

**CHAPTER II.4**

**Use of Risk Analysis  
in Pollution Prevention**

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**SUMMARY**

Industrial pollution can be defined as the presence of toxic substances in air, water, or soil, often resulting from inefficiencies in production processes. The presence of these substances can present a health risk to humans or ecological systems. These risks can be estimated and compared using risk analysis methods. Therefore, risk analysis can serve to establish a priority of pollution problems based on the magnitude of risk that they pose either to human health or ecological systems.

Pollution can also be regarded as resources distributed in the wrong places, and pollution prevention at the source can be regarded as saving on resources and decreasing costs of production. Since economic risk analysis can indicate economic losses resulting from pollution, it can be used to encourage pollution prevention at the source as a means of improving the bottom line. Risk communication explains the data derived from toxicological risk analysis and economic risk analysis to decision makers in the most compelling manner to encourage pollution prevention at the source. This chapter will demonstrate some of the applications of risk analysis in dealing with industrial pollution.

*Key Words:* pollution prevention, source reduction, industrial, system analysis

## 1. MODERN RISKS ASSOCIATED WITH POLLUTION

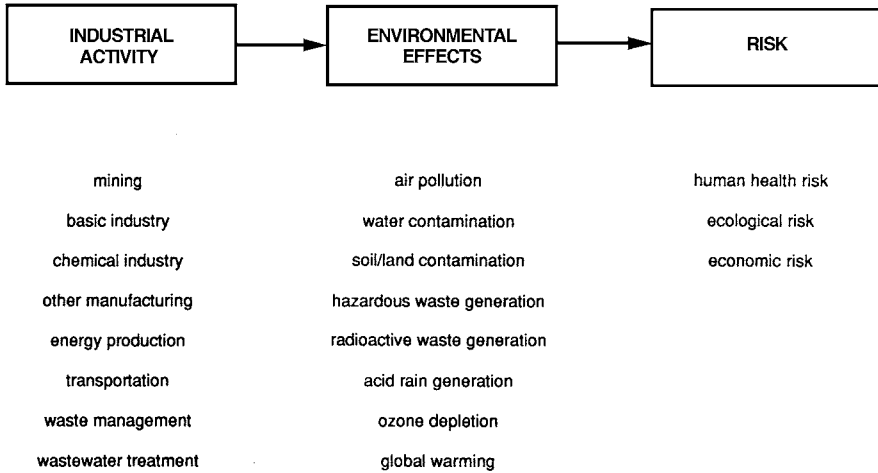
The following are examples of the changes in a modern industrial society that must be factored into risk analysis and risk management associated with industrial pollution.

1. Increased new risks such as those from nuclear plant accidents, radioactive waste, pesticides and other chemicals releases, oil spills, chemical plant accidents, ozone depletion, acid rain generation, and global warming.
2. Increased ability of scientists and equipment to measure contamination.
3. Increased number of formal risk analysis procedures capable of predicting *a priori* risks.
4. Increased role of governments in assessing and managing risks.
5. Increased participation of special interest groups in societal risk management (industry, workers, environmentalists, and scientific organizations), which increases the necessity for public information.
6. Increased citizen concern and demand for protection.
7. Realization that pollution is resources distributed in the wrong places; thus, by implementing clean technology, the companies have a chance to increase efficiency and profits.

Risk analysis can help manage technology in a more rational way to promote sustainability of desirable conditions of societies and eliminate those conditions that are detrimental to the well-being of humans (and ecosystems). [Figure 1](#) gives a schematic presentation of technological activities that can result in environmental pollution, which in turn results in risks to human and ecological health. Since many of these human and ecological health risks are associated with industrial pollution (air, soil, and water contamination), risk analysis can play a role in industrial pollution prevention by establishing the magnitude of risk associated with each pollution case and indicating which pollution prevention option will result in the highest reduction of risk (Shorthouse 1990/1991).

## 2. APPLICATION OF RISK ANALYSIS TO INDUSTRIAL POLLUTION PROBLEMS

In an ideal world, with unlimited resources, we could technically eliminate all industrial pollution and develop closed loop production systems with no waste generated. However, since our resources are limited, we should concentrate on the pollution problems causing most human health problems and environmental damage. Application of risk analysis to industrial pollution provides an opportunity to derive neutral sets of data and compare the magnitudes of problems in terms of human and environmental health and costs of alternatives. Until recently, most decisions regarding pollution management were made based on public perception. For example, a heavy smoker might tolerate a risk of 1:2 of emphysema, cancer, or heart disease, but would not tolerate a risk of 1:10,000 imposed on him by a factory releasing pollutants. Generally, the public accepts much greater voluntary risks than smaller

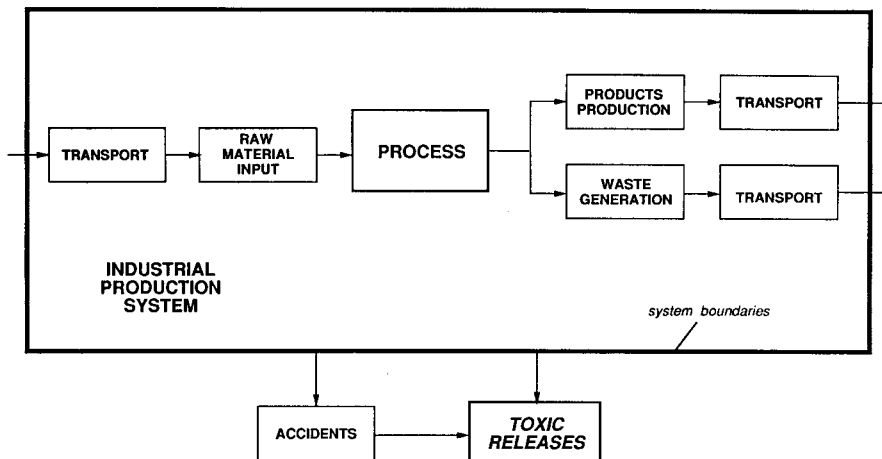


**Figure 1** Technological activities and their effects.

imposed (involuntary) risks (Slovic 1987). For example, dealing with hazardous waste sites is using up most of the U.S. Environmental Protection Agency’s (EPA) budget (Superfund), even though the health risks to population may be minimal. In last few years, the U.S. EPA and other federal agencies have emphasized risk analysis as a basic tool to determine the priority of environmental problems, rather than being pushed into action by the perception of risks (U.S. EPA 1990). Chapters on comparative risk analysis and setting environmental priorities address this problem in more detail (see [Chapters III.3](#) and [III.4](#)).

[Figure 2](#) depicts how a particular industrial plant can apply risk analysis at various points of production. Risks due to transport of raw materials, their input into process, production process, toxic releases, and products leaving the production process and their transport can be evaluated by using historical data, and measures could be taken to decrease the risks of accidents and resulting pollution. Within the plant, one can evaluate process safety (and probability for spill and/or accident that would result in pollution) by applying probabilistic risk analysis (see [Chapters I.4](#) and [I.5](#)). Based on this analysis, additional levels of safety may be introduced, and/or a change of equipment and process may be implemented. Based on probable magnitude of release resulting in air, water, and/or soil/land contamination, one can perform risk assessment of the effects of pollutants on human and ecological health. Similarly, “routine” releases can be evaluated using chemical risk analysis or carcinogen risk analysis.

With the passage of SARA, Title III law, a new opportunity appeared for an environmentally conscious design in manufacturing. Most manufacturing facilities have to submit a yearly inventory of pollution: routine toxic releases (as expressed in Toxic Release Inventories) and accidental releases in all media (air, water, soil, POTW, underground injection, off-site waste treatment facilities, etc.). Also, they have to reveal their pollution prevention, control, and waste management practices. Each industry filing a Toxic Release Inventory (TRI) report has an opportunity to



**Figure 2** Schematic presentation depicting various points of production in an industrial plant when risk analysis can be applied.

evaluate its practices using risk analysis. From measured concentration of pollutants in air, water, and/or soil, one can perform comparative risk assessments for each particular chemical or process and rank them according to the magnitude of risk (either probability of cancer or magnitude of exceeding reference doses [RfDs], air, or water criteria). Although the company may not violate any permits, it is conceivable that the potential exposures to toxic chemicals released from the plant may exceed safe levels. Each company can perform their own risk analysis. Numerous computer programs exist to simulate and evaluate health risks from chemicals (RISK-WARE 1994; see [Chapter II.6](#) on computer software for risk analysis). A good starting point for performing chemical risk analysis may be TRI reports, since they represent an inventory of pollution (even if incomplete).

Chemical risk analysis and economic risk analysis can be applied to evaluate various waste disposal practices. The impacts of alternatives could be evaluated using economic risk analysis, ecological risk analysis, and human health risk analysis, which could derive an optimal solution for a given problem. Based on such analyses, one can set priorities in pollution prevention. Description of risk assessments that could be performed by industries is described next.

## 2.1 Chemical Industry

Since the chemical industry deals with the largest number of toxic chemicals and processes, the application of risk analysis is most appropriate.

1. One could study the exposure of workers (from the existing data or from modeling routine releases) to raw materials, intermediates, releases, and final products (occupational safety standards). Based on these studies, one can devise reduction of releases of pollutants into the environment, with priority given to those posing the

greatest risk. Probabilistic risk analysis of the process safety (fault-tree analysis) could be used to pinpoint weak points in the system and thus decrease unintentional catastrophic releases. Attempts should be made to minimize the loss of chemicals (releases) during the process and establish safety measures to minimize the risk of other types of injuries (explosions, falls, etc.).

2. Hazardous wastes and/or toxic releases to air, water, and/or soil are other targets for risk analysis because of potential exposure of surrounding populations and ecosystems as the whole. TRI reports are an ideal starting point for such an analysis. Also, an economic analysis of various disposal options, recycling, and pollution prevention could point out optimal solutions.
3. Products themselves maybe highly toxic and, thus, may cause problems to the users that may outweigh benefits. However, it may be difficult to persuade a producer to stop producing a chemical that may be harmful and not really necessary (although the market has gotten used to it for various reasons), but brings financial rewards to the producer.

## 2.2 Other Manufacturing

One can perform risk assessments for any industry involving chemical pollution in a same manner as for chemical industry. Additional analysis may be performed on packaging material from a waste reduction point of view or economic risk analysis.

## 2.3 Hazardous Materials Handling and Pollution Control

Another argument for industrial pollution prevention could be by performing risk analysis of various pollution control options, which in many cases have led to environmental problems of great magnitude (soil contamination at Love Canal, dioxin contaminated soil in Missouri). Risk analyses of numerous hazardous waste sites indicates the magnitude of the problem, which was caused by the choice of inappropriate industrial pollution control option. Superfund risk assessments are part of standardized procedure in evaluating sites (U.S. EPA 1992b). Potential health and ecological risks associated with pollution control methods are

1. Exposure of workers and public to toxic chemicals (groundwater and surface water contamination):
  - a. Superfund sites (remedial investigation/feasibility study RI/FS) — Numerous such studies were performed both by the U.S. EPA and by industry to determine necessity and priority of cleanup of the site (U.S. EPA 1992a,b).
  - b. Other sites — Industry was often storing the waste on the premises or the plant, either in drums or partially degrading toxic chemicals and/or evaporating them by using lagoons. Such treatment of hazardous waste often results in site contamination and groundwater and surface water contamination.
2. Potential for generation of other, more potent, toxic chemicals by municipal solid waste incinerators. One of the byproducts in incineration performed at temperatures under 900°C is dioxin, a potent human toxicant and carcinogen (Mukerjee and Cleverly 1987). Also, incineration of other chlorinated organics results in chlorine generation, which in itself is highly toxic.

3. Contamination of waste water systems and waterways. Frequently, the largest number of toxic chemicals from the TRI list are released into sewers, eventually reaching POTW (publicly owned waste water treatment works) (Molak 1989). If such releases are done in a short period of time, they may cause die-off of microorganisms and subsequent pollution of waterways. Comprehensive ecological and economic risk analysis may point out the necessity for pollution prevention. For example, pollution of surface waters upstream increases cost of drinking water purification downstream in the communities depending on the river for drinking water. Such hidden costs could make a stronger argument from a business point of view for pollution prevention.

When pollution is evaluated from a system point of view, one can find that previously used options of treatment of hazardous waste are more risky (from a human health point of view and often from economic point of view) than pollution prevention. Thus, performing a risk analysis may be useful to make a case for pollution prevention.

## 2.4 Energy Production

Energy production is unfortunately often connected with industrial pollution. An increase of efficiency in energy consumption by industry can be regarded as pollution prevention. Different types of energy production, however, introduce different risks that could be evaluated and quantified. [Chapter IV.1](#) indicates some of the ways to improve safety in the nuclear industry. However, the Chernobyl accident may have altered the assumptions that have been made in conventional nuclear plants risk analysis, and some other energy sources may be preferable.

Although, in most cases, manufacturing plants do not have an option about which energy source to use, in some instances, they could opt for oil or gas vs. coal, based both on chemical risk assessment (lowest pollution option) or economic risk analysis.

## 2.5 Transportation

Transport of raw materials, finished products, and, very often, waste by industry also contributes to industrial pollution.

1. Air pollution. 60 to 70% of total air pollutants in any large city are generated by transport, both by industrial and individual vehicles. Major pollutants are CO, NO<sub>x</sub>, and organics which result in ozone development on the ground.
2. Routine and catastrophic spills of toxic chemicals during transport from production to consumers. The most frequent risks are posed by overturned trucks carrying gasoline or other oil products and toxic chemicals.
3. Routine and catastrophic oil spills (water and land). For example, the Exxon Valdez has alerted the public about ecological consequences of oil transportation. However, routine spills are even more hideous because total oil released by routine spills is twice that of the catastrophic spills.

Because of the pollution potential of transportation, more efficient flow of raw materials, products, and waste can be designed to minimize the amounts of materials carried and the types of carrier used. For example, per ton of material used, the least polluting and least expensive alternatives to trucks may be trains and/or boats (where applicable). From a system point of view, developing local markets for the products may be another way of decreasing pollution from transporting the products long distances.

### 3. APPLICATION OF RISK ANALYSIS FOR A PARTICULAR POLLUTION SOURCE

For each industrial pollution source, one can perform an environmental exposure assessment for the pollutants coming from that source. By comparing the particular exposure with the previously established criteria for that chemical (or derive the criteria using the risk assessment guidelines), one can establish possible human health and ecological risks from that industrial source. However, even in cases where the pollutant concentration in air, water, and/or soil do not exceed criteria, one could make a case for pollution prevention based on economic risk analysis. The scheme presented in [Figure 2](#) can be applied to a chemical plant that produces organic chemicals. For example, if plant X was found to use five processes that may result in catastrophic releases, a fault tree can be constructed for each process and for the overall plant (Shorthouse 1990/1991). Probabilistic risk analysis can evaluate the likelihood of an accident. Also, it can indicate amounts of toxic chemicals potentially released from such an accident. Chemical risk analysis can then evaluate possible adverse effects of such a spill on humans and ecological systems.

The human and ecological risks from routine releases can be evaluated separately based on known data of exposures and properties of the chemical. One can study both human health risk and economic risk. In many cases, it would be difficult to do a complete health risk analysis (air modeling, exposure modeling, etc.) for chemicals that companies have to report as TRI, since TRI provides only total yearly releases. However, in cases where patterns of releases are known, one can perform a valid chemical risk analysis and set priorities for pollution prevention.

Economic risk analysis based on TRI can be used to decrease pollution around companies, because TRI enables us to see the inefficiency of the process (forces company to evaluate its material flow). Data from TRI have used this approach to demonstrate economic losses in Hamilton County, Ohio, due to pollution (Molak 1989, 1991).

Based on a premise that pollution is resources distributed in the wrong places, economic losses of wasted resources in Hamilton county were calculated from total TRIs to amount to \$25 million (Molak 1989). Since TRIs report only 5 to 10% of released toxic chemicals, the estimated real value of loss is \$250 to \$500 million or \$250 to \$500 per person (Molak 1991). A rough estimate based on TRI in the United States is \$60 to \$120 billion. These numbers indicate that the cost analysis argument for waste reduction and pollution prevention may be compelling (Molak 1990).

A major objection to that argument is that it would take a lot more money to recapture pollutants from the smokestacks, waste water, or soil. This statement is valid only in the old paradigm of pollution control, where pollution is controlled at the end of the tailpipe. It is too late to capture pollutants at the end of the pipe, since at that point the entropy has already increased and large amounts of energy are needed to concentrate chemicals. However, prevention of losses of chemicals in the process itself or recycling of materials can bring about savings.

Often, it is difficult to prove that exposure to a given concentration of a particular pollutant causes harmful health effects, but since it cannot do any good, and companies are losing money on raw materials, it is prudent to prevent the pollution at the source.

#### 4. USE OF CHEMICAL INFORMATICS IN POLLUTION PREVENTION

In a complex industrial production plant, one way to understand the system under observation is to define its boundaries, as well as input and output material flows (Olbina 1991). A flow-chart diagram helps establish points of potential human and ecological health risks due to the release of toxic chemicals. Numerous computer risk assessment programs are available, which incorporate the previously or similarly described methods of risk analysis (RISKWARE 1994). [Chapter II.6](#) on software available for risk analysis can give the reader an update on the field and help the reader choose the most appropriate software for company needs. Based on the flow-chart diagrams and performed risk assessments, it is possible to find those processes where changes can be made to decrease risk and subsequently pollution. Pollution prevention strategies can be based on priorities obtained by carefully executed comprehensive risk analysis. All material and energy inputs and outputs can be accounted for and efficiency in production can be maximized. Reduction in material loss through releases to air, water, and/or soil can then be regarded as improvement in efficiency or process optimization. Comprehensive cost analysis could indicate where the profits could be most improved if pollution prevention were implemented.

#### 5. CONCLUSION

Application of risk analysis to industrial pollution has demonstrated that

1. Risk analysis can help establish priorities for pollution prevention in a particular production system by first dealing with toxic chemicals and processes that result in the highest human and ecological health risks.
2. Pollution can be regarded as resources distributed in the wrong places. The old paradigm of pollution control is economically less desirable than pollution prevention, as can be demonstrated by application of economic risk analysis.
3. Both economic and often public health cases for introduction of waste minimization and pollution prevention can be made by using risk analysis.

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## QUESTIONS

1. Define industrial pollution.
2. How can industrial pollution be viewed in terms of resource?
3. What is pollution prevention?
4. What is waste minimization?
5. What are the modern risks associated with industrial pollution?
6. List major industrial activities.
7. List major environmental effects of modern industrial activities.
8. How can risk analysis be used in pollution prevention?