

Environmental Engineering FE CBT Exam

Knowledge: Health Hazards and Risk Assessment with 8 Example Problems

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1 Toxicology and Dose-Response Principles

1.1 Fundamental Toxicological Definitions and Concepts

Toxicology is the study of adverse effects of chemical, physical, or biological agents on living organisms. In environmental risk assessment, understanding toxicological endpoints is critical for establishing regulatory discharge standards, remediation cleanup goals, and occupational exposure limits.

- **Toxin vs. Toxicant:** A *toxin* is a biological poison produced naturally by living organisms (e.g., botulinum toxin, aflatoxin). A *toxicant* is a toxic substance produced by human anthropogenic activity (e.g., PCBs, TCE, heavy metals).
- **Dose (D):** The amount of a substance administered to or absorbed by an organism per unit of body weight over a specified timeframe (mg/kg-day).
- **Response (R):** The proportion of an exposed population exhibiting a specific biological reaction or adverse health outcome (e.g., mortality, organ damage, tumor formation).
- **Acute Toxicity:** Adverse health effects occurring rapidly (within minutes to days) following a single exposure or short-term high-dose exposure.
- **Chronic Toxicity:** Adverse health effects resulting from long-term, low-dose, repeated or continuous exposure over months, years, or a lifetime.

1.2 Lethal Dose and Lethal Concentration Metrics

Acute toxicity is quantitatively evaluated in laboratory animal assays using standardized lethal dose metrics:

Lethal Dose (LD_{50}) and Lethal Concentration (LC_{50})

- **LD_{50} (Lethal Dose 50%):** Statistically calculated single dose required to kill 50% of a test population under controlled conditions. Units: mg/kg.
- **LC_{50} (Lethal Concentration 50%):** Concentration in air or water that kills 50% of test organisms over a specified exposure duration. Units: mg/m³, ppm_v, or mg/L.

Inverse Relationship of Toxicity: A lower LD_{50} or LC_{50} value indicates a **higher chemical toxicity**, because a smaller quantity of the substance is required to cause lethal outcomes.

Table 1: Toxicity Classification Scale Based on Oral LD_{50} in Rats

Toxicity Category	Oral LD_{50} (mg/kg)	Probable Lethal Dose (Human)	Representative Chemicals
Extremely Toxic	< 5	A few drops (< 0.05 mL)	Dioxin (TCDD), Botulinum
Highly Toxic	5 – 50	1 teaspoon ($\approx$ 4 mL)	Parathion, Cyanide, Nicotine
Moderately Toxic	50 – 500	1 ounce ($\approx$ 30 g)	Chlordane, Phenol, Aniline
Slightly Toxic	500 – 5,000	1 pint ($\approx$ 500 g)	Malathion, TCE, Benzene
Practically Nontoxic	5,000 – 15,000	1 quart ($\approx$ 1 kg)	Glyphosate, Ethanol
Relatively Harmless	> 15,000	> 1 kg	Sucrose, Sodium Chloride

1.3 Dose-Response Curves and Threshold Effects

The dose-response curve plots cumulative response on the vertical axis against log-transformed dose on the horizontal axis.

1.3.1 Non-Carcinogenic Threshold Curves

Non-carcinogenic toxicological effects (e.g., hepatotoxicity, neurotoxicity, nephrotoxicity) exhibit a biological **threshold**. Below this critical dose, cellular repair mechanisms fully compensate for chemical damage, resulting in zero observable adverse effects.

- **NOAEL (No-Observed-Adverse-Effect Level):** Highest experimental dose level at which no statistically significant increase in adverse health effects is detected relative to control (mg/kg-day).
- **LOAEL (Lowest-Observed-Adverse-Effect Level):** Lowest experimental dose level at which statistically significant adverse health effects are first observed (mg/kg-day).
- **Benchmark Dose (BMD):** Lower bound dose corresponding to a predetermined benchmark response rate (e.g., 5% or 10% excess risk).

1.3.2 Carcinogenic Non-Threshold Model

Cancer risk modeling operates under the conservative regulatory assumption of a **linear non-threshold dose-response relationship**. It is assumed that even a single molecule of a genotoxic carcinogen interacting with DNA can initiate somatic cell mutation leading to malignant transformation. Thus, zero threshold dose exists for carcinogens; any non-zero exposure conveys a non-zero incremental cancer risk.

1.4 Derivation of Reference Dose (RfD) and Cancer Slope Factor (CSF)

1.4.1 Reference Dose (RfD) for Non-Carcinogens

The Reference Dose (*RfD*) is an estimate of daily oral exposure to the human population likely to be without appreciable risk of deleterious non-cancer effects during a lifetime.

Reference Dose (*RfD*) Equation

$$RfD = \frac{NOAEL \text{ (or LOAEL)}}{\prod UF \cdot MF} = \frac{NOAEL}{UF_H \cdot UF_A \cdot UF_S \cdot UF_L \cdot UF_D \cdot MF} \quad (1)$$

where $UF_H, UF_A, UF_S, UF_L, UF_D$ are uncertainty factors (default = 10 each), and MF is modifying factor.

For inhalation exposures, the equivalent parameter is **Reference Concentration (*RfC*)** in mg/m^3 .

1.4.2 Cancer Slope Factor (CSF) for Carcinogens

The Cancer Slope Factor (*CSF*) represents the upper-bound (95% UCL) lifetime incremental cancer risk per unit dose of a carcinogen.

Cancer Slope Factor (*CSF*) Definitions

$$CSF = \frac{\text{Incremental Lifetime Cancer Risk}}{\text{Lifetime Average Daily Dose (LADD)}} \quad (2)$$

Units of *CSF*: $(\text{mg}/\text{kg}\cdot\text{day})^{-1}$. **Inhalation Unit Risk (*IUR*):** Upper-bound excess cancer risk per $\mu\text{g}/\text{m}^3$ inhaled continuously over 70 years.

2 Human Health Exposure Assessment and Intake Dosing

2.1 Exposure Pathways and Conceptual Site Models

A complete exposure pathway consists of five primary elements: (1) Contaminant Source, (2) Release Mechanism, (3) Transport Medium, (4) Exposure Point, and (5) Exposure Route & Receptor.

2.2 General Intake Dose Equation

The U.S. EPA Risk Assessment Guidance for Superfund (RAGS) standardizes chemical intake calculations:

General Human Health Intake Dose Formula

$$I = \frac{C \cdot IR \cdot EF \cdot ED}{BW \cdot AT} \quad (3)$$

where I = Intake Dose (ADD or LADD) in mg/kg-day, C = Concentration, IR = Intake rate, EF = Exposure frequency (days/yr), ED = Exposure duration (yrs), BW = Body weight (kg), AT = Averaging time (days).

2.3 Averaging Time (AT) Distinctions

- **Non-Carcinogenic Effects (ADD):** $AT_{\text{non-cancer}} = ED \text{ (years)} \times 365 \text{ days/year}$.
- **Carcinogenic Effects (LADD):** $AT_{\text{cancer}} = 70 \text{ years} \times 365 \text{ days/year} = 25,550 \text{ days}$.

2.4 Specific Route Exposure Equations

1. **Water Ingestion:** $ADD_{\text{water}} = \frac{C_{\text{water}} \cdot IR_{\text{water}} \cdot EF \cdot ED}{BW \cdot AT}$ ($IR_{\text{water}} = 2.0 \text{ L/day}$, $BW = 70 \text{ kg}$).
2. **Air Inhalation:** $ADD_{\text{air}} = \frac{C_{\text{air}} \cdot InhR \cdot EF \cdot ED}{BW \cdot AT}$ ($InhR = 20 \text{ m}^3/\text{day}$).
3. **Soil Ingestion:** $ADD_{\text{soil}} = \frac{C_{\text{soil}} \cdot IR_{\text{soil}} \cdot 10^{-6} \cdot EF \cdot ED}{BW \cdot AT}$ ($IR_{\text{soil}} = 100 \text{ mg/day}$).
4. **Dermal Absorption:** $DAD = \frac{C_{\text{water}} \cdot SA \cdot K_p \cdot t_{\text{event}} \cdot EV \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT}$.

Table 2: Standard EPA Exposure Defaults for Residential Receptors

Parameter	Symbol	Adult	Child (1-6 yrs)
Body Weight	BW	70 kg	15 kg
Water Intake Rate	IR_{water}	2.0 L/day	1.0 L/day
Air Inhalation Rate	$InhR$	20 m ³ /day	10 m ³ /day
Soil Ingestion Rate	IR_{soil}	100 mg/day	200 mg/day
Exposure Frequency	EF	350 days/yr	350 days/yr
Exposure Duration	ED	24 yrs (adult) / 30 yrs (total)	6 yrs
Lifetime Averaging Time	AT_{cancer}	25,550 days	25,550 days
Skin Surface Area	SA	18,000 cm ²	6,600 cm ²

3 Risk Characterization Methods**3.1 Non-Carcinogenic Hazard Characterization****Hazard Quotient (HQ) and Hazard Index (HI)**

$$HQ = \frac{ADD}{RfD} \quad \boxed{\text{HQ} \leq 1.0: \text{adverse effects generally not expected; HQ} > 1.0: \text{further evaluation warranted}} \quad (4)$$

$$HI = \sum_{i=1}^n HQ_i = \sum_{i=1}^n \frac{ADD_i}{RfD_i} \quad \boxed{\text{HI} \leq 1.0: \text{adverse effects generally not expected}} \quad (5)$$

3.2 Carcinogenic Risk Characterization**Carcinogenic Risk Equations**

$$Risk = ILCR = LADD \times CSF \quad (\text{For Low Dose} \leq 0.01) \quad (6)$$

$$Risk = 1 - \exp(-LADD \times CSF) \quad (\text{For High Dose} > 0.01) \quad (7)$$

Target EPA Risk Range: 10^{-6} to 10^{-4} . Point of Departure / De Minimis: 1×10^{-6} .

4 Workplace and Occupational Health Standards

4.1 Occupational Exposure Limits

OSHA PELs (legally binding), ACGIH TLVs (recommended health guidelines), NIOSH RELs.

4.2 TWA and Chemical Mixture Formulations

Occupational TWA and Mixture Index (E_m)

$$TWA = \frac{\sum_{i=1}^n C_i \cdot t_i}{\sum_{i=1}^n t_i} = \frac{C_1 t_1 + C_2 t_2 + \cdots + C_n t_n}{8.0 \text{ hours}} \quad (8)$$

$$E_m = \sum_{i=1}^n \frac{C_i}{PEL_i} = \frac{C_1}{PEL_1} + \frac{C_2}{PEL_2} + \cdots + \frac{C_n}{PEL_n} \quad (E_m > 1.0 \implies \text{Limit Exceeded}) \quad (9)$$

5 Physical, Radiation, and Noise Hazards

5.1 Radiation Dosimetry and Inverse Square Law

Radiation Activity

Activity: $A(t) = A_0 e^{-\lambda t}$, where $\lambda = \frac{0.693}{t_{1/2}}$. Equivalent Dose: $H = D_{\text{rad}} \times Q$ (1 Sv = 100 rems). Inverse Square Law:

$$I_1 \cdot d_1^2 = I_2 \cdot d_2^2 \implies I_2 = I_1 \left(\frac{d_1}{d_2} \right)^2 \quad (10)$$

5.2 Sound Pressure Level and OSHA Noise Dose

Sound Pressure Level and OSHA Noise Formulas

$$SPL = 20 \log_{10} \left(\frac{P}{P_0} \right) \quad (P_0 = 20 \mu\text{Pa}) \quad SPL_{\text{total}} = 10 \log_{10} \left(\sum 10^{SPL_i/10} \right) \quad (11)$$

OSHA Permitted Duration (T) and Noise Dose (D):

$$T = \frac{8}{2^{(L-90)/5}} \quad D(\%) = 100 \sum \frac{C_i}{T_i} \quad TWA_{\text{dBA}} = 16.61 \log_{10} \left(\frac{D}{100} \right) + 90 \quad (12)$$

6 Overview of Solved Exam Practice Problems

Table 3: Summary Matrix of 8 Solved Practice Problems

No.	Problem Topic & Focus	Core NCEES Equation / Concept Tested	Target Page
1	Non-Carcinogenic Drinking Water Hazard Quotient	$ADD = \frac{C \cdot IR \cdot EF \cdot ED}{BW \cdot AT}$ and $HQ = \frac{ADD}{RfD}$	Page 7
2	Cumulative Hazard Index (HI) for Metal Mixture	$HI = \sum HQ_i = \sum \frac{ADD_i}{RfD_i}$ for liver toxicants	Page 8
3	Incremental Lifetime Cancer Risk ($ILCR$)	$LADD = \frac{C \cdot IR \cdot EF \cdot ED}{BW \cdot LT \cdot 365}$ and $ILCR = LADD \times CSF$	Page 9
4	Dermal Absorbed Dose (DAD) from Bathing	$DAD = \frac{C_{water} \cdot SA \cdot K_p \cdot t_{event} \cdot EV \cdot EF \cdot ED \cdot 10^{-3}}{BW \cdot AT}$	Page 10
5	OSHA Workplace Chemical Mixture Index (E_m)	$E_m = \sum \frac{C_i}{PEL_i}$ for additive organic vapor solvents	Page 11
6	Gamma Radiation Inverse Square Law & Shielding	$I_2 = I_1 \left(\frac{d_1}{d_2} \right)^2$ dose rate calculations	Page 12
7	Industrial Noise Addition & Sound Pressure Level	$SPL_{total} = 10 \log_{10} \left(\sum 10^{SPL_i/10} \right)$	Page 13
8	OSHA Cumulative Workplace Noise Dose (D)	$T = \frac{8}{2^{(L-90)/5}}$ and $D = 100 \sum \frac{C_i}{T_i}$	Page 14

7 8 Example Problems

Example Problem 1: Non-Carcinogenic Drinking Water Hazard Quotient

Problem.

An adult resident (body weight = 70 kg) consumes 2.0 L/day of drinking water contaminated with cadmium at a concentration of 0.015 mg/L for an exposure duration of 24 years, 350 days per year. The chronic oral Reference Dose (RfD) for cadmium is 5.0×10^{-4} mg/kg-day.

Calculate the Hazard Quotient (HQ) for this resident and determine if the non-carcinogenic exposure level and interpret the result as a non-cancer screening indicator under EPA Superfund guidance.

Select the correct answer:

- (A) $HQ = 0.41$; adverse effects generally not expected ($HQ \leq 1.0$)
- (B) $HQ = 0.82$; adverse effects generally not expected ($HQ \leq 1.0$)
- (C) $HQ = 1.23$; further evaluation warranted ($HQ > 1.0$)
- (D) $HQ = 1.64$; further evaluation warranted ($HQ > 1.0$)

Solution

Step 1: Identify Given Exposure Parameters: Contaminant concentration $C = 0.015$ mg/L, $IR = 2.0$ L/day, $EF = 350$ days/yr, $ED = 24$ yrs, $BW = 70$ kg, $RfD = 5.0 \times 10^{-4}$ mg/kg-day.

Step 2: Calculate Non-Carcinogenic Averaging Time (AT): $AT = ED \times 365$ days/year = $24 \times 365 = 8,760$ days.

Step 3: Calculate Average Daily Dose (ADD):

$$ADD = \frac{C \cdot IR \cdot EF \cdot ED}{BW \cdot AT} = \frac{0.015 \times 2.0 \times 350}{70 \times 365} = 4.1096 \times 10^{-4} \text{ mg/kg-day} \quad (13)$$

Step 4: Calculate Hazard Quotient (HQ):

$$HQ = \frac{ADD}{RfD} = \frac{4.1096 \times 10^{-4}}{5.00 \times 10^{-4}} = 0.8219 \approx 0.82 \quad (14)$$

Since $HQ = 0.82 \leq 1.0$, non-cancer adverse effects are generally not expected under the screening assumptions.

Correct Answer: (B)

Example Problem 2: Cumulative Hazard Index (HI) for Chemical Mixture**Problem.**

A groundwater aquifer supplying a municipal well contains three chlorinated solvents that cause non-carcinogenic hepatotoxicity (liver damage). The calculated Average Daily Dose (ADD) values and chronic Reference Doses (RfD) for an exposed adult resident are given below:
Calculate the cumulative Hazard Index (HI) for this mixture and interpret whether the result is a screening flag indicating that further non-cancer evaluation is warranted.

Select the correct answer:

- (A) HI = 0.95; adverse effects generally not expected (HI $\leq$ 1.0)
- (B) HI = 2.95; further evaluation warranted (HI $>$ 1.0)
- (C) HI = 4.15; further evaluation warranted (HI $>$ 1.0)
- (D) HI = 5.80; further evaluation warranted (HI $>$ 1.0)

Solution

Step 1: Calculate Individual Hazard Quotients ($HQ_i = ADD_i/RfD_i$):

- $HQ_{TCE} = \frac{1.20 \times 10^{-3}}{5.00 \times 10^{-4}} = 2.400$
- $HQ_{PCE} = \frac{2.10 \times 10^{-3}}{6.00 \times 10^{-3}} = 0.350$
- $HQ_{1,1-DCE} = \frac{8.00 \times 10^{-4}}{4.00 \times 10^{-3}} = 0.200$

Step 2: Sum Individual HQ Values to Find Hazard Index (HI):

$$HI = \sum HQ_i = 2.400 + 0.350 + 0.200 = 2.950 \approx 2.95 \quad (15)$$

Since $HI = 2.95 > 1.0$, the result is a screening flag; further evaluation is warranted, but adverse effects are not demonstrated by HI alone.

Correct Answer: (B)

Example Problem 3: Incremental Lifetime Cancer Risk (ILCR) from Drinking Water**Problem.**

A municipal water supply contains arsenic at a steady concentration of 0.008 mg/L. An adult resident ($BW = 70$ kg) drinks 2.0 L/day of this water for 30 years, 350 days per year. The EPA Cancer Slope Factor (CSF) for oral exposure to inorganic arsenic is $1.50 \text{ (mg/kg-day)}^{-1}$. Assume a standard 70-year lifetime. Calculate the Incremental Lifetime Cancer Risk ($ILCR$) for this resident and determine if it falls within the EPA Superfund target risk range (10^{-6} to 10^{-4}).

Select the correct answer:

- (A) $ILCR = 4.28 \times 10^{-6}$; Below allowable regulatory action limit
- (B) $ILCR = 9.40 \times 10^{-5}$; Within target risk range (10^{-6} to 10^{-4})
- (C) $ILCR = 1.41 \times 10^{-4}$; Exceeds upper target risk threshold of 10^{-4}
- (D) $ILCR = 3.43 \times 10^{-4}$; Exceeds upper target risk threshold of 10^{-4}

Solution

Step 1: Identify Given Carcinogenic Exposure Parameters: Arsenic $C = 0.008$ mg/L, $IR = 2.0$ L/day, $EF = 350$ days/yr, $ED = 30$ yrs, $BW = 70$ kg, $CSF = 1.50 \text{ (mg/kg-day)}^{-1}$, $AT_{\text{cancer}} = 25,550$ days.

Step 2: Calculate Lifetime Average Daily Dose ($LADD$):

$$LADD = \frac{0.008 \times 2.0 \times 350 \times 30}{70 \times 25,550} = \frac{168.0}{1,788,500} = 9.3933 \times 10^{-5} \text{ mg/kg-day} \quad (16)$$

Step 3: Calculate Incremental Lifetime Cancer Risk ($ILCR$):

$$ILCR = LADD \times CSF = (9.3933 \times 10^{-5}) \times 1.50 = 1.409 \times 10^{-4} \approx 1.41 \times 10^{-4} \quad (17)$$

Since $ILCR = 1.41 \times 10^{-4} > 10^{-4}$, cancer risk **exceeds upper bound of EPA target risk range**.

Correct Answer: (C)

Example Problem 4: Dermal Absorbed Dose (DAD) from Residential Bathing**Problem.**

A residential well contaminated with benzene ($C_{\text{water}} = 0.050$ mg/L) is used for daily showering. An adult resident ($BW = 70$ kg) bathes once per day ($EV = 1$ event/day) for 0.35 hours/event. The total exposed skin surface area is $SA = 18,000$ cm², and the dermal permeability coefficient for benzene in water is $K_p = 0.015$ cm/hr.

The exposure occurs 350 days/year for an exposure duration of 24 years. Calculate the non-carcinogenic Average Daily Dermal Absorbed Dose (DAD) in mg/kg-day.

Select the correct answer:

- (A) $DAD = 6.47 \times 10^{-5}$ mg/kg-day
- (B) $DAD = 1.84 \times 10^{-4}$ mg/kg-day
- (C) $DAD = 6.70 \times 10^{-4}$ mg/kg-day
- (D) $DAD = 1.35 \times 10^{-3}$ mg/kg-day

Solution

Step 1: Calculate Absorbed Dose Per Event (DA_{event}):

$$DA_{\text{event}} = 0.050 \text{ mg/L} \times 0.015 \text{ cm/hr} \times 0.35 \text{ hr} \times 10^{-3} \text{ L/cm}^3 = 2.625 \times 10^{-7} \text{ mg/cm}^2\text{-event} \quad (18)$$

Step 2: Calculate Daily Dermal Absorbed Dose (DAD):

$$DAD = \frac{(2.625 \times 10^{-7}) \times 18,000 \times 1 \times 350}{70 \times 365} = \frac{1.65375}{25,550} = 6.4725 \times 10^{-5} \approx 6.47 \times 10^{-5} \text{ mg/kg-day} \quad (19)$$

Correct Answer: (A)

Example Problem 5: OSHA Workplace Chemical Mixture Exposure Index (E_m)**Problem.**

An industrial hygiene survey at an automotive spray-painting facility measures airborne concentrations of three organic solvent vapors in the worker breathing zone over an 8-hour shift. The measured 8-hour TWA concentrations and OSHA Permissible Exposure Limits ($PELs$) are listed below:

Assuming additive toxicological effects on the central nervous system, calculate the mixture exposure index (E_m) and determine whether workplace atmospheric standards are violated.

Select the correct answer:

- (A) $E_m = 0.855$; In compliance with OSHA mixture standards ($E_m \leq 1.0$)
- (B) $E_m = 1.125$; Out of compliance with OSHA mixture standards ($E_m > 1.0$)
- (C) $E_m = 1.450$; Out of compliance with OSHA mixture standards ($E_m > 1.0$)
- (D) $E_m = 1.800$; Out of compliance with OSHA mixture standards ($E_m > 1.0$)

Solution

Step 1: Calculate Ratios and Sum Mixture Index (E_m):

$$E_m = \frac{75}{200} + \frac{45}{100} + \frac{60}{200} = 0.375 + 0.450 + 0.300 = 1.125 \quad (20)$$

Since $E_m = 1.125 > 1.0$, OSHA limit is **violated**.

Correct Answer: (B)

Example Problem 6: Radiation Exposure Rate and Inverse Square Law**Problem.**

A technician standing at a distance of 2.0 meters from an unshielded Cobalt-60 (^{60}Co) sealed gamma source receives an exposure dose rate of 15.0 mrem/hr.

If the technician steps back to a distance of 5.0 meters from the source, calculate the new gamma dose rate and determine the maximum permissible exposure time per 8-hour shift to avoid exceeding a daily administrative limit of 20.0 mrem.

Select the correct answer:

- (A) Dose rate = 6.0 mrem/hr; Maximum exposure time = 3.33 hours
- (B) Dose rate = 2.4 mrem/hr; Maximum exposure time = 8.00 hours (Limit not exceeded)
- (C) Dose rate = 2.4 mrem/hr; Maximum exposure time = 8.33 hours
- (D) Dose rate = 0.96 mrem/hr; Maximum exposure time = 8.00 hours (Limit not exceeded)

Solution

Step 1: Calculate Gamma Dose Rate at 5.0 m (I_2):

$$I_2 = 15.0 \text{ mrem/hr} \times \left(\frac{2.0 \text{ m}}{5.0 \text{ m}} \right)^2 = 15.0 \times 0.16 = 2.40 \text{ mrem/hr} \quad (21)$$

Step 2: Calculate Maximum Permissible Exposure Time:

$$t_{\max} = \frac{20.0 \text{ mrem}}{2.40 \text{ mrem/hr}} = 8.33 \text{ hours} \implies \text{Full 8.0-hr shift is safe } (D_{\text{shift}} = 19.2 \text{ mrem} \leq 20 \text{ mrem}) \quad (22)$$

Correct Answer: (B)

Example Problem 7: Addition of Incoherent Industrial Noise Sources**Problem.**

A manufacturing plant operates three large centrifugal blowers simultaneously in an indoor equipment room. When operated individually, the sound pressure levels measured at a central workstation are:

- Blower 1: $SPL_1 = 88$ dBA
- Blower 2: $SPL_2 = 91$ dBA
- Blower 3: $SPL_3 = 85$ dBA

Calculate the combined total sound pressure level (SPL_{total}) at the workstation when all three blowers operate concurrently.

Select the correct answer:

- (A) $SPL_{total} = 88.0$ dBA
- (B) $SPL_{total} = 91.5$ dBA
- (C) $SPL_{total} = 93.4$ dBA
- (D) $SPL_{total} = 98.0$ dBA

Solution

Step 1: Sum Sound Power Ratios:

$$\sum = 10^{8.8} + 10^{9.1} + 10^{8.5} = 630,957,344 + 1,258,925,412 + 316,227,766 = 2,206,110,522 \quad (23)$$

$$SPL_{total} = 10 \log_{10}(2,206,110,522) = 93.436 \approx 93.4 \text{ dBA} \quad (24)$$

Correct Answer: (C)

Example Problem 8: OSHA Cumulative Noise Exposure Dose (D)**Problem.**

An industrial machine operator is exposed to varying high-noise levels during an 8-hour workday, recorded as follows:

- 2.0 hours at 95 dBA
- 3.0 hours at 90 dBA
- 3.0 hours at 85 dBA

Using OSHA 29 CFR 1910.95 criteria (90 dBA 8-hr PEL, 5 dBA exchange rate), calculate the worker's cumulative noise dose ($D\%$) and equivalent 8-hour TWA noise level (TWA_{dBA}).

Select the correct answer:

- (A) $D = 87.5\%$; $TWA = 89.0$ dBA (In compliance)
- (B) $D = 106.25\%$; $TWA = 90.4$ dBA (Exceeds OSHA PEL)
- (C) $D = 125.0\%$; $TWA = 91.6$ dBA (Exceeds OSHA PEL)
- (D) $D = 150.0\%$; $TWA = 93.0$ dBA (Exceeds OSHA PEL)

Solution

Step 1: Calculate Permitted Duration (T_i) and Cumulative Dose ($D\%$): $T_{95} = 4.0$ hr, $T_{90} = 8.0$ hr, $T_{85} = 16.0$ hr.

$$D(\%) = 100 \times \left(\frac{2.0}{4.0} + \frac{3.0}{8.0} + \frac{3.0}{16.0} \right) = 100 \times (0.50 + 0.375 + 0.1875) = 106.25\% \quad (25)$$

$$TWA = 16.61 \log_{10}(1.0625) + 90 = 90.437 \approx 90.4 \text{ dBA} \quad (26)$$

Since $D = 106.25\% > 100\%$, standard is **exceeded**.

Correct Answer: (B)