



3. The nighttime temperature during the Bhopal disaster was roughly 40 °C. The boiling point of MIC is 39.1 °C. Assuming the pressure was about 1 atm during that night, in what state of matter would MIC mostly be at 40 °C?
4. Atmospheric air is a mixture of several gases. The two most dominant components in dry atmospheric air are 22% oxygen (molar mass is 32 g/mol) and 78% nitrogen (28 g/mol). MIC has a molar mass of 57 g/mol. (Assume that the gases in this context are ideal gases and the density of ideal gases are proportional to their molar masses.)
- Is a mole of MIC gas “heavier” or “lighter” than atmospheric air?
  - What is the significance of gaseous MIC being “heavier” or “lighter” than the atmospheric air?
5. According to the Occupational Safety and Health Administration (OSHA) in the United States, exposure as little as 3 ppm of MIC is immediately dangerous to human life and health.

$$3 \text{ ppm} = (7 \times 10^{-3} \text{ mg of MIC}) / (1 \text{ liter of air}) \quad \text{Note: } 1000 \text{ liters} = 1 \text{ m}^3$$

Mountaineer Field at Milan Puskar Stadium is located in Morgantown, West Virginia and serves as the home field for the West Virginia Mountaineers football team. Let us calculate the amount of MIC required to fill the football field up to a height of 2.0 m.

- The football field occupies an area of roughly  $5.5 \times 10^3 \text{ m}^2$ . What is the volume of air (in cubic meters,  $\text{m}^3$ ) of the football field up to a height of 2.0 m?

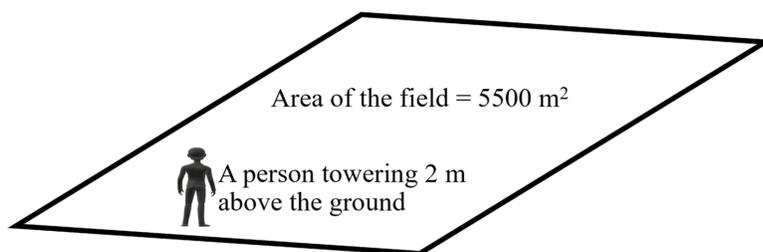


Figure 1. Mountaineer football field with a 2.0 m person towering above the ground (Figure not drawn to scale)

- Hypothetically, how many grams of MIC needs to be spilled onto the football field (assuming MIC gas hovers 2.0 m above the ground) for it to be dangerous to the football-watching audience, according to OSHA? (Use OSHA’s 3 ppm exposure limit and the volume of the air on the football field to obtain the lethal MIC dose in grams. Also, the hypothetical danger is to the football-watching audience standing at ground level.)
- How many metric tons is the amount that you calculated in grams? (1 metric ton = 1000 kilogram)
- During the day of the Bhopal disaster, nearly 30 of the 42 metric tons (tonnes) of MIC stored in Tank 610 of the pesticide plant escaped within a matter of an hour. How many Mountaineer football fields would the 30 metric tons of lethal amount of MIC fill? (Use OSHA’s determined exposure limit you calculated for 5(c) above.) Write your final answer in two significant figures.

6. MIC was used in the manufacture of a variety of carbamate pesticides. The four reactions below show how MIC was synthesized. Write a balanced reaction for each of the four steps.
- Petroleum coke (C) was reacted with oxygen to produce CO.
  - CO and chlorine were reacted to produce phosgene ( $\text{COCl}_2$ ).
  - Phosgene and methylamine ( $\text{CH}_3\text{NH}_2$ ) were reacted to produce methylcarbamoyl chloride ( $\text{CH}_3\text{NHCOCI}$ ) plus HCl.
  - Methylcarbamoyl chloride was then pyrolyzed to yield MIC ( $\text{CH}_3\text{NCO}$ ) and HCl.
7. What are some ways we can educate people to prevent these kind of incidents from happening or to mitigate the effects if they occur? (Consider people from every field, directly or indirectly connected to the chemical industries.)