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Plastic Pellets in the Aquatic Environment: Sources and Recommendations

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Contents and Acknowledgements

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LIST OF ABBREVIATIONS

ABS	acrylonitrile/butadiene/styrene
AIMS	American Institute of Merchant Shipping
CMC	Center for Marine Conservation
CSO	combined sewer overflow
DOT	Department of Transportation
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
HDPE	high-density polyethylene
ITF	Interagency Task Force on Persistant Marine Debris
LDPE	low-density polyethylene
MARPOL	International Convention for the Prevention of Pollution by Ships
MPPRCA	Marine Plastic Pollution Research and Control Act of 1987
MPRSA	Marine Protection, Research, and Sanctuaries Act of 1972
NPDES	National Pollutant Discharge Elimination System
NOAA	National Oceanographic and Atmospheric Administration
OCPD	EPA Oceans and Coastal Protection Division
OWOW	EPA Office of Wetlands, Oceans, and Watersheds
PBT	polybutylene terephthalate
PCB	polychlorinated biphenyl
PE	polyethylene
PET	polyethylene terephthalate
PP	polypropylene
PS	polystyrene
PVC	polyvinyl chloride
QC	quality control
RCRA	Resource Conservation and Recovery Act
SAN	styrene/acrylonitrile
SB	styrene-butadiene
SMA	styrene-maleic anhydride
SOP	standard operating procedure
SPI	Society of the Plastics Industry, Inc.
TiO2	titanium dioxide

TSCA	Toxic Substances Control Act
TSS	total suspended solids
UL	Underwriters Laboratory
USCG	United States Coast Guard

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**Plastic Pellets in the Aquatic Environment:
Sources and Recommendations**

EPA842-S-93-001

Executive Summary

Disclaimer: The information in this website is entirely drawn from a 1992 publication, and has not been updated since the original publication date. Users are cautioned that information reported at that time may have become outdated.

The U.S. Environmental Protection Agency (EPA) is concerned about the amounts and types of debris in our oceans and on our beaches. This debris can have economic, esthetic, and ecological impacts and can come from both land- and sea-based sources. One debris item that has become of particular concern to EPA is the plastic pellet.

EPA's Oceans and Coastal Protection Division (OCPD) of the Office of Wetlands, Oceans, and Watersheds (OWOW) initiated the study described in this report to make a comprehensive assessment of the sources, fate, and effects of pellets in the aquatic environment, and to determine what can be done to control and prevent their release to the environment. The goals of the study were to

- Summarize what is known about the presence and impacts of pellets in the aquatic environment,
- Identify and evaluate how pellets escape into the environment, and
- Recommend ways to control or prevent future pellet releases.

This study promotes EPA's national policy on pollution prevention, which is based on the Pollution Prevention Act of 1990 (HR 5931). EPA's policy is to (1) reduce or prevent pollution at the source whenever possible, and (2) to assist the State and Local governments and the private sector in achieving source reduction. The study results, therefore, will help to implement EPA's policy by assisting the plastics industry in implementing voluntary pellet-control programs to reduce the release of pellets into the aquatic environment. This report represents the first comprehensive assembly of information regarding the presence and ecological effects of pellets in the aquatic environment, and is expected to become a basic reference for EPA and industry.

What is a Plastic Pellet?

Plastic (resin) pellets are the raw materials that are melted and molded to create plastic products. Plastic may be formed into pellets of various shapes (e.g., spherical, ovoid, cylindrical), sizes (range: 1- to 5-mm diameter), and colors (most commonly clear, white, or off-white). The wide variety of plastic products produced internationally has created a demand for many different polymers, or resins. An estimated 60 billion pounds of resin, most of which are formed into pellets, are manufactured annually in the United States. The most commonly produced resins include polyethylene, polypropylene, and polystyrene.

After being formed, the pellets are packaged and transported to processors for molding into plastic products. At many points in their creation, tranport, and use, pellets may be spilled and carried by rainwater and drainage systems into the aquatic environment. Once in the environment, the pellets will either float or sink: pellets that are heavier than water will sink to the bottom and pellets that are lighter than water will either float at the surface or become suspended in the water column somewhere between the surface and the bottom. This study focuses primarily on pellets that float.

The Environmental Problem: Sources, Fate, and Effects

Historically, several sources of pellets in the aquatic environment have been suggested, including direct discharges and improper wastewater disposal by the plastics industry, spillage from trucks, railcars, and ships, improper use of pellets, and waste disposal and sewer discharges by cities. The findings of the EPA Harbor Studies Program and Combined Sewer Overflow (CSO) Studies Program concluded that significant land-based pellet sources exist, and the plastics industry is a likely source of the releases.

Pellets released by the plastics industry flow into the aquatic environment by two routes.

- **CSO and storm-water discharges** - Spilled pellets may be carried by rainwater into storm-water drains, which in turn transport the water into the municipal wastewater treatment systems. The pellets may be then discharged into the aquatic environment through storm-water discharges or, where the sewage and storm sewers are combined, through CSO discharges.
- **Direct spills into the aquatic environment -** Pellets may be spilled directly into waterways, such as during cargo handling operations at ports or during cargo transport at sea.

The presence of pellets in U.S. coastal waters was first reported in the early 1970s, and pellets have since been reported in most of the World's oceans. More recently, EPA studies of aquatic debris (EPA Harbor Studies Program) revealed widespread distribution of plastic pellets in U.S. harbors located on the Atlantic, Pacific, and Gulf coasts, and pellets were among the most common items found in most of the harbors. Pellets were found in 13 out of 14 harbors sampled. The greatest number of pellets was found in the Houston Ship Channel at Houston, Texas, where over 250,000 pellets were collected in one sample alone. Notably, Houston has one of the greatest concentrations of plastics industry facilities in the United States.

During its CSO Studies Program, EPA also found pellets in the municipal wastewater treatment systems of Philadelphia and Boston. For example, pellets comprised over one-half of the manmade debris collected at one Philadelphia, Pennsylvania, storm-water discharge. Pellets were also found in samples collected from four sewage treatment plants; based on the study findings, EPA has estimated that over 20,000 pellets per day may be present in the sewage treated by one Philadelphia plant. The pellets are removed from the sewage dur-ing sewage treatment. The presence of pellets in the plant shows that the pellets are released from land-based sources, and could be released to the aquatic environment during treatment plant shutdowns or through CSOs and stormwater discharges during rainy periods.

The persistence of a pellet in the aquatic environment may be measured in years, depending on the resin type, the types and amounts of additives, and the reactions of the resins and additives to environmental processes (e.g., weathering, sunlight, wave action). Once in the environment, pellets may be transported by storm-water runoff, rivers, and water currents to areas far away from the source.

There are several documented accounts describing pellet and other plastic ingestion by wildlife, most notably by seabirds and sea turtles; however, impacts or biological effects of the pellets have not been clearly defined or demonstrated conclusively in most wildlife. Seabirds ingest pellets more frequently than any other animal, and approximately one-quarter of all seabird species are known to ingest pellets. Pellets ingested by seabirds are suspected to cause false feelings of satiation (i.e., the birds feel as though they have eaten) and reduce the feelings of hunger. Ultimately, this may result in a decrease in energy reserves and the ability to survive adverse environmental conditions. Suspected impacts on sea turtles, fish, and other aquatic life have been less frequently reported and studied.

Although pellets may not be as esthetically displeasing as other items of debris, such as sewage- and medical- debris, the quantities present and their persistence in the environment are cause for notice. One overseas investigator went so far as to suggest that, if high numbers of pellets continue to be deposited on certain New Zealand beaches, someday people in that area may be sunbathing on plastic-sand beaches instead of natural-sand beaches.

The Plastics Industry

The Society of the Plastics Industries, Inc. (SPI), worked with EPA to develop an understanding of operations within the plastics industry and identify potential sources of pellet losses to the environment. SPI is the major national trade association of the plastics industry. Its membership consists of more than 2,000 companies that are responsible for approximately 75% of the $100 billion total sales of plastics and plastic products in the United States. These companies supply raw materials (e.g., pellets), manufacture plastics and plastic products, and design, construct, and manufacture equipment and machinery used by the plastics industry. This study was completed with the voluntary cooperation and assistance of SPI and seven companies in the plastics industry.

For the purposes of the study, the plastics industry was divided into three major sectors.

- **Pellet producers**, which create the polymers, form the pellets, and ship the pellets to contract packagers or processors.
- **Pellet transporters/contract packagers**, which are intermediate pellet handlers. Transporters carry bulk shipments between the industry sectors via railcars, bulk trucks, and freight trucks . Contract packagers repackage bulk shipments into smaller containers (e.g., bags and cardboard boxes), which are shipped to processors.
- **Pellet processors**, which mold the pellets into user products.

To determine how pellets are released to the environment from each of these three sectors, SPI arranged for each industry sector to be visited by the study team. Seven companies (two producers, two transporters/contract packagers, and three processors) were visited during this study.

Study Findings

Several pellet release pathways were identified for each of the three industry sectors described above. Most of the release pathways were common to all three sectors, with only a few being unique to one or two sectors. The pathways may be categorized into eight general areas where pellet releases are a problem.

- **Poor communication between industry management, company management, and management of related industries (e.g., shipping industry).** Not all company managers have recognized the pellet problem and the need to control pellet releases. Pellet spillage information, such as the condition of packages and the receipt of unsealed rail hopper cars, is shared between companies only occasionally.
- **Lack of employee awareness and inadequate training.** Employees are generally unaware of the environmental effects of pellets and their own responsibility for controlling pellet releases to the environment. For example, one major release pathway is through package damage caused by improper operation of forklifts while moving pallets. Cargo handlers may allow pellets to escape into the environment because they are unaware of the hazards of pellets.
- **Inadequate containment facilities and apparatuses.** Most companies have few or no cooling-, waste-, or storm-water containment systems, including portable screens, in place for controlling pellet releases to the environment. Pellets that are present in these waters may be discharged into municipal storm and sanitary sewers or into natural drainage systems.
- **Careless routine operations.** Whenever pellets are handled, there is the potential for pellet spillage. Manual pellet handling is more likely to result in spills than handling by mechanical conveying systems (i.e., pneumatic systems that move pellets by using air flowing through sealed pipes). However, if pneumatic systems are not properly maintained and closed, pellets may leak through openings in the system. Pellets may be released also during the transfer of damaged, unrepaired packaging.
- **Inadequate housekeeping practices.** If pellets are not quickly picked up after they are spilled, they may be scattered and eventually released into the environment. Pellets may be transported throughout interior and exterior areas of a facility via shoes and clothing, vehicle tires, wind, and

storm-water runoff.

- **Easily damaged or leaky packaging.** Paper and cardboard packaging is easily damaged during transport and handling and, in fact, may be designed to be easily broken when loading molding machines. Damaged or leaky packaging is a major source of pellet loss to the environment; valved, self-sealing bags may not completely close, thereby allowing pellets to leak from the opening.
- **Improper shipping practices.** Improperly sealed rail hopper car valves, poorly maintained transporting vessels, and inappropriate cargo handling practices may release large numbers of pellets to the environment.
- **Lack of recycling.** Some companies do not attempt to re- cycle spilled pellets and, instead, dispose the pellets with other facility trash.

Recommendations

Existing Federal regulations provide a basis for controlling the release of plastic materials, including plastic pellets, into the aquatic environment. The recently revised National Pollutant Discharge Elimination System permit program guidelines [40 CFR 122.26(b)(12)] enable regulators and municipalities to impose significant penalties to a company or sewage treatment plant operator if pellets are present in their storm-water discharge in violation of their permit. Although penalties alone will not completely control the release of pellets, they can encourage companies to implement control measures. Ultimately, controlling releases of plastic pellets into the aquatic environment is the responsibility of the plastics industry.

In response to the early findings of this pellet study and other EPA studies conducted since 1988, SPI founded a Resin Pellet Task Force to investigate the pellet problem. In July 1991, following the findings of the task force, SPI initiated *Operation Clean Sweep*, an industry-wide education campaign aimed at committing the plastics industry to the total containment of pellets. It is anticipated that SPI and the industry will use this EPA comprehensive study along with campaign literature and information to control pellet releases from industry sources to the aquatic environment.

The release of pellets from pellet producers, transporters/contract packagers, and processors can be controlled through actions identified in this study. Recommendations to the plastics industry are

- **Adopt the SPI 1991 *Pellet Retention Environmental Code* and the 1992 *Processor's Pledge*.** The code is a commitment to total containment of plastic pellets, and was developed by SPI's resin-producing members in response to findings of this and other EPA studies. This code encourages source reduction activities to prevent releases, and suggests ways to recapture pellets that are spilled.
- **Educate employees and train them to minimize pellet spillage and loss.** Employees must recognize their role in preventing releases.
- **Install pellet containment systems or use portable containment apparatuses.** The use of inexpensive portable screens or similar devices can effectively control pellets at the spill source.

- **Institute pellet containment activities during routine plant operations.** For example, cleaning pneumatic lines into a portable screen before breaking connections will minimize pellet loss through spillage.
- **Improve the quality and frequency of pellet spill cleanup procedures.** Frequent vacuuming and broom-sweeping collect pellets before they escape into the environment.
- **Use puncture-resistant packaging and minimize the use of valved bags.** The use of reinforced valveless bags, such as polypropylene woven bags that are sewn shut, would minimize pellet loss due to damaged or incompletely sealed packaging.
- **Inspect shipping containers before loading and after offloading of pellets.** Containers may be resealed or repaired before additional pellets are lost, and pellets may be recovered instead of being released into the environment.
- **Inspect shipping vehicles (e.g., rail hopper cars, bulk trucks, freight trucks) before and after loading and offloading of pellets.** This will prevent spillage from leaking railcar and truck valves, and securing the valves with tamper-resistant cable will discourage pellet loss due to vandalism.
- **Recycle spilled pellets.** By recycling spilled pellets, the plastics industry can recover revenue that would have been lost by disposing them, and will minimize pellet releases to the environment during trash disposal.

Many of the recommended control mechanisms are currently available and are being voluntarily implemented by some companies within the plastics industry. Most of the mechanisms, such as employee education, portable screens, and improved housekeeping, control pellet releases immediately at the source; these mechanisms can be easily and inexpensively implemented. Systems that direct spilled pellets into one containment area are effective but are more expensive to implement.

The Next Step

The plastics industry should play a major role in protecting the environment by voluntarily implementing the recommendations identified in this report, which includes adopting SPI's *Pellet Retention Environmental Code* and *Processor's Pledge*.

EPA will continue to work with SPI and the plastics industry to implement the recommendations, and will assess industry progress in eliminating pellet releases.

Using the existing regulatory framework for guidance, EPA will continue to monitor stormwater effluents for compliance. Previous | Table of Contents | Next

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Plastic Pellets in the Aquatic Environment:
Sources and Recommendations

1.0 Study Background and Objectives

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Over the past few years, public and scientific awareness has increased concerning the aesthetic, economic, and biological hazards associated with persistent manmade debris in the aquatic environment. In response to public and Congressional concerns about the debris, the White House Domestic Policy Council formed an Interagency Task Force on Persistent Marine Debris in 1987. The Interagency Task Force (ITF) was chaired by the National Oceanic and Atmospheric Administration (NOAA) with participation by 12 Federal agencies, including the Environmental Protection Agency (EPA). The ITF was directed to "assess the problem and the need for research, identify potential reduction measures, and consider alternative actions to address the problem of plastic marine pollution" (ITF, 1988).

As a result of increased reports of resin pellet ingestion by aquatic wildlife and evidence that the ingested pellets may be harming the wildlife, the ITF identified resin pellets (also known as plastic pellets) as a debris problem that required additional research. These resin pellets are the raw materials from which plastic products are manufactured. When released into the environment, these pellets either may float on or near the water surface, may become suspended at mid-depths, or may sink to the bottom of a water body. Whether a specific pellet floats or sinks depends on the type of polymer used to create the pellet, on additives used to modify the characteristics of the resin (pellet), and on the density of the receiving water. The pellets most commonly found in the environment are composed of polyethylene, polystyrene, and polypropylene (EPA, 1990a). These compounds are also among the most commonly used resins (Pruter, 1987).

The ITF (1988) and others (e.g., Pruter, 1987; Colton *et al.*, 1974; Ryan, 1988b) listed several suspected sources of pellets in the environment including: (1) pellet manufacturers, (2) ships transporting the pellets, (3) pellet processors, and (4) other pellet transportation vehicles. However, evidence was unavailable to support or confirm the importance of the suspected sources. Therefore, discussions of likely sources were limited to suspicions or educated guesses. As a result, one of the recommendations of the Task Force was for Federal agencies to conduct research to determine land-based and water-based sources of marine debris including plastic pellets.

The Task Force did not address whether plastic pellets in the environment and resulting environmental problems were associated with historical releases or were related to current releases. However, in the late 1980s, the Society of the Plastics Industry, Inc. (SPI), had reported that plastic pellets in the environment may have been the result of historical inputs and that the industry had addressed these releases (SPI, as cited in CMC, 1988). In contrast, Heneman (1990) reported a 200% to 400% increase in the numbers of pellets present in the North Atlantic Ocean between 1972 and 1987. In addition, recent results from EPA studies conducted in several U.S. harbors (EPA, 1990b, 1992a,b) found widespread distribution of plastic pellets, most of which were not weathered and were probably released recently. The EPA studies found that

- Plastic pellets are present in harbor areas that are inaccessible to cargo ships and other major ship traffic, implying that these vessels are not the only source of plastic pellets in the environment (EPA, 1990b, 1992a,b).
- Harbors of cities with older combined sewer overflow (CSO) systems contained significant percentages of pellets in the floatable debris (EPA, 1990b, 1992a,b).
- Harbors near known production, transport, and processing centers had higher concentrations of pellets (EPA, 1990b, 1992a,b).
- Pellets are present in CSO and storm water outfall discharges and solids collected in sewage treatment facilities (EPA, 1992c).

These findings suggest that the plastics industry remains a likely source of pellet releases into the environment and indicate that significant land-based pellet sources currently exist.

Additionally, in its 1990 Report to the Congress, *Methods to Manage and Control Plastic Wastes*, EPA identified plastic pellets as an item of particular concern (EPA, 1990a) due to increasing evidence suggesting ecological impacts from these materials. EPA also included an action item to determine the source(s) of plastic pellets to the environment and to evaluate control options.

1.1 Study Objectives

As part of EPA's response to the action item included in the Report to the Congress (EPA, 1990a), a study was initiated to determine possible land-based sources of plastic pellets within the plastics industry, including pellet manufacturers (producers), transporters, and processors. The objectives of this study were to (1) identify and locate possible sources of pellet releases into the environment, (2) evaluate the significance of each source as a pellet release pathway, and (3) recommend mechanisms for controlling or preventing the release of pellets.

To obtain the information necessary to meet these objectives, EPA implemented several investigations. These investigations were to

- Review the literature on plastic pellet characteristics.
- Summarize pellet producing and processing methods used in the plastics industry.
- Determine the procedures used to transport the pellets between the various manufacturing sectors.
- Summarize the literature on the environmental effects of plastic pellets when released into the environment.
- Conduct site visits to selected facilities in the various sectors of the plastics industry to observe and evaluate all potential release points to the environment and to evaluate the techniques for controlling pellet releases.
- Continue marine debris studies in the U.S. harbors.
- Evaluate potential sources of aquatic debris into coastal waters.
- Maintain an ongoing dialogue with SPI.

This report presents the study findings and recommendations. Included are discussions of the following major topics.

- Chemical and physical properties of pellets, including additives and their effects on pellet behavior in the environment (Section 2).
- Geographical distribution of pellets and the known and suspected impacts of pellets in the aquatic environment (Section 3).
- Generic descriptions of manufacturing and transport operations of each plastics industry sector (pellet producing, transporting/packaging, and processing operations) (Section 4).
- Summaries of observations made during the visits to several facilities in each industry sector (Section 4).
- Identifications of likely pellet release points in each sector of the industry (Section 4).
- Existing regulatory framework and other government and industry efforts to address the pellet problem (Section 5).
- Recommendations for controlling pellet releases (Section 5).

1.2 Acknowledgment

The study was completed with the assistance and cooperation of the Society of the Plastics Industry, Inc., which is a major trade organization representing the plastics industry. Information was gathered through discussions at SPI meetings in Washington, DC, and through site visits to seven different companies (two pellet producers, two transporters/packagers, and three processors), which were arranged by SPI in response to a request for voluntary study participants. Information gathered at and supplied by these companies was invaluable to this study.

2.0 Pellet Characterization

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The demand for a wide variety of plastic products has, necessarily, created a demand for many different resins (polymers) and resin blends. Resins are synthesized from petroleum or natural gas derivatives, such as

- Acetylene: Polyvinyl chloride (PVC), polyurethane
- Benzene: Polystyrene (PS), polyurethane, acrylonitrile/butadiene/styrene (ABS)
- Butadiene: Polyurethane, ABS
- Ethylene: Polyethylene [high-density (HDPE) and low-density (LDPE)], PS, polyethylene terephthalate (PET), PVC, ABS, polyurethane, polyesters
- Methane: PET, polyurethane
- Naphthalene: Polyurethane
- Propylene: Polypropylene (PP), polyurethane, polyester
- Toluene: Polyurethane foams, elastomers, polyesters; also used to derive benzene
- Xylene: PS, PET, ABS, unsaturated polyesters, polyurethane

By blending polymers, creating new polymers, and incorporating additives, resins may be tailored according to the desired application and end product (EPA, 1990a).

An estimated 60 billion pounds of resin are manufactured annually in the United States, most of which is pelletized. If each pound of pelletized HDPE contains approximately 22,000 pellets (Mr. Ronald Bruner, Society of the Plastics Industry, Inc., personal communication, August 1991, Washington, DC), and this estimated number is applied to all pelletized resins, more than 1 quadrillion pellets may be produced annually. Pelletized resins, or, simply, pellets, are produced in several shapes (e.g., spherules, beads, disks, and cylindrical nibs), sizes, and colors, a few of which are shown in Figure 1 below. Resins may also be produced in other easily transported forms, including granules, flakes, and powders (EPA, 1990a).

Two major resin types are produced: thermoplastic resins and thermoset resins (EPA, 1990a). Thermoplastic resins can be melted or reprocessed without damaging or changing the chemical or physical properties of the polymer; they are highly malleable but become rigid when cooled. Because the difference may be narrow between the melting point of a thermoplastic resin and the temperature at which the resin may decompose, thermoplastic resins are kept in a liquid (melted) state for a minimum amount of time and are pelletized as soon as possible (EPA, 1990a).

Thermoplastic resins comprised 83% and 84% of the annual U.S. resin sales in 1989 and 1990, respectively (Table 1); U.S. resin sales increased 5.5% in 1990 after no increase in 1989 (Martino, 1991). The most commonly used thermoplastic resins include LDPE, PVC, HDPE, and PP; these resins accounted for 61% of the total resin production in 1990 (EPA, 1990a). Common products made of thermoplastic resins include milk bottles and other food containers.

In contrast to thermoplastic resins, thermoset resins are stronger when exposed to high temperatures, tend to be rigid, infusible, and insoluble, and cannot be remelted and reformed. Thermoset resins often are shipped to processors in liquid form, where the resin is cured and molded (EPA, 1990a). The most commonly used thermoset resins include phenolics and polyurethane resins. Thermoset resins typically are used in building materials and automotive parts (EPA, 1990a).

Thermoplastic and thermoset resins are further categorized according to the volume produced and the market demand for the resin. The categories and the uses of the resins are listed below.

- **Commodity resins** These resins are produced in large quantities and are used as the raw materials for many plastic products. These resins are labeled as commodities because they are commonly used and are not refined or differentiated by the resin manufacturers. Commodity resins, such as LDPE, PVC, and HDPE, are the least expensive resins to produce (EPA, 1990a).
- **Transitional resins** These resins are produced less frequently than commodity resins but more frequently than engineering/performance resins (discussed below). Transitional resins, such as PP, ABS, and acrylics, are also more expensive to purchase than commodity resins (EPA, 1990a).
- **Engineering/performance resins** These resins have narrowly defined applications and are produced by only a few companies. Engineering/performance resins, such as polycarbonate and nylon, are the most expensive resins to produce (EPA, 1990a).

2.1 Pellet Additives

Some resins are used in the pure-polymer form, but, more frequently, the properties of the polymer must be changed to produce the desired end product. Additives are used to alter the physical characteristics of the polymer, such as aesthetic properties (e.g., color), physical properties (e.g., heat-resistance and hardness), and the ability to be further processed (e.g., porosity) (EPA, 1990a). Table 2 shows additives, additive concentrations, and typical polymers to which the additives are applied.

The type of additive determines when and how the additive is applied to a polymer. Two methods are used to incorporate additives: (1) the additive (solid or liquid) is mixed with the polymer, or (2) the additive is reacted chemically with the polymer (the additive is bonded with the polymer).

In ecological discussions, this distinction is very important when considering leaching of the additives into the environment and potential toxicological effects of the additives. Additives physically mixed with the polymer may be more likely to leach out because the additive is not chemically bound to the polymer; leaching would be determined by the miscibility (ability to be mixed) of the additive and polymer and by environmental conditions (e.g., temperature). Additives incorporated through chemical reactions cannot leach out of the plastic unless the plastic is broken down chemically (EPA, 1990a).

As previously stated, additives are used to change certain physical properties of the polymer to produce a desired product. Typically, these changes affect aesthetic properties, durability, or ease of processing of the resin. Some additive-containing pellets may be designed for controlled environmental release of chemical additives. For example, Rutherford and Withycombe (1985) patented a process (U.S. Patent 4,542,162) for forming plastic pellets containing repellents for use in controlling animals, birds, and insects. The action of the repellent requires the intentional dispersion of pellets in a given area. Thus, this and other applications for pellets may involve intentional, as opposed to accidental, introduction of pellets into the environment.

2.2 Pellet Behavior in the Aquatic Environment

Many types of resin pellets float in fresh water or sea water (Table 3). Basically, pellets and granules with specific gravities lower than water will float, and pellets with higher specific gravities than water will sink. Additives may affect polymer density, thereby influencing whether a pellet will float in water. Because salinity affects water density, a particular resin pellet could float in sea water but sink in fresh water.

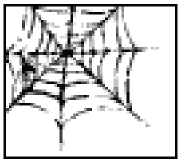
Most additives are used in moderate to low concentrations (Table 2), and the additives may not significantly alter the pellet's ability to float in fresh water or sea water. However, some additives and polymer modifications will result in significant changes in the pellet specific gravity and, therefore, will affect the pellet's ability to float or sink in water. The changes in specific gravity that were caused by the introduction of additives (fiber/flake reinforcements or particulate fillers) into six commodity resins are shown in Table 4.

Hydrodynamic processes, such as turbulence and surface tension, may affect a pellet's ability to float. For example, turbulence may either submerge pellets that would normally float at the surface, or resuspend pellets that would normally sink below the surface or to the bottom. Also, waters with high surface tension, such as waters containing a debris slick or discharge from a municipal sewage system, may either support particles with a density greater than water or keep an otherwise buoyant particle submerged.

Limited data are available that describe the biological and chemical activity of pellets in the environment. Van Franeker (1985) reported that many additives are known to be toxic and that toxic effects from the plastics additives may be more significant in aquatic organisms than was previously thought. Ryan*et al.*(1988) suggested that compounds used in the manufacture of plastics may be assimilated by organisms that ingest the pellets. Known and suspected biological effects of pellets in the environment are discussed in greater detail in Section 3.3.

The persistence of a pellet in the environment may be measured in years, depending on the resin type, the types and amounts of additives, and the reactions of the resins and additives to environmental processes. EPA (1990a) estimated that the lifetime of plastic products range from less than 1 year to more than 10 years, depending on the product. In the aquatic environment, the lifetimes can be affected by biological or chemical fouling, heat buildup within the plastic, degradation by microscopic organisms, and availability of atmospheric oxygen (EPA, 1990a).

Because pellets are small, lightweight, buoyant (if the pellet's specific gravity is lower than that of water), persistent, and ubiquitous in the aquatic environment, they are a potential hazard to aquatic organisms who ingest the pellets mistaking them for prey. Section 3.0 addresses the geographical distribution of pellets, sources of pellets to the aquatic environment, and impacts of pellets on birds, turtles, other biota, and humans.



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3.0 The Pellet Problem

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Plastic pellets are among the smallest items of debris discharged into the aquatic environment. They are, therefore, not as visible (aesthetically displeasing) or as obviously harmful as larger forms of debris, such as discarded fishing gear, medical wastes, etc. This is evidenced by their exclusion from debris inventories reported from the annual beach cleanups (i.e., CMC, 1989, 1990) and from all but one of the National parks studied by Cole *et al.* (1990). However, these small plastic pellets are often mistaken for food by aquatic animals, particularly seabirds.

3.1 Geographical Distribution

Although plastic pellets are one of the least noticeable forms of plastic pollution, they are ubiquitous in the oceans and on beaches. They have been reported in the sediments and the surface waters of coastal areas and oceans throughout the world (Table 5); data are limited regarding the presence of pellets in rivers, streams, and lakes. The ubiquity of pellets is demonstrated by their presence in remote areas of the world, such as beaches of the South Pacific (Gregory, 1977) and Hawaii (EPA, 1992b). Among the earliest records of pellets in the environment were the studies by Carpenter *et al.* (1972) and by Carpenter and Smith (1972). These studies reported pellets in the Atlantic Ocean along the southern coast of New England and in the Sargasso Sea, respectively. Several other authors also have reported pellets in the Atlantic Ocean (e.g., Colton *et al.*, 1974; Hays and Cormons, 1974; Morris, 1980; van Franeker and Bell, 1988; Ryan *et al.*, 1988). In the Pacific Ocean, pellets have been reported in northern waters (e.g., Wong *et al.*, 1974, as cited in Pruter, 1987; Dahlberg and Day, 1985; Day *et al.*, 1990) and in southern waters (Gregory, 1977). Pellets have been reported along the coasts of the Mediterranean Sea (Shiber, 1979, 1982, 1987), and the Gulf of Mexico and Caribbean Sea (Carr, 1987; Cole *et al.*, 1990). Most pellets found in marine waters have been identified as polyethylene (PE), polypropylene (PP), or polystyrene (PS) (CEE, 1987).

Under the ongoing Harbor Studies Program, the Environmental Protection Agency (EPA) has conducted studies of floating aquatic debris in harbors along the coastal United States since October 1988 (EPA, 1990b, 1992a,b; Trulli *et al.*, 1990; Redford *et al.*, 1992). The debris was collected by conducting net tows at the water surface to a maximum depth of 0.5 m. Over 200 different types of manmade debris were counted. By the end of 1991, sampling had been conducted in 13 cities and the Mid-Atlantic Bight during a total of 20 surveys.

Plastic pellets were among the most common items found during the Harbor Studies Program, comprising approximately 94% (by number) of all debris collected. The pellets were generally ovoid, cylindrical, square, discoid, or irregularly spherical in shape, and were approximately 5 mm or less in diameter (see Figure 2 below). Most of the pellets were clear, white, or off-white, but several other colors (such as black, green, yellow, amber, orange, blue, etc.) were also observed in the samples. Visual assessments made by a polymer chemist confirmed that a variety of pure polymers and additive-containing pellets were found in the samples (Mr. Elmer Bradbury, Battelle Memorial Institute, personal communication, February 1991). The descriptions are also consistent with EPA's description of PE and PP pellets (EPA, 1990a).

Plastic pellets were found in the harbors of 13 of the 14 cities surveyed and in the Mid-Atlantic Bight (Table 6), and in 29 of the 32 sampling areas (two to four areas were sampled within each city). Mayagüez, Puerto Rico, was the only major study area in which pellets were not found. Pellets were not found in Hampton Roads, Norfolk, or in the Weymouth/Neponset Rivers, Boston, but they were found in other areas in these harbors.

Plastic pellets were the most common item (by number of items) in eight cities (Houston, New York, Tacoma, Baltimore, Boston, Oakland, Philadelphia, and San Juan), and were among the ten most common items in three additional cities (San Francisco, Miami, and Seattle) and in the Mid-Atlantic Bight. [*Note:* In all, only 20 debris items were collected in the Mid-Atlantic Bight, and the percent composition should be considered with caution.] Pellets were the 14th most common item in Norfolk.

Of all cities surveyed, the greatest number, variety, and percentage of pellets were collected in the Houston Ship Channel at Houston, Texas. Over 700,000 pellets were collected during the Houston surveys combined (approximately 98% of all Houston debris). One sample alone contained more than 225,000 pellets. Although pellets of many colors and shapes were collected, most of the pellets from Houston were clear, white, or off-white and ovoid. Notably, Houston has one of the greatest concentrations of plastics industries in the United States and several pellet industries are located along the Houston Ship Channel. Most of the pellets were found in Buffalo Bayou, which is inaccessible to shipping traffic.

A high percentage of aquatic debris collected in Tacoma, Washington, was pellets (78%). Unlike the pellets from the Houston Ship Channel, those from Tacoma were similar to each other in size, shape, and color. Most of the Tacoma pellets (2732 pellets out of 3834 pellets) were found in a single sample. These observations suggest that the pellets may have originated from a single source.

The New York/New Jersey Harbor complex, ranked second by number (11,266 plastic pellets) and third in percentage of plastic pellets (39%). In samples collected from the Hudson and East Rivers around Manhattan Island, pellets varied considerably in color, shape, and condition, indicating possibly several sources of entry into the environment. Some pellets from these areas were embedded in grease, tar, or other organic matter (including fecal matter), which might be expected to accumulate on debris flowing from combined sewer overflows (CSO). In samples collected from the Kills (the water mass separating Staten Island from New Jersey), pellets were of a more uniform size, shape, and color.

Immediately following a February 1992 survey of the harbor at Honolulu, Hawaii, the presence of pellets was studied at the beach along Kahana Bay on the northeastern coast of Oahu. Most of the pellets collected at Kahana Bay were white or off-white, and many were weathered or discolored. Several black pellets were also found in each sample. Based on enumerations along three transects, the average number of pellets on the beach at Kahana Bay was 105 pellets per m2 (range: 88 to 115 pellets per m2). The pellets were found interspersed with other manmade debris, including light sticks, net floats, plastic food containers, and plastic pieces, and natural debris such as driftwood and seaweed, and were concentrated in the portions of the transects that were farthest from the water. According to the Chief Scientist, many more pellets and types of pellets were present on the same beach in 1989 than were present during the survey (Mr. David Redford, EPA, personal communication, February 1992). The decreased numbers of pellets may have been due to heavy storm activity during the two weeks prior to the survey, which would have resuspended beached pellets in rough surf conditions at high tide.

Two additional pellet-related items, plastic powder and flattened pellets, were found in several cities. Plastic powder, an intermediate form of the raw material used to make pellets and molded products, was observed floating on the water's surface and was collected in considerable volume along with other debris. In Houston, this powder was initially thought to be grain dust from nearby grain elevators, and was discarded as natural debris (i.e., not anthropogenic in origin); Figure 3 shows plastic powder collected in Houston. However, during the pellet producer site visits conducted under the present study, the investigators recognized the powder, and plastics industry personnel verified that the material was plastic powder. For additional verification of these conclusions, the investigators removed some of the material from the Houston samples and heated the material in a metal spoon. The grains melted and subsequently solidified into an amorphous mass after cooling. The mass appeared to be plastic, although this was not confirmed by chemical analysis. Survey scientists do not recall collecting this powder in other cities, but again the material may have been overlooked as natural debris.

Thin, irregularly shaped plastic disks approximately 1 cm in diameter (see Figure 4) were identified in samples collected from several different harbors. At the time, these disks could not be identified, and they were subsequently counted and recorded as miscellaneous plastic pieces. However, several disks identical to ones collected during the surveys were found during a site visit to a pellet producer. The plastic disks, found among plastic pellets, were scattered along railroad tracks and beneath hopper cars in the loading and cleaning areas of the producing facility. Plastics industry personnel identified the disks as plastic pellets that had been flattened by rail hopper cars.

3.2 Sources Identified in the Literature

Several researchers have suggested possible sources of pellets to the aquatic environment (Table 5), including

- Direct discharges and improper waste water disposal by the plastics industry
- Waste disposal and sewer discharges by cities
- Spillage from trucks, trains, and ships during loading, transport, or unloading
- Improper use of pellets, such as for packing material, for insulation, and for bearings to facilitate the movement of cargo boxes and other heavy objects.

Unfortunately, most studies focused on reporting pellet distributions and abundances, and the source identifications were based mostly on empirical evidence rather than on direct evidence. As presented in Section 3.2.1, the recent EPA studies of U.S. harbors (EPA, 1990b, 1992a,b) and CSOs (EPA, 1992c) have provided some direct evidence that storm sewers, CSOs, and direct spillage into the waterways are sources of pellets to the aquatic environment.

3.2.1 EPA's Harbor Studies Program

As discussed in Section 3.1, EPA has conducted studies of floating aquatic debris in selected harbors of the United States. One objective of the EPA Harbor Studies Program was to identify potential sources of floatable debris collected during the surveys. Several possible sources of pellets were identified based on field observations and conversations with local authorities; these sources were CSOs and storm sewers, storm-water runoff, and spillage from loading docks.

The results of surveys in New York, Boston, and Houston, for example, indicated that CSOs and storm sewers were sources of pellets in the aquatic environment. In the Kills area of New York Harbor, the cleanliness and uniform size, shape, and color of the collected pellets (as in Tacoma), indicate a possible single source. Because the pellets were mixed with other debris typically discharged from storm sewers or CSOs, storm sewers and CSOs are likely the discharge points for pellets released by the plastics industry and related transporters.

In Boston, the majority of the pellets was collected from the Charles River on the freshwater side of the locks near the Museum of Science. There is no commercial shipping on the River and there are no known pellet industries along the banks of the River. This suggests that pellets are entering the environment through storm sewers or CSOs that receive storm-water runoff and other drainage from pellet industries.

As previously discussed, extremely large numbers of pellets were collected from every area of the Houston Ship Channel. Large numbers of pellets were found above or west of the turning basin in Buffalo Bayou, where there is no commercial shipping and tidal fluctuations are minimal (<0.5 ft). Because of the lack of shipping and the unlikely transport of pellets by tidal currents, pellets found in Buffalo Bayou were most likely discharged from storm sewers (Houston has no CSOs) or carried into the Channel directly by storm-water runoff.

The results of surveys in Tacoma and Houston indicated that spillage at loading and shipping docks is another source of pellets in the aquatic environment. In Tacoma, a local resident reported that a crate of pellets was spilled into the harbor 2 months prior to the Tacoma survey, thereby establishing the possibility that a single discharge was a possible source of the collected pellets (Mr. David Redford, EPA, personal communication, March, 1989). An-other resident stated that pellets were regularly observed on local beaches; this would indicate that pellet spills may be common to the Tacoma area. In addition, the fact that people are noticing pellets during recreational activities indicates that pellets are frequently present in large numbers; large numbers would make the pellets more obvious and easier to distinguish from natural debris.

In Houston, pellets also were collected in massive numbers in the middle area of the Houston Ship Channel (areas below or east of the turning basin). These pellets probably entered the channel through several sources, including spills at the loading dock, spills aboard ship, or spills at industrial sites where pellets are carried by rain water into the storm sewers or are blown into waterways. Pellets discharged into Buffalo Bayou would also be transported to areas east of the turning basin. Discussions with a local longshoreman indicated that during ship loading operations pellet packaging often was punctured by forklift tines. When the pellets were transferred from the dock to the ships, thousands of pellets would spill onto the dock and directly into the Channel. He also indicated that pellets spilled onto the docks were swept directly into the Channel during routine maintenance of the area.

3.2.2 EPA's CSO Studies Program

In older cities of the northeastern United States, CSO discharges of raw sewage and street litter are common during heavy rainstorms. Studies conducted under the EPA-sponsored CSO Studies Program examined the types and amounts of floatables discharged from selected CSOs and storm sewers, as well as floatables captured by bar screens and settled out in the scum of sewage treatment facilities in Philadelphia and Boston. Final data show that pellets are present in the sewage treatment plant scum (small-sized, floating material at the surface of the settling tanks) samples (Table 7), in CSO samples of both cities, and in the storm sewer samples collected in Philadelphia (Table 6). No storm sewers were sampled in Boston. [*Note:* One pellet was found in the CSO discharge in Philadelphia; these data should be viewed with caution because it was not determined that the CSO had discharged during the study.] The data from this study indicate that pellets are entering municipal sewerage systems from land-based sources, and are subsequently entering the aquatic environment through CSO and storm sewer discharges.

3.3 Fate and Impacts

There are several documented accounts describing pellet and other plastic debris ingestion by wildlife, most notably by seabirds and sea turtles (Table 8). Generally, impacts or biological effects of the pellets have not been clearly defined in most wildlife, and, to date, direct correlations between pellet ingestions and effects have not been demonstrated conclusively. This may be attributable to the fact that the studies typically use stranded and beached animals, and most animals that die at sea either sink to the bottom or are consumed by predators before they are found by humans (Laist, 1987).

3.3.1 Birds

The ingestion of pellets by seabirds has been reported worldwide (Table 8), and seabirds ingest plastic pellets more frequently than do any other taxon (Ryan, 1990). Sileo *et al.* (1990) reported that 80 species, or approximately one-quarter of all seabird species, are known to ingest plastic debris. Pellets are the most common form of plastic debris ingested by seabirds (EPA, 1990a; Ryan, 1990). Day (1980) estimated that polyethylene pellets remain in the digestive tracts of birds for 10 to 15 months (see Figure 5).

Several factors affect the vulnerability of a seabird population to the presence of pellets.

- **Frequency of regurgitation** - Birds with a limited ability to regurgitate are most likely to be effected by pellet ingestion. Debris loads in birds are a function of the ratio of the rates of ingestion and regurgitation (Ryan, 1990).
- **Foraging habits** - Birds that feed by pursuit diving are the most likely to ingest pellets, and birds that feed by plunging and piracy are the least likely to ingest pellets (Day et al., 1985).
- **Pellet color** - Seabirds are more likely to ingest pellets that are light-colored (e.g., white, tan, brown, yellow) than those of any other color (Sileo *et al.*, 1990; Day *et al.*, 1985). This color preference has been attributed to the pellet's similarity to common food sources, such as fish eggs, crustaceans, etc. (Day *et al.*, 1985).
- **Prey type** - Pellets pose the greatest threat to plankton-feeding species, such as shearwaters, petrels, prions, phalaropes, and auklets (Fry *et al.*, 1987).
- **Proximity to pellet sources** - Logically, the closer that a seabird is to a release point, the more likely it is to encounter and ingest pellets (EPA, 1990a; van Franeker and Bell, 1988).
- **Proximity to areas where pellets accumulate** - Species that feed at the ocean surface are more likely to ingest plastic, most probably because they are more likely to be exposed to floating plastic (Sileo *et al.*, 1990).

The effects on seabirds of ingested pellets and other plastic debris were summarized recently by Ryan (1990) at the Second International Conference on Marine Debris (Shomura and Godfrey, 1990). Ryan (1990) stated that anthropogenic debris may have three specific effects on seabirds: (1) diminished foraging ability or a decreased foraging efficiency, (2) physical damage (e.g., intestinal blockage), and (3) physiological effects from the absorption of toxic chemicals associated with the pellets.

Diminished foraging ability appears to be the most serious effect of pellets on seabirds. The presence of pellets in the stomachs of seabirds may create false feelings of satiation, decrease the storage volume of the stomach, and reduce foraging. Ultimately, this will reduce the ability of the seabirds to accumulate the energy (fat) reserves necessary for migration, reproduction, molting, and survival of adverse environmental conditions (Day *et al.*, 1985; Ryan, 1988a, 1990). These effects would occur most likely in procellariiform seabirds, which, compared to other seabirds, experience the highest incidence of plastic ingestion (Ryan, 1988a). However, a few pellets in a bird's stomach are not likely to have an adverse affect, primarily because many seabirds retain indigestible materials in their stomachs to aid in digestion (Furness, 1985; Ryan, 1988a, 1990), although Wallace (1985) believed that the birds could be chronically stressed. Studies to determine a critical pellet volume have not been reported.

Studies of potential impacts caused by pellet ingestions generally have indicated that physical damage probably occurs in only a small number of seabirds. Day (1980) reported that ingestions increased the gizzard volumes of some auklets, resulting in the full distension of the gizzards and a potential reduction in hunger. Where individuals that had ingested large numbers of pellets, the pellets were found embedded in sockets in the gizzard wall, but no effects (good or bad) were noted. Day *et al.* (1985) subsequently reported that ingested pellets reduce the storage volume of seabird stomachs.

In a controlled study of the effects of large numbers of PE pellets in white-chinned petrels, Ryan and Jackson (1987) reported no significant changes in digestive efficiency between test and control birds. Several authors have document lacerations by sharp debris (e.g., Day *et al.*, 1985; Fry *et al.*, 1987, Ryan and Jackson, 1987); however, because pellets are generally round and smooth, it is unlikely that pellets lacerate stomach linings in seabirds.

Finally, plastic pellets in the environment may contain chemicals that are toxic to seabirds. These toxic substances may be additives that were intentionally mixed into the resin to achieve specific properties, or contaminants that were adsorbed by the pellets from the environment. Carpenter *et al.* (1972) reported the adsorption by pellets of organochlorine compounds from ambient seawater. Day (1980) noted a decreased ability to reproduce in pellet-ingesting birds, which he attributed to the hydrocarbon pollutants associated with plastic. Ryan *et al.* (1988) provided the only direct evidence of a correlation between plastic loads and PCBs in seabirds, but Ryan (1990) speculated that paint chips and tar balls may contribute more significantly than do pellets to the total toxic chemical load in seabirds.

Further studies are needed to determine if pellet ingestion leads to poor bird condition or if poor bird condition leads to pellet ingestion (Connors and Smith, 1982; Bourne and Imber, 1982; Ryan, 1987, 1990).

3.3.2 Turtles

Balazs (1985) found that marine turtles ingest many items of floating debris, including plastic pellets (e.g., unfoamed polystyrene beads). Evidence suggested that plastic material passes through the digestive tracts and are voided naturally. However, Balazs (1985) also reported that ingested debris may cause potentially serious problems in sea turtles, such as lost nutrition, reduced absorption of nutrients, and adsorption of plasticizers. In addition, small plastic fragments may adversely affect turtles during digestion when pellets or fragments are ground together by muscular contractions, and pinocytotic absorption of the resulting microscopic plastic particles could occur. The latter phenomenon was suggested to occur also in albatrosses [Pettit *et al.*, 1981, as cited in Balazs (1985)].

Balazs (1985) suggested several explanations for ingestion by turtles.

- Marine organisms encrusting plastic debris may be a desirable food source or may mask the artificial nature of the debris, thereby inhibiting a rejection reflex by the sea turtles.
- Under conditions of extreme hunger when available food stocks are limited, sea turtles may feed on items that they would not normally eat.
- Prey that has consumed debris is ingested by a predator. Balazs suggested that the increasing volumes of plastic particles in the oceans make this mechanism distinctly possible.

Balazs concluded that additional research is needed in regard to incidence and effects of plastic ingestions by sea turtles.

Carr (1987) discussed the significance of nondegradable debris, including pellets, to sea turtles during early developmental stages. Because manmade and natural debris and planktonic organisms accumulate along convergences, Carr concluded that young, advanced pelagic-stage sea turtles are vulnerable to the presence of pellets in the oceans owing to the turtles' close association with the convergences. The findings of Plotkin (1988) and Plotkin and Amos (1990) support Carr's conclusion.

3.3.3 Other Biota

Although most of the published literature describing ingestion and biological effects of pellets concerns seabirds and sea turtles, a few studies have discussed associations between pellets and other organisms, including fish [(Carpenter *et al.*, 1972; Karter *et al.*, 1973, 1976; Colton *et al.*, 1974; Mr. Frank Steimle, National Marine Fisheries Service (NMFS), personal communication, August 1991)], several invertebrates (Carpenter *et al.*, 1972; Karter *et al.*, 1973; Mr. Frank Steimle, National Marine Fisheries Service (NMFS), personal communication, August 1991), and, potentially, baleen whales (Walker and Coe, 1990). Secondary ingestions of pellets by seabirds were reported by Wehle and Coleman (1983, as cited in Wallace, 1985); the investigators reported that the birds had consumed other birds and fish that had ingested pellets.

A few investigators have reported colonization on pellets by biological organisms that are normally epibionts on *Sargassum* floats and other floating organisms. The epibionts reported include hydrozoans and diatoms (Carpenter and Smith, 1972; Winston, 1982; Gregory, 1983), bryozoans, coralline algae, coiled calcareous annelids and other calcareous worm tubes, and foraminiferids (Gregory, 1983). Accumulations of organic matter and tar or oil have also been observed on pellets (Wilber, 1987; Redford *et al.*, 1992); the presence of these materials could increase the possibility that an animal might confuse the pellets with its natural food sources. Finally, one study reported that pellets might be useful to some species: Karter *et al.* (1973) found that polychaete worms used pellets to build dwelling tubes.

3.3.4 Aesthetic and Economic

Several authors have documented the human aesthetic (Gregory, 1983; Wallace, 1985; Wilber, 1987; Klemm and Wendt, 1990) and economic (Wallace, 1985) impacts of pellets in the environment. Although plastic pellets may not be as aesthetically displeasing as other items of debris, such as sewage-related and medical-related debris, the quantities present and their persistence in the environment are cause for notice. Gregory (1977) speculated that someday man will sunbathe on *plastic sand beaches*; Klemm and Wendt (1990) labeled the combination of pellets and plastic fragments *beach confetti*, but believed its presence was not a celebration. The aesthetic impacts of pellets to recreational areas were discussed by Wallace (1985) and CEE (1987).

A final impact of pellets in the environment may be measured in terms of economic costs. The loss of feedstock and the costs of replacing the feedstock may be offset only if the pellets are recaptured and recycled instead of replacing them (Wallace, 1985). The economic incentive to recycle spilled pellets was evident during the site visits of the present study, where several of the companies were already actively collecting and recycling waste pellets and other plastic scrap.

4.0 Pellet Sources to the Environment

Disclaimer: The information in this website is entirely drawn from a 1992 publication, and has not been updated since the original publication date. Users are cautioned that information reported at that time may have become outdated.

Because, as reported in the literature, plastic pellets are frequently mistaken for food by a variety of aquatic animals (Section 3.0), attention must be given to the sources of the pellets in the environment. One of the objectives of this study is to identify the sources of pellet release into the environment within the plastic industry. To this end, the Society of the Plastics Industry, Inc. (SPI), arranged for each sector of the industry pellet producers, transporters/contract packagers, and processors to be visited by the study team. The site visits were arranged with the understanding by all parties that the names of the visited companies would remain confidential. Each company was assigned a letter in the order in which it was visited (i.e., the first company was assigned the letter A, the second company was assigned the letter B, and so on).

The degree to which the observations reflect the overall conditions and practices of the plastics industry was not determined. Only at Company C did officials state that no inordinate maintenance or housekeeping activities were performed prior to the visit and that operations were conducted as usual during the visit.

In this section, the equipment and operations of each sector are described generally, and each general description is followed by a description of the sector's site visits. Sources of pellet release into the environment from each respective sector are also presented.

4.1 Organization of the Plastics Industry

For the purposes of this study, the plastics industry consists of three major sectors: pellet producers, transporters/contract packagers, and processors. Figure 6 shows the organization of the industry and, specifically, the flow of plastic pellets within each sector and among the sectors. The sectors are defined as

- Producers - Discussed in Section 4.2, illustrated in Figure 6(a) below
- Transporters/Contract Packagers - Discussed in Section 4.3, illustrated in Figure 6(b) below
- Processors - Discussed in Section 4.4, illustrated in Figure 6(c) below.

Many of the operations described in the following sections may, in reality, occur in more than one industry sector. For example, operations relating to pellet packaging and storage occur at producers as well as contract packagers, and conveying systems exist in all three sectors. Operations are typically described in the industry sector that has primary responsibility for conducting the operation.

Estimates were not available of the numbers of companies from each sector in the U.S. plastics industry. SPI has approximately 2200 member companies, which are estimated to represent 75% of the total dollar volume of the plastics industry. SPI estimates that their membership represents 98% of the pellet producers, but only 10% of the total number of companies within the industry (Ms. Maureen Healey, SPI, personal communication, April 1992).

4.2 Pellet Producers

The pellet producers create the polymers and extrude the pellets. The Environmental Protection Agency (EPA) (1990a) reported that a total of 477 resin-producing facilities were operating in the United States, based on U.S. Bureau of the Census (1988) estimates. Most of the 55,000 workers employed by the producers reside in Texas, New Jersey, West Virginia, Pennsylvania, Louisiana, Ohio, Michigan, and California.

A diagram showing the flow of pellets through a pellet producer is presented in Figure 6(a) above.

4.2.1 Producer Equipment and Operations

Polymerization
The production of plastic pellets begins with polymerization. Polymerization is the chemical reaction(s) through which low-molecular-weight organic molecules (monomers) are linked to form long monomer chains, or polymers. Polymers are produced through either of two methods: bulk polymerization or solution/suspension polymerization.

- **Bulk polymerization** produces a hot, very viscous liquid called a melt. Melts are pelletized immediately or subsequent to the incorporation of additives. Polymers produced through bulk polymerization processes include low-density polyethylene (LDPE), polystyrene (PS), polyvinyl chloride (PVC), and polymethyl methacrylate.
- **Solution/suspension polymerization** produces powders, not liquids, after the polymer is separated from the carrier solvent and dried; drying ensures minimal carryover of the carrier solvent. The powders may be subsequently melted and formed into either pellets or end-products.

Polymers produced through this process include high-density polyethylene (HDPE), polypropylene (PP), PS, and PVC.

The ultimate use of polymers typically involves one or more stages in which the polymer is in pellet form.

Pelletizers

High-volume pelletizing systems have been developed that can process over 5000 lb of pellets per hour (2268 kg/h) (Hunt, 1978), or approximately 110,000,000 pellets per hour. The most common types of pelletizing equipment include dicers, strand pelletizers, die-face pelletizers, and centrifugal pelletizers.

- **Dicers** - Dicers produce pellets by feeding a quenched (cooled) strip of polymer through rotating knives that slice against a stationary bed knife, thereby shearing the strip into pellets (Mark *et al.*, 1987).
- **Strand Pelletizers** - Strand pelletizers force molten polymer through a row of orifices (usually round), thereby producing continuous strands that are 2 to 4 mm dia. The strands are quenched in a water bath and passed through a multiknife rotor that operates against a fixed blade. The strands are cut into 1- to 5-mm lengths, depending on the feed rate and rotor revolutions per minute. Most resins can be pelletized by this method, but very brittle or fragile resins must be pelletized by another method (Mark *et al.*, 1987).
- **Die-Face Pelletizers** - Die-face pelletizers pass molten resin through a die face, cut the resin into pellets as it passes through the die face, and cool the hot pellets by applying either air or water. This method differs from dicers or strand pelletizers that pelletize already cooled resin strands. The types of die-face pelletizers differ only in the method by which the pellets are cooled (i.e., air, water, or a combination of air and water). Pellets are removed from the cooling/carrier fluid by allowing them to settle or float in a tank, depending on the polymer, and air-cooled pellets are transferred to storage silos. Examples of die-face pelletizers include water ring, underwater, and rotary knife pelletizers (Mark *et al.*, 1987).
- **Centrifugal Pelletizers** - Centrifugal pelletizers feed molten resin into a rotating drum that contains circumferential holes. Centrifugal force extrudes the molten resin through the holes and forces the strands away from the drum face. The extruded polymer is then cut by a stationary knife that is mounted away from the drum face. The momentum of the severed pellets carries the pellets into a cooling system (Mark *et al.*, 1987).

The type of pelletizer used determines the size and shape of the pellets produced. Most modern pelletizers are large, enclosed, fully automated systems, where the pellet flow is controlled within the pelletizer.

Conveying Systems

Conveying systems are used to move pellets between plant operations, such as between the pelletizers, drying systems, and the storage silos, between the storage silos and the packaging or shipping containers, and between the silos or packaging and molding machines. The potential for pellet spillage is present during each conveyance. The rate of pellet entry into the conveying system cannot exceed the rate of pellet delivery from the conveying system, otherwise pellet spills will occur.

Pellet conveying systems can be either pneumatic or mechanical. Pneumatic systems may use either dilute-phase or dense-phase systems. Dilute-phase systems are low-pressure systems that use high-velocity air and a high air-to-pellet ratio to move the pellets into receiving vessels (e.g., storage silos, rail hopper cars). A vacuum can also be used to pull the air and pellets into the receiving vessel. Dense-phase systems are high-pressure, low-velocity systems with a low air-to-pellet ratio. In dense-phase systems, the conveyor is filled with pellets and pressurized; the flow of pressurized air carries the pellets through the conveying line.

Figure 7 (below) shows a pneumatic conveying system in a pellet-blending operation (e.g., where pelletized colorants are mixed with pure HDPE pellets). Each of these operations also requires properly sequenced procedures to avoid spills.

Mechanical conveyors also are used for in-plant pellet movement. These conveyors generally are used to transport pellets across short distances, as well as in operations that cannot be completed by using a pneumatic system (e.g., operations that require a continuously high pellet-delivery rate). Most mechanical conveyors use a rigid driven screw to move the pellets through a conduit. Because the screw shaft is flexible, these conveyors are suitable only where straight conduit runs can be installed.

Mechanical conveying systems may be used to transport pellets from transporting vessels (e.g., rail hopper cars and bulk trucks) either to storage areas or directly to other packaging or processing operations. Generally, the transporter empties the pellets into a hopper that, in turn, feeds a mechanical conveyor. These mechanical conveyors may also be used to transfer pellets from bag- or box-emptying stations to, for example, a blending silo or a bagging machine. In addition, mechanical conveyors may be used also to volumetrically feed pellets to a blending operation.

4.2.2 Site Visit Observations

Two pellet producers, Company F and Company G, were visited during this study. Both companies were visited on February 5, 1991.

Company F
Company F is a large manufacturer of HDPE polymers in pelletized form. Company F also produces PE powders and other nonpellet polymer products; most of the powders are subsequently pelletized.

The company operates several pelletizers during routine operations. In the extruder observed during the visit, PE powder is melted, the liquid polymer is extruded through a die, and the resulting polymer bead is cut into pellets. The pellets are first water-cooled, then air-dried, and are pneumatically conveyed to storage silos. Pressure sensors throughout the pneumatic system monitor the pellet transfer, enabling the operators to detect potential blockages and thereby prevent spills. During routine operations, pellets may be removed for quality control inspection after they have been cooled. In addition, the system may be opened for maintenance or corrective action (i.e., purging during system shutdowns); all waste pellets removed from the extruders during maintenance or corrective action are placed in specially labeled waste bins and recycled; no PE is disposed into landfills.

Pellets are stored in large silos until transferred into either rail hopper cars or bulk trucks; over 90% of the pellets produced by Company F are directly loaded into these bulk-transport vessels. Less than 10% is loaded into gaylords or paper bags (bagged pellets are primarily for overseas shipment). Spills in the bagging areas are cleaned up immediately and the spilled pellets are recycled.

All rail hopper cars and bulk trucks are thoroughly cleaned inside and outside before loading, and outside after loading. Before loading, the inside of the car must be cleaned to remove all residual trapped and clinging pellets as well as other contaminants (e.g., dust) that may be present. Pellets are removed first by suctioning; residual pellets are then washed out with water. The water rinse is performed in an enclosed area where residual pellets are washed into the facility drainage and containment system (discussed in detail below). Several pounds of residual pellets may be washed out of a rail hopper car.

Pellets are pneumatically transferred into rail hopper cars or bulk trucks through a closed loading system where the spreader is connected directly onto the loading spout so that the loading spout does not have to be reconnected at each loading port. After loading, the outside of each rail hopper car or bulk truck is rinsed, and the rinse water is directed into the facility drainage system. The pellets are shipped either directly to a processor or to a contract packager for repackaging (e.g., bulk shipments bags or gaylords). The processor or packager returns the empty rail hopper cars or bulk trucks to Company F.

The Company F property is graded so that storm-water and wastewater drain from all areas of the plant into a facility containment system for recapturing plastic pellets and powders (see Figure 8 below). The containment system consists of a series of dams, skimmers, and surface booms arrayed within a weir that runs along two sides of the facility grounds.

A major focus of the site visit was to observe this pellet-recovery system that the company has been refining for several years. The first stages of the recovery system were installed in late 1980. The current recovery system consists of two fixed skimmers and two floating skimmers within a weir. By the end of 1991, it is expected that additional modifications to the system will more effectively control the flow of pellets under the dams.

The storm water and wastewater drain into the weir system; PE pellets and powder are carried by the water into this system. A water spray (see Figure 9 below) is directed at the surface of the water to prevent the pellets from moving back into the storm-water drainage system and concentrates the pellets and moves them toward the first fixed skimmer.

The first fixed skimmer is a motor-driven paddle skimmer comprising several rectangular paddles and a drive system that is attached to the weir walls. It is designed to operate under normal weather and operating conditions (se Figure 10 below). The paddles skim the pellets and powder from water surface and push them up a trough to street level. As the pellets are skimmed from the surface, the water passes under the retaining wall immediately downstream of the paddles. At street level, the paddles push the pellets off the end of the trough into a containment area. The contaminated (unclean) pellets are collected from this containment area and are shipped loose via truck to a recycler or to be sold as scrap. According to Company F officials, this first fixed skimmer generates a very large (but unknown) volume of recyclable material; during the site visit, approximately 100 cubic feet of waste pellets was observed in the containment area of the first fixed skimmer (see Figure 11 below).

During normal conditions, the first fixed skimmer is nearly 100% effective in removing powders and pellets. However, during and after periods of heavy precipitation, the fixed-skimmer system is breached by high water levels, and the paddles become partially or totally submerged and do not skim the pellets from the surface; according to company officials, this was the condition just prior to and during the site visit. By contrast, during periods of drought or abnormally light precipitation, the water level can drop so low that the paddles are completely out of the water. In either of these two situations, the first fixed-skimmer system cannot operate properly, allowing the pellets to bypass the skimmer and proceed downstream to the second fixed-skimmer system.

The second fixed skimmer is located several hundred yards downstream of the first fixed skimmer. The second fixed skimmer and its pellet containment area are configured identically to the first fixed skimmer and its containment area. A white mass of accumulated pellets and powders was observed between the two fixed skimmers. The mass resulted from either a breach of the first fixed-skimmer system or entry into the weir system in the storm-water runoff from areas downstream of the first fixed skimmer. The water level had not yet receded, and the paddles were completely submerged in the water and could not skim pellets from the surface. Pellets and powder were also accumulating on the downstream side of the second fixed skimmer and in front of a fixed surface boom located downstream of the second skimmer; this accumulation was likely the result of a breach of the second fixed-skimmer system.

A short distance downstream of the surface boom are two retention ponds. The first pond holds the wastewater before it is pH-adjusted. The water flows from the first pond through the pH-adjusting station and into the second retention pond. No pellets could be seen at the upstream side of the pH-adjusting station.

In the second retention pond, a portable surface boom is positioned in front of waste-water culverts that lead to the facility outfall. Pellets and powders collected at this point are removed by using a vacuum (see Figure 12 below). From this basin, the water passes into the environment through the culverts, through a water quality monitoring station and the outfall, and through a small stream into a nearby river.

Three times each week, one 24-h sample is collected at the outfall water-quality monitoring station. Total suspended solids (TSS), along with all other National Pollutant Discharge Elimination System (NPDES) analytes, are measured for each sample. Company F officials stated that the water sampler may not collect pellets, but it does collect powder. Only one pellet could be seen along the banks of the stream immediately below the outfall, despite the heavy rainfall and extremely large numbers of pellets in the weir.

Despite torrential rainfall the previous night, the Company F containment system was extremely effective in preventing the discharge of pellets. Company F developed this relatively simple but effective system, in part, to comply with NPDES permit regulations that limit TSS discharges. Prior to developing this system, Company F exceeded the NPDES permitted levels for TSS owing to the presence of polymer powder and pellets. However, the company recognizes the environmental hazards that pellets pose and is making a commitment to minimize its contribution to the problem. The company also recognizes the economic advantages to recovering and recycling waste pellets.

Company F officials believe that the successful operation of their pellet containment system is accomplished through a combination of physical plant systems and employee commitment. As a result, all new employees are trained in pellet spill prevention and cleanup. In addition, Company F has made a video of its pellet containment measures; this video is required viewing by all new operators.

Currently, company officials estimate that the recovery system is nearly 100% efficient under normal operating conditions, as evidenced by the absence of pellets at and beyond the outfall. However, during periods of heavy rainfall, the efficiency of the system decreases allowing plastic powder and, to a lesser degree, pellets to be discharged into the environment. On the day of the site visit, the heavy rainfall had stopped before the visit began, and the recovery system was returning to normal conditions. Company F anticipates that future system modifications (scheduled to be completed by the end of 1991) will control powder and pellet discharges during abnormal conditions (i.e., heavy rainfall).

Company G

The second pellet producer visited under this study was Company G. Company G manufactures approximately 600 million pounds of pellets each year, the bulk of which are shipped by rail hopper car. Pellet manufacturing is only one of several operations at this facility. Pellets are also bagged or boxed onsite, and a portion of the pellets are shipped by using bulk trucks.

Drainage ditches are located along the roads throughout the Company G facility. All storm-water and wastewater runoff are directed into the facility drainage system for treatment and are discharged into the river adjacent to the property. Disposable surface booms were located at several junctions in the drainage ditch system. The surface booms prevent floating material, such as plastic pellets, from backflowing into nonpellet-related areas of the facility.

The first area observed was the rail hopper car loading area. The rail hopper car loading area is paved and has drainage gutters or troughs between each pair of rails. Pellets spilled during loading are washed into the gutters and carried into the facility drainage system. Pellets could be seen throughout the rail hopper car loading area, on the ground, and in the gutters. Pellets, including those that had been flattened underneath rail hopper cars, were also visible throughout the area.

At the point where the gutters discharge into the facility drainage system, Company G had installed a simple containment system. After flowing from the gutters, the pellets are collected by using concrete barriers that act as fixed skimmers in a reservoir separated from the facility drainage system. (The water in the reservoir is deeper than the water in the drainage system.) Pellets enter the reservoir from beneath the fixed skimmers and float to the surface of the reservoir. An electrically-powered surface skimmer pumps floating pellets and water from the surface of the reservoir into a box-shaped basket made of small-mesh (smaller than the diameter of the pellets) screens. This system continuously skims the pellets and collects them in the screened baskets where they remain until they are removed by Company G employees. The screened baskets are checked twice each workshift and pellets are removed.

Water flows through the screened baskets into the reservoir and into the facility drainage system under a second fixed skimmer. The second fixed skimmer prohibits the flow of pellets into the drainage system, even during periods of heavy precipitation. (Both fixed skimmers extend well above the normal water level in the reservoir.) Additional small, portable floating skimmers are used at strategic locations to capture any pellets that enter the containment system from other areas of the facility.

The rail hopper car cleaning area was also visited; this area was located some distance from the loading facility. Before loading, the interiors of the rail hopper cars are completely cleaned to remove residual pellets. These pellets are rinsed onto the ground and are directed by using a water spray into troughs alongside the rails. The troughs transport the pellet-laden wastewater to a collection reservoir where it passes through a small-mesh screen capturing the pellets.

During the site visit, piles of pellets were visible on the ground throughout the rail hopper car cleaning area and the area's containment system had overflowed; in some areas, pellets were piled as high as 1 ft. The containment system in the rail hopper car cleaning area, configured similar to the system in the rail hopper car loading area, was completely clogged with pellets, and several employees were shoveling the pellets into barrels for disposal (the barrels were then emptied into dumpsters). An employee said that this pellet-overflow condition was typical during periods of heavy rainfall and during unusually busy periods. It was unclear whether the containment system at the rail hopper car cleaning area was linked to the facility drainage system. It was also unclear whether the runoff in the rail hopper car cleaning area and surrounding areas (where pellets covered the ground) was directed into the drainage system or elsewhere.

Scattered pellets and small patches of accumulated pellets were observed on walkways and in the parking areas of the rail hopper car loading area and the rail hopper car cleaning area. Loose pellets from the rail hopper car cleaning area apparently were tracked to areas outside the rail hopper car cleaning area. The fate of these pellets was not identified during this site visit.

Pellets collected by using the containment systems described above are recycled. Company G officials estimated that between 25,000 and 60,000 lb of recyclable pellets are recovered each month from the rail hopper car cleaning area alone. No estimates were available for the total volume of pellets recycled by the facility each month. In addition, Company G officials stated that rail hopper car valves are often found open when the empty rail hopper car returns to the rail hopper car cleaning area; a source of pellet release to the environment.

No pellets were visible at the facility outfall that discharges into the nearby river. However, the area of the outfall was not closely scrutinized owing to time limitations and resumption of rainfall. Considering the extremely large numbers of pellets that were seen in the rail hopper car cleaning area and the lack of visible pellet accumulations at the outfall, the containment system at Company G appears to be effective in controlling the release of pellets into the environment.

Because of the lack of time, the resin powder production area and the pellet extruding areas could not observed during the site visit. In addition, maintenance activities in these areas and employee awareness of the environmental hazards posed by plastic pellets were not discussed during the visit.

4.2.3 Sources of Pellet Releases from Producers

Officials of Company F and Company G were able to provide insight into several sources of pellet releases, including sources that the companies were attempting to control. Through the site visit observations, discussions with industry officials, and a review of existing literature, several sources of pellet release were identified at pellet production facilities.

- **Incompletely sealed conveying systems.** The systems may be opened for routine maintenance, repairs, and quality control inspections. The systems may also release pellets if the systems are operating incorrectly or are not completely resealed after maintenance and other expected routine operations. A significant source of pellet releases is through leaks from connections to rail hopper cars and bulk trucks, particularly when connecting and disconnecting the system and the valves on the rail car and trucks.
- **Damaged or leaky packaging.** Paper bags, in particular, are easily damaged, allowing pellets to flow freely from the bag. Also, incompletely sealed packaging, such as unsealed bag valves, release pellets.
- **Rail hopper car and bulk truck cleaning operations.** Waste pellets are allowed to fall onto the ground and become entrained in wastewater. Once on the ground, the pellets may flow along with the water into the facility drainage system, or the pellets may be washed away by storm-water runoff into areas outside of the facility. This is particularly significant at facilities lacking a containment system that is designed to retain pellets.
- **Lack of a containment system.** Uncontrolled waste-water and storm-water runoff will lead to the loss of pellets into the environment.
- **Failure of the containment system during heavy rainfall.** Containment systems may not be designed to operate correctly during periods of moderate to heavy rainfall. Company F was in the process of addressing this release mechanism.
- **Infrequent or inadequate housekeeping.** Spilled or loose pellets that are not quickly recovered through good housekeeping practices may be lost to the environment. Loose pellets may be tracked into every area of a facility via forklifts and employee's shoes and clothing.

- **Unsealed or unsecured rail hopper car valves.** These valves may be improperly or inadequately sealed, thereby allowing loss of pellets through seepage through a small opening or by enabling vandals to open the valve. Pellets also may spill from valves and connection hoses that are not completely emptied before a rail hopper car or a bulk truck is moved.
- **Lack of employee awareness.** Employees may not be properly educated in regard to the hazards posed by pellets in the aquatic environment.

Observations at the two exemplary facilities visited during this study indicate that effective pellet containment measures can be developed and implemented at pellet production facilities. The number of pellet production facilities in the U.S. that have installed such containment measures is not known.

4.3 Pellet Transporters / Contract Packagers

The pellet transporters and contract packagers are the mechanisms by which plastic pellets move from the producer to the processor. The pellet transporters carry bulk shipments (in rail hopper cars or bulk trucks) of pellets from the producer to the contract packagers and processors, and carry repackaged shipments (in bags or gaylords) from the contract packagers to the processors. The major methods of transporting pellets include cargo and containerized ships, rail hopper cars, and bulk or freight trucks. Cargo ships are being replaced increasingly by containerized ships as the preferred vessels for overseas pellet shipments.

The contract packagers, or, simply, packagers, receive from producers bulk shipments of pellets in rail hopper cars and bulk trucks, and break down these bulk shipments into smaller containers such as bags and gaylords. These smaller containers are subsequently carried by transporters to other contract packagers or processors. In the following discussion, the term *packagers* refers to those facilities that only repackage or store pellets (i.e., contract packagers), and does not refer to packaging operations of pellet producers.

Each time pellets are moved, whether within a facility or between separate facilities, the potential exists for a pellet spill and subsequent release into the environment. The type of packaging may also affect the potential for a pellet spill. Pellet transport and packaging methods are discussed in the following sections. A flow diagram is again presented in Figure 6(b).

The numbers of transporters and contract packagers operating in the U.S. are not known.

4.3.1 Equipment and Operations

Equipment and operations at pellet transporters and packagers involve moving and repackaging large volumes of pellets, such as in rail hopper cars, and small volumes, such as in bags and gaylords. Some producers ship pellets by rail hopper car or bulk truck directly to the processors that use large volumes of pellets. However, pellets are often repackaged into smaller containers for shipment to processors that use small volumes of pellets.

Packaging
Pellet producers may ship pellets either in bulk shipments (i.e., rail hopper cars or bulk trucks) or in smaller packages. Frequently, bulk shipments are sent to contract packagers, where pellets are packaged into smaller containers, such as bags, gaylords, or cardboard drums, for storage and shipment by freight truck. The capacities of bags and gaylords (i.e., 50 and 1000 lb, respectively) are limited, and mechanical conveyors (i.e., forklifts) are needed at the offloading point. The extra handling involved in filling, handling, and emptying these smaller containers makes this method of shipping prone to accidental spills at the plants and in transit.

Several different types of bags are used for shipping pellets, and each bag type has advantages and disadvantages (Table 9). The most commonly used bag material is paper, which has the advantage that it can be broken easily for quick emptying by the processor, but has the disadvantage that it can be easily broken or torn during shipment and storage. Bags are also made of PE or woven PP. Bag openings are either open-mouthed or equipped with a valve that is incorporated into the bag. Valved bags are filled by placing the valve over filling tubes and releasing the pellets into the bags directly from the storage silos, a process that is very quick and inexpensive. These bags are designed to be self-sealing; once a bag is filled full, the mass of pellets inside the bag presses the bag valve shut. The advantage of valved, self-sealing bags is that filling and sealing are completed at one machine, eliminating the need for additional equipment to seal the bag; however, the disadvantage to valved bags is that the valves often leak. Sew-close bags and heat-sealed bags require additional handling and equipment to seal the opening.

Bags typically are stacked onto a wooden pallet covered with a cardboard tray to catch pellets that leak from valves or punctured bags. When all of the bags have been stacked on the pallet, the entire pallet and the bags are wrapped in plastic to prevent the bags from shifting during shipment and to retain any pellets that leak from valves or bag punctures. The wrapped pallets are moved by using a forklift to storage areas or onto freight trucks.

Cardboard gaylords are lined with a large plastic bag to contain the pellets. Gaylords usually are set on a wooden pallet to be moved via forklift. The gaylords typically are filled by conveyor and sealed.

Bags and gaylords are moved to storage areas and to shipping vehicles (i.e., freight trucks) by using forklifts or other similar equipment. Depending on the spill maintenance protocols at a facility, punctured bags or gaylords may be repaired or the pellets may be repackaged into a new container. Spilled pellets may be recovered and recycled, or unusable pellets may be disposed into the municipal waste system.

Shipping
For nearly 20 years, rail hopper cars have been available for bulk pellet transport. Rail hopper cars have a 100-ton capacity, or approximately 4.4 billion pellets per hopper car. A rail hopper car can have either a single tank or be compartmented into two or more tanks. On top of the cars are ports that couple with a conveyor system for pellet loading, and on the bottom are ports that couple with conveyors for rapid flow of pellets during unloading to bulk storage facilities. Each port has a rotatable tube valve that controls the pellet flow rate by increasing or decreasing the opening of the discharge slot. Each top and bottom port is

equipped with a cap that must be secured over the port whenever the rail hopper car is not being loaded or unloaded. If these caps are not secured or if there is vandalism of the caps, spillage can result (see Figure 13 below).

There are two kinds of trucks used to transport pellets: bulk trucks and freight trucks. Bulk trucks are used to transport large volumes of pellets where rail service is unavailable. The design and operating features of bulk trucks are similar to those of rail hopper cars, and all are loaded and unloaded similarly. Bulk trucks have a 50-ton capacity or approximately 2 billion pellets (22,000 pellets per pound) per truck.

Freight trucks and cargo/containerized ships transport bag- and gaylord-packaged pellets. Pellets may also be transported aboard ship in bulk shipments. Pruter (1987) has reported that pellets have been used as ball bearings on the decks of ships to ease the movement of cargo, and pellets would likely enter waterways as a result of this practice. Because they completely enclose bulk and packaged pellet shipments, contain pellet spills, and prevent leakage to the environment, sea containers are increasingly becoming the preferred method of shipping pellets.

The costs of shipping by ocean-going vessels are relatively low as compared to air freight costs, thereby making the former method attractive for shipping pellets overseas. According to EPA (1990a), the world fleet of containerized ships had grown from 508 fully containerized ships and 597 partially containerized ships in 1976 (<5% of the world fleet), to 1097 and 1720 ships, respectively, in 1988 (12% of the world fleet). Therefore, with the use of containerized ships increasing, pellets are more likely to be transported by using these vessels than by using cargo ships filled with bulk shipments of pellets.

Blending and Storage Blending is the mixing of polymer pellets (or powders) with additives by using either a continuous-blending process or blending in batches. Continuous-blending processes require the coordinated, steady input of each ingredient into the blender. The pellet feed streams may be either volumetrically or gravimetrically metered from a feed hopper. Controlled feeders generally deliver the pellets by free fall into a blending unit.

Storage silos are used primarily by the large, high-volume producers, packagers, or processors. Pellets are conveyed from the silos to packaging or processing areas through permanent instrument-monitored conveying lines.

Warehouses are used typically by the low-volume processors to store smaller containers. Packages are mechanically transported (a pallet load on a forklift) to the molding area. Pellet deliveries may be in bags or cardboard drums anchored on a pallet, in large boxes, or in large bulk bags. These units are likely to be offloaded from trucks and handled with a forklift.

4.3.2 Site Visit Observations

Two pellet transporters/contract packagers, Company B and Company C, were visited during this study.

Both companies were visited on February 4, 1991.

Company B

Company B ships and packages many different commodity, transitional, and engineering resins in pelletized form. Photographs were not permitted to be taken during this site visit.

Company B receives on the average approximately 300 rail hopper cars (or 54 million pounds) of pellets annually. Officials stated that approximately 99.75% of the pellets (179,500 lb out of each 180,000-lb shipment) received by Company B are repackaged and shipped to processors, and 0.25% of the pellets are lost or recycled. The facility has 500,000 ft2 of available storage space.

Plastic pellets are received from rail hopper cars in a graveled area adjacent to the rear of the facility. The pellets are transferred by pneumatic conveyor directly from the rail hopper cars to the packaging areas. Before offloading the pellets, a portable screen is placed beneath the valve outlet of the rail hopper car. This screen is used to capture pellets that escape during coupling and uncoupling of the rail hopper car's valve; loose pellets fall from the valve and from the conveyer system hose. The screen consists of windowscreen-sized mesh mounted on a 1- 3-ft rectangular frame made of 2- 4-in. lumber. The screen can easily be handled and moved by one person. Pellets captured by the screen are temporarily placed in a specially designated bin and are eventually sent to a recycler.

Despite the use of the screened boxes, a large number of loose pellets were seen along the siding (a short track connecting a railroad directly with the premises of a business concern) where the rail hopper cars are unloaded; the presence of these pellets could indicate improper use of the screened boxes. These pellets had become interspersed with the large stones that formed the bed of the siding. Only large pellet spills had been cleaned up in this area; stray pellets were not recovered. Drainage routes for the rail hopper car siding areas were not observed and, therefore, the release of pellets from this area could not be assessed.

Two packaging operations were observed at Company B. The first packaging operation was the filling of valved paper bags. Paper bags are manually placed over a spout and the pellets are pneumatically transferred into the bags. After filling, some of the bags pass through a quality control checkpoint, where the weight of the bags is checked; bags that fail the quality control check are retained. The filled bags are then passed along the conveyer belt to a wooden pallet. Once the pallet is loaded, the pallet and the load are wrapped with plastic and moved via forklift to the storage area. In some cases, the bags are palletized for temporary storage before being individually stacked in large shipping containers or truck trailers.

Pellets were seen to be leaking from the bagging machine valve before bags were placed over the valve and after bags had been removed. Pellets were also seen to be leaking from incompletely sealed bag valves while the bags were being moved by the conveyer. As a result, pellets were scattered on the floor beneath the entire bagging system. Employees were observed sweeping the pellets and collecting them for recycling. The pellets were not removed from areas immediately underneath the bagging machine, presumably because of safety considerations during machine operation. However, areas around the machine were swept nearly clean.

The second packaging operation was the filling of 1000-lb-capacity gaylords. As in the bagging process, pellets were pneumatically transferred into the gaylords through a spout. The plastic bags lining the gaylords, as well as the gaylord themselves, were sealed shut. Some pellets were scattered on the floor in this area, but no one was observed sweeping. Each gaylord contains a significantly larger volume of pellets than does each paper bag. Because residual pellets fall from the spouts at both bagging and boxing operations, pellets may be lost more frequently from the bagging machine spouts than from the gaylord machine spouts. This is probably a function of the number of gaylord/paper bag changes that are made in a given period.

Wood-framed screens were installed along the edge of the shipping docks; these screens are of the same mesh size as those used beneath the rail hopper cars, but frames at the docks are larger that the portable frames. The screens are designed to catch any pellets that might leak from broken packages or that could be tracked onto the dock from other areas of the facility. At the time of the visit, screens were installed only at those docks that have a concrete overhang, and the screens were installed below the overhang. Company B was in the process of developing a method for installing screens beneath docks lacking an overhang. Although most of the pellets appeared to be recovered before they could enter the environment, pellets were seen in rainwater flowing from the shipping docks into facility storm drains.

Company B stated that they occasionally receive information from processors regarding package damage and pellet loss during transit. Most of the information relates to exported shipments, and less information is received in regard to domestic shipments. Approximately 99% of all international shipments are in paper valve bags, which are inspected for damage by independent inspectors during cargo vessel onloading. In some cases, the inspectors photograph damaged shipments and notify Company B of pellet loss. Company B is not notified of pellet spillage or loss during offloading at the receiving port. However, most large shipments are sealed in containerized cargo vessels where pellet spillage during shipment would be minimal.

Pellets that escape onto the parking lot and into the storm-water drain are removed by another set of screens, one coarse and one fine, installed just inside the storm drains. The fine screen is the same as that in the screens used under the loading docks and rail hopper car outlets. A small number of pellets were seen on the screens over the observed storm drains. Other storm drains were submerged owing to the heavy rains and flooding and, consequently, only a few drains were seen during the visit. The frequency with which these storm-drain screens were cleaned was not noted during the visit.

Throughout the visit, employees were observed sweeping and collecting spilled pellets, particularly in the packaging area. In addition to hand-sweeping, large street-type cleaners routinely sweep the aisles and receiving areas. To monitor the effectiveness of routine maintenance procedures at the facility, Company B developed an environmental inspection check list (see Figure 14 below). The frequency of these inspections was not noted during the site visit.

Company B officials estimated that the annual pellet spillage is 10,000 to 30,000 lb during packaging and 2000 to 10,000 lb during shipping and warehousing. Spilled pellets are collected in specially labeled containers and are recycled. Company B officials were aware of the SPI efforts to educate the industry about the problems associated with pellet releases, and recommended that the SPI information be made available in bilingual form.

The company's quality assurance office is in the process of developing written protocols for routine maintenance and spill cleanup; these protocols will be written in English and Spanish. During training, the company plans to discuss economic and environmental reasons for strict adherence to quality control and maintenance protocols.

Company C

Company C receives and packages bulk shipments of many different pellet types. A few photographs taken during the visit are presented below.

Company C is located in one section of a large industrial park that includes at least one other pellet packager/transporter. The company receives and packages bulk shipments of many different pellet types. Company C officials stated that it packages and ships approximately 65 million pounds of pellets per month, and between a minimum of 5000 to 10,000 lb and a maximum of 20,000 lb of spilled pellets are recycled each month. The company also handles plastic powders that are shipped in supersacks (8 X 4 X 4 ft).

Company C receives bulk shipments of pellets in rail hopper cars that offload at a railroad siding behind the facility. This railroad siding is paved with large stones and a storm-water ditch and drain are located alongside the siding area. Pellets are transferred pneumatically from the rail hopper cars into storage silos located in the packaging areas of the facility. The rail hopper car valves are not resecured after the cars are emptied. No screens or other containment apparatuses are used during the coupling and uncoupling of the pneumatic hoses. Although company officials stated that attempts are made to recover large pellet spills in the siding area, many pellets were lodged between the stones throughout the siding area and in the stormwater ditch (see Figure 15 below). Pellets are carried by storm water through the drain and into a storm-water interceptor that retains storm water from Company C as well as from several other businesses in the industrial park.

Pellets are also pneumatically transferred from the silos to the bagging or packaging machines. At the bagging machine, the paper bag valve is manually placed over a spout, and the pellets are blown into the bag. The bag valve seals when the bag is removed from the spout and falls onto a conveyor, and the pellets inside the bag press against the valve end and seal the opening.

The filled bags are passed by conveyer belt onto a wooden pallet covered with a cardboard tray. The cardboard tray is used to capture pellets that may spill from leaking valves or bag punctures. Company C officials believe that the cardboard trays on pallets are only somewhat, but not entirely, effective. Once the pallet is loaded with bags, the pallet is wrapped with plastic and moved via forklift, to a storage area.

Pellets were seen on the floor beneath the bagging machine (see Figure 16 below). Residual pellets also were seen to be spilling from the spout before and after a bag was secured. After the filled bag was placed on the conveyer, pellets were seen to be leaking through incompletely sealed valves. Similar, but not as dense, were accumulations of pellets found beneath other parts of the machine and the conveyer. No spill cleanups were observed in this area.

After packaging, bags of pellets are moved by using a forklift into the warehouse where they are stored until shipment. Scattered pellets, pellet spills, and several punctured bags and gaylords were observed throughout the warehouse. Several spills were the result of leaky valves. Spills and/or breakages seemed to be a common occurrence throughout the warehouse and loose pellets were obvious in every aisle. Spills in storage areas are swept up and disposed in recycling bins.

Palleted bags of pellets are transferred via forklifts onto truck trailers at the loading dock. Pellets in torn or broken bags are repackaged at the dock before they are loaded on to the truck. Large numbers of pellets were observed in the loading dock area (see Figure 17 below). Because no pellet containment systems were installed at either the loading docks or over the parking lot storm drains, pellets spilled at or near the docks can fall onto the outside pavement. These pellets would be carried by storm water to storm drains located several feet away in the middle of the parking lot (see Figure 18 below).

The storm drains in the railroad siding area and in the facility parking lot empty into a storm-water interceptor adjacent to the industrial park where Company C is located (see Figures 19 and 20 below). Because several inches of rain had fallen (and continued to fall) on the day of the visit, the storm-water interceptor contained a very large number of pellets. In some areas of the storm-water interceptor, the pellets formed a mass across the surface and were scattered along the high water line among the debris (see Figures 21 and 22 below). Because Company C is not the only pellet-handling facility in the industrial park, it is highly unlikely that all of the pellets in the interceptor came from Company C. Once in the interceptor, the pellets would be transported downstream and into nearby waterways.

Broom-sweeping was observed throughout the facility. Company C officials stated that the entire facility is broom-swept and vacuumed at least once daily, and broom-swept throughout the day as needed. During training, managers are instructed to clean up all spills within a few hours; on a typical workday, this would involve broom-sweeping recyclable pellets two or three times. The parking lot and loading dock areas are swept once weekly and large spills are cleaned up as soon as possible. Pellets collected during routine maintenance and spill cleanups are recycled.

During the discussions after the site visit, Company C officials identified three pellet-release points. These areas were (1) the rail hopper cars, particularly when a load of pellets is quality-control inspected before offloading (valves are opened briefly to collect a subsample of the load); (2) the storm drain in the siding area where spilled pellets are washed into the municipal drainage system; and (3) the loading docks, where pellets are washed into the parking lot storm drains.

Company C officials believed that more pellets are lost from bag breakage than from accidental spills or leaking bag valves, although all bag valves tend to leak regardless of the bag material. Other than general housekeeping (e.g., sweeping), no special measures have been instituted at Company C to minimize pellet release into the environment. However, Company C is installing pellet containment systems at a new facility.

Company C officials felt that their employees are not well-informed in regard to environmental concerns associated with plastic pellets, although the SPI literature has been discussed at monthly Company C meetings. The officials recognized that employee awareness of the environmental impact of pellets is directly related to the investment that management is willing to make in employee education.

4.3.3 Sources of Pellet Releases from Transporters/Contract Packagers

Through the site visit observations, discussions with industry officials, and a review of existing literature, several sources of pellet release were identified at pellet transporters/packagers. These sources included

- **Incompletely sealed bags or leaking bag valves.** Valved bags do not seal as well as bags that are sewn or heat-sealed. Pellets were seen leaking from valves at the bagging machines and in the storage areas.
- **Improper bag storage practices.** Pallets of bags may be stacked too high, causing excessive pressure on and rupture of lower bags. Also, the exterior plastic wrapping of pallets is only temporarily effective and is ineffective once the pallet is broken open or the bags have shifted. Pallets may be lacking a cardboard tray, thereby allowing loose pellets to fall to the ground.
- **Lack of employee awareness.** Officials at both facilities stated that the SPI educational materials had been posted but that employees remained generally unaware of the environmental hazards posed by pellets.
- **Inadequate training of forklift operators.** The cause of packaging damage that was most frequently cited by the packagers was punctures by forklift tines.
- **Infrequent routine maintenance.** Pellet spills were seen throughout the packaging facilities. Typically, only broom sweeping was used to recover pellets, and vacuuming was used infrequently. Pellets were tracked from one area to another by clothing, shoes, forklifts, and other vehicles.
- **Improperly or inadequately sealed or secured rail hopper car valves.** Spills occur when the hopper tube is rotated to the open position before coupling to the conveying system. Also, port caps are frequently not closed or sealed after the car is emptied, thereby allowing residual pellets to escape along the rail right-of-way. Finally, unsecured rail hopper car ports (top and bottom) may be opened by vandals, allowing pellets to spill onto the ground.
- **Lack of a containment system or other control mechanisms.** Transfer of pellets from rail hopper cars to inside areas. If there is no screening in place over storm drains at loading docks, parking lots, etc., or the screens are not cleaned routinely, pellets are carried by storm-water runoff into the municipal storm sewers or into natural drainage areas. Recent revisions to the National Pollutant Discharge Elimination System (NPDES) permit program prohibit the release of pellets in storm-water runoff.
- **Improper handling of pellet cargo at ship docks and aboard ship.** Spilled pellets may be

swept into the waterway instead of being recovered from docks and ship decks.

- **Overfilling of storage silos.** If the delivery rate of the conveying system exceeds the rate at which the receptacle can receive the pellets, spills will result.
- **Displacement of the conveyor system ports.** Incomplete connections between conveying systems and shipping vehicles are known to result in pellet spills.

Observations at the two companies indicate that inexpensive control measures can be developed and quickly implemented at pellet transporter/contract packagers.

4.4 Pellet Processors

Pellet processors mold the pellets into fabricated user products. More than 12,000 pellet processors were operating in the United States in 1988, and employed a work force of approximately 580,000 workers Nationwide (U.S. Bureau of the Census, 1988; EPA, 1990a). According to SPI, this accounting is dependent upon the definition of processor used during the census (Mr. Ronald Bruner, SPI, personal communication, January 1992).

The terms *converter* and *processor* are used in this Section to refer to the production of plastic goods from pellets and granules. After conversion of the polymer pellets to commercial and industrial products, the potential for spills and entry into the environment is eliminated. However, ancillary handling of the pellets is required prior to molding.

4.4.1 Equipment and Operations

At the processors [see Figure 6(c)], pellets are fed into molding or conversion systems where the pellets are melted and formed into user products. Manual addition of pellets to a feed hopper on a molding unit frequently is performed at small conversion operations. However, as the size of the converter output (and the numbers of pellets used) increases, the use of automated pellet-handling systems increases.

Pellets are manually, mechanically, or pneumatically conveyed from storage silos or bags and gaylords into the blender/converter hopper. Manual loading of pellets may be into a bag, drum, or box hopper, from which the pellets are mechanically or pneumatically conveyed to the next operation in the feed sequence (i.e., screening, blending, or drying).

Pellet spills may occur during any of the manual and mechanical transfers to downstream equipment. Spills are less likely in a pneumatic system where the feed transport is contained and the fill/flow rates are monitored and controlled. After the feed has entered a hopper on the conversion unit, there is little potential for a spill during normal operation. There is some possibility for a spill, however, when the product produced in the conversion unit is changed and the hopper is emptied manually.

Two primary processes are performed by conversion equipment. The initial process is to fuse and consolidate the feed pellets. The second process is to shape and cool the product. These process functions are performed by several different types of equipment, and the pellet-use rate may be controlled or demand-based. Most of the conversion equipment utilizes pellets fed from a hopper.

4.4.2 Site Visit Observations

Three pellet processors, Company A, Company D, and Company E, were visited during this study. Company A was visited on August 22, 1990, and Company D and Company E were visited on February 4, 1991.

Company A

For several years, Company A has produced food-grade plastic containers made from HDPE, LDPE, PP, and PS pellets, and pellets containing pigmentation [e.g., titanium oxide (TiO_2)]. Company A granted permission to photograph all phases and areas of their facility.

At Company A, bulk pellet shipments are pneumatically transferred from bulk trucks to the facility's primary storage hoppers or silos (see Figure 23 below). Each hopper holds approximately 60,000 lb of plastic pellets or granules. Company A officials stated that the pellets commonly escape into the environment during connection and disconnection at the pneumatic transfer tube (see Figure 24 below), and pellets also occasionally escape from the hopper air vent when the hopper is accidentally overfilled. Pellets were seen beneath and in the vicinity of the hoppers (see Figure 25 below).

The pellets are then pneumatically transferred through the conveying system from the storage hoppers into a small room adjacent to the processing room. Connections to the various internal operations, including internal storage hoppers, are manually made in this small room. At the internal storage hoppers, pellets are removed manually through a slide valve on the bottom of the hoppers. Company A officials noted that pellet spillage has been observed during connection changes, and pellets were seen on the floor and accumulated in the fence guard surrounding the interior storage hoppers (see Figure 26 below).

Pellets are added to the molding machines either manually, pneumatically, or by a combination of these methods. Company A officials stated that there is little likelihood of pellet leak- age in the pneumatic delivery system once the pellets are inside the plant, except in the cases of equipment malfunctions. Plastic scrap produced during the injection molding process was observed on top of several molding machines (see Figure 27 below), and pellets also were observed on top of one manually loaded machine.

Accumulations of pellets were observed in several expansion joints in the concrete floor of the shipping area and in other areas of the plant (see Figure 28 below). Pellets also were seen in the expansion joints in the printing shop, even though no pellets are handled in this area. Company A officials explained that pellets cling to forklift tires, workers' clothing and shoes, etc., and are transported throughout all interior and exterior areas of the facility. The pellets are then swept up during routine maintenance and are disposed of in the facility's dumpster.

Because the facility parking lot slopes toward the building, water historically leaked into the shipping area during rainfall. To correct this problem, a catchment basin was installed near the overhead exterior doors of the shipping area to intercept the storm-water runoff from the parking lot before it can flow into the facility (see Figure 29 below). The catchment basins serve as collection points for pellets released in the transfer area and in other exterior areas of the facility. During the site visit, a number of pellets were found in this catchment basin. All runoff from the facility, including runoff from the parking lot, catchment basins, and roof, flows down the driveway and into the street (see Figure 30 below). Once in the street, the runoff flows along the curb to a storm-water interceptor, where it enters a municipal storm-sewer system.

Until recently, Company A officials were unaware of the hazards to aquatic life posed by plastic pellets floating on the surface of the ocean, and to their knowledge, employees were not aware of the hazards. These officials believed that employees would be generally apathetic toward the pellet issue. However, Company A officials also believed that the pellets used at their facility would not float in water. They tested this theory by placing handfuls of LDPE, HDPE, PS, and polyethylene-base TiO_2 pellets into a small container of tap water. Only the LDPE and HDPE pellets floated, the PS pellets floated initially and sank after gentle agitation, and the TiO_2 pellets sank immediately. Similar results were found subsequently when the same pellet types were added to saline water (at room temperature and 30-32 ppt salinity).

Because food-grade containers are produced at Company A, the cleanliness of the physical plant is closely monitored. Company A officials frequently stated that the facility is routinely swept clean of pellets, both inside and outside, and that the pellets are discarded into an onsite dumpster. The dumpster contents are collected by a commercial waste hauler and is subsequently disposed into the municipal waste stream.

Company D

For over 50 years, Company D has produced specially molded products for a diverse clientele. Most of the pellets used by Company D are engineering (or performance) resins that have a limited range of uses and narrowly defined applications; these pellets are the most expensive pellets available. Company D production runs are limited in size and small volumes of any one particular pellet type are used. The company has the capability to extrude small amounts of special blends of pellets. As much as possible, the company purchases precolored pellets, but may color pellets as needed.

The company purchases pellets in small quantities. These pellets typically are shipped by truck in bags or gaylords and are subsequently stored in the receiving area until used. The trucks are offloaded at the loading docks; no materials are handled outside the loading docks. A storm-water drain was located next to the building and at the bottom of dock incline; a few pellets were seen near the drain and along the dock wall. No pellet-containment devices were seen in the loading dock area.

Company D had recently expanded their shipping and receiving area to accommodate a growth in business. Pallets of bagged pellets and gaylords were stored in one area, and packaged products were stored in another area. Loose pellets could be seen beneath the pallets and, occasionally, scattered on the floor.

In general, pellets are manually loaded into the molding equipment, but Company D can load the pellets directly from gaylords, if necessary. Employees are encouraged to avoid spills, primarily because the pellets are expensive and spilled pellets are not recycled. Scattered pellets were observed on the floor beneath and around the molding equipment.

A few pellets were present in the cooling-water tanks adjacent to the molding machines; molded parts are placed in these tanks to be cooled before inspection and packaging. The cooling water is disposed of into the facility drains, which in turn feed into the municipal sewer system. Officials stated that pellets could enter this cooling water only through accidental spills during manual machine loading.

Maintenance protocols require that the work areas, including the areas around the molding machines, be cleaned at the end of each shift. The floors are swept, vacuumed, and mopped every other day. Spilled pellets typically are broom-swept and disposed into a refuse container. No effort is made to recycle or reclaim materials, and waste pellets are disposed of into the municipal waste stream. Routine maintenance and spill-cleanup protocols appear to be the primary methods for controlling pellet releases into the environment.

Company D officials stated that the employees are trained to minimize spills primarily for economic reasons (the pellets are expensive) as opposed to environmental reasons. The officials were aware of the SPI educational efforts, but the information was not disseminated or otherwise posted in the facility for the workers to read. Workers had not been briefed or otherwise trained with regard to pellet-related environmental concerns.

Company E

Company E is an injection molder that manufactures specialty parts for industrial applications; no consumer items are manufactured. These specialty parts are made of engineering resins, such as polycarbonate and nylon. The company has resin-handling approval from the Underwriters Laboratories (UL); this approval is used as a measure of quality assurance and is issued after successful spot inspections by UL.

Company E receives pellets by truck, and the pellets typically are packaged in either paper bags or gaylords. Company E officials stated that pellet packaging often arrives punctured or torn; the receiving clerk records the condition of the pellets, and Company E may ask for compensation from the shipper or packager if the damages are extensive. Scattered pellets were observed in and around the loading docks and in the facility parking lot. A storm drain was located at the bottom of the inclined driveway at the docks. Because rainfall was heavy during the visit, there was a heavy flow of water through the drain and into a storm-water ditch a few feet from the warehouse. Pellets could be seen in this storm-water ditch.

Small quantities of a wide variety of pellets are stored at the facility; however, there are no storage silos at the facility. All pellet packages are stored above floor level; the packages are stacked both manually and via forklift, depending on the size of the shipment and the storage location. Loose pellets were seen throughout the storage or warehousing areas, primarily in areas where routine sweeping would not reach them. Specifically, pellets were seen under loaded pallets and pallet racks, between storage racks, and between stacks of bags. Very few pellets were seen in the working areas of the warehouse, and an employee was seen broom-sweeping a small pellet spill.

The injection molding machines are loaded manually, and small numbers of pellets were found around and underneath the molders. Company E officials stated that all spilled material is disposed of in a dumpster and is not recycled because spilled pellets may be contaminated with a mixture of grease, oil, absorbent materials, dust, etc., as well as other pelletized resins. The equipment is completely cleaned and vacuumed between each production run to prevent crosscontamination between different products.

The facility generally was clean, and there were no accumulated plastic-scrap piles. A few pellets were visible in cracks in the concrete floor and in areas inaccessible to routine maintenance equipment. Company E officials believe that good housekeeping practices are the best way to control pellet loss.

No containment apparatuses, such as screening over drains or catchment devices under the loading docks, are in place at the facility. The company appears to follow effective routine maintenance protocols, as evidenced by the presence of very small numbers of pellets throughout the facility. The employee in charge of shipping and receiving seemed conscientious about sweeping up spilled pellets and taking every precaution to ensure that spilled pellets do not become a safety hazard.

Company E officials were aware of the problems that plastic pellets pose to the environment, and recognized that they may be contributing to the problems. Issues were not discussed regarding employee education about the environmental hazards of plastic pellets.

4.4.3 Sources of Pellet Releases from Processors

During routine operations at pellet processors, pellets are most likely to be released prior to the actual conversion (molding) process. Through the site visit observations, discussions with industry officials, and a review of the existing literature, several pellet release pathways were identified at pellet processing facilities. These sources included

- **Uncontrolled manual pellet handling.** Spills occur during the manual feeding of pellets into molding equipment, or during reconnection of pneumatic lines to the molding machines. Pellet spills while refitting molding equipment when changing products to be molded and during the addition of coloring pellets (i.e., TiO_2 pellets) to the polymer pellets.
- **Improper unloading and warehousing procedures.** Pellet packaging is not carefully inspected before offloading or is damaged during offloading, and pellets may be spilled onto the ground and throughout the receiving area. Improperly warehoused packages (e.g., stacked haphazardly or too high, punctured while moving to storage) may fail and result in pellet spills.

- **Inadequate housekeeping.** Spilled pellets that are not quickly recovered are tracked throughout a facility and may be released into the environment.
- **Lack of wastewater control.** Cooling water from the molding machines is discharged into municipal wastewater systems; this water may contain pellets that are spilled in the molding area.
- **Lack of control of storm-water runoff.** Pellets spilled at the loading dock or transported into the parking lot are carried by storm-water runoff into storm sewers or into natural drainage basins.
- **Disposal of waste pellets into dumpsters.** Waste pellets may be lost to the environment through municipal landfilling and other solid waste disposal methods.

Observations at the facilities visited during this study indicate that pellet control measures can be developed and implemented at pellet processing facilities. None of the visited facilities processed large volumes of pellets, and the facilities did not mass produce consumer products. Sources of pellet loss and general housekeeping and operation procedures may be different at larger-scale facilities than at these smaller-scaled processors. However, the pellet release points identified above should be applicable to all processors.

4.5 Summary of Identified Sources

The representativeness of the visited companies as indicators of pellet release and containment conditions industry-wide could not be determined. The possibility that the visited companies represented best-case conditions is suggested by the fact that the companies volunteered to participate in the study; companies with significant pellet containment problems would not volunteer access to a regulatory agency regardless of assurances of no regulatory assessment or action. The fact that the two visited producers, Companies F and G, recognized the uniqueness of their containment systems and developed materials highlighting the systems, supports this possibility.

Despite the unknown representativeness, the study team was able to identify several pellet release points in each sector. No attempt was made to rank the release points in order of significance or quantities released. Basically, the release pathways may be categorized into eight general areas where deficiencies may exist. These areas are

- **Lack of communication between industry management.** Not all company managers have recognized the pellet problem and the need to control pellet releases. Pellet spillage information, such as the condition of packages and the receipt of unsealed rail hopper cars, is shared between companies only occasionally.
- **Inadequate employee awareness and training.** Employees are generally unaware of the hazards posed by pellets and the employees' responsibility for causing and controlling releases. A major release pathway is through package damage caused by improper operation of forklifts while moving pallets. Cargo handlers may allow pellets to fall into waterways because they are unaware of the hazards of pellets.
- **Inadequate facilities.** With the exception of the producers visited during this study, companies have few or no cooling-, waste-, or storm-water containment systems in place, including portable

screens and facility wide containment systems. Pellets may be entrained in these waters and are discharged into municipal storm and sanitary sewers or into natural drainage systems.

- **Careless routine operations.** Whenever pellets are handled there is the potential for pellet spillage. Manual pellet handling is more likely to result in spills than handling by pneumatic conveying systems. However, if pneumatic systems are not properly maintained and closed, pellets may leak through openings in the system. Pellets may be released also during the transfer of damaged, unrepaired packaging.
- **Inadequate housekeeping practices.** If pellets are not quickly recovered after they are spilled, they may be dispersed and eventually released into the environment. Pellets may be transported throughout interior and exterior areas of a facility via shoes and clothing, vehicle tires, wind, and waste- and storm-water runoff.
- **Easily-damaged or leaky packaging.** Paper and cardboard packaging are easily damaged during transport and handling, and, in fact, may be designed to be easily broken when loading molding machines. However, damaged packaging is a major source of pellet loss to the environment. In addition, the valves in self-sealing bags may not completely close, allowing pellets to leak from the opening.
- **Improper shipping practices.** If a rail hopper car valve or port is not sealed or secured sufficiently, pellets may leak onto the right-of-way or vandals may easily open the valves and release large numbers of pellets. In addition, pellets may be spilled onto loading docks, ships' decks, and cargo holds, and be washed overboard into waterways.
- **Lack of recycling.** Some companies do not attempt to recycle spilled pellets and, instead, dispose the pellets into the municipal waste stream.

The identified pellet release pathways can be eliminated by implementing a few simple control mechanisms. Several possible control mechanisms were identified based on the site visits conducted during this study, and recommendations to the plastics industry were developed. Recommendations for controlling pellet releases, including the legal framework for controlling the releases, are described in Section 5.0.

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5.0 Controlling Pellet Resources

Disclaimer: The information in this website is entirely drawn from a 1992 publication, and has not been updated since the original publication date. Users are cautioned that information reported at that time may have become outdated.

The Environmental Protection Agency (EPA) is concerned about the presence of pellets in the aquatic environment for several reasons: (1) pellets are ubiquitous; (2) pellets have been found in considerable quantities in coastal areas of the United States; and (3) laboratory studies and field observations suggest that ingested pellets may harm or kill aquatic wildlife, including several endangered or threatened species. These issues were detailed in Section 3.0 of this report.

Pellets are released to the environment as a result of plastics industry activities, and major transport pathways to the environment were highlighted during the site visits to several industry companies (Section 4.0). During the site visits, Company officials stated that during normal operations, most of the released pellets can be captured easily by existing pellet containment systems. However, under severe weather conditions (heavy rainfall) many of the pellets may escape even the best pellet containment systems. Unfortunately, once plastic pellets are released into the environment they cannot be easily recovered, therefore, the most realistic mitigation measure available is the prevention of discharges.

EPA believes that immediate industry action is needed to prevent pellet releases to the environment. Effective prevention of pellet releases requires both the implementation of appropriate voluntary control measures as well as a regulatory framework. Section 5.1 presents recommendations to the plastics industry for preventing and controlling pellets releases to the environment. The current regulatory framework and steps being taken by the industry to control pellet releases are included in Section 5.2.

5.1 Recommendations to the Plastics Industry

The following recommendations for preventing and controlling pellets releases to the environment were developed based on the site visit observations (described in Section 4.0), knowledge of plastics industry operations, a literature review, industry recommendations (SPI, 1991), and Department of Transportation (DOT) Cargo Security Advisory Standards (49 CFR Part 101). Concurrent with this study, the Society of the Plastics Inducstry, Inc. (SPI) has also developed recommendations for controlling pellet releases; these recommendations have been incorporated into the following discussion. The specific recommendations are organized according to eight general areas: industry management; education and training; equipment and facilities; routine operations; maintenance and housekeeping; packaging; shipping; and recycling and waste disposal. Table 10 is a summary of the recommendations and indicates the sectors to which to each recommendation applies.

5.1.1 Industry Management

Poor communication between industry management and management of related industries hampers the identification and elimination of pellet release pathways. Despite the SPI efforts to educate the industry, some company managers did not understand the pellet problem and the need to control pellet releases. Information is rarely shared between companies in regard to pellet spillage, the condition of shipped packages, and the receipt of unsealed rail hopper cars.

The following are recommendations for controlling the release of pellets into the aquatic environment through improving industry management practices.

- **Adopt and implement SPI's 1991 *Pellet Retention Environmental Code* and 1992 *Processor's Pledge.*** The code and pledge are presented and discussed in greater detail in Section 5.2.3.
- **Conduct self evaluations to identify problem areas.** The checklists developed by SPI (1991) should be used by each sector (Appendix).
- **Encourage information-sharing between companies.** The information transfer should include pellet containment system successes, identification of problem areas (e.g., the manufacturer should notify a processor if the rail hopper cars return with valves open and unsealed), and other industry successes and failures in pellet containment. This communication should extend between companies of the same sector (manufacturer to manufacturer, etc.) and between companies of different sectors (manufacturer to packager, processor to manufacturer, etc). Good examples of information transfer are the Dow Chemical and Paxon Polymers videotapes of their containment systems.
- **Continue developing educational materials, advertising in trade journals, conducting presentations at professional meetings, sending mailings, and producing videotapes for distribution throughout the industry.**

5.1.2 Education and Training

The least expensive and the most effective first step to controlling the release of pellets into the aquatic environment is through education. Many industry officials believe that pellet releases result more from improper employee attitudes than from equipment failure. This would indicate that employee education is critical to the success of any corrective action. Recommendations are to

- **Educate key officials and company managers regarding the fate and effects of plastic pellets and the economic disadvantages of pellet loss.** Despite SPI's efforts, some company officials remain unaware of the environmental impacts of pellets, and, therefore, industry-wide education and education and training within each company is needed. Stress the economic considerations of controlling pellet releases, the economic benefits of recovering and recycling lost pellets, and the economic disadvantages (loss of feedstock, loss of recycling revenues) and regulatory penalties [National Pollutant Discharge Elimination System (NPDES) permit violations] for releasing pellets. Also, use modern teamwork practices to solve problems, and build a consensus and commitment to the task (SPI, 1991).
- **Educate company employees regarding the environmental hazards of pellets and employee responsibility in instituting corrective actions.** If employees feel involved or responsible they may provide simple and useful solutions to eliminating pellet release pathways. This can be accomplished through (1) conduct of employee awareness programs to educate personnel of the need to prevent pellet loss. This could include posting SPI educational material (described in Section 5.2.3), throughout the facilities, particularly in areas where pellets are frequently spilled. A short presentation (i.e., lunchtime seminar) and forum for discussion should be initiated with the employees; (2) establishing boundaries of responsibility for spill response and cleanup (SPI, 1991). For example, designate one or more persons per shift who will be responsible for ensuring prompt and thorough spill cleanup within a specified work area, or for monitoring and managing a pellet retention program; and (3) initiating a system of rewards for creative solutions for pellet containment and exemplary performance in preventing pellet loss to the environment.
- **Train pellet handlers to operate equipment, particularly forklifts, in a manner that minimizes the potential for pellet loss.** For example, train the forklift operators to exercise greater caution when handling pallets of pellets, such as ensuring that the tines of the forklift are properly aligned before contacting the pallet.
- **Train longshoremen and other cargo handlers regarding proper pellet handling procedures (49 CFR Part 101).** CMC (1988) also recommended that these workers be trained in the handling all cargo wastes.

5.1.3 Equipment and Facilities

Many companies have few cooling-, waste-, and storm-water containment systems for controlling the release of pellets from the facility, or methods for immediately controlling spilled pellets. Recommendations for controlling pellet releases to the aquatic environment by improving existing equipment and facilities are presented below.

- **Install a containment system to capture storm-water runoff from pellet-handling facilities.** The design of these systems must take into account worst case storm-water discharges; SPI (1991) recommends a system capable of handling "50- to 100-year high" conditions. Within the containment system, install baffles, skirts, booms, surface skimmers, and vacuum systems to accumulate and remove pellets (SPI, 1991). Two possible containment systems could be installed: (1) an area-specific containment systems in each pellet handling area. Area-specific containment systems would be the primary pellet containment systems and the facility-wide system would serve as a backup; or (2) a facility-wide containment systems, such as the systems used at Companies F and G (detailed in Section 4.2.2). These systems are effective in controlling pellet releases from facilities covering a large area and handling large volumes of pellets.

- **Improve dry cleanup procedures, particularly in areas subject to storm-water runoff.** By allowing pellets to be entrained in storm-water runoff, the pellets are further contaminated by compounds in the storm water (SPI, 1991).
- **Install connecting hoses equipped with valves that will close automatically when the connection is broken.** Hoses of this type are commonly available.
- **Direct the cleaning water flow from rail hopper cars and bulk trucks through a screen to capture the pellets directly rather than allowing the pellets to spill onto the ground.** This simple control measure would immediately capture the pellets at the release point, rather than relying on elaborate passive control systems to recapture the pellets downstream.
- **Seal expansion joints in concrete floors with a flexible material to eliminate the pellet-collecting contour.** Pellets that accumulate in these joints are difficult to recover by broom sweeping, and may have to be recovered either manually or by vacuuming. Sealing the joints would facilitate cleaning and would not interfere with the expansion and contraction of the concrete.
- **Install alarms in the pellet conveying system that will alert operators to a breach of the system.** Increase the capacity of air conveying systems to prevent clogging, and install a bag house or filter bag assembly in the transfer lines to minimize surges in unloading lines that cause pellets to be vented into the environment (SPI, 1991).
- **Pave all pellet handling areas, including loading docks and rail sidings.** Pellets accumulate between paving stones and gravel making pellet recovery difficult if not impossible.
- **Place screening in storm drains.** The mesh of the screening should be smaller than the smallest pellet handled at the facility. Regularly clean the storm drain screens to prevent drain clogging and overflow.
- **Place control devices, such as bag houses and cyclones, where they can be serviced without losing pellets.** If these devices are placed atop silos or bins, pellets accumulate on top of the bins or silos and are washed down by rainfall or blown by wind (SPI, 1991).
- **Equip bag-handling stations with vacuum hoses to facilitate spill cleanup.**
- **Use tarps or containment devices to collect pellets as they are spilled.** This facilitates cleanup, minimizes contamination of the pellets (so that they can be recycled), and permits quick pellet recovery by containing them (SPI, 1991).
- **Install grating at doorways for wiping feet.** During the site visits, pellets were observed in areas of the facilities where only foot traffic could have transported the pellets.
- **Modify loading systems so that transfer lines can be completely emptied, with any residual pellets being contained when loading ceases (SPI, 1991).** Use stainless steel elbows on all transfer lines, and cycle the outlet valves while the air is flowing through the rail hopper car or bulk truck during pellet unloading.

5.1.4 Routine Operations

Whenever pellets are handled there is the potential for pellet spillage, and implementing a few simple practices would decrease the potential for spillage during routine operations. Recommendations for controlling pellet releases to the aquatic environment by modifying and improving routine operations are presented below.

- **Place portable screens underneath connection points when making and breaking all connections.** The screens should be placed under the valve before the connection is made, and remain in place during pellet transfer and valve disconnection. These screens are inexpensive, easily-moved, and are an effective method for containing pellets at the discharge point. For example, the screens used by Company B consisted of a frame made of 2- 4-in. cut lumber that was covered on one side by wire screening (Section 4.3.2). Additional suggestions include (1) use screens when conducting quality control (QC) checks, breaking into conveying systems, etc., (2) conduct sampling only in areas protected by containment procedures (SPI, 1991), and (3) use wide-mouth containers or polybags for collecting pellet samples. These containers have wide openings that facilitate filling (SPI, 1991).
- **Place permanent screens along the exterior edge of the loading docks.** These screens will capture pellets leaking from punctured containers and incompletely sealed bag valves, and those pellets tracked onto the loading dock from other areas of the facility. The screen mesh should be smaller than the diameter of the smallest pellets handled at the facility.
- **Completely empty transport and storage vessels before disconnecting from the conveying system.** This would minimize the possibility of overfilling a vessel and reduce leakage while making or breaking connections.
- **Supervise longshoremen and other cargo handlers during cargo loading and unloading to ensure proper pellet containment (49 CFR Part 101).**
- **Inspect cargo immediately upon receipt, and note the condition of shipping containers and parcels on the carrier's receipt (49 CFR Part 101).**
- **Inspect seals on rail hopper cars before unloading.** Allow only authorized persons to remove the shipping seals (49 CFR Part 101). This ensures that only persons properly trained to prevent or contain pellet spills will break the seals. Document broken seals and the notify the shipper of the seal condition.
- **Check outlet tubes for pellets before moving railcars or trucks.** Visually inspect the connection ports of both the tube and the pneumatic-system hose. Purge lines before unhooking them and lift hoses to assist purging process (SPI, 1991).
- **Secure outlet caps and seals before moving full or empty rail hopper cars and trucks.**
- **Insist on warehouse and other handling procedures that minimize bag and box punctures and pellet spillage (SPI, 1991).**
- **Do not sweep pellets off of loading docks into the water (SPI, 1991).**
- **Repair punctured bags immediately (SPI, 1991).**

5.1.5 Maintenance and Housekeeping

If pellets are not quickly recovered after they are spilled, they will be dispersed and will likely be released into the environment. Therefore, improvements to standard maintenance and housekeeping practices are recommended for controlling pellet releases. These recommendations include the following.

- **Improve daily and routine housekeeping and spill response procedures both inside and outside the facility.** Insist on prompt spill cleanup and make spill cleanup the responsibility of the person(s) causing the spill. Pellets left for someone else to clean up will quickly disperse and recovery of all pellets will be difficult if not impossible. Spilled pellets also poses a safety hazard to the employees.
- **Invest more time in routine housekeeping.** The more often loose pellets are collected, the less likely the pellets are to be released into the environment.
- **Initiate vacuuming procedures to collect and contain spilled pellets.** Pellets are lightweight and broom sweeping may disperse some of the pellets rather than gather them.
- **Develop standard operating procedures (SOPs) for containing and cleaning up spills (SPI, 1991).**
- **Conduct routine inspections for the presence of loose pellets on the facility grounds including parking lots, drainage areas, driveways, etc.** Pellets entrained in storm-water runoff from any area will impact compliance with NPDES permits (see Section 5.2.1).

5.1.6 Packaging

Damaged packaging is a major source of pellet loss to the environment; this fact was evident throughout the site visits. Therefore, several recommendations can be made to prevent pellet loss through leaky packaging.

- **Design puncture-resistant shipping containers.**
- **Use reinforced bags, such as woven polypropylene bags, and line larger containers with puncture-resistant material.**
- **Minimize the use of valved bags or seal valved bags immediately after filling.**
- **Use sea containers instead of break bulk packaging.** Pellets in sea containers cannot be released during shipment.
- **Improve palleting methods.** Move and stack bags immediately after filling to avoid seepage from valves, and stack bags on pallet in tight, interlocking patters. Shrink- or stretch-wrap pallet to stabilize stacks and help contain lost pellets. Use corrugated cardboard caps on the top and on the bottom of pallets to minimize puncturing or tearing bags and to contain loose pellets. Finally, block and brace outbound loads to avoid broken bags in transit (SPI, 1991).
- **Tape leaks or replace leaking bags immediately (SPI, 1991).**
- **Inspect pellet packaging, particularly pellets bagged in unreinforced paper or cardboard packages/gaylords, before offloading.** This will prevent pellet release through the gap between the vehicle and the loading dock.

5.1.7 Shipping Vehicles

Changes to current shipping practices and vehicles can decrease the likelihood of pellet releases to the aquatic environment. Therefore, several recommendations can be made to the shipping industry and users of the shipping industry.

- **Use containers for cargo shipping rather than individual pallets.** The shipping containers will contain spilled pellets and will prevent them from dispersing among other cargo, onto the docks, on the deck of vessels, etc.
- **Identify the person responsible for sealing the ports on rail hopper cars and bulk trucks and have the person document the completion of the seal (49 CFR Part 101).** This will establish the responsibility for correctly sealing the car and a method for tracking the point at which a seal is broken and pellets are released.
- **Close and secure the rail hopper car valve with strong wire or aircraft cable in addition to the normal sealing mechanism.** This redundancy increases the time and effort that a vandal must expend to break the seal and release the pellets. Close hatches and reapply cable seals after inspecting or sampling the pellets. Insist on strict procedures that require outlet caps to be properly closed before rail hopper cars are moved, and request customers to do the same when returning empty cars (SPI, 1991).
- **Document the condition of bags and cargo containers and rail hopper car seals, and promptly notify the manufacturer of problems (e.g., damaged packages, broken valve seals) (49 CFR Part 101).**
- **Visually confirm that each compartment and tube of shipping vehicles is empty (SPI, 1991).** In addition, sweep, blow, vacuum, or rinse the exterior surfaces of loaded rail hopper cars to remove loose pellets before cars leave the containment area. Direct pellet flow into a screened bin or into the containment system. Also, air lance into containers to remove residual pellets in rail hopper cars and trucks (SPI, 1991).
- **Inspect interiors of trailers and sea containers for damaged walls, defective floors, or other defects that may puncture pellet packaging.** Cover defects with corrugated cardboard or, if necessary, insist on a replacement vehicle, sweep or vacuum any loose pellets in trucks or sea containers, and contain and dispose of any pellets from previous shipments properly when cleaning ship holds or sea containers after break-bulk shipments (SPI, 1991).
- **Consider vandalism exposure when selecting leased track sites.** Establish security procedures as needed (SPI, 1991). Advise companies to report problems to the delivering railroad as well as to the shipper, and utilize security personnel.
- **Avoid on-deck pellet stowage (SPI, 1991).** Stow other products on top and place resin containers in ship wells.
- **Do not jettison pellets or containers of pellets.**
- **Seal empty rail hopper cars and bulk trucks before returning to the shipper.** This will prevent loss of residual pellets.

5.1.8 Recycling and Waste Disposal

Many companies either do not recycle waste pellets, or recycle the pellets only sporadically. Minimizing the loss of recyclable pellets into the municipal waste streams could decrease the likelihood of their eventual release into the aquatic environment. Therefore, several recommendations can be made in regard to pellet recycling and the disposal of waste pellets.

- **Store waste pellets in properly labeled containers.** Do not permit loose pellets to accumulate on the ground or on floors (SPI, 1991). Install a minimum of one pellet-specific waste container in each pellet-handling area; separate containers should be used for recyclable and nonrecyclable pellets.
- **Inspect and confirm proper handling and storage procedures if an outside vendor is used for waste removal.** Insist on no-loss-to-the-environment procedures (SPI, 1991).
- **Recycle or resell waste pellets.** Use incineration and controlled landfilling only when recycling or resale are inappropriate. Consider using waste pellets in a fuel blending program (SPI, 1991). Properly handle "heels," and ensure that they are collected and recycled, resold, or disposed of properly. The preferred pellet disposal method is by recycling, followed by reuse, incineration by approved methods, or deposit in a controlled landfill (SPI, 1991).
- **Check broken and discarded packaging for residual pellets.**

5.2 Existing Control Measures

Several measures exist for preventing and controlling the release of pellets to the aquatic environment. An extensive regulatory framework is available that consists of international treaties and Federal legislation; several Federal agencies have developed policies and programs in response to plastic debris-related regulations. Industry has also adopted policies and implemented programs geared toward controlling the release of plastics and, consequently, pellets into the environment. Descriptions of these regulations, programs, and policies are presented below.

5.2.1 Legal Framework

Several legal authorities, such as international conventions and Federal regulations, have been developed for controlling the release of plastic materials into the aquatic environment. This reviews some of the legal authorities for controlling the disposal of plastic wastes from vessels into navigable waters (water-based sources) and the disposal of plastic debris from land-based sources, such as industry and sanitary and storm-sewer systems.

Water-Based Sources
The United States is a signatory to **Annex V of the Protocol of 1978 Relating to the International Convention for the Prevention of Pollution from Ships (MARPOL Protocol of 1973/78)** (hereafter referred to as MARPOL Annex V). Under the terms of the Convention, MARPOL Annex V became effective on December 31, 1988. The treaty prohibits the at-sea disposal of all plastic wastes generated during normal shipboard operations.

MARPOL Annex V cannot be used as a mechanism for controlling land-based releases of pellets into the environment because the treaty applies only to releases at sea and is not applicable to land-based sources. In addition, MARPOL Annex V applies only to vessels of signatory nations; vessels from nonsignatory nations are not bound by the treaty's restrictions, but signatory nations are obligated to provide facilities for the reception of plastic wastes at ports (Anon., 1988b).

The **Marine Plastic Pollution Research and Control Act, Public Law 100-220 (MPPRCA)** implements the provisions of MARPOL Annex V by amending the Act to Prevent Pollution From Ships as amended in 1901 (ITF, 1988). MPPRCA also implements several other pieces of legislation introduced in the Congress in 1986 and 1987 (CMC, 1988).0

The MPPRCA specifically prohibits the disposal of plastics at-sea by U.S.-registered vessels in any waters, and foreign-registered vessels in navigable waters (i.e., bays, sounds, other inland waterways, and coastal waters) and the exclusive economic zone (waters to 200 miles offshore) of the United States (ITF, 1988; CMC, 1988). The law assigns the responsibility of developing regulations for implementing the MPPRCA, implementing and enforcing the regulations, and establishing civil penalties for violations to the United States Coast Guard (USCG).

Several requirements of the MPPRCA that are applicable to pellet releases include

- **Public Outreach -** The National Oceanographic and Atmospheric Administration (NOAA) and EPA are required to develop and conduct public outreach programs for educating the public about the problems associated with the disposal of plastic and other debris into the aquatic environment.
- **Waste-Reception Facilities -** All ports and terminals that receive oceangoing vessels of ò400 gross tons or >500,000 lb of commercial fishing products in a calendar year must have adequate waste-handling and waste-reception facilities for collecting shipboard wastes. Pellets spilled on loading docks, ships' decks, and in cargo holds may be considered shipboard wastes (A.T. Kearney, 1991).
- **Waste Management Plan -** All U.S. vessels must develop and implement shipboard waste management plans that address the provisions of MARPOL Annex V. The USCG is authorized to prosecute any vessel, foreign or domestic, that disposes of plastics within 200 miles of the U.S. coast (CMC, 1988).

Another Federal law that may apply to water-based releases of pellets into the environment is the **Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA)**, which is commonly referred to as the Ocean Dumping Act. Under the MPRSA, no U.S. vessel may transport any material, including plastic, for the purpose of dumping the material into the ocean unless the vessel has a permit to dump from EPA; EPA does not grant permits for the dumping of plastics into the ocean and regulations implementing the MPRSA also prohibit such dumping.

In addition to Federal laws and international treaties to which the United States is a signatory, states and local governments may regulate the disposal of wastes from vessels in waters under their jurisdiction. Bean (1987) suggested that state and local strategies should focus on shore-based or dockside controls, including at-sea waste-storage requirements and provisions for adequate waste-disposal facilities at ports.

Land-Based Sources

The discharge of pellets from outfalls or other land-based point sources into coastal or inland waters is subject to regulation under Section 402 of the **Clean Water Act** (Bean, 1987). Prior to November 16, 1990, permit guidelines for the plastics industries controlled only the pH of the effluent and did not limit the discharge of solid or suspended particles (Bean, 1987). On November 16, 1990, EPA published the final revisions to the NPDES regulations for storm-water discharges. Section 122 of Title 40 [40 CFR 122.26(b)(12)] defines materials considered to be significant in storm-water discharges and plastic pellets are specifically named as significant materials. Therefore, pellets can be subject to regulation under the NPDES permit guidelines.

The new storm-water discharge regulations require selected industries to obtain NPDES permits for all storm sewers that carry storm water from industrial sites into public waterways (Bain and Mummert, 1991). Applicable industrial discharges include storm-water runoff from industrial plant yards, immediate access roads and railroad sidings, drainage ponds, material handling sites, refuse sites, wastewater sites, equipment handling/main-tenance areas, residual treatment areas, and loading/unloading areas (40 CFR 122.26) (Bain and Mummert, 1991). Areas excluded from NPDES permitting include lands separate from those above mentioned areas, such as employee parking lots where runoff from the lots does not mix with runoff from areas of industrial activity (Bain and Mummert, 1991).

Other Federal laws that may apply to land-based releases of pellets into the environment include

- **Rivers and Harbors Act of 1899 (Refuse Act) -** Although the Refuse Act of 1899 has been superseded by the NPDES permit program of the Clean Water Act, it does contain a prohibition against the unpermitted deposit of "material of any kind" that is likely to be transported into navigable waters, other than what would be carried by sewers (CMC, 1988). According to CMC (1988), it is possible that the Refuse Act of 1899 "could be used to prosecute against, for example, an industrial source of large quantities of plastic pellets or a landfill operated in such a way that refuse could be washed into rivers."
- **Toxic Substances Control Act (TSCA) of 1976 -** Under TSCA, EPA has the authority to require the testing of new and existing chemical substances entering the environment, and, subsequently, the authority to regulate these substances (EPA, 1990a). EPA (1990a) stated that a serious impact of plastics disposal in water bodies is the injury to and death of marine animals that mistake plastics for food. However, EPA has historically applied its authority to substances more acutely toxic than plastic materials, and the focus is on the toxicity of the chemicals and not on the effects of the products in which the chemicals are used (EPA, 1990a).
- **Resource Conservation and Recovery Act of 1976 (RCRA) -** RCRA defines hazardous waste as "a solid waste . . . which because of its . . . physical [or] chemical . . . characteristics may . . . pose a substantial present or potential hazard to . . . the environment when improperly treated, stored, transported, or disposed of." Based on this definition, Bean (1987) considers plastic trash (e.g., pellets in the solid waste stream) to be hazardous waste. Because the focus of the EPA's RCRA program focuses on chemical toxicity and generators that produce this type of waste in the course of manufacturing other products, EPA does not regulate pollution by plastic trash under the

authority of the RCRA (Bean, 1987).

Additional strategies to reduce plastic marine pollution from land-based sources should be aimed at state and local governments (Bean, 1987). To date, no states have enacted laws restricting pellet releases, although several states have enacted laws limiting the use of plastic products such as beverage yokes (Bean, 1987) or requiring the use of degradable material in lobster/crab traps and pots (ITF, 1988). Bean (1990) encouraged the development of recyclable or degradable plastics as the solution to plastics pollution (and the growing contribution of plastic to the solid-waste stream), and recommended solid-waste disposal laws of general applicability in lieu of a major shift to degradable or recyclable plastics or nonplastic alternatives.

5.2.2 Government Programs and Policy

The MPPRCA (described in detail in Section 5.2.1) requires that EPA, NOAA, and the Secretary of Transportation jointly develop marine debris public education programs. To date, in addition to the present study, EPA has sponsored several activities that directly address the issue of pellets in the environment (Redford, 1990), including

- Preparing the 1990 Report to the Congress, *Methods to Manage and Control Plastic Wastes* (EPA, 1990a)
- Revising NPDES permit requirements for storm-water discharges (40 CFR 122)
- Developing a strategy for enforcing provisions of the Clean Water Act in regard to combined sewer overflow (CSO) discharges
- Initiating studies of CSOs as sources of aquatic debris, including pellets (EPA, 1992b)
- Initiating field investigations of floating debris in harbors of the United States (EPA, 1990b, 1992a; Trulli *et al.*, 1990; Redford *et al.*, 1992)
- Initiating a pilot program for monitoring the presence of pellets on U.S. beaches. This program is being conducted in conjunction with the National Park Service.

The **National Ocean Pollution Planning Act of 1978** required that NOAA prepare 5-year plans for researching and monitoring ocean pollution, including the problems of entanglement and ingestion of debris by marine organisms. In 1987, NOAA convened a workshop to establish the National marine pollution research priorities. Marine debris was among the top five research priorities and the identification of the pellet sources and effects on the environment were specifically named. The proceedings of the workshop were used to develop the *Federal Plan for Ocean Pollution Research, Development, and Monitoring for Fiscal Years 1988-1992.*

Under the sponsorship of NOAA and the National Marine Fisheries Service (NMFS), the Shipping Industry Marine Debris Education Plan was developed to educate all commercial vessel operators and crew of the MARPOL Annex V provisions and to encourage voluntary compliance with those provisions (Wallace, 1990). Components of the plan that directly involve pellet releases include

- Case studies of current levels of awareness of MARPOL Annex V provisions; the emphasis is on positive-action cases (i.e., those companies that have changed their plastics handling and disposal practices). Model waste-minimization plans are also outlined.
- MARPOL Annex V Education Kit containing legal and environmental issues pertaining to the disposal of debris from ships
- Liaison with international shipping trade associations as vehicles for disseminating debris-related information (as opposed to contacting each individual shipping company) and placing public service announcements in trade publications to reach all plastics industries.

The Department of Transportation (DOT) does not consider plastic pellets to be acutely hazardous (acutely hazardous substances include explosives, toxic chemicals, etc.) and, therefore, have not developed regulations for transporting pellets or remediating pellet spills from rail hopper cars (Mr. Fred Pritchard, DOT, personal communication, November 1991, Washington, DC). However, DOT has developed Cargo Security Advisory Standards (49 CFR Part 101) for securing cargo transport. These standards were developed based on concerns over the security (prevention of vandalism and theft) of expensive or controlled products (e.g., appliances, alcohol, firearms); engineering/performance resins may be considered in this cargo classification (F. Pritchard, ibid.). Although the Cargo Security Advisory Standards carry no enforcement powers and are intended only to be recommendations, they provide several good suggestions for controlling pellet releases from rail hopper cars in railroad yards and along the railroad right-of-way. Applicable recommendations have been incorporated into Section 5.1.

5.2.3 Industry Programs and Initiatives

In response to the implementation of MARPOL Annex V regulations and increasing evidence of the harmful effects of plastics in the aquatic environment, the plastics industry and merchant shipping industry have initiated programs and developed policies aimed at controlling the release of plastics, including pellets, into the oceans and waterways.

Plastics Industry Programs
In addition to the voluntary cooperation of SPI and the seven companies visited in the present study (Section 4.0), SPI has initiated other activities designed to inform and educate the plastics industries in regard to the effects of released pellets on the environment.

To alert pellet producers of the hazards of pellet releases into the environment, SPI hosted a briefing for pellet producers in September, 1986. Discussions prompted by a Center for Marine Conservation (CMC) presentation on marine debris, as well as presentations of industry pellet reclamation activities, eventually led to a public service campaign (discussed below). In September 1987, the SPI Board of Directors issued an official policy statement in regard to marine debris and the plastics industry's pledge to solve the problem. In regard to pellets specifically, the statement clearly stated that SPI was dedicated to eliminating conditions under which pellets are released by manufacturers and transporters (Bruner, 1990).

In 1987, SPI, NOAA, and CMC jointly initiated a campaign to educate the industry about the hazards of plastics to wildlife. The campaign focused on all types of plastic debris and their respective target audiences. Pellets, whose target audience was the major pellet producers and processors, was one of five target points of the campaign (SPI, 1990). SPI prepared a Marine Debris Briefing and Education Kit for the campaign, which included posters, stickers, brochures, written information, and pellet-related materials carrying the caption *Please Don't Feed the Birds* including a photograph of a single pellet (see Figure 31 below). The kit was designed so that individual companies could initiate internal information campaigns and educate employees about the environmental hazards posed by pellets. Several recommendations were discussed for controlling pellet releases during manufacture, shipping, and handling. SPI distributed these kits to 1500 SPI-member companies and frequently published portions of the kits in trade magazines. In 1988, the kit was also presented to the international community; SPI President Larry Thomas distributed copies to the International Association of Plastics Directors. By the end of 1989, more than 1000 column-inches of advertisement space (25 appearances in 10 publications) or news coverage had been devoted to the entire campaign (Bruner, 1990; SPI, 1990). These kits continue to be distributed upon request, and the pellet photograph appeared in trade magazines through 1990.

EPA studies between 1988 and 1992 (EPA, 1990b, 1992a,b,c) found that pellet releases continue to be an environmental problem. In response to these findings SPI founded a Resin Pellet Task Force to investigate the problem. In November 1990, following the findings of the Resin Pellet Task Force, SPI initiated a second campaign entitled *Operation Clean Sweep*, targeted at the plastics industry and its customers (see Figure 32 below). The 1991 *Pellet Retention Environmental Code* (see Figure 33 below) and the 1992 *Processor's Pledge* (see Figure 34 below) are an integral part of this campaign. SPI hasasked its member resin-producing companies to sign the *Pellet Retention Environmental Code* and, thereby, commit to "the total containment of plastic pellets throughout their lifespan and to [operate] in full compliance with environmental laws and regulations impacting on pellet containment" (SPI, 1991). By the end of August 1991, nearly two-thirds of the companies had signed and agreed to the code, and the remaining companies were considering the matter (Mr. Ronald Bruner, SPI, personal communication, August 28, 1991, Washington, DC.). The *Processor's Pledge* was developed and introduced to SPI's processor members in the summer of 1992 in an effort to make that segment of the industry more aware of the importance of preventing pellet loss. *Operation Clean Sweep* was introduced to the plastics industry at the National Plastics Trade Show in July 1991, in Chicago, Illinois. The campaign was also discussed with representatives of plastics industries from over 25 countries at the International Association of Plastics Directors in June 1991. SPI is considering development of multilingual copies of the campaign materials for distribution.

Initiatives by Individual Companies
Several companies have initiated programs to control the release of plastic pellets into the environment. Good examples of effective control measures were observed at pellet producer Companies F and G (Section 4.2.2) and contract packager Company B (Section 4.3.2).

Merchant Shipping Initiatives
CMC (1988) reported that the American Institute of Merchant Shipping (AIMS), a national trade association for many U.S.-flagged merchant vessels, has given testimony to the Congress in support of the provisions of MARPOL Annex V. AIMS supports mandatory training of merchant seamen regarding plastic pollution prevention and achievement of compliance with MARPOL Annex V standards.

5.3 Recommendations to Regulators

A logical resource for identifying problem areas within a facility are the Federal, state, and local inspectors that routinely visit the three sectors. This does not mean that these inspectors should be empowered to fine or otherwise penalize the facility operators. Instead, the inspectors could take the opportunity to point out pellet containment and release problems during their routine inspections.

Therefore, the following recommendations have been developed for regulators.

- **Educate local, state, and Federal inspectors.** These inspectors generally have greater access to the facilities than do any other regulatory official. Although the inspectors have no regulatory authority over pellet containment, the fact that a regulatory official identifies a potential problem may encourage better containment practices.
- **Establish guidelines for sealing the ports on rail hopper cars, bulk trucks, and other shipping vehicles.** The DOT Cargo Security Advisory Guidelines, published in 49 CFR Part 101, include several recommendations that have been incorporated into this report.
- **Encourage shipping companies to notify the shipper and receiver when broken or damaged seals are observed.** Although pellets are not considered by DOT to be hazardous materials, spillage by vandalism should be reported to the shipper, particularly if no preventive measures have been taken (e.g., rail hopper car valve not sealed or inadequately sealed).

5.4 Summary of Recommendations

Existing Federal regulations, such as the MPPRCA, provide a basis for requiring controls over the release of all plastic materials, including pellets, into the aquatic environment. Provisions of the recently finalized storm- water discharge rules specifically target pellets in storm-water discharge. All facilities are advised that they need to be mindful of pellet contamination of storm water and the need to comply with any applicable terms of their permit regarding pellets. However, penalties alone cannot control the release of pellets; the penalties can only encourage companies to implement control measures. Ultimately, controlling pellet releases into the environment is the responsibility of the plastics industry, and effective controls should be continued and enhanced through voluntary industry programs.

Controlling pellet releases can begin with proper training and education of plastics industry managers and employees and by increasing awareness of the hazards posed by pellets and of the economic incentives for controlling releases. Capital investments in containment systems may be necessary to control releases at facilities that handle large volumes of pellets, but inexpensive control measures, such as portable screens or tarps, may be adequate for controlling releases at small-volume companies. All facilities could improve routine housekeeping measures by increasing the frequency of sweeping and including the use of vacuums to recover spilled pellets.

In conclusion, several mechanisms for controlling pellet releases are currently available, and most of the mechanisms, such as education, portable screens, and improved housekeeping, would be inexpensive to implement. Facilitywide containment systems have been shown to be effective pellet control mechanisms, but these systems may not be necessary at smaller facilities or at facilities that effectively control pellet spills where they occur.

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Note: This information is provided for reference purposes only. Although the information provided here was accurate and current when first created, it is now outdated.

6.0 Glossary

Disclaimer: The information in this website is entirely drawn from a 1992 publication, and has not been updated since the original publication date. Users are cautioned that information reported at that time may have become outdated.

Additive
: Used to alter the physical characteristics of a polymer, such as the esthetic and physical properties and the ability to be further processed.

Conveyor
: A machine that transports materials from one place to another.

Culvert
: A sewer or drain crossing under a road.

Effluent
: Flow of waste water released from a facility.

Epibiont
: Organism that lives attached to another organism but without benefit or detriment to the host.

Extrusion
: Shaping plastic by forcing through a die.

Gaylord
: Large, 1000-lb capacity, cardboard box used for shipping pellets.

Gizzard

A muscular enlargement of the digestive tract of a bird.

Hopper
: A receptacle in which materials are held in readiness for unloading or dispersing.

Melt
: A hot, very viscous liquid produced by the process of bulk polymerization.

Monomer
: A molecule that can be chemically bound as a unit of a polymer.

Neuston
: Small- to medium-size organisms that live on or under the surface film of water bodies.

Pellet
: Resins that are generally spherical, ovoid, or cylindrical in shape, and between 1 and 5 mm dia.

Pelletizer
: Equipment used to create pellets from polymers. The type of pelletizer used determines the size and shape of the pellets.

Packager
: Sector of the plastics industry that breaks down bulk shipments of pellets into smaller containers such as bags and gaylords; also called contract packager.

Processor
: Sector of the plastics industry that molds the pellets into fabricated user-products.

Producer
: Sector of the plastics industry that creates the polymers and extrudes the pellets.

Transporter
: Sector of the plastics industry that moves or carries the pellets between the pellet producers, packagers, and processors.

Pinocytotic
: Active ingestion of fluid by a cell, by invagination of the cell membrane to form vesicles.

Pneumatic
: Operated by compressed air.

Polymer

A natural or synthetic compound consisting of smaller inter-linked molecules.

Polymerize

To make or combine into a polymer.

Railroad siding

A length of railroad track that is connected to the main track.

Resin

A polymer synthesized from petroleum or natural gas derivatives.

Skimmer

A motor-driven paddle device consisting of several rectangular paddles and a drive system. The paddles skim pellets from water surface into a containment system.

Thermoplastic Resins

Resins that can be melted or reprocessed without damaging or changing the chemical or physical properties of the polymer. Resins are highly malleable but become rigid when cooled.

Thermoset Resins

Resins that tend to be rigid, infusible, and insoluble, and cannot be remelted and reformed.

Weir

A mechanical device that controls the level and flow of water by using dams or similar mechanical devices.

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Plastic Pellets in the Aquatic Environment: Sources and Recommendations

To view this table, please use a browser with table capability.

Table 1. Annual U.S. Resin Sales.

[Adapted from Martino (1991)]

Resin	**% Annual Sales(a)**		**Resin**	**% Annual Sales(a)**	
	1989	**1990**		**1989**	**1990**
Thermoplastic Resins			**Thermoplastic Resins (cont.)**		
Low-density polyethylene (LDPE)	18.5	19.3	Polycarbonate	1.1	1.0
Polyvinylchloride (PVC) and copolymers	14.7	15.1	Polyphenylene-based alloys	0.3	0.3
High-density polyethylene (HDPE)	14.0	13.8	Styrene/acrylonitrile (SAN)	0.2	0.2
Polypropylene (PP) and copolymers	12.5	13.2	Polyacetyl	0.2	0.2
Polystyrene (PS)	8.8	8.4	Cellulosics	0.2	0.1
Thermoplastic polyester polyethylene terephthalate (PET)	3.6(b)	3.8(b)	**Thermoset Resins**		
Thermoplastic polyester polybutylene terephthalate (PBT)	----	----	Phenolics	4.9	4.6

Acrylonitrile/butadiene/sytrene (ABS)	2.1	2.0	Polyurethane	5.5	5.3
Other styrenics	2.0	1.8	Urea and melamine	2.4	2.3
Other vinyls	1.5	1.5	Polyester, unsaturated	2.3	2.0
Polyamide (nylon)	1.0	0.9	Epoxy	0.8	0.8
Acrylic	1.3	1.2	Alkyd	0.6	0.5
Thermoplastic elastomers	0.9	0.9	Others	0.5	0.5

NA: Not available.
(a)Based on total annual sales of 58,251 and 61,480 billion pounds of resin in 1989 and 1990, respectively.
(b)Value is for PET, PBT, and other thermoplastic polyester resins.

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Plastic Pellets in the Aquatic Environment: Sources and Recommendations

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Table 2. Characteristics and Uses of Plastics Additives.

[Adapted from EPA, 1990a]

Examples or Types of Additives	Additive Conc. (lb) (a)	Typical Polymers Using Additive
Antimicrobials - Increase resistance to microorganisms Oxybisphenoxarsine; isothiazalone	Low (<1)	Polyurethane, PVC, PE
Antioxidants - Prevent deterioration during processing and long-term use Phenolics; amines; phosphates; thioesters	Low (<1)	Impact styrene, ABS, polyolefins
Antistatic agents - Control static buildup during processing and in final product Amine salts; phosphoric acid esters; polyethers	Low (<1)	PVC, polyurethane, polyolefins
Blowing agents - Add porosity to produce foamed plastics Azobisformamide; chlorofluorocarbons; pentane	Moderate (1-5)	Polyurethane, PVC, PP, PS, ABS

Catalysts and curing agents - Facilitate polymerization and curing of resins Numerous	Low (<1)	Polyurethane
Colorants - Enhance appearance of consumer products Organic and inorganic pigments and dyes	Low (1-2)	Numerous
Fillers - Enhance physical properties (e.g., hardness) and reduce production costs Minerals (e.g., calcium carbonate wood flours)	High (10-50)	Unsaturated polyester, PVC
Flame retardants - Reduce combustibility Aluminum trihydrate; antimony oxide; halogenated hydrocarbons; organophosphates	High (10-20)	Various
Free-radical initiators - Assist in polymerization and curing processes Peroxides; azo compounds	Low (<1)	LDPE, PS, PVC, acrylics, PE
Heat stabilizers - Improve heat resistance or prevent degradation by heat Organotin mercaptides; lead compounds; barium, cadmium, and zinc soaps	Moderate (1-5)	PVC
Impact modifiers - Improve strength and impact resistance Methacrylate butadiene styrene; chlorinated PE; acrylic polymers; ethylene vinyl acetate	High (10-20)	Polyolefins, PVC, engineering plastics
Lubricants and mold release agents - Improve viscosity, reduce friction between resin and surrounding surfaces Fatty acids; alcohols and amides; esters; metallic stearates; silicones; soaps; waxes	Low (<1)	PVC, PS, polyolefins
Plasticizers - Soften rigid polymers and make them more flexible Phthalates; aliphatic di-and tri-esters; polyesters; phosphates; trimellitates	High (20-60)	PVC, cellulosics
Reinforcers - Improve physical properties Glass fibers, wood flours	High (10-40)	Epoxy, unsaturated polyester

Ultraviolet stabilizers - Prevent or inhibit degradation by ultraviolet light Hindered amines; hydroxybenzophenones; carbon black; hydroxybenzotriazoles	Low (<1)	Polyolefins, PE, PP, polycarbonate, PS, PVC

(a) Additive concentration in final product (pounds additive per 100 lb of resin), ranked high, moderate, or low.

Plastic Pellets in the Aquatic Environment: Sources and Recommendations

To view this table, please use a browser with table capability.

Table 3. Polymer Densities.

[Adapted from EPA (1990a) and Anon. (1988a)]

Resin	Density (g/mL)	Resin	Density (g/mL)
Thermoplastic Resins		**Thermoplastic Resins (continued)**	
Polystyrene (PS)	1.04-1.08	Styrene/acrylonitrile (SAN)	1.02-1.08
Other styrenics [e.g., styrene-butadiene and styrene-based latexes, styrene-maleic anhydride (SMA), styrene-butadiene (SB) polymers]	1.05-1.14	Polyphenylene-based alloys (i.e., modified phenylene oxide and modified phenylene	1.06-1.10
Low-density polyethylene (LDPE)	0.89-0.94	High-density polyethylene (HDPE)	0.94-0.96
Thermoplastic polyester polyethylene terephthalate (PET)	1.29-1.40	Thermoplastic polyester polybutylene terephthalate (PBT)	1.30-1.38
Polyvinylchloride and copolymers (PVC)	1.30-1.58	**Thermoset Resins**	
Polyamide (nylon)	1.07-1.08	Phenolics	1.24-1.32
Acrylonitrile/butadiene/sytrene (ABS)	1.01-1.08	Polyurethane	1.17-1.28

Polypropylene and copolymers (PP)	0.89-0.91	Polyester, unsaturated	1.01-1.46
Thermoplastic elastomers	NA	Epoxy	1.11-1.48
Acrylic	1.17-1.20	Alkyd	1.30-1.40
Polycarbonate	1.2	Urea and melamine	1.47-2.00(b)
Cellulosics	1.09-1.24	Others (small-volume thermoplastic and thermoset resins)(c)	NA(c)
Polyacetal	1.41-1.42	**Sea water**	1.02-1.03
Other vinyls (e.g., polyvinly acetate, polyvinyl butyrol, polyvinylidinechloride)	1.16-1.35	**Fresh water**	<1.015

NA: Not available.
(a) Value is for PET, PBT, and other thermoplastic polyester resins combined.
(b)Densities are for filled molding systems; values for unfilled pellets were not available.
(c)Includes polymothyl pentene (density: 0.83-0.84 g/mL), polyimide (density: 1.36-1.43 g/mL), and polyetherimide (density: 1.27 g/mL).

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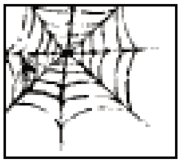

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Plastic Pellets in the Aquatic Environment: Sources and Recommendations

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Table 4. Effects of Two Additives to the Densities of Selected Commodity Resins.

[Adapted from Anon. (1988a)]

Polymer	**Density without Additive (g/mL)**	**Density with Additive(a,b) (g/mL)**
ABS	1.01 to 1.08	1.18 to 1.61(a)
Polyamide (nylon)	1.07 to 1.08	1.13 to 1.62(a)
Polyethylene	0.92 to 0.975	1.18 to 1.28(a)
Polypropylene	0.89 to 0.91	1.04 to 1.23(a) 1.22 to 1.17(b)
Polystyrene	1.04 to 1.08	1.20 to 1.50(a)
PVC	1.30 to 1.58	1.42 to 1.50(a) 1.30 to 1.70(b)

(a) Additive: Fiber/flake reinforcer.
(b) Additive: Particulate filler.

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Plastic Pellets in the Aquatic Environment: Sources and Recommendations

To view this table, please use a browser with table capability.

Table 5. Pellet Observations and Suspected Pellet Sources.

(PE: polyethylene; LDPE: low-density polyethylene; HDPE: high-density polyethylene; PS: polystyrene; PP: polypropylene)

Geographical Area of Study	**Observations**	**Source(s) Discussed**
ATLANTIC OCEAN		
Southern New England (Carpenter *et al.*, 1972)	PS pellets (0.1- to 2-mm dia) common in Niantic Bay, Buzzards Bay, Vineyard Sound, Rhode Island Sound, Great Salt Pond, Long Island Sound, and Block Island Sound; average 0.01 to 1 pellet per cubic meter. Pellets in several fish.	Effluent from plastics manufacturers or PS producers in southern New England.
Sargasso Sea (Carpenter and Smith, 1972)	50 to 12,000 particles per square kilometer (mean: 3500 particles per square kilometer); lowest concentrations near the Gulf Stream.	Waste dumping from cities or cargo ships.

Cape Cod to Cape Canaveral and areas south (Colton *et al.*, 1974; Colton, 1974)	PS and PE pellets (<5-mm dia); 61 to 148 pellets per square kilometer south of Cape Canaveral, and 8318 pellets per square kilometer between Cape Cod and Cape Canaveral.	Wastewater discharge from plastics plants. Most PS and PE pellets entered open coastal waters between Block Island and eastern Long Island.
South Atlantic Bight from North Carolina to Cape Canaveral (van Dolah *et al.*, 1980)	Percent occurrence of PS pellets on each cruise ranged from 15% to 34 %. Tar and pellets were widespread throughout study area.	Shipping traffic and entrainment from other areas via currents.
Eastern Canada and Bermuda (Gregory, 1983)	In Bermuda, PE pellets averaged 5000 pellets per linear meter of beach, (occasionally >10,000 pellets per linear meter). In eastern Canada, a maximum of 10 PE pellets per linear meter. Lifetime of pellets suspected to be as low as 3 years. Pellets encrusted with pseudoplanktonic biota.	Released at dump sites or spillage along Atlantic seaboard, spillage during storage, handling, and transportation activities.
Bermuda, Bahamas, and Martha's Vineyard, MA (Wilber, 1987)	>75% of neuston tows in north Sargasso Sea contained pellets. High concentrations (2000 per square meter) on Bermuda and Bahamas beaches, where they are deposited by ocean currents. Pellets often embedded in tar balls ("plasto-tarballs").	Spillage and loss at coastal manufacturing and shipping sites.
Cape Basin area of South Atlantic (Morris, 1980)	White PE or PP pellets (3- to 5-mm dia) between 1333 and 3600 pellets per square kilometer; pellets and tarballs most common contaminants in area.	No immediate source known other than through cargo loss.
Southwestern Cape Province, South Africa (Ryan, 1988b)	Predominance of PE and other polyolefin pellets, most of which were <10 mg. Pellets may be lost during handling and released into the sea via drainage lines.	Pellets lost during transport or by manufacture of user products in industrial areas; may enter South Africa via oceanic circulation from the South Atlantic.

PACIFIC OCEAN		
North Pacific (Wong *et al.*, 1974, as cited in Pruter, 1987)	Round, colorless pellets (1-5-mm dia) in 64% of tows along 35ø N longitude. Plastics industry.	Manufacturer outfalls; spillage from trucks, ships, and trains while loading or unloading; and when used as ball bearings to move cargo.
North Pacific Ocean (Day *et al.*, 1990)	Pellets found in 6% of total stations and 10% of stations with plastic. Collected primarily in transitional and nearshore waters east of Japan. Highest density was 6500 per square kilometer north of Hawaiian Islands.	Not discussed.
New Zealand (Gregory, 1977)	PE and PP pellets, ovoid and spheruloid (greater than or equal to 5-mm dia); 10,000 to 40,000 pellets per meter on beaches in narrow zone along driftline or spread across the back beach and washover flat.	Spillage at ports or via streams and storm water drainage after spills at inland processing plants.
Alaska (Day, 1980 and Jarrell, pers. commun. as cited in Day, 1980)	Substantial amounts of pellets; PE common but PS unknown. Also reported approximately 500,000 lb of PP pellets were dumped into the ocean during a dock strike in Costa Rica.	Effluent of plastic manufacturers and during loading and unloading of ships at ports.
North Pacific Ocean (Day *et al.*, 1986)	Highest densities of plastic debris along 40ø N; pellets comprised 0.5% of all plastic debris and occurred at nearly 4% of the stations.	Not discussed.
North of Hawaii (Dahlberg and Day, 1985)	Pellets in neuston samples collected along latitudes 31ø N and 34ø N; densities must be relatively high to have been collected at all.	Not discussed.
North Pacific Ocean and Bering Sea (Day and Shaw, 1987)	Very low concentrations of pellets in the subarctic Pacific, especially near the Alaskan coast.	Not discussed.
MEDITERRANEAN SEA		

Beaches of Lebanon (Shiber, 1979)	PE, PS, and polymethyl methacrylate pellets fairly common on most beaches. Predominant pellet shape was oval to round (2- to 5-mm dia).	Waste disposal by several plastics factories or cargo lost at sea.
Beaches of Costa del Sol, Spain (Shiber, 1982)	Pellets (2.7 to 4.5 mm) present on all beaches sampled (13); abundant on four beaches and common on most others. Mostly LDPE (87%), HDPE (8%), and ethylvinyl acetate (4%). Encrusting biota absent on pellets, indicating recent introduction to marine environment.	Careless disposal practices at seven nearby plastics factories, or loss during sea shipment and cargo unloading.
Coast of Spain (Shiber, 1987)	Spherules in great variety of shapes and colors, often tar-covered, abundant on most beaches. Pellets found were predominantly PE.	Some correlation between abundance and location of 190 plastics factories in area; cargo loss during transport in Atlantic Ocean and Mediterranean Sea.
GULF OF MEXICO AND CARIBBEAN SEA		
Costa Rica and Caribbean Sea (Carr, 1987)	Large numbers of pellets on green sea turtle nesting beach in Costa Rica.	Industrial wastewater.
Padre Island National Seashore (Cole *et al.*, 1990; Miller, pers. commun.)	All pellets were white and the same size and shape; 73% of plastic debris and 69% of all debris were pellets.	Unclear whether from single or multiple discharges or from a spill.
ESTUARIES, HARBORS, AND OTHER COASTAL AREAS		
Harbors of the United States (Trulli *et al.*, 1990; EPA, 1990b, 1992a,b; Redford *et al.*, 1991)	Many different resins in assorted sizes, shapes, and colors found in all harbors studied except Mayagüez, PR. Hundreds to hundreds-of-thousands of pellets in each harbor.	Industrial and municipal storm water and CSO discharges.

Kahana Bay, Oahu, Hawaii (EPA, 1992b)	Average of 105 pellets per m2 were present between low and high tide lines, concentrated mostly among other anthropogenic and natural debris near high tide lines. Pellets appeared clean but weathered, likely polyethylene.	Commercial shipping or carried by ocean currents from distant land-based sources.
Sanitary systems in Philadelphia, PA and Boston, MA (EPA, 1992c)	Many pellet types collected in storm water outfalls and in scum samples from sewage treatment plant. All clean, PE pellets collected at one storm water outfall.	Storm water discharges from plastics industry.
Sewage outlet pipes at factories near Long Island, NY (Hays and Cormons, 1974)	1- to 13-mm-dia PS pellets found as far as 1.1 km downstream of one industrial outfall. PE pellets also found near outfalls in MA, CT, and NJ.	Industrial effluent.
Bristol Channel, UK (Morris and Hamilton, 1974)	0 to 20,000 PS pellets per square meter unevenly distributed in sediments. PS beads incorporated into polychaete tubes, and becoming common in plankton samples.	Effluent from a PS manufacturer.
Severn Estuary and Bristol Channel, UK (Karter *et al.*, 1973, 1976, as cited in Pruter, 1987)	In 1973, 1-mm PS pellets found in mud, sand, and on cooling water intake screens at nuclear power plants. Many polychaete worm tubes constructed almost entirely of pellets. PS spherules found in some flounder. By 1976, pellets virtually absent in all locations noted in 1972 and 1973.	Effluent from plastics industry.

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Table 6. Pellets Found during EPA Aquatic Debris Programs.

[Adapted from EPA (1990, 1992a,b,c), Trulli *et al.*(1990); and Redford *et al.*(1992)

Survey	Area Sampled	Number	Percent
Harbor Studies Program (a)			
Boston I	Charles River	2,684	30
	Chelsea River	0	0
	Mystic River	7	2
	President Roads	10	6
	Weymouth/Neponset Rivers	0	0
Boston II	Charles River	453	23
	Chelsea River	2	1
	Mystic River	45	6
	President Roads	0	0
New York I	Manhattan Island	2,039	25
	The Narrows and Lower Bay	461	8
New York II	Manhattan Island	617	21
	The Narrows and Lower Bay	548	27
	Staten Island	7,601	78

Philadelphia	Schuylkill River Delaware River - Camden Delaware River - Philadelphia	461 197 219	32 23 42
Mid-Atlantic Bight	Wilmington Canyon to Norfolk Canyon	1	5 (b)
Baltimore I	Inner Harbor Middle Harbor Patapsco River	600 110 70	20 12 15
Baltimore II	Inner Harbor Middle Harbor	2,625 524	46 27
Baltimore III	Inner Harbor Middle Harbor Patapsco River	1,972 698 7	23 19 4
Norfolk	Elizabeth River Hampton Roads	135 0	2 0
Miami I	Miami River Dodge Island Little River	56 51 7	3 11 1
Miami II	Miami River Dodge Island Nearshore Atlantic	68 173 1	3 18 2
Houston I	Upper Ship Channel Middle Ship Channel Lower Ship Channel	106,759 352,790 15,660	98 99 98
Houston II	Upper Ship Channel Middle Ship Channel	38,199 186,936	96 97
Seattle	Duwamish Waterway Lake Union Ship Channel	20 4	8 1
Tacoma	Commencement Bay	3,834	78
San Francisco	San Francisco Bay	297	9
Oakland	San Francisco Bay	279	18
Mayagüez	Bahia de Mayagüez to Puerto Real	0	0
San Juan	San Juan Harbor	714	23

Honolulu	Honolulu Harbor Ala Wai Canal	181 2	5 <1
Combined Sewer Overflow (CSO) Studies Program (c)			
Philadelphia	Combined Sewer Overflow Stormwater Discharges Northeast Sewage Treatment Plant (d) Southeast Sewage Treatment Plant (d) Southwest Sewage Treatment Plant (d)	1 1,898 3,420 49,500 24,880	13 65 3 24 6
Boston	Combined Sewer Overflow Deer Island Sewage Treatment Plant (d) Chelsea Street Headworks (Bar Screen) (d) Ward Street Headworks (Bar Screen) (d)	981 810 0 0	11 4 0 0

(a) EPA (1990, 1992a,b); Trulli et al. (1990); Redford et al. (1992).
(b) 20 items were collected in the Mid-Atlantic Bight.
(c) EPA (1992c).
(d) Numbers of pellets present in 100% of each facility's solid wastes, based on collection and analysis of 10% of the solid wastes at each.

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Table 7. Pellets Collected Each Day at Sewage Treatment Facilities in Philadelphia and Boston

[EPA (1992c)]

Location	Number Day 1 (a)	Number Day 2 (a)
Philadelphia		
Northeast WPCP	2,110	1,310
Southeast WPCP	22,820	26,680
Southwest WPCP	5,520	19,360
Boston		
Ward Street HW	0	0
Chelsea HW	0	0
Deer Island STP	650	160

WPCP: Water Pollution Control Plant
HW: Headworks
STP: Sewage Treatment Plant
(a): Daily totals calculated based on the analysis of 10% of the screenings and scum present each day

at each facility.

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Table 8. Pellet Ingestions and Potential Effects.

Geographical Location	Species Reported	Description of Ingestion or Effects
BIRDS		
Alaska (Day, 1980)	Northern fulmars, sooty shearwaters, short-tailed shearwaters, red-legged kittiwake, thick-billed murre, Cassin's auklet, parakeet auklet, tufted puffin, horned puffin, fork-tailed storm-petrel, Leach's storm-petrel, northern phalarope, glaucous gull, black-legged kittiwake, and least auklet.	Ingestions likely due to pellet resemblance to natural prey, and will increase as annual plastics production and use of pellets increase. Some particles embedded in gizzard walls; mean residence time in gizzards may be approximately 15 months. Hydrocarbon pollutants associated with the pellets may decrease reproductive ability of seabirds.
California (Chu, pers. commun., as cited in Day *et al.*, 1985)	Sooty shearwaters	Ingestions

Galapagos Islands (Anon., 1981, as cited in Day *et al.*, 1985)	Blue-footed booby	Secondary ingestion of raw plastic.
Monterey Bay, CA (Baltz and Morejohn, 1976)	Northern fulmars, pink-footed shearwaters, sooty shearwaters, short-tailed shearwaters, Heermann's gull, and black-legged kittiwake.	Ingestions of PE pellets in stomachs of 6 seabird species.
New Zealand (Imber, pers. commun., as cited in Day *et al.*, 1985)	Great-winged petrels, kerguelen petrels, Cook's petrels, blue petrels, broad-billed prions, antarctic prions, fairy prions, Parkinson's petrels, white-faced storm-petrels, salvin's prions, and sooty shearwaters.	Ingestions in low to high numbers.
Chatham Islands and Gough Island (Bourne and Imber, 1982)	Broad-billed prions and white-faced storm-petrels.	Pellets normally found in the gizzard, and birds containing pellets often lacked food in the proventriculus. Difficult to determine whether pellet ingestion is a cause or an effect of starvation. Secondary ingestion by great skuas that consume old, pellet-containing prions.
Eastern Canada (Brown *et al.*, 1981, as cited in Day *et al.*, 1985)	Greater shearwaters and sooty shearwaters	Ingestions reported.
South Africa (Furness, 1983, as cited in Day *et al.*, 1985)	Greater shearwaters	PS spheres ingested.
Dutch coast (van Franeker, 1985)	Fulmars	>50% of stomachs contained pellets; toxic additives in pellets may be assimilated by birds.

Midway Island and Oahu Island, Hawaii (Fry *et al.*, 1987)	Wedge-tailed shearwaters	60% of birds contained pellets (majority were PP and PE) and plastic fragments; toxicity of additives and organochlorine pollutants may be less significant hazard than obstruction/impaction of the gut of seabirds; risks to chicks may differ from risks to adults.
Scottish colonies (Furness, 1985)	Procellariiform seabirds (Leach's petrels, Manx shearwaters, and fulmars)	Fulmars and Leach's petrels select debris according to their preference for particular prey sizes. Only equivocal statistical evidence for an influence of ingested plastic on body mass. Pellets not found in British storm petrels.
Laboratory experiment. (Ryan, 1988a)	Chickens	Even under ideal feeding conditions, plastic-loaded birds cannot forage as efficiently as plastic-free birds. Large loads of plastic impair feeding by reducing meal size, which may, therefore, limit accumulation of fat reserves essential for reproduction, migration, and molting.
Antarctica (van Franeker and Bell, 1988)	Wilson's storm petrels, southern fulmars, and Cape petrels.	Pellets comprised 73% of all ingested particles (combined for all species); plastic particles remaining in the gizzards of petrels may persist for months or years if not regurgitated. Decrease fitness is a likely consequence of ingestion by chicks and adults. Most plastics originate in wintering areas outside the Antarctic.

South Africa and Southern hemisphere (Ryan, 1987)	Blue petrels, great shearwaters, white-faced storm-petrels, pintado petrels, thin-billed prion, antarctic prion, salvin's prion, sooty shearwater, grey phalarope, arctic skua, Cory's shearwaters, grey-backed storm-petrel, broad-billed prion, kerguelen petrel, subantarctic skua, soft-plumaged petrel, great-winged petrel, Atlantic petrel, and white-chinned petrel.	Three factors determine the rate of pellets (and plastic) ingestion: foraging technique, dietary specialization, and density of pellet (pollutants) in the foraging area. Procellariiform seabirds exhibit the largest plastic loads owing to foraging patterns at the sea surface. Secondary ingestion of plastic through contaminated prey is uncommon and was found only in subantarctic skua which preys on small petrels containing plastic particles.
Gough Island, South Atlantic Ocean (Ryan *et al.*, 1988)	Great shearwaters (females only)	Positive correlation between polychlorinated biphenyl (PCB) and plastic loads in the species; PCBs likely were derived from ingested plastic particles, and these PCBs contribute significantly to the total body load of PCBs in great shearwaters.
Long Island Sound (Hays and Cormons, 1974)	Gulls and terns	PS pellets found in tern and gull pellets (regurgitated indigestible food).
Southern Indian Ocean (Ryan and Jackson, 1987)	White-chinned petrels	PE pellets lost 1% of their mass after 12 days (half-life equal to at least 1 year); no instances of intestinal obstruction or physical damage to the birds; ingested plastic seldom impairs digestive efficiency in seabirds.
Hawaii (Sileo *et al.*, 1990))	Seabirds	80 species, or approximately 25% of all seabird species, are known to ingest plastic debris.

Bodega Harbor, CA (Connors and Smith, 1982)	Red phalaropes	6 of 7 birds contained plastic particles, most of which were PE pellets. Plastic ingestion may be producing physiological effects that threaten successful migration and breeding in regions remote from the pollution sources.
Galapagos Islands and South Atlantic Ocean (Wehle and Coleman, 1983, as cited in Wallace, 1985)	Blue-footed boobies, short-eared owls, broad-billed prion, and South Polar skua.	Secondary ingestion of pellets from food source: blue-footed boobies and short-eared owls consumed fish containing pellets, and broad-billed prion consumed a skua containing pellets.
TURTLES		
Texas coast (Plotkin and Amos, 1990)	Loggerhead, green, hawksbill, and Kemp's ridley turtles.	Pellets were ingested by eight turtles, and comprised 7% of all ingested debris.
Texas coast (Amos, pers. commun., as cited in Balazs, 1985)	Green turtle	PE spherules in mouth of stranded, dead sea turtle.
South Africa (Hughes, 1970, 1974, as cited in Balazs, 1985)	Loggerhead turtles	6% of stranded posthatchlings contained pellets in stomach.
Florida (Meylan, 1984, as cited in Balazs, 1985)	Hawksbill turtles	PS pellets and other manmade materials in stomachs.
Florida East Coast and Caribbean Sea (Carr, 1987)	Loggerhead and green sea turtles	Resemblance to Sargassum floats may account for ingestions; young sea turtles vulnerable during open-ocean associations with Sargassum rafts; large numbers of pellets found on green sea turtle nesting beach.
Hawaii and worldwide (Balazs, 1985)	Sea turtles	Marine turtles eat a wide variety of synthetic material, including pellets. Effects of toxic chemicals released by these materials and physical obstruction of the digestive tracts are two possible adverse impacts.

Mediterranean Sea (Gramentz, 1988)	Loggerhead turtles	Pellets, crude oil, and tarballs apparently are ingested and excreted.
Texas coast (Plotkin and Amos, 1988)	Loggerhead, green, and hawksbill sea turtles	PE pellets ingested by 9% of necropsied turtles; high probability that sea turtles inhabiting Texas coast will come into contact with debris.
Texas coast (Shaver, 1991, pers. commun.)	Kemp's ridley sea turtles	2% (2 out of 101 turtles) contained pellets; one turtle was wild and one was reared in captivity.
FISH AND INVERTEBRATES		
Severn Estuary (Karter *et al*., 1973, as cited in Shiber, 1982 and Pruter, 1987)	Flounder and polychaetes	Ingestions by flounder. Polychaetes incorporate pellets into dwelling tubes.
New York Bight (Steimle, 1991 (pers. commun.)	Lobster and winter flounder	Low numbers of pellets ingested, and more common in lobsters than in winter flounder.
Southern New England (Carpenter *et al*., 1972)	Grubby, winter flounder, white perch, and silversides (fish), and one chaetognath (arrow worm)	PS pellets in stomachs of 8 out of 14 species of fish and one chaetognath; speculated that pellets could cause intestinal blockage in smaller fish.
OTHER BIOTA		
North American waters (Walker and Coe, 1990)	Baleen whales	Suggested that filter-feeding makes baleen whales vulnerable to incidental debris ingestion; stomachs of stranded baleen whales should be examined.
Canada and Bermuda (Gregory, 1983)	Epibionts	Epibionts on pellets include coralline algae, bryozoans, calcareous annelids, and foraminiferans.
Caribbean Sea and waters off Florida (Winston, 1982)	Epibionts	Plastics (including pellets) encrusted with bryozoan (Electra tenella); success of this species on the east coast attributed to its colonizing of drifting smooth-surfaced plastic.
ESTHETIC AND ECONOMIC EFFECTS		

New Zealand (Gregory, 1977)	Humans	Concentrations ranged from <1 pellet per meter of beach to >20,000 pellets per meter, and may lead to esthetically displeasing plastic sand beaches.
Worldwide (Wallace, 1985)	Humans	Pellets have a negative effect on recreational activities; economic impact due to loss of raw materials that must be replaced.
Bermuda (Wilber, 1987)	Humans	Beachgoers shocked by the presence of high numbers of pellets; pellets and plastic fragments embed in tarballs and become plasto-tarballs.
United States (Klemm and Wendt, 1990)	Humans	Labeled combination of plastic debris and pellets beach confetti.

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Table 9. Comparisons of Most Commonly Used Pellet Bags.

Bag Material	Opening	Sealing Method	Puncture Ranking (a)	Retention Ranking (b)	Cost per bag ($)
Polypropylene woven	Open mouth	Sewn	1	1	0.27 to 0.32
Polypropylene woven	Valve	Self-sealed	1	2	0.45 to 0.55
Paper (4-ply paper, 1-ply polyethylene liner)	Valve	Self-sealed	2	2	0.35 to 0.40
Polyethylene form-fill and seal (FF and S)	Open mouth	Heat-sealed	3	1	0.25 to 0.30

(a) Ability to resist puncturing. 1: Greatest, 3: Least.
(b) Ability to retain pellets with minimal loss when bag is not broken. 1: Greatest, 2: Least.
Source: United DC: Mr. Marc Levine (President), personal communication, 30 July 1991, Houston, TX.

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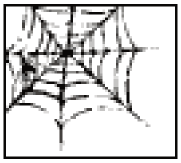

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Table 10. Summary of Recommendations to the Plastics Industry According to Industry Sector.

Recommendation	Prod	Tran / Pack	Proc
Management			
Adopt and implement SPI's *Pellet Retention Environmental Code.*	_/	_/	_/
Conduct self evaluations to identify problem areas.	_/	_/	_/
Encourage information sharing between companies.	_/	_/	_/
Continuing developing educational materials.	_/	_/	_/
Education and Training			
Educate key officials and company managers regarding the fate and effects and the economic disadvantages of pellet loss.	_/	_/	_/
Educate company employees regarding environmental hazards and employee responsibility for corrective actions.	_/	_/	_/
Train pellet handlers to operate equipment, particularly fork lifts, in a manner that minimizes the potential for pellet loss.	_/	_/	_/

Train longshoremen and other cargo handlers regarding proper pellet handling procedures.		_/	
Equipment and Facilities			
Install a containment system to capture storm water runoff.	_/	_/	_/
Improve dry cleanup procedures.	_/	_/	_/
Install connecting hoses equipped with valves that will close automatically when the connection is broken.	_/	_/	_/
Direct the water flow from rail hopper cars and bulk trucks through a screen to capture the pellets rather than spilling them onto the ground.	_/		
Seal expansion joints in concrete floors with a flexible material.	_/	_/	_/
Install alarms in the pellet conveying system.	_/	_/	_/
Pave all pellet handling areas, including loading docks and rail sidings.	_/	_/	_/
Place screening in storm drains.	_/	_/	_/
Place control devices where they can be serviced without losing pellets.	_/	_/	_/
Equip bag-handling stations with vacuum hoses to facilitate spill cleanup.	_/	_/	_/
Use tarps or containment devices to collect pellets as they are spilled.	_/	_/	_/
Install grating at doorways for wiping feet.	_/	_/	_/
Modify loading systems so that transfer lines can be completely emptied, with any residual resin being contained when loading ceases.	_/	_/	
Routine Operations			
Place portable screens underneath connection points when making and breaking all connections.	_/	_/	_/
Place permanent screens along the exterior edge of the loading docks.		_/	
Completely empty transport and storage vessels before disconnecting from the conveying system.		_/	_/
Supervise longshoremen and other cargo handlers during cargo loading and unloading to ensure proper pellet containment.		_/	

Inspect cargo immediately upon receipt and note the condition of shipping containers and parcels on the carrier's receipt.		_/	_/
Inspect seals on rail hopper cars before unloading.		_/	_/
Check outlet tubes for pellets before moving rail hopper cars or trucks.		_/	_/
Secure outlet caps and seals before moving full or empty rail hopper cars and trucks.	_/	_/	_/
Insist on handling procedures that minimize punctures and pellet spillage.	_/	_/	_/
Do not sweep pellets off loading docks and into the water.		_/	
Repair punctured bags immediately	_/	_/	_/
Maintenance and Housekeeping			
Improve daily and routine housekeeping and spill response procedures.	_/	_/	_/
Develop SOPs for containing and cleaning up spills.	_/	_/	_/
Conduct routine inspections for the presence of loose pellets on the facility grounds, including parking lots, drainage areas, driveways, etc.	_/	_/	_/
Packaging			
Design puncture-resistant shipping containers.	_/	_/	
Use reinforced bags and line containers with puncture-resistant material.	_/	_/	
Minimize the use of valved bags, or seal valved bags immediately after filling.	_/	_/	
Use sea containers instead of break bulk packaging.	_/	_/	
Improve palleting methods.	_/	_/	
Tape leaks or replace leaking bags immediately.	_/	_/	_/
Inspect pellet packaging before offloading.		_/	_/
Shipping Vehicles			
Use containers for cargo shipping rather than individual pallets.	_/	_/	
Identify the person responsible for sealing the ports on rail hopper cars and bulk trucks, and document sealing.	_/	_/	

Close and secure the rail hopper car valve with strong wire or aircraft cable in addition to the normal sealing mechanism.	_/	_/	_/
Visually confirm that each compartment and tube of shipping vehicles is empty.		_/	_/
Inspect interiors of trailers and sea containers for defects that may puncture pellet packaging.	_/	_/	
Consider vandalism exposure when selecting leased track sites.	_/	_/	
Avoid on-deck pellet stowage.		_/	
Do not jettison pellets or containers of pellets.		_/	
Seal empty rail hopper cars and bulk trucks before returning them to shipper.		_/	_/
Recycling and Waste Disposal			
Store waste pellets in properly labeled containers.	_/	_/	_/
Inspect and confirm proper handling and storage procedures if an outside vendor is used for waste removal.	_/	_/	_/
Recycle or resell waste pellets.	_/	_/	_/
Check broken and discarded packaging for residual pellets.	_/	_/	_/

Prod: Producers.
Tran: Transporters.
Pack: Contract packagers.
Proc: Processors.
_/ : checked

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