I. INTRODUCTION

1. Air Pollution - General Nature of the Problem

2. Types of Air Pollutants

3. Sources of Air Pollution

4. Effects of Air Pollution

5. Air Pollution in India.
Two major issues, population explosion and nuclear war have gained worldwide attention for the last four decades as one of them marks the qualitative decline of human life while the other relates to the total destruction of human civilisation. But the biggest and most tragic problem man faces is the pollution of his environment. The pollution of human environment is multidimensional and can have local and global ramifications. Man has tried to conquer the environment. To man the overall environment has been a challenge, something to alter and change, crush and overcome. Technological progress brought about fundamentally different routes of matter and energy transfer in the environment which has disturbed Nature's delicate balance and equilibrium.

Two basic reasons lie behind the worldwide pollution of all kinds that we witness today. They are man's reckless reproduction and technological overdevelopment. Until recently, however people paid no attention to the long term consequences of their activity. Various developments in industrial and agricultural practices, and the growth of numerous cities have added many pollutants in the form of gases, liquids and solid wastes into the environment quite freely. Many substances of industrial, agricultural and domestic origin are not used by organisms and take no part in biological cycle of the biosphere or at any rate they are present there for a long time without decomposing or degrading. As a result, the Nature has lost its
capacity for self purification and can not cope with the alien load which man throws into it.

Tension and even crisis situation have arisen more than once in mankind's relationship with the nature during its historical evolution, but for the first time in many thousands of years man has come into a major conflict with the Nature as in recent decades there has been qualitative shifts in Nature's balance. It is this that has gripped the attention of people all over the world and consequently defence of the environment has come up as one of the most pressing problems of the day:

On the continents the harmful influence of industrial and other wastes is more or less localised although they affect considerable areas such as river basins, cities, inland seas and coastal waters and tend to produce a global effect. Air pollution has however, already attained global proportions.

I.1 AIR POLLUTION: General Nature of the Problem

From the beginning of time until 1900 AD, the population of the world increased to 1.7 billion. By 1974 world population had reached 3.9 billion, and the awesome figure of 7 billion is estimated by the year 2000 AD (Wark and Warner 1976). Increase in population combined with high standards of living has led to an intensified concentration of air pollutants in localized areas.
Air pollution is caused by wastes remaining from the ways we produce our goods, transport ourselves and our goods, and generate the energy to heat and light the places where we live, play and work. The major cause of air pollution is combustion and combustion is essential to man. When perfect or stoichiometric combustion occurs the hydrogen and carbon in the fuel combine with oxygen from the air to produce heat, light, carbon dioxide and water vapour. However, impurities in the fuel, poor fuel-to-air ratio, or too high or too low combustion temperatures cause the formation of such side products as carbon-monoxide, nitrogen oxides, fly ash and unburned hydrocarbons— all air pollutants.

The air around us (the atmosphere) is the most important part of our natural environment. Human activity, however, has polluted the air with biologically harmful substances and it is only in exceptional cases that the pollution is still insignificant. Air pollution is not a new problem. It has been around us for centuries. The atmosphere has always been polluted to some degree. But a scientific and technical review of the history of air pollution cannot commence much before the year 1850, for before that time, though there was much talk about the obnoxiousness of smoke, little knowledge was available and so no progress was made in the control of pollutants (Halliday, 1961).
In the past, industry, agriculture, and individual polluters have found it more economical to discharge waste products into the atmosphere than to exercise waste control. In general the organization or activity causing the pollution did not suffer from the consequences of the pollution; likewise, those who benefitted from a reduction in air pollution resulting from the installation of control equipment did not directly bear the cost of the equipment. In recent years, as the public has become increasingly concerned with environmental problems, air has come to be regarded as a resource within the public domain. Hence air pollution is considered a public problem, a concern not only of those who discharge the pollutants but also of those who may suffer as a result.

To have a clear and scientific understanding of the term air pollution, knowledge of chemical composition of 'clean' or 'normal' dry atmospheric air is required. Table I(1) lists the chemical composition of dry atmospheric air typically found in rural areas or over the oceans far from the land masses.

World Health Organisation (WHO) defined 'Air Pollution' as follows:

"Air pollution occurs when one or several air pollutants are present in such amounts for such a long period in the outside air that they are harmful to humans, animals, plants or properties, contribute to damage or may impair the well-being or use of property to a measurable degree" (Leithe, 1971).
### Table I(1): Chemical Composition of 'Normal' Dry Atmospheric Air

<table>
<thead>
<tr>
<th>Component</th>
<th>By volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N₂</strong></td>
<td>78.084 ± 0.0004%</td>
</tr>
<tr>
<td><strong>O₂</strong></td>
<td>20.946 ± 0.002%</td>
</tr>
<tr>
<td><strong>Ar</strong></td>
<td>0.934 ± 0.0010%</td>
</tr>
<tr>
<td><strong>CO₂</strong></td>
<td>0.033 ± 0.0010%</td>
</tr>
<tr>
<td><strong>Ne</strong></td>
<td>18.180 ± 0.040 ppm</td>
</tr>
<tr>
<td><strong>He</strong></td>
<td>5.240 ± 0.004 ppm</td>
</tr>
<tr>
<td><strong>Kr</strong></td>
<td>1.140 ± 0.010 ppm</td>
</tr>
<tr>
<td><strong>Xe</strong></td>
<td>0.087 ± 0.001 ppm</td>
</tr>
<tr>
<td><strong>N₂O</strong></td>
<td>0.500 ± 0.110 ppm</td>
</tr>
<tr>
<td><strong>CH₄</strong></td>
<td>2.0 ppm</td>
</tr>
<tr>
<td><strong>H₂</strong></td>
<td>0.5 ppm</td>
</tr>
<tr>
<td><strong>O₃</strong></td>
<td>0.01 ppm</td>
</tr>
<tr>
<td><strong>Rn</strong></td>
<td>10⁻¹³ ppm</td>
</tr>
</tbody>
</table>

(Ref: Ledbetter, 1972)
The pollutants in the atmosphere do not remain in the same quantity as they are emitted from the sources. The small particles and gaseous pollutants are removed from the air by the four mechanisms which are as follows (McCormac, 1971):

1) Chemical reactions in the atmosphere, although this may sometimes result in the production of new and toxic substances.

2) Scavenging by rain and snow, a process called washout.

3) Scavenging by cloud droplets which subsequently grow into precipitation, a process called rainout and washout.

4) Adsorption at the underlying surface sometimes called dry deposition.

Air pollutants can be classified in two general classes (Seinfeld, 1975):

1. Primary Pollutants: Those emitted directly from sources.

2. Secondary Pollutants: Those formed in the atmosphere by chemical interactions among atmospheric constituents and primary pollutants.
I.2: TYPES OF AIR POLLUTANTS:

Air pollutants are of the following major types (Laurent Hodges, 1973).

**Particulate Matter:**

Solid or liquid aerosols suspended in the atmosphere are referred to as particulate matter. They are of wide range of sizes varying from greater than 100 μm to less than 0.1 μm. Particles larger than 10 μm consist mainly of dust, coarse dirt, fly ash from industrial and erosion processes (Wilfried, 1972). The dust is usually so heavy that it is mostly deposited near its source. The smaller smoke particles remain longer in the air and affect larger areas. They are breathed into the lungs, where they remain permanently and blacken the tissues (Kenneth, 1980).

The 'Air Quality Criteria Document for Particulate Matter', published in 1969, defines the term 'particle' as "any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small gas molecules (0.0015 micrometer in diameter) but smaller than about 500 micrometers. The term total suspended particulate matter (TSP) refers to this entire range of airborne particles, whereas fine suspended particulate matter (FSP) is generally thought of as having a diameter smaller than approximately 1 to 2 microns (Frederica and Ahmed, 1979).
Particulate matter arise either from condensation processes or from dispersion processes (erosion, grinding, spraying, etc.). Particles less than 0.1 \( \mu \) undergo random Brownian motions resulting from collision with individual molecules. The characteristics of atmospheric particles are given in Table I(2). Most of the particles are removed from the atmosphere by gravitational settling.

Table I(2): Characteristics of Atmospheric Particles.

<table>
<thead>
<tr>
<th>Typical size</th>
<th>Name</th>
<th>Principal Nature</th>
<th>Settling speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.1 ( \mu )</td>
<td>Aitken particles</td>
<td>Combustion aerosols</td>
<td>Less than 8 ( \times 10^{-7} ) m/sec.</td>
</tr>
<tr>
<td>0.1 - 1 ( \mu )</td>
<td>Large particles</td>
<td>Combustion Product and Photochemical aerosols.</td>
<td>Intermediate</td>
</tr>
<tr>
<td>&gt; 1 ( \mu )</td>
<td>Giant particles</td>
<td>Natural and Industrial dust</td>
<td>Greater than 4 ( \times 10^{-5} ) m/sec.</td>
</tr>
</tbody>
</table>

(Ref: Laurent Hodges, 1973).

One of the most common effects of air pollution is the reduction in visibility resulting from the absorption and scattering of light by airborne solid and liquid materials. Air
borne particles can be chemically inert or chemically active substances. They may be inert but absorb chemically active substances from the atmosphere, or they may combine to form chemically active species. Depending upon its chemical composition and physical state, particulate matter causes wide damage to materials. Particles will soil painted surfaces, clothing and curtains merely by settling on them. More importantly, particulate matter can cause direct chemical damage either by intrinsic corrosiveness or by the action of corrosive chemicals absorbed or adsorbed, by inert particles emitted into the atmosphere. Metals ordinarily can resist corrosion in dry air alone or even clean moist air. However, hydrophilic particles commonly found in the atmosphere can corrode metal surfaces with no other pollutants present.

Animal health may suffer when the animal feeds on plants covered by toxic particulates. Such toxic compounds may be absorbed into the plant tissues or may remain as a surface contaminant of the plants. Fluorosis in animals has been attributed to their ingestion of vegetation covered with fluoride-containing particulate matter. The pollutants enter the human body mainly via the respiratory system. Damage to the respiratory organs may follow directly, since it has been estimated that over 50 per cent of the particles between 0.01 and 0.1 µm that penetrate into the pulmonary compartment will be deposited there (Wark and Warren, 1976).
Since the particulate matter is non-gaseous, its concentration in the atmosphere cannot be expressed in volume units and the accepted unit is the micrograms per cubic meter ($\mu g/m^3$).

**Sulphur Oxides**

The most important sulphur oxide emitted by pollution sources is sulphur dioxide ($SO_2$), although some sulphur trioxide ($SO_3$) is also generally produced in amount no more than a few percent of the $SO_2$. Sulphur dioxide is a nonflammable, nonexplosive, colourless gas that causes a taste sensation at concentrations from 0.3 to 1.0 ppm in air. At concentrations above 3.0 ppm the gas has a pungent irritating odour. Sulphur dioxide is partly converted into sulphur trioxide or to sulphuric acid and its salts by photochemical or catalytic processes in the atmosphere. Sulphur trioxide and moisture form sulphuric acid. The oxides of sulphur in combination with particulate and moisture produce the most damaging effects attributed to atmospheric air pollution.

Actually only about one-third of the total sulphur oxides in the atmosphere are believed to be produced by man's activities. It has been estimated that sulphur oxides from man's activities is emitted into the atmosphere as 132 million metric tons, largely from coal and petroleum combustion (Laurent Hodges, 1973). Natural sources of sulphur are biologically produced.
hydrogen-sulphide \((H_2S)\) (arising from decay of organic matter). That is eventually oxidised to sulphur oxides and sulphates.

Since aerosols of sulphuric acid and other sulphates make up from 5 to 20 per cent of the total suspended particulate matter in urban air, they contribute significantly to the reduction in visibility.

**Carbon Monoxide**

Carbon monoxide \((CO)\) is a colourless and odourless gas. It is very stable and has a lifetime 2 to 4 months in the atmosphere. It originates from the incomplete combustion of carbonaceous material and is the air pollutant emitted in the largest quantity (except, when \(CO_2\) is considered as pollutant). Carbon monoxide appears to have no detrimental effects on material surfaces. However, there are many studies which show that high concentrations of carbon monoxide can cause physiological and pathological changes and ultimately death. Carbon monoxide is a poisonous inhalent that deprives the body tissues of necessary oxygen.

**Hydrocarbons**

Hydrocarbons are chemical compounds containing only carbon and hydrogen. They may be open chain or cyclic compounds The
light hydrocarbons are gaseous at ordinary temperature. The motor vehicles contribute significant amounts of hydrocarbons in the atmosphere. Hydrocarbons are a very important component of photochemical smog. The naturally occurring hydrocarbon, methane, is the principle constituent of the fuel known as natural gas. It is colourless and odourless. Heavier hydrocarbons, such as those that occur naturally, e.g., petroleum are liquids.

The gaseous and volatile liquid hydrocarbons are the ones of particular interest as air pollutants. Hydrocarbons with more than about 12 carbon atoms are not present in the atmosphere in the concentration high enough to be of concern.

Studies of the carcinogenicity of certain classes of hydrocarbons do indicate that some cancers appear to be caused by exposure to aromatic hydrocarbons found in soot and tars. Identifiable airborne carcinogenic hydrocarbons are mostly Polynuclear aromatic hydrocarbons (Wark and Warner, 1976).

**Oxides of Nitrogen**

Although many different oxides of nitrogen are known, only nitric oxide (NO) and nitrogen dioxide (NO₂) are emitted to the atmosphere by man in significant quantities. They are formed by reaction of the nitrogen and oxygen in the atmosphere when
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combustion takes place at high temperature (typically exceeding 1100°C). Nitrogen dioxide can react with moisture present in the atmosphere to form nitric acid, which can cause considerable corrosion of metal surfaces. Nitrogen dioxide absorbs visible light and at a concentration of 0.25 ppm will cause appreciable reduction in visibility.

I.3: SOURCES OF AIR POLLUTION

Man-made pollution sources can conveniently be grouped under single or point sources, multiple or area sources and line sources. Point sources such as mills, power plants, oil refineries and pulp and paper mills etc. with their tall stacks are usually identified as major contributors to air pollution. Area sources are equally bad, residential areas, apartments, office buildings, hospitals and scattered point sources in an area are the greatest contributors. Line sources such as express ways so far seem to affect only vehicle drivers. However, in the narrow streets of the cities the automobiles constitute a great health hazards to the general public, not only because of its large quantity of pollutants but also because it emits the poison at breathing level. The US Public Health Service has cataloged the major sources of pollutants as follows (Wilfred Bach, 1972):

(1) Motor Vehicles: The exhaust gases from motor vehicles with gasoline and diesel engines are responsible for a considerable
(sometimes even predominant) degree for the pollution of air especially in cities. The toxicant level in the exhaust gases depends strongly on the driving conditions. While the CO₂ level is not important as a toxicant, the actual air pollutants occurring in the exhaust gas of the gasoline engines are CO, gaseous paraffinic and olefinic hydrocarbons originating from the cracking of the fuel, combusted fuel components, more highly condensed, especially polycyclic aromatic hydrocarbons and soot. Some polycyclic aromatics are considered to be carcinogenic.

(2) **Industry:** It is known fact that the air pollution is predominant in dense industrial areas. However, it depends upon the sizes and types of industries. It is the second greatest source of air pollution. Industrial processes produce special type of pollutants - sulphuric acid, hydrogen chloride, hydrocarbons, formaldehyde, formaldehyde, various alcohols and many other sophisticated chemical compounds, characteristic of our technological society.

(3) **Power Plants:** In power plants energy is generated by burning coal and oil. Because sulphur is one of the ingredients of these fuels power plants are the greatest contributors to sulphur dioxide (SO₂) pollution. Beside the power plants, as the greatest source of particulate matter, some polynuclear aromatic hydrocarbons are also emitted by the power plants.
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(4) **Space Heating:** Space heating is a source of air pollution in Western countries.

**I.4: EFFECTS OF AIR POLLUTION**

Air pollution causes physical, chemical and biological change or damage (Ledbetter, 1972).

**i. Physical:**

Some of the effects of air pollution are physical in nature, such effects are attributable to the transmission of or the absorption or reflection of electromagnetic radiations or sound waves or to the removal of pollutants from the air by physical means such as sedimentation, impaction, absorption and adsorption.

Physical effects may be visual (dirtiness or visibility attenuation), acoustical (noise or blast propagation), molecular energetic (electrical energy of ionization or kinetic energy of heat).

Dirtiness affects exposed surfaces and is especially noticeable on clothes, buildings, automobiles and even trees and plants, just as long as the colour of the particulate contrasts with that of the surface. Dirtiness also clogs air filters in autos, air conditioners, air compressors and so on. Obs-curation
or visibility attenuation is frequently taken as a measure of the degree of air pollution. Dirtiness or soiling indices have also been formulated.

Noise and blast may cause structural damage from overpressures or from fatigue.

Changes in the radiations or ions in our atmosphere may result from upsets in space radiations, especially solar activity, or from radiations from nuclear devices or locally from heat sources, lightening and other means. These radiations and ions cause disruptions of communication that utilize atmospheric transmission, and they can cause chemical and biological damage.

ii. **Chemical:**

The chemical entities in the atmosphere are subject to continuous change at greatly varying rates to other forms. As a result of this there occurs the cycles of certain elements and molecules in the environment for example, Carbon, Nitrogen, Sulphur cycles etc. Some of these species may cause atmospheric pollution.

The upper atmosphere receives most energetic photons and results in the ozone destruction at heights of 15-20 km. If there is a destruction of ozone layer, skin cancer occurs in living beings.
Oxidation reactions of air pollutants that occur at surfaces are more dangerous. Corrosion is enhanced by many of the common pollutants found in the atmosphere, but especially by the acid forming gases and particles and the acid mists. Corrosion occurs only slowly in arctic and desert regions and is most rapid in areas of industrial and salt spray pollution. Chemical erosion which is also frequently called corrosion, is important in some instances, e.g., acids on concrete and stone structures, hydrogen fluoride on glass, acid forming particles on paints and similar surface reactions.

iii. Biological:

(A) Effects on human health:

If the damage by one pollutant is of the same nature as that from another, but the actions of the substances are independent of each other, the pollutants are termed synergistic. There is considerable toxicological evidence to support the idea that there is a threshold concentration below which no physiological damage occurs.

Gaseous pollutants are inhaled and absorbed into the bloodstream in much the same manner as oxygen. Particles are breathed in with the air and deposited at varying efficiencies in different portions of the respiratory tract.
The correlation of smoking, air pollution on the microscale, with respiratory diseases, especially bronchities and lung cancer, has shown a very strong consistency.

The majority of the correlation efforts have been made to link respiratory diseases to air pollution. Lung cancer deaths have increased steadily. Most of this increase probably resulted from smoking. Particulate levels have been correlated with increased incidence of common colds and gastric cancer. Heart disease has been linked with broncho constriction related to general air pollution and sulphur dioxide.

(B) Effects on animals:

Although the evidence is not as well documented as it is for humans, it is apparent that many of the air pollution episodes which have been disastrous to man have been less accommodating on animals.

In addition to being subjected to suffering the ill effects of breathing polluted air, animals can become ill by eating fodder contaminated by air pollutants. Although the ambient air concentration may be low to cause any adverse effect, through inhalation, an accumulation and concentration of air borne contaminants by vegetation may cause poisoning in animals, when they eat the contaminated vegetation. Fluorides, arsenic,
molybdenum, lead and zinc have been identified as the responsible agents in several such occurrences.

(C) Effects on vegetation:

The pollutants which have the greatest potential for affecting the growth of crops and trees are SO$_2$, NO$_x$ and HF (Roberts, 1984). Of somewhat lesser severity are chlorine, hydrogen chloride, ammonia and mercury. In general, the gaseous pollutants enter the plants with air through the stomata in the course of the normal respiration of the plant. Damage can range from reduction in growth rate to complete death of the plant.

I.5: AIR POLLUTION IN INDIA

While the problem of air pollution is largely confined to the industrially advanced and technologically oriented countries, India though not industrialised to the same extent is not free from air pollution. It is an accepted fact that almost all large cities in India are exposed to the dangers of air pollution. Throughout India one encounters pockets of severe air pollution. While thermal power station is a major source of air pollution in a few industrialized cities peculiar and almost unique problem in all Indian towns and cities is the smothering smoke that envelops the sky in the evening like a haze, from burning cow-dung cakes, raw coal and dry wood from countless homes (Chandrasekhar, 1976).
In the second half of this century, India attained tremendous progress in the field of agricultural production, industrialization and overall social and economic advancement. And consequently all this progress with increased transportation contributes significantly to 'air pollution' mostly in urban environment and to a lesser extent in rural areas also.

Regular monitoring of air pollution trends in 10 cities since 1978 by the National Environmental Engineering Research Institute (NEERI), Nagpur, has shown that Calcutta is the most polluted city in terms of suspended particulate matter and sulphur dioxide pollution and Cochin the least polluted. Table I(3) gives air quality data for some of the important cities of India.

Table I(3): Air Quality in Selected Cities in India - 1982
(Annual 24 hrs average)

<table>
<thead>
<tr>
<th>City</th>
<th>SPM $\mu g/m^3$</th>
<th>SO$_2$ $\mu g/m^3$</th>
<th>NO$_x$ $\mu g/m^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ahmedabad</td>
<td>234</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>2. Bombay</td>
<td>148</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>3. Calcutta</td>
<td>418</td>
<td>81</td>
<td>24</td>
</tr>
</tbody>
</table>

(Contd....)
<table>
<thead>
<tr>
<th></th>
<th>City</th>
<th>SPM</th>
<th>Tr</th>
<th>Micrograms per cubic meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Cochin*</td>
<td>89</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Delhi</td>
<td>328</td>
<td>33</td>
<td>32</td>
</tr>
<tr>
<td>6</td>
<td>Hyderabad</td>
<td>173</td>
<td>14</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>Jaipur</td>
<td>279</td>
<td>Tr</td>
<td>18</td>
</tr>
<tr>
<td>8</td>
<td>Kanpur</td>
<td>307</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>9</td>
<td>Madras</td>
<td>145</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>Nagpur</td>
<td>161</td>
<td>10</td>
<td>9</td>
</tr>
</tbody>
</table>

Ref.: NEERI, Nagpur. Annual Report, 1982-83. Tr: Trace
SPM: Suspended particulate matter. *Seven month average.

The survey revealed that the ambient level of sulphur dioxide was 81 micrograms per cubic meter in Calcutta, while in Cochin it was 7 micrograms per cubic meter. The coastal cities of Bombay, Madras and Cochin had low pollution in terms of suspended particulate matter because of high humidity. Calcutta with 418 micrograms was the most polluted city followed by Delhi with 328.

Studies conducted by NEERI have revealed that the level of pollution due to automobile exhausts in Indian cities is reaching figures quite comparable with other major cities of the world (NEERI, 1983). In another report, Bombay is shown to have 62.5% air pollution by automobile exhausts and this value is reported to be the highest of all polluted urban environment in the world (Sah, 1985).
Evidence in India already links respiratory diseases, disorder of lungs, stunted growth in children and cancer with increased air pollution levels. Respiratory diseases are 12 times the national average in Delhi. In Calcutta, 60% of the population suffers from respiratory disorders caused by air pollution. In Bombay air pollution levels are already very high and the situation is not any better in other metropolitan cities (Bhushan, 1986).

The Bhopal Episode

Bhopal episode (1984) received a world-wide attention from all sections of the society as the disaster was of grave concern to Indians in particular, and to the world in general. The incident occurred in the early hours of December 3rd, 1984. Within a period of about 40-50 minutes, about 25 to 30 tons of methyl-isocyanate (MIC) was vapourized or decomposed and released into the atmosphere from Union Carbide Company India Ltd. (UCCIL). The release of a cloud containing MIC and thermally formed products between 12.30 and 1.30 a.m. caught all the residents of the area unaware as most of them were asleep.

The death toll after ten hours, was reported to be about 460; in the next 24 hours it rose to 700; and in few days to 2,500. Some deaths were reported in another four weeks, i.e., the entire tragedy took place in a period of less than a month; most of it, within a week.
Damage due to MIC was mostly to two systems, the respiratory system and the eyes. The damage to the respiratory system was more severe and permanent than to the eyes where damage appeared superficial and generally recoverable (Dave, 1985).