HEALTH AND ENVIRONMENTAL PROTECTION

IN

PESTICIDE MANUFACTURING

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Preface

Christoph Schneider wrote this paper as a 1986 YSSP, working in the Environment Program with Dr. Carol Miller. The topic, "Health and Environmental Protection in Pesticide Manufacturing" is of current global significance, and Christoph has been successful in providing a useful overview.

R.E. Munn
Head, Environment Program

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1. INTRODUCTION

Debate on the safety of pesticide manufacturing has been stimulated by a significant increase in the scale and complexity in the manufacturing technologies involved and the occurrence of major accidents, for example in Bhopal, India, and Seveso, Italy (Table 1.1.). New technological and managerial techniques are needed to manufacture pesticides with acceptable levels of safety. The accidental release of toxic substances must be controlled. In the foreseeable future, crop protection will continue to depend on the use of pesticides, and pesticide manufacturing should taken into account both environmental and economic goals.

This report focuses on economically feasible control measures and management strategies for dealing with risk situations during the manufacture of pesticides. The concepts discussed herein are primarily directed to industrial and public authorities in developing countries. Environmental and health considerations throughout the technological life cycle of pesticide manufacture are elaborated.

2. THE ISSUE

2.1. General Considerations

In today's world with continuing growth in population, particularly in developing countries, it is important to secure a consistent food supply. Some governments and participants in the agricultural chemical industry claim that crop yields would drop by over sixty-five percent if pesticides were not used (UNEP, 1985). These same sources report that despite some risks to health caused by pesticide poisoning and damage to the natural environment during the production or the handling of end-products, the benefits of pesticide use outweigh the costs.

Table 1.1. Major Industrial Accidents in the Twentieth Century

YEAR	ACCIDENT	SITE	NUMBER OF FATALITIES
1921	Explosion in chemical plant	Oppau, Germany	561
1942	Coal-dust explosion	Honkeiko Colliery, China	1,572
1947	Fertilizer ship explosion	Texas City, USA	562
1956	Dynamite truck explosion	Cali, Columbia	1,100
1974	Explosion in chemical plant	Flixborough, UK	28[a]
1975	Mine explosion	Chasnala, India	431
1976	Chemical leak	Seveso, Italy	0(?)[b]
1979	Biological/chemical warfare plant accident	Novosibirsk, USSR	300
1984	Natural gas explosion	Mexico City	452+[c]
1984	Poison gas leak	Bhopal, India	2,500[d]

[a]3,000 evacuated
[b]700 evacuated, hundreds of animals killed, 200 cases of skin disease
[c]4,258 injured, 31,000 evacuated
[d]100,000 evacuated, 50,000 severely impaired

Source: Bowonder, Kasperson, and Kasperson, 1985

In the face of continued or increased pesticide use and consequently also production, public awareness, and concern for environmental problems has been stimulated. This has often led to the demand for more stringent controls in the areas of manufacture, retail, and application of pesticide products. Potential environmental problems arise from the conditions under which pesticidal chemical products are produced, the characteristics of input, intermediate and output products and contaminants, and worker ignorance. Problems occur when a toxic chemical departs from the regulated and controlled flow throughout its technological life cycle.

For pesticides, the manufacturing stage of the life cycle consists of multi-step chemical synthesis and a variety of formulating processes leading to multiple product outputs. Pesticide synthesis technology emphasizes the chemical aspects over the engineering aspects of the production process, and pesticide synthesis is regarded as a segment of the fine chemical industry. Various feed stocks are received from the heavy chemical sector and are utilized to produce the active ingredients of pesticides that must still be formulated by a variety of processes to make the products usable to the consumer.

2.2. Characteristics of Pesticidal Chemicals

In the United States, the Environmental Protection Agency (EPA) designates chemicals and wastes to be hazardous to man and the environment based on four criteria:

(1) toxicity (includes persistence and bioaccumulation)

(2) reactivity (includes stability)

(3) ignitibility

(4) corrosiveness

These characteristics will vary depending on whether the product is in gas, liquid, or solid form. The potential for cross-contamination is also emerging as a significant concern.

Pesticides are toxic by definition and each one has a certain level of biological and chemical reactivity. Reactivity depends on the control of the production process, the quality of the raw materials, and the conditions during handling and storage. The characteristics of pesticides must be understood to enable appropriate handling and storage. Corrosive and flammable chemicals must have appropriate containers.

The persistence of pesticides is most prominent in the soil. The persistence depends on the chemical agent's half-life and the properties of the receiving environment. Fugitive emissions from manufacturing plants add to the pesticide load in an affected area. The danger of persistence increases depending on the toxicity of the chemical. Degradation, volitization, binding with atmospheric and soil elements, and general absorption lead to the depletion of the persisting pesticide in the soil (Jury, et al. 1983).

Bioaccumulation is related to persistence because a non-persisting pesticide will rarely bioaccumulate in the environment. When pesticidal chemicals or wastes are accidentally or purposely released from their regulated pathway and reach surroundings where accumulation may occur in the biota, the rate of repair of the environment must be considered. Once an area has experienced contamination and organisms have been damaged or eliminated, then the rate of dispersion and dilution of the toxic pesticide, and the rate of biological regeneration will regulate the speed with which the environment will recover from the unnatural shock.

A pesticidal chemical must be stable enough not to decompose under the feasible range of conditions of manufacture, storage, and transportation (UNIDO, 1983). A stabilizer may have to be added to the chemical to ensure that no degradation will occur if the pesticide comes into contact with heat, air, light, water, certain metallic substances or oxides. Pesticidal chemicals can become flammable because of the solvents used. Each situation that makes a pesticide less stable increases the risk of molecular transformation and potential hazard to the environment.

Cross-contamination of pesticides has become a very serious problem in formulation plants which handle multiple active ingredients. The interaction of chemical compounds may result in a combined product with an unpredictable toxicity level. The properties of a pesticide product must be consistent. This means that the same product should always have the same color, flowability, and emulsifiability regardless of where the pesticide was manufactured as long as utilization occurs before the expiry date (UNIDO, 1983).

2.3. Possible Damaging Effects on Environment and Health

In the event that an accident should occur at a pesticide manufacturing plant or that emissions contain excessive quantities of chemical, then the effects will be felt throughout the human and envrionmental systems. The consequences may be immediate and visible or they may be more subtle and exhibit longer term effects on the natural ecosystem, human and animal health, and the economic, social and cultural systems. The negative effects can flow in a wide spread fashion and include areas that were not the target of the original direct effects of an accidental or casual emission.

In general, the main, direct potential hazards that operating pesticide plants pose to the environment are those concerning exhaust air, waste water and other wastes, accidental spillage, fires, and explosions (Agrochem. Manuf. Div., 1985). The direct impacts may be mediated by air, water, and soil and affect human health, animal and plant life. The impacts on air quality are caused by odors, gasses, and dusts from storage and transportation. Noise pollution, also transmitted through the air, is caused by the utilization of jet and hammer mills on the production site. Fish kill and the death of wildlife and domestic animals can be the result of contaminated groundwater which is itself caused by leaching and run-off. Polluted water may contain sufficient toxic chemical to render it unsuitable for domestic or industrial supply or the support of healthy marine life. Crop and forest areas might also suffer contamination, disease, and reduced yield as a result of air and water pollution. In addition, contamination may reach a level sufficient to impair microbial processes in soils, ruin aesthetic values and put the environment of endangered species and historical properties in jeopardy. Appropriate management, limitations on waste disposal and exhaust emissions, and monitoring will aid in preventing and controlling the more obvious and predictable hazards (Harmon, 1979).

Health effects in workers, residents, animals and other living organisms may be experienced in regions where exhaust and waste emissions from a pesticide plant are above a desirable threshold level. The range of consequences are termed acute, subacute, and chronic intoxication. Acute poisoning is immediate and can lead to death, while subacute leads to weakness and illness over time (i.e. workers unable to carry out their jobs), and chronic intoxication results from frequent and continued low level exposure that eventually may lead to serious medical consequences (Trape, 1985).

Other effects, often referred to as secondary effects because they are not the direct result of an overdose of toxic pesticidal substances, include the loss of personal happiness, reduced productivity of the population, and negative socio-economic impacts due to population migration and compensation. Areas can become unfavourable for living comfortably; the population may relocate (or be relocated) and depletion of the tax base for public services follows, leading to further deterioration of the living environment, eventually forcing government to request more money from industry which in turn raises product costs causing inflation and the process continues (D'Appolonia, 1982).

Jain and Hutchings (1978) suggest that a population influx due to economic possibilities (such as employment), and renewed prosperity in a region can lead to water pollution via inadequate sewage and garbage disposal systems, and a change in land use often resulting in further environmental and social damage if there is insufficient advanced planning. The introduction of a pesticide manufacturing industry into an area without appropriate local consultation can lead to disruptions of regional planning, local economies, and the environment (Jain and Hutchings, 1978). However, as long as health and environmental hazards are anticipated, controlled, or prevented, pesticide manufacturing can make a positive contribution to both local prosperity and the general economy.

3. RISK MANAGEMENT STRATEGIES

Appropriate management strategies are essential for dealing with risk situations. The basis of these strategies lies with actions to decrease the frequency of accident initiating events, to decrease the size of the hazard and to determine the most effective use of resources to achieve risk reduction. Some concepts or instruments required to implement such strategies are now discussed.

3.1. Assessment

In the literature on technological risk analysis procedures for assessing a possible risk situation have been developed (Cox and Slater, 1983). Such procedures generally stress that a list of possible failures throughout the production process must be drawn up, an estimate of the frequency of each failure must be made, and the consequences of failures (singly or in combination) are to be subsequently estimated.

Consequence estimation of failures in chemical manufacturing is usually done using comparisons with similar cases that have either occurred in the past or been simulated in the laboratory. Local doctors and monitoring agencies which conduct consistent, yet random epidemiological studies of human populations and environmental quality reviews collect the vital statistics that allow consequences of production failures to be estimated. In this case the extent of the consequences are estimated using the available data and postulated extrapolations. The agencies may also perform toxicological and ecotoxicological experiments in the laboratory. These laboratory trials allow the consequences of a chemical release into the environment to be estimated prior to an actual incident in the field. The problems with consequence estimation lie mainly in the uncertainties concerning the exact extent of a toxic chemical's effect in large scale, wide-spread doses, and the susceptibility of each individual relative to the type of chemical and the level of exposure.

The results of medical and environmental investigations are summarized and analyzed and recommendations for technological and managerial support systems are developed. As many of the risks as possible must be anticipated and calculated so that integrated policy approaches can be recognized and implemented. As a result of the Bhopal disaster, many chemical producers and manufacturers throughout the world are implementing risk analysis and are re-evaluating their safety, accident prevention, and industrial hygiene practices (Spurrier, 1985).

Three main types of events must be assessed:

(1) routine events,

(2) anticipated malfunctions, and

(3) severe impact, low probability events.

Routine events include the planned release into the environment of solid, liquid, or gaseous waste. Such routine releases must be controlled and monitored to ensure a margin of safety.

The anticipated malfunctions are primarily accidents which have something to do with plant maintenance and equipment replacement. In the presence of any repair and maintenance system some instruments may fail and material fatigue may arise. If such malfunctions have been anticipated, a strategy can be implemented to reduce the risk of its occurrence, switch to back-up systems, or negate the hazard, should an accident happen. With preventative and contingency planning, risks to the inhabitants and the environment can be neutralized.

Severe impact, low probability events must also be assessed. Often, these result from the simultaneous occurrence of several events, none of which would be catastrophic on its own. Precautions should be extensive and only an unexpected and drastic surprise could come about so suddenly that no control or containment would be possible. It is advisable to have emergency contingency plans for such a situation.

3.2. Quality Control and Analytical Service

Quality control includes the review of compliance with technological operating procedures, the quality of the pesticide product, the safety of the working environment, and the effectiveness of environmental protection procedures. Each plant would require an internal quality control specialist (or group), who is independent of the production control. This specialist should work closely with the management of the company and ensure that environmental protection plans are developed, understood, and implemented. The quality control specialist should be consulted on investment decisions involving facility and production expansion, compliance with national laws and regulations regarding pollution, building standards, employee safety, and training.

Each company should also have access to an external auditing team. The auditing team usually consists of experts from industry, government, and the public sector. The purpose of external audits is to survey the operation on a consistent basis and to report to management on compliance with environmental protection plans, and guidelines or standards for safe operation. Regular and expected audits have had the effect of stimulating management to maintain and promote the environmental, safety, and health aspects of pesticide manufacturing plants (Agrochem. Manuf. Div., 1985).

The government and/or its appropriate agency should hold each company responsible for company practices. External audit reports showing both the deficiencies identified and the remedial responses provide an excellent tool for demonstrating that responsibilities have been met.

An analytical service unit should be available to support protection and safety through chemical monitoring and analysis. Ideally, the central authority (government/agency) could provide this service to many plants. This authority should not only promote regulation and control, but should also be involved in industrial expansion, economic growth, and technical change. The authority should encourage intra-industry excellence by the monitoring and adoption of safety standards and by education with respect to health, safety, and environmental protection practices.

3.3. Risk Reduction

When attempting to attain appropriate safety levels, the potential hazards must first be foreseen and the methods for controlling them must be available and usable. Several methods can be employed to achieve risk reduction. The most widely used and effective are waste management, technological control, personnel training and systems monitoring.

In managing hazardous wastes from a pesticide manufacturing plant, it is wise to utilize specific strategies for reducing overall risks. These procedures include:

(1) process modification to minimize waste quantities generated,

(2) the transfer of waste to another industry for use,

(3) the reprocessing of waste to recover materials and energy, and

(4) the treatment of wastes into less harmful states that can be assimilated by the environment (D'Appolinia, 1982).

If an appropriate mix of these strategies is adopted by a production facility, there is a substantial reduction in the possibility of fugitive or accidental emissions of toxic industrial wastes into the environment. Each method is a key element in the larger scope of an integrated management policy for health and environmental safety.

Technological controls can not only reduce the frequency of accidents or other emissions, but also reduce the magnitude of any detrimental effects. In this area of management, there are three ways to control pesticide production systems output. They are:

(1) preventative or cause control,

(2) remedial control, and

(3) promotion of research and development.

In the first case the key idea is to prevent an accidental or fugitive emission before it happens by detecting and adjusting for preliminary disturbances. The effectiveness of management depends on the availability of advance knowledge of the source of a hazard or disturbance. It is management's responsibility to adjust for expected or unexpected variations in the specified process (Figure 3.1.). In the second case of remedial control there is a discrepancy between the actual situation and the standard system. If a deviation from the normal state exists, then some action must be taken to rectify the situation. The Bhopal disaster might have been avoided had something been immediately done about the excessive pressure in the methylisocyanate (MIC) storage tank when it was first noticed. The final effective method for arriving at appropriate control and safety measures it to promote applicable research and development. Ongoing research is expected to be directed towards the development of pesticides that are less toxic and less damaging to the environment as long as the consumers are willing to pay the price for the research. Most larger companies that have built pesticide manufacturing plants in developing countries do undertake this method of control to reduce future uncertainties, but there is often a lag in time before the information reaches and is implemented by the affiliate in the developing country.

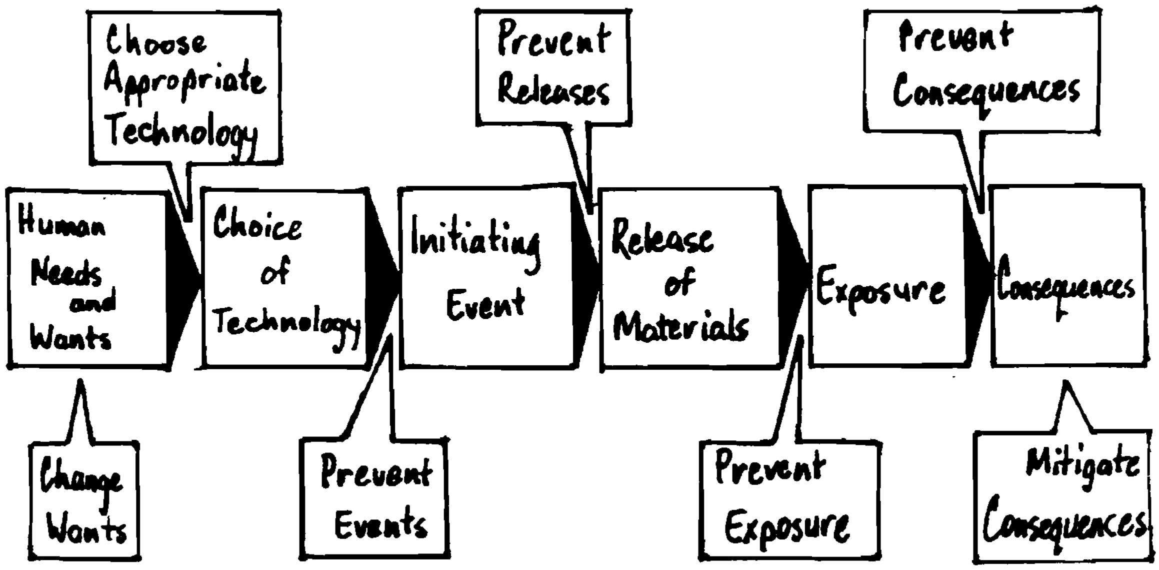

Figure 3.1. Points of management intervention for minimizing the risks and effects of an accidental or fugitive emission.
Source: Bowonder, Kasperson, and Kasperson, 1985

3.4. Education and Training

One of the most important methods to attain risk reduction is to adequately train plant operators and to regularly monitor performance. It is crucial for safe and efficient operation of the plant that all staff, whether managerial, technical, scientific or technically trained labor, is properly trained and informed. A key ingredient towards the effective and simultaneously environmentally protective operation of the facility is to employ experienced, high-calibre professionals in the decisive management positions. Senior department heads and special staff at intermediate levels must have proper education, training and expertise (UNIDO, 1983). There should exist a regular, well-designed training program for plant operators and maintenance mechanics because it is this personnel that has the most direct influence on the manufacturing process. In addition, staff turnover should be kept to a minimum, so that employees can develop experience, proficiency and safety awareness (UNIDO, 1983). Monitoring of the personnel, the condition of the facility and the production process will ensure early recognition of deviations from prescribed rules or specified standards.

3.5. Economics of Risk Reduction

Financial gains may be increased by reacting to specific economic stimuli while remaining environmentally conscious. Economically, the most advantageous condition would be to have optimal resource use while also achieving risk reduction. It is now accepted that economic losses (resulting from compensation and shut-downs), grow with the continuing delay of pollution control and environmental protection plan implementation. Therefore, the economic goals of a pesticide firm should be served both by increasing agricultural chemical productivity and maintaining reasonable levels of environmental protection (Harmon, 1979).

Between countries (or smaller administrative units) there should exist a jointly specified threshold level of potential risk respected in each country, and especially by the "upstream" users. Above such a level, the cost of liability may exceed the cost of environmental protection measures.

The gravest risk situation is ignorance; there is often no belief in potential hazard until it becomes reality. Risks are not taken seriously until it is too late to take preventative measures and society is left to pay for the damages. In trying to objectively educate an industry, society or individuals, problems arise if the risk/benefit balance is distorted, if there is a tendency to give maximum weight to the risk side of the equation and minimum weight to the benefit side, or if the likelihood of occurrence is given only slight consideration. In a number of societies, the goal of economic growth usually results in particularly strong pressures not to hinder technological innovation and economic development through environmental protection regulations (Gillespie, 1979).

As long as the aforementioned methods of management control are integrated into a feasible safety policy within the spectrum of set standards and specified regulations, then the potential risks to health and environment in the presence of pesticide manufacturing will be substantially reduced.

4. ENVIRONMENTAL AND HEALTH CONSIDERATIONS THROUGHOUT THE TECHNOLOGICAL LIFE CYCLE OF PESTICIDE MANUFACTURING

If a company plans to renovate, expand, or build a new pesticide production plant it is crucial that health and environmental protection be considered right from the beginning of the planning, siting, design and engineering stages. The earlier that health and environmental factors are incorporated, the less is the risk of an accident in the following stages and the more economically feasible is the decision to keep costs low while still meeting specifications.

In the production of pesticides there is a series of stages ranging from product development and registration, through plant design, siting and construction, operation and maintenance, to product transportation, marketing, and storage, that must be completed before a product is actually put to use in the field (Figure 4.1.). In addition to normal plant operations, special consideration must also be given to the possible decommissioning of the plant and unpredictable incidents such as accidents, sabotage and war. Different risks of an accidental leak, spillage, and explosion, or knowingly dumping wastes, excess product, and used containers may be associated with different stages and specific measures must be undertaken to reduce each potential hazard. These measures include proper planning, safety procedures, monitoring, control, education, and training.

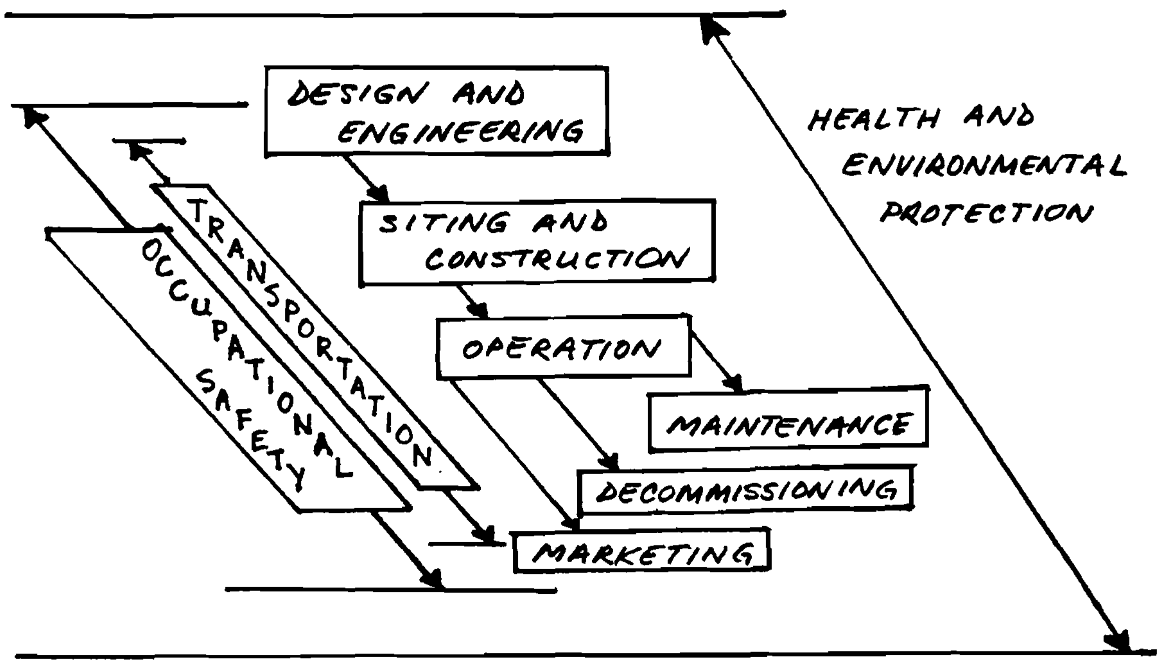

Figure 4.1. Technological Life Cycle Stages for Pesticide Manufacturing

Each vulnerable point throughout the technological chain must be supported through monitoring, backup technology and contingency plans. In order for good management to erase the weak spots and enhance risk reduction, the potential hazards must first be identified. Once potential hazards have been identified, they must be categorized according to the likelihood that they will occur (Harmon, 1979). The list of hazards will be shorter and likelihoods are reduced if the control and safety systems employed are effective.

The stages of the technological life cycle of pesticide manufacture and the associated health and environmental protection possibilities are now discussed.

4.1. Design and Engineering of the Production Facility

In order to include all essential safety and control measures in a pesticide company's policy framework and to have them subsequently be a part of normal plant operations, the measures must be considered at the conceptual or design stage. The results of risk analysis are used both in decisions such as permits to build new plants and in providing detailed information for improving the safety of present plant design (Cox and Slater, 1983). Before a pesticide manufacturing facility can be designed and engineered, a number of prerequisites must be fulfilled. These key issues include industrial hygiene and safety, and environmental protection. Another factor to be taken into account is the economic saving for the company and for the region if all protective aspects are considered ahead of time. Companies will save due to the utilization of practices such as waste recycling, the environment will benefit, and the regional authorities will be spared the energy and costs required to clean up after a chemical accident. At this stage, both the short and long term costs (or risks) and benefits are to be considered. When designing a new production facility, the economically preferred criteria are maximum input utilization and minimum or no waste. Excess output and equipment rinsings should be recycled when possible rather than simply disposed of in a less productive and environmentally damaging manner. This technology does exist and there is no question that it is also the economically preferred strategy, but it may prove to be costly if an attempt is made to convert an already established facility.

The best engineering plan of a pesticide manufacturing facility is achieved with complete knowledge of available technology on the synthesis and formulation of pesticidal chemicals. Technical comprehension should range from the basic construction concepts to effluent treatment and everything in between. Chemical and waste characteristics, volumes of production, and rates of flow are essential factors in plant design when complying with environmental specifications. The choice of technology for pesticide manufacturing often depends on environmental considerations if there are some prescribed codes or regulations. In developing countries caution is advised in the selection of technology, where it is being imported from, and for what reason. In these areas it is not always clear whether foreign investment and transfer of technology are of greater importance than health and ecological aspects.

Answers to potential environmental problems can be resolved by combining government initiative and support with sound planning and engineering. The hazard potential of a plant may be present, but it is possible, without undue difficulty, to redesign or design and build it in such a way as to be safe on a chosen site (Cox and Slater, 1985).

4.2. Siting and Construction of the Chemical Factory

The siting of a pesticide plant must consider the unique characteristics of the surrounding environment (Figure 4.2.). The construction of plant buildings should not interfere with rivers, irrigation ditches, other water courses and drainage systems in the vicinity. At a potential site soil samples ought to show that the soil structure is of the correct density, porosity and capable of supporting heavy buildings and machinery. Locations adjacent to timber mills, petrol stations, and other high-risk areas should be avoided. The manufacturing and storage facilities should have a certain buffer zone between it and agricultural land, wildlife parks, and population centers. The slope on which the pesticide factories are to be built must be flat in order to lower construction costs and to simplify environmental monitoring and control procedures. Building a plant where there are extensive fluctuations in the climate increases construction costs and the risks of weather influencing a chemical process being performed in the plant.

Site selection must provide for a sufficient source of labour in the vicinity and allowances must be made in the construction plans for the increase in waste that will accompany the immigration of a population into the region. So as to assess possible environmental impacts, a survey must be conducted of the existing conditions at the proposed site, and the probable quantity of wastes generated by the planned factory. Clearing areas for and around the plant may lead to surface runoff which is in turn associated with soil erosion and the eventual dispersion of

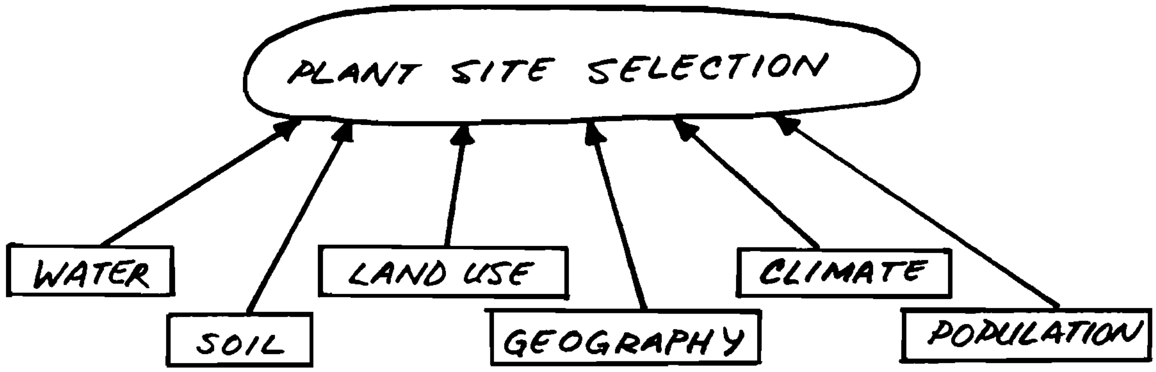

Figure 4.2. Influences on siting and construction.

environmentally hazardous plant effluents. It is important to choose a location for a pesticide plant which is not easily susceptible to natural disasters and still has the potential for expansion.

The timing of construction is crucial. For this reason it is of primary importance to consider the season in which construction is to take place. The risks to the environment and to the health of construction workers increase at times when the weather is unstable and the patterns are uncertain. The plant should be built so that an efficient transport system for inputs, outputs, and waste products can be linked to plant operations. The evaporation ponds, waste storage areas, and incinerator would be most effective if constructed on the site, thereby lowering the risks of disposal because transportation risks are minimized and the disposal facilities are distanced from the outside environment and population. On-site facilities can be more easily monitored and controlled. To further reduce potential hazards, the manufacturing facility should be characterized by impervious and slightly sloped floors, flameproof and earthed equipment, dust collectors with properly designed explosion vents, and an automatic sprinkler system (Agrochem. Manuf. Div., 1985). The MIC plant in Bhopal was constructed with numerous faults that led to disaster. There was a lack of linkages between equipment and control panels, a lack of general safeguards, a lack of automatically operated emergency systems and inadequate safety equipment (Castleman and Purkavastha, 1985).

The process of chemical synthesis is different from that of formulation and requires different equipment; therefore, the synthesis plant has some different construction specifications from those of a formulation plant. The basic safety measures for hazard reduction should be adjusted to the nature and complexity of the production technology.

4.3. Operation of the Production Facility

In the synthesis of pesticides the first step consists of the production of toxic starting materials, intermediates and active ingredients like benzene, camphen, dicyclopentadiene, chlorine, and methyl and ethyl alcohols, just to name a few. These are then processed further or formulated into pesticides to be available to the consumer. The synthesis process often requires complex chemical reactions, making the process vulnerable to a wide range of potential deviations. The greater the complexity of the processing chain and the greater the number and variety of intermediates or catalytic chemicals, the higher is the risk of realizing a potential hazard. Therefore, it is crucial to have special analyses for the control of chemical syntheses.

Formulation processes are usually simple and generally involve no chemical reactions. The most common types of formulation operations are the blending of liquids or the dissolving of a solid in a liquid. The final products in liquid formulation plants are mainly emulsifiable concentrates and solutions and rarely require a production process involving extreme temperatures and pressures that are common to the synthesis procedures. Pesticide formulation requires carrier and inert materials (fillers), absorbants and solvents that may themselves be potentially contaminating if expelled into the environment (Panfil, 1983).

In choosing the types of pesticides to be manufactured, certain selection factors are necessary. These include:

(1) a continuing shift in the requirement for different types of pesticides,

(2) the potential disturbance of the ecological system,

(3) the implications for standardization and quality control, and

(4) a proficiency in processing methods and technologies.

The basis for safe handling in the operation stage of pesticide manufacturing is knowledge of the physico-chemical and biological properties, and the reaction process of a particular product (Knuesli, 1985). To further reduce risks with additional information, the pesticide manufacturer requires knowledge of the intermediate and auxiliary chemicals handled in production and the adjuvents needed in formulation. Deviations from the prescribed quality of a pesticidal chemical, with respect to active ingredient content or composition, may cause harm to the environment and risk to the producer and user. In Seveso, where an intermediate required for herbicide manufacture was being synthesized, a runaway reaction caused a pressure increase that forced a valve to break and toxic vapour was released into the environment. It is imperative to control and monitor the reaction process to avoid or prevent ignition, fire and explosion, as well as to protect employees against exposure to critical levels of chemicals and to protect the inhabited and non-inhabited environment against dangerous emissions such as exhaust gas, liquid and solid wastes and products.

A serious concern which arises when dealing with the processing of chemicals is the complex waste that may be created. This complex waste consists of production wastes, waste waters from equipment rinsings, dumping of excess product and failed batches, and the disposal of containers. It is wise for a pesticide company to immediately activate equipment which removes any toxic materials because such a move will generate future savings and continued protection of the surroundings. Many pollution control techniques which reduce emissions produce economic benefits by reducing product loss and recovering usable compounds. The main methods for safely dealing with wastes are as follows: using filters and scrubbers for the decontamination of air, waste water treatment facilities to decontaminate and purify waste water, and incineration of toxic solid and liquid wastes (Agrochem. Manuf. Div., 1985). Even a safety conscious waste disposal technique such as incineration can lead to air pollution if special filters are not used. Between each formulation of a different pesticide product, the equipment is rinsed with solvent which must be carefully disposed of through the waste system. Wastes must be fully examined and the contents must be known. Appropriate methods of control can be implemented before any emission to the environment is allowed.

The effectiveness of treatment processes must be consistently evaluated and monitored during the life time of the plant. The main idea behind successful waste disposal is to retain the residual chemicals and attempt to neutralize the toxic substances or to enhance their degradation rather than to simply flush them into the environment through a drain or sewage system.

In developing countries the disposal of used input, output, or waste containers is often difficult due to the many ingenious uses for such containers. People in these regions often do not understand the dangers that they impose on themselves, their children and animals, and on their environment if, for example, water collected in the containers is used for drinking and watering small patches of crops

(WHO, 1985). It is, thus, essential that particularly these developing countries have programs for the safe cleaning, recycling, or permanent disposal of used containers.

Another high risk segment of pesticide plant operation involves the storage and inventory of reagents, intermediates, products and wastes. Both pesticide synthesis and formulation manufacturing plants require stable, durable and weather impermeable storage facilities for input as well as output products for two main reasons:

(1) it is becoming increasingly popular in the pesticide chemical industry to utilize batch process technology, which means that a large quantity of inputs must be readily available for bursts of multi-product output, and

(2) the pesticide market is a seasonal one resulting in stock build-up ahead of the buying season.

The storage facilities ought to be constructed to allow space not only for full pesticide containers, but also for empty containers awaiting disposal. The storage warehouse should be equipped with the necessary paraphernalia to control and clean-up accidental spills. The duration of storage should also be kept to a minimum. The prolonged storage of the intermediate MIC in Bhopal was inviting disaster because the smallest ingress of water, caustic soda, or even MIC itself is sufficient enough to set in motion a heat-generating chemical reaction (Bowonder, Kasperson, and Kasperson, 1985).

4.4. Transportation of Pesticidal Chemicals

Transportation is a leading area of risk in the technological life cycle of pesticide production. In this area accidents may not be as large as factory mishaps, but the frequency of an unexpected calamity on the route is greater than at most other stages of the cycle. The transportation of pesticidal chemicals need not be especially risky if necessary precautions are taken.

A wide variety of safety precautions can be taken with respect to the condition of the vehicle and the route, but the increased risks of transport are attributed to the fact that the results of the accident, such as spills or escaped gases, may be in isolated regions or difficult to contain in densely populated regions. To reduce these additional risks, special packing and care are required for the transportation of most raw materials, intermediates, and active pesticide materials. It is also strongly recommended that the labelling of pesticide containers include directions for how the product is to be handled during its movement. A technique for reducing the risks is to minimize the length of the transport routes and to ensure that the mode chosen is efficient, practical and safe. Decreasing the distance travelled requires that there be easy access to the plant and storage facilities.

An important step towards securing the safe transport of chemicals is the proper training and monitoring of staff. The staff involved with relocating the various chemical substances and final pesticide products must be educated in the toxicological and ecotoxicological properties of the substances. The production and transportation stages of pesticide manufacturing both require highly trained and motivated staff monitored by a high level of management attention.

Each of the transportation modes (whether road, rail, sea, or air), must be a storm-proof network. The greater the frequency of use of a particular route or vehicle, the greater the importance for continual controls and services. Any time pesticides are being moved, it is imperative that they have their own compartment and that they are not together with foodstuffs and other goods destined for human or animal consumption (UNIDO, 1983). The pesticide containers must be secured during transport so not to be damaged in a fashion that would lead to leakages. Transporters of toxic chemicals must be informed as to the best decontamination procedures for their vehicles, which should be inspected at regular intervals (UNIDO, 1983). The roads, railway tracks and stations, airports, harbours, or shipping routes chosen should be both physically and politically safe. Although the risk of an accident during transport is not always apparent, vehicles moving pesticidal chemicals must carry documentation about the type, origin and destination of the load.

In many countries, transporters of pesticides are obligated to follow set rules. To prevent or cope with accidents that may occur during the moving process, the agency (government, industry, or private) responsible for monitoring and compliance should be clearly designated. Numerous international regulations and agreements have been designed for transport by road, rail, sea, and air. They include: Guidelines of the International Civil Aviation Organization (CIAO), the International Air Transport Association (IATA), the International Marine Organization (IMO), the International Convention on Transport of Dangerous Goods by Road (ADR), and the International Regulations concerning the Carriage of Dangerous Goods by Rail (RID) (UNEP, 1985).

4.5. Marketing of Pesticide Products

Other important aspects of the pesticide marketing process, where safety measures for health and environmental protection are still the responsibility of the manufacturer, include packaging, labelling, and storage before sale to the consumer. The industrial pesticide producer, whether he is synthesizing or formulating a product, should have close coordination with the packaging manufacturer when considering required packaging regulations (UNIDO, 1983). The flammable and non-flammable pesticide products should be stored separately and in a well ventilated area during their life at the plant or any time during distribution. The same rule goes for keeping herbicides separate from the insecticides and fungicides to lower the potential of extensive environmental damage should the products cross-contaminate and be released. The containers must be leak and break proof for a predictable length of time and they must withstand transport, handling and the climatic and storage conditions to which they may be exposed (WHO, 1985). When locating a storage area for the containers, the surrounding land and use thereof is to be carefully surveyed. Ideally the store should be constructed out of solely non-flammable materials. In addition, every pesticide warehouse or retail store should be insulated and outfitted with automatic ventilators (UNIDO, 1983).

The size of the containers should be limited so that no single rupture could release a dangerous amount of chemical. Drums should have a protective coating and be tightly sealed (WHO, 1985). The final formulated pesticide products that are sold to consumers should be in packages designed to limit hazards during pouring, mixing and refilling. The active ingredient, intermediate, or finished product pesticide containers should be clearly labelled, giving concise instructions on use and on the avoidance of hazards. Proper labelling enhances safety and reduces the risk of misuse (Figure 4.3.). A label must also give information on the approved name and content of active ingredient in the pesticide product, proprietary name, net weight of contents, batch or reference number, date of manufacture and the name of the manufacturer (WHO, 1985). For more hazardous pesticide compounds, possibly being shipped between synthesis and formulation plants, the label must include information on the severity of the toxicity of the product, and on the procedures for storage and disposal of the product and empty containers (UNIDO, 1983).

The area of pesticide application has been the most popular with respect to the hazardous impacts on man and nature. Research, regulation, and an overall increased education of the user have all contributed to substantial risk reductions in field operations.

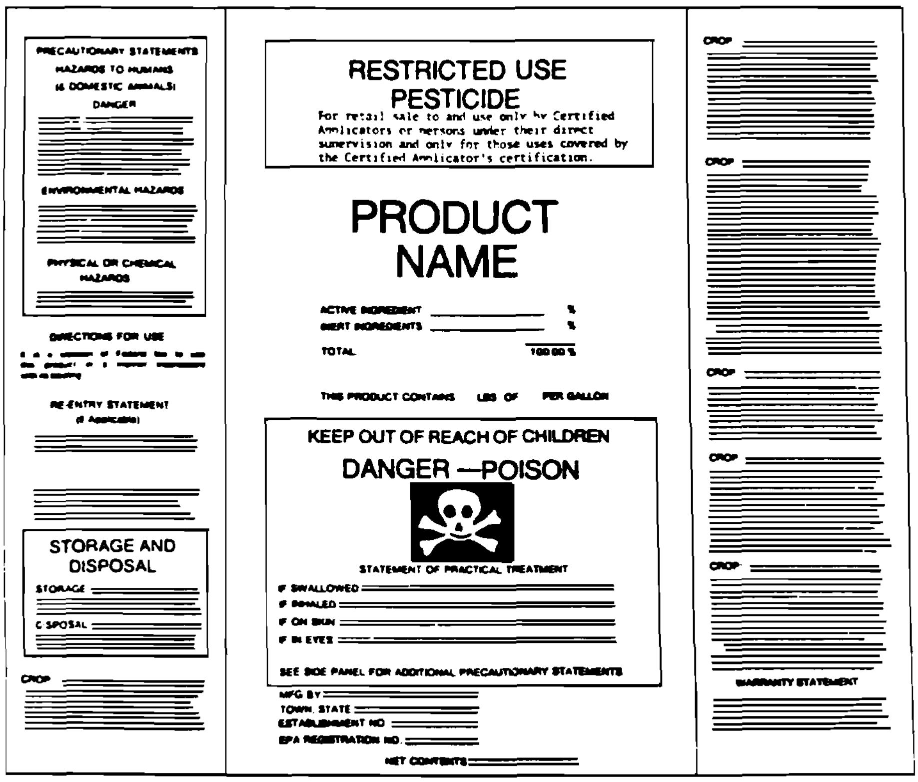

Figure 4.3. Proper format of a pesticides label.
Source: UNIDO, 1983

4.6. Condition of the Pesticide Plant

Equipment and buildings depreciate and as a result they require regular maintenance or replacement to ensure smooth running operation with as little potential threat to human health and the environment as possible. Health protection devices and the production machinery must be properly maintained and functioning in order to prevent continuous exposure of workers and to reduce the risk of an accident. The safety valve of the reactor in Seveso had an inadequate protective device, so the toxic vapours blew into the atmosphere over an area southeast of the plant (Bisanti, et. al., 1981). In Bhopal virtually all of the safety systems designed to prevent the release or to neutralize the escaping deadly vapour cloud were either of insufficient capacity, in disrepair, or shut-down. In fact, the accident actually occurred during maintenance activities (Castleman and Purkavastha, 1985). Safe operation and production efficiency are both enhanced with continuous maintenance. Environmental protection and economic goals are related at the maintenance stage. Monetary savings exist for a pesticide company which is not forced to shut-down for extensive repairs or compensate for damage to the environment and humans.

Maintenance staff must be continually prepared to deal with spillages or breakdowns (UNIDO, 1983). Preventive maintenance consists of monitoring, control, and necessary adjustments to prevent a breakdown of equipment during the operation thereof; breakdown maintenance requires the swift and proper repair of failed equipment. New developments in production, packaging techniques and equipment need to be brought to the attention of pesticide producers, to modernize existing plants or establish new facilities (Panfil, 1983).

An appropriate maintenance and repair system creates confidence in production, continued desire for successful innovation and expansion, and a good safety record. The maintenance system must cover everything from internal transportation methods and processing equipment to waste disposal and emergency alarm systems.

If a plant has swift identification and repair of deteriorating elements or malfunctions, then employees can more easily concentrate their efforts in other risk saturated areas of the production process. Worker safety mindedness and consciousness play a key role in maintaining a well-functioning pesticide manufacturing plant with low probability of an unexpected malfunction (Knuesli, 1985).

4.7. Decommissioning of the Chemical Plant

There are times when a pesticide plant may experience severe financial difficulties and be forced into bankruptcy, times when research and development of new products has created different demands, or simply times when equipment and machinery become faulty or obsolete. The problems of dismantling and disposing of the facility arise. Leaving the plant standing or careless removal of the components can lead to direct environmental damage. The concern not only lies with the plant buildings and machinery, but also with left-over stored pesticide products, other active ingredients and wastes. In developed countries, it is somewhat easier to deal with the dismantelling dilemma because there is a reasonably large resale market for used equipment, but this market is often inaccessible for the developing countries. Often, it is less expensive for a pesticide company to just abandon the plant rather than to dispose of it in a protective manner.

The dismantelling should take place during a season when weather will not cause the unanticipated dispersion of toxic substances into the surroundings. It is essential to have an expert in environmental management available to determine whether dismantelling is necessary, which is the preferred technology to follow, and how the chemical residuals may be safely decomposed or removed. Although it may be difficult to achieve, it would be to society's advantage if this entire process were under the control of an expert agency.

4.8. Occupational Safety

The health of workers involved in the synthesis and formulation of pesticides and the quality of the working environment are at risk unless special precautions are taken. The manufacturer plays a key role in educating and training the workers so that they have sufficient knowledge about the raw materials and final products, the production process, and how to deal with both routine and critical situations should they arise. Employees must also be educated in maintenance needs and safety, hygiene, and environmental considerations (UNIDO, 1983). High employee turnover and the desire to reduce management staff led to untrained people doing hazardous tasks at the Bhopal plant. Also in Bhopal, employees noticed irritating MIC vapours three hours before the plume of gas was emitted, but nothing was reported because this was recognized as a frequent occurrence (Castleman and Purkavastha, 1985). Employees at a pesticide manufacturing plant must have access to protective and safety equipment, protective clothing, respirators, fire blankets and qualified medical aid (WHO, 1985).

In the areas where pesticides are produced and used, antidotes should be easily available for people who have been contaminated. In each plant every employee should be required to wear monitoring devices which are capable of registering the amount of and duration of exposure to pesticides or other toxic substances utilized in the processing (Table 4.1.). If exposure of a worker is suspected, he should be under observation for the time interval between exposure and expected appearance of symptoms. Any treatment must be immediate to reduce the risk of long term discomfort and sickness. Skin contact is the most common cause of poisoning, while inhalation is probably one of the quickest ways of being poisoned (UNIDO, 1983). Operators must be instructed to keep the facility as clean as possible, void of dust, open flames and the build-up of static electricity. Training and educating the operators reduces the chance of operator error or equipment malfunction.

Table 4.1. Workplace limits to chemical exposures set by the American Conference of Governmental Industrial Hygienists.

CHEMICAL	PARTS PER MILLION[a]
Carbon monoxide	50.00
Chloroform	25.00
Methylamine	10.00
Benzene	10.00
Acetic acid	10.00
Cyanogen	10.00
Phosgene	0.10
Methyl isocyanate	0.02

[a]Time-weighted averages for 8-hour exposure
Source: Bowonder, Kasperson, and Kasperson, 1985

A set of internationally accepted standards with respect to the education and training of pesticide manufacturing plant employees should be documented. As a result of general lack of education and training, the World Health Organization (WHO) conservatively estimates that approximately 500,000 people suffer agrochemical poisoning for a variety of reasons each year in developing countries and that some 5,000 of these die (UNEP, 1985).

4.9. Unpredictable Incidents

The major operational risks associated with the technolgical life cycle of the manufacture of pesticides have been discussed in the preceding part of this paper. Routine variations, anticipated malfunctions and severe impact, low probability events can be brought under control through preventive technology and personnel training. The probability of more extreme events such as a large scale industrial accident, sabotage, or war are relatively low as long as the necessary precautions are implemented, the political situation in the region is stable, and the industry makes no local enemies. Even though such risks appear to be very low, provisions must be made in case an unpredictable event should become reality. In order to compensate for unexpected situations emergency contingency plans must be drawn up and publicized to the potentially affected population.

In case of disaster, accident, power failure, or damage to equipment, emergency and evacuation plans should be agreed upon by all parties concerned (i.e. plant operators and management, local authorities, hospitals and fire brigade services), in order to limit the consequences of an incident. The result of not having such plans are vividly demonstrated in the Bhopal accident. The time immediately following an accident is the most crucial and qualified personnel, proper equipment, and clear and understandable instructions must be available.

In the event of a mishap the hazard area is to be first identified, and subsequently isolated. In the plant itself, an alarm should sound and the regularly practiced evacuation procedure should commence. Persons exposed to the chemical should be immediately treated and placed under medical observation (UNIDO, 1983). As a result of different locations and varying weather conditions no one recommendation will be appropriate in all accident situations. Personnel should take simple steps for immediate action and a technically competent person should soon be on hand to analyze the extent of the release and assess the actual hazard.

One of the key steps in dealing with an emergency situation in pesticide manufacturing is to inform the public without hesitation once the hazard has been identified. In order to reduce the risk of panic, public discomfort and discontent, environmental damage and even loss of life, a designated agent should be responsible for releasing unbiased and reliable information. In Bhopal, the public was not informed about the potential hazards to their health and environment posed by the plant, the operators were not aware of the grave consequences of the leak when it really happened, and doctors were not informed on how to treat affected victims (Bowonder, 1985). The agent can be associated with the national government and must act as the link between agencies and participants involved in the adverse situation. The plant's agent in Seveso only publicized full information on the toxic substances released in the accident nine days after it happened. Therefore, people were not immediately submitted to protective measures against the damages caused by all the poisonous chemicals (Bisanti, et. al., 1981). Past incidents can be analyzed to provide additional information on alternative and effective emergency contingency plans.

5. CONCLUSION

Pesticide manufacturing does not have to be a particularly feared or risky industry. Foresight, appropriate technology, personnel training and management should ensure a better, healthier environment and a higher level of productivity. Environmental protection must be considered a valuable resource and the costs for it must be paid now or in the future. Environmental protection measures should be promoted as an investment for every pesticide manufacturer.

The United Nations Industrial Development Organization (UNIDO) has brought forth many arguments for environmental protection. In the past industrial development has been viewed as a basis for economic growth and environmental protection has been seen as a separate and expensive goal. This paper argues that environmental protection *generates* resources through more efficient utilization of raw materials and preservation of valued environmental resources. UNIDO policy states that:

> "it is difficult to improve the environment without a strong economy, but it is also difficult to improve an economy without protected natural resources and a clean environment."

In reference to pesticide production the international organization's stand is that technology transfers to developing countries should cause no harm to the environment there; in addition, environmental protection technologies must be made available to the developing nations in order to reduce risks arising due to the introduction or expansion of the pesticide industry in these areas.

Awareness has increased about the hazards which exist when a pesticide production plant is present in a region. It is crucial that the methods to ensure safety to the environment, humans, and other non-target organisms are implemented. The technology, equipment and expertise for safe manufacturing of pesticides is available and can only be beneficial if efficiently utilized.

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