irr; pulm edema
β-Chloroprene [126-99-8] (2017)	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] (2002)	1 ppm	—	Skin; A4	94.54	Liver dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Crotonaldehyde [4170-30-3] (1998)	—	C 0.3 ppm	Skin; A3	70.09	Eye & URT irr
Crufomate [299-86-5] (1996)	5 mg/m^3	—	A4; BEI$_C$	291.71	Cholinesterase inhib
Cumene [98-82-8] (2020)	5 ppm	—	A3	120.19	URT adenoma; neurological eff
Cyanamide [420-04-2] (1977)	2 mg/m^3	—	—	42.04	Skin & eye irr
Cyanazine [21725-46-2] (2019)	0.1 mg/m^3 (I)	—	A3	240.70	Body weight, CNS & teratogenic eff
Cyanoacrylates, Ethyl [7085-85-0] and Methyl [137-05-3] (2018)	0.2 ppm	1 ppm	DSEN; RSEN	125.4 (Ethyl) 112.11 (Methyl)	Eye & URT irr; asthma
Cyanogen [460-19-5] (2016)	—	C 5 ppm	—	52.04	Eye & URT irr
Cyanogen bromide [506-68-3] (2015)	—	C 0.3 ppm	—	105.92	Eye & resp tract irr; pulm edema
Cyanogen chloride [506-77-4] (2014)	—	C 0.3 ppm	—	61.48	Pulm edema; eye, skin, & URT irr
Cyclohexane [110-82-7] (2020)	100 ppm	—	BEI	84.16	CNS impair; eye & URT irr
Cyclohexanol [108-93-0] (1986)	50 ppm	—	Skin; BEI	100.16	Eye irr; CNS impair
Cyclohexanone [108-94-1] (2003)	20 ppm	50 ppm	Skin; A3; BEI	98.14	Eye & URT irr
Cyclohexene [110-83-8] (2020)	20 ppm	—	—	82.14	Liver eff
Cyclohexylamine [108-91-8] (1995)	10 ppm	—	A4	99.17	URT & eye irr
Cyclonite [121-82-4] (1996)	0.5 mg/m^3	—	Skin; A4	222.26	Liver dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
* Clothianidin [210880-92-5] (2021)	0.1 mg/m^3 (I)		A4	249.67	Male & female repro system dam; neurobehavioral & neurodevelopment impair; body weight eff
Coal dust (1998)					
Anthracite [8029-10-5]	0.4 mg/m^3 (R)	—	A4	—	Lung dam; pulm fibrosis
Bituminous or Lignite [308062-82-0]	0.9 mg/m^3 (R)	—	A4	—	Lung dam; pulm fibrosis
Coal tar pitch volatiles [65996-93-2], as benzene soluble aerosol (1991)	0.2 mg/m^3	—	A1; BEI$_P$	—	Cancer
Cobalt [7440-48-4] and inorganic compounds, as Co (2019)	0.02 mg/m^3 (I)	—	DSEN;RSEN; A3; BEI	58.93 Varies	Pulm func changes
Cobalt carbonyl [10210-68-1], as Co (1983)	0.1 mg/m^3	—	—	341.94	Pulm edema; spleen dam
Cobalt hydrocarbonyl [16842-03-8], as Co (1983)	0.1 mg/m^3	—	—	171.98	Pulm edema; lung dam
Copper [7440-50-8] (1990)				63.55	Irr; GI; metal fume fever
Fume, as Cu	0.2 mg/m^3	—	—		
Dusts and mists, as Cu	1 mg/m^3	—	—		
Cotton dust, raw, untreated (2010)	0.1 mg/m^3 (T)	—	A4	—	Byssinosis; bronchitis; pulm func
Coumaphos [56-72-4] (2006)	0.05 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	362.80	Cholinesterase inhib
Cresol, all isomers [95-48-7; 106-44-5; 108-39-4; 1319-77-3] (2010)	20 mg/m^3 (IFV)	—	Skin; A4	108.14	URT irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Dibutyl phenyl phosphate [2528-36-1] (1990)	0.3 ppm	—	Skin; BEI_C	286.26	Cholinesterase inhib; URT irr
Dibutyl phosphate [107-66-4] (2009)	5 mg/m^3 (IFV)	—	Skin	210.21	Bladder, eye, & URT irr
Dibutyl phthalate [84-74-2] (1990)	5 mg/m^3	—	—	278.34	Testicular dam; eye & URT irr
Dichloroacetic acid [79-43-6] (2005)	0.5 ppm	—	Skin; A3	128.95	URT & eye irr; testicular dam
Dichloroacetylene [7572-29-4] (1995)	—	C 0.1 ppm	A3	94.93	Nausea; PNS impair
o-Dichlorobenzene [95-50-1] (1996)	25 ppm	50 ppm	A4	147.01	URT & eye irr; liver dam
p-Dichlorobenzene [106-46-7] (1993)	10 ppm	—	A3	147.01	Eye irr; kidney dam
3,3'-Dichlorobenzidine [91-94-1] (1996)	— (L)	—	Skin; A3	253.13	Bladder cancer; eye irr
1,4-Dichloro-2-butene [764-41-0] (1993)	0.005 ppm	—	Skin; A2	124.99	URT & eye irr
Dichlorodifluoromethane [75-71-8] (1996)	1000 ppm	—	A4	120.91	Card sens
1,3-Dichloro-5,5-dimethylhydantoin [118-52-5] (1979)	0.2 mg/m^3	0.4 mg/m^3	—	197.03	URT irr
1,1-Dichloroethane [75-34-3] (1996)	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] (1996)	5 ppm	10 ppm	Skin; A4	143.02	URT & eye irr; nausea

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
• Cyclopentane [287-92-3] (2021)	1000 ppm (EX)	—		70.13	CNS impair
Cyhexatin [13121-70-5] (1995)	5 mg/m^3	—	A4	385.16	URT irr; body weight eff; kidney dam
• Cyromazine [66215-27-8] (2021)	2 mg/m^3 (I)	—	A4	166.19	Body weight & hematological eff
2,4-D [94-75-7] (2017)	10 mg/m^3 (I)	—	A4	221.04	Thyroid eff; kidney tubular dam
DDT [50-29-3] (1995)	1 mg/m^3	—	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] (2002)	0.05 mg/m^3 (IFV)	—	Skin; BEI_C	258.34	Cholinesterase inhib
Demeton-S-methyl [919-86-8] (2014)	0.05 mg/m^3 (IFV)	—	Skin; DSEN; A4; BEI_C	230.30	Cholinesterase inhib
Diacetone alcohol [123-42-2] (1987)	50 ppm	—	—	116.16	URT & eye irr
Diacetyl [431-03-8] (2012)	0.01 ppm	0.02 ppm	A4	86.10	Lung dam (Bronchiolitis obliterans-like illness)
Diazinon [333-41-5] (2003)	0.01 mg/m^3 (IFV)	—	Skin; A4; BEI_C	304.36	Cholinesterase inhib
Diazomethane [334-88-3] (1996)	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] (1994)	0.5 ppm	—	Skin; BEI_C	173.29	Eye & URT irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Diethylamine [109-89-7] (2013)	5 ppm	15 ppm	Skin; A4	73.14	URT, eye, & skin irr
2-Diethylaminoethanol [100-37-8] (1994)	2 ppm	—	Skin	117.19	URT irr; CNS convul
Diethylene glycol monobutyl ether [112-34-5] (2013)	10 ppm (IFV)	—	—	162.23	Hematologic, liver & kidney eff
Diethylenetriamine [111-40-0] (1985)	1 ppm	—	Skin	103.17	URT & eye irr
‡ Di(2-ethylhexyl)phthalate [117-81-7] (1999)	(5 mg/m³)	—	( ); A3	390.54	(LRT irr)
N,N-Diethylhydroxylamine [3710-84-7] (2013)	2 ppm	—	—	89.14	URT irr
Diethyl ketone [96-22-0] (1998)	200 ppm	300 ppm	—	86.13	URT irr; CNS impair
Diethyl phthalate [84-66-2] (1999)	5 mg/m³	—	A4	222.23	URT irr
Difluorodibromomethane [75-61-6] (1986)	100 ppm	—	—	209.83	URT irr; CNS impair; liver dam
Diglycidyl ether [2238-07-5] (2007)	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] (2018)	10 ppm	—	Skin; A3; BEI	87.12	Liver, embryo & fetal dam; repro, renal & teratogenic eff
Dimethylamine [124-40-3] (2014)	5 ppm	15 ppm	DSEN; A4	45.08	URT & GI irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Dichlorofluoromethane [75-43-4] (1980)	10 ppm	—	—	102.92	Liver dam
Dichloromethane [75-09-2] (1999)	50 ppm	—	A3; BEI	84.93	COHb-emia; CNS impair
1,1-Dichloro-1-nitroethane [594-72-9] (1986)	2 ppm	—	—	143.96	URT irr
1,3-Dichloropropene [542-75-6] (2004)	1 ppm	—	Skin; A3	110.98	Kidney dam
2,2-Dichloropropionic acid [75-99-0] (2000)	5 mg/m³ (I)	—	A4	143.00	Eye & URT irr
Dichlorotetrafluoroethane [76-14-2] (1996)	1000 ppm	—	A4	170.93	Pulm func
Dichlorvos [62-73-7] (2014)	0.1 mg/m³ (IFV)	—	Skin; DSEN; A4; BEI_C	220.98	Cholinesterase inhib
Dicrotophos [141-66-2] (2002)	0.05 mg/m³ (IFV)	—	Skin; A4; BEI_C	237.21	Cholinesterase inhib
Dicyclopentadiene [77-73-6], including Cyclopentadiene (2019)	0.5 ppm	1 ppm	—	132.21	URT, LRT, & eye irr; CNS eff
Dicyclopentadienyl iron, as Fe [102-54-5] (1990)	10 mg/m³	—	—	186.03	Liver dam
Dieldrin [60-57-1] (2010)	0.1 mg/m³ (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 (2008)	100 mg/m³ (IFV)	—	Skin; A3	Varies	Dermatitis
Diethanolamine [111-42-2] (2009)	1 mg/m³ (IFV)	—	Skin; A3	105.14	Liver & kidney dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Dinitro-o-cresol [534-52-1] (2019)	0.2 mg/m^3 (IFV)	—	Skin	198.13	Basal metabolism
3,5-Dinitro-o-toluamide [148-01-6] (2007)	1 mg/m^3	—	A4	225.16	Liver dam
Dinitrotoluene [25321-14-6] (1997)	0.2 mg/m^3	—	Skin; A3; BEI$_M$	182.15	Card impair; repro eff
1,4-Dioxane [123-91-1] (1999)	20 ppm	—	Skin; A3	88.10	Liver dam
Dioxathion [78-34-2] (2002)	0.1 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	456.54	Cholinesterase inhib
1,3-Dioxolane [646-06-0] (2002)	20 ppm	—	—	74.08	Hematologic eff
Diphenylamine [122-39-4] (1996)	10 mg/m^3	—	A4	169.24	Liver & kidney dam; hematologic eff
Dipropyl ketone [123-19-3] (1981)	50 ppm	—	—	114.80	URT irr
* Dipropylene glycol methyl ether (DPGME) [13429-07-7; 13588-28-8; 20324-32-7; 34590-94-8; 55956-21-3] (2021)	50 ppm	—	—	148.20	Liver & CNS eff
Diquat [85-00-7; 2764-72-9; 6385-62-2], as the cation (1996)	0.5 mg/m^3 (I) 0.1 mg/m^3 (R)	— —	Skin; A4 Skin; A4	Varies	LRT irr; cataract LRT irr; cataract
Disulfiram [97-77-8] (1995)	2 mg/m^3	—	A4	296.54	Vasodilation; nausea
Disulfoton [298-04-4] (2002)	0.05 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	274.38	Cholinesterase inhib
Diuron [330-54-1] (1996)	10 mg/m^3	—	A4	233.10	URT irr
Divinylbenzene [1321-74-0] (1990)	10 ppm	—	—	130.19	URT irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
bis(2-Dimethylaminoethyl) ether [3033-62-3] (2000)	0.05 ppm	0.15 ppm	Skin	160.26	URT, eye, & skin irr
Dimethylaniline [121-69-7] (1996)	5 ppm	10 ppm	Skin; A4; BEI$_M$	121.18	MeHb-emia
Dimethyl carbamoyl chloride [79-44-7] (2018)	0.005 ppm	—	Skin; A2	107.54	Nasal cancer; URT irr
Dimethyl disulfide [624-92-0] (2007)	0.5 ppm	—	Skin	94.20	URT irr; CNS impair
Dimethylethoxysilane [14857-34-2] (1996)	0.5 ppm	1.5 ppm	—	104.20	URT & eye irr; headache
Dimethylformamide [68-12-2] (2018)	5 ppm	—	Skin; A3; BEI	73.10	Liver dam; eye & URT irr
1,1-Dimethylhydrazine [57-14-7] (1995)	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] (2019)	1 ppm (IFV)	—	DSEN; A3	Varies	Hematologic & body weight eff
Dimethyl phthalate [131-11-3] (2005)	5 mg/m^3	—	—	194.19	Eye & URT irr
Dimethyl sulfate [77-78-1] (1995)	0.1 ppm	—	Skin; A3	126.10	Eye & skin irr
Dimethyl sulfide [75-18-3] (2004)	10 ppm	—	—	62.14	URT irr
Dinitrobenzene, all isomers [99-65-0; 100-25-4; 528-29-0; 25154-54-5] (2018)	0.15 ppm (IFV)	—	Skin; BEI$_M$	168.11	MeHb-emia; eye dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Ethylamine [75-04-7] (2013)	5 ppm	15 ppm	Skin	45.08	URT irr
Ethyl amyl ketone [541-85-5] (2007)	10 ppm	—	—	128.21	Neurotoxicity
* Ethyl benzene [100-41-4] (2021)	20 ppm	—	OTO; A3; BEI	106.16	URT & eye irr; ototoxicity; kidney eff; CNS impair
Ethyl bromide [74-96-4] (1996)	5 ppm	—	Skin; A3	108.98	Liver dam; CNS impair
Ethyl tert-butyl ether [637-92-3] (2013)	25 ppm	—	A4	102.18	URT & LRT irr; CNS impair
Ethyl butyl ketone [106-35-4] (1998)	50 ppm	75 ppm	—	114.19	CNS impair; eye & skin irr
Ethyl chloride [75-00-3] (1995)	100 ppm	—	Skin; A3	64.52	Liver dam
Ethylene [74-85-1] (2005)	200 ppm	—	A4	28.05	Asphyxia
Ethylene chlorohydrin [107-07-3] (1996)	—	C 1 ppm	Skin; A4	80.52	CNS impair; liver & kidney dam
Ethylenediamine [107-15-3] (1996)	10 ppm	—	Skin; A4	60.10	—
Ethylene dibromide [106-93-4] (1995)	—	—	Skin; A3	187.88	—
Ethylene dichloride [107-06-2] (1996)	10 ppm	—	A4	98.96	Liver dam; nausea
Ethylene glycol [107-21-1] (2017)	25 ppm (V)	50 ppm (V) 10 mg/m^3 (I, H)	A4	62.07	URT irr
‡ Ethylene glycol dinitrate [628-96-6] (1985)	(0.05 ppm)	(—)	Skin	152.06	(Vasodilation; headache)
Ethylene oxide [75-21-8] (1990)	1 ppm	—	A2; Skin; BEI	44.05	Cancer; CNS impair

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES			MW	TLV® Basis
	TWA	STEL	Notations		
Dodecyl mercaptan [112-55-0] (2014)	0.1 ppm	—	DSEN	202.40	URT irr
Endosulfan [115-29-7] (2009)	0.1 mg/m^3 (IFV)	—	Skin; A4	406.95	LRT irr; liver & kidney dam
Endrin [72-20-8] (1996)	0.1 mg/m^3	—	Skin; A4	380.93	Liver dam; CNS impair; headache
Enflurane [13838-16-9] (1996)	75 ppm	—	A4	184.50	CNS impair; card impair
Epichlorohydrin [106-89-8] (1997)	0.5 ppm	—	Skin; A3	92.53	URT irr; male repro
EPN [2104-64-5] (2019)	0.1 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	323.31	Cholinesterase inhib
Ethane [74-84-0]	*See* Appendix F: Minimal Oxygen Content (D, EX)			30.07	Asphyxia
Ethanol [64-17-5] (2009)	—	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] (2003)	0.05 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	384.48	Cholinesterase inhib
2-Ethoxyethanol [110-80-5] (2003)	5 ppm	—	Skin; BEI	90.12	Male repro & embryo/fetal dam
2-Ethoxyethyl acetate [111-15-9] (2003)	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] (1996)	5 ppm	15 ppm	A4	100.11	URT, eye, & GI irr; CNS impair; skin sens

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Ferrovanadium dust [12604-58-9] (1990)	1 mg/m³	3 mg/m³	—	—	Eye, URT, & LRT irr
Flour dust (2014)	0.5 mg/m³ (I)	—	RSEN	—	Asthma; URT irr; bronchitis
Fludioxonil [131341-86-1 (2018)	1 mg/m³ (I)	—	A3	248.20	Liver & kidney dam
Fluorides, as F (1996)	2.5 mg/m³	—	A4; BEI	Varies	Bone dam; fluorosis
Fluorine [7782-41-4], as F (2019)	0.1 ppm	C 0.5 ppm	—	38.00	Fluorosis; eye irr
Folpet [133-07-3] (2017)	1 mg/m³ (I)	—	DSEN; A3	296.60	Liver dam; body weight eff
Fonofos [944-22-9] (2006)	0.1 mg/m³ (IFV)	—	Skin; A4; BEI_C	246.32	Cholinesterase inhib
Formaldehyde [50-00-0] (2017)	0.1 ppm	0.3 ppm	DSEN; RSEN; A1	30.03	URT & eye irr; URT cancer
Formamide [75-12-7] (2020)	1 ppm	—	Skin; A3	45.04	Hematological eff; liver cancer; developmental toxicity
Formic acid [64-18-6] (1987)	5 ppm	10 ppm	—	46.02	URT, eye, & skin irr
Furfural [98-01-1] (2017)	0.2 ppm	—	Skin; A3; BEI	96.08	URT & eye irr
Furfuryl alcohol [98-00-0] (2017)	0.2 ppm	—	Skin; A3	98.10	URT & eye irr
Gallium arsenide [1303-00-0] (2007)	0.0003 mg/m³ (R)	—	A3	144.64	LRT irr
Gasoline [86290-81-5] (2003)	300 ppm	500 ppm	A3	Varies	URT & eye irr; CNS impair
Germanium tetrahydride [7782-65-2] (1986)	0.2 ppm	—	—	76.63	Hematologic eff

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Ethyleneimine [151-56-4] (2009)	0.05 ppm	0.1 ppm	Skin; A3	43.08	URT irr; liver & kidney dam
Ethyl ether [60-29-7] (1976)	400 ppm	500 ppm	—	74.12	CNS impair; URT irr
Ethyl formate [109-94-4] (2012)	—	100 ppm	A4	74.08	URT irr
2-Ethylhexanoic acid [149-57-5] (2007)	5 mg/m³ (IFV)	—	—	144.24	Teratogenic eff
2-Ethyl-1-hexanol [104-76-7]	(5 ppm)		A3		URT irr; eye irr
Ethylidene norbornene [16219-75-3] (2014)	2 ppm	4 ppm	—	120.19	URT & eye irr
Ethyl isocyanate [109-90-0] (2014)	0.02 ppm	0.06 ppm	Skin; DSEN	71.10	URT & eye irr
Ethyl mercaptan [75-08-1] (2004)	0.5 ppm	—	—	62.13	URT irr; CNS impair
N-Ethylmorpholine [100-74-3] (1986)	5 ppm	—	Skin	115.18	URT irr; eye dam
Ethyl silicate [78-10-4] (1986)	10 ppm	—	—	208.30	URT & eye irr; kidney dam
Fenamiphos [22224-92-6] (2006)	0.05 mg/m³ (IFV)	—	Skin; A4; BEI_C	303.40	Cholinesterase inhib
Fensulfothion [115-90-2] (2005)	0.01 mg/m³ (IFV)	—	Skin; A4; BEI_C	308.35	Cholinesterase inhib
Fenthion [55-38-9] (2006)	0.05 mg/m³ (IFV)	—	Skin; A4; BEI_C	278.34	Cholinesterase inhib
Ferbam [14484-64-1] (2009)	5 mg/m³ (I)	—	A4	416.50	CNS impair; body weight eff; spleen dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Hexachlorobutadiene [87-68-3] (1995)	0.02 ppm	—	Skin; A3	260.76	Kidney dam
Hexachlorocyclopentadiene [77-47-4] (1996)	0.01 ppm	—	A4	272.75	URT irr
Hexachloroethane [67-72-1] (1996)	1 ppm	—	Skin; A3	236.74	Liver & kidney dam
Hexachloronaphthalene [1335-87-1] (1986)	0.2 mg/m^3	—	Skin	334.74	Liver dam; chloracne
Hexafluoroacetone [684-16-2] (1986)	0.1 ppm	—	Skin	166.02	Testicular & kidney dam
Hexafluoropropylene [116-15-4] (2010)	0.1 ppm	—	—	150.02	Kidney dam
Hexahydrophthalic anhydride, all isomers [85-42-7; 13149-00-3; 14166-21-3] (2015)	—	C 0.005 mg/m^3 (IFV)	RSEN	154.17	Sens
Hexamethylene diisocyanate [822-06-0] (1988)	0.005 ppm	—	BEI	168.22	URT irr; resp sens
Hexamethylenetetramine [100-97-0] (2020)	1 mg/m^3 (IFV)	—	DSEN; A4	140.19	Dermal sens
Hexamethyl phosphoramide [680-31-9] (1996)	—	—	Skin; A3	179.20	URT cancer
n-Hexane [110-54-3] (1998)	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] (1982)	500 ppm	1000 ppm	—	86.17	CNS impair; URT & eye irr
1,6-Hexanediamine [124-09-4] (1992)	0.5 ppm	—	—	116.21	URT & skin irr
Hexazinone [51235-04-2] (2020)	3 mg/m^3 (I)	—	A4	252.30	Hematological & liver eff

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Glutaraldehyde [111-30-8], activated or unactivated (2015)	—	C 0.05 ppm	DSEN; RSEN; A4	100.11	URT, skin, & eye irr; CNS impair
Glycidol [556-52-5] (1996)	2 ppm	—	A3	74.08	URT, eye, & skin irr
Glyoxal [107-22-2] (2014)	0.1 mg/m^3 (IFV)	—	DSEN; A4	58.04	URT irr; larynx metaplasia
Grain dust (oat, wheat, barley) (1986)	4 mg/m^3	—	—	NA	Bronchitis; URT irr; pulm func
Graphite (all forms except graphite fibers) [7782-42-5] (1991)	2 mg/m^3 (R)	—	—	—	Pneumoconiosis
Hafnium [7440-58-6] and compounds, as Hf (1996)	0.5 mg/m^3	—	—	178.49	URT & eye irr; liver dam
Halothane [151-67-7] (1996)	50 ppm	—	A4	197.39	Liver dam; CNS impair; vasodilation
Hard metals containing Cobalt [7440-48-4] and Tungsten carbide [12070-12-1], as Co (2016)	0.005 mg/m^3 (T)	—	RSEN; A2	—	Pneumonitis
Helium [7440-59-7]	*See* Appendix F: Minimal Oxygen Content (D)			4.00	Asphyxia
Heptachlor [76-44-8] and Heptachlor epoxide [1024-57-3] (1990)	0.05 mg/m^3	—	Skin; A3	373.32 389.40	Liver dam
Heptane, isomers [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
Hexachlorobenzene [118-74-1] (1997)	0.002 mg/m^3	—	Skin; A3	284.78	Porphyrin eff; skin dam; CNS impair

Substance [CAS No.] (*Documentation* date)	TWA (ADOPTED VALUES)	STEL (ADOPTED VALUES)	Notations (ADOPTED VALUES)	MW	TLV® Basis
Hydrogen sulfide [7783-06-4] (2010)	1 ppm	5 ppm	—	34.08	URT irr; CNS impair
Hydroquinone [123-31-9] (2014)	1 mg/m^3	—	DSEN; A3	110.11	Eye irr; eye dam
2-Hydroxypropyl acrylate [999-61-1] (2014)	0.5 ppm	—	Skin; DSEN	130.14	Eye & URT irr
* Imazosulfuron [122548-33-8] (2021)	10 mg/m^3 (I)	—	A4	412.80	Thyroid & liver hypertrophy
Indene [95-13-6] (2008)	5 ppm	—	—	116.15	Liver dam
Indium [7440-74-6] and compounds, as In (1990)	0.1 mg/m^3	—	—	114.82	Pulm edema; pneumonitis; dental erosion; malaise
Indium tin oxide [50926-11-9], as In (2019)	0.0001 mg/m^3 (R)	—	DSEN; A3	Varies	Pulm func; pulm fibrosis
‡ Iodine and iodides, as iodone (2008)					
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)
* Iodoform [75-47-8] (2021), as elemental iodine	0.001 ppm (IFV)	—	Skin; A4	393.73	Thyroid eff; fetal/neonatal dam
Iron oxide (Fe_2O_3) [1309-37-1] (2006)	5 mg/m^3 (R)	—	A4	159.70	Pneumoconiosis
Iron pentacarbonyl [13463-40-6], as Fe (1982)	0.1 ppm	0.2 ppm	—	195.90	Pulm edema; CNS impair
Iron salts, soluble, as Fe (1990)	1 mg/m^3	—	—	Varies	URT & skin irr
Isoamyl alcohol [123-51-3] (1990)	100 ppm	125 ppm	—	88.15	Eye & URT irr

Substance [CAS No.] (*Documentation* date)	TWA (ADOPTED VALUES)	STEL (ADOPTED VALUES)	Notations (ADOPTED VALUES)	MW	TLV® Basis
1-Hexene [592-41-6] (2000)	50 ppm	—	—	84.16	CNS impair
sec-Hexyl acetate [108-84-9] (2020)	20 ppm	50 ppm	—	144.21	CNS impair; URT & eye irr
Hexylene glycol [107-41-5] (2017)	25 ppm (V)	50 ppm (V) 10 mg/m^3 (I, H)	—	118.18	Eye & URT irr
Hydrazine [302-01-2] (1995)	0.01 ppm	—	Skin; A3	32.05	URT cancer
Hydrogen [1333-74-0]	*See* Appendix F: Minimal Oxygen Content (D, EX)			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
Hydrogen chloride [7647-01-0] (2002)	—	C 2 ppm	A4	36.47	URT irr
Hydrogen cyanide and cyanide salts, as CN (1994)					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^3	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] (1996)	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

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Ketene [463-51-4] (2020)	—	C 0.05 ppm	—	42.04	Lung dam; pulm edema; URT & eye irr
Lead [7439-92-1] and inorganic compounds, as Pb (1995)	0.05 mg/m^3	—	A3; BEI	207.20 Varies	CNS & PNS impair; hematologic eff
Lead chromate [7758-97-6], as Cr(VI) (2018)	0.0002 mg/m^3 (I)	0.0005 mg/m^3 (I)	DSEN; RSEN; A1; BEI	323.22	Lung & sinonasal cancer; resp tract irr; asthma
Lindane [58-89-9] (1996)	0.5 mg/m^3	—	Skin; A3	290.85	Liver dam; CNS impair
Lithium hydride [7580-67-8] (2015)	—	C 0.05 mg/m^3 (I)	—	7.95	Eye & resp tract irr
L.P.G. (Liquefied petroleum gas) [68476-85-7]	*See* Appendix F: Minimal Oxygen Content (D, EX)			—	Asphyxia
Magnesium oxide [1309-48-4] (2003)	10 mg/m^3 (I)	—	A4	40.32	URT; metal fume fever
Malathion [121-75-5] (2003)	1 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	330.36	Cholinesterase inhib
Maleic anhydride [108-31-6] (2014)	0.01 mg/m^3 (IFV)	—	DSEN; RSEN; A4	98.06	Resp sens
Manganese [7439-96-5], elemental and inorganic compounds, as Mn (2013)	0.02 mg/m^3 (R) 0.1 mg/m^3 (I)	—	A4	54.94 Varies	CNS impair
Manganese cyclopentadienyl tricarbonyl [12079-65-1], as Mn (1992)	0.1 mg/m^3	—	Skin	204.10	Skin irr; CNS impair
Mercury [7439-97-6], alkyl compounds, as Hg (1992)	0.01 mg/m^3	0.03 mg/m^3	Skin	Varies	CNS & PNS impair; kidney dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Isobutanol [78-83-1] (2002)	50 ppm	—	—	74.12	Skin & eye irr
Isobutyl nitrite [542-56-3] (2019)	—	C 1 ppm	A3; BEI$_M$	103.12	MeHb-emia; Vasodilation
* Isoflurane [26675-46-7] (2021)	50 ppm	—	A4	184.49	Embryo/fetal dam; maternal body weight eff; CNS impair; cognitive decrements
Isooctyl alcohol [26952-21-6] (1990)	50 ppm	—	Skin	130.23	URT irr
Isophorone [78-59-1] (1995)	—	C 5 ppm	A3	138.21	Eye & URT irr; CNS impair; malaise; fatigue
Isophorone diisocyanate [4098-71-9] (1988)	0.005 ppm	—	—	222.30	Resp sens
2-Isopropoxyethanol [109-59-1] (1990)	25 ppm	—	Skin	104.15	Hematologic eff
Isopropylamine [75-31-0] (2020)	2 ppm	5 ppm	Skin	59.11	URT & ocular irr; visual impair
N-Isopropylaniline [768-52-5] (1990)	2 ppm	—	Skin; BEI$_M$	135.21	MeHb-emia
Isopropyl ether [108-20-3] (1979)	250 ppm	310 ppm	—	102.17	Eye & URT irr
Isopropyl glycidyl ether [4016-14-2] (1979)	50 ppm	75 ppm	—	116.18	URT & eye irr; dermatitis
Kaolin [1332-58-7] (1996)	2 mg/m^3 (E, R)	—	A4	—	Pneumoconiosis
Kerosene [8008-20-6; 64742-81-0]/Jet fuels, as total hydrocarbon vapor (2003)	200 mg/m^3 (P)	—	Skin; A3	Varies	Skin & URT irr; CNS impair

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Methylacetylene [74-99-7] (2017)	1000 ppm (EX)	—	—	40.07	CNS impair
Methylacetylene-propadiene mixture [59355-75-8] (2017)	1000 ppm (EX)	1250 ppm (EX)	—	40.07	CNS impair
Methyl acrylate [96-33-3] (2014)	2 ppm	—	Skin; DSEN; A4	86.09	Eye, skin, & URT irr; eye dam
Methylacrylonitrile [126-98-7] (2011)	1 ppm	—	Skin; A4	67.09	CNS impair; eye & skin irr
Methylal [109-87-5] (1987)	1000 ppm	—	—	76.10	Eye irr; CNS impair
Methylamine [74-89-5] (2013)	5 ppm	15 ppm	—	31.06	Eye, skin, & URT irr
Methyl n-amyl ketone [110-43-0] (1987)	50 ppm	—	—	114.18	Eye & skin irr
N-Methylaniline [100-61-8] (1992)	0.5 ppm	—	Skin; BEI_M	107.15	MeHb-emia; CNS impair
* 2-Methyl-2-butene [513-35-9] (2021)	10 ppm	—	—	70.13	Clastogenic eff
Methyl bromide [74-83-9] (1997)	1 ppm	—	Skin; A4	94.95	URT & skin irr
Methyl tert-butyl ether [1634-04-4] (2002)	50 ppm	—	A3	88.17	URT irr; kidney dam
Methyl n-butyl ketone [591-78-6] (1998)	5 ppm	10 ppm	Skin	100.16	Peripheral neuropathy; testicular dam
Methyl chloride [74-87-3] (1996)	50 ppm	100 ppm	Skin; A4	50.49	CNS impair; liver, kidney, & testicular dam; teratogenic eff

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Mercury [7439-97-6], all forms except alkyl, as Hg (1994)				200.59	
Aryl compounds	0.1 mg/m^3	—	Skin	Varies	CNS impair; kidney dam
Elemental and inorganic forms	0.025 mg/m^3	—	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] (2009)	200 ppm	250 ppm	Skin; BEI	32.04	Headache; eye dam; dizziness; nausea
Methomyl [16752-77-5] (2014)	0.2 mg/m^3 (IFV)	—	Skin; A4; BEI_C	162.20	Cholinesterase inhib; male repro dam; hematologic eff
Methoxychlor [72-43-5] (1996)	10 mg/m^3	—	A4	345.65	Liver dam; CNS impair
2-Methoxyethanol [109-86-4] (2006)	0.1 ppm	—	Skin; BEI	76.09	Hematologic & repro eff
2-Methoxyethyl acetate [110-49-6] (2006)	0.1 ppm	—	Skin; BEI	118.13	Hematologic & repro eff
4-Methoxyphenol [150-76-5] (1992)	5 mg/m^3	—	—	124.15	Eye irr; skin dam
1-Methoxy-2-propanol [107-98-2] (2013)	50 ppm	100 ppm	A4	90.12	Eye & URT irr
Methyl acetate [79-20-9] (2013)	200 ppm	250 ppm	—	74.08	Headache; dizziness; nausea; eye dam (degeneration of ganglion cells in the retina)

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Methyl formate [107-31-3] (2015)	50 ppm	100 ppm	Skin	60.05	CNS impair; URT irr; eye dam
Methylhydrazine [60-34-4] (1995)	0.01 ppm	—	Skin; A3	46.07	URT & eye irr; lung cancer; liver dam
Methyl iodide [74-88-4] (1996)	2 ppm	—	Skin	141.95	Eye dam; CNS impair
Methyl isoamyl ketone [110-12-3] (2013)	20 ppm	50 ppm	—	114.20	CNS impair; URT irr
Methyl isobutyl carbinol [108-11-2] (2020)	20 ppm	40 ppm	—	102.18	URT & eye irr; dizziness; headache
Methyl isobutyl ketone [108-10-1] (2010)	20 ppm	75 ppm	A3; BEI	100.16	URT irr; dizziness; headache
Methyl isocyanate [624-83-9] (2014)	0.02 ppm	0.06 ppm	Skin; DSEN	57.05	URT & eye irr
Methyl isopropyl ketone [563-80-4] (2011)	20 ppm	—	—	86.14	Embryo/fetal dam; neonatal toxicity
Methyl mercaptan [74-93-1] (2004)	0.5 ppm	—	—	48.11	Liver dam
Methyl methacrylate [80-62-6] (2015)	50 ppm	100 ppm	DSEN; A4	100.13	URT & eye irr; body weight eff; pulm edema
‡ Methylnaphthalene, all isomers 1-Methylnaphthalene [90-12-0] and 2-Methylnaphthalene [91-57-6] (2007)	(0.5 ppm)	—	Skin; A4	142.20	(LRT irr); lung dam ( )
Methyl parathion [298-00-0] (2009)	0.02 mg/m³ (IFV)	—	Skin; A4; BEI_C	263.20	Cholinesterase inhib
Methyl propyl ketone [107-87-9] (2007)	—	150 ppm	—	86.17	Pulm func; eye irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Methyl chloroform [71-55-6] (1996)	350 ppm	450 ppm	A4; BEI	133.42	CNS impair; liver dam
Methylcyclohexane [108-87-2] (1987)	400 ppm	—	—	98.19	URT irr; CNS impair; liver & kidney dam
Methylcyclohexanol [25639-42-3] (2004)	50 ppm	—	—	114.19	URT & eye irr
2-Methylcyclohexanone [*see* methylcyclohexanone, all isomers] 589-92-4; 591-24-2; 1331-22-2] (2020)	20 ppm	—	—	112.17	Liver eff; CNS impair
2-Methylcyclopentadienyl manganese tricarbonyl [12108-13-3], as Mn (1986)	0.2 mg/m³	—	Skin	218.10	CNS impair; lung, liver, & kidney dam
Methyl demeton [8022-00-2] (2007)	0.05 mg/m³ (IFV)	—	Skin; BEI_C	230.30	Cholinesterase inhib
Methylene bisphenyl isocyanate [101-68-8] (1988)	0.005 ppm	—	—	250.26	Resp sens
4,4'-Methylene bis(2-chloroaniline) [101-14-4] (2018)	0.01 ppm (IFV)	—	Skin; A2; BEI	267.17	Bladder cancer; MeHb-emia
Methylene bis(4-cyclohexylisocyanate) [5124-30-1] (1988)	0.005 ppm	—	—	262.35	Resp sens; LRT irr
4,4'-Methylenedianiline [101-77-9] (1995)	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

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES				
	TWA	**STEL**	**Notations**	**MW**	**TLV® Basis**
Monochloroacetic acid [79-11-8] (2006)	0.5 ppm (IFV)	—	Skin; A4	94.50	URT irr
Monocrotophos [6923-22-4] (2002)	0.05 mg/m^3 (IFV)	—	Skin; A4; BEI_C	223.16	Cholinesterase inhib
Monomethylformamide [123-39-7] (2019)	1 ppm	—	Skin	59.07	Embryo/fetal & liver dam; teratogenic eff
Morpholine [110-91-8] (1996)	20 ppm	—	Skin; A4	87.12	Eye dam; URT irr
Naled [300-76-5] (2014)	0.1 mg/m^3 (IFV)	—	Skin; DSEN; A4; BEI_C	380.79	Cholinesterase inhib
Naphthalene [91-20-3] (2014)	10 ppm	—	Skin; A3; BEI	128.19	URT irr; cataracts; hemolytic anemia
β-Naphthylamine [91-59-8] (1987)	— (L)	—	A1	143.18	Bladder cancer
Natural gas [8006-14-2]	*See* Appendix F: Minimal Oxygen Content (D, EX)			—	Asphyxia
Natural rubber latex [9006-04-6], as inhalable allergenic proteins (2014)	0.0001 mg/m^3 (I)	—	Skin; DSEN; RSEN	Varies	Resp sens
Neon [7440-01-9]	*See* Appendix F: Minimal Oxygen Content (D)			20.18	Asphyxia

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES				
	TWA	**STEL**	**Notations**	**MW**	**TLV® Basis**
Methyl silicate [681-84-5] (1986)	1 ppm	—	—	152.22	URT irr; eye dam
α-Methylstyrene [98-83-9] (2010)	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] (2019)	0.07 ppb SL 0.7 mg/100 cm^2	0.3 ppb	Skin; DSEN; RSEN	166.70	Resp sens
Methyl vinyl ketone [78-94-4] (2019)	—	C 0.01 ppm	—	70.10	Upper resp dam; leukopenia
Metribuzin [21087-64-9] (1996)	5 mg/m^3	—	A4	214.28	Liver dam; hematologic eff
Mevinphos [7786-34-7] (2003)	0.01 mg/m^3 (IFV)	—	Skin; A4; BEI_C	224.16	Cholinesterase inhib
Mica [12001-26-2] (2020)	0.1 mg/m^3 (R)	—	—	—	Pneumoconiosis
Mineral oil, excluding metal working fluids (2010)				Varies	URT irr
Pure, highly and severely refined	5 mg/m^3 (I)	—	A4		
Poorly and mildly refined	— (L)	—	A2		
Molybdenum [7439-98-7], as Mo				95.95	LRT irr
Soluble compounds (2003)	0.5 mg/m^3 (R)	—	A3		
Metal and insoluble compounds (2001)	10 mg/m^3 (I) 3 mg/m^3 (R)	— —	— —		

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Nitrogen [7727-37-9]	*See* Appendix F: Minimal Oxygen Content (D)			14.01	Asphyxia
Nitrogen dioxide [10102-44-0] (2012)	0.2 ppm	—	A4	46.01	LRT irr
Nitrogen trifluoride [7783-54-2] (1992)	10 ppm	—	BEI_M	71.00	MeHb-emia; liver & kidney dam
Nitroglycerin [55-63-0] (1985)	0.05 ppm	—	Skin	227.09	Vasodilation
Nitromethane [75-52-5] (2000)	20 ppm	—	A3	61.04	Thyroid eff; URT irr; lung dam
1-Nitropropane [108-03-2] (1995)	25 ppm	—	A4	89.09	URT & eye irr; liver dam
2-Nitropropane [79-46-9] (1995)	10 ppm	—	A3	89.09	Liver dam; liver cancer
N-Nitrosodimethylamine [62-75-9] (1995)	— (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_M	137.13	MeHb-emia
5-Nitro-o-toluidine [99-55-8] (2019)	1 mg/m^3 (IFV)	—	A3	152.16	Liver dam
Nitrous oxide [10024-97-2] (1995)	50 ppm	—	A4	44.02	CNS impair; hematologic eff; embryo/fetal dam
Nonane [111-84-2] (2012)	200 ppm	—	—	128.26	CNS impair
Octachloronaphthalene [2234-13-1] (1976)	0.1 mg/m^3	0.3 mg/m^3	Skin	403.74	Liver dam
Octane [111-65-9], all isomers (1999)	300 ppm	—	—	114.22	URT irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Nickel [7440-02-0] and inorganic compounds including Nickel subsulfide, as Ni (1998)					
Elemental [7440-02-0]	1.5 mg/m^3 (I)	—	A5; BEI	58.71	Dermatitis; pneumoconiosis
Soluble inorganic compounds (NOS)	0.1 mg/m^3 (I)	—	A4; BEI	Varies	Lung dam; nasal cancer
Insoluble inorganic compounds (NOS)	0.2 mg/m^3 (I)	—	A1; BEI	Varies	Lung cancer
Nickel subsulfide [12035-72-2], as Ni	0.1 mg/m^3 (I)	—	A1; BEI	240.19	Lung cancer
Nickel carbonyl [13463-39-3], as Ni (2014)	—	C 0.05 ppm	A3	170.73	Lung irr
Nicotine [54-11-5] (1992)	0.5 mg/m^3	—	Skin	162.23	GI dam; CNS impair; card impair
Nitrapyrin [1929-82-4] (2019)	10 mg/m^3 (IFV)	20 mg/m^3 (IFV)	A4	230.93	Liver dam
‡ Nitric acid [7697-37-2] (1997)	(2 ppm)	(4 ppm)	( )	63.02	(URT & eye irr; dental erosion)
Nitric oxide [10102-43-9] (1992)	25 ppm	—	BEI_M	30.01	Hypoxia/cyanosis; nitrosyl-Hb form; URT irr
p-Nitroaniline [100-01-6] (1996)	3 mg/m^3	—	Skin; A4; BEI_M	138.12	MeHb-emia; liver dam; eye irr
Nitrobenzene [98-95-3] (1996)	1 ppm	—	Skin; A3; BEI_M	123.11	MeHb-emia
p-Nitrochlorobenzene [100-00-5] (2008)	0.1 ppm	—	Skin; A3; BEI_M	157.56	MeHb-emia
4-Nitrodiphenyl [92-93-3] (1996)	— (L)	—	Skin; A2	199.20	Bladder cancer
Nitroethane [79-24-3] (1986)	100 ppm	—	—	75.07	URT irr; CNS impair; liver dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Pentachloronitrobenzene [82-68-8] (1996)	0.5 mg/m³	—	A4	295.36	Liver dam
Pentachlorophenol [87-86-5] (2014)	0.5 mg/m³ (IFV)	1 mg/m³ (IFV)	Skin; A3; BEI	266.35	URT & eye irr; CNS & card impair
Pentaerythritol [115-77-5] (2013)	10 mg/m³	—	—	136.15	GI irr
Pentane, all isomers [78-78-4; 109-66-0; 463-82-1] (2014)	1000 ppm	—	—	72.15	Narcosis; resp tract irr
2,4-Pentanedione [123-54-6] (2011)	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] (2000)	50 ppm	100 ppm	—	130.20	URT irr
Peracetic acid [79-21-0] (2014)	—	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] (2020)	0.5 ppm	—	—	102.45	MeHb-emia; fluorosis
Perfluorobutyl ethylene [19430-93-4] (2004)	100 ppm	—	—	246.10	Hematologic eff
Perfluoroisobutylene [382-21-8] (1992)	—	C 0.01 ppm	—	200.04	URT irr; hematologic eff
Persulfates, as persulfate [7727-21-1; 7727-54-0; 7775-27-1] (2006)	0.1 mg/m³	—	—	Varies	Skin irr
Phenol [108-95-2] (1996)	5 ppm	—	Skin; A4; BEI	94.11	URT irr; lung dam; CNS impair
‡ Phenothiazine [92-84-2] (1986)	(5 mg/m³)	—	Skin; ( )	199.26	(Eye photosens; skin irr) ( )

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® 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] (2015)	1 mg/m³	2 mg/m³	—	90.04 (anhy) 126.00 (dihy)	URT, eye, & skin irr
p,p'-Oxybis(benzenesulfonyl hydrazide) [80-51-3] (2000)	0.1 mg/m³ (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] (1999)				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] (1987)	2 mg/m³	—	—	—	URT irr; nausea
Paraquat [4685-14-7], as the cation (2018)	0.05 mg/m³ (I)	—	Skin; A4	257.18	Lung dam; URT irr
Parathion [56-38-2] (2003)	0.05 mg/m³ (IFV)	—	Skin; A4; BEI	291.27	Cholinesterase inhib
Particles (insoluble or poorly soluble) not otherwise specified		*See* Appendix B			
Pentaborane [19624-22-7] (1976)	0.005 ppm	0.015 ppm	—	63.17	CNS convul & impair
Pentachloronaphthalene [1321-64-8] (1984)	0.5 mg/m³ (IFV)	—	Skin	300.40	Liver dam; chloracne

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Phosphine [7803-51-2] (2019)	0.05 ppm	C 0.15 ppm	A4	34.00	Resp tract irr; pulm edema
Phosphoric acid [7664-38-2] (1992)	1 mg/m^3	3 mg/m^3	—	98.00	URT, eye, & skin irr
Phosphorus (yellow) [12185-10-3] (2003)	0.1 mg/m^3	—	—	123.92	LRT, URT, & GI irr; liver dam
Phosphorus oxychloride [10025-87-3] (1990)	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^3	3 mg/m^3	—	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] (2019)	SL 25 µg/100 cm^2	C 0.1 ppb (V)	Skin; DSEN; RSEN	134.10	Eye, skin & resp tract irr; resp sens; anaphylaxis
Phthalic anhydride [85-44-9] (2017)	0.002 mg/m^3 (IFV)	0.005 mg/m^3 (IFV)	Skin; DSEN; RSEN; A4	148.12	Resp sens; asthma
m-Phthalodinitrile [626-17-5] (2009)	5 mg/m^3 (IFV)	—	—	128.14	Eye & URT irr
o-Phthalodinitrile [91-15-6] (2012)	1 mg/m^3 (IFV)	—	—	128.13	CNS convul; body weight eff
Picloram [1918-02-1] (1996)	10 mg/m^3	—	A4	241.48	Liver & kidney dam
Picric acid [88-89-1] (1992)	0.1 mg/m^3	—	—	229.11	Skin sens; dermatitis; eye irr
Pindone [83-26-1] (1992)	0.1 mg/m^3	—	—	230.25	Coagulation
Piperazine and salts [110-85-0], as piperazine (2014)	0.03 ppm (IFV)	—	DSEN; RSEN; A4	86.14	Resp sens; asthma

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
N-Phenyl-β-naphthylamine [135-88-6] (1996)	— (L)	—	A4	219.29	Cancer
m-Phenylenediamine [108-45-2] (1996)	0.1 mg/m^3	—	A4	108.05	Liver dam; skin irr
o-Phenylenediamine [95-54-5] (1995)	0.1 mg/m^3	—	A3	108.05	Anemia
p-Phenylenediamine [106-50-3] (1996)	0.1 mg/m^3	—	A4	108.05	URT irr; skin sens
Phenyl ether [101-84-8] (1979)	1 ppm (V)	2 ppm (V)	—	170.20	URT & eye irr; nausea
Phenyl glycidyl ether [122-60-1] (2014)	0.1 ppm	—	Skin; DSEN; A3	150.17	Testicular dam
Phenylhydrazine [100-63-0] (1996)	0.1 ppm	—	Skin; A3	108.14	Anemia; URT & skin irr
Phenyl isocyanate [103-71-9] (2015)	0.005 ppm	0.015 ppm	Skin; DSEN; RSEN	119.10	URT irr
Phenyl mercaptan [108-98-5] (2004)	0.1 ppm	—	Skin	110.18	CNS impair; eye & skin irr
Phenylphosphine [638-21-1] (1992)	—	C 0.05 ppm	—	110.10	Dermatitis; hematologic eff; testicular dam
Phorate [298-02-2] (2005)	0.05 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	260.40	Cholinesterase inhib
* Phosgene [75-44-5] (2021)		C 0.02 ppm	—	98.92	URT irr; pulm edema; emphysema

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Propionic acid [79-09-4] (1990)	10 ppm	—	—	74.08	Eye, skin, & URT irr
Propoxur [114-26-1] (2016)	0.5 mg/m^3 (IFV)	—	A3; BEI_C	209.24	Cholinesterase inhib
Propyl acetate isomers [108-21-4; 109-60-4] (2018)	100 ppm	150 ppm	—	102.13	URT & eye irr; CNS impair
Propylene [115-07-1] (2006)	500 ppm	—	A4	42.08	Asphyxia; URT irr
Propylene dichloride [78-87-5] (2014)	10 ppm	—	DSEN; A4	112.99	URT irr; body weight eff
‡ Propylene glycol dinitrate [6423-43-4] (1985)	(0.05 ppm) ( )	( )	Skin; BEI_M	166.09	Headache; (CNS impair) ( )
Propylene glycol ethyl ether [1569-02-4] (2019)	50 ppm	200 ppm	Skin	104.17	CNS impair; eye & URT irr
Propylene oxide [75-56-9] (2014)	2 ppm	—	DSEN; A3	58.08	Eye & URT irr
Propyleneimine [75-55-8] (2009)	0.2 ppm	0.4 ppm	Skin; A3	57.09	URT irr; kidney dam
‡ n-Propyl nitrate [627-13-4] (1976)	(25 ppm)	(40 ppm)	BEI_M	105.09	(Nausea; headache)
Pyrethrum [8003-34-7] (1996)	5 mg/m^3	—	A4	345 (avg.)	Liver dam; LRT irr
Pyridine [110-86-1] (2004)	1 ppm	—	A3	79.10	Skin irr; liver & kidney dam
Quinone [Cyclohexane] (1987)	0.1 ppm	—	—	108.09	Eye irr; skin dam

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Platinum [7440-06-4], and soluble salts (1981)					
Metal	1 mg/m^3	—	—	195.09	Asthma; URT irr
Soluble salts, as Pt	0.002 mg/m^3	—	—	Varies	Asthma; URT irr
Polyvinyl chloride [9002-86-2] (2008)	1 mg/m^3 (R)	—	A4	Varies	Pneumoconiosis; LRT irr; pulm func changes
Portland cement [65997-15-1] (2010)	1 mg/m^3 (E, R)	—	A4	—	Pulm func; resp symptoms; asthma
Potassium hydroxide [1310-58-3] (1992)	—	C 2 mg/m^3	—	56.10	URT, eye, & skin irr
* Prometon [1610-18-0] (2021)	0.5 mg/m^3 (I)	—	A4	225.29	Decreased body weight
* Prometryn [7287-19-6] (2021)	1 mg/m^3 (I)	—	A4	241.37	Liver & kidney dam; bone marrow eff; maternal/fetal toxicity
Propane [74-98-6]	*See* Appendix F: Minimal Oxygen Content (D, EX)			44.10	Asphyxia
Propane sultone [1120-71-4] (2006)	— (L)	—	A3	122.14	Cancer
n-Propanol (n-Propyl alcohol) [71-23-8] (2007)	100 ppm	—	A4	60.09	Eye & URT irr
2-Propanol [67-63-0] (2001)	200 ppm	400 ppm	A4; BEI	60.09	Eye & URT irr; CNS impair
Propargyl alcohol [107-19-7] (1992)	1 ppm	—	Skin	56.06	Eye irr; liver & kidney dam
β-Propiolactone [57-57-8] (1995)	0.5 ppm	—	A3	72.06	Skin cancer; URT irr
Propionaldehyde [123-38-6] (2002)	20 ppm	—	—	58.10	URT irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Silicon tetrahydride [7803-62-5] (2015)	5 ppm	—	—	32.12	URT irr
Silver [7440-22-4], and compounds (1992)					Argyria
Metal, dust and fume	0.1 mg/m^3	—	—	107.87	
Soluble compounds, as Ag	0.01 mg/m^3	—	—	Varies	
Simazine [122-34-9] (2016)	0.5 mg/m^3 (I)	—	A3	201.60	Hematologic eff
Sodium azide [26628-22-8] (1996)				65.02	Card impair; lung dam
as Sodium azide	—	C 0.29 mg/m^3	A4		
as Hydrazoic acid vapor	—	C 0.11 ppm	A4		
Sodium bisulfite [7631-90-5] (1996)	5 mg/m^3	—	A4	104.07	Skin, eye, & URT irr
Sodium fluoroacetate [62-74-8] (1994)	0.05 mg/m^3	—	Skin	100.02	CNS impair; card impair; nausea
Sodium hydroxide [1310-73-2] (1992)	—	C 2 mg/m^3	—	40.01	URT, eye, & skin irr
Sodium metabisulfite [7681-57-4] (1996)	5 mg/m^3	—	A4	190.13	URT irr
Starch [9005-25-8] (1996)	10 mg/m^3	—	A4	—	Dermatitis
Stearates(J) [57-11-4; 557-04-0; 557-05-1; 822-16-2] (2017)	10 mg/m^3 (I) 3 mg/m^3 (R)	—	A4	Varies	LRT irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Resin acids, as total Resin acids [8050-09-7] (2020)	0.001 mg/m^3 (I)	—	DSEN; RSEN	—	Asthma; resp & eye irr; dermal & resp sens
Resorcinol [108-46-3] (1996)	10 ppm	20 ppm	A4	110.11	Eye & skin irr
Rhodium [7440-16-6], as Rh (1996)				102.91	
Metal and Insoluble compounds	1 mg/m^3	—	A4	Varies	Metal = URT irr; Insoluble = LRT irr
Soluble compounds	0.01 mg/m^3	—	A4	Varies	Asthma
Ronnel [299-84-3] (2006)	5 mg/m^3 (IFV)	—	A4; BEI$_C$	321.57	Cholinesterase inhib
Rotenone (commercial) [83-79-4] (1996)	5 mg/m^3	—	A4	391.41	URT & eye irr; CNS impair
Selenium [7782-49-2] and compounds, as Se (1992)	0.2 mg/m^3	—	—	78.96	Eye & URT irr
Selenium hexafluoride [7783-79-1], as Se (2001)	0.05 ppm	—	—	192.96	Pulm edema
Sesone [136-78-7] (1996)	10 mg/m^3	—	A4	309.13	GI irr
Silica, crystalline — α-quartz [1317-95-9; 14808-60-7] and cristobalite [14464-46-1] (2010)	0.025 mg/m^3 (R)	—	A2	60.09	Pulm fibrosis; lung cancer
‡ Silicon carbide [409-21-2] (2003)				40.10	
Nonfibrous	10 mg/m^3 (I, E) 3 mg/m^3 (R, E)	—	—		(URT irr) ( ) (URT irr) ( )
Fibrous (including whiskers)	0.1 f/cc (F)	—	A2		(Mesothelioma); cancer

TLV®-CS

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Sulfur pentafluoride [5714-22-7] (2020)	—	C 0.001 ppm	—	254.11	Pulm edema
Sulfur tetrafluoride [7783-60-0] (1992)	—	C 0.1 ppm	—	108.07	Eye & URT irr; lung dam
Sulfuric acid [7664-93-9] (2004)	0.2 mg/m^3 (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] (2009)	0.1 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	322.43	Cholinesterase inhib
Synthetic vitreous fibers (2001)					
Continuous filament glass fibers	1 f/cc (F)	—	A4	—	URT irr
Continuous filament glass fibers	5 mg/m^3 (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
2,4,5-T [93-76-5] (1996)	10 mg/m^3	—	A4	255.49	PNS impair
Talc [14807-96-6] (2010)					
Containing no asbestos fibers	2 mg/m^3 (E, R)	—	A4	—	Pulm fibrosis; pulm func
Containing asbestos fibers	Use Asbestos TLV® (K)	—	A1	—	

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Stoddard solvent [8052-41-3] (1987)	100 ppm	—	—	140.00	Eye, skin, & kidney dam; nausea; CNS impair
Strychnine [57-24-9] (1992)	0.15 mg/m^3	—	—	334.40	CNS impair
Styrene [100-42-5] (2020)	10 ppm	20 ppm	OTO; A3; BEI	104.15	CNS & hearing impair; URT irr; peripheral neuropathy; visual disorders
Styrene oxide [96-09-3] (2020)	1 ppm	—	Skin; DSEN; A3	120.15	URT irr; blood changes
Subtilisins [1395-21-7; 9014-01-1], as 100% crystalline active pure enzyme (2007)	—	C 0.00006 mg/m^3	—	—	Asthma; skin, URT, & LRT irr
Sucrose [57-50-1] (1995)	10 mg/m^3	—	A4	342.30	Dental erosion
Sulfometuron methyl [74222-97-2] (2019)	5 mg/m^3 (IFV)	—	A4	364.38	Hematologic eff
Sulfotepp [3689-24-5] (2005)	0.1 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	322.30	Cholinesterase inhib
Sulfoxaflor [946578-00-3] (2019)	0.1 mg/m^3 (I)	—	A3	277.30	Liver & Testicular dam
Sulfur dioxide [7446-09-5] (2009)	—	0.25 ppm	A4	64.07	Pulm func; LRT irr
Sulfur hexafluoride [2551-62-4] (1986)	1000 ppm	—	—	146.07	Asphyxia
Sulfur monochloride [10025-67-9] (1986)	—	C 1 ppm	—	135.03	Eye, skin, & URT irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Tetrafluoroethylene [116-14-3] (2000)	2 ppm	—	A3	100.20	Kidney & liver dam; liver & kidney cancer
Tetrahydrofuran [109-99-9] (2005)	50 ppm	100 ppm	Skin; A3; BEI	72.10	URT irr; CNS impair; kidney dam
Tetrakis (hydroxymethyl) phosphonium salts (2014)					Liver dam
Tetrakis (hydroxymethyl) phosphonium chloride [124-64-1]	2 mg/m^3	—	DSEN; A4	190.56	
Tetrakis (hydroxymethyl) phosphonium sulfate [55566-30-8]	2 mg/m^3	—	DSEN; A4	406.26	
Tetramethyl lead [75-74-1], as Pb (1992)	0.15 mg/m^3	—	Skin	267.33	CNS impair
Tetramethyl succinonitrile [3333-52-6] (2019)	0.5 mg/m^3 (IFV)	—	Skin	136.20	Hypoglycemia; convul
Tetranitromethane [509-14-8] (1995)	0.005 ppm	—	A3	196.04	Eye & URT irr; URT cancer
Tetryl [479-45-8] (1988)	1.5 mg/m^3	—	—	287.15	URT irr
Thallium [7440-28-0] and compounds, as Tl (2010)	0.02 mg/m^3 (I)	—	Skin	204.37 Varies	GI dam; peripheral neuropathy
Thiacloprid [111988-49-9] (2019)	0.2 mg/m^3 (I)	—	Skin; A3	252.72	Liver dam; thyroid & CNS eff; cancer
4,4'-Thiobis(6-tert-butyl-m-cresol) [96-69-5] (2011)	1 mg/m^3 (I)	—	A4	358.52	URT irr
Thiodicarb [59669-26-0] (2020)	0.1 mg/m^3 (IFV)	—	DSEN; A3	354.50	Acetylcholinesterase inhib
Thioglycolic acid [68-11-1] and salts (2018)	1 ppm	—	Skin; DSEN	92.12	Eye & resp irr

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Tellurium [13494-80-9] and compounds (NOS), as Te, excluding hydrogen telluride (1992)	0.1 mg/m^3	—	—	127.60	Halitosis
Tellurium hexafluoride [7783-80-4], as Te (1992)	0.02 ppm	—	—	241.61	LRT irr
Temephos [3383-96-8] (2019)	1 mg/m^3 (I)	—	Skin; A4; BEI$_C$	466.46	Cholinesterase inhib
Terbufos [13071-79-9] (2002)	0.01 mg/m^3 (IFV)	—	Skin; A4; BEI$_C$	288.45	Cholinesterase inhib
Terephthalic acid [100-21-0] (1993)	10 mg/m^3	—	—	166.13	—
Terphenyls (o-, m-, p- isomers) [26140-60-3] (1980)	—	C 5 mg/m^3	—	230.31	URT & eye irr
1,1,2,2-Tetrabromoethane [79-27-6] (2019)	0.1 ppm	—	—	345.70	Eye & URT irr; pulm edema; liver dam
1,1,1,2-Tetrachloro-2,2-difluoroethane [76-11-9] (2008)	100 ppm	—	—	203.83	Liver & kidney dam; CNS impair
1,1,2,2-Tetrachloro-1,2-difluoroethane [76-12-0] (2008)	50 ppm	—	—	203.83	Liver & kidney dam; CNS impair
1,1,2,2-Tetrachloroethane [79-34-5] (1997)	1 ppm	—	Skin; A3	167.86	Liver dam
Tetrachloroethylene [127-18-4] (2001)	25 ppm	100 ppm	A3; BEI	165.80	CNS impair
Tetrachloronaphthalene [1335-88-2] (1992)	2 mg/m^3	—	—	265.96	Liver dam
Tetraethyl lead [78-00-2], as Pb (1996)	0.1 mg/m^3	—	Skin; A4	323.45	CNS impair
Tetraethyl pyrophosphate [107-49-3] (2007)	0.01 mg/m^3 (IFV)	—	Skin; BEI$_C$	290.20	Cholinesterase inhib

	ADOPTED VALUES				
Substance [CAS No.] (*Documentation* date)	**TWA**	**STEL**	**Notations**	**MW**	**TLV® Basis**
o-Toluidine [95-53-4] (1995)	2 ppm	—	Skin; A3; BEI_M	107.15	MeHb-emia; skin, eye, kidney & bladder irr
p-Toluidine [106-49-0] (1995)	2 ppm	—	Skin; A3; BEI_M	107.15	MeHb-emia
Tributyl phosphate [126-73-8] (2013)	5 mg/m^3 (IFV)	—	A3; BEI_C	266.31	Bladder, eye, & URT irr
Trichlorfon [52-68-6] (2020)	0.1 mg/m^3 (IFV)	—	A4; DSEN; BEI_C	257.44	Cholinesterase inhib
Trichloroacetic acid [76-03-9] (2014)	0.5 ppm	—	A3	163.39	Eye & URT irr
1,2,4-Trichlorobenzene [120-82-1] (1978)	—	C 5 ppm	—	181.46	Eye & URT irr
1,1,2-Trichloroethane [79-00-5] (1995)	10 ppm	—	Skin; A3	133.41	CNS impair; liver dam
Trichloroethylene [79-01-6] (2007)	10 ppm	25 ppm	A2; BEI	131.40	CNS impair; cognitive decrements; renal toxicity
Trichlorofluoromethane [75-69-4] (1996)	—	C 1000 ppm	A4	137.38	Card sens
Trichloronaphthalene [1321-65-9] (1986)	5 mg/m^3	—	Skin	231.51	Liver dam; chloracne
1,2,3-Trichloropropane [96-18-4] (2015)	0.005 ppm	—	A2	147.43	Cancer
1,1,2-Trichloro-1,2,2-trifluoroethane [76-13-1] (1996)	1000 ppm	1250 ppm	A4	187.40	CNS impair
Triethanolamine [102-71-6] (1993)	5 mg/m^3	—	—	149.22	Eye & skin irr
Triethylamine [121-44-8] (2015)	0.5 ppm	1 ppm	Skin; A4	101.19	Visual impair; URT irr
Triflumizole [68694-11-1] (2020)	1 mg/m^3 (I)	—	A4; DSEN	345.75	Liver changes
Trifluorobromomethane [75-63-8] (1986)	1000 ppm	—	—	148.92	CNS & card impair

	ADOPTED VALUES				
Substance [CAS No.] (*Documentation* date)	**TWA**	**STEL**	**Notations**	**MW**	**TLV® Basis**
Thionyl chloride [7719-09-7] (2010)	—	C 0.2 ppm	—	118.98	URT irr
Thiram [137-26-8] (2014)	0.05 mg/m^3 (IFV)	—	DSEN; A4	240.44	Body weight & hematologic eff
Tin [7440-31-5] and inorganic compounds [18282-10-5; 21651-19-4], excluding Tin hydride and Indium tin oxide, as Sn (2019)	2 mg/m^3 (I)	—	—	118.69 Varies	Pneumoconiosis
Tin [7440-31-5], organic compounds, as Sn (1996)	0.1 mg/m^3	0.2 mg/m^3	Skin; A4	Varies	Eye & URT irr; headache; nausea; CNS & immune eff
* Titanium dioxide [13463-67-7] (2021)					
Nanoscale particles	0.2 mg/m^3 (R)	—	A3	79.90	LRT irr; pneumoconiosis
Finescale particles	2.5 mg/m^3 (R)	—	A3	79.90	LRT irr; pneumoconiosis
Titanium tetrachloride, as HCl [7550-45-0] (2020)	—	C 0.5 ppm	A4	189.68	URT irr; URT dam
o-Tolidine [119-93-7] (1992)	—	—	Skin; A3	212.28	Eye, bladder, & kidney irr; bladder cancer; MeHb-emia
Toluene [108-88-3] (2020)	20 ppm	—	OTO; A4; BEI	92.14	CNS, visual, & hearing impair; female repro system eff; pregnancy loss
Toluene diisocyanate, 2,4- or 2,6- (or as a mixture) [584-84-9; 91-08-7] (2016)	0.001 ppm (IFV)	0.005 ppm (IFV)	Skin; DSEN; RSEN; A3; BEI	174.15	Asthma; pulm func; eye irr
m-Toluidine [108-44-1] (1996)	2 ppm	—	Skin; A4; BEI_M	107.15	Eye, bladder, & kidney irr; MeHb-emia

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
Vanadium pentoxide [1314-62-1], as V (2009)	0.05 mg/m^{3} (I)	—	A3	181.88	URT & LRT irr
Vinyl acetate [108-05-4] (2018)	10 ppm	15 ppm	A3	86.09	URT & eye irr
Vinyl bromide [593-60-2] (1999)	0.5 ppm	—	A2	106.96	Liver cancer
Vinyl chloride [75-01-4] (1999)	1 ppm	—	A1	62.50	Lung cancer; liver dam
4-Vinyl cyclohexene [100-40-3] (1996)	0.1 ppm	—	A3	108.18	Female & male repro dam
Vinyl cyclohexene dioxide [106-87-6] (1996)	0.1 ppm	—	Skin; A3	140.18	Female & male repro dam
Vinyl fluoride [75-02-5] (1998)	1 ppm	—	A2	46.05	Liver cancer; liver dam
N-Vinyl-2-pyrrolidone [88-12-0] (2003)	0.05 ppm	—	A3	111.16	Liver dam
Vinylidene chloride [75-35-4] (1999)	5 ppm	—	A4	96.95	Liver & kidney dam
Vinylidene fluoride [75-38-7] (1998)	500 ppm	—	A4	64.04	Liver dam
‡ Vinyltoluene [25013-15-4] (1996)	(50 ppm)	(100 ppm)	A4	118.18	(URT & eye irr)
Warfarin [81-81-2] (2016)	0.01 mg/m^{3} (I)	—	Skin	308.32	Bleeding; teratogenic

Substance [CAS No.] (*Documentation* date)	ADOPTED VALUES TWA	STEL	Notations	MW	TLV® Basis
1,3,5-Triglycidyl-s-triazinetrione [2451-62-9] (1997)	0.05 mg/m^{3}	—	—	297.25	Male repro dam
Trimellitic anhydride [552-30-7] (2014)	0.0005 mg/m^{3} (IFV)	0.002 mg/m^{3} (IFV)	Skin; DSEN; RSEN	192.12	Resp sens
Trimethylamine [75-50-3] (2013)	5 ppm	15 ppm	—	59.11	URT, eye, & skin irr
* Trimethyl benzene, isomers [25551-13-7, 526-73-8, 95-63-6, 108-67-8] (2021)	10 ppm	—	A4* *for 1,2,4-trimethyl benzene	120.19	CNS impair; hematologic eff
Trimethyl phosphite [121-45-9] (1986)	2 ppm	—	BEI$_{C}$	124.08	Eye irr; cholinesterase inhib
2,4,6-Trinitrotoluene [118-96-7] (2019)	0.1 mg/m^{3} (IFV)	—	Skin; BEI$_{M}$	227.13	MeHb-emia; liver dam; cataract
Triorthocresyl phosphate [78-30-8] (2016)	0.02 mg/m^{3} (IFV)	—	Skin; BEI$_{C}$	368.37	Neurotoxicity; cholinesterase inhib
Triphenyl phosphate [115-86-6] (1996)	3 mg/m^{3}	—	A4; BEI$_{C}$	326.28	Cholinesterase inhib
Tungsten [7440-33-7] and compounds, in the absence of Cobalt, as W (2017)	3 mg/m^{3} (R)	—	—	183.84 Varies	Lung dam
Turpentine [8006-64-2] and selected monoterpenes [80-56-8; 127-91-3; 13466-78-9] (2014)	20 ppm	—	DSEN; A4	136.00 Varies	Lung irr
Uranium (natural) [7440-61-1] (1996) Soluble and insoluble compounds, as U	0.2 mg/m^{3}	0.6 mg/m^{3}	A1; BEI	238.03 Varies	Kidney dam
n-Valeraldehyde [110-62-3] (1984)	50 ppm	—	—	86.13	Eye, skin, & URT irr

2022 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. Please refer to the ACGIH® TLV®/BEI® Development Process on the ACGIH® website (acgih.org/science/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development) for a detailed discussion covering this procedure, methods for input to ACGIH®, and deadline date for receiving comments.

	2022 NOTICE OF INTENDED CHANGES				
Substance [CAS No.]	**TWA**	**STEL**	**Notations**	**MW**	**TLV® Basis**
† Acetamiprid [135410-20-7]	0.05 mg/m³ (IFV)	—	A4	222.68	Steatosis, neurodevelopment impairement, immune system & CNS impair; male repro system dam; repro eff

	ADOPTED VALUES				
Substance [CAS No.] (*Documentation* date)	**TWA**	**STEL**	**Notations**	**MW**	**TLV® Basis**
Wood dusts (2015)				NA	
Western red cedar	0.5 mg/m³ (I)	—	DSEN; RSEN; A4		Asthma
All other species	1 mg/m³ (I)	—	—		Pulm func; URT & LRT irr
Carcinogenicity					
Oak and beech	—	—	A1		
Birch, mahogany, teak, walnut	—	—	A2		
All other wood dusts	—	—	A4		
* Xylene, all isomers [1330-20-7; 95-47-6; 106-42-3; 108-38-3] (2021)	20 ppm	—	OTO**; A4; BEI **for p-xylene and mixtures containing p-xylene	106.16	Eye & URT irr; hematologic eff; ototoxicity (for p-xylene and mixtures containing p-xylene); CNS impair
m-Xylene α,α'-diamine [1477-55-0] (2019)	—	C 0.018 ppm	Skin	136.20	Eye, skin, & GI irr
Xylidine (mixed isomers) [1300-73-8] (2002)	0.5 ppm (IFV)	—	Skin; A3; BEI_M	121.18	Liver dam; MeHb-emia
Yttrium [7440-65-5] and compounds, as Y (1988)	1 mg/m³	—	—	88.91	Pulm fibrosis
Zinc chloride fume [7646-85-7] (1992)	1 mg/m³	2 mg/m³	—	136.29	LRT & URT irr
Zinc oxide [1314-13-2] (2003)	2 mg/m³ (R)	10 mg/m³ (R)	—	81.37	Metal fume fever
Zirconium [7440-67-7] and compounds, as Zr (1996)	5 mg/m³	10 mg/m³	A4	91.22	Resp irr

	2022 NOTICE OF INTENDED CHANGES				
Substance [CAS No.]	TWA	STEL	Notations	MW	TLV® Basis
† Methylnaphthalene, all isomers [1321-94-4; 90-12-0; 91-57-6]	0.05 ppm SL 3 mg/100 cm^2	—	Skin; A4	142.19	URT irr; lung dam; liver eff
† Nitric acid [7697-37-2]		0.025 ppm (IFV)	( )	63.02	Pulmonary function, pulmonary edema
† Phenothiazine [92-84-2]	0.5 mg/m^3 (I)	—	Skin; DSEN; A4	199.27	Phototoxicity; Liver toxicity, Bone marrow toxicity; Spleen toxicity; Anemia
† n-Propyl nitrate [627-13-4] (1976)	5 ppm		BEI_M	105.09	Anemia; Methemoglobinemia
† Propylene glycol dinitrate [6423-43-4]	SL 0.02 mg/100cm^2	0.01 ppm	Skin; BEI_M	166.09	Headache; hypotension; cerebrovascular disease; cardiovascular disease; vasodilation
† Silicon carbide [409-21-2] (2003) Nonfibrous	3 mg/m^3 (R) 10 mg/m^3 (I)	—	—	40.10	Pulmonary dam Pulmonary dam
Fibrous (including whiskers)	0.1 f/cc (F)	—	A2		Lung fibrosis, cancer
† Tetrachlorvinphos [22248-79-9; 22350-76-1; 961-11-5]	0.5 mg/m^3 (I)		Skin; DSEN; A3; BEI_C	365.96	Liver effects, kidney effects, cholinesterase inhibition, and thyroid effects

	2022 NOTICE OF INTENDED CHANGES				
Substance [CAS No.]	TWA	STEL	Notations	MW	TLV® Basis
† Benzene [71-43-2]	0.02 ppm	0.1 ppm	Skin; A1; BEI	78.11	Myelodysplastic syndrome, acute myeloid leukemia, leukemia, hematologic eff, chromosomal dam
† Benzoquinone [106-51-4]	0.1 ppm SL 5 μg/100 cm^2		DSEN; A4		Eye irritation, URT irr, Ocular effects
† Divinylbenzene-ethylstyrene mixtures, as total divinylbenzene isomers [69011-19-4; [7525-62-4; 108-57-6; 105-06-6]	0.5 ppm		DSEN; A3	108.09	URT dam, lung dam
† Di(2-ethylhexyl)phthalate [117-81-7]	0.1 mg/m^3	—	Skin; A3	390.54	Male repro system dam; teratogenic eff
† 2-Ethyl-1-hexanol [104-76-7]	5 ppm		A3	130.23	URT irr, eye irr
† Ethylene glycol dinitrate [628-96-6]	SL 0.02mg/100cm^2	0.01 ppm	Skin; BEI_M	152.06	Headache; hypotension; cerebrovascular & cardiovascular disease; vasodilation
† Glycidyl methacrylate [106-91-2]	0.01 ppm		Skin; DSEN; A2	142.15	Upper respiratory tract irritation and damage, mutagenic effects, cancer
† Glyphosate [1071-83-6]	5 mg/m^3 (I)		A4	169.07	Body Weight Effects; liver damage; cataract
† Iodine and Iodides Iodine, as I [7553-56-2] Iodides, as I	 0.01 mg/m^3 (IFV) 0.01 mg/m^3 (I)		 Skin; A4 Skin; A4	 253.80 —	 Thyroid effects; maternal repro eff; fetal and neonatal dam

	2022 NOTICE OF INTENDED CHANGES				
Substance [CAS No.]	TWA	STEL	Notations	MW	TLV® Basis
Trimetacresyl phosphate [563-04-2]	0.05 mg/m³ (IFV)	—	—	368.36	Adrenal gland & female repro system dam
Triparacresyl phosphate [78-32-0]	0.05 mg/m³ (IFV)	—	—	368.36	Adrenal gland & female repro system dam
† Vinyltoluene, all isomers [25013-15-4]	10 ppm		A4	118.18	URT dam; lung dam

TLV®–CS

CHEMICAL SUBSTANCES AND OTHER ISSUES UNDER STUDY

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. 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® (acgih.org/science/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development).

The Under Study list is published each year by February 1 on the ACGIH® website (acgih.org/science/tlv-bei-guidelines/documentation-publications-and-data/under-study), 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, 2022. *After this date, please refer to the ACGIH® website* (acgih.org/science/tlv-bei-guidelines/documentation-publications-and-data/under-study) *for the up-to-date list.*

Chemical Substances

Acetyl salicylic acid
Acrolein
Alkyl acrylates
Anisidine
Antimony and compounds, as Sb
Bensulfide
Benzidine
Bifenazate
Buprofezin
1,3-Butadiene
Cadmium
Cadmium carbonate
Cadmium hydroxide
Cadmium nitrate
Captafol
Carbon dioxide
Carbon monoxide
Carbon nanotubes
Chlorodiphenyl, 42%
Chlorodiphenyl, 54%
Chloromethyl methyl ether
Cobalt carbonyl, as Co
Cobalt hydrocarbonyl
Copper
Desflurane
Diacetyl
Diazinon
Dicamba
3,3'-Dichlorobenzidine
Diesel exhaust
Difluorodibromomethane
Diiodomethyl p-tolyl sulfone

TLV®–CS

Dimethenamid-P
1,2-Dimethoxyethane
Dimethyl carbamoyl chloride
1,4-Dioxane
Enflurane
Epichlorohydrin
Ethyl acrylate
Ethyl ether
Ethylene
Fenoxycarb
Fentanyl
Fluorides
Formic Acid
Furan
Furfural
Furfuryl alcohol
Germanium tetrahydride
Gram negative bacterial endotoxins
Hafnium and compounds
Halothane
Hydrogen peroxide
2-Hydroxy-4-methoxybenzophenone (oxybenzene)
Imidacloprid
Indium and compounds
Isoprene
4-4'isopropylidene diphenol (BPA)
Lead and inorganic compounds, as Pb
Malathion
Manganese cyclopentadienyl tricarbonyl
Methyl acrylate
Methyl ethyl ketone (2-butanone)
Methyl n-butyl ketone (2-Hexanone)
2-Methylcyclopentadienyl manganese tricarbonyl
4, 4'-Methylene bis(2-chloroaniline)
Methylene bisphenyl isocyanate
Methyltetrahydrophthalic anhydride isomers
Metribuzin
Molybdenum
1-Naphthylamine
2-Naphthylamine (Beta)
Nickel and inorganic compounds, including Nickel subsulfide, as Ni
Nitroglycerin
Octachloronaphthalene
Parathion
Pentaborane
m-Phenylenediamine
o-Phenylenediamine
p-Phenylenediamine
Phosphoric acid
Phosphorus (white)
Phosphorus (yellow)
Phthalic anhydride
Propane sultone
Propylene dichloride (1,2-Dichloropropane)
Sevoflurane
Sodium hypochlorite
Sodium silicates
Stoddard solvent
Styrene Oxide
Subtilisins
Talc
Tetraethyl lead
1,2,3,6-Tetrahydrophthalic anhydride
Tetramethyl lead
Tin, organic compounds
Tolclofos-methyl
Trichloronaphthalene
Triclopyr
Triethanolamine
Trifloxystrobin
Trimellitic anhydride
Uranium and compounds
Vinylidene chloride
Vinylidene fluoride
Welding fumes

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® or BEI® is based. *See* the discussion under "TLV®/BEI® 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®-CS) Committee, accessible online at: acgih.org/about/volunteer-leadership/committees/committee-operations-manuals.

Minimal Oxygen Content

An oxygen (O_2)-deficient atmosphere is defined as one with an ambient pO_2 less than 132 torr (NIOSH, 1980). The minimum requirement of 19.5% oxygen at sea level (148 torr O_2, 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 pO_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® because the limiting factor is the available oxygen. Atmospheres deficient in O_2 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 pO_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® may differentiate TLVs® for nanomaterials.

Notation

A notation is a designation that appears as a component of the TLV® 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®-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/m³, respirable particles, and 10 mg/m³, 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 reading the *Documentation*. Each *Documentation* is a critical component for proper use of the TLV(s)® and to understand the TLV® basis. A complete list of the TLV® bases used by the Threshold Limit Values for Chemical Substances Committee may be found in their Operations Manual online at: (acgih.org/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-committee-operations-manuals).

Abbreviations used:

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

Notations/Endnotes

Biological Exposure Indices (BEIs®)

The notation "BEI" is listed in the "Notations" column when a BEI® (or BEIs®) 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® for Cholinesterase inhibiting pesticides or Methemoglobin inducers. They are as follows:

BEI_C = *See* the BEI® for Cholinesterase inhibiting pesticide
BEI_M = *See* the BEI® for Methemoglobin inducers
BEI_P = *See* the BEI® 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® section in this book and the *Documentation* of the TLVs® and BEIs® 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® 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.

References and Selected Reading

Campo P; Morata TC; Hong O: Chemical exposure and hearing loss. Disease-a-Month 59:119–138 (2013).
Hoet P; Lison D: Ototoxicity of toluene and styrene: state of current knowledge. Crit Rev Toxicol 38:127–170 (2008).
Morata TC; Campo O: Ototoxic effects of styrene alone or in concert with other agents: a review. Noise & Health 4(14):15–24 (2002).

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® that are based upon sensitization are meant to protect workers from induction of this effect. These TLVs® 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®). 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® *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®.

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 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_{50} (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

American Conference of Governmental Industrial Hygienists: Dermal absorption. In: Documentation of the Biological Exposure Indices, 7th ed., pp. 21–26. ACGIH®, Cincinnati, OH (2001).
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Wester RC; Maibach HI: Understanding percutaneous absorption for occupational health and safety. Int J Occup Environ Health 6(2):86–92 (2000).

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.

ADOPTED APPENDICES

APPENDIX A: Carcinogenicity

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 is supported by mechanistic evidence of key characteristics of carcinogens that are relevant 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 experimental animal evidence suggests mechanisms and/or dosimetry that the agent is unlikely to cause cancer in humans except under improbable 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 human data. *In vitro* or animal studies do not provide mechanistic evidence of key characteristics 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 demonstrating a lack of the key characteristics of carcinogenicity.

Note: Substances for which no human or experimental animal carcinogenicity data are available and no strong genotoxicity data have been reported are assigned no carcinogenicity designation.

Exposure to carcinogens must be kept to a minimum. Worker exposures to A1 carcinogens without a TLV® should be eliminated to the fullest extent

possible. 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® as indicated by the (L) endnote in the TLV® Table.

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

The goal of the TLV®-CS Committee is to recommend TLVs® 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® 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® because it is not possible to meet the standard level of evidence used to assign a TLV®. In addition, the PNOS TLV® 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®;
- 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® 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^3, respirable particles, and 10 mg/m^3, inhalable particles, until such time as a TLV® is set for a particular substance.

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

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

$$IPM\,(d_{ae}) = 0.5\,[1 + \exp(-0.06\,d_{ae})]$$
$$\text{for } 0 < d_{ae} \le 100\ \mu m$$

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

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

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

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

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

ln = natural logarithm
Γ = 11.64 μm
Σ = 1.5

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

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

where $F(x)$ = same as above, but with $\Gamma = 4.25$ μm 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 μm to 4.0 μm; 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

Particle Aerodynamic Diameter (μm)	Inhalable Particulate Matter (IPM) Fraction Collected (%)
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

Particle Aerodynamic Diameter (μm)	Thoracic Particulate Matter (TPM) Fraction Collected (%)
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

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

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

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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

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

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

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

where: T_{1STEL} = 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	325 ppm
	(250 ppm)	*(500 ppm)*
2) Cyclohexanone	2 ppm	7.5 ppm
	(20 ppm)	(50 ppm)
3) Methyl ethyl ketone	90 ppm	220 ppm
	(200 ppm)	*(300 ppm)*

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:

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

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 (ρO_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 ρO_2 level of 60 torr corresponds to 120 torr ρO_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 ρO_2 as the physiological limit that establishes an oxygen-deficient atmosphere and has defined an oxygen-deficient atmosphere as one with an ambient ρO_2 less than 132 torr (NIOSH, 1979). The minimum requirement of 19.5% oxygen at sea level (148 torr ρO_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 ρO_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 ρO_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 ρO_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_2 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 pO_2 of the atmosphere may be less than 120 torr.

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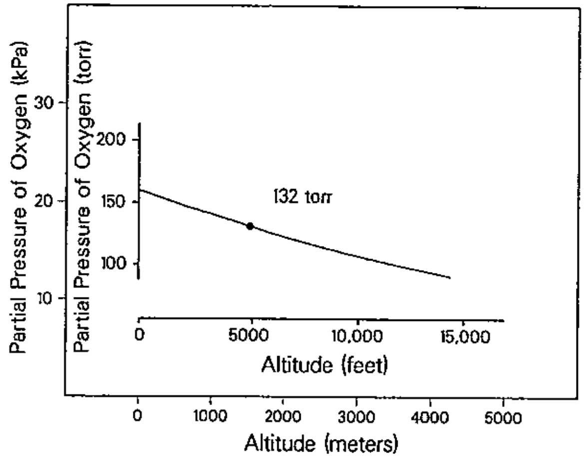

FIGURE F-1. Plot of oxygen partial pressure (pO_2) (expressed in torr and kPa) with increasing altitude (expressed in feet and meters), showing the recommended oxygen partial pressure of 132 torr.

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[A] (kilopascals)	pO_2 Equivalent, torr Dry Air at 20.948% O_2[B] (kilopascals)	%O_2 Equivalent, Dry Air at Sea Level[C] (percent)	Physiological Effect of pO_2 Levels[D]
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

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 [CAS]	Year Withdrawn	Reason
Acetylene [74-86-2]	2015	*See* Appendix F: Minimal Oxygen Content
Aliphatic hydrocarbon gases, Alkanes [C_1–C_4]	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

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

[A]Calculated from $P_{re:\,sea\,level} = 760 \times e^{-(altitude\ in\ feet/25970)}$

[B]Calculated from $pO_2 = 0.20948 \times 760 \times e^{-(altitude\ in\ feet/25970)}$

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

[D]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] (cont.)

Substance [CAS]	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
Piperazine dihydrochloride [142-64-3]	2012	*See* Piperazine and salts
n-Propyl acetate [109-60-4]	2018	*See* Propyl acetate isomers
Rosin core solder decomposition products (colophony) [8050-09-7]	2021	*See* Resin acids
Strontium chromate [7789-06-2], as Cr	2018	*See* Chromium and inorganic compounds
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

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 ($GGV\text{-}TWA_{mixture}$) 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_5 to C_{15} 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 $GGV\text{-}TWA_{mixture}$ should be handled according to the procedures found in the Introduction to the TLVs® (*see Peak Exposures*).

The reciprocal calculation mixture formula is:

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

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^{th} group (or component)

F_n = the liquid mass fraction of the n^{th} 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^3, round to the nearest 25. For calculated values between 100 and 600 mg/m^3, round to the nearest 50, and for calculated values > 600 mg/m^3, round to the nearest 200 mg/m^3.

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-

TLV®–CS

TABLE 1. Group Guidance Values

A	B	C	D
Hydrocarbon Group	McKee et al., 2005 (mg/m³)	UK-HSE 40/2000 (mg/m³)	ACGIH® Unique TLVs® and compounds with differing or additional critical effects (italics)*
C5–C6 Alkanes	1500	1800	Pentane, all isomers Hexane isomers *n-Hexane peripheral neuropathy**
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 *Toluene visual impairment, reproductive**
C9–C15 Alkanes	1200	1200	n-Nonane
C9–C15 Cycloalkanes	1200	800	
C9–C15 Aromatics	100	500	Trimethyl benzene, isomers Cumene *Naphthalene Hematologic effects** *Methylnaphthalene lung damage** *Indene liver damage**

*See limitation #2. These compounds have critical effects (TLV® 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® is not exceeded.

TLV®–CS

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/m³)
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 $GGV_{mixture}$ would be:

$$GGV_{mixture} = \frac{1}{\frac{.45}{1500} + \frac{.40}{1200} + \frac{.09}{200} + \frac{.06}{75}} = \frac{1}{.001884}$$

$$= 531 \text{ (rounded to 550 mg/m}^3\text{)}$$

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 $GGV_{mixture}$.

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BEIs®

2022 Biological Exposure Indices

Adopted by ACGIH®
with Intended Changes

BEIs®

Contents

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®) are guidance values for evaluating biological monitoring results. BEIs® 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® for chemicals for which the TLVs® 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® that better predict health effects than air levels and finally, BEIs® that are based on the levels in the environmentally exposed population. The BEI® generally indicates a concentration below which nearly all workers should not experience adverse health effects. The BEI® 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® are urine, blood, or exhaled air. The BEIs® 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® does not indicate a need to conduct biological monitoring. Conducting, designing, and interpreting biological monitoring protocols and the application of the BEI® 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®).

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® Chronology" section in each *Documentation* for a brief history of the BEI® recommendations and notations.

Documentation

It is essential that the user consult the specific BEI® *Documentation* before designing biological monitoring protocols and interpreting BEIs® 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® *Documentation* now provides a chronology that traces all BEI® 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.

BEIs®

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® 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® will continue to be expressed relative to creatinine; in other circumstances, no correction is recommended, and the BEI® will be expressed as concentration in urine (e.g., µg/L).

BEIs®

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®. When general population data are not available to make this assessment, the BEI® 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® value.

"Nq" = Nonquantitative

Biological monitoring should be considered for this compound based on the review; however, a specific BEI® 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® 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®. 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®

BEIs® are intended as guidelines to be used in the evaluation of potential health hazards in the practice of occupational hygiene. BEIs® 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® without incurring an increased health risk. If measurements in specimens obtained from a worker on different occasions exceed the BEI®, 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 workshift exceed the BEI®. 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® apply to 8-hour exposures, 5 days per week. Although modified work schedules are sometimes used in various occupations, the BEI® Committee does not recommend that any adjustment or correction factor be applied to the BEIs® (i.e., the BEIs® should be used as listed, regardless of the work schedule).

Use of the BEI® should be applied by a knowledgeable occupational health professional. Toxicokinetic and toxicodynamic information is taken into account when establishing the BEI®; thus, some knowledge of the metabolism, distribution, accumulation, excretion, and effect(s) is helpful in using the BEI® effectively. ACGIH® may be contacted for technical assistance on any BEI® issue. The BEI® 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® values are neither rigid lines between safe and dangerous concentrations nor are they an index of toxicity.

Note:

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

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (*Documentation* date) *Determinant*	*Sampling Time*	*BEI®*	*Notation*
ACETONE [67-64-1] (2014)			
Acetone in urine	End of shift	25 mg/L	Ns
ANILINE [62-53-3] (2020)			
Aniline in urine ★	End of shift	0.5 mg/L	—
ARSENIC, ELEMENTAL [7440-38-2] AND SOLUBLE INORGANIC COMPOUNDS (excludes gallium arsenide and arsine) (1998)			
Inorganic arsenic plus methylated metabolites in urine	End of workweek	35 µg As/L	B
BENZENE [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
1,3-BUTADIENE [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
2-BUTOXYETHANOL [111-76-2] (2006)			
Butoxyacetic acid (BAA) in urine ★	End of shift	200 mg/g creatinine	—

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (*Documentation* date) *Determinant*	*Sampling Time*	*BEI®*	*Notation*
CADMIUM [7440-43-9] AND INORGANIC COMPOUNDS (2015)			
Cadmium in urine	Not critical	5 µg/g creatinine	B
Cadmium in blood	Not critical	5 µg/L	B
CARBON DISULFIDE [75-15-0] (2008)			
2-Thioxothiazolidine-4-carboxylic acid (TTCA) in urine	End of shift	0.5 mg/g creatinine	B, Ns
CARBON MONOXIDE [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
CHLOROBENZENE [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
CHOLINESTERASE INHIBITING PESTICIDES (2017)			
Acetylcholinesterase activity in red blood cells and	End of shift	70% of individual's baseline activity**	Ns
Butyrylcholinesterase activity in serum or plasma	End of shift	60% of individual's baseline activity**	Ns

** The average of two baseline respective cholinesterase 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 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.

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (*Documentation* date) / *Determinant*	*Sampling Time*	*BEI®*	*Notation*
N,N-DIMETHYLACETAMIDE [127-19-5] (1993)			
N-Methylacetamide in urine	End of shift at end of workweek	30 mg/g creatinine	—
N,N-DIMETHYLFORMAMIDE [68-12-2] (2016)			
Total N-Methylformamide in urine**	End of shift	30 mg/L	—
N-Acetyl-S-(N-methylcarbamoyl) cysteine in urine	End of shift at end of workweek	30 mg/L	—
** Total N-Methylformamide represents the sum of N-Methylformamide and N-(Hydroxymethyl)-N-Methylformamide			
‡ 2-ETHOXYETHANOL (EGEE) [110-80-5] AND 2-ETHOXYETHYL ACETATE (EGEEA) [111-15-9] (1992)			
2-Ethoxyacetic acid in urine	End of shift at end of workweek	(100 mg/g creatinine)	—
ETHYL BENZENE [100-41-4] (2013)			
Sum of mandelic acid and phenylglyoxylic acid in urine	End of shift	0.15 g/g creatinine	Ns
ETHYLENE OXIDE [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.			
N-ETHYL-2-PYRROLIDONE [2687-91-4] (2018)			
5-Hydroxy-N-ethyl-2-pyrrolidone (5-HNEP) in urine★★	End of shift	—	Nq

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (*Documentation* date) / *Determinant*	*Sampling Time*	*BEI®*	*Notation*
CHROMIUM [7440-47-3] (2020)			
Total chromium in urine	End of shift at end of workweek	0.7 µg/L	Pop
COBALT [7440-48-4] AND INORGANIC COMPOUNDS, including Cobalt oxides but not combined with Tungsten carbide (2014)			
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
*CYCLOHEXANE [110-82-7] (2021)			
1,2-Cyclohexanediol in urine★	End of shift, end of workweek	50 mg/g creatinine	Ns
CYCLOHEXANOL [108-93-0] (2003)			
1,2-Cyclohexanediol in urine★	End of shift at end of workweek	—	Nq, Ns
Cyclohexanol in urine★	End of shift	—	Nq, Ns
CYCLOHEXANONE [108-94-1] (2003)			
1,2-Cyclohexanediol in urine★	End of shift at end of workweek	80 mg/L	Ns, Sq
Cyclohexanol in urine★	End of shift	8 mg/L	Ns, Sq
DICHLOROMETHANE [75-09-2] (2004)			
Dichloromethane in urine	End of shift	0.3 mg/L	Sq

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 (2020)			
Methemoglobin in blood	During or end of shift	5% of hemoglobin	B, Ns
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 CHLOROFORM [71-55-6] (2020)			
Methyl chloroform in end-exhaled air	Prior to shift at end of workweek	20 ppm	—
Methyl chloroform in urine	End of shift	700 μg/L	—
4,4'-METHYLENE BIS(2-CHLOROANILINE) (MBOCA) (2012) [101-14-4]			
Total MBOCA in urine ★	End of shift	—	Nq
METHYL ETHYL KETONE [78-93-3] (2012)			
Methyl ethyl ketone in urine	End of shift	2 mg/L	Ns

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (*Documentation* date) *Determinant*	*Sampling Time*	*BEI®*	*Notation*
FLUORIDES (2011)			
Fluoride in urine	Prior to shift	2 mg/L	B, Ns
Fluoride in urine	End of shift	3 mg/L	B, Ns
† FURFURAL [98-01-1] (2006)			
Furoic acid in urine ★	End of shift	200 mg/L	Ns
1,6-HEXAMETHYLENE DIISOCYANATE [822-06-0] (2014)			
1,6-Hexamethylene diamine in urine ★	End of shift	15 μg/g creatinine	Ns
n-HEXANE [110-54-3] (2018)			
2,5-Hexanedione in urine ★ ★	End of shift	0.5 mg/L	—
INDIUM [7440-74-6] AND INDIUM INORGANIC COMPOUNDS, including Indium tin oxide and Indium oxide (2020)			
Indium (In) in serum or plasma	Not critical	1 μg/L	—
LEAD AND INORGANIC COMPOUNDS [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*
PENTACHLOROPHENOL [87-86-5] (2013)			
Pentachlorophenol in urine★	Prior to last shift of workweek	—	Nq
PHENOL [108-95-2] (2005)			
Phenol in urine★	End of shift	250 mg/g creatinine	B, Ns
POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) (2016)			
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			
2-PROPANOL [67-63-0] (2005)			
Acetone in urine	End of shift at end of workweek	40 mg/L	B, Ns
‡ STYRENE [100-42-5] (2014)			
Mandelic acid plus phenylglyoxylic acid in urine	End of shift	(400 mg/g creatinine)	Ns
Styrene in urine	End of shift	(40 µg/L)	—
TETRACHLOROETHYLENE [127-18-4] (2008)			
Tetrachloroethylene in end-exhaled air	Prior to shift	3 ppm	—
Tetrachloroethylene in blood	Prior to shift	0.5 mg/L	—
TETRAHYDROFURAN [109-99-9] (2006)			
Tetrahydrofuran in urine	End of shift	2 mg/L	—

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (*Documentation* date) *Determinant*	*Sampling Time*	*BEI®*	*Notation*
METHYL ISOBUTYL KETONE [108-10-1] (2009)			
Methyl isobutyl ketone in urine	End of shift	1 mg/L	—
N-METHYL-2-PYRROLIDONE [872-50-4] (2006)			
5-Hydroxy-N-methyl-2-pyrrolidone in urine	End of shift	100 mg/L	—
NAPHTHALENE [91-20-3] (2012)			
1-Naphthol★ + 2-Naphthol★	End of shift	—	Nq, Ns
NICKEL [7440-02-0] AND INORGANIC COMPOUNDS (2020)			
Nickel in urine after exposure to elemental Nickel and poorly soluble compounds	Post-shift at end of workweek	5 µg/L	B
Nickel in urine after exposure to soluble compounds	Post-shift at end of workweek	30 µg/L	—
NITROBENZENE [98-95-3] (2013)			
Methemoglobin in blood	*See* Methemoglobin Inducers BEI®	—	—
PARATHION [56-38-2] (2019)			
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 exposure 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.

2022 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. Please refer to the ACGIH® TLV®/BEI® Development Process on the ACGIH® website (acgih.org/science/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development/) for a detailed discussion covering this procedure, methods for input to ACGIH®, and deadline date for receiving comments.

2022 NOTICE OF INTENDED CHANGES

Chemical [CAS No.] / *Determinant*	*Sampling Time*	*BEI®*	*Notation*
† ACRYLAMIDE [79-06-1]			
N-(2- Carbamoylethyl)valine (CbEV) in blood	Not critical	500 pmol/g globin*	B
S-(2-Carbamoyl-ethyl)mercapturic acid (AAMA) in urine	End of shift	800 µg/g creatinine *after 120 days of representative work/exposure to acrylamide	B
† 2-ETHOXYETHANOL [EGEE] [110-80-5] AND 2-ETHOXYETHYL ACETATE [EGEEA] [111-15-9]			
2-Ethoxyacetic acid in urine	End of shift at end of workweek	40 mg/g creatinine	

ADOPTED BIOLOGICAL EXPOSURE DETERMINANTS

Chemical [CAS No.] (*Documentation* date) / *Determinant*	*Sampling Time*	*BEI®*	*Notation*
TOLUENE [108-88-3] (2009)			
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
TOLUENE DIISOCYANATE-2,4- [584-84-9] or 2,6- [91-08-7] or as a mixture of isomers (2015)			
Toluene diamine in urine★,** ** Sum of 2,4- and 2,6- isomers	End of shift	5 µg/g creatinine	Ns
TRICHLOROETHYLENE [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
URANIUM [7440-61-1] (2009)			
Uranium in urine	End of shift	200 µg/L	—
XYLENES [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

2022 NOTICE OF INTENDED CHANGES

Chemical [CAS No.] *Determinant*	*Sampling Time*	*BEI®*	*Notation*
† FURFURAL [98-01-1]			
Furoic acid in urine ✱	End of shift	200 mg/L	Ns
† STYRENE [100-42-5]			
Mandelic acid plus phenylglyoxylic acid in urine	End of shift	150 mg/g creatinine	Ns
Styrene in urine	End of shift	20 µg/L	—

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

† = 2022 Revision or Addition to the Notice of Intended Changes
‡ = 2022 See Notice of Intended Changes (NIC)

CHEMICAL SUBSTANCES AND OTHER ISSUES UNDER STUDY

The BEI® 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® Science Group at 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® (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 (acgih.org/science/tlv-bei-guidelines/documentation-publications-and-data/under-study/), 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, 2022. *After this date, please refer to the ACGIH® website* (acgih.org/science/tlv-bei-guidelines/documentation-publications-and-data/under-study) *for the up-to-date list.*

Chemical Substances

Acrylamide
Acrylonitrile
Adipates
Arsenic
Atrazine
Benzene
Bisphenol A
Butadiene
Copper
3,3'-Dichlorobenzidine
Diethylhexyl adipate
Di(2-ethylhexyl)phthalate (DEHP)
Dimethylacetamide
Ethylene glycol
Ethylene glycol dinitrate
Heptane
Iodine
Methylcyclohexane
Nicotine
Nitrobenzene
Phthalates (see DEHP)
Platinum

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.

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
Diethylhydroxylamine	September 2021
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	June 2020
Methylcyclohexane	June 2020
Methyl formate	September 2005
Methyl isobutyl carbinol	June 2020
α-Methylstyrene	November 2010
Nitrobenzene	September 2013
Perfluorooctanoic acid	April 2007
Selenium	October 1995
Styrene oxide	September 2021
Thallium	November 2010
Trimethylbenzene	August 1999
Vanadium pentoxide	September 2009
Vinyl chloride	August 2002

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2022 Threshold Limit Values for Physical Agents in the Work Environment

Adopted by ACGIH®
with Intended Changes

Contents

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, and 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.

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. Please refer to the ACGIH® TLV®/BEI® Development Process on the ACGIH® website (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®

ACOUSTIC

INFRASOUND AND LOW-FREQUENCY SOUND

(*Documentation* Date – 2020)

These TLVs® address worker exposures to sound in the range of 1 to 100 Hz that can cause nonauditory effects on comfort, performance, and health. Exposures to sound in this frequency range can cause vibration of human body biological structures via the airborne transmission of low-frequency acoustical energy. Specifically, infrasound is defined as acoustical energy in the frequency range of 1 to < 20 Hz that is not detectable by the human ear. These TLVs® represent sound to which it is believed nearly all workers may be repeatedly exposed without adverse health effects that do not involve hearing.

The TLVs® do not apply to impulsive sound with durations of < 2 seconds. For all other exposures, the TLVs® are listed in Table 1. There are no time limits for these exposures. However, application of the TLVs® for Audible Sound, recommended to prevent noise-induced hearing loss, may provide a reduced acceptable exposure level with time. This reduction will depend upon the amount of attenuation allowed for hearing protection.

TLV®–PA

TABLE 1. TLVs® for Infrasound and Low-frequency Sound

Sound Pressure Level (SPL)	TLV®
Unweighted one-third octave bands [1] between 1 and 100 Hz	145 dB
Unweighted overall between 1 and 100 Hz	150 dB

[1] American National Standards Institute (ANSI), 2014

NOTE: Low-frequency sounds have been known to excite resonances in the upper torso of the human body primarily at frequencies between 50 and 100 Hz. Such an effect may cause worker annoyance and discomfort at levels below the TLVs described above and may warrant the reduction to a level where the problem disappears.

American National Standards Institute: ANSI/ASA S1.11-2014/Part 1/IEC 61260:1–2014 Electroacoustics-Octave-Band and Fractional-Octave-Band Filters – Part 1: Specifications. ANSI, New York (2014).

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.

TLV®–PA

AUDIBLE SOUND

(*Documentation* Date – 2018)

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 ≥ 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, 2014), 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 (± 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.

TLV®–PA

TABLE 1. Threshold Limit Values for Audible Sound[A]

	Duration per Day	Sound Pressure Level dBA[B]
Hours	24	80
	16	82
	8	85
	4	88
	2	91
	1	94
Minutes	30	97
	15	100
	7.50[C]	103
	3.75[C]	106
	1.88[C]	109
	0.94[C]	112
Seconds[C]	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

[A] 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).

[B] 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, 2014) Type 2, and set to use the A-weighted network with slow meter response.

[C] Limited by engineering control of the noise source if feasible. Administrative control is permissible if engineering control is infeasible.

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.

TLV®–PA

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.

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TLV®–PA

ULTRASOUND

(*Documentation* Date – 2001)

These TLVs® 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® 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® 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)(1) and IEC 804.(2)

TABLE 1. TLVs® for Ultrasound

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

[A] 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.

[B] 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^2; rms = root-mean-square).

References

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 FIELDS 0–300 GHz

STATIC MAGNETIC FIELDS

(*Documentation* Date – 2015)

These TLVs® 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.

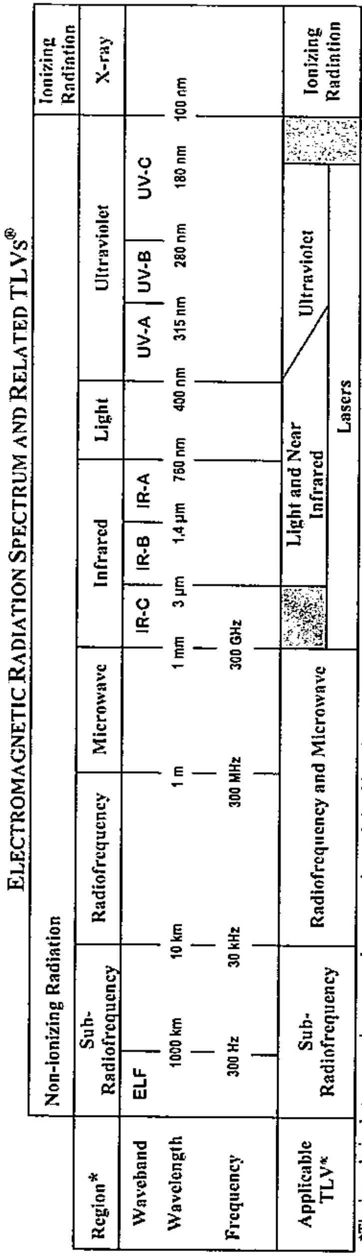
Routine occupational exposures should not exceed 2 tesla (T) in the general workplace environment, but can have ceiling values of 8 T for workers with special training and operating in a controlled workplace environment. Special training involves making workers aware of transient sensory effects that 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® are summarized in Table 1.

TABLE 1. TLVs® 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

ELECTROMAGNETIC RADIATION SPECTRUM AND RELATED TLVs®



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

SUB-RADIOFREQUENCY (30 kHz and below) MAGNETIC FIELDS

(*Documentation* Date – 2017)

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:

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

where: f = the frequency in Hz
B_{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).[1]

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 milliampere (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.

[1] 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.

TLV®–PA

Notes:

1. These TLVs® are based on an assessment of available data from laboratory research and human exposure studies. Modifications of the TLVs® 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® for time-weighted average exposures.
2. For workers wearing cardiac pacemakers, the TLV® 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® 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®. 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.

TABLE 1. TLVs® for Sub-Radiofrequency(30 kHz and below) Magnetic Fields

Frequency Range	TLV®
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

TLV®–PA

Modifications of the TLVs® 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® 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).

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

(*Documentation* Date – 2016)

These TLVs® 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® 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® 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:

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

where:

f = the frequency in Hz
E_{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® 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®.
3. Certain biological effects have been reported in laboratory studies at electric field strengths below those permitted in the TLV®; however, there is no convincing evidence at the present time that occupational exposure to such field levels leads to adverse health effects.

TLV®–PA

TABLE 1. Radiofrequency and Microwave TLVs®

Part A—Electromagnetic Fields[A] (f = frequency in MHz)

Frequency	Power Density, S (W/m^2)	Electric Field Strength, E (V/m)	Magnetic Field Strength, H (A/m)	Averaging Time E^2, H^2, or S (min)
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			$34000/f^{1.079}$
30 GHz–300 GHz	100			$68/f^{0.476}$

[A] 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® 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® is the limit of exposure averaged over any contiguous 0.01 m^2 of body surface. However, above 30 GHz the maximum power density is 1000 W/m^2 in any one square centimeter.

Part B—Maximum Induced and Contact Radiofrequency Currents (mA)[B]

Frequency	Through Both Feet	Through Either Foot	Grasping[B1]	Averaging Time
30 kHz–100 kHz	2000 f	1000 f	1000 f	0.2 s[C]
100 kHz–100 MHz	200	100	100	6 min[D]

[B] 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.

[B1] Maximum touch current is limited to 50% of the maximum grasping current.

[C] **I** is averaged over a 0.2 s period.

[D] **I** is averaged over a 6-minute period (e.g., for either foot or hand contact, i.e., I t < 60,000 mA^2-min). In this table, f is the frequency in Hz.

TLV®–PA

RADIOFREQUENCY/MICROWAVE RADIATION

(*Documentation* Date – 2016)

These TLVs® 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® represent conditions under which it is believed nearly all workers may be repeatedly exposed without adverse health effects.

The TLVs® 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® 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® 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®, and major hazard mechanisms and typical exposure scenarios that would be of concern.

A. For exposures to electric and magnetic free fields, TLVs® 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® can be relaxed. In nonuniform fields, spatial peak values of field strength may exceed the TLVs® 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 mA for (0.03 < f < 0.1 MHz) averaged over 0.2 s;
   where mA = milliampere

   I = 100 mA for (0.1 < f < 100 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 mA for (0.03 < f < 0.1 MHz) (where f is the frequency in MHz) averaged over 0.2 s

   I = 100 mA for (0.1 < f < 100 MHz) averaged over 6 min

TLV®–PA

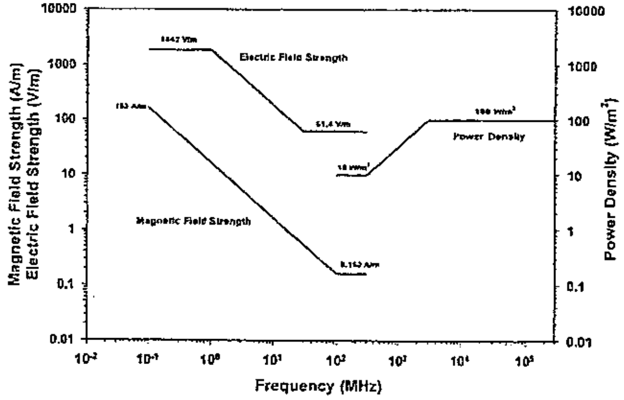


FIGURE 1. Threshold Limit Values (TLVs®) for Radiofrequency/Microwave Radiation in the workplace (for whole-body specific absorption rate [SAR] < 0.4 W/kg). (From IEEE Std. C95.1 – 2005a.

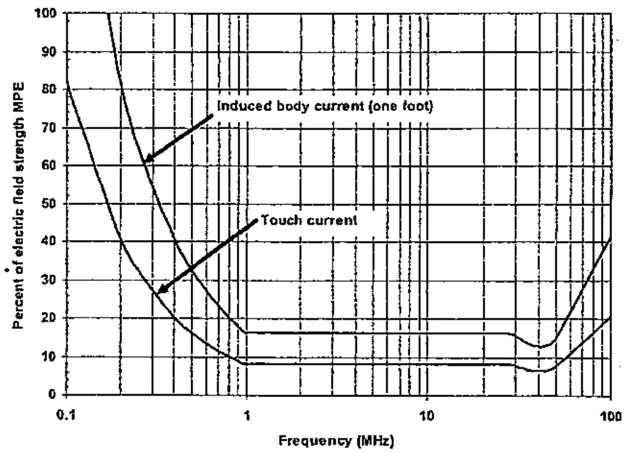


FIGURE 2. Percent of electric field strength TLVs® below which induced and contact current limits are *not* required from 0.1 to 100 MHz. (From IEEE Std. C95.1 – 2005a.

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® 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®. 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® 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/m²), 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® 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® 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® without adverse health effects. Nevertheless, personnel should not needlessly be exposed to higher levels of RF radiation, approaching the TLVs®, 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®, the fraction of the TLV® (in terms of E^2,

TABLE 2. Major Frequency Ranges Covered by the TLV®

	Part A – Frequency Range			
	30 kHz–100 kHz	100 kHz–100 MHz	100 MHz–300 MHz*	300 MHz–300 GHz
Electric Field	X	X	X	
Magnetic Field	X	X	X	
Power Density			X	X
Contact Current	X	X†		
	Part B – Hazard Mechanism			
	Electrical stimulation	**Thermal**		**Thermal**
Typical cause of injury	Contact current (current introduced into body from touching a charged conductor)	Contact current / possible RF heating of deeper tissues		RF heating of tissues
Typical injury	Electric shock (sometimes burns)	Burns (can be deep in tissue) Excessive whole body heating/ heat stress		
Example sources with potential overexposure	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^2, 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.

TLV®–PA

5. Above 3 GHz, relaxation of the TLV® conditions may be permissible under partial body exposure conditions.
6. The measurement of RF field should follow the recommendations given in IEEE C95.3-2021 (IEEE, 2021).

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 C95.3-2021. IEEE, New York (2021).

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).

TLV®–PA

OPTICAL RADIATION

LIGHT AND NEAR-INFRARED RADIATION

(*Documentation* Date – 2015)

These TLVs® 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®, the optical radiation spectrum is divided into the regions shown in the figure "The Electromagnetic Radiation Spectrum and Related TLVs®" found at the beginning of the section on Electromagnetic Fields 0–300 GHz.

Recommended Values

The TLVs® 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®. Figure 1 is a guide to the application of the TLVs® for visible and near-infrared sources.

The LNIR TLVs® 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_λ) 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.

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

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 ~ 2.8 hrs) in a day, an acceptable exposure is present when:

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

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

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

TLV®–PA

TLV®–PA

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

*Source Type**	Arc Sources	Discharge Lamps	Fluorescent Lamps and LEDs	Thermal Sources	Germicidal Lamps
	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 *See* UV TLV*	♦♦	♦	♦		♦♦
Blue-Light *See* LNIR Section 1	♦♦	♦♦	♦		
IR Cornea/Lens *See* LNIR Section 2	♦	♦		♦♦	
Infrared Retina *See* LNIR Section 3	f	f		♦	
Retinal Thermal *See* LNIR Section 4	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.

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

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

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_λ) weighted by the blue-light hazard function B(λ):

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

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

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

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

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

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

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

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(λ), should be used for L_B and E_B, as shown in Equations 5a and 5b.

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

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

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

TLV®–PA

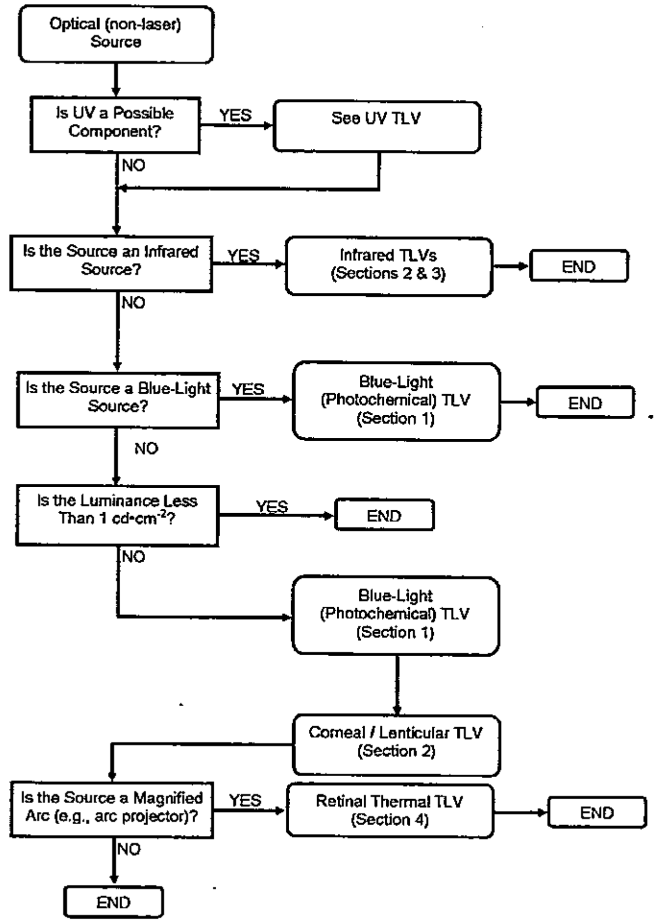


FIGURE 1. Evaluation scheme for visible and near-infrared radiation.

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TABLE 2. Retinal and UVR Hazard Spectral Weighting Functions

Wavelength (nm)	Aphakic Hazard Function A(λ)	Blue-Light Hazard Function B(λ)	Retinal Thermal Hazard Function R(λ)
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

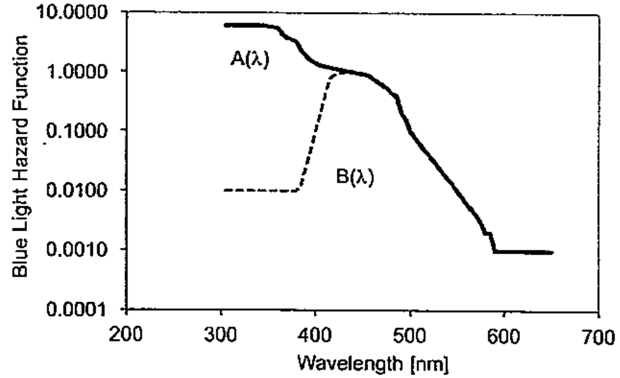

FIGURE 2. Blue-light (retinal photochemical) hazard function for normal eyes [B(λ)] and the aphakic hazard function [A(λ)].

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:

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

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

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

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

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

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 • cm^{-2}), the total effective radiance (L_{NIR}) as viewed by the eye is the integrated spectral radiance (L_λ) weighted by the thermal hazard function, R(λ).

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

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

Wavelength (nm)	Aphakic Hazard Function A(λ)	Blue-Light Hazard Function B(λ)	Retinal Thermal Hazard Function R(λ)
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:

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

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

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

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

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

Some meters provide a total time-integrated radiance emitted in units of J • cm^{-2} • 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® is a dose limit (called DL_R in this TLV®).

Determine the angular subtense (α) of the source in radians (rad). For circular lamps, α is the lamp diameter divided by the viewing distance. If the lamp is oblong, α 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.

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

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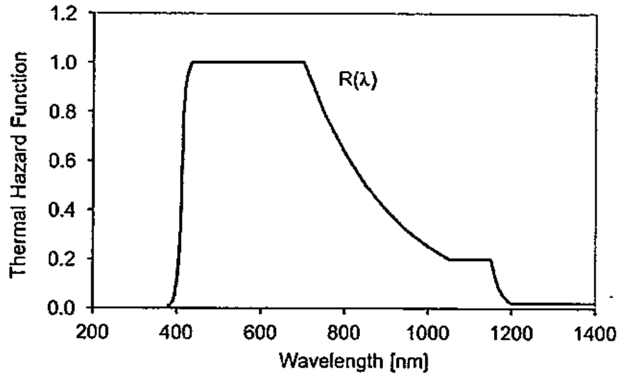

FIGURE 3. Retinal thermal hazard function [R(λ)].

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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 α is 0.029 rad.

Large sources are those with an angular subtense (α) 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 μs (10^{-6} s) through 0.00063 s, an acceptable exposure is present when Equation 12a is true. For pulse durations less than 1 μs, the TLV® is the same as that for 1 μs. 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.

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

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.

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

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.

* ULTRAVIOLET RADIATION (2021)

TLVs®

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. For those sources that subtend a greater angle, there is no need to measure an angle greater than 80 degrees.

The values do not apply to UV radiation exposure of photosensitive individuals or of individuals concomitantly exposed to photosensitizing agents (see Note 3). The values at wavelengths greater than 300 nm 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. The TLVs® in Table 1 apply directly to exposure of the cornea of the eye and provide conservative guidelines for skin exposures. If the eyes are protected, higher levels (Table 2) apply to exposures of the skin in the UV-C (180 to 280 nm) spectral region and below 300 nm.

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_{eff}). To determine E_{eff} for a broadband source weighted against the peak of the spectral effectiveness curve (270 nm), Equation 1 should be used.

$$E_{eff} = \sum_{180}^{400} E_\lambda \times S(\lambda) \times \Delta\lambda \qquad (1)$$

where: E_{eff} = effective irradiance relative to a monochromatic source at 270 nm [W/cm^2];
E_λ = spectral irradiance at a center wavelength

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

Small sources have an angular subtense (α) 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 α. The interaction is a maximum value for α (α_{max}) as a function of viewing duration (t [s]).

For viewing durations from 1 μs (10^{-6} s) through 0.00063 s, an acceptable exposure is present when Equation 12a above is true. For pulse durations less than 1 μs, the TLV® is the same as that for 1 μs. 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.

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

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

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

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.

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

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

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.

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

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

• 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, α 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.

TLV®–PA

TABLE 1. Ultraviolet Radiation TLV® and Relative Spectral Effectiveness

Wavelength[A] (nm)	TLV® (J/m²)[B]	TLV® (mJ/cm²)[B]	Relative Spectral Effectiveness, S(λ)
180	16260	1626	0.00185
190	16260	1626	0.00185
200	16260	1626	0.00185
205	16260	1626	0.00185
210	10233	1023	0.00293
215	4732	473	0.00634
220	2188	218	0.0137
225	1012	101	0.0297
230	468	46.8	0.0641
235	216	21.6	0.139
240	100	10	0.300
245	83	8.3	0.360
250	70	7.0	0.430
254[C]	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[C]	34	3.4	0.880
285	39	3.9	0.770
290	47	4.7	0.640
295	56	5.6	0.540
297[C]	65	6.5	0.460
300	100	10	0.300
303[C]	250	25	0.120
305	500	50	0.060
308	1200	120	0.026
310	2000	200	0.015
313[C]	5000	500	0.006
315	1.0×10^4	1.0×10^3	0.003
316	1.3×10^4	1.3×10^3	0.0024
317	1.5×10^4	1.5×10^3	0.0020
318	1.9×10^4	1.9×10^3	0.0016
319	2.5×10^4	2.5×10^3	0.0012
320	2.9×10^4	2.9×10^3	0.0010
322	4.5×10^4	4.5×10^3	0.00067
323	5.6×10^4	5.6×10^3	0.00054
325	6.0×10^4	6.0×10^3	0.00050
328	6.8×10^4	6.8×10^3	0.00044
330	7.3×10^4	7.3×10^3	0.00041
333	8.1×10^4	8.1×10^3	0.00037
335	8.8×10^4	8.8×10^3	0.00034
340	1.1×10^5	1.1×10^4	0.00028
345	1.3×10^5	1.3×10^4	0.00024
350	1.5×10^5	1.5×10^4	0.00020

TLV®–PA

[W/(cm² × nm)];

S(λ) = relative spectral effectiveness at the center wavelength (unitless);

Δλ = bandwidth around the center wavelength (nm);

More practically, E_{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_{exp}) based on E_{eff} is dose limited to 0.003 J/cm². That is,

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

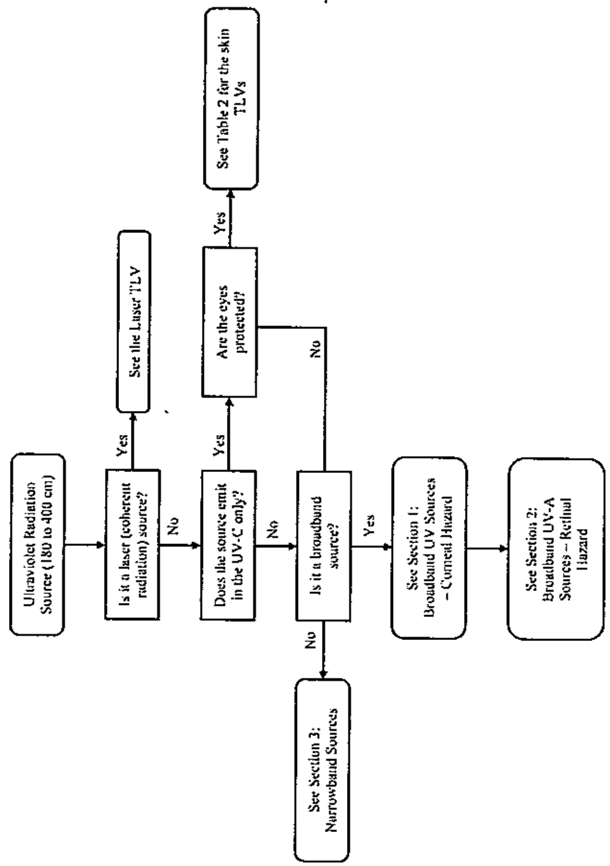


FIGURE 1. Flow chart for UV TLV®.

and for broadband sources a modified spectral weighting function S'(λ) can be applied (Figure 2) in Equation 1 to determine E_{eff}.

Table 3 gives TLV® 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.

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

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

The irradiance, $E_{UV\text{-}A}$ [mW/cm²], can be measured with an unfiltered meter that is sensitive to UV-A radiation. For daily exposure periods (t_{exp}) less than 1,000 seconds (17 minutes), the exposure is dose limited to 1,000 mJ/cm² as described in Equation 4.

$$1000\,[mJ/cm^2] \geq E_{UV\text{-}A}\,[mW/cm^2] \times t_{exp}[s]. \tag{4}$$

For daily exposure periods greater than 1.000 seconds (17 minutes), the exposure is rate limited to 1.0 mW/cm² as described in Equation 5.

$$1.0\,[mW/cm^2] \geq E_{UV\text{-}A}\,[mW/cm^2]. \tag{5}$$

TLV®–PA

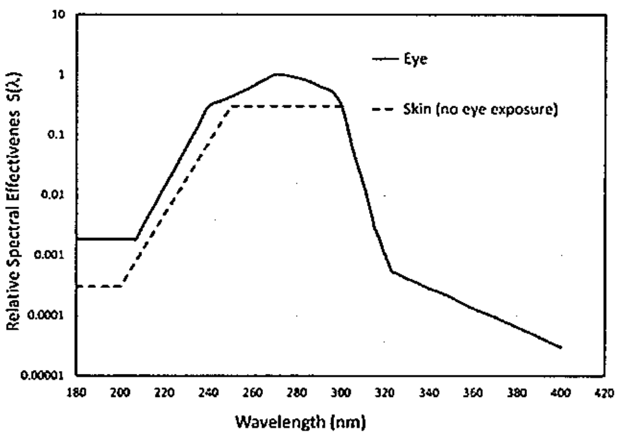


FIGURE 2. Hazard function (relative spectral effectiveness, S(λ)) for UV.

TABLE 1 (cont.). Ultraviolet Radiation TLV® and Relative Spectral Effectiveness

Wavelength[A] (nm)	TLV® (J/m²)[B]	TLV® (mJ/cm²)[B]	Relative Spectral Effectiveness, S(λ)
355	1.9×10^5	1.9×10^4	0.00016
360	2.3×10^5	2.3×10^4	0.00013
365[C]	2.7×10^5	2.7×10^4	0.00011
370	3.2×10^5	3.2×10^4	0.000093
375	3.9×10^5	3.9×10^4	0.000077
380	4.7×10^5	4.7×10^4	0.000064
385	5.7×10^5	5.7×10^4	0.000053
390	6.8×10^5	6.8×10^4	0.000044
395	8.3×10^5	8.3×10^4	0.000036
400	1.0×10^6	1.0×10^5	0.000030

[A] Wavelengths chosen are representative; other values should be interpolated at intermediate wavelengths.
[B] 1 mJ/cm² = 10 J/m²
[C] Emission lines of a mercury discharge spectrum.

TABLE 2. Ultraviolet Radiation TLV® and Relative Spectral Effectiveness for the Skin (UV-C)

Wavelength[A] (nm)	TLV® (J/m²)[B]	TLV® (mJ/cm²)[B]	Relative Spectral Effectiveness, S'(λ) (prime)
180	1.0×10^5	10000	3.0×10^{-4}
190	1.0×10^5	10000	3.0×10^{-4}
200	1.0×10^5	10000	3.0×10^{-4}
205	50120	5012	6.0×10^{-4}
210	25120	2512	1.19×10^{-3}
215	12540	1259	2.38×10^{-3}
220	6310	631.0	4.75×10^{-3}
225	3162	316.2	9.49×10^{-3}
230	1585	158.5	0.0189
235	794	79.4	0.0380
240	400	39.8	0.075
245	200	20.0	0.150
250	100	10	0.30
260	100	10	0.30
270	100	10	0.30
280	100	10	0.30
290	100	10	0.30
300	100	10	0.30

TLV®–PA

Skin Hazard

The TLV® (Table 1) values are conservative for skin exposure (see *Documentation*).

For UV-C (germicidal) wavelengths, if the eyes are protected, higher exposure values (Table 2) can be applied for narrowband sources (e.g., at 254 nm)

TABLE 3. Exposure Durations for Given Actinic UV Radiation Effective Irradiances

Duration of Exposure Per Day	Effective Irradiance, E_{eff} (mW/cm²)
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.

TLV®–PA

Narrowband Sources

Narrowband sources are comprised of one wavelength or a narrow band of wavelengths (e.g.,.5 to 10 nm). Locate the center wavelength (λ) in Table 1, and find the TLV_λ as an 8-hour dose limit in J/m² or mJ/cm². 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_{exp}) for a narrowband source can be expressed as Equation 6 using the Spectral Sensitivity (S_λ) from Table 1 and unfiltered irradiance (E_λ) [W/m² or mW/cm²].

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

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

The maximum exposure time (t_{max}) [s] for a narrowband source can be determined from Equation 7 using the TLV_λ and the unfiltered irradiance (E_λ) [W/m² or mW/cm²]. (Note: The energy and surface area units must match.)

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

Notes:

1. The probability of developing skin cancer de-pends 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 nonmelanoma cancers may differ from each other and depend on the UV exposure history. Because of their high spectral attenuation by the stratum corneum, UV-C wavelengths pose a much lower risk for delayed effects than UV-B (see Table 2).
2. Outdoor workers in latitudes within 40 degrees of the equator can be exposed outdoors to levels above the TLV®s in as little as 5 minutes around noontime during the summer.
3. Exposure to UV radiation concurrently with topical or systemic exposure to a variety of chemicals, including some prescription drugs, can result in skin erythema at sub-TLV® exposures. Hypersensitivity should be suspected if workers present skin reactions when exposed to sub-TLV® 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 220 nm. Refer to the latest version of the Chemical Substances TLV® for ozone. This is a particular problem at wavelengths less than 200 nm. Ozone-free UV-C lamps generally have a lamp envelope that heavily attenuate these shorter wavelengths.

TLV®–PA

LASERS

(*Documentation* Date – 2020)

TLVs®

These TLVs® 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® 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®. 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® 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® 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.

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^{-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

TLV®–PA

Source Size and Correction Factor C_E

The following considerations apply only at wavelengths in the retinal hazard region, 400–1400 nm (nanometers). Normally, a laser is a small source, which approximates a "point source" and subtends an angle less than α_{min}, which is 1.5 mrad for all values of t. However, any source that subtends an angle, α, greater than α_{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 α_{max} is defined as:

α_{max} = 5 mrad for t ≤ 0.625 ms
$\alpha_{max} = 200 \times t^{0.5}$ mrad for 0.625 ms < t < 0.25 s
α_{max} = 100 mrad for t ≥ 0.25 s, and
α_{min} = 1.5 mrad

Figure 1 illustrates the time dependence of α_{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 CE, as detailed in the Notes for Table 2.

TLV®–PA

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 CA (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 CB (to account for reduced photochemical sensitivity for retinal injury) is applied. The correction factor CC 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 CA, 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 s for a bright visible source to 10 s for an infrared source. The corrected TLV® on a per-pulse basis is:

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

where C_P = 1.0 for $t < t_{min}$ (i.e. 5 µs for 400–1050 nm and 13 µs for 1050–1400 nm) and for $t > t_{min}$, $C_P = 1.0$ for $\alpha < 5.0$ milliradians, 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 ≤ 700 nm, the corrected TLV® from Equation 1 applies if the average irradiance does not exceed the TLV® for continuous exposure. The average irradiance (i.e. the total accumulated exposure for *nt* s) should 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® 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 3×10^4 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 3×10^4 s with continuous exposures.

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

TLV®–PA

TLV®–PA

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/cm²	
	180 nm to 400 nm	10^{-11} to 10^{-9}	1 mJ/cm²	
UVC	180 nm to 260 nm	10^{-9} to 3×10^4	$3 \times 10^{0.033(260\ nm-\lambda)}$ mJ/cm²	TLV-C: 0.56 $t^{1/4}$ J/cm² for t ≤ 10 s (applies to 180 nm to 260 nm through 313 nm)
	260 nm to 280 nm*	10^{-9} to 3×10^4	3 mJ/cm²	
UVB	280 nm to 302 nm	"	3 mJ/cm²	
	303 nm	"	4 mJ/cm²	
	304 nm	"	6 mJ/cm²	
	305 nm	"	10 mJ/cm²	
	306 nm	"	16 mJ/cm²	
	307 nm	"	25 mJ/cm²	
	308 nm	"	40 mJ/cm²	
	309 nm	"	63 mJ/cm²	
	310 nm	"	100 mJ/cm²	
	311 nm	"	160 mJ/cm²	
	312 nm	"	250 mJ/cm²	
	313 nm	"	400 mJ/cm²	
	314 nm	"	630 mJ/cm²	
UVA	315 nm to 400 nm	10^{-9} to 10	0.56 $t^{1/4}$ J/cm²	
	315 nm to 400 nm	10 to 10^3	1.0 J/cm²	
	315 nm to 400 nm	10^3 to 3×10^4	1.0 mW/cm²	

Table 2. TLVs® for Direct Ocular Exposures (Intrabeam "Point-Source" Viewing) from a Laser Beam (Continued)

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

*Ozone (O_3) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV® for ozone.

Table 2. TLVs® for Direct Ocular Exposures (Intrabeam "Point-Source" Viewing) from a Laser Beam (Continued)

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®	
Light	400 to 700 nm	10^{-13} to 10^{-11}	1 × 10^{-7} J/cm^2	
	400 to 700 nm	10^{11} to 5 × 10^{-6}	2 × 10^{-7} J/cm^2	
	400 to 700 nm	5 × 10^{-6} to 10	1.8 $t^{3/4}$ × 10^{-3} J/cm^2	
	400 to 450 nm	10 to 100	10 mJ/cm^2	
	450 to 500 nm	10 to T_1	1 mW/cm^2	
	450 to 500 nm	T_1 to 100	10 C_B mJ/cm^2	
	400 to 500 nm	100 to 3 × 10^4	0.1 C_B mW/cm^2	
	500 to 700 nm	10 to 3 × 10^4	1.0 mW/cm^2	
IRA	700 to 1050 nm	10^{-13} to 10^{-11}	1.0 × 10^{-7} J/cm^2	
	700 to 1050 nm	10^{-11} to 5 × 10^{-6}	2.0 C_A × 10^{-7} J/cm^2	
	700 to 1050 nm	5 × 10^{-6} to 10	1.8 C_A × $t^{0.75}$ × 10^{-3} J/cm^2	
	700 to 1050 nm	10 to 3 × 10^4	C_A × 10^{-3} W/cm^2	
	1050 to 1400 nm	10^{-13} to 10^{-11}	C_C × 10^{-7} J/cm^2	
	1050 to 1400 nm	10^{-11} to 1.3 × 10^{-5}	2 C_C × 10^{-6} J/cm^2	
	1050 to 1400 nm	1.3 × 10^{-5} to 10	9.0 C_C $t^{0.75}$ × 10^{-3} J/cm^2	TLV-C: 35 J/cm^2
	1050 to 1400 nm	10 to 3 × 10^4	5.0 C_C × 10^{-3} W/cm^2	TLV-C: 3.5 W/cm^2

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}	$C_E \times 10^{-7}$ J/cm²
	400 to 700 nm	10^{-11} to 5×10^{-6}	$2\ C_E \times 10^{-7}$ J/cm²
	400 to 700 nm	5×10^{-6} to 10	$1.8\ C_E\ t^{0.75} \times 10^{-3}$ J/cm²
	400 to 700 nm	18×10^{-6} to 0.7	$1.8\ C_E\ t^{0.75} \times 10^{-3}$ J/cm²
	Dual Limits for 400 to 600 nm visible laser exposure for t > 0.7 s		
	Photochemical		
	For $\alpha \le 11$ mrad, the MPE is expressed as irradiance and radiant exposure*		
	400 to 600 nm	0.7 to 100	$C_B \times 10^{-2}$ J/cm²
	400 to 600 nm	100 to 3×10^{4}	$C_B \times 10^{-4}$ W/cm²
	For $\alpha > 11$ mrad, the MPE is expressed as radiance and integrated radiance*		
	400 to 600 nm	0.7 to 1×10^{4}	$100\ C_B$ J/(cm² sr)
	400 to 600 nm	1×10^{4} to 3×10^{4}	$C_B \times 10^{-2}$ W/(cm² sr)
	Thermal	*and*	
	400 to 700 nm	0.7 to T_2	$1.8\ C_E\ t^{0.75} \times 10^{-3}$ J/cm²
	400 to 700 nm	T_2 to 3×10^{4}	$1.8\ C_E\ T_2^{-0.25} \times 10^{-3}$ W/cm²

Notes for Table 2

C_A = Fig. 2; $C_B = 1$ for $\lambda = 400$ to ≤ 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® can be increased by correction factor C_E (use Table 3) provided that the angular subtense α of the source (measured at the viewer's eye) is greater than α_{min}. C_E depends on α as follows:

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

The angle referred to as α_{max} corresponds to the angular source size where the TLVs may be expressed as a constant time-integrated radiance or radiance dose (J/(cm² sr)) or radiance (W/(cm² sr)) and the TLVs for $\alpha > \alpha_{max}$ can be written in terms of integrated radiance $L_{TLV} \times t$ or radiance L_{TLV}.

$L_{TLV} = (1.7 \times 10^{5}) \times (TLV_{pt\ source})$ J/(cm² sr) for t < 0.625 µs for $400 < \lambda < 700$ nm

$L_{TLV} = 7.6\ t^{1/4}$ J/(cm² sr) for 0.625 ms < t < 0.25 s for $400 < \lambda < 700$ nm

$L_{TLV} = 4.8$ W/(cm² sr) for t > 100 s for $400 < \lambda < 700$ nm

Figure 5 illustrates these TLVs® 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® for skin exposure applies as noted in the footnote to "IRB & C," Table 4.

TABLE 4. TLVs® for Skin Exposure from a Laser Beam

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®
UV[A]	180 nm to 400 nm	10^{-13} to 3×10^4	Same as Table 2
Light & IRA	400 nm to 1400 nm	10^{-13} to 10^{-11}	$2\ C_A \times 10^{-3}$ J/cm²
	"	10^{-11} to 10^{-9}	$6\ C_A \times 10^{-3}$ J/cm²
	"	10^{-9} to 10^{-7}	$2\ C_A \times 10^{-2}$ J/cm²
	"	10^{-7} to 10	$1.1\ C_A \sqrt[4]{t}$ J/cm²
	"	10 to 3×10^4	$0.2\ C_A$ W/cm²
IRB & IRC[B]	1.401 to 10^3 µm	10^{-13} to 3×10^4	Same as Table 2

[A]Ozone (O_3) is produced in air by sources emitting ultraviolet (UV) radiation at wavelengths below 250 nm. Refer to Chemical Substances TLV® for ozone.

$C_A = 1.0$ for $\lambda = 400$–700 nm; *see* Figure 2 for $\lambda = 700$ to 1400 nm

[B]At wavelengths greater than 1400 nm, for beam cross-sectional areas exceeding 100 cm², the TLV® for exposure durations exceeding 10 s is:

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

where A_s is the irradiated skin area for 100 to 1000 cm², and the TLV® is 10 mW/cm² for irradiated skin areas exceeding 1000 cm² and is 100 mW/cm² for irradiated skin areas less than 100 cm².

Notes for Tables 2 and 3

"NTE": To protect the cornea and lens, the TLVs® for wavelengths between 400 nm and 1.4 µm, in Table 3 should not exceed:

Wavelength	Exposure, (t) Seconds	NTE (Second of Dual Limits)†
400 to 1400 nm	10^{-13} to 10^{-7}	$6\ C_A \times 10^{-2}$ J/cm²
400 to 1400 nm	10^{-7} to 10	$3.3\ C_A t^{1/4}$ J/cm²
400 to 1400 nm	10 to 3×10^4	$0.6\ C_A$ W/cm²

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

TABLE 3. TLVs® for Extended-Source Laser Viewing Conditions (Continued)

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®

These correspond to values of J/cm² for $10\ s \leq t < 100\ s$ and W/cm² for $t \geq 100\ s$ as measured through a limiting cone angle γ.

$\gamma = 11$ mrad for $0.7\ s \leq t < 100\ s$
$\gamma = 1.1 \times t^{0.5}$ mrad for $100\ s \leq t < 10^4\ s$
$\gamma = 110$ mrad for $10^4\ s \leq t < 3 \times 10^4\ s$
$T_2 = 10 \times 10^{(\alpha - 1.5)/98.5}$ for α expressed in mrad for $\lambda = 400$ to 1400 nm.

For exposure duration "t", the angle α_{max} is defined as:

$\alpha_{max} = 5$ mrad for $t \leq$ to 0.625 ms
$\alpha_{max} = 200\ t^{0.5}$ mrad for $0.625\ ms < t < 0.25\ s$, and
$\alpha_{max} = 100$ mrad for $t \geq 0.25\ s$
$L_p = 100\ C_B$ J/(cm² sr) for $0.7\ s \leq t < 10^4\ s$ and $L_e = C_B \times 10^{-2}$ W/(cm² sr) for $t \geq 10^4\ s$ as measured through a limiting cone angle γ.

TABLE 3. TLVs® for Extended-Source Laser Viewing Conditions (Continued)

Spectral Region	Wavelength	Exposure, (t) Seconds	TLV®	
IRA	700 to 1050 nm	10^{-13} to 10^{-11}	$C_E \times 10^{-7}$ J/cm²	
	700 to 1050 nm	10^{-11} to 5×10^{-6}	$5\ C_A C_E \times 10^{-7}$ J/cm²	
	700 to 1050 nm	5×10^{-6} to T_2	$1.8\ C_A C_E\ t^{0.75} \times 10^{-3}$ J/cm²	
	700 to 1050 nm	T_2 to 3×10^4	$1.8\ C_A C_E\ T_2^{-0.25} \times 10^{-3}$ W/cm²	
	1050 to 1400 nm	10^{-13} to 10^{-11}	$C_C C_E \times 10^{-7}$ J/cm²	
	1050 to 1400 nm	10^{-11} to 1.3×10^{-5}	$2\ C_C C_E \times 10^{-6}$ J/cm²	
	1050 to 1400 nm	13×10^{-6} to T_2	$9.0\ C_C C_E\ t^{0.75} \times 10^{-3}$ J/cm²	TLV-C: 35 J/cm²
	1050 to 1400 nm	T_2 to 3×10^4	$9.0\ C_C C_E\ T_2^{-0.25} \times 10^{-3}$ W/cm²	TLV-C: 3.5 W/cm²

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

$L_p = 100\ C_B$ J/(cm² sr) for $0.7\ s \leq t < 10^4\ s$ and $L_e = C_B \times 10^{-2}$ W/(cm² sr) for $t \geq 10^4\ s$ as measured through a limiting cone angle γ.

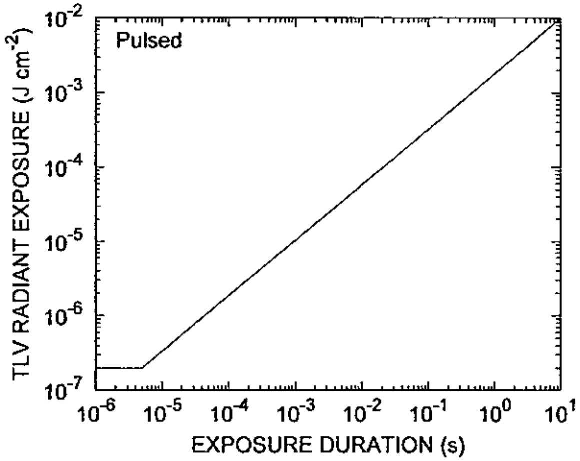


FIGURE 3a. TLV® for intrabeam viewing of laser beam (400–700 nm).

TLV®–PA

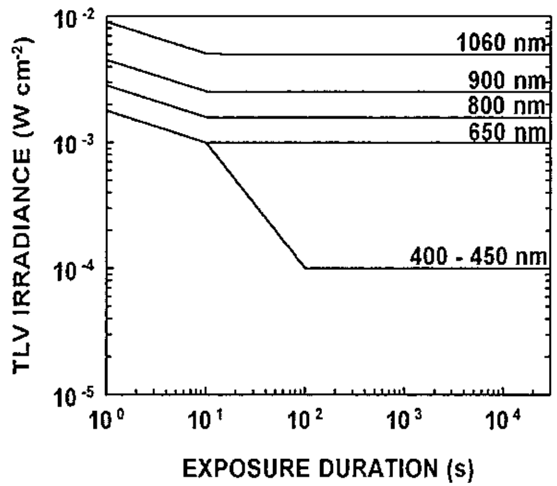


FIGURE 3b. TLV® for intrabeam (direct) viewing of CW laser beam (400–1400 nm).

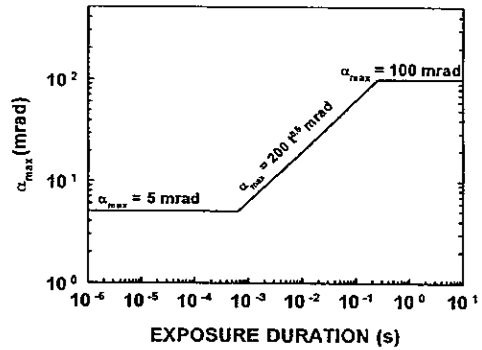


FIGURE 1. Variation of α_{max} with exposure duration.

TLV®–PA

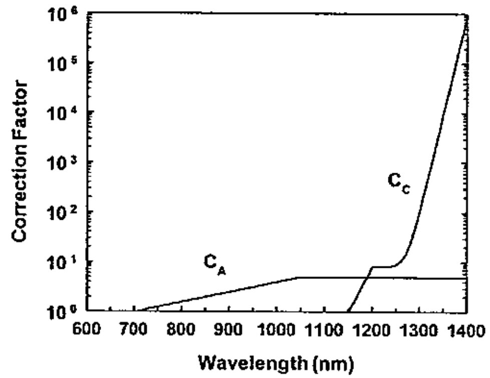


FIGURE 2. TLV® correction factors for λ = 700–1400 nm*
*For λ = 700–1049 nm, $C_A = 10^{[0.002(\lambda - 700)]}$; for λ = 1050–1400 nm, C_A = 5; for $\lambda \leq$ 1150 nm, C_C = 1; for λ = 1150–1200 nm, $C_C = 10^{[0.018(\lambda - 1150)]}$; and for λ = 1200–1399 nm, $C_C = 8 + 10^{[0.04(\lambda - 1250)]}$.

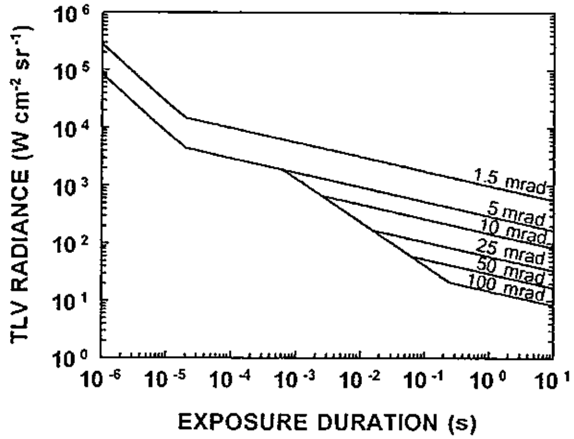


FIGURE 5. TLVs® in terms of radiance for exposures to extended-source lasers in the wavelength range of 400 to 700 nm.

TLV®–PA

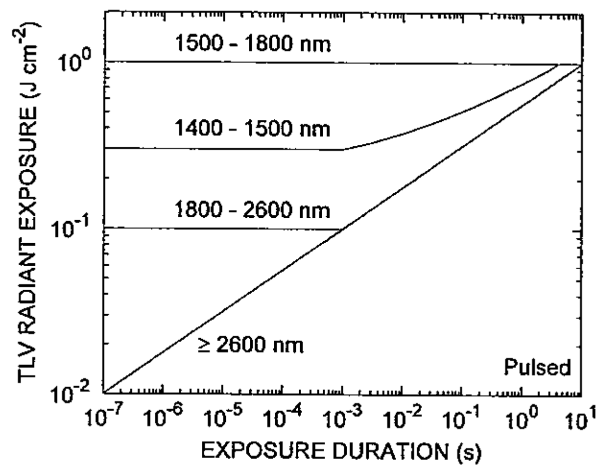


FIGURE 4a. TLV® for laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1400 nm).

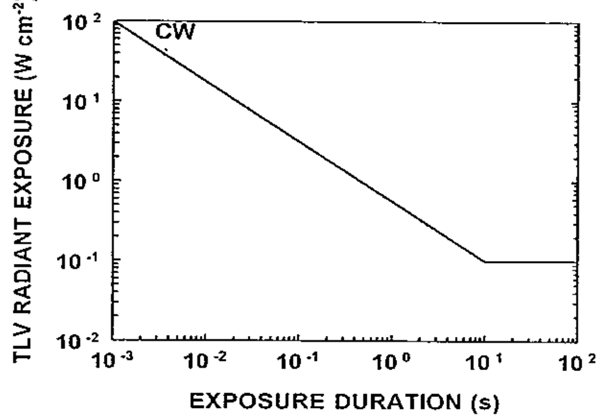


FIGURE 4b. TLV® for CW laser exposure of skin and eyes for far-infrared radiation (wavelengths greater than 1.4 μm).

TLV®–PA

IONIZING RADIATION
(*Documentation* Date – 2020)

TLVs®

ACGIH® has adopted as a TLV® for occupational exposure to ionizing radiation the guidelines of the National Council on Radiation Protection and Measurements (NCRP, 2018) and certain guidance from the International Council on Radiation Protection (ICRP, 2007). Ionizing radiation includes particulate radiation (α particles and β 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 greater than 12.4 electron volts (eV) corresponding to wavelengths less than approximately 100 nanometers (nm).

The guiding principles of ionizing radiation protection are:

- ***Justification:*** Actions to add, increase, reduce or remove a source of exposure to humans require justification (i.e., the action does more good than harm). All factors, both radiological and nonradiological, and particularly the economic, societal, psychological and environmental implications (including to nonhuman biota), should be considered in that justification (NCRP, 2018).
- ***Optimization of Protection:*** The likelihood of incurring exposures, the number of individuals exposed, and the magnitude of the dose to an individual should be kept as low as reasonably achievable, taking into account societal, economic and environmental factors (i.e., ALARA principle). More generally, optimization of protection is satisfied when the expenditure of further resources would be unwarranted by improvement in health and safety (both radiological and nonradiological). The level of protection should be the best under the prevailing circumstances, maximizing the margin of benefit over harm (NCRP, 2018).
- ***Dose Limit:*** The dose limit is the numeric protection criterion recommended by NCRP for management of dose to an individual for a given exposure situation that establishes a starting point, below which the options for optimization of protection should be evaluated for that particular exposure situation. If the initial circumstances for a particular exposure situation are such that the dose limit is exceeded, the first objective is to meet that dose limit, then optimization of protection should be applied. Dose limits do not apply to medical exposure of patients or exposure to ubiquitous background radiation (with the exception of elevated levels of radon in dwellings and the workplace, and to solar and cosmic radiation in certain occupational circumstances) (NCRP, 2018).

There is no identified dose threshold for those radiation effects classified as stochastic. The dose limits are selected so that the risk of inducing a fatal cancer during the lifetime of the exposed individual is less than 10^{-3} per year.*

There is also some question whether radiation-induced cataract formation has a low-dose threshold. Overall, the emphasis in radiation protection is on optimiza-

TLV®–PA

tion of protection.

TLV® guidelines are the dose limits shown in Table 1. Application of the ALARA principle is achieved through optimization of protection, which is to be applied in all exposure situations and is the methodology by which doses are managed in practice to be well below the dose limit (NCRP, 2018).

* This level of risk is based on the NCRP (2018) and ICRP (2007) estimate of a 5% lifetime risk of fatal cancer for a total exposure of one Sv distributed over occupational exposures of 20 mSv annual doses averaged over five years.

TABLE 1. Dose Limits for Management of Exposures to an Individual[A] (abstracted from NCRP, 2018)

Exposure Situation	Dose Limit (mSv)[B]
Effective Dose: *Stochastic Effects* Annual (≥ 18 years of age)	Should not exceed 50 mSv (millisievert)[C]
Cumulative (≥ 18 years of age)	Should not exceed 10 mSv times current age in years[D]
Minors under 18 years of age	Should not exceed 1 mSv per year
Embryo-fetus of pregnant worker following declaration of pregnancy	Should not exceed 0.5 mSv per month (equivalent dose in the embryo-fetus)[E]
Radon and Radon Daughters	Include in annual dose if activity concentration in air > 300 Bq m^{-3} after application of radon mitigation measures
Absorbed Dose[F]: *Tissue reactions*	
a) lens of the eye	Should not exceed 50 mGy per year in the lens of the eye
b) skin, hands and feet	Should not exceed 500 mGy in skin or extremities per year, averaged over the most highly exposed 10 cm^2 of skin

[A] Doses for stochastic effects are the effective doses from combined external and internal sources except from ubiquitous background radiation (with the exception of elevated levels of radon in the workplace, and solar and cosmic radiation in certain occupational circumstances). Doses for tissue reactions are the absorbed doses in the specified tissues. Definitions of absorbed dose and effective dose are given below.

[B] In all cases, the phrase "should not exceed" conveys that the first objective for management of dose to an individual is to meet the applicable numeric protection criterion, and then to apply optimization of protection. The phrase "should not exceed" is not intended to mean that the value is suitable as a regulatory dose limit. NCRP recognizes: (1) that there may be exposure situations in which initial doses to individuals are greater than the applicable numeric protection criterion, and (2) that the values are not a boundary between safe and unsafe exposures (NCRP, 2018).

TLV®–PA

[C] 10 mSv = 1 rem.

[D] NCRP acknowledges that, in practice, the costs and logistics of tracking doses may make cumulative lifetime recording difficult (NCRP, 2018).

[E] Situations in which a worker who has declared her pregnancy may be exposed to radioiodine should be minimized or avoided if possible because of the risk of congenital hypothyroidism (NCRP, 2018).

[F] If it is necessary to apply this recommendation to high-LET radiation, NCRP recommends that the absorbed dose in the skin or extremities or the lens of the eye should be multiplied by the biological effectiveness of the high-LET radiation that is appropriate for the tissue reaction (NCRP, 2018).

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). Sage Publications, Thousand Oaks, California (2007).

National Council on Radiation Protection and Measurements (NCRP): NCRP Report No 180, Management of Exposure to Ionizing Radiation: Radiation Protection Guidance for the United States. NCRP, Bethesda, MD (2018).

TLV®–PA

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

(*Documentation* Date – 2005)

TLV®–PA

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
(*Documentation* Date – 2018)

TLV®–PA

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® is on the hand, wrist, and forearm.

The TLV® 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® 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:

$$\mathrm{HAL} = 6.56 \ln D \left[\frac{F^{1.31}}{1 + 3.18 F^{1.31}}\right] \qquad (1)$$

(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

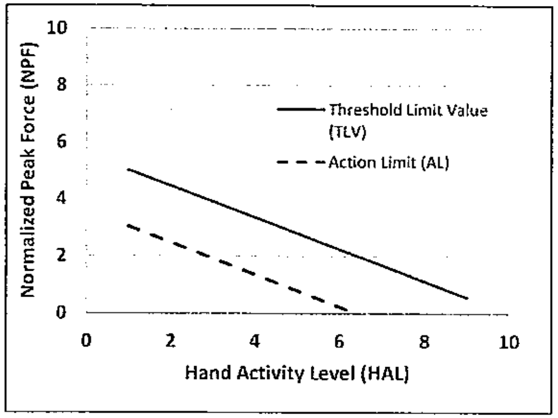
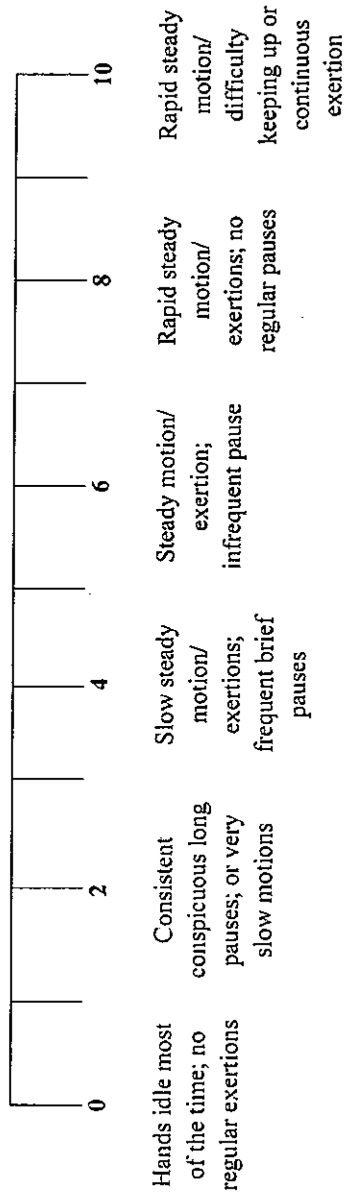


FIGURE 1. The Hand Activity TLV® for reduction of work-related musculoskeletal disorders based on hand activity level (HAL) and normalized peak hand force.

TLV®–PA



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) × 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® *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® 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® 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.

TLV®–PA

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;

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.

TLV®–PA

- contact stresses;
- low temperatures; or
- vibration

Employ appropriate control measures any time the TLV® is exceeded or an elevated incidence of work-related musculoskeletal disorders is detected.

Notes:

The actual TLV® 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**
   TLV: $NPF = 5.6 - 0.56 \times HAL$
   Action Limit: $NPF = 3.6 - 0.56 \times HAL$

   Or, equivalent description of lines:
   $NPF_{TLV} = 0.56\ (10 - HAL)$
   $NPF_{AL} = NPF_{TLV} - 2$

2. **Peak Force Index (PFI)**
   A value greater than 1.0 means that the respective limit is exceeded.
   $PFI_{TLV} = NPF/NPF_{TLV}$
   $PFI_{AL} = NPF/NPF_{AL}$

TLV®–PA

TABLE 1. TLVs® for Lifting Tasks:
≤ 2 Hours per Day with ≤ 60 Lifts per Hour
OR
> 2 Hours per Day with ≤ 12 Lifts per Hour

	Horizontal Zone[A]		
Vertical Zone	**Close: < 30 cm**	**Intermediate: 30 to 60 cm**	**Extended:[B] > 60 to 80 cm**
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	16 kg	7 kg	No known safe limit for repetitive lifting[D]
Knuckle height[E] to below shoulder	32 kg	16 kg	9 kg
Middle shin to knuckle height[E]	18 kg	14 kg	7 kg
Floor to middle shin height	14 kg	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]

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.

TLV®–PA

LIFTING

(*Documentation* Date – 2019)

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 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.

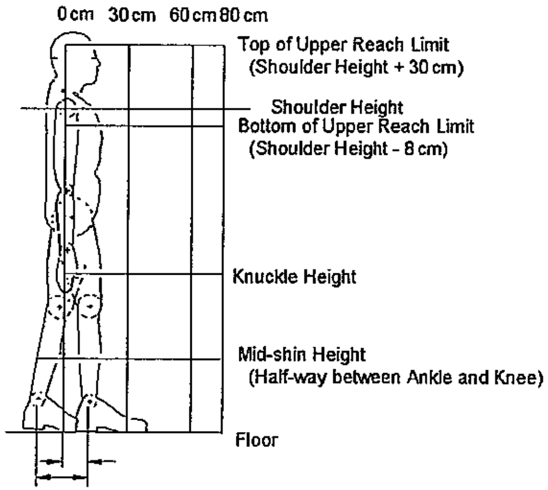


FIGURE 1. Graphic representation of hand location.

3. **Determine the lifting frequency** as the number of lifts a worker performs per hour.
4. **Use the TLV® 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®** 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® is represented by the lower of the two limits.

These TLVs® are designed to reduce the risk of low-back injuries associated with repeated lifting tasks. In addition to the low back, lifting and lowering tasks might expose other body regions to high stress. Depending on task parameters and specific posture requirements while lifting, joints such as shoulder, knee, elbow and wrist might be at equal or greater risk of injury than the low back. Additional research is needed to understand whole-body risk of injury from lifting. For example, expert opinion suggests that high frequency lifting while reaching at or above shoulder height might put a worker's shoulder at increased risk for injury even while the low-back loads are below the lifting TLVs®. Practitioners are encouraged to exercise professional judgement and supplement the lifting TLVs® with appropriate task-specific assessments in order to minimize injury risk to other body regions.

TABLE 2. TLVs® 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

	Horizontal Zone[A]		
Vertical Zone	**Close: < 30 cm**	**Inter-mediate: 30 to 60 cm**	**Extended:[B] > 60 to 80 cm**
Reach limit[C] or 30 cm above shoulder to 8 cm below shoulder height	14 kg	5 kg	No known safe limit for repetitive lifting[D]
Knuckle height[E] to below shoulder	27 kg	14 kg	7 kg
Middle shin to knuckle height[E]	16 kg	11 kg	5 kg
Floor to middle shin height	9 kg	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]

See Notes in Table 1.

TABLE 3. TLVs® for Lifting Tasks
> 2 Hours per Day with > 30 and ≤ 360 Lifts per Hour

	Horizontal Zone[A]		
Vertical Zone	**Close: < 30 cm**	**Inter-mediate: 30 to 60 cm**	**Extended:[B] > 60 to 80 cm**
Reach limit[C] from 30 cm above to 8 cm below shoulder height	11 kg	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]
Knuckle height[E] to below shoulder	14 kg	9 kg	5 kg
Middle shin to knuckle height[E]	9 kg	7 kg	2 kg
Floor to middle shin height	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]	No known safe limit for repetitive lifting[D]

See Notes in Table 1.

HAND–ARM VIBRATION

Documentation **Date – 2019)**

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®) 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^2 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® illustrated in Figure 1. It is not possible to specify a TLV® 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^2. 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® 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

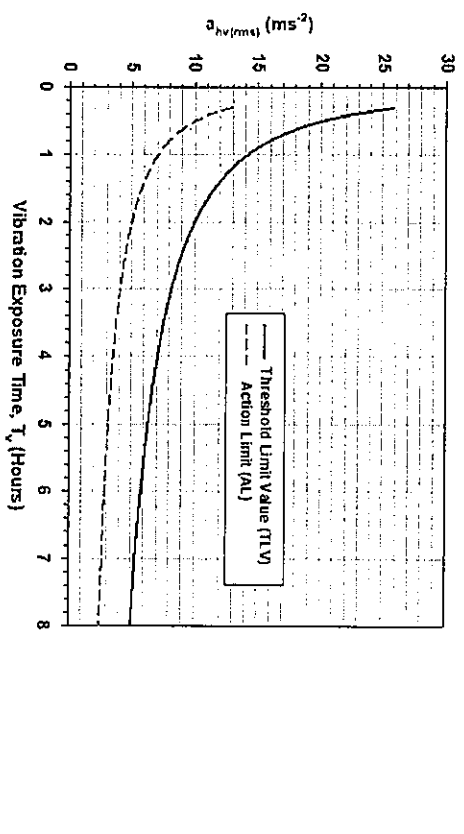


FIGURE 1. Threshold Limit Values (TLVs®) and Action Limits (ALs) associated with ANSI 2.70 Daily Exposure Limit Values (DELV) and Daily Exposure Action Values (DEAV), respectively.

TABLE 1. TLV® and AL Weighted Acceleration Levels

	Weighted Acceleration ($a_{hv(rms)}$ms^{-2})	
Vibration Exposure Time (hrs)	**TLV®**	**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 Tv (hrs):	$a_{hv(TLV)} = 5.0\left(\frac{8}{T_v}\right)^{\frac{1}{2}}$	
AL at Time Tv (hrs):	$a_{hv(AL)} = 2.5\left(\frac{8}{T_v}\right)^{\frac{1}{2}}$	
Time Duration Tv (hrs) to reach TLV®:	$T_v = \frac{200}{a^2_{hv(TLV)}}$	
Time Duration Tv (hrs) to reach AL:	$T_v = \frac{50}{a^2_{hv(AL)}}$	

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® 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® 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.

TLV®–PA

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).

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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^{th} one-third octave frequency band (*see* Figure 2)

a_{hi} = The rms acceleration in the i^{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.

TLV®–PA

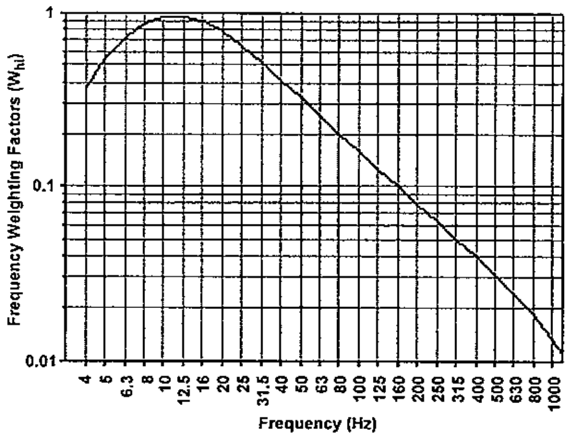

FIGURE 2. ISO Frequency Weighting Factors (ISO 5349-1, 2001a; ANSI S2.70, 2006).

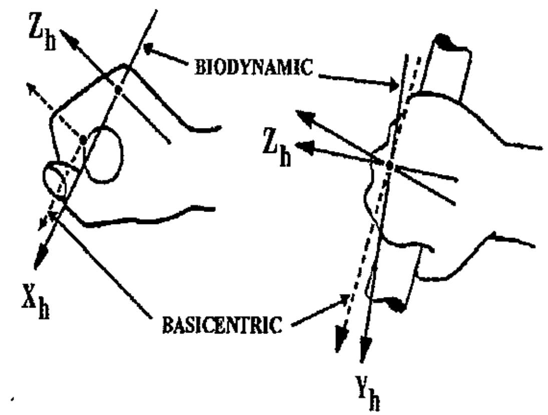

FIGURE 3. Biodynamic and basicentric coordinate systems for the hand, showing the directions of the acceleration components (ISO 5349, 2001a; ANSI S2.70, 2006).

TLV®–PA

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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® 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® can also be expressed as:

$$\%DC = (100\%) \cdot e^{((0.066 - (\%MVC/100\%))/0.143)}$$

The TLV® 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® applies to duty cycles within the range of 0.5% to 90%. The TLV® 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®. Static exertions of the hand, elbow or shoulder would not be expected to exceed 20 minutes.

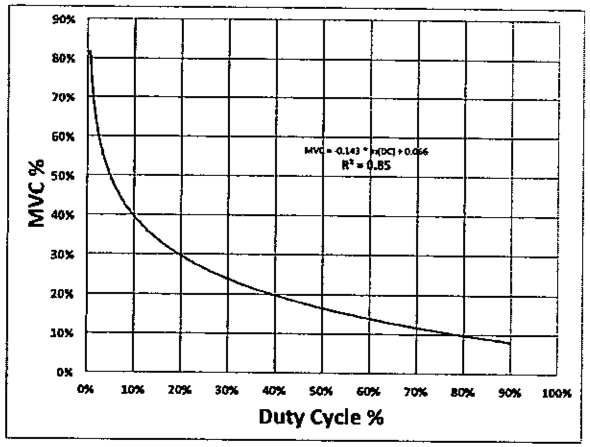

FIGURE 1. Fatigue TLV® for MVC (%) versus duty cycle (%).

TLV®–PA

NOTICE OF INTENDED CHANGE—† UPPER LIMB LOCALIZED FATIGUE

The reason for this NIC is to add language, including an equation to be applied over the range of the TLV.

The TLV in Figure 1 is recommended for work-place 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 per¬sistent upper limb musculoskeletal fatigue. Indi¬vidual, 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 protec¬tive 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 im¬portant 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.

TLV®–PA

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 maxi¬mum 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 computa¬tions. 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 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 can also be expressed as:

$$\%DC = (100\%) \cdot e^{((0.066 - (\%MVC/100\%))/0.143)}$$

The TLV 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 applies to duty cycles within the range of 0.5% to 90%. The TLV 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. Static exertions of the hand, elbow or shoulder would not be expected to exceed 20 minutes.

The minimum recovery time (RT) from an exertion performed during repetitive tasks can be estimated using:

$$RT = (ET / e^{((0.066\text{-}\%MVC)/0.143)}) - ET.$$

where ET is the exertion time. Duty cycle (DC) = ET / (ET+RT). This equation can be applied over the applicable range of the TLV, which is 0.5% to 90% DC, which corresponds to exertion levels ranging from approximately 10% to 80% MVC.

TLV®–PA

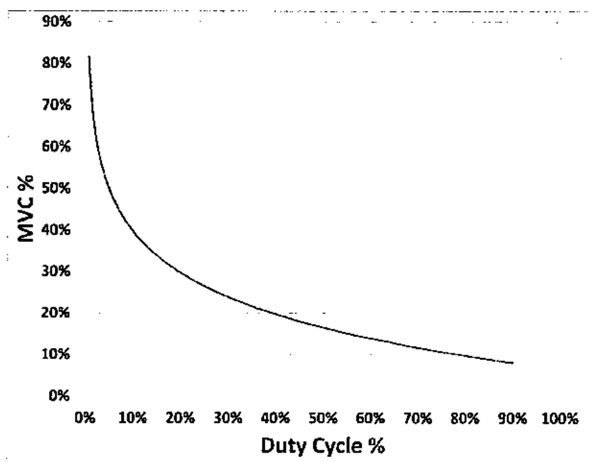

FIGURE 1. Fatigue TLV® for MVC (%) versus duty cycle (%).

TLV®–PA

WHOLE-BODY VIBRATION

(*Documentation* Date – 2020)

The Threshold Limit Values (TLVs®), 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 vector sum of the overall 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® 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 vector sum of the overall 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® 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® 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.

TLV®–PA

Notes:

1. The TLV® curve coincides with the upper boundary of the Health Guidance Caution Zones defined in ISO 2631-1 (ISO, 1997, 2003, 2010). The TLVs® refer to the maximum vector sum of the overall weighted rms accelerations in the three orthogonal axes 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

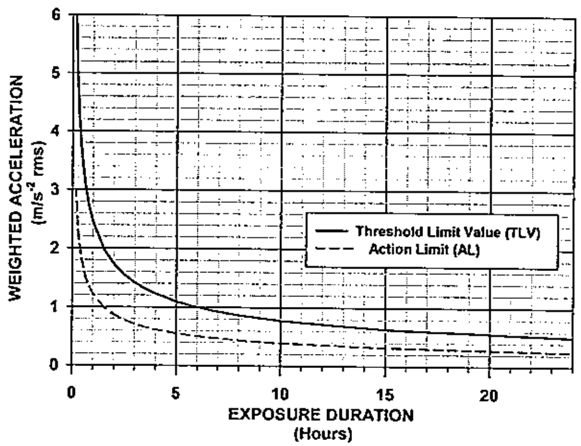

FIGURE 1. Threshold Limit Values (TLVs®) and Action Limits (ALs) associated with the upper boundary and lower boundary of the ISO 2631-1 Health Guidance Caution Zones, respectively (ISO, 1997, 2010). Note: Values are constant for exposures at and below 10 minutes.

TABLE 1. TLV® and AL Vector Sums of the Overall Weighted rms Accelerations (m/s^{-2} rms)

Duration (Hours)	TLV® (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

TLV® at Time T (hrs): $TLV^{®} = \frac{2.45}{\sqrt{T}}$ (m/s^{-2} rms)

AL at Time T (hrs): $AL = \frac{1.22}{\sqrt{T}}$ (m/s^{-2} rms)

Note: Equations do not apply for exposure durations shorter than 10 minutes.

TLV®–PA

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^{-2}). The gravitational acceleration, "g" = 9.81 ms^{-2}. The biodynamic coordinate system used for measuring the ac-celerations is illustrated in Figure 2. The procedures described in this *Documentation* apply to translation-al accelerations of the seated upright operator or occupant. Other postures and directions are addressed in ISO 2631-1 (ISO, 1997, 2003).
3. The TLVs® and ALs associated with the vector sum of the overall weighted rms accelerations 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 ISO 2631-5 provides guidance for assessing vibration with multiple shocks and should be considered for as-sessing exposures that include shocks or impacts that exceed 9.81 m/s2 (1 g peak). The alternative methods should be used in addition to the rms method (see Notes 7 and 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 light-weight 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 g.

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 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 assure 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 overall weighted rms ac-celeration in each axis (x, y, z) and the vector sum of the overall weighted rms accelerations for as-sessing health risk follows:

a. It is highly recommended that signal processing techniques be applied to generate the unweighted 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 (seat pan) 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_l) 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 in each axis (x, y, z). The calculation in the time domain is illustrated in Equation 1 (ISO, 1997, 2010):

$$a_{wl} = k_l\left(\frac{1}{T}\int_0^T a_{wl}^2(t)dt\right)^{\frac{1}{2}} \qquad (1)$$

where:

a_{wl} = The overall weighted rms acceleration in the l-axis, (l = x, y, or z) (m/s^{-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 (m/s^{-2})

T = Duration of the measurement(s)

The calculation in the frequency domain is illustrated in Equation 2:

$$a_{wl} = k_l\left(\sum[W_{li}a_{li}]^2\right)^{\frac{1}{2}} \qquad (2)$$

where:

a_{wl} = The overall weighted rms acceleration in the l-axis (l = x, y, or z) (m/s^{-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 in 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 overall weighted rms acceleration in each direction, x, y, and z, can be calculated as follows, in accordance with ISO 2631-1 (ISO, 1997, 2003, 2010):

$$a_{wl,e} = \left(\frac{\sum[a_{wlj}^2 \cdot T_j]}{\sum T_j}\right)^{\frac{1}{2}} \qquad (3)$$

where:

$a_{wl,e}$ = The equivalent overall weighted rms acceleration magnitude in either the l = x, y, or z direction (m/s^{-2} rms)

a_{wlj} = The overall weighted rms acceleration magnitude in either the l = x, y, or z direction for exposure period j (m/s^{-2} rms) (from Equations 1 or 2)

T_j = The duration for exposure period j (s)

c. The overall weighted rms accelerations may or may not be similar along the x, y, and z translational axes, as determined by Equations 1, 2, or 3. Therefore, the combined motion of all three axes is calculated as a vector sum of the overall weighted rms accelerations in the three orthogonal axes, a_v, and de-fined in Equation 4:

$$a_v = \left([1.4a_{wx}]^2 + [1.4a_{wy}]^2 + [a_{wz}]^2\right)^{\frac{1}{2}} \qquad (4)$$

The vector sum also applies to the energy-equivalent weighted rms accelerations in the x, y, and z directions calculated in accordance with Equation 3.

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TLV®–PA

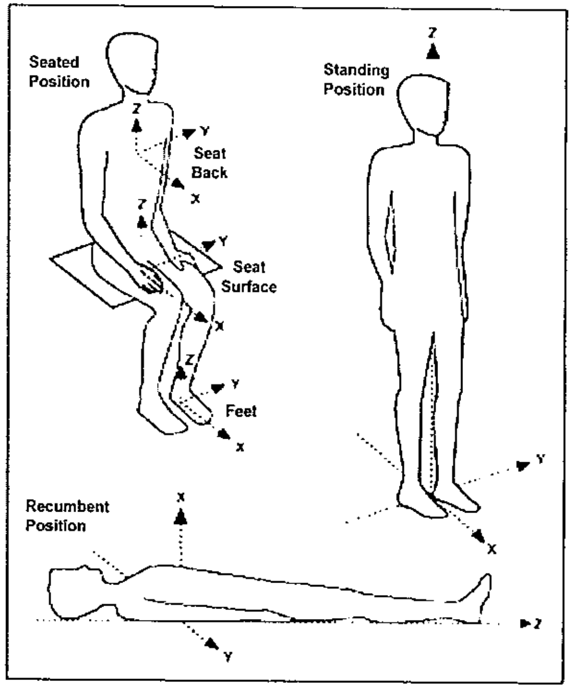

FIGURE 2. Biodynamic Coordinate System for the Seated, Standing, Recumbent Positions (Postures) (ISO, 1997, 2003, 2010). The coordinate system adheres to the right-hand rule for the seated and standing human.

TLV®–PA

6. A summary of the analysis procedure is as follows:
   If the vector sum of the overall weighted rms accelerations, 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® is exceeded for that exposure duration. It is recommended that the overall weighted rms accelerations in all three axes be reported, in addition to the vector sum.
   a. It may be desirable to calculate the daily vibration exposure (within a 24-hour period) standardized to an 8-hour reference period as follows:

$$a_{wl}(8) = \left(\frac{1}{T_0}\sum a^2_{wlj} \bullet T_j\right)^{\frac{1}{2}} \qquad (5)$$

where:

$a_{wl}(8)$ = The daily (8-hour) vibration exposure for the *l*-axis (m/s^{-2} rms)

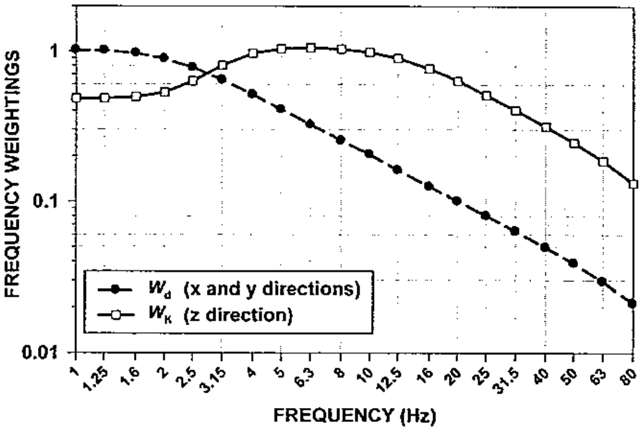

FIGURE 3. ISO 2631-1 Frequency Weightings W_d (x and y directions) and W_K (z direction) (ISO, 1997).

TLV®–PA

a_{wlj} = The overall weighted rms acceleration for the *l*-axis over the time period T_j, (*l* = x, y, or z) (m/s^{-2} rms) (from Equations 1 or 2)

T_0 = The reference duration of 8 hours or 28,800 seconds

The vector sum standardized to an 8-hour reference period, $a_v(8)$, can then be calculated using Equation 4.

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 containing occasional or substantial shocks, or transient vibration. In addition to the rms method described above, the fourth power Vibration Dose Value (VDV) may be calculated in each direction as:

$$VDV = k_l\left(\int_0^T [a_{wl}(t)^4]\, dt\right)^{\frac{1}{4}} \qquad (6)$$

It is noted that, unlike the overall weighted rms 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® in any direction is defined by a *VDV* value of 17.0 $ms^{-1.75}$ and shall not be exceeded for the exposure duration. The AL in any direction is defined by a *VDV* value of 8.5 $ms^{-1.75}$. It is highly recommended that vibration mitigation activity be undertaken to reduce any *VDV* falling between 8.5 and 17.0 $ms^{-1.75}$. The *VDV* method should not be applied to exposures lasting more than 6 hours. For exposures lasting more than 6 hours, the TLVs® 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® 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).
9. When the daily exposure duration is unknown or expected to vary on different days, and the assumption can be made that the estimate of the seat pan vector sum, a_v, is expected to represent the exposure associated with the majority of daily exposures, the time duration, *T*, to reach the TLV® can be estimated as:

$$T = \frac{(6.0)}{a_v^2} \tag{7}$$

Likewise, the time duration, *T*, to reach the AL can be estimated as:

$$T = \frac{(1.5)}{a_v^2} \tag{8}$$

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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. 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

(*Documentation* Date – 2018)

Introduction

The cold stress TLVs® 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® 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.

TLV®–PA

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

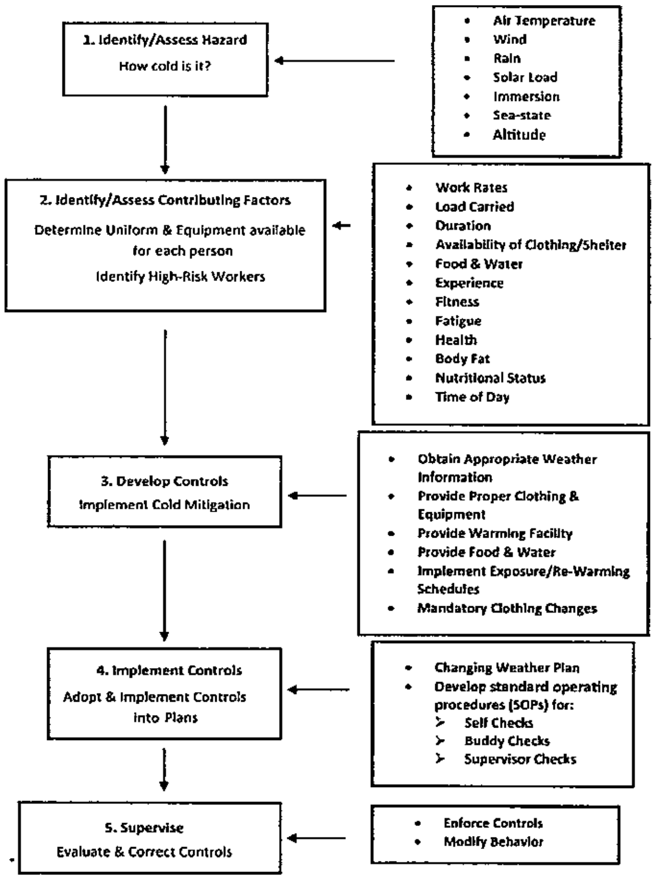

FIGURE 1. Risk Management Process for Evaluating Cold Stress and Strain.

Source: Department of the Army: Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508). Falls Church, VA (2005).

TLV®–PA

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.

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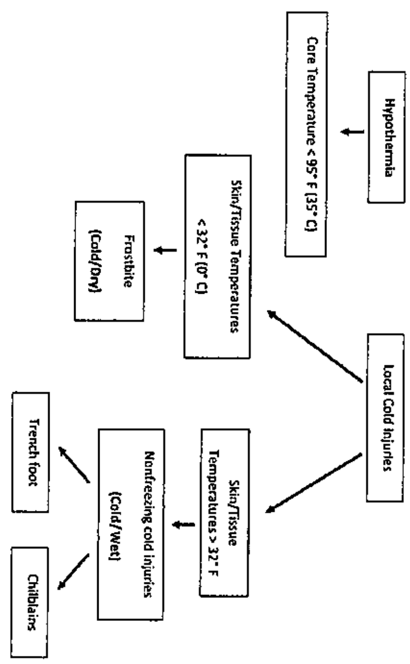

FIGURE 2. Types of cold injuries.

Source: Department of the Army: Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508). Falls Church, VA (2005).

TLV®–PA

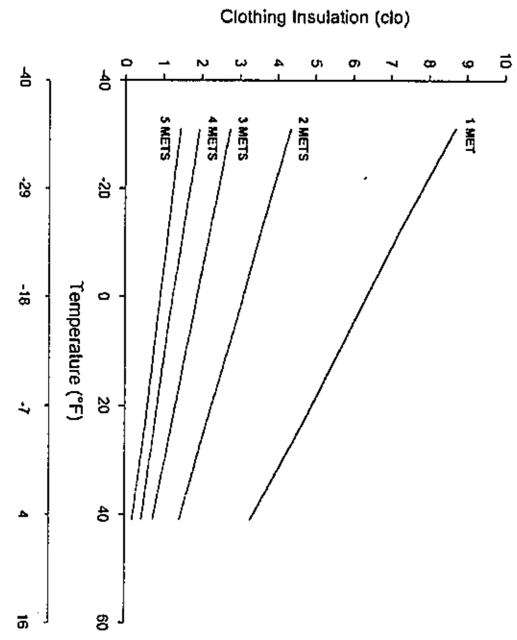

FIGURE 3. Approximate amount of clothing insulation needed at different air temperatures and physical activity levels. Wind speed is assumed to be less than 5 mph (2.2 m/s). 1 MET refers to energy expenditure at rest (58.2 W/m²). One clo of insulation is the clothing necessary to allow a resting person 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).

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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 °F	Core Temperature °C	Physiological Changes
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
Severe Hypothermia	82.4	28.0	Ventricular fibrillation likely; hypoventilation
	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).

Frostbite cannot occur if the air temperature is above 32°F (0°C). Wet skin 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 nongloved 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-

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TABLE 2. Intensity of Exercise for Selected Outdoor Activities

Sedentary 100 Watts (1 MET)	Easy work 250 Watts (2–3 METS)	Moderate work 450 Watts (4–5 METS)	Hard work 600 Watts (6 METS)
• Sleeping • Seated, quiet	• Walking (on level surface) at 3–4 km/h • Snowmobiling	• Walking in loose snow/sand at 2.5 mph, no load • Walking on hard surface at 3.5 mph, < 40-lb load • Handling 50-kg bags • Pick and shovel work	• Walking on hard surface at 3.5 mph, 40-lb load • Walking in loose sand at 2.5 mph with load • Snowshoeing

Source: Department of the Army: Prevention and Management of Cold-Weather Injuries. Technical Bulletin Medical 508 (TB MED 508). Falls Church, VA (2005).

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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).

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TABLE 4. Wind Chill Temperature Index. Frostbite Times are for Exposed Facial Skin

Air Temperature (°C)

Wind Speed (km/h)	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
5	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	[illegible]
10	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	[illegible]	[illegible]
15	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	[illegible]	[illegible]
20	1	-5	-12	-18	-24	-30	-37	-43	-49	[illegible]	[illegible]	[illegible]
25	1	-6	-12	-19	-25	-32	-38	-44	-51	[illegible]	[illegible]	[illegible]
30	0	-6	-13	-20	-26	-33	-39	-46	-52	[illegible]	[illegible]	[illegible]
35	0	-7	-14	-20	-27	-33	-40	-47	-53	[illegible]	[illegible]	[illegible]
40	-1	-7	-14	-21	-27	-34	-41	-48	-54	[illegible]	[illegible]	[illegible]
45	-1	-8	-15	-21	-28	-35	-42	-48	[illegible]	[illegible]	[illegible]	[illegible]
50	-1	-8	-15	-22	-29	-35	-42	-49	[illegible]	[illegible]	[illegible]	[illegible]
55	-2	-8	-15	-22	-29	-36	-43	-50	[illegible]	[illegible]	[illegible]	[illegible]
60	-2	-9	-16	-23	-30	-36	-43	-50	[illegible]	[illegible]	[illegible]	[illegible]
65	-2	-9	-16	-23	-30	-37	-44	-51	[illegible]	[illegible]	[illegible]	[illegible]
70	-2	-9	-16	-23	-30	-37	-44	-51	[illegible]	[illegible]	[illegible]	[illegible]
75	-3	-10	-17	-24	-31	-38	-45	-52	[illegible]	[illegible]	[illegible]	[illegible]
80	-3	-10	-17	-24	-31	-38	-45	-52	[illegible]	[illegible]	[illegible]	[illegible]

FROSTBITE GUIDE

Low risk of frostbite for most people

Increasing risk of frostbite for most people in 10 to 30 minutes of exposure

[illegible]

High risk for most people in 2 to 5 minutes of exposure

[illegible]

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).

1" rule. This states that the cold shock response with increased water aspiration 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.

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 "overdressed" 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-

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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⁻¹	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		
9	20		>120	>120	23	16	12	9	8	8	6			
11	25		>120	42	19	13	10	8	7	6				
13	30		>120	28	16	12	9	7	6					
16	35		>120	23	14	10	8	6						
18	40		>120	20	13	9	7	6						
20	45		>120	18	12	8	7							
22	50		>120	16	11	8	6							

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)

ages and soups should be provided at the work site as they provide calories and increase morale.

For work at or below -12°C (10.4°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°C (60.8°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°C (30.2°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°C (30.2°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°C (19.4°F).

Employees should be excluded from work in cold at -1°C (30.2°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°C (-11.2°F) with wind speeds < 2 m/sec (5 mph), or air temperatures below -18°C (0°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).

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‡HEAT STRESS AND STRAIN

Warning: While the TLV® 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®. 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® has a small margin of safety. Therefore, those working near the TLV® should be warned to drink water regularly and be alert for dizziness, lightheadedness, nausea, and headache.

Goal: The goal of this TLV® 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® 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®, 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.

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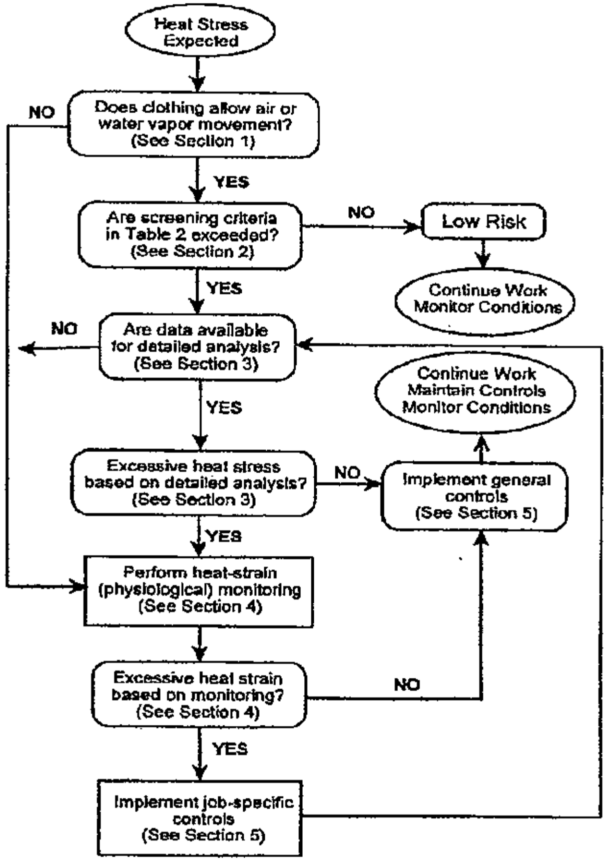

FIGURE 1. Evaluating heat stress and strain.

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.

TABLE 1. Clothing-Adjustment Factors for Some Clothing Ensembles*

Clothing Type	Addition to WBGT [°C]
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:

$$WBGT_{out} = 0.7\ T_{nwb} + 0.2\ T_g + 0.1\ T_{db}$$

Without direct exposure to the sun:

$$WBGT_{in} = 0.7\ T_{nwb} + 0.3\ T_g$$

where:

T_{nwb} = natural wet-bulb temperature (sometimes called NWB)
T_g = globe temperature (sometimes called GT)
T_{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.

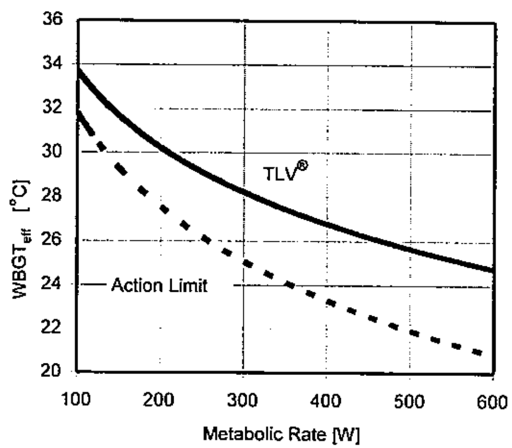

FIGURE 2. TLV® (solid line) and Action Limit (broken line) for heat stress. $WBGT_{eff}$ is the measured WBGT plus the Clothing-Adjustment Factor.

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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 trad-itional 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 avail-able 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.

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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).

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

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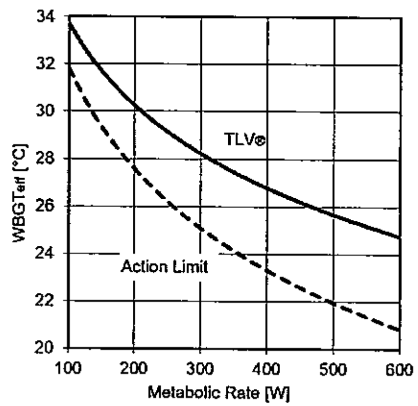
TABLE 2. Screening Criteria for TLV® and Action Limit for Heat Stress Exposure

Allocation of Work in a Cycle of Work and Recovery	TLV® (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 to75%	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®" 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® or Action Limit (Figure 2). Because the values are more protective, they are not intended to prescribe work and recovery periods.

FIGURE 1. TLV and Action Limit for Heat Stress



bolic rate. While energy expenditure is best measured by oxygen consumption, various methods of estimation are available. Assignment of a category is among the least accurate methods but relatively easy to use. Table 1 provides useful categories of metabolic heat generation.

The TLV uses the WBGT (as defined above) index to estimate the environmental contributions to heat stress (International Organization for Standardization (ISO) 1998). WBGT uses air or dry-bulb temperature (T_{db}), natural wet-bulb temperature (T_{nwb}) and globe temperature (T_g). The determination of WBGT depends on whether it is measured in direct sun ($WBGT_{out/sun}$) or in shaded or indoor conditions ($WBGTi_{n/shade}$) as follows:

$$WBGT_{out/sun} = 0.7\ T_{nwb} + 0.2\ T_g + 0.1\ T_{db} \quad (3)$$

$$WBGTi_{n/shade} = 0.7\ T_{nwb} + 0.3\ T_g. \quad (4)$$

$WBGT_{eff}$ is the *effective* WBGT, which is the WBGT adjusted for clothing. Clothing affects the ability to dissipate internal heat to the ambient environment. To account for the effects of clothing, Clothing Adjustment Values (CAVs) are provided in Table 2 for some clothing configurations. The CAVs are expressed as equivalent values of WBGT that are added to the ambient WBGT to yield an effective WBGT ($WBGT_{eff}$).

Time-Weighted Averaging (TWA) of 1 hour can be used to assess changing heat stress exposures. TWAs of greater than an hour may result in unacceptable exposures.

Acclimatization is a physiological adaptation that improves an individual's ability to tolerate heat stress. Acclimatization requires physical activity under heat stress conditions like those anticipated for the work. With a recent history of heat stress exposures of at least 2 continuous hours for 5 of the last 7 days, a worker may be considered acclimatized for the purposes of the TLV. Acclimatization declines when activity under heat stress conditions is discontinued. A noticeable loss occurs after 4 days and may be completely lost in 3 weeks. A person may not be fully acclimatized to a sudden or episodic higher level of heat stress.

A Heat Stress Management Program (HSMP) sets workplace policy and

TABLE 1. Metabolic Rate Categories and the Representative Metabolic Rate with Example Activities

Category	Assigned Metabolic Rate [W]	Examples
Rest	115	Sitting
Light 115 to 235 W	180	Sitting with light manual work with hands or hands and arms and driving. Standing with some light arm work and occasional walking.
Moderate 235 to 360 W	300	Sustained moderate hand and arm work, moderate arm and leg work, moderate arm and truck work, or light pushing and pulling. Normal walking.
Heavy 360 to 470 W	415	Intense arm and trunk work, carrying, shoveling, manual sawing; pushing and pulling heavy loads; and walking at a fast pace.
Very Heavy > 470 W	520	Very intense activity at fast to maximum pace.

Note: 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).
Source: (International Organization for Standardization (ISO) 2017).

includes written plans for training, heat stress hygiene practices, surveillance, physiological monitoring, recordkeeping, and an emergency plan. Triggers for and components of an HSMP are presented below.

General Controls in an HSMP are those actions to protect workers that apply when heat stress is expected to be a hazard. They apply broadly to workplaces and exposure conditions. General Controls include training, heat stress hygiene practices, environmental surveillance, policies on acclimatization, policies on recognizing heat-related symptoms and first aid, and emergency planning.

Job Specific Controls in an HSMP are those actions that may be taken to control heat stress during particular heat stress exposure conditions. Job Specific Controls can be used to reduce the heat stress level to acceptable levels and include the traditional hierarchy of engineering controls, administrative controls, and personal cooling. After implementing Job Specific Controls, it is necessary to continue to assess their effectiveness and to make adjustments as needed.

Evaluation Process: The evaluation process should be started if heat stress is expected, for example, if: (1) there are reports of discomfort or other symptoms

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TABLE 2. Clothing Adjustment Values (CAV) added to WBGT to estimate $WBGT_{eff}$

Clothing Type	CAV [°C]
Short Sleeves and Pants of Woven Material	-1.0
Work Clothes (Long Sleeve Shirt and Pants)	0
Cloth (woven material) Coveralls	0
SMS Polypropylene Coveralls	0.5
Polyolefin Coveralls	1
Double Layer Woven Clothing	3
Limited-Use Vapor-Barrier Coveralls with Hood	11
Adding a Hood (Full Head and Neck Covering; not Face)	+1.0

Notes:
1. These values must not be used for completely encapsulating suits, often called Level A as defined by OSHA.
2. CAVs cannot be added for multiple layers.
3. Coveralls assume that only undergarments are worn underneath, not a second layer of clothing.
4. There is no evidence to suggest that respirators or face coverings add to the heat stress burden.

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associated with heat stress; (2) professional judgment indicates heat stress conditions; or (3) the Heat Index or air temperature is 27 °C (80 °F). When heat stress is suspected, establishing an HSMP that includes the General Controls (see Table 5) is recommended.

Four methods to evaluate the level of heat stress, with increasing levels of complexity and increasing levels of professional expertise, are presented below. The TLV and AL is represented by Method 2.

Method 1: Screening Criteria Based on $WBGT_{eff}$. This screening criteria are an approximation of the TLV and AL as presented in Figure 1. Screening criteria for heat stress exposure considers the contributions of environment, metabolic work demands, work-rest pattern, clothing, and acclimatization state. Table 3 provides the screening criteria.

If the estimated TWA-$WBGT_{eff}$ is less than the criteria for unacclimatized workers found in Table 3, then there is little risk of excessive exposures to heat stress.

If the estimated TWA-$WBGT_{eff}$ are above the criteria for unacclimatized workers found in Table 3, but below the limits for acclimatized workers, then an HSMP that includes the General Controls in Table 5 is recommended.

If there are observed signs or reports of symptoms of heat-related disorders, such as fatigue, nausea, dizziness, and lightheadedness, then establishing an HSMP with General Controls is recommended.

Method 2: TLV Analysis. Method 1 (Table 3) is a screening step that requires less effort than a full evaluation. The actual TLV and AL are based on the TWAs of WBGTeff and task metabolic rate (M). A task analysis is used to compute

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TABLE 3. Screening Criteria using $WBGT_{eff}$ (°C) for Acclimatized and Unacclimatized Workers

Allocation of Work in a Cycle of Work and Recovery	Metabolic Rate for Acclimatized Workers				Metabolic Rate for Unacclimatized Workers			
	Light	Moderate	Heavy	Very Heavy	Light	Moderate	Heavy	Very Heavy
75 to 100%	31.0	28.0	–	–	28.0	25.0	–	–
50 to75%	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:
1. See Table 1 for metabolic work demand categories.
2. 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 (midrange) value of Table 1. 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%).
3. WBGT values are expressed to the nearest 0.5 °C.
4. If work and rest environments are different or work and rest are distributed over more than 1 location, 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. Note that the metabolic rate for rest is already factored into the screening limit.
5. Values in the table assume 8-hour workdays in a 5-day workweek with conventional breaks.
6. Because the physiological strain associated with Heavy and Very Heavy work among less fit workers regardless of WBGT may be unsustainable, screening criteria values are not provided for near continuous work and for up to 25% rest in an hour for Very Heavy. The screening criteria are not recommended, and, instead, a TWA analysis and/or physiological monitoring should be used.
7. Table 3 is intended as an initial screening tool to evaluate whether a heat stress situation may exist and thus the table is more protective than the TLV or AL. Because the values are more protective, they are not intended to prescribe work and recovery periods.

TABLE 4. Guidelines for Physiologic Monitoring of 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. When monitoring for safety, exceeding these guidelines indicates a need to better control exposures. When monitoring individuals, excessive heat strain indicates a time to cease an exposure and allow for recovery. One or more of the following measures may indicate excessive heat strain, and an individual's exposure to heat stress should be discontinued when any of the following occur:

- Sustained (several minutes) heat rate is in excess of 180 bpm (beats per minute) minus the individual's age in years (180 – age), for healthy individuals with normal cardiac response.
- Measured or estimated core temperature increases by more than 1 °C from pre-job temperature if the pre-job temperature is less than 37.5 °C.
- Recovery heart rate at one minute after a peak work effort is greater than 120 bpm.
- Exposure should stop with signs or symptoms of heat exhaustion or heat stroke or with a request to stop regardless of what physiological monitoring may indicate.

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TWAs for $WBGT_{eff}$ and M. The TWA window should capture at least 1 cycle of work and recovery period within a 1-hour period. The values of TWA-$WBGT_{eff}$ and TWA-M are compared to the TLV and AL lines in Figure 1.

If the exposure is below the AL, the heat stress exposure is acceptable. While no further action is necessary, consider establishing an HSMP that includes General Controls (see Table 5).

If the TWA analysis indicates an exposure between the AL and TLV, then an HSMP that includes General Controls (see Table 5) is recommended.
If the exposure is above the TLV, then an HSMP with General and Job Specific Controls (see Table 5) is recommended to bring the exposure below the TLV or acceptable limits.

Method 3: Advanced Heat Stress Evaluation. Advanced methods for evaluating heat stress consider a time limit or greater detail in understanding the major contributors to the heat stress exposure. Two methods with extensive use and verification are the Predicted Heat Strain (PHS) (International Organization for Standardization (ISO) 2021b) and the US Army Heat Stress Decision Aid (HSDA) (Potter et al. 2017).

Regardless of the outcome of the analysis, an HSMP is recommended. These alternative methods may also provide insight into Job Specific Controls (see Table 5) that would reduce the risk of heat-related disorders.

Method 4: Heat Strain and Physiologic Monitoring. The likelihood 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. There are various approaches to monitoring heat strain. These include core temperature (e.g., using ingestible temperature pills or time series heart rate-derived core temperature), tympanic temperature, skin temperature, and heat strain indices (e.g., heart rate and core temperature).

Table 4 provides guidance for acceptable levels of heat strain when using physiologic monitoring. However, the values should not be considered as TLVs. If excessive heat strain occurs, then appropriate Job Specific Controls (see Table 5) should be implemented to a sufficient extent to control the heat strain, to bring the exposure level below the TLV, or to a level that is acceptable by an advanced method. Professional judgement is necessary to select the appropriate frequency and methodology of physiological monitoring considering the magnitude of the heat stress expected.

Heat Stress Management Program. The elements of a written heat stress management program include at least General Controls and include Job Specific Controls when there is a possibility of exposures greater than the TLV or AL or indicated by an alternative method of evaluation. Table 5 lists some key elements of a HSMP.

The principal objective of a HSMP is the prevention of excessive heat strain among workers that may result in heat-related disorders. A HSMP sets policy and includes written plans for training, heat stress hygiene practices, surveillance, physiological monitoring, recordkeeping, and an emergency plan. The trainings in the HSMP should discuss acclimatization and warn: (1) workers to be alert to

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unexpected fatigue, dizziness, lightheadedness, nausea, and headache; and (2) coworkers and supervisors to be alert to other workers for signs of heat-related disorders such as confusion, agitation, irritability, delirium, seizures, loss of consciousness, and physiological monitoring measures that mark excessive heat strain. The HSMP should remind workers with personal risk factors that may lower tolerance to heat stress that they may be at greater risk for heat-related disorders. Lower tolerance is associated with: (1) a prior history of heat stroke or episodes of heat exhaustion; (2) health conditions or medications that affect the cardiovascular system, water and electrolyte balance, metabolism, or thermoregulation; (3) acclimatization state; and (4) lower aerobic capacity, obesity, pregnancy, or age.

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TABLE 5. Elements of a Heat Stress Management Program

General controls are essential elements of an HSMP. Job-specific controls are added as appropriate.

General Controls

- Training: Provide verbal and written instructions for pre-job and annual training programs with information about heat stress and strain, heat disorders, mitigation plan, and emergency response plan in a language and format that is understood by workers and supervisors.
- Heat Stress Hygiene Practices: Fluid replacement, self-monitoring of symptoms, maintain good health status, appropriate breaks with shade, and modify expectations based on acclimatization.
- Policies: Acclimatization plan, early recognition of heat-related signs and symptoms in other workers and actions to take, and on self-determination.
- Environmental surveillance.
- Medical clearance and counseling by a healthcare provider.
- Emergency Response Plan: The worker who appears to be confused, disoriented, irritable, or has malaise, chills or seizures, should be managed as a medical emergency and needs aggressive cooling, and emergency transport and continuous observation.

Job-Specific Controls

- Engineering controls that reduce the metabolic rate, provide general air movement, reduce process heat and water vapor release, provide shade, shield radiant heat sources, and adjust clothing requirements, among others.
- Administrative controls that set acceptable exposure times, allow sufficient recovery, and limit physiological strain.
- Personal cooling (air, liquid, ice) that is effective for the specific work practices and conditions.
- Physiological monitoring.

2022 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. 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® (acgih.org/science/tlv-bei-guidelines/policies-procedures-presentations/tlv-bei-development/).

The Under Study list is published each year by February 1 on the ACGIH® website (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, 2022. *After this date, please refer to the ACGIH® website* (acgih.org/science/tlv-bei-guidelines/documentation-publications-and-data/under-study) *for the up-to-date list.*

Physical Agents

1. Acoustic
    - Audible sound
2. Optical Radiation
    - Light and Near-infrared radiation
3. Ergonomics
    - Over shoulder work
    - Push/Pull
4. Thermal Stress
    - Cold stress

Other Issues Under Study

1. Appendix B: Personal Physiologic Monitoring in the Workplace
2. Head supported mass and neck loading
3. Hypobaric pressure

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).

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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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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. (Pancardo 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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* APPENDIX C: STATEMENT ON FATIGUE AND ITS MANAGEMENT IN THE WORKPLACE

This Appendix addresses the underlying causes of mental fatigue in the workplace and provides some generally applicable strategies that can reduce accidents and injuries attributable to excessive fatigue. Excessive mental fatigue can have devastating effects on workplace safety and worker health and has contributed to many disasters such as Three Mile Island and the Exxon Valdez oil spill (Folkard and Lombardi, 2006). Mental fatigue and workplace sleepiness are primarily a function of time awake, time of day, and work/rest patterns. Occupational, social, and environmental factors often prevent individuals from obtaining the recommended 7–9 hours of daily sleep (Caldwell et al., 2019) which leads to sleep loss that is often compounded by non-standard or rotating shifts that disrupt the body clock or misalign it with occupational and social demands (Caldwell et al., 2019). Many occupations such as nursing, medicine, transportation, and public safety often require work shifts that extend well beyond 8 hours (Caldwell et al., 2019; Rogers et al., 2004). Also, in the US, millions of individuals take a second job sometimes in what is now called the "gig economy."

When sleep duration drops below 7 h/day, there is a graded degradation in cognitive function. After 5 days of sleep restricted to 5 h/day, measures of vigilance declined an average 12% (compared to those sleeping 7 h/day); and when sleep was restricted to 3 h/day, the degradation in performance averaged 26% (Belenky et al., 2003). In addition, many workers suffer from sleep disorders that impair workplace functioning (Caldwell et al., 2019).

Workplace mental fatigue can also result from long duration shifts with intense mental demands without sufficient interspersed rest periods, as well as long boring tasks such as monitoring automatic processes or operating vehicles. Work periods >8 h increase risk of accidents and at 12 h the risk doubles (Caldwell et al., 2019; Wagstaff and Sigstad Lie, 2011). Physical (musculoskeletal) fatigue and the injuries that can result also occur in the workplace but will not be addressed here (Waters and Dick, 2015).

In the US, unlike the European Union, national standards for work hours do not exist although industries such as aviation and trucking are federally regulated (Caldwell et al., 2019).

Fatigue Impact

Regardless of the sources of fatigue, failure to implement mitigation strategies can degrade performance and health.

Performance effects. Reduced sleep exerts cumulative adverse effects on cognitive performance that include reduced vigilance, increased lapses of attention, degradation in short term memory, logical reasoning and impulse control, and episodes of involuntary sleep (Caldwell et al., 2019). Remaining awake for 20–24 hours produces performance decrements equivalent to blood alcohol levels of 0.08–0.10% (Caldwell et al., 2019). Shift work which disrupts circadian cycles often compounds the impact of insufficient sleep. In certain circumstances, the combination of long work hours and shift work can increase accident rates by 50–100% (Wagstaff and Sigstad Lie, 2011). It is not possible to fully adapt to non-standard sleep/wake schedules, and recovery from chronic

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sleep loss is slow and often incomplete (Belenky et al., 2003).

Health effects. Chronic insufficient, disrupted, and/or disordered sleep has been associated with chronic diseases such as diabetes and hypertension and with psychological conditions, including depression and anxiety. Substance abuse, suicide, obesity, and overall mortality also have been associated with insufficient and/or disordered sleep (Caldwell et al., 2019; IOM, 2006). Furthermore, sleep disturbances increase the risk of infectious and inflammatory diseases including colds, influenza, and herpes zoster (shingles), and some epidemiological research suggests shift work (which often results in sleep restriction as well as circadian disruption) may increase the risk of certain types of cancers (Caldwell et al., 2019).

Fatigue Countermeasures

Adequate sleep is essential for proper fatigue management even though obtaining it and avoiding circadian disruptions are difficult in modern society. However, fatigue can be mitigated in part with proven countermeasures (Caldwell and Caldwell, 2017). Any countermeasures implemented should be customized to the specific workplace and type of work in question. Various factors not discussed in this document such as environmental stressors (e.g., heat, cold), physical demands, and other factors should be taken into account.

Education. Personnel must be educated about the dangers of fatigue, the importance of adequate sleep, and facts about the slow recovery from sleep loss. Workers cannot manage problems if they are not fully aware of them.

Good sleep habits. Various strategies can optimize the restorative potential of available off-duty sleep opportunities. Employees should receive training on good sleep habits and other behavioral interventions.

Naps. Naps are valuable when full consolidated sleep periods are not feasible. Proper timing, sufficient length, and optimal placement within the circadian pattern are beneficial for workplace performance and using the correct practices can avoid post-nap sleepiness (sleep inertia).

Rest breaks. Short on-the-job rest breaks also positively impact alertness for short periods of time. They are most beneficial when employees can stand and engage in physical activity and/or social interactions. However, depending on the circumstances, napping, as discussed below, can also be an effective strategy.

Proper lighting. Light management can positively influence alertness and circadian alignment, but intensity, wavelength, exposure time, and correct placement with regard to circadian phase are essential. Properly timed bright light, particularly when blue-enriched, can increase arousal and facilitate better adaptation to a new schedule or to time zone changes. Blocking unwanted light exposure with special glasses can improve adaptation to night work and avoid increased alertness immediately prior to sleep (ACGIH, 2018). Lighting customized for individual tasks and for workers with impaired vision can also be helpful (National Telecommunications Safety Panel, 2009).

Caffeine. Caffeine is a non-prescription stimulant that is safe in moderate doses (Wikoff et al., 2017). It enhances alertness in rested and sleep-deprived individuals. Caffeine in moderate doses can be obtained in single servings of coffee, tea, soft drinks, energy drinks, or caffeinated gum. Eighty percent of the US population regularly consumes caffeine, often for its alertness-enhancing properties (McLellan et al., 2016).

Sleep/alerting drugs. When scheduling, environmental, or work factors pre-

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vent proper rest, medications may be an option. Hypnotics can promote off-duty sleep, if opportunities for sleep are available, and stimulants can increase wakefulness if sleep-deprivation is unavoidable. The choice of hypnotics should take into account the speed and duration of its effects. Both prescription and over-the-counter options are available. Correct hypnotic use can improve sleep without creating post-sleep hangover effects. Prescription hypnotics or stimulants are not typically provided to workers except for the treatment of a diagnosed sleep disorder such as primary insomnia, sleep apnea, narcolepsy or idiopathic hypersomnia. However, the stimulants modafinil and armodafinil are indicated for treatment of excessive sleepiness associated with shift work sleepiness disorder, narcolepsy, and obstructive sleep apnea; and both medications can enhance the alertness of shift workers.

Behavioral sleep-optimization techniques. When sleeping difficulties arise, sleep-optimization strategies such as stimulus control, relaxation, and cognitive therapies should be considered. These approaches, as well as meditation/mindfulness training, may be effective; however, positive results may take time to achieve.

Identification/treatment of sleep disorders. This important countermeasure is often overlooked, but any condition that negatively affects the restorative value of sleep can adversely impact workplace performance. Diagnosis and treatment of sleep disorders such as insomnia, sleep apnea, restless legs syndrome, and periodic limb movement disorder will optimize on-the-job alertness and worker safety.

Fatigue monitoring technologies. Real-time monitoring of operator fatigue is usually not feasible but monitoring off-duty sleep can be beneficial. Continuous sleep/wake measurement via wrist actigraphy contribute to fatigue management since it assesses whether workers are obtaining 7 to 8 hours of daily sleep. However, worker privacy issues need to be carefully considered before implementing any type of monitoring program.

Bio-mathematical models. Combining actigraph-based sleep monitoring with mathematical fatigue-prediction models can track and reduce employee fatigue. Such models use validated algorithms that estimate individual fatigue as a function of sleep/wake patterns. Use of the Sleep, Activity, Fatigue, and Task-Effectiveness (SAFTE) model or other validated models (e.g., the Unified Model) can identify overly-fatiguing work schedules (Caldwell et al., 2019).

Science-based shift-schedule planning. Designing work/rest schedules based on proven scientific principles is essential for avoiding fatigue-related adverse effects on performance, health, and morale in the workplace. Advice on factors such as the optimal number of consecutive night shifts, shift rotation periods, time between shifts, and shift lengths is available from a variety of sources (Caldwell et al., 2019).

Fatigue Risk Management Systems (FRMS). An FRMS can reduce fatigue-associated risks by formally implementing procedures to ensure employees are getting sufficient sleep and are monitored for fatigue-related problems and organizations have controls to minimize fatigue-related errors (Caldwell et al., 2019; Lerman et al., 2012). It is essential that any plan be customized for the specific workplace and occupational tasks in question. It also is necessary to consider cultural factors when formulating guidance for specific workplaces. The schedules of some societies and occupations may differ from those of most industrial societies. For example, practices that are common in U.S. manufac-

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turing facilities may not be feasible for agrarian settings or among populations in which long afternoon rest periods that offer sleep opportunities are common.

Conclusions and Recommendations

Given the present state of knowledge, ACGIH® considers that fatigue from excessive sleepiness in the workplace is a serious health, performance, and safety hazard. However, evidence-based strategies can promote better sleep, optimize sleep/wake and work scheduling, and mitigate the impact of fatigue in real-world settings. Organizations are advised:

1. All personnel should be educated about the nature of workplace fatigue and that: a) fatigue is a serious problem; b) it is due to physiological changes in the brain and more than a state of mind; and c) it can be mitigated with proven strategies.
2. Mitigation strategies should include: a) workplace-based modifications (i.e., optimal lighting, workplace napping facilities, appropriate rest-break planning, and science-based scheduling practices); b) personnel-based practices (i.e., behavioral strategies for better sleep, proper use of alertness/sleep aids, and effective light-exposure management); and c) screening for disorders such as sleep apnea that degrade sleep.
3. Interventions should be implemented using a formal, carefully planned FRMS that is evidence-based, data driven, cooperatively designed, and integrated into the organization. It should be continuously improved, fully justified, and accepted by the workforce and management, including senior leaders as a safety and health priority.

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2022 Biological Agents

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BIOLOGICAL AGENTS

Biological agents include bacteria, fungi, viruses, arachnids, algae and parasites. The term "biological agent" refers to a substance of biological origin that is capable of producing an adverse health effect (e.g., an infection or a hypersensitivity, irritant, inflammatory, or other adverse response). Bioaerosols are aerosols composed of or derived from living organisms and can include both viable and nonviable organisms and viruses, fragments, toxins, and particulate waste. Biological agents are ubiquitous in nature but may be amplified in man-made environments and materials. Many of these biological agents also contain or release, due to metabolic activity or decomposition of nutrients and substrates, endotoxins, mycotoxins, antigens, allergens, and/or microbial volatile organic compounds (mVOCs). Humans are frequently exposed, day after day, to a wide variety of these contaminants at varying concentrations (usually very low levels that do not elicit a response or pose a health risk) that do not necessarily result in harm.

TLVs® exist for certain substances of biological origin, including cellulose; subtilisins (proteolytic enzymes); and some gases and mVOCs produced by living organisms (e.g., carbon dioxide, methanol, and acetaldehyde). However, a majority of the remainder of the biological agents of concern are microbiological in nature. For the reasons identified below, there are no TLVs® against which to compare environmental air concentrations of microbial agents.

Indoor biological contamination can be defined as the presence of: a) bioaerosols likely to cause or predispose humans to health effects; b) inappropriate indoor airborne concentrations of bioaerosols, as determined through the consideration of space type or occupancy purposes; or c) indoor microbial growth, amplification, or remnants of biological growth, or sources of infectious agents or pathogens, either deposited, accumulated, or amplified, that may become aerosolized and to which humans may be exposed.

ACGIH® has developed and separately published guidance on the assessment, control, remediation, and prevention of bioaerosols.(1) The ACGIH Bioaerosols Committee concurs that, at this time, the measurement and analysis of airborne concentrations of bioaerosols cannot be relied upon to determine whether conditions and exposures pose an adverse health risk. The ACGIH®-recommended approach to assessing a bioaerosol exposures relies on visually inspecting buildings; assessing occupant adverse health symptoms; evaluating building performance, including ventilation; identifying potential environmental sources of amplification or accumulation; and dissemination, and applying professional judgment to the information to form an informed opinion concerning the potential for exposure to bioaerosols. 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 (i.e., microbial air sampling) detects a single, or predominant, biological contaminant. More commonly, microbial air sampling 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

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bioaerosol sources and mechanisms by which occupants 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 misleading. Interpretation of sample results is highly subjective and often NOT based upon scientific or evidence-based information. Due to the challenges related to repeatable airborne contaminant measurement and analytical methods, ill-defined dose–response relationships, individual susceptibility, and inherent variability in background concentrations, there are no TLVs® for airborne concentrations of: a) total culturable or countable bioaerosols (e.g., total bacteria, fungi, or viruses); b) specific culturable or countable bioaerosols (e.g., *Aspergillus fumigatus*); c) infectious agents (e.g., *Legionella pneumophila*, SARS-COV-2, or *Mycobacterium tuberculosis*); or d) assayable biological contaminants (e.g., endotoxins, mycotoxins, antigens, or many of the mVOCs).

BA

A. **Total culturable or countable bioaerosols.** Culturable bioaerosols are those bacteria, viruses, and fungi that can be sampled by recognized and accepted methods, and subsequently grown in culture media in the laboratory. Such results are reported as the number of colony-forming units (CFU) per volume sampled (e.g., cubic meter of air). Countable bioaerosols are those fungal spores, bacterial cells, and other material that can be identified and counted by microscope. A general TLV® 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 environmental and non-agricultural 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 agent involved and the individual's susceptibility to it. Therefore, an appropriate exposure limit for one bioaerosol may be entirely inappropriate for another, and neither may be generalizable to a broad population.
   3. 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, even when the same basic sampling methods are used.
   4. The inherent temporal and spatial variability of fungal spores, bacteria, and other suspended bioaerosol concentrations in outdoor and indoor environments makes collecting a few to several "grab samples" to estimate a time-weighted average (TWA) exposure an unreliable approach. The number of samples required to overcome this limitation is often infeasible for assessments outside of research settings.
   5. 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® for individual culturable or countable bioaerosols have not been established to prevent hypersensitivity, irritant, infectious toxic, or other adverse health responses. At present, information relating culturable or countable bioaerosol concentrations to adverse health

effects consists largely of case reports and qualitative exposure assessments. The data available are 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, some investigators use the airborne 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, at best, crude estimates of human exposure. Personal sampling for actual effector agents would be needed to establish data necessary to derive a TLV.
   2. Bioaerosol components and concentrations vary widely within and among different occupational, residential 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 one or more orders of magnitude higher (or lower) than long-term average concentrations and are unlikely to represent occupant exposures accurately. Some organisms and sources release aerosols as "concentration bursts," which may only rarely be detected by limited grab sampling. Nevertheless, such episodic and transient bioaerosol releases may produce significant health effects.
   3. In studies (e.g., single workplaces or homes), 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 adverse health complaints.

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C. **Infectious agents.** Suitable human exposure–response relationships for infectious bioaerosols have not been developed for the majority of microorganisms and viruses. At present, air-sampling protocols for infectious agents are extremely limited. Air sampling is not practical to determine TWA or transient exposures in most environments. They can be useful for academic research endeavors or as a part of an overall informed assessment of potential exposure to infectious bioaerosols. In most routine exposure settings, public health measures, such as immunization, active case finding, source control, and medical treatment, remain the primary defenses against infectious bioaerosols. Facilities with an increased risk of transmitting airborne infectious diseases (e.g., microbiology laboratories, animal-handling facilities, and health-care settings) should employ engineering controls (such as ventilation and filtration) to minimize airborne concentrations of infectious agents and subsequent exposures. Further, such facilities should implement administrative controls and provide personal protective equipment (PPE), such as appropriate respiratory protection, to reduce worker exposures

BIOLOGICAL AGENTS UNDER STUDY

The Bioaerosols Committee notes that there are no biological agents under study by ACGIH®. However, ACGIH® solicits information, especially data, which may assist it in the establishment of TLVs® for biological agents. 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.

Agents

None

to infectious bioaerosols.

D. **Other biologically-derived contaminants.** Endotoxins, mycotoxins, antigens, allergens, and mVOCs are detected using chemical, immunological, or biological assays. Evidence does not yet support TLVs® or BEIs® 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 biologically-derived contaminants have been observed in experimental studies and occasionally in epidemiologic surveys. Therefore, exposure limits for certain assayable, biologically-derived airborne contaminants may be possible in the future. In addition, innovative molecular techniques have increasingly become available for specific bioaerosols or biologically-derived contaminants that previously were 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 ACGIH® evaluate the potential for proposing exposure guidelines for selected biological agents. Such information should be sent in electronic format to the ACGIH® Science Group at science@acgih.org.

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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	Trichlorfon
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	β-Propiolactone
57-74-9	Chlordane
58-89-9	Lindane (γ-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
65-85-0	Benzoic acid [*see* Benzoic acid and Alkali benzoates]
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

CAS NUMBER INDEX

71-55-6	Methyl chloroform (1,1,1-Trichloroethane)
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

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

CAS

CAS NUMBER INDEX

108-46-3 .... Resorcinol
108-67-8 .... 1,3,5-Trimethyl benzene [*see* Trimethyl benzene, isomers]
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

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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
513-35-9 .... 2-Methyl-2-butene
526-73-8 .... 1,2,3-Trimethyl benzene [*see* Trimethyl benzene, isomers]
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)
532-32-1 .... Sodium benzoate [*see* Benzoic acid and Alkali benzoates]
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]

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540-88-5 .... tert-Butyl acetate [*see* Appendix G]
541-85-5 .... Ethyl amyl ketone (5-Methyl-3-heptanone)
542-56-3 .... Isobutyl nitrite
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]
582-25-2 .... Potassium benzoate [*see* Benzoic acid and Alkali benzoates]
583-60-8 .... 2-Methylcyclohexanone [*see* Methylcyclohexanone, all isomers]
584-84-9 .... Toluene-2,4-diisocyanate (TDI)
589-34-4 .... 3-Methylhexane [*see* Hexane, isomers]
589-92-4 .... 4-Methylcyclohexanone [*see* Methylcyclohexanone, all isomers]
590-18-1 .... cis-2-Butene
590-35-2 .... 2,2-Dimethylpentane [*see* Heptane, isomers]
591-24-2 .... 3-Methylcyclohexanone [*see* Methylcyclohexanone, all 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

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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
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 phosphoramide
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
961-11-5	Tetrachlorvinphos [mixed isomers]
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_2O_3)
1309-48-4	Magnesium oxide
1309-64-4	Antimony trioxide
1310-58-3	Potassium hydroxide
1310-73-2	Sodium hydroxide
1314-13-2	Zinc oxide

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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)
1330-43-4	Sodium tetraborate, anhydrous [*see* Borate compounds, inorganic]
1331-22-2	Methylcyclohexanone, mixed isomers [*see* Methylcyclohexanone, all isomers]
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 α,α'-diamine
1563-66-2	Carbofuran
1569-02-4	Propylene glycol ethyl ether
1610-18-0	Prometon
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-triazinetrione
2528-36-1	Dibutyl phenyl phosphate
2551-62-4	Sulfur hexafluoride
2687-91-4	N-Ethyl-2-pyrrolidone

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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
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]
7287-19-6 .... Prometryn
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
7440-28-0 .... Thallium
7440-31-5 .... Tin
7440-33-7 .... Tungsten
7440-36-0 .... Antimony
7440-37-1 .... Argon
7440-38-2 .... Arsenic

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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
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

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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....Dipropylene glycol methyl ether (DPGME)
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)
55566-30-8....Tetrakis (hydroxymethyl) phosphonium sulfate
55956-21-3....Dipropylene glycol methyl ether (DPGME)
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
66215-27-8....Cyromazine
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)
68694-11-1....Triflumizole
74222-97-2....Sulfometuron methyl
86290-81-5....Gasoline
95465-99-9....Cadusafos
111988-49-9....Thiacloprid
122548-33-8....Imazosulfuron
128639-02-1....Carfentrazone-ethyl

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13588-28-8....Dipropylene glycol methyl ether (DPGME)
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
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
20324-32-7....Dipropylene glycol methyl ether (DPGME)
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
22248-79-9....Tetrachlorvinphos [(Z) - isomer]
22350-76-1....Tetrachlorvinphos [(E) - isomer]
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....Trimethyl benzene, mixed isomers [*see* Trimethyl benzene, isomers]
25639-42-3....Methylcyclohexanol

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Endnotes and Abbreviations

- * 2022 Adoption.
- ‡ See Notice of Intended Changes (NIC).
- ( ) Adopted values or notations enclosed are those for which changes are proposed in the NIC.
- † 2022 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® 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® *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^3 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® section).
- BEI_C: *see* BEI® for Cholinesterase Inhibiting Pesticides
- BEI_M: *see* BEI® for Methemoglobin Inducers
- BEI_P: *see* BEI® 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.
OTO = Ototoxicant; *see* definition in the "Definitions and Notations" section.
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.
SL = Surface Limit; *see* definition in the "Introduction to the Chemical Substances".
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^3 = Milligrams of substance per cubic meter of air.

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ภาคผนวก ง11

มาตรฐานตามกฎกระทรวง เรื่อง กำหนดมาตรฐานในการบริหารจัดการ และดำเนินการด้านความปลอดภัยอาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง พ.ศ. 2559 ประกาศในราชกิจจานุเบกษา เล่ม 133 ตอนที่ 91 ก วันที่ 17 ตุลาคม 2559

กฎกระทรวง

กำหนดมาตรฐานในการบริหาร จัดการ และดำเนินการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง พ.ศ. ๒๕๕๙

อาศัยอำนาจตามความในมาตรา ๕ วรรคหนึ่ง และมาตรา ๘ วรรคหนึ่ง แห่งพระราชบัญญัติความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงาน พ.ศ. ๒๕๕๔ รัฐมนตรีว่าการกระทรวงแรงงานออกกฎกระทรวงไว้ ดังต่อไปนี้

ข้อ ๑ ในกฎกระทรวงนี้

"อุณหภูมิเวตบัลบ์โกลบ" (Wet Bulb Globe Temperature - WBGT) หมายความว่า

(๑) อุณหภูมิที่วัดเป็นองศาเซลเซียสซึ่งวัดนอกอาคารที่ไม่มีแสงแดดหรือในอาคารมีระดับความร้อนเท่ากับ ๐.๗ เท่าของอุณหภูมิที่อ่านค่าจากเทอร์โมมิเตอร์กระเปาะเปียกตามธรรมชาติ (natural wet bulb thermometer) บวก ๐.๓ เท่าของอุณหภูมิที่อ่านค่าจากโกลบเทอร์โมมิเตอร์ (globe thermometer) หรือ

(๒) อุณหภูมิที่วัดเป็นองศาเซลเซียสซึ่งวัดนอกอาคารที่มีแสงแดด มีระดับความร้อนเท่ากับ ๐.๗ เท่าของอุณหภูมิที่อ่านค่าจากเทอร์โมมิเตอร์กระเปาะเปียกตามธรรมชาติ บวก ๐.๒ เท่าของอุณหภูมิที่อ่านค่าจากโกลบเทอร์โมมิเตอร์ และบวก ๐.๑ เท่าของอุณหภูมิที่อ่านค่าจากเทอร์โมมิเตอร์กระเปาะแห้ง (dry bulb thermometer)

"ระดับความร้อน" หมายความว่า อุณหภูมิเวตบัลบ์โกลบในบริเวณที่ลูกจ้างทำงานตรวจวัดโดยค่าเฉลี่ยในช่วงเวลาสองชั่วโมงที่มีอุณหภูมิเวตบัลบ์โกลบสูงสุดของการทำงานปกติ

"สภาวะการทำงาน" หมายความว่า สภาวะแวดล้อมซึ่งปรากฏอยู่ในบริเวณที่ทำงานของลูกจ้างซึ่งรวมถึงสภาพต่าง ๆ ในบริเวณที่ทำงาน เครื่องจักร อาคาร สถานที่ การระบายอากาศ ความร้อน แสงสว่าง เสียง ตลอดจนสภาพและลักษณะการทำงานของลูกจ้างด้วย

"งานเบา" หมายความว่า ลักษณะงานที่ใช้แรงน้อยหรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายไม่เกิน ๒๐๐ กิโลแคลอรีต่อชั่วโมง เช่น งานเขียนหนังสือ งานพิมพ์ดีด งานบันทึกข้อมูล งานเย็บจักร งานนั่งตรวจสอบผลิตภัณฑ์ งานประกอบชิ้นงานขนาดเล็ก งานบังคับเครื่องจักรด้วยเท้า การยืนคุมงาน

"งานปานกลาง" หมายความว่า ลักษณะงานที่ใช้แรงปานกลางหรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายเกิน ๒๐๐ กิโลแคลอรีต่อชั่วโมง ถึง ๓๕๐ กิโลแคลอรีต่อชั่วโมง เช่น งานยก ลาก ดัน หรือเคลื่อนย้ายสิ่งของด้วยแรงปานกลาง งานตอกตะปู งานตะไบ งานขับรถบรรทุก งานขับรถแทรกเตอร์

"งานหนัก" หมายความว่า ลักษณะงานที่ใช้แรงมากหรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายเกิน ๓๕๐ กิโลแคลอรีต่อชั่วโมง เช่น งานที่ใช้พลั่วตักหรือเครื่องมือลักษณะคล้ายกัน งานขุด งานเลื่อยไม้ งานเจาะไม้เนื้อแข็ง งานทุบโดยใช้ค้อนขนาดใหญ่ งานยก หรือเคลื่อนย้ายของหนักขึ้นที่สูงหรือที่ลาดชัน

หมวด ๑
ความร้อน

ข้อ ๒ ให้นายจ้างควบคุมและรักษาระดับความร้อนภายในสถานประกอบกิจการที่มีลูกจ้างทำงานอยู่มิให้เกินมาตรฐาน ดังต่อไปนี้

(๑) งานที่ลูกจ้างทำในลักษณะงานเบาต้องมีมาตรฐานระดับความร้อนไม่เกินค่าเฉลี่ยอุณหภูมิเวตบัลบ์โกลบ ๓๔ องศาเซลเซียส

(๒) งานที่ลูกจ้างทำในลักษณะงานปานกลางต้องมีมาตรฐานระดับความร้อนไม่เกินค่าเฉลี่ยอุณหภูมิเวตบัลบ์โกลบ ๓๒ องศาเซลเซียส

(๓) งานที่ลูกจ้างทำในลักษณะงานหนักต้องมีมาตรฐานระดับความร้อนไม่เกินค่าเฉลี่ยอุณหภูมิเวตบัลบ์โกลบ ๓๐ องศาเซลเซียส

ข้อ ๓ ในกรณีที่ภายในสถานประกอบกิจการมีแหล่งความร้อนที่อาจเป็นอันตราย ให้นายจ้างติดป้ายหรือประกาศเตือนอันตรายในบริเวณดังกล่าว โดยให้ลูกจ้างสามารถมองเห็นได้ชัดเจน

ในกรณีที่บริเวณการทำงานตามวรรคหนึ่งมีระดับความร้อนเกินมาตรฐานที่กำหนดในข้อ ๒ ให้นายจ้างดำเนินการปรับปรุงหรือแก้ไขสภาวะการทำงานทางด้านวิศวกรรม เพื่อควบคุมระดับความร้อนให้เป็นไปตามมาตรฐาน และจัดให้มีการปิดประกาศและเอกสารหรือหลักฐานในการดำเนินการปรับปรุงหรือแก้ไขดังกล่าวไว้ เพื่อให้พนักงานตรวจความปลอดภัยสามารถตรวจสอบได้

ในกรณีที่ไม่สามารถดำเนินการให้เป็นไปตามวรรคสองได้ ให้นายจ้างจัดให้มีมาตรการควบคุมหรือลดภาระงาน และต้องจัดให้ลูกจ้างสวมใส่อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลตามที่กำหนดไว้ในหมวด ๔ ตลอดเวลาที่ทำงาน

หมวด ๒
แสงสว่าง

ข้อ ๔ นายจ้างต้องจัดให้สถานประกอบกิจการมีความเข้มของแสงสว่างไม่ต่ำกว่ามาตรฐานที่อธิบดีประกาศกำหนด

ข้อ ๕ นายจ้างต้องใช้หรือจัดให้มีฉาก แผ่นฟิล์มกรองแสง หรือมาตรการอื่นที่เหมาะสมและเพียงพอเพื่อป้องกันมิให้แสงตรงหรือแสงสะท้อนจากแหล่งกำเนิดแสงหรือดวงอาทิตย์ที่มีแสงจ้าส่องเข้านัยน์ตาลูกจ้างโดยตรงในขณะทำงาน ในกรณีที่ไม่อาจป้องกันได้ ต้องจัดให้ลูกจ้างสวมใส่อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลตามที่กำหนดไว้ในหมวด ๔ ตลอดเวลาที่ทำงาน

ข้อ ๖ ในกรณีที่ลูกจ้างต้องทำงานในสถานที่มืด ทึบ และคับแคบ เช่น ในถ้ำ อุโมงค์ หรือในที่ที่มีลักษณะเช่นว่านั้น นายจ้างต้องจัดให้มีอุปกรณ์ส่องแสงสว่างที่เหมาะสมแก่สภาพและลักษณะงาน โดยอาจเป็นชนิดที่ติดอยู่ในพื้นที่ทำงานหรือติดที่ตัวบุคคลได้ หากไม่สามารถจัดหาหรือดำเนินการได้ ต้องจัดให้ลูกจ้างสวมใส่อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลตามที่กำหนดไว้ในหมวด ๔ ตลอดเวลาที่ทำงาน

หมวด ๓
เสียง

ข้อ ๗ นายจ้างต้องควบคุมระดับเสียงมิให้ลูกจ้างได้รับสัมผัสเสียงในบริเวณสถานประกอบกิจการที่มีระดับเสียงสูงสุด (peak sound pressure level) ของเสียงกระทบหรือเสียงกระแทก (impact or impulse noise) เกิน ๑๔๐ เดซิเบล หรือได้รับสัมผัสเสียงที่มีระดับเสียงดังต่อเนื่องแบบคงที่ (continuous steady noise) เกินกว่า ๑๑๕ เดซิเบลเอ

ข้อ ๘ นายจ้างต้องควบคุมระดับเสียงที่ลูกจ้างได้รับเฉลี่ยตลอดเวลาการทำงานในแต่ละวัน (Time Weighted Average-TWA) มิให้เกินมาตรฐานตามที่อธิบดีประกาศกำหนด

ข้อ ๙ ภายในสถานประกอบกิจการที่สภาวะการทำงานมีระดับเสียงเกินมาตรฐานที่กำหนดในข้อ ๗ หรือมีระดับเสียงที่ลูกจ้างได้รับเกินมาตรฐานที่กำหนดในข้อ ๘ นายจ้างต้องให้ลูกจ้างหยุดทำงานจนกว่าจะได้ปรับปรุงหรือแก้ไขให้ระดับเสียงเป็นไปตามมาตรฐานที่กำหนด และให้นายจ้างดำเนินการปรับปรุงหรือแก้ไขทางด้านวิศวกรรม โดยการควบคุมที่ต้นกำเนิดของเสียงหรือทางผ่านของเสียงหรือบริหารจัดการเพื่อควบคุมระดับเสียงที่ลูกจ้างจะได้รับให้ไม่เกินมาตรฐานที่กำหนด และจัดให้มีการปิดประกาศและเอกสารหรือหลักฐานในการดำเนินการปรับปรุงหรือแก้ไขดังกล่าวไว้ เพื่อให้พนักงานตรวจความปลอดภัยสามารถตรวจสอบได้

ในกรณีที่ไม่สามารถดำเนินการตามวรรคหนึ่งได้ นายจ้างต้องจัดให้ลูกจ้างสวมใส่อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลตามที่กำหนดไว้ในหมวด ๔ ตลอดเวลาที่ทำงาน เพื่อลดระดับเสียงที่สัมผัสในหูเมื่อสวมใส่อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลแล้ว โดยให้อยู่ในระดับที่ไม่เกินมาตรฐานตามที่กำหนดไว้ในข้อ ๗ และข้อ ๘

การคำนวณระดับเสียงที่สัมผัสในหูเมื่อสวมใส่อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลตามวรรคสองให้เป็นไปตามที่อธิบดีประกาศกำหนด

ข้อ ๑๐ ในบริเวณที่มีระดับเสียงเกินมาตรฐานที่กำหนดในข้อ ๗ หรือข้อ ๘ นายจ้างต้องจัดให้มีเครื่องหมายเตือนให้ใช้อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลติดไว้ให้ลูกจ้างเห็นได้โดยชัดเจน

ข้อ ๑๑ ในกรณีที่สภาวะการทำงานในสถานประกอบกิจการมีระดับเสียงที่ลูกจ้างได้รับเฉลี่ยตลอดระยะเวลาการทำงานแปดชั่วโมงตั้งแต่ ๘๕ เดซิเบลเอขึ้นไป ให้นายจ้างจัดให้มีมาตรการอนุรักษ์การได้ยินในสถานประกอบกิจการตามหลักเกณฑ์และวิธีการที่อธิบดีประกาศกำหนด

หมวด ๔
อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคล

ข้อ ๑๒ นายจ้างต้องจัดให้มีและดูแลให้ลูกจ้างใช้อุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลตามความเหมาะสมกับลักษณะงานตลอดเวลาที่ทำงาน ดังต่อไปนี้

(๑) งานที่มีระดับความร้อนเกินมาตรฐานที่กำหนด ให้สวมใส่ชุดแต่งกาย รองเท้า และถุงมือสำหรับป้องกันความร้อน

(๒) งานที่มีแสงตรงหรือแสงสะท้อนจากแหล่งกำเนิดแสงหรือดวงอาทิตย์ที่มีแสงจ้าส่องเข้านัยน์ตาโดยตรง ให้สวมใส่แว่นตาลดแสงหรือกระบังหน้าลดแสง

(๓) งานที่ทำในสถานที่มืด ทึบ และคับแคบ ให้สวมใส่หมวกนิรภัยที่มีอุปกรณ์ส่องแสงสว่าง

(๔) งานที่มีระดับเสียงเกินมาตรฐานที่กำหนด ให้สวมใส่ปลั๊กลดเสียงหรือที่ครอบหูลดเสียง

ข้อ ๑๓ ให้นายจ้างบำรุงรักษาอุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคลให้อยู่ในสภาพที่ใช้งานได้อย่างปลอดภัย รวมทั้งจัดให้ลูกจ้างได้รับการฝึกอบรมเกี่ยวกับวิธีการใช้และบำรุงรักษาอุปกรณ์คุ้มครองความปลอดภัยส่วนบุคคล และเก็บหลักฐานการฝึกอบรมไว้ ณ สถานประกอบกิจการเพื่อให้พนักงานตรวจความปลอดภัยสามารถตรวจสอบได้

หมวด ๕
การตรวจวัดและวิเคราะห์สภาวะการทำงาน และการรายงานผล

ข้อ ๑๔ นายจ้างต้องจัดให้มีการตรวจวัดและวิเคราะห์สภาวะการทำงานเกี่ยวกับระดับความร้อน แสงสว่าง หรือเสียงภายในสถานประกอบกิจการ

หลักเกณฑ์ วิธีการตรวจวัด และการวิเคราะห์สภาวะการทำงานเกี่ยวกับระดับความร้อน แสงสว่าง หรือเสียง รวมทั้งระยะเวลาและประเภทกิจการที่ต้องดำเนินการให้เป็นไปตามที่อธิบดีประกาศกำหนด

ในกรณีที่นายจ้างไม่สามารถตรวจวัดและวิเคราะห์สภาวะการทำงานตามวรรคหนึ่งได้ ต้องให้ผู้ที่ขึ้นทะเบียนตามมาตรา ๙ หรือนิติบุคคลที่ได้รับใบอนุญาตตามมาตรา ๑๑ แห่งพระราชบัญญัติความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงาน พ.ศ. ๒๕๕๔ เพื่อเป็นผู้ให้บริการในการตรวจวัดและวิเคราะห์สภาวะการทำงานเกี่ยวกับระดับความร้อน แสงสว่าง หรือเสียงภายในสถานประกอบกิจการ แล้วแต่กรณี เป็นผู้ดำเนินการแทน

ให้นายจ้างเก็บผลการตรวจวัดและวิเคราะห์สภาวะการทำงานดังกล่าวไว้ ณ สถานประกอบกิจการเพื่อให้พนักงานตรวจความปลอดภัยสามารถตรวจสอบได้

ข้อ ๑๕ ให้นายจ้างจัดทำรายงานผลการตรวจวัดและวิเคราะห์สภาวะการทำงานตามแบบที่อธิบดีประกาศกำหนด พร้อมทั้งส่งรายงานผลดังกล่าวต่ออธิบดีหรือผู้ซึ่งอธิบดีมอบหมายภายในสามสิบวันนับแต่วันที่เสร็จสิ้นการตรวจวัด และเก็บรายงานผลการตรวจวัดและวิเคราะห์สภาวะการทำงานดังกล่าวไว้ ณ สถานประกอบกิจการ เพื่อให้พนักงานตรวจความปลอดภัยสามารถตรวจสอบได้

หมวด ๖
การตรวจสุขภาพและการรายงานผล

ข้อ ๑๖ ให้นายจ้างจัดให้มีการตรวจสุขภาพลูกจ้างที่ทำงานในสภาวะการทำงานที่อาจได้รับอันตรายจากความร้อน แสงสว่าง หรือเสียง และรายงานผล รวมทั้งดำเนินการที่เกี่ยวข้องกับการตรวจสุขภาพของลูกจ้างตามพระราชบัญญัติความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงาน พ.ศ. ๒๕๕๔

บทเฉพาะกาล

ข้อ ๑๗ ให้ผู้ซึ่งขึ้นทะเบียนเป็นผู้รับรองรายงานการตรวจวัดและวิเคราะห์สภาวะการทำงานกับกรมสวัสดิการและคุ้มครองแรงงานตามกฎกระทรวงกำหนดมาตรฐานในการบริหารและการจัดการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง พ.ศ. ๒๕๔๙ มีสิทธิดำเนินการตรวจวัดและวิเคราะห์สภาวะการทำงานเกี่ยวกับระดับความร้อน แสงสว่าง หรือเสียงภายในสถานประกอบกิจการตามข้อ ๑๔ ต่อไปจนกว่าการขึ้นทะเบียนจะสิ้นอายุ

ในกรณีที่ไม่มีผู้ซึ่งขึ้นทะเบียนตามวรรคหนึ่ง และยังไม่มีการออกกฎกระทรวงกำหนดรายละเอียดของบุคคลที่จะขอขึ้นทะเบียนหรือนิติบุคคลที่จะขอรับใบอนุญาตตามมาตรา ๙ หรือมาตรา ๑๑ แห่งพระราชบัญญัติความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงาน พ.ศ. ๒๕๕๔ เพื่อเป็นผู้ให้บริการในการตรวจวัดและวิเคราะห์สภาวะการทำงานเกี่ยวกับระดับความร้อน แสงสว่าง

หรือเสียงภายในสถานประกอบกิจการ แล้วแต่กรณี ให้ผู้ซึ่งสำเร็จการศึกษาไม่ต่ำกว่าระดับปริญญาตรี สาขาอาชีวอนามัย หรือเทียบเท่า ที่เคยขึ้นทะเบียนตามกฎกระทรวงกำหนดมาตรฐานในการบริหารและการจัดการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง พ.ศ. ๒๕๔๙ หรือให้ผู้ซึ่งสำเร็จการศึกษาไม่ต่ำกว่าระดับปริญญาตรี สาขาอาชีวอนามัย หรือเทียบเท่า และมีประสบการณ์เป็นผู้รับรองรายงานการตรวจวัดและวิเคราะห์สภาวะการทำงาน ไม่น้อยกว่าสามปี สามารถดำเนินการตรวจวัดแทนผู้ทำการตรวจวัดตามกฎกระทรวงนี้ไปพลางก่อนได้

ข้อ ๑๘ กรณีที่นายจ้างทำการตรวจวัดและวิเคราะห์สภาวะการทำงานเกี่ยวกับระดับความร้อน แสงสว่าง หรือเสียงภายในสถานประกอบกิจการตามกฎกระทรวงกำหนดมาตรฐานในการบริหารและการจัดการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง พ.ศ. ๒๕๔๙ ก่อนที่กฎกระทรวงนี้จะมีผลใช้บังคับ และมีระยะเวลายังไม่ครบหนึ่งปีนับแต่วันที่ทำการตรวจวัด ให้ถือว่านายจ้างได้ดำเนินการตรวจวัดตามกฎกระทรวงนี้แล้ว จนกว่าจะครบระยะเวลาหนึ่งปี

ให้ไว้ ณ วันที่ ๗ ตุลาคม พ.ศ. ๒๕๕๙
พลเอก ศิริชัย ดิษฐกุล
รัฐมนตรีว่าการกระทรวงแรงงาน

หมายเหตุ :- เหตุผลในการประกาศใช้กฎกระทรวงฉบับนี้ คือ โดยที่มาตรา ๘ วรรคหนึ่ง แห่งพระราชบัญญัติความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงาน พ.ศ. ๒๕๕๔ บัญญัติให้รัฐมนตรีว่าการกระทรวงแรงงานมีอำนาจออกกฎกระทรวงกำหนดให้นายจ้างบริหาร จัดการ และดำเนินการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงาน ซึ่งในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง สมควรจะต้องมีระบบการบริหาร จัดการ และดำเนินการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานที่ได้มาตรฐาน อันจะทำให้ลูกจ้างมีความปลอดภัยในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียงยิ่งขึ้น จึงจำเป็นต้องออกกฎกระทรวงนี้

ภาคผนวก ง12

มาตรฐานตามประกาศกรมสวัสดิการและคุ้มครองแรงงาน

เรื่อง มาตรฐานระดับเสียงที่ยอมให้ลูกจ้างได้รับเฉลี่ยตลอด

ระยะเวลาการทำงานในแต่ละวัน

ประกาศในราชกิจจานุเบกษา เล่ม 135 ตอนพิเศษ 19 ง

ลงวันที่ 26 มกราคม 2561

ประกาศกรมสวัสดิการและคุ้มครองแรงงาน

เรื่อง มาตรฐานระดับเสียงที่ยอมให้ลูกจ้างได้รับเฉลี่ยตลอดระยะเวลาการทำงานในแต่ละวัน

โดยที่กฎกระทรวงกำหนดมาตรฐานในการบริหาร จัดการ และดำเนินการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง พ.ศ. ๒๕๕๙ กำหนดให้นายจ้างต้องควบคุมระดับเสียงที่ลูกจ้างได้รับเฉลี่ยตลอดระยะเวลาการทำงานในแต่ละวันมิให้เกินมาตรฐานตามที่อธิบดีประกาศกำหนด

อาศัยอำนาจตามความในข้อ ๘ แห่งกฎกระทรวงกำหนดมาตรฐานในการบริหาร จัดการ และดำเนินการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับความร้อน แสงสว่าง และเสียง พ.ศ. ๒๕๕๙ อธิบดีกรมสวัสดิการและคุ้มครองแรงงานจึงออกประกาศไว้ดังต่อไปนี้

ข้อ ๑ ประกาศนี้เรียกว่า “ประกาศกรมสวัสดิการและคุ้มครองแรงงาน เรื่อง มาตรฐานระดับเสียงที่ยอมให้ลูกจ้างได้รับเฉลี่ยตลอดระยะเวลาการทำงานในแต่ละวัน”

ข้อ ๒ ประกาศนี้ให้ใช้บังคับเมื่อพ้นกำหนดเก้าสิบวันนับแต่วันประกาศในราชกิจจานุเบกษา

ข้อ ๓ นายจ้างต้องควบคุมระดับเสียงที่ลูกจ้างได้รับเฉลี่ยตลอดระยะเวลาการทำงานในแต่ละวัน (Time Weighted Average-TWA) มิให้เกินมาตรฐานตามตารางแนบท้ายประกาศ โดยหน่วยวัดระดับเสียงดังที่ใช้ในประกาศนี้ใช้หน่วยเป็น เดซิเบลเอ

ประกาศ ณ วันที่ ๑๓ ธันวาคม พ.ศ. ๒๕๖๐
อนันต์ชัย อุทัยพัฒนาชีพ
ผู้ตรวจราชการกระทรวง รักษาราชการแทน
อธิบดีกรมสวัสดิการและคุ้มครองแรงงาน

(ตารางแนบท้ายประกาศ)

ตารางมาตรฐานระดับเสียงที่ยอมให้ลูกจ้างได้รับเฉลี่ยตลอดระยะเวลาการทำงานในแต่ละวัน

ระดับเสียงเฉลี่ยตลอดเวลาการทำงาน (TWA) ไม่เกิน (เดซิเบลเอ)	ระยะเวลาการทำงานที่ได้รับเสียงต่อวัน*	
	ชั่วโมง	นาที
๘๒	๑๖	-
๘๓	๑๒	๔๒
๘๔	๑๐	๕
๘๕	๘	-
๘๖	๖	๒๑
๘๗	๕	๒
๘๘	๔	-
๘๙	๓	๑๑
๙๐	๒	๓๑
๙๑	๒	-
๙๒	๑	๓๕
๙๓	๑	๑๖
๙๔	๑	-
๙๕	-	๔๘
๙๖	-	๓๘
๙๗	-	๓๐
๙๘	-	๒๔
๙๙	-	๑๙
๑๐๐	-	๑๕
๑๐๑	-	๑๒
๑๐๒	-	๙
๑๐๓	-	๗.๕
๑๐๔	-	๖
๑๐๕	-	๕
๑๐๖	-	๔
๑๐๗	-	๓
๑๐๘	-	๒.๕
๑๐๙	-	๒
๑๑๐	-	๑.๕
๑๑๑	-	๑

หมายเหตุ * ระยะเวลาการทำงานที่ได้รับเสียงและระดับเสียงเฉลี่ยตลอดเวลาการทำงาน (TWA) ให้ใช้ค่ามาตรฐานที่กำหนดในตารางข้างต้นเป็นลำดับแรก หากไม่มีค่ามาตรฐานที่กำหนดตรงตามตารางให้คำนวณจากสูตรดังนี้

$$T = \frac{๘}{๒^{(L-๘๕)/๓}}$$

เมื่อ T หมายถึง เวลาการทำงานที่ยอมให้ได้รับเสียง (ชั่วโมง)

L หมายถึง ระดับเสียง (เดซิเบลเอ)

ในกรณีค่าระดับเสียงเฉลี่ยตลอดเวลาการทำงาน (TWA) ที่ได้จากการคำนวณมีเศษทศนิยมให้ตัดเศษทศนิยมออก

ภาคผนวก ง13
ประกาศกระทรวงอุตสาหกรรม เรื่อง มาตรการคุ้มครองความปลอดภัยในการประกอบกิจการโรงงานเกี่ยวกับสภาวะแวดล้อมในการทำงาน พ.ศ. 2546

ประกาศกระทรวงอุตสาหกรรม

เรื่อง มาตรการคุ้มครองความปลอดภัยในการประกอบกิจการโรงงานเกี่ยวกับสภาวะแวดล้อมในการทำงาน

พ. ศ. 2546

อาศัยอำนาจตามความในข้อ 18 แห่งกฎกระทรวงฉบับที่ 2 (พ.ศ. 2535) ออกตามความในพระราชบัญญัติโรงงาน พ.ศ. 2535 อันเป็นพระราชบัญญัติที่มีบทบัญญัติบางประการที่เกี่ยวกับการจำกัดสิทธิและเสรีภาพของบุคคล ซึ่งมาตรา 29 ประกอบกับมาตรา 35 มาตรา 48 กับมาตรา 50 ของรัฐธรรมนูญแห่งราชอาณาจักรไทย บัญญัติให้กระทำได้โดยอาศัยอำนาจตามบทบัญญัติแห่งกฎหมาย รัฐมนตรีว่าการกระทรวงอุตสาหกรรมออกประกาศไว้ดังต่อไปนี้

ข้อ 1. ในประกาศนี้

"ระดับความร้อน" หมายความว่า อุณหภูมิความร้อนในบริเวณที่ปฏิบัติงาน ตรวจวัดเป็นอุณหภูมิเวทบัลบ์โกลบ (Wet Bulb Globe Temperature : WBGT) เฉลี่ยในช่วงเวลาสองชั่วโมงที่มีอุณหภูมิเวทบัลบ์โกลบสูงสุดของการทำงานปกติ

"อุณหภูมิเวทบัลบ์โกลบ" หมายความว่า อุณหภูมิซึ่งวัดเป็นองศาเซลเซียส คำนวณได้จากสูตร ต่อไปนี้

WBGT = 0.7 NWB + 0.3 GT (ในกรณีในอาคารหรือนอกอาคารที่ไม่มีแสงแดด)

WBGT = 0.7 NWB + 0.2 GT + 0.1 DB (ในกรณีนอกอาคารที่มีแสงแดด)

โดยที่ NWB (Natural Wet Bulb Temperature) คืออุณหภูมิที่อ่านค่าจากเทอร์โมมิเตอร์กระเปาะเปียกตามธรรมชาติ วัดเป็นองศาเซลเซียส

GT (Globe Temperature) คืออุณหภูมิที่อ่านค่าจากโกลบเทอร์โมมิเตอร์ วัดเป็นองศาเซลเซียส

DB (Dry Bulb Temperature) คือ อุณหภูมิที่อ่านค่าจากเทอร์โมมิเตอร์กระเปาะแห้ง วัดเป็นองศาเซลเซียส

"งานเบา" หมายความว่า ลักษณะงานที่ใช้แรงน้อยหรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายไม่เกิน 200 กิโลแคลอรี/ชั่วโมง เช่น งานเขียนหนังสือ งานพิมพ์ดีด งานบันทึกข้อมูล งานเย็บจักร งานนั่งตรวจสอบผลิตภัณฑ์ งานประกอบชิ้นงานขนาดเล็ก งานบังคับเครื่องจักรด้วยเท้า การยืนคุมงาน เป็นต้น หรืองานที่เทียบเคียงได้กับงานดังกล่าว

"งานปานกลาง" หมายความว่า ลักษณะงานที่ใช้แรงปานกลางหรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายเกินกว่า 200 กิโลแคลอรี/ชั่วโมง ถึง 350 กิโลแคลอรี/ชั่วโมง เช่น

ประกาศในราชกิจจานุเบกษา ฉบับประกาศทั่วไป
เล่ม 120 ตอน พิเศษ 138ง เมื่อวันที่ 3 ธันวาคม 2546

งานยก ลาก ดัน หรือเคลื่อนย้ายสิ่งของด้วยแรงปานกลาง งานตอกตะปู งานตะไบ งานขับรถบรรทุก งานขับรถแทรกเตอร์ เป็นต้น หรืองานที่เทียบเคียงได้กับงานดังกล่าว

"งานหนัก" หมายความว่า ลักษณะงานที่ใช้แรงมาก หรือใช้กำลังงานที่ทำให้เกิดการเผาผลาญอาหารในร่างกายเกินกว่า 350 กิโลแคลอรี/ชั่วโมง ถึง 500 กิโลแคลอรี/ชั่วโมง เช่น งานที่ใช้พลั่วหรือเสียม ขุดตัก งานเลื่อยไม้ งานเจาะไม้เนื้อแข็ง งานทุบโดยใช้ฆ้อนขนาดใหญ่ งานยกหรือเคลื่อนย้ายของหนักขึ้นที่สูงหรือที่ลาดชัน เป็นต้น หรืองานที่เทียบเคียงได้กับงานดังกล่าว

หมวด 1
ความร้อน

ข้อ 2. บริเวณปฏิบัติงานต้องมีระดับความร้อนไม่เกินกว่ามาตรฐานที่กำหนดไว้ในตารางท้ายหมวดนี้

ข้อ 3. บริเวณปฏิบัติงานที่มีระดับความร้อนเกินกว่ามาตรฐานตามข้อ 2 ผู้ประกอบกิจการโรงงานต้องปิดประกาศเตือนให้ทราบถึงบริเวณที่มีความร้อนสูงเกินมาตรฐานที่กำหนด

ข้อ 4. ในกรณีที่ภายในบริเวณปฏิบัติงานมีระดับความร้อนเกินมาตรฐาน ตามข้อ 2 ผู้ประกอบกิจการโรงงานต้องดำเนินการปรับปรุงหรือแก้ไขให้บริเวณปฏิบัติงานมีระดับความร้อนอยู่ในเกณฑ์มาตรฐาน หากได้ดำเนินการปรับปรุงหรือแก้ไขแล้ว ไม่สามารถควบคุมให้เป็นไปตามมาตรฐานดังกล่าวได้ ผู้ประกอบกิจการโรงงานต้องจัดหาอุปกรณ์ป้องกันอันตรายส่วนบุคคล เช่น ชุดแต่งกาย รองเท้าและถุงมือเพื่อป้องกันความร้อน สำหรับผู้ที่จะเข้าไปในบริเวณดังกล่าว ตลอดจนต้องจัดให้มีการอบรมการใช้อุปกรณ์ป้องกันอันตรายส่วนบุคคลด้วย

ตารางแสดงมาตรฐานระดับความร้อน

ความหนักเบาของงาน	มาตรฐานระดับความร้อน ค่าเฉลี่ยอุณหภูมิเวทบัลบ์โกลบ (WBGT) กำหนดเป็นองศาเซลเซียส
เบา	34.0
ปานกลาง	32.0
หนัก	30.0

หมวด 2
แสงสว่าง

ข้อ 5. ผู้ประกอบกิจการโรงงานต้องป้องกันมิให้มีแสงตรง หรือแสงสะท้อนส่องเข้าตาคนงานในการปฏิบัติงาน

ข้อ 6. ผู้ประกอบกิจการโรงงานต้องจัดให้มีแสงสว่างเพียงพอแก่การทำงานอย่างทั่วถึง สามารถมองเห็นสิ่งกีดขวาง และส่วนที่อาจก่อให้เกิดอันตรายจากการเคลื่อนไหวของเครื่องจักร หรืออันตรายจากไฟฟ้า ตลอดจนบันไดขึ้นลงและทางออก ในเวลามีเหตุฉุกเฉินอย่างชัดเจน ตามหลักเกณฑ์ดังต่อไปนี้

(1) ลานถนนและทางเดินนอกอาคารโรงงาน ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 20 ลักซ์ (LUX) หรือ 2 ฟุต-แคนเดิล (Foot Candle)

(2) บริเวณทางเดินในอาคารโรงงาน ระเบียง บันได ห้องพักผ่อน ห้องพักฟื้นของพนักงาน ห้องเก็บของที่มิได้มีการเคลื่อนย้าย ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 50 ลักซ์

(3) บริเวณการปฏิบัติงานที่ไม่ต้องการความละเอียด ได้แก่ บริเวณการสีข้าว สางฝ้าย หรือการปฏิบัติงานขั้นแรกในกระบวนการอุตสาหกรรมต่าง ๆ และบริเวณจุดขนถ่ายสินค้า ป้อมยาม ลิฟท์ ห้องเปลี่ยนเสื้อผ้าและบริเวณตู้เก็บของ ห้องน้ำและห้องส้วม ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 100 ลักซ์

(4) บริเวณการปฏิบัติงานที่ต้องการความละเอียดน้อยมาก ได้แก่ งานหยาบที่ทำที่โต๊ะ หรือเครื่องจักร ชิ้นงานมีขนาดใหญ่กว่า 750 ไมโครเมตร(0.75 มิลลิเมตร) การตรวจงานหยาบด้วยสายตา การนับ การตรวจเช็คสิ่งของที่มีขนาดใหญ่ และบริเวณพื้นที่ในโกดัง ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 200 ลักซ์

(5) บริเวณการปฏิบัติงานที่ต้องการความละเอียดน้อย ได้แก่ บริเวณที่ปฏิบัติงานเกี่ยวกับงานรับจ่ายเสื้อผ้า การทำงานไม้ที่มีชิ้นงานขนาดปานกลาง งานบรรจุน้ำลงขวดหรือกระป๋อง งานเจาะรู ทากาว หรือเย็บเล่มหนังสือ ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 300 ลักซ์

ในบริเวณการปฏิบัติงานที่มีขนาดของชิ้นงานตั้งแต่ 125 ไมโครเมตร (0.125 มิลลิเมตร) ได้แก่งานเกี่ยวกับงานประจำในสำนักงาน เช่น งานพิมพ์ดีด เขียนและอ่าน งานประกอบรถยนต์และตัวถัง การทำงานไม้อย่างละเอียด ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 400 ลักซ์

(6) บริเวณการปฏิบัติงานที่ต้องการความละเอียดปานกลาง ได้แก่ งานเขียนแบบ งานระบายสี พ่นสีและตกแต่งสีอย่างละเอียด งานพิสูจน์อักษร งานตรวจสอบขั้นสุดท้ายในโรงงานผลิตรถยนต์ ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 600 ลักซ์

(7) บริเวณการปฏิบัติงานที่ต้องการความละเอียดสูง โดยมีขนาดของชิ้นงานตั้งแต่ 25 ไมโครเมตร (0.025 มิลลิเมตร) ได้แก่ บริเวณที่ปฏิบัติงานเกี่ยวกับการตรวจสอบงานละเอียด เช่น การปรับเทียบมาตรฐานความถูกต้องและความแม่นยำของอุปกรณ์ การระบายสี พ่นสี และตกแต่งชิ้นงานที่ต้องการความละเอียดมากเป็นพิเศษ งานย้อมสี ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 800 ลักซ์ ในบริเวณการปฏิบัติงานเกี่ยวกับการตรวจสอบ การตัดเย็บเสื้อผ้าด้วยมือ การตรวจสอบและตกแต่งสินค้าสิ่งทอ สิ่งถักหรือเสื้อผ้าที่มีสีอ่อนขั้นสุดท้ายด้วยมือ การคัดแยกและเทียบสีหนังที่มีสีเข้ม การเทียบสีในงานย้อมผ้า ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 1200 ลักซ์

(8) บริเวณการปฏิบัติงานที่ต้องการความละเอียดสูงมาก ได้แก่ งานละเอียดที่ต้องทำบนโต๊ะหรือเครื่องจักร เช่น ทำเครื่องมือและแม่พิมพ์ที่มีรายละเอียดขนาดเล็กกว่า 25 ไมโครเมตร (0.025 มิลลิเมตร) งานตรวจสอบตรวจวัดชิ้นส่วนที่มีขนาดเล็กหรือชิ้นงานที่มีส่วนประกอบขนาดเล็ก งานซ่อมแซมสินค้า สิ่งทอ สิ่งถักที่มีสีอ่อน งานตรวจสอบและตกแต่งชิ้นส่วนของสินค้าสิ่งทอ สิ่งถักที่มีสีเข้มด้วยมือ ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 1600 ลักซ์

(9) บริเวณการปฏิบัติงานที่ต้องการความละเอียดสูงมากเป็นพิเศษ ได้แก่ การปฏิบัติงานเกี่ยวกับการตรวจสอบชิ้นงานที่มีขนาดเล็กมาก การเจียระไนเพชร การทำนาฬิกาข้อมือในกระบวนการที่มีขนาดเล็ก การถัก ซ่อมแซมเสื้อผ้าถุงเท้าที่มีสีเข้ม ความเข้มของการส่องสว่างต้องไม่น้อยกว่า 2400 ลักซ์

ข้อ 7. ความเข้มของการส่องสว่าง ณ ที่ปฏิบัติงานหรือลักษณะการปฏิบัติงานนอกเหนือจากที่กำหนดไว้ในข้อ 6 ผู้ประกอบกิจการโรงงานต้องจัดให้มีความเข้มของการส่องสว่าง เทียบเคียงไม่ต่ำกว่าหลักเกณฑ์ที่ได้กำหนดไว้

หมวด 3
เสียง

ข้อ 8. ผู้ประกอบกิจการโรงงานต้องควบคุมมิให้บริเวณปฏิบัติงานในโรงงานมีระดับเสียงเกินกว่ามาตรฐานที่ได้กำหนดไว้ในตารางท้ายหมวดนี้

ข้อ 9. ห้ามมิให้บุคคลเข้าไปในบริเวณที่มีเสียงดังเกินกว่า 140 เดซิเบลเอ

ข้อ 10. บริเวณปฏิบัติงานที่มีระดับเสียงเกินกว่ามาตรฐานตามข้อ 8 ผู้ประกอบกิจการโรงงานต้องปิดประกาศเตือนให้ทราบถึงบริเวณที่มีเสียงดังเกินมาตรฐานที่กำหนด

<u>ตารางแสดงมาตรฐานเปรียบเทียบระดับเสียงเฉลี่ยที่ยอมรับได้กับเวลาการทำงานในแต่ละวัน</u>

เวลาการทำงานที่ได้รับเสียงใน 1 วัน (ชม.)	ระดับเสียงเฉลี่ยตลอดเวลาการทำงาน ไม่เกิน (เดซิเบลเอ)
12	87
8	90
6	92
4	95
3	97
2	100
1 ½	102
1	105
½	110
¼ หรือน้อยกว่า	115

<u>หมายเหตุ</u> หากเวลาการปฏิบัติงานไม่มีค่ามาตรฐานที่กำหนดตรงตามตารางข้างต้น ให้คำนวณ โดยใช้สูตร

$$T = \frac{8}{2^{(L-90)/5}}$$

เมื่อ T หมายถึง เวลาการทำงานที่ยอมให้ได้รับเสียง (ชั่วโมง)

L หมายถึง ระดับเสียง (เดซิเบลเอ)

ในกรณีค่าระดับเสียงเฉลี่ยตลอดเวลาการทำงาน ที่ได้จากการคำนวณมีเศษทศนิยมให้ตัดเศษทศนิยมออก

หมวด 4
การตรวจวัดและวิเคราะห์สภาวะแวดล้อมในการทำงาน

ข้อ 11. ผู้ประกอบกิจการโรงงาน ต้องจัดให้มีการตรวจวัด วิเคราะห์ และจัดทำรายงานสภาพแวดล้อมในการทำงานเกี่ยวกับระดับความร้อน แสงสว่างและเสียงอย่างน้อยปีละ 1 ครั้ง โดยมีเจ้าหน้าที่ความปลอดภัยในการทำงานระดับวิชาชีพหรือผู้สำเร็จการศึกษาไม่ต่ำกว่าปริญญาตรีทางด้านวิทยาศาสตร์เป็นผู้รับรองรายงาน และให้เก็บรายงานดังกล่าวไว้ ณ ที่ตั้งโรงงานให้พร้อมสำหรับการตรวจสอบของพนักงานเจ้าหน้าที่

ข้อ 12. การตรวจวัดความร้อน บริเวณที่ทำการตรวจวัดต้องเป็นบริเวณที่มีการปฏิบัติงานอยู่ในสภาพการทำงานปกติ การตรวจวัดต้องเป็นบริเวณที่มีระดับความร้อนสูง และต้องตรวจวัดในเดือนที่มีอากาศร้อนของปี ประเภทหรือชนิดของโรงงานที่ต้องดำเนินการตรวจวัดความร้อนตามที่กำหนดไว้ในบัญชีที่ 1 ท้ายประกาศนี้

ข้อ 13. การตรวจวัดแสงสว่าง บริเวณที่ทำการตรวจวัดต้องเป็นบริเวณที่มีการปฏิบัติงานในสภาพการทำงานปกติ การตรวจวัดต้องเป็นบริเวณที่มีความเข้มของการส่องสว่างต่ำ โดยกำหนดให้โรงงานจำพวกที่ 3 ทุกประเภทต้องทำการตรวจวัดแสงสว่าง

ข้อ 14. การตรวจวัดระดับเสียง บริเวณที่ทำการตรวจวัดต้องเป็นบริเวณที่มีการปฏิบัติงานในสภาพการทำงานปกติ การตรวจวัดต้องเป็นบริเวณที่มีระดับเสียงสูง ประเภทหรือชนิดของโรงงานที่ต้องดำเนินการตรวจวัดเสียงตามที่กำหนดไว้ในบัญชีที่ 2 ท้ายประกาศนี้

ข้อ 15. วิธีการตรวจวัดและวิเคราะห์ให้เป็นไปตามหลักมาตรฐานสากล เช่น มาตรฐานของ Occupational Safety & Health Administration (OSHA) มาตรฐานของ National Institute Occupational Safety and Health (NIOSH) เป็นต้น หรือวิธีอื่นใดที่กรมโรงงานอุตสาหกรรมเห็นชอบ

หมวด 5

เบ็ดเตล็ด

ข้อ 16. ประกาศฉบับนี้ให้ใช้บังคับเมื่อพ้นกำหนดหนึ่งร้อยแปดสิบวัน นับแต่วันที่ประกาศในราชกิจจานุเบกษา เป็นต้นไป

ประกาศ ณ วันที่ 6 พฤศจิกายน พ.ศ. 2546

(นายสมศักดิ์ เทพสุทิน)

รัฐมนตรีว่าการกระทรวงอุตสาหกรรม

บัญชีท้ายประกาศกระทรวงอุตสาหกรรม

เรื่อง มาตรการคุ้มครองความปลอดภัยในการประกอบกิจการโรงงานเกี่ยวกับสภาวะแวดล้อมในการทำงาน พ.ศ. 2546

บัญชีที่ 1 ประเภทหรือชนิดของโรงงานที่ต้องทำการตรวจวัดความร้อน

ลำดับที่	ตามประเภทหรือชนิดของโรงงานในบัญชีท้ายกฎกระทรวง (พ.ศ. 2535) ออกตามความในพระราชบัญญัติโรงงาน พ.ศ. 2535
11(3)(4)	โรงงานผลิตน้ำตาลทรายดิบ น้ำตาลทรายขาว หรือการทำให้บริสุทธิ์
22(3)	โรงงานสิ่งทอที่ทำการฟอก ย้อมสี หรือแต่งสำเร็จด้ายหรือสิ่งทอ
38(1)(2)	โรงงานผลิตเยื่อกระดาษจากไม้หรือวัสดุอื่น การทำกระดาษ กระดาษแข็ง หรือกระดาษที่ใช้ในการก่อสร้างชนิดที่ทำจากเส้นใย หรือแผ่นกระดาษไฟเบอร์
51	โรงงานผลิต ซ่อม หล่อ หรือหล่อดอกยางนอก หรือยางในสำหรับยานพาหนะที่เคลื่อนที่ด้วยเครื่องกล คน หรือสัตว์
54	โรงงานผลิตแก้ว เส้นใยแก้วหรือผลิตภัณฑ์แก้ว
57(1)	โรงงานทำซีเมนต์ ปูนขาว หรือปูนปลาสเตอร์
59	โรงงานประกอบกิจการเกี่ยวกับการถลุง หลอม หล่อ รีด ดึง ผลิตเหล็ก หรือเหล็กกล้าในขั้นต้น
60	โรงงานประกอบกิจการเกี่ยวกับการถลุง ผสมทำให้บริสุทธิ์ หลอม หล่อ รีด ดึง หรือผลิตโลหะขั้นต้น ซึ่งมิใช่เหล็กหรือเหล็กกล้า
61	โรงงานผลิต ตบแต่ง ดัดแปลง หรือซ่อมแซมเครื่องมือ หรือเครื่องใช้ที่ทำด้วยเหล็กหรือเหล็กกล้า และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องมือหรือเครื่องใช้ดังกล่าว
62	โรงงานผลิต ตบแต่ง ดัดแปลง หรือซ่อมแซมเครื่องเรือน หรือเครื่องตบแต่งภายในอาคารที่ทำจากโลหะหรือโลหะเป็นส่วนใหญ่ และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องเรือน หรือเครื่องตกแต่งดังกล่าว
63	โรงงานประกอบกิจการเกี่ยวกับผลิตภัณฑ์โลหะสำหรับใช้ในการก่อสร้าง
64	โรงงานประกอบกิจการเกี่ยวกับผลิตภัณฑ์โลหะ
65	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมเครื่องยนต์ เครื่องกังหัน และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องยนต์ หรือเครื่องกังหันดังกล่าว

บัญชีที่ 1 ประเภทหรือชนิดของโรงงานที่ต้องทำการตรวจวัดความร้อน

ลำดับที่	ตามประเภทหรือชนิดของโรงงานในบัญชีท้ายกฎกระทรวง (พ.ศ. 2535) ออกตามความในพระราชบัญญัติโรงงาน พ.ศ. 2535
66	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมเครื่องจักร สำหรับใช้ในการกสิกรรมหรือการเลี้ยงสัตว์ และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องจักรดังกล่าว
67	โรงงานประกอบกิจการเกี่ยวกับเครื่องจักร ส่วนประกอบ หรืออุปกรณ์ของเครื่องจักรสำหรับประดิษฐ์โลหะ หรือไม้
68	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมเครื่องจักรสำหรับอุตสาหกรรมกระดาษ เคมี อาหาร การปั่นทอ การพิมพ์ การผลิตซีเมนต์หรือผลิตภัณฑ์ดินเหนียว การก่อสร้าง การทำเหมืองแร่ การเจาะหาปิโตรเลียม หรือการกลั่นน้ำมัน และรวมถึงส่วนประกอบของเครื่องจักรดังกล่าว
74(1)	โรงงานประกอบกิจการเกี่ยวกับการทำหลอดไฟฟ้า หรือดวงโคมไฟฟ้า
77	โรงงานประกอบกิจการเกี่ยวกับรถยนต์ หรือรถพ่วง
78	โรงงานประกอบกิจการเกี่ยวกับจักรยานยนต์ จักรยานสามล้อ หรือจักรยานสองล้อ
79	โรงงานประกอบกิจการเกี่ยวกับอากาศยาน หรือเรือโฮเวอร์คราฟท์
80	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมล้อเลื่อน ที่ขับเคลื่อนด้วยแรงคน หรือสัตว์ ซึ่งมิใช่จักรยาน และรวมถึงส่วนประกอบหรืออุปกรณ์ของผลิตภัณฑ์ดังกล่าว
88	โรงงานผลิต ส่ง หรือจำหน่ายพลังงานไฟฟ้า
98	โรงงานซักรีด ซักแห้ง ซักฟอก รีด อัด หรือย้อมผ้า เครื่องนุ่งห่ม พรม หรือขนสัตว์
100(6)	โรงงานประกอบกิจการเกี่ยวกับการตบแต่งหรือเปลี่ยนแปลงคุณลักษณะของผลิตภัณฑ์หรือส่วนประกอบของผลิตภัณฑ์โดยไม่มีการผลิต ด้วยวิธีการอบชุบด้วยความร้อน
102	โรงงานประกอบกิจการเกี่ยวกับการผลิต และหรือจำหน่ายไอน้ำ

<u>หมายเหตุ</u> : โรงงานลำดับที่ 61-68 และ 77-80 เฉพาะโรงงานที่มีการหล่อหลอมโลหะเท่านั้น
โรงงานลำดับที่ 98 เฉพาะโรงงานที่มีการฟอก ย้อมสีเท่านั้น

บัญชีที่ 2 ประเภทหรือชนิดของโรงงานที่ต้องทำการตรวจวัดเสียง

ลำดับที่	ตามประเภทหรือชนิดของโรงงานในบัญชีท้ายกฎกระทรวง (พ.ศ. 2535) ออกตามความในพระราชบัญญัติโรงงาน พ.ศ. 2535
3(1)	โรงงานที่ประกอบกิจการเกี่ยวกับการโม่ บด หรือย่อยหิน
11(3)(4)	โรงงานผลิตน้ำตาลทรายดิบ น้ำตาลทรายขาว หรือการทำให้บริสุทธิ์
14	โรงงานประกอบกิจการเกี่ยวกับการทำน้ำแข็ง หรือตัด ซอย บด หรือย่อยน้ำแข็ง
20(3)	โรงงานประกอบกิจการเกี่ยวกับการทำน้ำอัดลม (เฉพาะที่บรรจุขวดแก้ว)
22(2)	โรงงานประกอบกิจการเกี่ยวกับการทอ หรือการเตรียมเส้นด้ายยืนสำหรับการทอ
34(1)(2)(3)(4)	โรงงานประกอบกิจการเกี่ยวกับการเลื่อย ไส ซอย เซาะร่อง การทำวงกบ ขอบประตู ขอบหน้าต่าง บานหน้าต่าง บานประตู หรือส่วนประกอบที่ทำด้วยไม้ของอาคาร การทำไม้วีเนียร์ หรือไม้อัดทุกชนิด การทำฝอยไม้ การบด ป่น หรือย่อยไม้
38(1)	โรงงานผลิตเยื่อจากไม้ หรือวัสดุอื่น
53(9)	โรงงานประกอบกิจการเกี่ยวกับการล้าง บด หรือย่อยพลาสติก
61	โรงงานผลิต ตบแต่ง ดัดแปลง หรือซ่อมแซมเครื่องมือ หรือเครื่องใช้ที่ทำด้วยเหล็กหรือเหล็กกล้า และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องมือหรือเครื่องใช้ดังกล่าว
62	โรงงานผลิต ตบแต่ง ดัดแปลง หรือซ่อมแซมเครื่องเรือน หรือเครื่องตบแต่งภายในอาคารที่ทำจากโลหะหรือโลหะเป็นส่วนใหญ่ และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องเรือน หรือเครื่องตกแต่งดังกล่าว
63	โรงงานประกอบกิจการเกี่ยวกับผลิตภัณฑ์โลหะสำหรับใช้ในการก่อสร้าง
64	โรงงานประกอบกิจการเกี่ยวกับผลิตภัณฑ์โลหะ
65	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมเครื่องยนต์ เครื่องกังหัน และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องยนต์ หรือเครื่องกังหันดังกล่าว
66	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมเครื่องจักร สำหรับใช้ในการกสิกรรมหรือการเลี้ยงสัตว์ และรวมถึงส่วนประกอบหรืออุปกรณ์ของเครื่องจักรดังกล่าว
67	โรงงานประกอบกิจการเกี่ยวกับเครื่องจักร ส่วนประกอบ หรืออุปกรณ์ของเครื่องจักรสำหรับประดิษฐ์โลหะ หรือไม้

บัญชีที่ 2 ประเภทหรือชนิดของโรงงานที่ต้องทำการตรวจวัดเสียง

ลำดับที่	ตามประเภทหรือชนิดของโรงงานในบัญชีท้ายกฎกระทรวง (พ.ศ. 2535) ออกตามความในพระราชบัญญัติโรงงาน พ.ศ. 2535
68	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมเครื่องจักรสำหรับอุตสาหกรรมกระดาษ เคมี อาหาร การปั่นทอ การพิมพ์ การผลิตซีเมนต์หรือผลิตภัณฑ์ดินเหนียว การก่อสร้าง การทำเหมืองแร่ การเจาะหาปิโตรเลียม หรือการกลั่นน้ำมัน และรวมถึงส่วนประกอบของเครื่องจักรดังกล่าว
77	โรงงานประกอบกิจการเกี่ยวกับรถยนต์ หรือรถพ่วง
78	โรงงานประกอบกิจการเกี่ยวกับจักรยานยนต์ จักรยานสามล้อ หรือจักรยานสองล้อ
79	โรงงานประกอบกิจการเกี่ยวกับอากาศยาน หรือเรือโฮเวอร์คราฟท์
80	โรงงานผลิต ประกอบ ดัดแปลง หรือซ่อมแซมล้อเลื่อน ที่ขับเคลื่อนด้วยแรงคน หรือสัตว์ ซึ่งมิใช่จักรยาน และรวมถึงส่วนประกอบหรืออุปกรณ์ของผลิตภัณฑ์ดังกล่าว
88	โรงงานผลิต ส่ง หรือจำหน่ายพลังงานไฟฟ้า

<u>หมายเหตุ</u> : โรงงานลำดับที่ 61-68 และ 77-80 เฉพาะโรงงานที่มีการปั๊มและเจียรโลหะเท่านั้น