IV. ENGINEERING CONTROLS

Worker exposure to pesticides can occur during manufacturing and formulation when chemicals spill, leak, or discharge from the process system and contaminate areas where workers are present. The most frequently reported industrial exposure occurs during the transfer of materials [29]. Product packaging, drum and barrel filling, and bag or sack filling are typical transfer operations with high exposure risks. The entry of workers into systems, equipment, or enclosures that are contaminated may occur inadvertently, but routine servicing, nonscheduled maintenance, and process monitoring appear to be the kind of activities with potential for significant exposure. [29].

Both types of exposure can be controlled and reduced by the proper design, construction, use, and maintenance of plant equipment. Engineering controls are less influenced by unpredictable human factors than are work practices. They are usually more reliable and effective, and when coupled with a well-designed preventive maintenance program, constitute the preferred control strategy. However, due to the wide variety of processes and equipment used in the pesticide industry, detailed engineering specifications must vary with the situation in a specific facility. Differences between processes exist in the operating pressures and temperatures, in the toxicity of the materials handled, in the physical properties of the materials, and in the climatic conditions, all of which affect the design of engineering controls.

Current workplace air standards (29 CFR 1910 Subpart Z) and previous NIOSH criteria documents dealing with pesticides (Appendices III and IV) have circumvented the problems associated with specific facility situations by establishing environmental (workplace air) exposure limits which dictate a performance standard but leave actual design of controls to employers. Engineering controls should prevent exposures greater than those specified.

The general principles of control strategy and engineering controls for pesticides are best illustrated by reviewing past instances of exposure and observations made during recent plant visits. Exposure caused through pesticide escape from equipment into work areas can be by avoided by enclosing and isolating process systems. In those cases where exposure occurs when workers enter contaminated process areas, application of remote handling techniques to sampling and equipment servicing operations will provide protection. Engineering controls are applicable in existing operations through retrofitting. In new plants, appropriate controls should be incorporated in the original designs.

In the following sections, the basic processes involved in pesticide manufacture and formulation are described. Some cases of worker exposure and pesticide escape are cited and discussed and suggestions for appropriate engineering controls are made.

Following this process overview is a review of specific problems common to both pesticide manufacturing and formulating operations, including materials transfer, packaging, leakage, intentional or unintentional discharges, equipment maintenance, and process monitoring. The equipment and areas where failure or employee exposure are likely to occur are identified. Engineering controls that can be implemented to control these exposures are described.

Manufacturing Processes

The methods and processes used in pesticide manufacture vary as greatly as the chemical structures of the products. Manufacturing can be accomplished on a continuous basis, on a batch basis, or on a semicontinuous basis. Despite the variety of processes, most pesticide manufacturing can be broken down into the same basic process steps.

First, raw materials are made available for processing. Some starting materials are delivered and stored at the plant. However, because many pesticide operations are part of a larger integrated chemical plant, raw materials are often produced on site. For example, chlorine, an ingredient in the manufacture of many pesticides [296], is produced by some companies for use in their pesticide synthesis [8(p 24)]. Raw material storage and dispensing operations have their own health hazards. For instance, the human carcinogen vinyl chloride is a raw material used in making endrin [8(p 32)]. Maddy and Edmiston [297] reported an exposure to hexachlorocyclopentadiene, another ingredient in pesticide manufacturing, in the transfer of raw materials. The following are examples of intermediates used in the production of pesticides: arsenic trioxide, acrolein, ammonia, aniline, atrazine, benzene, bromine, bromochloromethane, butyl mercaptan, carbon disulfide, cresol, dioxane, diphenylamine, epichlorohydrin, ethylene dibromide, ethylene oxide, formaldehyde, hydrogen sulfide, methyl chloride, phenol, phosgene, sodium hydroxide, sulfuric acid, thionyl chloride, and trichloroethylene [298]. Some of these chemicals are also registered pesticides.

The next basic part of pesticide manufacturing is actual production of the pesticide chemical. In the processing of natural pesticides, such as pyrethrum, refining is the only step. Otherwise, production begins with synthesis of the pesticide in a single or multistep chemical process. Virtually every basic type of organic chemical reaction is involved in the manufacture of pesticides [298]. Monitoring the chemical reaction as it takes place allows an optimization of the pesticide synthesis, but exposures have occurred from opening sample ports [128] and from analyzing samples [297].

Synthesis is usually performed in reactors which may be equipped with coils for temperature control and with an impeller for mixing. Maintenance of such pesticide reactor equipment has resulted in serious worker exposures [113].

The next step in the manufacturing process is the separation of the pesticide from unreacted ingredients, such as sulfuric acid in DDT manufacturing, from by-products, such as sodium sulfate in DDT manufacturing [296], and from solvents, such as dioxane in monuron manufacturing [298]. Separation is performed using various equipment, such as filters, extractors, strippers, and centrifuges. Centrifuging has been a potential emission source in the manufacturing of aryloxyalkanoic acids [299]. Some residual pesticide will be present in the separated materials; therefore, containment and treatment may be necessary before disposal or reuse. Brown [143] reported eye and skin injury from exposure in a manufacturing plant where unused reactants were recycled to synthesize triazapentadienes.

Pesticidal chemicals are usually further refined in another purification step. In some cases, impurities in pesticides may pose a greater health hazard than the pesticide itself. A number of cases of toxic reaction to tetrachlorodibenzodioxin (TCDD) contamination in chlorinated phenol-derived pesticides have been reported [53,124]. The equipment commonly used to purify pesticides includes extractors, stills, evaporators, and dryers. When ventilating air passing through that equipment is used to transport contaminants, it may also carry pesticides. Such operations require controls to prevent worker exposure.

The final major step in pesticide manufacture is that of packaging. Depending on customer requirements, pesticides may be packaged in a variety of vessels ranging from small glass containers to railroad cars. The packaging system used is a function of product form, ie, powder, dust, liquid, granular solid, or gas. The packaging operation may be performed remotely with automatic dispensing, weighing, and sealing equipment but is more frequently performed with a local exhaust system or without any specific controls. A packaging operation in which there is no attempt to limit the entrance of pesticide vapors, gases, dusts, or aerosols into the atmosphere of the workplace has a large potential for worker exposure [8].

Formulating Processes

While manufacturing is a chemical process yielding technical grade pesticidal chemicals, formulation is a physical process yielding a finished pesticide product with the form and strength required for its specific use. There are over 40,000 Federally registered pesticide formulations, but the physical form of each is limited to a few basic categories as discussed below [1].

(a) Dusts

Dusts are formulated for use without additional processing. The active ingredient or pesticide is diluted to a concentration usually ranging from 0.1 to 20.0% by mixing with a diluent or carrier [300]. Ingredients commonly used as carriers in dusts include flour, lime, gypsum, sulfur, sand, clay, and talc. Although these ingredients are described as inert with respect to pesticide strength, several are recognized health hazards: Talcs sometimes contain asbestos fibers, and certain allotropes of sulfur are effective pesticides in themselves. Other additives include stabilizers and dyes.

As are most formulation operations, formulation of dusts is a batch process. An example is the formulation of mercurous chloride into its final form. First, the mercurous chloride is emptied from its container into a mill. After grinding, it is transferred to a mixer for blending with fine clay and a vegetable dye to add color. Mills used for grinding dusts include hammer mills, impact mills, vertical roller mills, and fluid energy mills. The blending of solids is performed in a rotary drum mixer. The final product is packaged in 10-gallon fiber drums [296].

Hartwell and Hayes [301] compared the health effects of worker exposure during formulation of parathion and mevinphos dusts and measured the frequency of poisoning cases and inhibition of cholinesterase (ChE) activity. The study indicated that concentrations of airborne dust were frequently high enough to produce severe symptoms in exposed workers. Engineering controls that would prevent such exposures include local exhaust systems operated together with an effective general ventilation system and a clean, filtered air supply. With proper attention to the design of such systems, one can readily control airborne dust.

(b) Wettable Powders

Powders may be formulated for dispersion in water before use. Wettable powders can be made with the same equipment as dusts. These powders usually contain 15-75% active ingredient, 1-2% surfactants, and the balance is made up of inerts [300]. For instance, DDT has been blended with silica, a wetting agent, and a dispersing agent, to yield a 76% DDT wettable power. Subsequently, the mixture is ground to the desired particle size and packaged in 50-pound bags [296].

Wolfe and Armstrong [18] conducted a survey of potential worker exposures in the formulation of 50% DDT wettable powder. They found that the worker who dispensed ingredients into the blender had a potential exposure of 33 mg DDT/hour. The bagger who filled 50-pound bags had a potential exposure of 160 mg/hour, while the bagger of 4- and 5-pound bags had a potential exposure of 539 mg/hour. These differences in exposure levels are directly related to the number of containers handled by the bagger, to the number of container opening and closing operations, and to the number of filling operations, all of which have exposure potential. Wettable powders can be controlled with systems of similar design to those required for dusts.

(c) Granules

Granular formulations are intended for direct aerial and ground application. Their compositions are similar to those of dusts, but the method of preparation is different. A granular carrier within a 30-60 mesh particle size, such as vermiculite, diatomaceous earth, ground corn cobs, or bentonite is impregnated with a solution of the active ingredient. Insoluble solid pesticides are melted for impregnation. The actual process involves spraying the carrier with active ingredients while the material is mixed in a ribbon or drum blender [300].

Deeken [134] reported six cases of chloracne arising from exposure to 2,6-dichlorobenzonitrile, the active ingredient used in a granular formulation. Contamination of workers' skin and clothing can be controlled by complete enclosure of the operation within a ducting system and remote operation or monitoring of the spraying operation. A secondary measure of protection would be provided by a well-designed local exhaust system to assure continuous removal of airborne particulates or mists.

(d) Emulsifiable Concentrates

Emulsifiable concentrates represent the liquid phase equivalent of wettable powders. The concentration of active ingredient usually ranges from 15-80%; surfactants constitute about 5%; and the balance is an organic solvent such as xylene, methyl isobutyl ketone (MIBK), or amyl acetate [300]. The ingredients are blended in an impeller-agitated mixing tank. For example, disulfoton, an OP, is dissolved in xylene, and packaged in 1-, 30-, and 55-gallon drums [296].

(e) Liquid Formulations

Liquid formulations are ready-made for application by spray or dip. Pesticide solutions are often formulated by dissolving active ingredients in the appropriate solvent. The solution is agitated in a mix tank, often equipped with cooling coils which maintain a desired reaction temperature. Before being pumped into containers, the solution may be filtered. Examples of such formulations are trifluralin, 4 pounds/gallon, in aromatic naptha (mineral spirits), and 20% pyrethrin in deodorized kerosene [296]. Such formulations may be packaged in metal containers ranging from a 1-quart to 55-gallon capacity.

Maddy and Edmiston [297] reported three cases of mevinphos poisoning among formulators handling liquid pesticides in open systems. The most frequent cause of exposure was from malfunctions in the mixing tanks or from worker entry into these tanks. By their nature, liquid formulations and emulsifiable concentrates are more easily controlled than dusts and are more amenable to enclosure and isolation.

(f) Aerosols and Fumigants

An aerosol is characterized by its form of packaging and by the suspension of fine solid or liquid particles that result in its application. These pesticides are held under pressure in cans or bottles and are applied directly from their containers by spraying. Aerosols usually consist of 2% or less of the active ingredient, and the remaining ingredients consist of a solvent, a propellant such as nitrogen or carbon dioxide, and any of a wide range of additives. Because such formulations are widely used in homes, they may contain odor suppressants, perfumes, antimildews, repellents, or synergists such as piperonyl sulfoxide, propylisome, or piperonyl butoxide. The purpose of the synergist is to promote the action of the pesticide [296].

Fumigant formulations are generally self propelled; the active ingredient concentration is usually 90% or more and the propellant is 10% or less. Methyl bromide is stored in closed refrigerated systems and packaged in gas cylinders, together with chloropicrin whose lacrimating effect serves as a warning agent [296].

Maddy and Edmiston [297] cited the case of a pesticide formulation worker who was burned by methyl bromide when it escaped from a closed distribution system. The filling and handling of pressurized containers carry a risk of explosion or other release of material. California recorded an instance of eye injury when an exploding can of insecticide caused chemical conjunctivitis [297]. In processes used to prevent condensation and corrosion within the container, many gases are dried over silica gel before packaging, leaving contaminated silica gel that must eventually be removed and replaced.

Problems in pressurized systems frequently arise from leaks at joints, connections, on-off valves, and pressure relief valves. In some cases, corrosion within the system is a result of chemical interaction with lubricants and sealers. Engineering controls that can be applied include remote handling and monitoring, pressure sensors, and frequent maintenance to detect corroded or loose fittings before failure occurs.

Equipment and Process Controls

Certain basic types of equipment and processes are used in both the manufacture and formulation of pesticides. The equipment is subject to failures and other problems resulting in worker exposure. The following sections discuss some of the particular equipment involved, particular modes of failure, and the common problems associated with pesticide operations. Specific cases of reported worker exposures to pesticides are cited and discussed as well as the engineering methods that should be used to prevent such exposures.

(a) Materials Transfer

The specific hardware associated with materials transfer includes piping systems, pumps, valves, couplings, belt conveyors and bucket elevators, hoppers and receiving bins, and holding and dispensing tanks. Pipes, hoses, and lines are potential sources of pesticide emissions since they may rupture and leak at joints. Pipe rupture can result from improper materials usage, excessive pressures, excessive temperatures, vibration or chafing, and corrosion or clogging. All piping should be constructed of the appropriate material necessary to withstand the anticipated pressures, temperatures, vibration, and corrosion. Pipe runs should be mounted in a position to avoid accidental impacts.

A case in which a pressure hose burst and sprayed two employees who were using the hose to fill a drum was reported in 1975 [29]. The author stated that even though the employees were wearing safety equipment, they both experienced undesirable health effects as a result of the exposure. This problem was subsequently solved in this case through replacement of the flexible hose by a metal pipe. If a flexible hose is absolutely necessary, then it should be replaced periodically as part of a basic preventive maintenance program.

Pesticide emissions can occur at pipe joints that are flanged and bolted. Even if the system is originally tested and found to be tight, normal vibration and deterioration of gaskets and "O" rings will eventually cause leaks. Wherever feasible, welding of pipe joints can be used to avoid these problems.

Exposures frequently occur when piping systems are opened to remove obstructions. An employee was exposed to dibromochloropropane while attempting to unplug a line [26]. While further details of this case were not available, such exposure can usually be prevented by isolating the line in question and by flushing it with a solvent rather than by opening the system.

Auxiliary piping systems that are not actually conveying pesticides also have the potential to cause pesticide exposure. In a case in California [29], a hot water line ruptured and sprayed an employee and a conveyor belt carrying diazinon powder. The powder, in turn, splashed on the employee, and he later substained first degree chemical and thermal burns. This incident demonstrates that proper design, material selection, location, and maintenance of piping systems are important in preventing worker exposures.

Pumps present many of the same exposure problems as do piping systems. Joints and seals, materials selection, cleaning, and batch changes are common problems. Pumps also require preventive maintenance if unscheduled shutdowns are to be avoided. Part of this maintenance program should include a thorough check of all moving parts, and particularly a check of the pump seals for signs of leakage. Two cases were reported [29,297] of worker exposure to pesticides during a pump repair operation and indicate that pumps be cleaned to reduce the possibility of exposure before they are worked on. This is done by purging the pump with a solvent and washing down the pump exterior.

Langner [302] suggested that pumps handling cancer suspect agents should be provided with vacuum lines and shrouds around the seals to remove any substances that might leak during operation. When the materials handled are not highly toxic or volatile, the pump can be mounted on a grating over a collecting sump or can be surrounded with a dike or curb. In these cases, separate arrangements are necessary to clean up and remove spilled material. Cleanup often can be handled using sorbents, diluents, or a local exhaust system attached to the pump.

Leaks at couplings can cause worker exposures to pesticides during connecting and disconnecting operations. At least two cases of workers being heavily exposed to pesticides while in the process of coupling or uncoupling a line have been reported [29,297]. Exposures of this type may be prevented through the use of a dripless connector. Conveyors and bucket elevators have a potential for serious exposure problems since they frequently are not operated in enclosed systems. Pesticides can escape at feed, transfer, and dump points. Therefore, belt conveyors and bucket elevators should be enclosed in a duct, which is connected to an efficient local exhaust system.

Enclosed conveyors and elevators must be entered by maintenance personnel to clear jams, to lubricate moving parts, to replace and repair components, and to adjust belts and rollers. The enclosed system must, therefore, contain suitable hatches for performance of maintenance and also for removal of accumulations of dirt and solids.

Hoppers and bins are generally open-topped and may represent another serious exposure problem. During filling, the air displaced by the incoming material is usually laden with dust, and dust is also produced during emptying. These containers have to be entered when they become clogged and when their levels need to be manually checked.

Dust emissions from bins and hoppers can be controlled through the installation of local exhaust systems and with the provision of lids for use when filling. Dumping can be performed remotely and the dust removed by local exhausts. Problems of caking, bridging, and rat-holing in hoppers can be solved through the use of low-pressure pneumatic blasting devices built into the hopper walls and operated remotely to improve material flow and to eliminate the need for workers to free the material by poking and prodding.

Holding tanks are generally close-topped liquid containers. Workers at storage tanks may be exposed to pesticides in air displaced by venting or filling, or by leakage from seams and connections. The air escaping from tanks can also cause undesirable health effects. Spillage from tank caps can occur when tanks are overfilled accidently, or when high temperatures result in expansion of the tank contents. Pressure relief valves can release pesticide-laden air. Tanks must often be entered for cleaning or replacement of the lining. Checking liquid levels in tanks is often performed by opening a port and using a dipstick.

Several engineering controls including remote liquid level sensors, ventilation lines for pressure relief valves, and concrete dikes to contain spills; temperature and pressure sensors can be added to reduce pesticide emissions. Level sensors can be arranged to operate automatic shut-off valves at any desired liquid level. Systems can be fitted with pressure-sensing devices, so that when the integrity of enclosures or seals is lost, pumps may be automatically shut off [8(p 56)].

(b) Packaging

Packaging is a special case of materials transfer but deserves individual attention since it is in the packaging operation that significant opportunities for exposures occur. The chance for exposure increases because the system is usually open at this point.

Pesticides can be packaged in a variety of forms including powder, liquid, dust, granules, or pressurized aerosol. The material is contained in a hopper or tank and is dispensed into the package by weight or volume. In manual packaging operations, the containers are placed and removed at the packaging station and transferred to the sealing station by employees. Considerable potential exists for worker exposure due to displaced air, dust, overflows, spillage, improper sealing during filling, lack of or poor ventilation, failure of bags, rupture of delivery hoses and lines, and a variety of other causes. While automatic systems can suffer from similar failures, the operation can be entirely enclosed and can be remotely operated and controlled to prevent worker exposure.

Packaging equipment subject to failure includes the entire piping and mechanical system of the filling machinery, delivery hoses, conveyor belts, weight or volume sensors, lifting and transfer mechanisms, and the containers themselves. The containers can vary from small glass bottles to fiber drums and bags to 55-gallon drums and railroad tank cars.

Comer et al [12] conducted tests for body front exposure in three formulating plants during formulation of 4 and 5% carbaryl dusts. The workers studied were at bagging or mixing stations, generally areas of greatest potential contamination. One of the factors observed as causing occasional high exposure values was malfunctioning of the bag filler spout mechanism, resulting in excess billowing dust. The formulating plant workers' mean respiratory potential exposure as determined by contamination of respirator filter pads was 1.1 mg/hour of work activity. To compare values, the authors also conducted tests on spraymen operating tractor-drawn airblast equipment as they applied 0.045% carbaryl spray in fruit orchards. For spraymen, the mean potential exposure value was 0.09 mg/hour. While the above report does not provide any additional details, it is likely that the bagging operation was not protected by an efficient local exhaust and hood system which could have materially reduced the fugitive carbaryl dust noticed in the study.

Open transfers are encountered where repeated emptying or filling of small containers makes permanent conduits for transfer impractical. Airborne exposures were reported [299] in the open packaging of DDVP into aerosol cans. Following filling, the cans travelled down a conveyor line to the capping station. The distance was apparently long enough so that evaporation from the cans could be the only apparent cause of the illness.

At least four cases of employees being splashed with pesticide during liquid packaging operations were reported in

California in 1975 [29]. In the first case, methomyl was splashed on an employee while he was filling containers. If a closed and automatic packaging system had been used, this exposure would not have happened. In the second case, a worker was filling and capping drums of mevinphos when some of the chemical splashed on his arm. Again, a remotely controlled automatic packaging system could have prevented the exposure. In the third case, a broken nozzle sprayed an employee on the face, chest, and legs. Suitable enclosures or a remote control system could have also prevented this exposure case. In the fourth case, an employee was splashed in the eyes with sodium pentachlorophenol while filling 50-gallon drums. To minimize splashing, employees could "bottom fill" drums, not "top fill" them [8(p 27)], and should wear eye protection. More effective protection would be provided by remote-controlled filling operations.

Flexible or quick disconnect attachments could solve these problems encountered in pesticide packaging operations. An example is shown in Figure XIV-1. Plastic bags secured with shock cords were used by one manufacturer/formulator where rigid connections were not appropriate [8(p 97)]. A flexible bellows duct can also be used as a rapid connect/disconnect system as seen in Figure XIV-2.

Air displacement is another source of pesticide emissions during packaging. As air leaves a container being filled, its countercurrent flow tends to entrain materials and carry them into the surrounding area. Such an emission can lead to worker exposures, as reported in the bagging of propargite [29]. During packaging of liquid, a vapor return line from the receiver to the dispenser can control potential emissions. Such a device has wide application in the petroleum industry [8(p 81)].

A local exhaust ventilation system can collect dust-laden air displaced during solids packaging operations (Figures XIV-2 and XIV-3). This type of ventilation system only protects workers when it is properly designed and installed. Airflow must have sufficient velocity to entrain the airborne contaminants and to be directed away from the worker, past the pesticide material to the hood, thus ensuring that contaminants do not pass through the workers' breathing zone. Maddy and Edmiston [297] pointed out the importance of hood location in protecting a fungicide bagger by ventilation.

Exhaust ventilation systems may be used in conjunction with other systems. The exhaust ventilation in the packaging operation in one plant has been complemented with a vacuum system for collecting spilled or leaked materials [8(p 57)]. In addition, a fresh-air duct and plenum system provides make-up air without crosscurrents to interfere with exhausting hoods. Although complete enclosure of packaging operations may be difficult because of the requirement for frequent changes of containers, the three systems together are effective in controlling personal exposure.

Examples of worker exposure discussed above illustrate the need and the methods for eliminating exposure during pesticide packaging operations. The occasional gross overexposure or repeated low level exposure to a toxic chemical certainly warrants the implementation of positive packaging controls.

(c) Equipment Leakage

Most items of equipment used in formulating or manufacturing plants may develop leaks. A comprehensive preventive maintenance program is a necessity if leaks are to be detected, prevented, and controlled. In addition to piping systems and pumps that have been discussed previously, leaks can be anticipated in reactors, filters, separators (including solvent strippers, extractors, condensors, and scrubbers), dryers, doors, and inspection ports.

Locations where pesticide emissions from reactors can occur include vents, charging doors, sampling ports, and agitator seals. Releases can also occur if pressure buildup is sufficient to operate the pressure relief valves when a reactor is manually loaded, or when a dipper is used to obtain samples of the reaction mixture during processing. Reactor vessels should be maintained at pressure negative to the atmosphere so that all leaks are inward.

Releases during charging and venting can be controlled through the installation of local exhaust systems. Exposures during sampling can be eliminated through the installation of valves that do not permit workers to be exposed to pesticides when obtaining samples. Agitator seals can leak due to loss of flexibility and normal deterioration, or as the result of drive shaft eccentricity. This type of leakage can only be controlled by inspection and replacement of worn seals.

Davay [128] reported a case of fatal kidney damage in a worker exposed to methyl bromide during its manufacture. The worker was exposed during a shift when the reflux reaction of methanol with liquid bromide was proceeding in the reaction vessel. He worked for 3 hours within a radius of about 12 feet from the sampling and filling valves near the receiving vessels. Findings revealed that methyl bromide apparently escaped from an open sampling valve which the worker noticed and closed. Death occurred 18 days later as a result of severe injury to the central nervous system and kidneys. This accident could probably have been prevented if the sampling valve had been connected to a buzzer, indicator, or warning flag when it was opened.

Filters are used to separate solids from liquids or gases. Leakage is generally due to deterioration of seals, gaskets, and filter frames, allowing the pressure release of pesticidal chemicals. Additional exposure can result when the filters are replaced or cleaned. Leaks can be spotted and exposure controlled through regular inspection and maintenance.

Leaks from separators occur when pressure buildup causes pressure relief valves to operate and to release air containing high concentrations of pesticides. Engineering controls that are applicable to prevent releases from scrubbers and separators include local exhaust systems to remove vented contaminants from pressure relief valves and pressure sensors that can give advance warning of excessive pressure buildup.

Dryers are used in pesticide manufacture to remove solvents from slurries and to obtain a powdered pesticide product.

Pesticide emissions from dryers can occur when the airstream is ducted to an exhaust system, whenever there is a mechanical or materials failure, and when the powdered pesticide is removed or dispensed. Stationary local exhaust ventilation dedicated to one system can reduce or eliminate these emissions. However, it is important to ensure that the entire ducting system is operated at a pressure lower than ambient atmospheric pressure and that fans and ducting are properly sized and free of severe bends or obstructions which might restrict airflow.

When the dried pesticide chemical is dumped from the dryer, workers may be exposed to the dust. A blender-dryer in an endrin manufacturing plant developed a problem of this nature [299]. The pesticide was dispensed through a gate valve at the base of the blender-dryer. The valve was operated by an employee allowing the pesticide to enter the packaging hopper. When operating the valve, the employee was in the direct path of the dust rising from the hopper with considerable exposure potential. The dispensing system should be operated remotely through an electrically controlled valve, and the discharge chute should make a direct connection to the hopper.

Leaks can also occur when doors or inspection ports are left open or are not properly closed. All doors and ports should be equipped with a self-closing mechanism, or with a device that will provide a warning or system shutoff until the door or port is fully closed and latched.

The escape of materials through ducting can be minimized or eliminated by maintaining the duct interior pressure at a pressure less than ambient atmospheric. This same principle is applied in ventilation ducting where fans are located at the downstream end of the system to ensure that any leaks in the ductwork are into the duct and not from the duct to the outside envircnment.

When leaks occur, it is essential that they be detected and controlled immediately. Equipment for leak detection may include line sensors to measure pressure and flow, or chemical sensors to detect the presence of a substance outside the system. Many such leak detection systems can be integrated into a general warning and alarm system and can also act to operate shutoff valves or to shut down entire systems. Visual detection of leaks can be aided by adding a dye to pesticides. Odorous chemicals may be added to liquids or gases to serve as a leak detection device. For physical inspection, suspected leak areas can be painted with soap solution or a similar indicator.

Certain operations may be amenable to complete containment in separate buildings or in closed rooms, thus providing a "secondary containment" of spilled liquids or dust. All operations can be controlled and monitored remotely, and in the event of a leak, the entire room can be purged or flushed before maintenance workers are permitted to enter. Operational areas should be in buildings well removed from personnel service buildings such as locker rooms, showers, cafeterias, and offices.

For certain leaks, temporary control may be effected through the utilization of local exhaust systems with flexible hoses and portable hoods, or with a vacuum system to clean up spills. Leaking gases and vapors, or liquids with high vapor pressures may diffuse too rapidly to be contained by such temporary measures, and forced air purging of the entire area may be required.

An exposure recorded in California [297] led to the application of forced air ventilation in a formulating operation. The employee involved had removed his safety equipment while working near a holding tank containing mevinphos. A forced air ventilation system was subsequently installed to remove emission concentrations in the holding tank area.

(d) Equipment Maintenance

The maintenance of chemical processing equipment in the manufacture and formulation of pesticides requires a variety of cleaning and maintenance tasks that may expose workers as they use equipment. During 1975, California reported that equipment maintenance operations ranked second to material transfer operations in causing pesticide exposures in the pesticide formulation industry [29].

Two cases were reported in which workers were exposed to pesticides while repairing pumps [29,297]. In both cases, residual pesticides were responsible for the exposure. The investigators suggested that pumps should be cleaned in a "remote mechanical manner" before maintenance is attempted, suggesting that pumps should be purged, disconnected, and thoroughly washed down with solvents or water prior to maintenance work.

Components of many items of equipment require periodic inspection and replacement. Examples are filters, gaskets, packings, linings, refractory materials, shaft seals, and so on. A recent report [299] on heptachlor manufacture noted the exposure hazard inherent in the servicing of a process filter. Unclogging blocked transfer lines or cleaning out tanks may require that closed systems be opened or that workers actually enter pesticide-contaminated equipment. An exposure to DBCP in California reportedly occurred when an employee attempted to clear a plugged line [29].

The variety of products produced by batch processing in many formulating plants calls for frequent isolating, purging, cleaning, and reconnecting of equipment. Systems with a need for frequent maintenance or cleaning should be installed in duplicate to permit a given unit to be withdrawn from service and to allow a process to continue without exposing maintenance personnel. Special attention must be paid to the design and testing of connections that must be frequently broken and reconnected for equipment maintenance or cleaning purposes.

Closed equipment cleaning and blockage cleaning can be facilitated if water, compressed air, and steam supply connections are permanently installed on or in equipment. Similarly, purging can also be facilitated if appropriate connections are available.

Grinders and mills require periodic cleaning and replacement of the rollers or balls. To perform these operations, it is often necessary for maintenance staff to enter the equipment. Before this is allowed to occur, the grinder or mill should be thoroughly cleaned with solvents and steam and tested to ensure that the equipment is effectively decontaminated.

Weight hoppers can present a servicing hazard to persons not employed by the using facility, since the weighing mechanism is usually serviced by an outside company whose employees might not be as conscious of pesticide hazards as the regular plant employees. Steam cleaning of weight hoppers and scales is recommended before maintenance work is permitted.

Mixers and blenders have to be cleaned periodically and their moving parts serviced and lubricated. Again, thorough cleaning with solvents and steam is necessary before workers are permitted to enter.

Vibrating screens and filtering systems must be opened periodically for screen or filter replacement or for the removal of oversize particles. Screens and filter systems frequently contain heavy concentrations of dust which can produce respiratory, eye, and skin exposures if the dust is not removed before the system is opened. Similar conditions are encountered in the maintenance of belt conveyors and bucket elevators.

(e) Process Monitoring

Monitoring the various processes encountered in the manufacture and formulation of pesticides may require visual observation, measurement of physical parameters, or collection of chemical samples. If these operations are conducted through an open port or access door, the worker involved may be exposed to pesticides.

A recent report indicated the potential for worker exposure during sampling [299]. In some cases, samples were taken by opening a valve and allowing the sample to run into a container, while at other times, samples were taken by lowering a dipper into the chemicals through an inspection port. The latter process can result in severe exposures. Pressure can build up in a reaction vessel, so that subsequent opening of the sample port can splash pesticides around and beyond the opening. When using the sample dipper, the employee could potentially come into contact with the rim of the sampling port, or could insert the dipper too far into the mixture and immerse his hand. Another problem with sample ports is that employees frequently leave them open, which permits continual exposure of all workers in the vicinity.

Sampling systems that require the use of hand-operated dippers should be eliminated in favor of those that are controlled by a valve. Sampling done indirectly through closed-loop sampling systems can prevent exposures [8(p 80)].

Many operations in process monitoring can and should be performed remotely. Direct observations of physical or chemical processes can be made through view ports or through the use of remote television monitors and receivers. If a large number of sensors are used to monitor operation of equipment, readouts can be displayed on a central control panel which can also serve alarm and security functions.

(f) Environmental Discharges

While the discharge of pesticidal chemicals from industrial plants is certainly an environmental concern, it is also another cause of worker exposure. Ventilation system exhausts, process air from drying operations, and vapors from pressure relief valves can release pesticides into the air. Overloaded systems can also contribute to this problem. A case was reported [29] of a worker in a plant manufacturing sulfuryl fluoride gas who suffered effects from the gas released by an overloaded scrubber. The company owning this plant planned to install a larger scrubber system capable of handling the fumes.

Plant runoff, drainage, and process waste water may leave pesticides deposited in or near working areas. These releases can eventually result in undesirable accumulations and resultant exposure hazards. Materials may also be drawn back into the plant through recirculation from exhaust stacks into fresh air intakes caused by poor design, location, or unfavorable winds. All gases and liquids exhausted from the plant or otherwise disposed of should be freed of their pesticide content before release.

Discharge air may be cleaned by physical treatment in cyclone separators, scrubbers, baghouses, or electrostatic precipitators, or may be treated chemically by flaring, catalytic afterburners, or absorption towers [303]. Discharge water may be purified before release by filtration, settling, or by chemical treatment [304]. It is emphasized that chemical decontamination and neutralization are preferred cleaning methods. The mere separation of pesticides from discharge streams adds to the problem of disposing of recovered materials. For example, periodic emptying of a dust collector requires that provisions be made to prevent dust from again becoming airborne [297]. Application of wet methods may be useful in these instances.