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ESTIMATES OF THE VOLUME OF MSW AND SELECTED COMPONENTS IN TRASH CANS AND LANDFILLS

Final Report

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

INTRODUCTION

The current intense debate over federal, state, and local waste management policies is taking place in an environment rich in speculation and opinion, but poor in factual evidence about the true contribution of various materials and products to the total quantity of municipal solid waste that must be managed.

The fact is that until now, there has been no comprehensive database available to policy-makers and the public that characterizes the volume of the various components of municipal solid waste (MSW). As a result, many estimates have been made and published--without any real scientific basis--that have had a profound impact on waste management policies. In the case of plastics, volume estimates reported in the news media have ranged from 30 percent to 70 percent of MSW.

This report presents the results of independent research which offers the first comprehensive, systematic characterization of the relative volumes of the components of MSW. The research was sponsored by the Council for Solid Waste Solutions. The report describes the development of an experimentally derived set of conversion factors which have enabled researchers to use an existing database that characterizes the weights of MSW components to determine the volume of those components in landfills. This research is important because, simply put, landfills do not close because they are overweight, they close because they have reached their volume capacity.

RESEARCH APPROACH

Franklin Associates, Ltd., prepares for the U.S. Environmental Protection Agency (EPA) a widely used database characterizing the weight of various materials and product categories in municipal solid waste. The challenge presented was to find conversion factors for each product category in MSW that would allow existing weight data to be converted into volume equivalents--expressed in cubic yards under landfill conditions.

A comprehensive search for existing data identified only one source of reliable and scientifically measured weight-to-volume factors--data from actual landfill excavations conducted by The Garbage Project, of the University of Arizona at Tucson.

An analysis of The Garbage Project's database produced a set of conversion factors for most materials. However, in order to ensure a consistent, scientific, and more reliable database for the volume of materials in MSW, an experimental program was also initiated as a joint project between Franklin Associates, Ltd. and The Garbage Project.

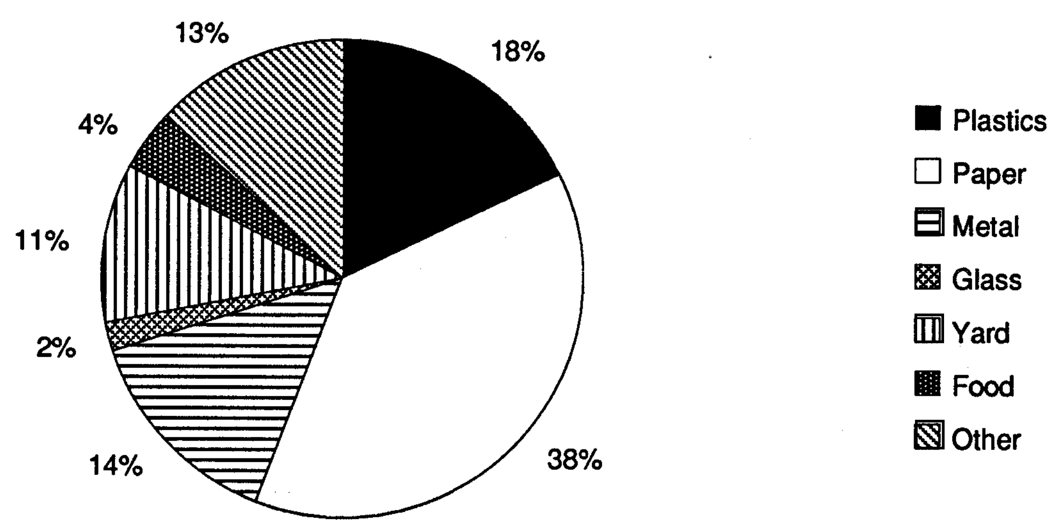
The project involved obtaining samples from landfill excavations. The wastes were sorted by material category and subjected to pressure in a specially designed machine. Representative categories of both plastics and paper products typically disposed in landfills were developed. Weight-to-volume (density) measures were obtained over a designated wide range of conditions. The experiments were carried out by graduate students at the University of Arizona under the direction of Dr. William L. Rathje and Wilson W. Hughes.

SUMMARY OF FINDINGS

The research reported here determined that the total volume of plastic products in municipal solid waste was 18 percent in 1986 under landfill conditions. This corresponds to the widely published estimate that plastic products were 7.3 percent by weight of MSW in 1986 as reported in the Franklin Associates, Ltd. waste characterization report for the EPA. The volume (%)-to-weight (%) ratio for plastic products was determined to be (2.5:1).

Paper and paperboard are the dominant materials in MSW, occupying 38 percent by volume. Metals account for 14 percent, glass for 2 percent, and other materials represent 28 percent of the volume of municipal solid waste.

VOLUME OF MATERIALS IN MSW

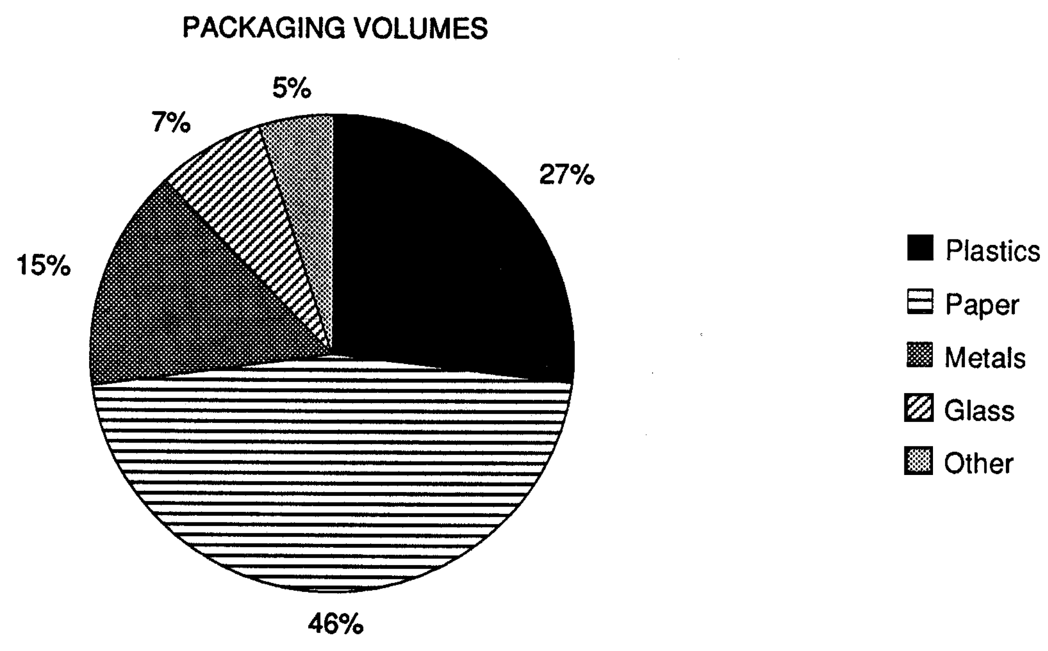


In the process of determining weight-to-volume factors for the various materials in the municipal waste stream, Franklin Associates, Ltd. assumed that the density factors for durable products would be similar to the density factors for nondurable products. This assumption was made because the researchers were unable to develop statistically reliable conversion factors for durable products such as appliances, furniture, and tires.

The disposal of durable products is frequently different from the disposal of other discarded products, such as packaging. Plastic products in MSW, excluding durables, were found to be 16 percent by volume and 6.2 percent by weight for 1986, based on the database developed by Franklin Associates for EPA.

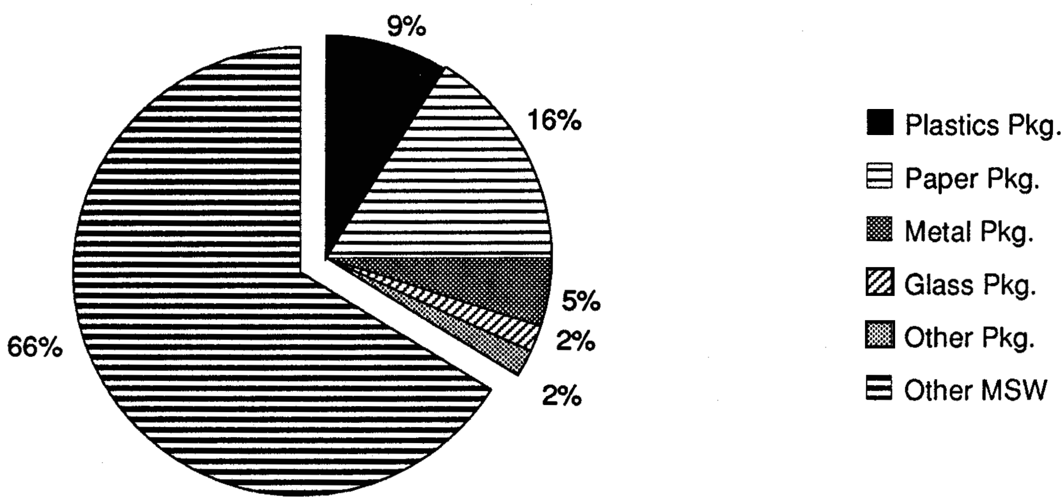
PACKAGING VOLUME

Plastics packaging accounted for 27 percent of the total volume of the packaging component in municipal solid waste in 1986. Paper and paperboard amounted to 46 percent of packaging, metals were 15 percent, and glass was 7 percent of packaging.



The packaging component represented approximately 34 percent of the total volume of municipal solid waste generated in the U.S. in 1986: Plastics packaging accounted for 9 percent of total MSW volume, paper and paperboard packaging amounted to 16 percent, metal containers equaled 5 percent of MSW, and glass packaging accounted for 2 percent of the volume of municipal solid waste.

PACKAGING VOLUME IN MSW



VOLUME(%)-TO-WEIGHT(%) RATIOS

The volume(%)-to-weight(%) ratio for plastics, which is (2.5:1), is higher than other material categories because plastics are so light in weight. There has been general agreement in the past that plastics occupy a greater percentage of volume than weight in the waste stream. However, as previously indicated, estimates of the volume of plastics in MSW have ranged from 30 percent to 70 percent, compared to the 18 percent result produced by this research, which used actual landfill samples.

WEIGHT/VOLUME FACTORS: TOTAL MSW

Material	Weight (%)	Landfill Volume (%)	Ratio Vol.(%)/Wt.(%)
Plastics	7.3	18	2.5:1
Paper/paperboard	35.6	38	1.1:1
Metal	8.7	14	1.6:1
Glass	8.4	2	0.2:1
Yard wastes	20.1	11	0.6:1
Food	8.9	4	0.4:1
Apparel	1.3	3	1.9:1
Other	9.7	10	1.0:1

VALIDITY OF RESULTS

Some assessment of error must be made for this new volume database. As is described in detail in the full report which follows, the experimental values derived from this research are reproducible within +/- 20 percent. Franklin Associates, Ltd. believes these are outside limits and that the actual results may be more accurate. However, the researchers prefer to apply a conservative confidence range to the results of this research because, to our knowledge, it is the first of its kind completed in the U.S.

Using the +/- 20 percent confidence range, the maximum volume (%)-to-weight(%) ratio of (2.5:1) is almost certainly between the limits of (2.0:1) and (3.0:1), with (2.5:1) the most probable volume(%)-to-weight(%) ratio for plastics in MSW. Therefore, our estimate that plastics are 18 percent by volume of MSW is almost certainly between the limits of 14 percent and 22 percent for 1986.

Another measure of validity is a comparison of the new experimentally derived volume factors developed with this research, to the historical data from actual landfill samples taken by The Garbage Project. When comparing five broad categories in the two databases, all are within three percentage points. Given the range of accuracy in the two databases, this comparison is comforting.

In addition, the comparisons of actual landfill weight percentages by broad material categories are similar for The Garbage Project samples from four different landfills, compared to Franklin Associates' calculated weight percentages which were derived independently for EPA.

ESTIMATES OF THE VOLUME OF MSW AND SELECTED COMPONENTS IN TRASH CANS AND LANDFILLS

INTRODUCTION

The current intense nationwide interest in municipal solid waste management, which began to accelerate in 1986, has stimulated the demand for factual information of all kinds regarding MSW. One of the primary needs is reliable information on the contributions of various materials and products to the total quantities of MSW that must be managed.

Municipal solid waste can be measured by weight and by volume. In practice, some landfill operators charge fees based on actual weight (tons), while many others charge on a volume basis (cubic yards). However the incoming wastes are measured, landfill lifetime is based on the volumes of waste that are received, compacted, and covered for long-term disposal. The volume measurement is thus very important to solid waste management planners, whether they are dealing with landfilling or with the alternatives: source reduction, recycling, composting, or burning in waste-to-energy incinerators.

Measuring the weight or volume of mixed municipal solid waste provides no insight into the contribution of the individual components--products made of paper, plastics, metals, glass, etc.--in the MSW. There are two ways to estimate the weight percentages of MSW components. The first is to sample, sort, and weigh the various components at the landfill or elsewhere. The second is to perform a materials flow analysis, which is based on national production data for the MSW components, adjusted for import/exports and other factors. MSW sampling studies have been done at numerous locations. In addition, there is a widely-used national database utilizing the materials flow methodology to characterize the components in MSW by weight for the years 1960 to 2000; this database has been developed, updated, and refined by Franklin Associates, Ltd. for the U.S. EPA (and others) over a period of many years.

There has been no systematic database characterizing the volume of the various components of MSW. As a result, many estimates have been made and published, and decisions regarding solid waste management have been made, without any real scientific basis. This report presents the results of a study, sponsored by the Council for Solid Waste Solutions, which presents the first comprehensive, systematic characterization of the relative volumes of the components of MSW. The report describes the development of an experimentally derived set of conversion factors which enable data from the MSW-by-weight database to be converted to a volume database. Results of the analysis are also presented.

HISTORICAL DATA ON WASTE VOLUMES

The main purpose of this report is to examine the volume (as opposed to weight) of the components of solid waste. Of particular interest are data on plastics. The first step of the analysis was to search the historical literature for volume data and other information. Then, telephone and personal interviews were conducted across the country to find all available information on this subject. This section is a summary of those findings.

MSW Density

The majority of the studies identified were completed in the early 1970s when municipal solid waste research was being funded at a significant level. Few of these studies were relevant to this work for two reasons. First, in the early 1970s plastics were not of much interest because they were a very small percentage of MSW. Most work from that era deals with mixed waste. The second reason is that the volume of plastics or other individual components in MSW was not yet an issue.

Private sources all across the U.S. were contacted about recent experimental and theoretical work on the weight and volume relationship of individual components. From these sources, six major studies and several key personal contacts were identified. From the studies and personal contacts, data were gathered on the densities (weight per unit volume) of average MSW, aggregate plastics, and various plastic components as discarded, in compactor trucks, in landfills, and baled. The compiled data are shown in Tables 1 and 2. These tables contain virtually all of the data available.

Table 1 summarizes our findings for total MSW. The values shown here are widely accepted in the waste industry as being typical, realizing that in any given situation a single measurement of density could be substantially different from the values shown. MSW as discarded in trash cans is considered to have a density of about 100 pounds per cubic yard, although any given trash can may have a density ranging from 50 pounds per cubic yard to several hundred pounds per cubic yard, depending on the particular materials present, moisture content, and whether the trash components were already crushed or broken to some degree. Nevertheless, we will consider 100 pounds per cubic yard as a typical and common value for MSW in trash cans.

Table 1

DENSITY DATA FOR TOTAL MSW
(Pounds per cubic yard)

MSW As Discarded	MSW In Compactor Trucks	MSW In Landfills	Baled MSW 3/
100 (1) 1/	600 (1)	800 (5)	1,458 (8)
105 (5)	810 (4)	1,000-1,400 (7)	890-1,560 (9)
	563 (5)		1,134 (9)
	667-800 (6)		1,080 (9)
	600-1,000 (7) 2/		1,430 (9)

1/ Numbers in parenthesis refer to reference numbers (at the end of this report).
2/ This range is based on 600 pounds per cubic yard for residential compactor trucks and 800-1,000 pounds per cubic yard from commercial trucks.
3/ Data from high-density balers.

Source: Franklin Associates, Ltd.

In compactor trucks and landfills, the trash is compacted to achieve volume reduction for efficient transportation and disposal. In the compactor truck, pressures average perhaps 50 pounds per square inch in the trash as a result of the compaction by the hydraulic ram. As shown in Table 1, this results in MSW densities that range from about 600 to 1,000 pounds per cubic yard. This also is highly variable, depending on individual situations.

At the landfill site, the compactor truck dumps its load, which is spread out and run over by a compaction vehicle. This action by the compaction vehicle is important. Under the wheel of the vehicle, pressures as great as several thousand pounds per square inch may be exerted. This action breaks glass containers, ruptures plastic bottles, and further compresses many other items. As the material is covered in the landfill, the weight of the waste and soil will exert a steady, sustained pressure; this pressure will typically be about one pound per square inch for each yard depth of waste and cover. A typical pressure is about 10 to 20 pounds per square inch, but pressure is much lower near the top of the landfill and greater at depths of more than 60 feet. Therefore, the action of the compaction vehicle is important in final volume densities. As shown in Table 1, typical landfill densities in a modern properly-operated landfill are in the range of about 800 to 1,400 pounds per cubic yard. However, these density values include some construction debris and industrial wastes deposited with MSW. We estimate the density of MSW alone to be in the range of 800 to 1,000 pounds per cubic yard.

Baled MSW is generally considered to have the same or perhaps slightly greater density than continuously compacted MSW. Bale densities were obtained as an additional check on our data. As shown in Table 1, bale densities range from 890 to 1,560 pounds per cubic yard, which is further confirmation of the reasonableness of our selected range of 800 to 1,000 pounds per cubic yard for MSW.

Discarded Plastic Densities

Table 2 summarizes the results of plastics density values found in the literature and from personal interviews. None of the literature sources (1 to 6) were completely satisfactory in terms of reporting reproducible experimental results verified by other researchers. In some sources the details of the methodologies used were incomplete or missing entirely, and in others it was difficult to determine if the numbers generated were even based on actual experiments. In some cases, the values result from estimates only. Telephone calls to the authors were made to clarify issues. The identified sources, the quality, and the relevance of the data to the goals of this particular study are questionable in most cases.

As shown in Table 2, a wide variety of data were found, but very little comparison is possible between different researchers. One exception is the data for baled plastics. We found more data for bales than for other categories, and these values are helpful. Balers reach compression pressures generally in the range of 50 to 200 pounds per square inch, and baled densities are generally considered to approximate or exceed landfill densities for film, and also for rigid plastics, if air trapping is minimized. This can be achieved by puncturing bottles or removing closures prior to baling.

In summary, an exhaustive search for quantitative descriptions of discarded plastics volumes resulted in a meager database. It was judged to be unsuitable as a basis for policy decisions.

EXPERIMENTAL PROGRAM

Program Goals

In order to develop a consistent, scientific, and more reliable database for the volume of materials in solid waste, an experimental program was developed as a joint project between FAL and the University of Arizona. The experiments were carried out by the staff of The Garbage Project of the Department of

Table 2

HISTORICAL DENSITY DATA FOR DISCARDED PLASTICS
(Pounds per cubic yard)

Product Category	As Discarded		In Compactor Truck		In Landfill		Baled	
Mixed Plastics	35	(1)	150	(1)			756	(10)*
	80	(3)	160	(3)				
			189	(4)				
Mixed Containers	33.5	(1)	140	(1)	218	(5)	342-373	(12)
	38.1	(5)	171	(5)				
PET bottles	34	(4)	42-49	(4)			256	(6)
	40	(4)					571-623	(13)
	28	(13)					541	(14)
							315-631	(10)
							460	(4)
HDPE bottles	22-24	(4)					550	(11)
	24	(4)					427	(12)
	22	(11)					595	(14)
Plastic packaging	49.3	(5)	493	(5)	986	(5)		
					189	(6)		
Miscellaneous Items								
Film	23.8	(1)	250	(1)*			756	(10)**
Fast food packaging					261	(2)		
Diapers					308	(2)		
LDPE film							451	(14)
PVC film***							1351	(14)
EPS foam							180	(10)

* Mostly film.
** Baled aggregate, mostly film.
*** Industrial PVC scrap, not MSW.

PET: Polyethylene terephthalate
HDPE: High-density polyethylene
LDPE: Low-density polyethylene
PVC: Polyvinyl chloride
EPS: Expanded polystyrene

Source: Franklin Associates, Ltd.

Anthropology, Bureau of Applied Research in Anthropology, University of Arizona, Tucson, under the direction of William L. Rathje and Wilson W. Hughes. Their report is included as Appendix B.

The goal of the program was to sort wastes obtained from household trash bags picked up from the curb into nine categories, and to compress and crush the samples taken from each category in order to develop a reproducible compaction database which could be used to develop trash can and landfill densities. Weight to volume relationships were obtained by finding the sample density (pounds per cubic yard) under a wide range of conditions. Similar experiments were conducted on materials obtained from landfill excavations in order to establish the validity of the experimental procedures.

Methodology

Waste Categories. The waste was categorized into six materials: glass, steel, aluminum, paper and paperboard, plastics, and other packaging. Sufficient solid waste density data exist for glass, steel, and aluminum, so they were not included in the experimental program. The "other packaging" category is quite diverse and accounts for only about 2 percent by weight of MSW. Because the amount is so small, it was omitted from further consideration.

The two remaining categories are paper and paperboard and plastics. Not only are these large and important categories, but their response to compression is difficult to quantify. For example, a glass bottle breaks (or doesn't break) and a metal can crushes permanently under compression, both in a way that is relatively easy to measure and to characterize. On the other hand, paper and plastic materials behave in a more complex manner. Plastic is especially difficult to characterize because of its resilience, or its tendency to resume its shape after pressure is removed. While paper is somewhat easier to characterize, its place as the dominant material in solid waste makes it important to characterize accurately.

The living area wastes were separated into nine categories prior to conducting the compression tests. These categories were developed using two criteria. First, waste products were grouped based on material and broad crushability characteristics, and second, the categories need to be composed of products so that they are consistent with existing waste composition databases in order to maximize the usefulness. Table 3 is a listing of the nine categories, with examples of products included.

Table 3

WASTE CATEGORIES FOR COMPRESSION EXPERIMENTS

A NONPACKAGING PAPER
- paper plates, tissues, towels, mail, stationery, magazines, newsprint, forms, greeting cards

B CORRUGATED PAPERBOARD PACKAGING

C PAPERBOARD BOXES
- food boxes (cereals, etc.), detergent boxes, milk cartons, beer six-pack holders (if closed on all sides)

D OTHER PACKAGING--PAPER AND PAPERBOARD
- paper bags and wrapping papers, paper towel rolls, molded pulp egg cartons, bottle/can holders (if open on one or more sides), butcher paper, cups, hinged fast-food boxes, cigarette wrappers

E PLASTIC FILM PACKAGING
- bags and wrappers (trash, food, etc.), baggies, food wrap films, wet-wipes packs, condiment packets, bubble packing

F PLASTIC RIGID PACKAGING CONTAINERS
- bottles, jars, tubs and lids, microwave trays, hard cosmetic cases, bottle basecups

G OTHER PLASTIC PACKAGING
- cookie trays, six-pack rings and holders, flexible tubes, all polystyrene foam

H NONPACKAGING PLASTIC
- plastic cups and utensils, pens, razors, toys, plastic food serving trays, hangers, Easter grass, sponges

I COMPOSITE/MIXTURES (papers and plastics)
- blister packs, juice concentrate containers, spiral-wound dough containers, diapers

At times it was not easy to classify materials, but experienced sorters seldom encounter difficulties. In this study, the sorting crews were primarily graduate students, many of them doctoral candidates, and all were trained and experienced in material identification. They were careful and meticulous, leading to very low classification error.

Compression Machine. A hydraulic compression machine designed to compress trash was used by the University of Arizona to carry out these studies.

The lower part of the machine is a straight-walled metal container approximately the same size as a trash can. When the container is filled, a loosely-fitting flat metal and wood lid with the same cross-sectional shape as the container is placed on top of the trash. A vertical hydraulic cylinder is then swung into place so that when the cylinder moves down it forces the metal lid downward, compressing the trash. As the cylinder moves downward, a stylus points at a metal measuring tape indicating the position of the lid in inches and fractions of an inch. These measurements are calibrated and converted into a volume measurement of the entrapped trash. At the same time, an air pressure gauge in the hydraulic system reads the air pressure in the system. These pressure readings are calibrated and can be converted into either the force of the plate on the trash, or the average pressure exerted over the face of the plate.

The container has movable walls, which can result in a container with less volume and a smaller cross-sectional area. In this configuration, high pressures can be applied to the trash, but readings are less accurate.

Sources of Fresh Waste. Because of the limited availability of landfill samples and the need to obtain trash can densities, fresh trash was compacted. Household trash was picked up from curbside by the Tucson, Arizona, Sanitation Division, Department of Operations. The trash bags were loaded into an open truck so as not to compact them, and were delivered to the Garbage Project's sorting area located on the University of Arizona campus.

No special instructions were given to the Department of Public Works with regard to selection of trash bags. The goal was to receive mixed waste in typical condition from households. A variety of trash was needed to obtain reasonably representative product samples. Visual inspection of the trash confirmed that there were no unusual product characteristics.

The trash in the samples represented the wide variety of products that would be found in any city in the U.S. While selecting samples from only one waste stream on a small number of days might lead to distortion <u>if composition were being studied</u>, it is valid for sorting to obtain a sufficient number of samples for each product or material category. Here the requirement is simply that the product trash be diverse and reasonably typical of U.S. households, which it was.

Overview of Sorting and Compression Procedures. Household trash was delivered to the sorting area and placed in a covered holding bin. Trash bags were taken from the bin one at a time and placed on a sorting table. A single bag was opened, and a first sort was made into four barrels surrounding the sorting table. The first sort was into four categories: (1) paper and paperboard; (2) plastic; (3) mixtures/composites; and (4) discards. The discards contained trash not normally found in the living area (such as yard wastes) and food wastes.

The paper and paperboard barrel and the plastics barrel were then taken to other sorting tables for the second sort. Both paper and paperboard and plastics were each sorted into the four categories as shown in Table 3. This then resulted in a total of eight plastic and paper and paperboard categories, plus the mixture/composite category from the first sort.

Each of the plastic sort barrels was lined with a plastic bag. When a barrel became full, the bag was tied. A code number was written directly on the bag, and it was weighed. The weight of the bag itself was previously determined and the scale was set to read the net weight of the trash in the bag. The weight of each bag was recorded, and the bag was moved to the compression machine area.

Each bag was then loaded into the machine and readied for compression. A three-person team is required for operation. One person operates the compressed air valve, which controls the hydraulic cylinder, and at the same time reads a pressure gauge, calling out 5 psi increments. At each calling, a second person reads the cylinder position stylus, and the third person records the data.

The pressure is then released, the cylinder is swung aside, and the trash is removed and visually examined before being taken to a discard container.

Landfill Samples. A crucial part of this study was the determination of density of landfill samples. In June 1989, a backhoe was taken to the Tucson Los Reales landfill, and excavations were made. (See Appendix B for details.) Several time horizons were sampled (identified by dates on newspapers). They were primarily 1983 to 1985. From each time horizon, as many as eleven samples of each of the nine categories (Table 3) were obtained, although fewer were obtained for some categories. The sorting, weighing, and marking was similar to that described for fresh samples, although product identification was more difficult because of deterioration and staining.

The landfill samples were then hauled back to the compression machine and tested in an identical fashion to the fresh samples. Compression is necessary to remove air and replicate in situ landfill conditions.

A concern that might be raised is that samples from only a single landfill were collected. This would be a significant issue if we were determining <u>composition</u>. However, whether the people served by this landfill are typical U.S. consumers is a moot point. We were sorting by material for our samples, so that all we need is representative products. Cereal boxes are the same anywhere in the U.S., as are plastic detergent bottles, corrugated boxes, and so on. The products pulled from the Los Reales landfill were clearly typical in that regard.

A more important issue is whether the material is in typical landfill condition. To examine that issue we studied the samples taken from landfills in different geographical locations by The Garbage Project team. The three geographical locations reported were northern California, northern Illinois (Chicago area), and Tucson. Detailed studies including weights, volumes, moisture, and physical appearance were made. On the average, little difference between landfills was noted. If wastes are well compacted and daily cover is used to deter moisture entering from outside the landfill, conditions inside landfills are similar.

The conclusion reached is that there is more variability within a single landfill, than between averages of different landfills. While we feel that our landfill samples are reasonably representative, we acknowledge that sampling is a possible source of error. Efforts are underway to obtain samples from other landfills to perform additional sorting and compression tests to further examine the validity of the initial sampling program.

DATA AND CALCULATIONS

Using the waste material density values supplied by The Garbage Project (Appendix B), as well as other data sources, density factors were determined for 23 material and product categories in trash cans and in landfills. These factors are summarized in Appendix A, Table A-1. That table is repeated here as Table 4, and a brief discussion of those factors is included below. The density factors, reported in pounds per cubic yard, were then multiplied by the national quantity of waste (in pounds) to obtain the national volume of waste in cubic yards. Appendix A, Table A-2 outlines our derivation of packaging and living area discards (in tons or pounds) from our earlier EPA MSW database (15), which are the widely-accepted data for trash <u>discards</u>. Thus, Tables A-1 and A-2 resulted in summary Tables 5 and 6. (Interim tables are included in Appendix A as Tables A-3 through A-6.)

Tables 5 and 6 report waste volumes for two subcategories of total MSW. Those are the two highly visible waste fractions which we have called packaging and living area trash. The term packaging is self-explanatory. Living area wastes are those

TABLE 4

SUMMARY OF DENSITY FACTORS

	Trash Can Density (lb/cuyd)	References	Landfill Density (lb/cuyd)	References
PACKAGING				
Glass Containers				
Beer & soft drink	600	4,18	2,800	18,23
Other containers	700	4,18	2,800	18,23
Steel Containers				
Beer & soft drink	150	4,18	557	23
Food cans	200	4,18	557	23
Other packaging	250	21	557	23
Aluminum				
Beer & soft drink	60	4,18	250	4,18
Other packaging	45	21	550	21
Paper and Paperboard				
Corrugated	43	22	750	22
Other paperboard	42	22	819	22
Paper packaging	48	22	740	22
Plastics				
Film	84	22	667	22
Rigid containers	53	22	355	22
Other packaging	28	22	165	22
Wood Packaging	600	21	800	21
Other Misc. Packaging	203	21,22	1,014	22
NONPACKAGING				
Nondurable Paper				
Newspapers	170	22	798	22
Books, magazines	170	22	798	22
Nondurable Plastic	69	22	313	22
Rubber	170	21,23	343	23
Textiles	48	21,23	435	21,23
Food	500	21	2,000	23
Yard	500	19,20	1,500	19,20

Note: Also included in Appendix as Table A-1.

TABLE 5

TRASH CAN AND LANDFILL VOLUME OF PACKAGING DISCARDED TO MSW ORIGINATING FROM HOMES AND BUSINESSES - 1986

	Discards (mil tons)	Weight % of Discards	Average Trash Can Density (lb/cuyd)	Packaging Volume in Trash Cans (mil cuyd)	Volume % of Packaging Subtotal in Trash Cans	Average Landfill Density (lb/cuyd)	Packaging Volume in Landfills (mil cuyd)	Volume % of Packaging Subtotal in Landfills
Glass Containers	10.7	25.0	654	32.7	2.6	2,816	7.6	6.6
Steel Containers	2.7	6.3	212	25.5	2.0	557	9.7	8.4
Aluminum	1.1	2.6	54	41.1	3.3	310	7.1	6.2
Paper and Paperboard	20.4	47.7	44	935.6	74.6	764	53.4	46.4
Plastics	5.6	13.1	53	210.4	16.8	356	31.5	27.4
Wood	2.1	4.9	600	7.0	0.6	792	5.3	4.6
Other Misc. Packaging	0.2	0.5	200	2.0	0.2	1,000	0.4	0.3
Total	43	100	68	1254	100	744	115	100

Note: For more detail see Appendix Tables A-5 and A-6.

TABLE 6

TRASH CAN AND LANDFILL VOLUME OF COMPONENTS OF MSW ORIGINATING FROM LIVING AREAS OF HOUSES - 1986

	Discards (mil tons)	Weight % of Discards	Average Trash Can Density * (lb/cuyd)	Living Area Discards Volume in Trash Cans (mil cuyd)	Volume % of Living Area Discards Subtotal in Trash Cans	Average Landfill Density (lb/cuyd)	Living Area Discards Volume in Landfills (mil cuyd)	Volume % of Living Area Discards Subtotal in Landfills
PACKAGING								
Glass Containers	8.9	17.4	657	27.1	3.0	2,781	6.4	4.7
Steel Containers	1.6	3.1	204	15.7	1.8	561	5.7	4.2
Aluminum	1.0	2.0	53	37.8	4.2	317	6.3	4.6
Paper and Paperboard	6.8	13.3	44	307.1	34.5	777	17.5	12.9
Plastics	4.3	8.4	53	161.6	18.2	355	24.2	17.8
Other Misc. Packaging	0.1	0.2	200	1.0	0.1	1,000	0.2	0.1
Packaging Subtotal	22.7	44.4	83	550.3	61.8	753	60.3	44.4
NONPACKAGING								
Nondurable Paper	17.9	35.0	170	210.6	23.7	797	44.9	33.1
Nondurable Plastic	1.6	3.1	69	46.4	5.2	314	10.2	7.5
Other	8.9	17.4	215	82.7	9.3	877	20.3	15.0
Nonpackaging Subtotal	28.4	55.6	167	339.7	38.2	753	75.4	55.6
GRAND TOTAL	51	100	115	890	100	753	136	100

* Densities differ slightly from those in Table 5 because the product mix differs slightly.

Note: For more detail see Appendix Tables A-3 and A-4.

discarded materials which people see inside their homes. It includes common household trash discarded in kitchens, bedrooms, etc., but excludes major appliances, tires, yard wastes, and other items which are not usually put into trash cans inside living areas. The reason for focusing on these subcategories is that these are the highly visible wastes which people observe on a daily basis, and on which people base many of their opinions and intuitions about wastes.

Figures 1 and 2 further illustrate these two components of MSW. Figure 1 shows that packaging is 31 percent by weight of the total MSW discarded. Figure 1 also shows the percent composition for various types of packaging by weight as reported in Table 5. Figure 2 shows the living area wastes. These wastes are 36 percent of total MSW by weight. Living area wastes also include about one-half of the packaging materials shown in Figure 1. About one-half of packaging is discarded at home, and about one-half at restaurants, other businesses, recreational areas, etc. Table 6 shows that packaging is about 44 percent of the living area wastes.

Details on the composition of these two waste subcategories can be found in Appendix C.

Glass Containers

Trash can density factors are based on the fact that most glass containers are thrown into the trash unbroken. Data from curbside collection programs where glass is collected separately, supplemented with FAL measurements, were used to estimate the trash can densities. Beer and soft drink containers were determined to have a density of 600 pounds per cubic yard, while food jars, which are thicker-walled and heavier, have a density of 700 pounds per cubic yard. As shown in Table 5, the composite density for glass containers in the trash can was 654 pounds per cubic yard.

The case for landfill density is much more complex. Examination of landfills reveals that glass occurs in three stages of integrity: whole bottles, broken pieces that retain some shape and trap air, and pieces so small (less than 1/2-inch) that they trap no air. For small pieces, a value of 4,400 pounds per cubic yard, which is the theoretical density of glass with no air trapping, was used. For intermediate pieces and whole bottles, The Garbage Project has determined that an average density is 1,200 pounds per cubic yard. They have also determined that 50 percent of glass in landfills is small pieces, while the remaining 50 percent is whole bottles and large pieces. This results in a composite landfill density of approximately 2,800 pounds per cubic yard.

Figure 1. Composition of MSW and Packaging Components discarded in 1986
(In percent of total weight)

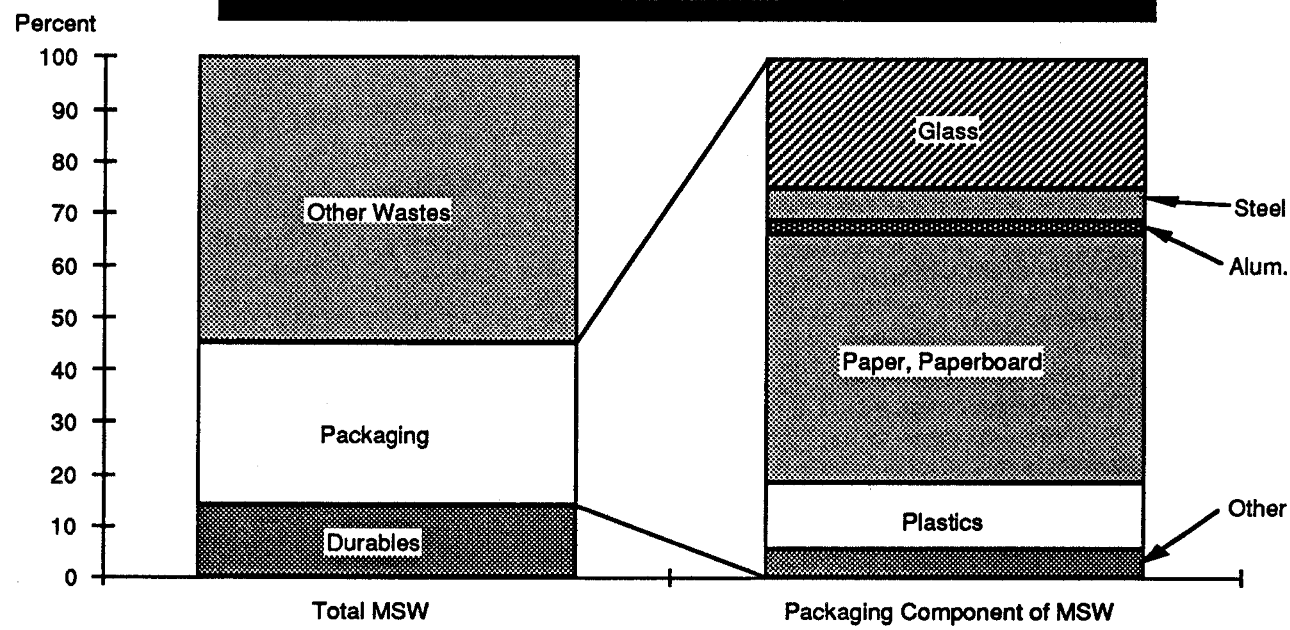
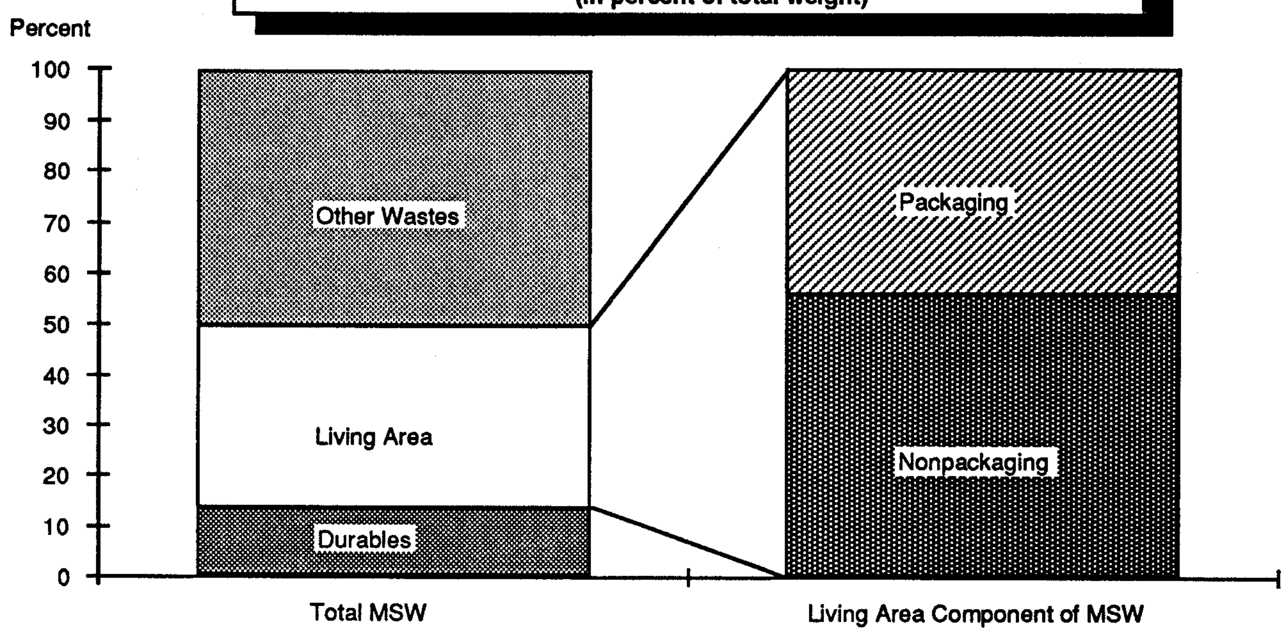


Figure 2. Composition of MSW and Living Area Components discarded in 1986
(In percent of total weight)



Tables 5 and 6 show that while glass is a significant fraction of solid waste when measured by weight (17 percent of living area trash, 25 percent of packaging), the volume fraction is much smaller. It ranges from 7 percent of packaging landfill trash to about 3 percent of packaging trash at the trash can.

Metals

Steel and aluminum containers dominate the metals fraction of the highly-visible solid waste.

Steel beer and soft drink cans currently account for only about 0.2 percent by weight of packaging in MSW, but food cans are 4.0 percent, while other steel containers and pails account for 2.1 percent of packaging (15).

Steel containers are found in trash cans in a wide range of compacted states. They range from nearly undamaged to substantially flattened cans. The density of food cans (the most common steel container found in household trash) is 200 pounds per cubic yard, while beer and soft drink cans are 150 pounds per cubic yard. This results in a composite average of 212 pounds per cubic yard for steel cans as found in trash cans (Table 5).

Visual inspections of landfills reveal that steel cans are rigid and resist complete flattening, but do become quite flat when run over several times by the compaction vehicle. Many steel cans are dented, bent, and nearly flattened. The Garbage Project measures the landfill density for steel to be 557 pounds per cubic yard. For comparison, we find 540 pounds per cubic yard of mechanically flattened cans in recycling centers. We expect the density of steel cans in landfills to be less, but other pieces of steel and steel pails would tend to increase the average density.

Aluminum beer and soft drink cans account for 1.6 percent of packaging in MSW by weight, while other products such as sheets of foil, foil trays, and other aluminum products account for 0.9 percent (15). Aluminum cans are easily bent, and are rarely found whole in a landfill. Moderate pressure will compact aluminum cans from their whole trash can density of 60 pounds per cubic yard to 250 pounds per cubic yard in landfills. This corresponds to a can being reduced from its near 5-inch height to a nearly 2-inch height. By comparison, mechanically-processed recycled aluminum cans achieve a density of 560 pounds per cubic yard.

Aluminum foil products, if discarded flat, could achieve a density of 4,500 pounds per cubic yard, the density of aluminum. However, they frequently are wadded, trapping air.

No reliable data were found on density of foil products, but their occurrence is at such a low level that their contribution to volume is very small. We conducted experiments on a limited number of samples and found an average trash can density of foil products of 45 pounds per cubic yard and a landfill density of 550 pounds per cubic yard. The composite density for all aluminum products is 54 pounds per cubic yard in trash cans and 310 pounds per cubic yard in the landfill.

Metals in 1986 comprised only about 4 percent by weight of solid waste (15). Tables 5 and 6 show that they comprise 15 percent of the landfill packaging waste by volume, and as low as 6 percent by volume for trash can volume of packaging living area waste.

Paper and Paperboard

Paper and paperboard products comprise 40 percent of solid waste by weight (15), and are by far the dominant materials on that basis. Table 4 shows a wide range of trash can densities for various paper products, ranging from a low of about 40 pounds per cubic yard for boxes to 170 pounds per cubic yard for flat paper goods such as newspapers and magazines.

However, paper is the most readily compressible material in solid waste, leading to landfill densities approaching 800 pounds per cubic yard. In fact, all paper products achieve nearly the same landfill density. One of the factors leading to the high density is that paper becomes wet in a landfill, losing its structural strength to some degree. On a volume basis, paper comprises about 58 percent of living area trash in the trash can and 46 percent at the landfill, but for total packaging the percentage drops from 76 percent in the trash can to 47 percent at the landfill.

Plastics

Plastics packaging is categorized into three readily identifiable groups based on crushability. Film is the densest, with a trash can density of 84 pounds per cubic yard and a landfill density of 667 pounds per cubic yard. Rigid containers, consisting primarily of bottles and jars, are next. Many of these products are discarded with the lids on, making them resist crushing at low pressures. However, examination in landfills shows that virtually all plastic containers are flattened, even with lids screwed on securely. Thus, their density increases from 53 pounds per cubic yard in the trash can to 355 pounds per cubic yard in the landfill, a six-fold increase in density.

The third plastics packaging category is in "other packaging," which includes a wide variety of special products, such as 6-pack rings and cookie trays, but the category primarily consists of plastic foam products. This results in the lowest density of any material in the trash can or landfill at 28 and 165 pounds per cubic yard. The maximum density of foam products is limited by the manufactured density, as no crushing of the foam air cells was observed in landfill samples.

Nonpackaging products include cups, utensils, pens, razors, toys, and many other items. The density is similar to that of containers, ranging from 69 to 313 pounds per cubic yard.

Table 5 shows a composite average of packaging densities for plastics as 53 pounds per cubic yard in the trash can and 356 pounds per cubic yard at the landfill. Table 6 shows that living area trash was similar, with densities of 53 and 355 pounds per cubic yard for plastics packaging.

Other Components of Waste

Table 5 shows that other packaging components contribute an insignificant amount to solid waste and do not merit further discussion. However, Table 6 shows that other nonpackaging components of living area wastes are 17 percent by weight and 9 to 15 percent by volume.

Volume Factors for MSW

Because the results of this work give a reasonably complete and experimentally based set of trash can and landfill volume factors which dovetails with the EPA-Franklin Associates waste composition database, our analysis can be expanded to look at total MSW. An exception to this is the lack of any density data on durable goods, which includes items such as major appliances, tires, and furniture. The Garbage Project has not found major appliances nor furniture in their 101-sample historical database from landfill excavations.

Applying our volume factors to MSW excluding durables results in the calculations summarized in Table 7. Figure 3 illustrates an important point about the weight and volume percents listed in Table 7. The top of Figure 3 illustrates that weight percents for discarded and landfilled materials are the same. This is because the discarding, hauling, and compacting do not result in changes of weight. The bottom part of Figure 3 shows that there are remarkable changes in volume. The landfilled volume is only about 14 percent of the as discarded trash can value. The primary reason why studying the volume factors are important is because they more truly relate to solid waste impacts.

Table 7 shows that in the trash can and at the landfill, MSW volume is dominated by paper and paperboard, with all other components being small by comparison. The selected factors at the bottom of Table 7 show that paper and paperboard account for

Figure 3a. Weight of packaging discards in MSW, 1986 (in millions of tons)

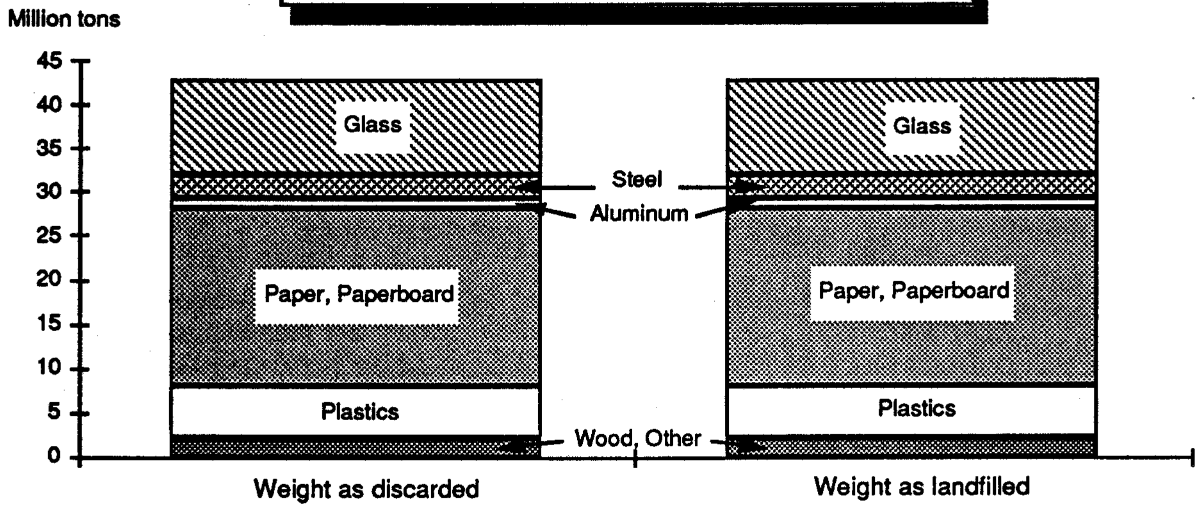


Figure 3b. Volume of packaging discards in MSW, 1986 (in millions of cubic yards)

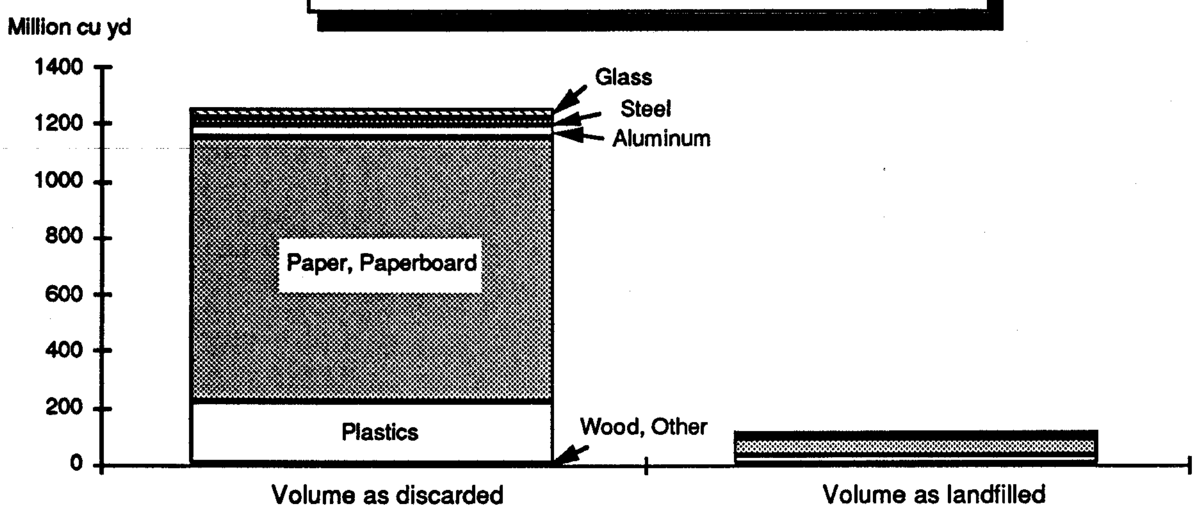


TABLE 7

TRASH CAN AND LANDFILL VOLUME FOR MSW (EXCLUDING DURABLES) - 1986

	Discards (mil tons)	Weight % of Discards	Average Trash Can Density (lb/cuyd)	Trash Can Volume (mil cuyd)	Trash Can Volume (%)	Average Landfill Density (lb/cuyd)	Landfill Volume (mil cuyd)	Landfill Volume (%)
PACKAGING								
Glass Containers	10.7	8.8	654	32.7	1.7	2,816	7.6	2.8
Steel Containers	2.7	2.2	212	25.5	1.3	557	9.7	3.6
Aluminum	1.1	0.9	54	41.0	2.1	310	7.1	2.6
Paper and Paperboard	20.4	16.8	44	935.6	48.4	764	53.4	19.6
Plastics	5.6	4.6	53	210.4	10.9	356	31.5	11.5
Wood	2.1	1.7	600	7.0	0.4	792	5.3	1.9
Other Misc. Packaging	0.2	0.2	200	2.0	0.1	1,000	0.4	0.1
Packaging Subtotal	42.8	35.2	68	1,254.2	64.9	744	115.0	42.1
NONPACKAGING PRODUCTS								
Nondurable Paper	29.7	24.4	170	349.3	18.1	798	74.4	27.3
Nondurable Plastic	2.0	1.6	69	58.0	3.0	313	12.8	4.7
Apparel	1.8	1.5	48	75.0	3.9	435	8.3	3.0
Other	2.0	1.6	133	30.1	1.6	392	10.2	3.7
Nonpackaging Subtotal	35.5	29.2	139	512.4	26.5	672	105.7	38.7
NONPRODUCT WASTES								
Yard Wastes	28.3	23.3	500	113.2	5.9	1,500	37.7	13.8
Food	12.5	10.3	500	50.0	2.6	2,000	12.5	4.6
Other	2.6	2.1	2,500	2.1	0.1	2,500	2.1	0.8
GRAND TOTAL	122	100	126	1932	100	892	273	100
PAPER AND PLASTIC SUBTOTALS (PACKAGING + NONPACKAGING)								
Paper	50.1	41.2	78	1,284.9	66.5	784	127.8	46.8
Plastic	7.6	6.2	57	268	13.9	343	44.3	16.2

Note: For more detail see Appendix Tables A-7 and A-8.

67 percent of the trash can volume, and 47 percent of the landfill volume. Plastic products account for 14 percent of the trash can volume and 16 percent of the landfill volume. The only other major category on Table 7 is yard wastes at 6 percent of the trash can volume and 14 percent of the landfill volume.

An important calculation that can be made from Table 7 is the volume percent to weight percent ratio. For plastics, these are 2.2 in the trash can and 2.6 in the landfill (excluding durables).

Comments on Validity

There are several ways to assess the validity of these results. There are no other data that directly confirm or challenge these results, but there are related and derived data that show a general validity. Four of these are mentioned here.

Perhaps the best validation of the plastics values is The Garbage Project historical database. The most relevant measures are those published recently (17) for 14 samples taken from three landfills from the 1980 to 1984 time horizon. The average weight percent of plastics was 5.7 and the volume percent was 12.2, leading to a landfill ratio of 2.1. These samples contain no durables and the results compare well with our results of 6.2 percent by weight and 16 percent for volume for MSW (excluding durables) for 1986 (Table 7). Our values are higher, but because of the low number of samples for The Garbage Project data, these values appear to be in agreement within experimental ranges. In addition, the paper samples measured by The Garbage Project have an elevated moisture content. When corrections are made to exclude acquired moisture, the percent of paper drops and the percent of plastics rises. This brings these two databases even closer together.

Another validation is the overall density of MSW calculated from our sets of volume factors. Each volume factor (with few exceptions) is an experimentally-determined value, typically from more than one source. The entire set of factors was agreed upon by the project team before final calculations. The composite trash can density was 126 pounds per cubic yard, close to the "rule of thumb" of 100 pounds per cubic yard, and within the range of 100 to 150 pounds per cubic yard based on our own measurements. The calculated composite landfill density was 892 pounds per cubic yard. This is within the "rule of thumb" range of 800 to 1,000 pounds per cubic yard for modern landfills as discussed earlier.

We suggest that the overall validity of the composite values implies a probable validity of the carefully-derived individual factors. It is highly unlikely that the relationships between individual factors are greatly in error.

Finally, the Garbage Project report in Appendix B contains a statistical analysis of the landfill volume factors. This analysis shows the results of the landfill volume experiments to be reproducible at the 95 percent confidence level within approximately ± 20 percent of the average for each value. Combining these values into a composite yields a result with even greater confidence.

Although error analysis of a complex set of numbers with widely varying sources and accuracy is not straightforward, we believe that the results and conclusions presented in this study are accurate to better than ± 20 percent. For example, our volume percent to weight percent ratio for plastics in MSW (excluding durables) of 2.6 is between 2.0 and 3.0, with the most probable value of 2.6. In a similar fashion, the percent of volume occupied by plastics in the municipal waste stream (including durables) at the landfill is between 14 and 22 percent, with the most probable value being 18 percent.

SUMMARY AND OVERVIEW OF PACKAGING TRASH

Table 8 is a compilation of data from the preceding tables for the packaging component of solid waste. As can be seen, the traditional use of weight factors to characterize solid waste differs greatly from the volume perspective. The ratios of the volume percent to weight percent show this clearly. In trash cans, glass, metal, and other packaging (primarily wood), have ratios less than one, which means that they occupy little space in the trash cans. These three categories together account for 39 percent of the weight, but only 7 percent of the trash can volume. Paper clearly dominates the trash can volume, accounting for three-fourths of the total, with the very bulky nature of corrugated containers being a major factor. However, at the landfill, this changes markedly. Corrugated and other paper products become wet and compact much better than many other components, resulting in a lowering of volume percent to less than one-half.

The factors reported at the bottom of Table 8 show that packaging accounts for 65 percent of all MSW at the highly visible trash can level. The packaging fraction is markedly less at the landfill--42 percent by volume--but still is dominant.

SUMMARY AND OVERVIEW OF LIVING AREA TRASH

Table 9, which is similar to the previous table on packaging, summarizes the living area trash data. Living area trash accounts for 42 percent by weight of MSW (excluding durables), 46 percent by volume in the trash can, and one-half of MSW by volume in the landfill. Once again, two materials dominate--plastic and paper, but by weight there is four times

TABLE 8

SUMMARY OF VOLUME FACTORS FOR THE PACKAGING COMPONENTS OF MSW

	Weight % Packaging Subtotal	Volume % of Packaging Subtotal in Trash Cans	Trash Can Ratio (Volume%/ Weight%)	Volume % of Packaging Subtotal in Landfills	Landfill Ratio (Volume%/ Weight%)
Glass	25.0	2.6	0.1	6.6	0.3
Metal	8.9	5.3	0.6	14.6	1.6
Paper and Paperboard	47.7	74.6	1.6	46.4	1.0
Plastics	13.1	16.8	1.3	27.4	2.1
Other Packaging	5.3	0.7	0.1	5.0	0.9
Total	100	100		100	

Packaging as a % of Total MSW (excluding durables)

by weight	35%
by trash can volume	65%
by landfill volume	42%

Note: Derived from Table 5.

TABLE 9

SUMMARY OF VOLUME FACTORS FOR COMPONENTS OF MSW ORIGINATING IN LIVING AREAS

	Weight % of Living Area Subtotal	Volume % of Living Area Subtotal in Trash Cans	Trash Can Ratio (Volume%/ Weight%)	Volume % of Living Area Subtotal in Landfills	Landfill Ratio (Volume%/ Weight%)
Glass	17.4	3.0	0.2	4.7	0.3
Metal	5.1	6.0	1.2	8.8	1.7
Paper and Paperboard	48.3	58.2	1.2	46.0	1.0
Plastics	11.5	23.4	2.0	25.3	2.2
Other	17.7	9.4	0.5	15.2	0.9
Total	100	100		100	

Living Area Trash as a % of Total MSW (excluding durables)

by weight	42%
by trash can volume	46%
by landfill volume	50%

Packaging as a % of Living Area Trash

by weight	44%
by trash can volume	62%
by landfill volume	44%

Note: Derived from Table 6.

more paper than plastic. Nondurable paper is a prominent component of paper and paperboard, consisting of relatively dense newspapers and other "flat" paper products. This leads to much lower trash can volumes and slightly lower landfill volumes than previously found for packaging. For paper, the volume fraction is reduced to about twice that of plastic in the landfill. The ratio of volume percent to weight percent for plastic is about 2 for both trash can and landfill locations. This is the largest ratio when compared to other materials, resulting from plastics' resistance to crushing.

SUMMARY AND OVERVIEW OF MSW (EXCLUDING DURABLES)

Table 10 summarizes volume factors for MSW, excluding durables. Paper accounts for 41 percent by weight, with food and yard wastes accounting for 34 percent. By weight, plastic is only 6.2 percent. However, plastic is 14 percent of trash can volume and 16 percent of landfill volume. Once again, the ratio of volume percent to weight percent is highest for plastics (2.6), but it still occupies far less landfill space than paper and paperboard products, only slightly more than yard wastes.

OVERVIEW OF MSW (INCLUDING DURABLES)

In order to develop a set of volume factors consistent with the EPA-FAL weight database for all municipal solid waste, which includes durable goods, the previous analysis was extended to include durables (e.g., appliances, furniture, tires). Durable goods account for about 20 million tons (14 percent) of the net discards of MSW each year.

Since no density factors are available for durables, we used known factors for similar products. Table A-8 was modified so that the glass, steel, aluminum, plastics, and other miscellaneous materials reflect the quantities of those materials in durables (Table A-9). These modifications are summarized in Table 11.

Comparing Table 11, which includes durables, with Table 10 reveals that the percentage of metals is up substantially, while paper drops as a percentage of the total. This, of course, is because durables have a high metal content, but contain very little paper. As a result of adding in durables, plastics increase to 18 percent by volume, with a volume percent to weight percent ratio of 2.5.

TABLE 10

SUMMARY OF MSW VOLUME FACTORS (EXCLUDING DURABLES)

	Weight %	Trash Can Volume %	Ratio (Volume%/ Weight%)	Landfill Volume %	Ratio (Volume%/ Weight%)
Glass	8.8	1.7	0.2	3	0.3
Metal	3.1	3.4	1.1	6	2.0
Paper and Paperboard	41.2	66.5	1.6	47	1.1
Plastics	**6.2**	**13.9**	**2.2**	**16**	**2.6**
Yard Wastes	23.3	5.9	0.3	6	0.3
Food	10.3	2.6	0.3	3	0.3
Other *	7.1	6.0	0.8	19	2.7
Total	100	100		100	

*Includes wood, apparel, footwear and other miscellaneous materials.

Note: Derived from Table 7.

TABLE 11

SUMMARY OF MSW VOLUME FACTORS (INCLUDING DURABLES)

	Weight (%)	Landfill Volume (%)	Ratio (Volume%/ Weight%)
Glass	8.4	2	0.2
Metal	8.7	14	1.6
Paper and Paperboard	35.6	38	1.1
Plastics	**7.3**	**18**	**2.5**
Yard Wastes	20.1	11	0.6
Food	8.9	4	0.4
Apparel	1.3	3	1.9
Other*	9.7	10	1.0
Total	100.0	100	

* Includes wood, footwear and many other miscellaneous materials.

Note: Derived from Table A-9.

REFERENCES

1. Sellers, V.R. **A Case Study Analyzing the Volume of Residential Plastics.** Franklin Associates, Ltd. Prairie Village, Kansas. February 1989.

2. Rathje, W.L., et al. The Garbage Project. University of Arizona, Tucson. Various published and unpublished reports and personal communications.

3. Jones, T.A., et al. **Recycling Markets and Management - Strategies for Connecticut.** Yale School of Organization and Management for the Connecticut Resources Recovery Authority. August 1988.

4. Rankin, S. **Recycling Plastics in Municipal Solid Wastes.** Center for Plastics Recycling Research at Rutgers. The State University of New Jersey. January 1989.

5. Hunt, R.G. and W.L. Bider. **Analysis of Environmental and Economic Impacts of Waste Reduction Procedures and Policies.** Franklin Associates, Ltd. for U.S. Environmental Protection Agency, Office of Solid Waste. Washington, DC. December 1977.

6. Fuller, E.E. and J. Schlegal. Excerpts from **Plastic Packaging Recycling: The Challenges and Opportunities.** Business Communications Company, Inc. Norwalk, Connecticut. 1988.

7. Conversation with Jeff Douglas, Waste Management, Inc. Chicago, Illinois.

8. "Transfer of Baled Wastes Is One Solution." **Waste Age.** December 1988.

9. Technical data on Seico and HRB balers.

10. Conversation with Richard Gamble. Gamble & Associates. California.

11. Data from Waste Management, Inc.

12. Conversation with Harold Wilson. Can-Man Company. Manhattan, Kansas.

13. Conversation with representative of Empire Returns, Inc. Utica, New York.

14. Conversation with U.S. Recycling Industries. Denver, Colorado.

15. Franklin, M. **Characterization of Municipal Solid Waste in the United States, 1960 to 2000 (Update 1988).** Franklin Associates, Ltd. for the U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. April 1988.

16. **Modern Plastics.** January 1988 and earlier years.

17. Rathje, W.L., W.W. Hughes, G.H. Archer, D.C. Wilson, and E.S. Cassells. **Digging in Landfills.** The Garbage Project. University of Arizona, Tucson. Presented at the Fifth Annual Conference on Solid Waste Management and Materials Policy. New York City. January 1989.

18. Franklin Associates estimates based on experimental data.

19. Taylor, A.C. and R.M. Kashmanian. **Study and Assessment of Eight Yard Waste Composting Programs Across the United States.** U.S. Environmental Protection Agency. December 1988.

20. John Christopher Madole Associates. **Yard Waste Management Action Plan for San Jose, California.** Final Draft Report. March 1988.

21. Estimates only, no experimental data were found.

22. Appendix B, Table 20.

23. Appendix B, Table 21.

APPENDICES

The Appendices consist of three sections. Section A is a set of nine tables that form the database for the calculations in this report. Section B is a report on the experimental program prepared by The Garbage Project, University of Arizona. Section C is an explanation of the derivation of high interest segments of solid waste.

APPENDIX A

TABLE A-1

SUMMARY OF DENSITY FACTORS

	Trash Can Density (lb/cuyd)	References	Landfill Density (lb/cuyd)	References
PACKAGING				
Glass Containers				
Beer & soft drink	600	4,18	2,800	18,23
Other containers	700	4,18	2,800	18,23
Steel Containers				
Beer & soft drink	150	4,18	557	23
Food cans	200	4,18	557	23
Other packaging	250	21	557	23
Aluminum				
Beer & soft drink	60	4,18	250	4,18
Other packaging	45	21	550	21
Paper and Paperboard				
Corrugated	43	22	750	22
Other paperboard	42	22	819	22
Paper packaging	48	22	740	22
Plastics				
Film	84	22	667	22
Rigid containers	53	22	355	22
Other packaging	28	22	165	22
Wood Packaging	600	21	800	21
Other Misc. Packaging	203	21,22	1,014	22
NONPACKAGING				
Nondurable Paper				
Newspapers	170	22	798	22
Books, magazines	170	22	798	22
Nondurable Plastic	69	22	313	22
Rubber	170	21,23	343	23
Textiles	48	21,23	435	21,23
Food	500	21	2,000	23
Yard	500	19,20	1,500	19,20

TABLE A-2

DERIVATION OF LIVING AREA WASTE FROM THE MSW DATABASE

	Database (mil tons)	Fraction In Living Area	Living Area Waste (mil tons)
PACKAGING			
Glass Containers			
Beer & soft drink	4.4	0.80	3.5
Other containers	6.3	0.85	5.4
Subtotal	10.7		8.9
Steel Containers			
Beer & soft drink	0.1	0.80	0.1
Food cans	1.7	0.85	1.4
Other packaging	0.9	0.05	0.05
Subtotal	2.7		1.6
Aluminum			
Beer & soft drink	0.7	0.80	0.6
Other packaging	0.4	0.90	0.4
Subtotal	1.1		0.9
Paper and Paperboard			
Corrugated	11.4	0.10	1.1
Other paperboard	5.1	0.60	3.1
Paper packaging	3.9	0.67	2.6
Subtotal	20.4		6.8
Plastics			
Film	2.0	0.75	1.5
Rigid containers	2.8	0.80	2.2
Other packaging	0.8	0.80	0.6
Subtotal	5.6		4.4
Wood Packaging	2.1	0.00	0.0
Other Misc. Packaging	0.2	0.70	0.1
Packaging Subtotal	42.8		22.7
NONDURABLE GOODS			
Paper			
Newspapers	8.8	0.92	8.1
Books, magazines	4.4	0.75	3.3
Office papers	5.0	0.10	0.5
Commercial printing	3.2	0.70	2.2
Other nonpackaging papers	8.3	0.46	3.8
Plastic	2.0	0.80	1.6
Apparel	1.8	0.50	0.9
Footwear	1.2	0.90	1.1
Other	0.8	0.80	0.6
Nondurable Goods Subtotal	35.5		22.2
DURABLE GOODS			
Major Appliances	2.6	0.00	0.0
Rubber Tires	1.7	0.00	0.0
Other Durables	14.9	0.00	0.0
Durable Goods Subtotal	19.2		0.0
OTHER WASTES			
Food	12.5	0.50	6.3
Yard	28.3	0.00	0.0
Misc. Inorganic	2.6	0.00	0.0
Other Wastes Subtotal	43.4		6.3
GRAND TOTAL	140.9		51.1

Note: Totals may not agree due to rounding.

TABLE A-3

VOLUME OF LIVING AREA WASTE IN TRASH CANS - 1986

	Database (mil tons)	Weight % of Discards	Trash Can Density (lb/cuyd)	Trash Can Volume (mil cuyd)	Volume % of Total Discards	Volume % of Packaging Materials
PACKAGING						
Glass Containers						
Beer & soft drink	3.5	6.8	600	11.7		
Other containers	5.4	10.6	700	15.4		
Subtotal	8.9	17.4		27.1	3.0	4.9
Steel Containers						
Beer & soft drink	0.1	0.2	150	1.3		
Food cans	1.4	2.7	200	14.0		
Other packaging	0.1	0.2	250	0.4		
Subtotal	1.6	3.1		15.7	1.8	2.9
Aluminum						
Beer & soft drink	0.6	1.2	60	20.0		
Other packaging	0.4	0.8	45	17.8		
Subtotal	1.0	2.0		37.8	4.2	6.9
Paper and Paperboard						
Corrugated	1.1	2.2	43	51.2		
Other paperboard	3.1	6.1	42	147.6		
Paper packaging	2.6	5.1	48	108.3		
Subtotal	6.8	13.3		307.1	34.5	55.8
Plastics						
Film	1.5	2.9	84	35.7		
Rigid containers	2.2	4.3	53	83.0		
Other packaging	0.6	1.2	28	42.9		
Subtotal	4.3	8.4		161.6	18.2	29.4
Misc. Packaging	0.1	0.2	203	1.0	0.1	0.2
Packaging Subtotal	22.7	44.4		550.3	61.8	100.0
NONPACKAGING						**Volume % of Nonpackaging Materials**
Nondurable Paper						
Newspapers	8.1	15.9	170	95.3		
Books, magazines	3.3	6.5	170	38.8		
Office papers	0.5	1.0	170	5.9		
Commercial printing	2.2	4.3	170	25.9		
Other nonpkg paper	3.8	7.4	170	44.7		
Subtotal	17.9	35.1		210.6	23.7	62.0
Plastics	1.6	3.1	69	46.4	5.2	13.7
Apparel	0.9	1.8	48	37.5	4.2	11.0
Footwear, misc.	1.7	3.3	170	20.0	2.2	5.9
Food	6.3	12.3	500	25.2	2.8	7.4
Nonpackaging Subtotal	28.4	55.6		339.7	38.2	100.0
GRAND TOTAL	51.1	100.0		890.0	100.0	-

Average density 115 lb/cuyd
Packaging density 82 lb/cuyd

Packaging as a % of Living Area Waste
Weight 44%
Volume 62%

TABLE A-4

VOLUME OF LIVING AREA WASTE IN LANDFILLS - 1986

	Database (mil tons)	Weight % of Discards	Landfill Density (lb/cuyd)	Landfill Volume (mil cuyd)	Volume % of Total Discards	Volume % of Packaging Materials
PACKAGING						
Glass Containers						
Beer & soft drink	3.5	6.8	2,800	2.5		
Other containers	5.4	10.6	2,800	3.9		
Subtotal	8.9	17.4		6.4	4.7	10.6
Steel Containers						
Beer & soft drink	0.1	0.2	557	0.4		
Food cans	1.4	2.7	557	5.0		
Other packaging	0.1	0.2	557	0.4		
Subtotal	1.6	3.1		5.7	4.2	9.5
Aluminum						
Beer & soft drink	0.6	1.2	250	4.8		
Other packaging	0.4	0.8	550	1.5		
Subtotal	1.0	2.0		6.3	4.6	10.4
Paper and Paperboard						
Corrugated	1.1	2.2	750	2.9		
Other paperboard	3.1	6.1	819	7.6		
Paper packaging	2.6	5.1	740	7.0		
Subtotal	6.8	13.3		17.5	12.9	29.1
Plastics						
Film	1.5	2.9	667	4.5		
Rigid containers	2.2	4.3	355	12.4		
Other packaging	0.6	1.2	165	7.3		
Subtotal	4.3	8.4		24.2	17.8	40.1
Misc. Packaging	0.1	0.2	1,014	0.2	0.1	0.3
Packaging Subtotal	22.7	44.4		60.2	44.4	100.0
						Volume % of Nonpackaging Materials
NONPACKAGING						
Nondurable Paper						
Newspapers	8.1	15.9	798	20.3		
Books, magazines	3.3	6.5	798	8.3		
Office papers	0.5	1.0	798	1.3		
Commercial printing	2.2	4.3	798	5.5		
Other nonpkg paper	3.8	7.4	798	9.5		
Subtotal	17.9	35.0		44.9	33.1	59.5
Plastic	1.6	3.1	313	10.2	7.5	13.6
Apparel	0.9	1.8	435	4.1	3.0	5.5
Footwear, misc.	1.7	3.3	343	9.9	7.3	13.1
Food	6.3	12.3	2,000	6.3	4.6	8.4
Nonpackaging Subtotal	28.4	55.6		75.4	55.6	100.0
GRAND TOTAL	51.1	100.0		135.7	100.0	-

Average density	753	lb/cuyd
Packaging density	754	lb/cuyd

Packaging as a % of Total Waste

Weight	44%
Volume	44%

TABLE A-5

VOLUME OF HOUSEHOLD AND BUSINESS PACKAGING WASTE IN TRASH CANS - 1986

	Database (mil tons)	Weight % of Discards	Trash Can Density (lb/cuyd)	Trash Can Volume (mil cuyd)	Volume % of Packaging Discards
PACKAGING					
Glass Containers					
Beer & soft drink	4.4	10.3	600	14.7	
Other containers	6.3	14.7	700	18.0	
Subtotal	10.7	25.0		32.7	2.6
Steel Containers					
Beer & soft drink	0.1	0.2	150	1.3	
Food cans	1.7	4.0	200	17.0	
Other packaging	0.9	2.1	250	7.2	
Subtotal	2.7	6.3		25.5	2.0
Aluminum					
Beer & soft drink	0.7	1.6	60	23.3	
Other packaging	0.4	0.9	45	17.8	
Subtotal	1.1	2.6		41.1	3.3
Paper and Paperboard					
Corrugated	11.4	26.6	43	530.2	
Other paperboard	5.1	11.9	42	242.9	
Paper packaging	3.9	9.1	48	162.5	
Subtotal	20.4	47.7		935.6	74.6
Plastics					
Film	2.0	4.7	84	47.6	
Rigid Containers	2.8	6.5	53	105.7	
Other packaging	0.8	1.9	28	57.1	
Subtotal	5.6	13.1		210.4	16.8
Wood	2.1	4.9	600	7.0	0.6
Misc. Packaging	0.2	0.5	203	2.0	0.2
TOTAL	42.8	100.0		1,254.3	100.0

Average density 68 lb/cuyd

Packaging as a % of Total MSW (excluding durables)
- Weight 35.2 %
- Volume 65.5 %

Ratio of volume % to weight 1.9

TABLE A-6

VOLUME OF HOUSEHOLD AND BUSINESS PACKAGING WASTE IN LANDFILLS - 1986

	Database (mil tons)	Weight % of Discards	Landfill Density (lb/cuyd)	Landfill Volume (mil cuyd)	Volume % of Packaging Discards
PACKAGING					
Glass Containers					
Beer & soft drink	4.4	10.3	2,800	3.1	
Other containers	6.3	14.7	2,800	4.5	
Subtotal	10.7	25.0		7.6	6.7
Steel Containers					
Beer & soft drink	0.1	0.2	557	0.4	
Food cans	1.7	4.0	557	6.1	
Other packaging	0.9	2.1	557	3.2	
Subtotal	2.7	6.3		9.7	8.4
Aluminum					
Beer & soft drink	0.7	1.6	250	5.6	
Other packaging	0.4	0.9	550	1.5	
Subtotal	1.1	2.6		7.1	6.1
Paper and Paperboard					
Corrugated	11.4	26.6	750	30.4	
Other paperboard	5.1	11.9	819	12.5	
Paper packaging	3.9	9.1	740	10.5	
Subtotal	20.4	47.7		53.4	46.5
Plastics					
Film	2.0	4.7	667	6.0	
Rigid containers	2.8	6.5	355	15.8	
Other packaging	0.8	1.9	165	9.7	
Subtotal	5.6	13.1		31.5	27.4
Wood	2.1	4.9	800	5.3	4.6
Misc. Packaging	0.2	0.5	1,014	0.4	0.3
TOTAL	42.8	100.0		114.9	100.0

Average density 745 lb/cuyd

Packaging as a % of Total MSW (excluding durables)
Weight 35.2 %
Volume 40.8 %

Ratio of volume % to weigl 1.2

TABLE A-7

TRASH CAN VOLUME OF MSW - 1986 (EXCLUDING DURABLES)

	Discards (mil tons)	Weight (% of total)	Trash Can Density (lb/cu yd)	Trash Can Volume (mil cu yd)	Volume (% of total)
PACKAGING					
Glass Containers					
Beer & soft drink	4.4		600	14.7	
Other containers	6.3		700	18.0	
Subtotal	10.7	8.8		32.7	1.7
Steel Containers					
Beer & soft drink	0.1		150	1.3	
Food cans	1.7		200	17.0	
Other packaging	0.9		250	7.2	
Subtotal	2.7	2.2		25.5	1.3
Aluminum					
Beer and soft drink	0.7		60	23.3	
Other packaging	0.4		45	17.8	
Subtotal	1.1	0.9		41.1	2.1
Paper and Paperboard					
Corrugated	11.4		43	530.2	
Other paperboard	5.1		42	242.9	
Paper packaging	3.9		48	162.5	
Subtotal	20.4	16.8		935.6	48.4
Plastics					
Film	2.0		84	47.6	
Rigid containers	2.8		53	105.7	
Other packaging	0.8		28	57.1	
Subtotal	5.6	4.6		210.4	10.9
Wood Packaging	2.1	1.7	600	7.0	0.4
Other Misc. Packaging	0.2	0.2	203	2.0	0.1
Packaging Subtotal	42.8	35.2		1,254.3	64.9
NONDURABLE GOODS					
Paper					
Newspaper	8.8	7.2	170	103.5	5.4
Books and magazines	4.4	3.6	170	51.8	2.7
Office papers	5.0	4.1	170	58.8	3.0
Commercial printing	3.2	2.6	170	37.6	1.9
Other nonpackaging	8.3	6.8	170	97.6	5.1
Subtotal	29.7	24.4		349.4	18.1
Plastics	2.0	1.6	69	58.0	3.0
Apparel	1.8	1.5	48	75.0	3.9
Footwear	1.2	1.0	170	14.1	0.7
Other	0.8	0.7	100	16.0	0.8
Food	12.5	10.3	500	50.0	2.6
Yard	28.3	23.3	500	113.2	5.9
Misc. Inorganics	2.6	2.1	2,500	2.1	0.1
Nondurable Goods Subtotal	78.9	64.8		677.8	35.1
GRAND TOTAL	121.7	100.0		1,932.1	100.0
DENSITY	126 lb/cuyd				
Packaging as a % of Total Waste					
Weight	35.2 %				
Volume	64.9 %				
Paper totals	50.1	41.2		1,285	66.5
Plastic totals	7.6	6.2		268	13.9
Total (paper + plastic)	57.7	47.4		1,553	80.4
Volume % to Weight % Ratios					
Paper	1.6				
Plastics	2.2				

Note: Paper totals are paper packaging + nondurable paper.
Plastic totals are plastic packaging + nondurable plastic.

TABLE A-8

VOLUME OF LANDFILLED MSW - 1986 (EXCLUDING DURABLES)

	Discards (mil tons)	Weight (% of total)	Landfill Density (lb/cu yd)	Landfill Volume (mil cu yd)	Volume (% of total)
PACKAGING					
Glass Containers					
Beer & soft drink	4.4		2,800	3.1	
Other containers	6.3		2,800	4.5	
Subtotal	10.7	8.8		7.6	2.8
Steel Containers					
Beer & soft drink	0.1		557	0.4	
Food cans	1.7		557	6.1	
Other packaging	0.9		557	3.2	
Subtotal	2.7	2.2		9.7	3.6
Aluminum					
Beer & soft drink	0.7		250	5.6	
Other packaging	0.4		550	1.5	
Subtotal	1.1	0.9		7.1	2.6
Paper and Paperboard					
Corrugated	11.4		750	30.4	
Other paperboard	5.1		819	12.5	
Paper packaging	3.9		740	10.5	
Subtotal	20.4	16.8		53.4	19.6
Plastics					
Film	2.0		667	6.0	
Rigid containers	2.8		355	15.8	
Other packaging	0.8		165	9.7	
Subtotal	5.6	4.6		31.5	11.5
Wood Packaging	2.1	1.7	800	5.3	1.9
Misc. Packaging	0.2	0.2	1,014	0.4	0.1
Packaging Subtotal	42.8	35.2		114.9	42.1
NONDURABLE GOODS					
Paper					
Newspaper	8.8	7.2	798	22.1	8.1
Books and magazines	4.4	3.6	798	11.0	4.0
Office papers	5.0	4.1	798	12.5	4.6
Commercial printing	3.2	2.6	798	8.0	2.9
Other nonpackaging	8.3	6.8	798	20.8	7.6
Subtotal	29.7	24.4		74.4	27.3
Plastic	2.0	1.6	313	12.8	4.7
Apparel	1.8	1.5	435	8.3	3.0
Footwear	1.2	1.0	343	7.0	2.6
Other	0.8	0.7	500	3.2	1.2
Food	12.5	10.3	2,000	12.5	4.6
Yard	28.3	23.3	1,500	37.7	13.8
Misc. Inorganics	2.6	2.1	2,500	2.1	0.8
Nondurable Goods Subtotal	78.9	64.8		158.0	57.9
GRAND TOTAL	121.7	100.0		272.9	100.0

DENSITY 892 lb/cuyd

Packaging as a % of Total Waste

Weight	35.2 %
Volume	42.1 %

Paper totals	50.1	41.2		127.8	46.8
Plastics totals	7.6	6.2		44.2	16.2
Total (paper + plastic)	57.7	47.4		172.1	63.1

Volume % to Weight % Ratios

Plastics	2.6
Paper	1.1

Note: Paper totals are paper packaging + nondurable paper.
Plastic totals are plastics packaging + nondurable plastics.

TABLE A-9

LANDFILL VOLUME OF MSW - 1986 (INCLUDING ESTIMATES FOR ALL WASTES)

	Discards (mil tons)	Weight (% of total)	Landfill Density (lb/cu yd)	Landfill Volume (mil cu yd)	Volume (% of total)
Glass					
Beer & soft drink	4.4	3.1	2,800	3.1	0.9
Other glass (inc. durables)	7.4 +	5.3	2,800	5.3	1.6
Glass Subtotal	11.8	8.4		8.4	2.5
Steel					
Beer & soft drink	0.1	0.1	557	0.4	0.1
Food cans	1.7	1.2	557	6.1	1.8
Other steel (inc. durables)	8.8 +	6.2	557	31.6	9.4
Steel Subtotal	10.6	7.5		38.1	11.3
Aluminum					
Beer & soft drink	0.7	0.5	250	5.6	1.7
Other aluminum (inc. durables	1.0 +	0.7	550	3.6	1.1
Aluminum Subtotal	1.7	1.2		9.2	2.7
Paper and Paperboard					
Corrugated	11.4	8.1	750	30.4	9.0
Other paperboard	5.1	3.6	819	12.5	3.7
Paper packaging	3.9	2.8	740	10.5	3.1
Newspapers	8.8	6.2	798	22.1	6.5
Books and magazines	4.4	3.1	798	11.0	3.3
Office papers	5.0	3.6	798	12.5	3.7
Commercial printing	3.2	2.3	798	8.0	2.4
Other nonpackaging	8.3	5.9	798	20.8	6.2
Paper Subtotal	50.1	35.6		127.8	37.9
Plastics Packaging					
Film	2.0	1.4	667	6.0	1.8
Rigid containers	2.8	2.0	355	15.8	4.7
Other packaging	0.8	0.6	165	9.7	2.9
Other Plastic (inc. durables)	4.7 +	3.3	313	30.0	8.9
Plastic Subtotal	10.3	7.3		61.5	18.2
Wood (inc. durables)	5.8 +	4.1	800	14.5	4.3
Other Misc. Packaging	0.2	0.1	1,014	0.4	0.1
Apparel	1.8	1.3	435	8.3	2.5
Footwear	1.2	0.9	343	7.0	2.1
Misc. Materials (inc. durables)	3.9 +	2.8	800	9.8	2.9
Food	12.5	8.9	2,000	12.5	3.7
Yard	28.3	20.1	1,500	37.7	11.2
Misc. Inorganics	2.6	1.8	2,500	2.1	0.6
GRAND TOTAL	140.8	100.0		337.3	100.0

AVERAGE DENSITY 835 lb/cuyd

Volume % to Weight % Ratios	
Paper	1.1
Plastics	2.5

Note: "+" indicates values changed from Table 8 to reflect durables and other omitted categories.

APPENDIX B

VOLUME OF SOLID WASTES UNDER DIFFERING LANDFILL CONDITIONS: COMPACTION EXPERIMENTS ON FRESH AND LANDFILL REFUSE FROM TUCSON, ARIZONA

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TABLE OF CONTENTS

INTRODUCTION

Refuse volume is an extremely important measure for solid wastes planning and management. Estimates of refuse volumes can provide critical information on (1) rates at which landfills are filling up, (2) efficacy of recycling programs in increasing landfill use-life (through reducing the landfilled waste-stream), and (3) changes in refuse volume through time as biodegradation affects the characteristics of the landfilled wastes. Unfortunately, it has been very difficult to get accurate figures on the volume of various categories of refuse--both for fresh refuse as it is deposited at the landfill and landfill refuse which has undergone the effects of several years of deposition. Because most studies of solid waste characteristics have measured weight and not volume, knowledge of the volume and density of solid wastes are, at best, lightly treated or ignored. In addition, little is known of the effects of natural and cultural deposition processes on the behavior of materials in the landfill (as compared to fresh refuse collected from off the street). For example, residential refuse is often (but not always) compacted in garbage trucks prior to deposition. Different types of trucks have different characteristics of compaction. In addition, the characteristics of compacting and covering at the landfill face might produce significant effects on the volume characteristics of the materials. After burial, natural biodegradation and possibly mechanical breakdown of materials might also alter the volume characteristics of the landfilled materials.

This study presents the first attempt to examine two types of refuse--fresh residential refuse from Tucson, Arizona and landfilled refuse (primarily of residential origin) from the Los Reales landfill in Tucson, Arizona--

specifically to study the volume of the refuse as it is related to variability in compaction pressures.

METHODS

A total of 1,666 pounds (4,248 gallons) of refuse were collected and compacted between May and June of 1989: 559 pounds (2,448 gallons) fresh refuse and 1,107 pounds (1,800 gallons) of landfill refuse.

Fresh Refuse Sampling

Fresh household refuse samples were for the most part collected from two census tracts in Tucson, Arizona: one low income census tract of mixed ethnicity located near the downtown area (tract 10) and one moderate income, primarily anglo tract located to the northeast of the downtown area (tract 6). All refuse samples were brought to the analysis site on the campus of the University of Arizona and the materials hand-segregated into nine paper, plastic, and composite fractions. Sampling was performed by the City of Tucson Department of Sanitation. All non-paper and non-plastic materials were discarded. The nine categories used for the separation were (1) Non-packaging Paper, (2) Corrugated Cardboard Packaging, (3) Paperboard Boxes, (4) Other Packaging Paper and Paperboard, (5) Plastic Film Packaging, (6) Plastic Rigid Packaging Containers, (7) Other Plastic Packaging, (8) Non-packaging Plastic, and (9) Composite/Mixtures (see Form 1). In addition, a few samples of aluminum cans were prepared for comparative purposes. Preparation consisted of filling plastic sample bags with between 20 and 30 gallons of a waste category, cutting holes in the bag to facilitate compaction, and tagging the sample with a material code (A through I--see Form 1) and sample number. Samples were prepared on May 9, 11, and 17.

Landfill Excavation

Landfill refuse sampling started on June 13, 1989 at the Los Reales Landfill, Tucson, Arizona. Sampling was facilitated by the City of Tucson Department of Sanitation. Samples were taken in two manners: (1) large sized pieces of paper and plastic were gleaned from the debris brought up by a backhoe bucket along the sides of backhoe trenches; (2) backhoe loads were shoveled onto a one inch by two inch mesh screen and the paper and plastic fractions collected. Initial samples were composed of mixed residential and commercial refuse—deposits of corrugated cardboard and office paper were mixed with deposits of residential refuse (newsprint, food wastes, yard trimmings, junk mail, etc.). Initial date of deposition of these deposits (based on reading the dates printed on newspapers) was March 1986. In the early afternoon the trench was extended to the west to avoid a deposit of medical waste (syringes, etc.). Dates on this refuse indicated a deposition period in 1983 although lower deposits dated to 1979. The 1983 refuse was darker in color, moister, and appeared to be more decomposed. In the late afternoon of June 13 the trench was extended to the east where medical wastes and mixed commercial/residential refuse was encountered and sampled.

The second day of landfill refuse sampling occurred on June 20, 1989 at the Los Reales landfill. In the morning, samples were taken from a trench to the southwest of the June 13 trench. Initial samples dated to 1983. By mid-morning the trench was extended to the west to avoid large deposits of commercial refuse on the east end of the trench. Upper levels of the trench (down to about 5 feet) were mixed residential and commercial refuse dating to 1983, while lower levels (lower than 5 feet to at least 9 feet) were 1977-1978 residential refuse. In the early afternoon, in order to avoid demolition and construction debris deposits in the west end of the trench, a new trench was started to the east of the existing trench (but still west of the June 13 trench).

The third day of landfill refuse sampling occurred on June 27, 1989 at the old Tempe landfill site underneath the Rio Salado parkway. Three additional samples of refuse were gleaned from backhoe piles of refuse dated to 1967-1971.

In summary, landfill refuse was collected from largely residential solid wastes dating to 1983 from the Los Reales landfill in Tucson, Arizona. Some commercial refuse was mixed in with a number of the samples. Three samples of late 1960s residential refuse were included from the Rio Salado landfill, Tempe, Arizona. Samples were prepared as described above for fresh refuse on June 14, 15, 21, and 30.

Compactor

The compactor used in the refuse experiments was provided by Mobil Chemical company. The compactor was composed of a box-shaped cylinder with a hydraulic piston. Refuse was put into the cylinder and the piston was lowered. Measurements were taken of changes in the volume of the refuse under various pressures.

The cylinder was composed of four curved metal plates on a metal footing. Each metal plate formed one side of the cylinder with the edges overlapping forming a nearly square aperture in the basic "open" configuration. Small hydraulic pistons were attached to the outside of each plate which permitted the plates to be contracted into a "closed" mode. In the closed configuration the cylinder was completely round on top. In the open mode, a wood and metal plate, fitted to the cylinder aperture, was placed on top of the refuse. In the closed mode the metal plate of the piston (a "Miller Fluid Power" hydraulic piston, model "B+61R2N" (250 psi, 6" bore, 1.75" rod diameter, 30 stroke) was used to directly depress the refuse. All compaction experiments for this report were conducted in the open mode. A tape was attached to the bottom of the piston's metal plate which was used to measure the distance from the bottom of the cylinder to the bottom of the piston. A "Span Instruments" pressure gauge was used to measure the pressure in the line immediately prior to entry on the piston (0-100 psi). A rented air compressor was used to drive the piston.

Recorded Variables

The following variables were recorded for each refuse sample (see Form 2):

1. **Material.** This was one of 9 types specified by Franklin Associates for the study (see Form 1). In addition some additional samples (aluminum for example) were also recorded.

2. **Number.** The number of the sample. In general, a target of 10 samples per material was specified. In some cases, due to the infrequency with which certain materials were discarded, less than this number were procured. In some cases, due to potential biasing factors involved with compaction runs (eg. insufficient holes in sample bags to permit air escape during compaction), additional samples were analyzed.

3. **Weight.** The weight of the sample was measured on an "Ohaus" electronic scale to the hundredth of a pound.

4. **Plate.** The condition of the cylinder was recorded--either "open" or "closed" mode.

5. **Type.** The type of refuse, either fresh refuse or refuse excavated from a landfill, was recorded.

6. **Year.** The year the refuse was generated was recorded--the present year

for fresh refuse, or the year of the landfilled refuse (as recorded from still-readable newsprint dates).

7. Bin Volume. The volume of the refuse sample was measured using the standard Garbage Project technique of measurement within a marked 32 or 20 gallon plastic garbage can (or "bin"). Measurement was in gallons and precise to the gallon.

8. Compactor Volume 1. Four measurements were made of the volume of the refuse sample in the compactor. Measurements were taken using a metal ruler thrust into each corner of the cylinder and measuring up to the refuse. Measurements were precise to the nearest inch and were converted to volume by multiplying the average of the four measurements by the area of the cylinder.

9. Compactor Volume 2. Four additional measurements were made of the volume of the refuse sample in the compactor after the placement of the wood and metal plate on top of the refuse (the plate exerted 0.0504 psi on the refuse--only measured in open mode). These were taken in an identical manner to the Compactor Volume 1. Measurements were taken to the top of the plate and were precise to the eighth of an inch. Volume was derived by subtracting the width of the plate from the average of the measurements and multiplying this number by the area of the cylinder.

10. Compactor Measurements. The distance that the refuse had compacted was measured from the tape on the piston at 21 specific points: contact of the piston with the refuse (2 psi), 5 psi to 100 psi in 5 psi increments (read off of the pressure gauge, and at 100 psi after a 30 second delay.

11. Compactor Volume 3. Four measurements of the volume of the refuse sample after the piston had been withdrawn from the cylinder. Measurements were taken in a fashion identical to Compactor Volume 2 (the metal and wooden plate was left in place). This measurement recorded the "springback" of the material after pressure had been released (see Form 2).

Procedure

Three persons recorded the variables--a person to control the piston movement, a person to read off the distance measurements, and a person to record. After measuring weight and "Bin Volume", the samples were placed in the compactor and "Compactor Volume 1" was measured. In the open mode, the wood and metal plate was then placed on the refuse and "Compactor Volume 2" was measured. The piston would then be lowered onto the refuse. On contact with the refuse, the distance would be measured (this was given the value of 2 psi) and then at 5 psi intervals. The person controlling the piston would call off the pressure and the person reading the tape would respond by calling off the distance. These were written on the form by the recorder. After 100 psi had been reached the pressure was held for 30 seconds and a further measurement taken. The piston was rescinded and the "springback" volume was recorded. Compaction experiments on the fresh refuse samples were conducted on May 9, 11, 16, and 17 while experiments on the landfill refuse samples were conducted on June 14, 15, 22, and 30.

Analysis

The measurements were input into a spreadsheet program pre-set to convert the raw data into the reporting units. Using the recorded weight of the sample, volumes recorded at various pressures were converted into densities (in pounds per cubic yard). The resultant data are presented in Tables 1-19 and Figures 1-18. Each table is composed of a column with the pressure in psi, a set of columns--one for each sample, numbered 1 to n--with densities, and some summary statistics columns (mean, standard deviation, n, and the coefficient of variation). In the pressure column, the measurements "bin vol1" refers to the Garbage Project's volume measuring method (see 'Compactor", above), "com1" is the initial volume measurement.

RESULTS

Results concern sampling, comparison of fresh and landfill samples, and variability within refuse categories.

Sampling

The least frequently found categories (those where less than 10 samples could be procured were the other plastic packaging, non-packaging plastic, and composite/mixtures categories for fresh refuse. In the landfill refuse these three categories were also infrequently found, as well as, other packaging paper and paperboard boxes categories.

Comparison of Fresh and Landfill Refuse Samples

In all cases except for the other plastic packaging category the average coefficient of variation (the average of the standard deviations divided by the averages) for the fresh refuse samples were greater than the landfill refuse. This suggests that for all of the categories except other packaging plastic the amount of variability within measurements with respect to the average was less for the landfill refuse. The most dramatic differences were for non-packaging paper, corrugated cardboard, rigid plastic packaging, and composite/mixtures. This suggests that there are significant differences between landfill and fresh refuse. It is likely that processes of refuse deposition, waste degradation, and others have altered the characteristics of the materials. The resultant material mix acts somewhat more regularly (see variability, below). It is possible that the materials have lost some of their resilience through time, such that resistance to pressure is decreased.

Clearly the landfill refuse is considerably denser regardless of the pressure applied. Part of the reason for this is probably elevated moisture levels in the landfill refuse, but part of the difference is likely the reduction in particle size of the refuse pieces through refuse truck compaction, landfill compaction, and degradation of the materials. For example, most of the paperboard boxes and rigid plastic containers found in the landfills were crushed (compared to the fresh refuse boxes and containers which were invariably whole). The categories showing the least dramatic increases in density from fresh refuse to landfill refuse were the plastics categories--especially plastic film packaging, other plastic packaging, and non-packaging plastic. This suggests the possible role of permeability (and moisture content) in altering the compaction characteristics of the materials--such that more permeable materials--paper--become more dense (with increasing moisture). In addition, it may suggest greater structural breakdown of paper elements such that particle size has decreased for these categories (increasing density).

Variability

Variability within refuse categories affects the confidence with which sample statistics may be applied to produce estimates for trash can and landfill densities.

Trash Can Densities. In nearly every category of fresh refuse there was at least one outlier sample whose compaction curve did not cluster with the other samples (see Figures 1 to 10). For example, samples 1, 2, and 8 for the fresh refuse non-packaging paper were low density outliers. In the case of non-packaging paper, sample 1 was predominantly newsprint while sample 8 was primarily wallpaper. It is quite possible that some of the newsprint and the wallpaper were crumpled (exhibiting low densities) as some of these kinds of materials were noticed during the sample preparation. It is probable that (1) composition of the category (the specific mix of products, packaging, and other items) and (2) condition of the materials (crumpled, crushed, moist) affected how the materials behaved under pressure.

The lowest deviations with respect to the average (coefficient of variation) were paperboard boxes, other packaging, film plastic, other plastic, non-packaging paper. Aluminum had extremely low deviations. The highest densities achieved at maximum pressure for fresh refuse were film plastic (619.1 Lbs/cu yd) and composite/mixtures (647.4 Lbs/cu yd). The least dense (as expected) were the aluminum can samples (98.6 Lbs/cu yd).

Averages for low pressure (0.434 psi), fresh refuse densities with the 95 percent confidence intervals are listed in Table 20. The highest density materials were the composite/mixtures category (mostly diapers--202 Lbs. per cu. yd.), non-packaging paper (85 Lbs. per cu. yd), and plastic film packaging (84 Lbs. per cu. yd.). The least dense material was other plastic packaging (28 Lbs. per cu. yd.).

Landfill Pressure Densities. In contrast to the fresh refuse samples, there were very few outliers in the landfill sample distributions (see Figures 11-18). Averages for estimated landfill pressures (8.683 psi held for 30 seconds) and the 95 percent confidence intervals for the average are listed in Table 20. The most dense material was (once again) the composite/mixtures category (1014 Lbs. per cu. yd.). Paper categories were considerably more dense than plastic categories, film plastic (667 Lbs. per cu. yd.) the only plastic category even close in density to the lowest paper category (other packaging

TABLE 1
FRESH REFUSE NON-PACKAGING PAPER EXPERIMENTS

	SAMPLE NUMBER											STANDARD		
PSI	1	2	3	4	5	6	7	8	9	10	AVERAGE	DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)													
bin vol1	9.446	20.152	131.871	90.282	105.925	162.730	136.154	17.381	142.451	132.627	94.902	58.114	10	0.612
com1	10.591	25.775	166.324	142.337	137.417	230.900	193.191	17.157	161.701	152.455	123.785	77.945	10	0.630
com2	17.642	38.834	195.916	162.671	164.782	241.267	205.642	21.330	179.047	176.792	140.392	82.316	10	0.586
0.174	17.243	34.047	193.933	142.999	155.776	239.313	200.230	19.308	166.381	163.308	133.254	80.487	10	0.604
0.434	33.314	48.478	280.125	184.100	210.255	274.932	230.032	25.561	209.492	208.554	170.484	97.706	10	0.573
0.868	73.007	71.070	325.860	214.998	285.012	345.675	270.256	41.812	282.757	242.090	215.254	112.308	10	0.522
1.302	87.983	86.120	354.825	227.739	359.595	367.145	311.050	56.880	309.847	275.291	243.647	122.549	10	0.503
1.737	110.688	103.101	383.211	276.980	405.017	391.460	331.926	62.511	342.679	310.812	271.838	130.334	10	0.479
2.171	127.086	116.193	395.879	316.956	422.820	419.223	360.999	66.459	377.697	332.247	293.556	136.376	10	0.465
2.605	149.188	155.748	409.414	353.388	442.260	437.855	402.089	72.571	413.956	356.858	319.333	138.341	10	0.433
3.039	149.188	197.843	416.534	399.282	463.574	458.220	445.558	79.920	434.827	373.456	341.840	143.022	10	0.418
3.473	163.397	252.420	431.544	433.024	487.046	480.572	462.214	86.488	457.916	391.674	364.630	144.141	10	0.395
3.907	180.596	271.118	439.462	458.877	499.697	496.726	480.164	91.502	474.720	418.921	381.178	146.463	10	0.384
4.342	201.843	271.118	447.676	488.012	513.022	514.003	499.565	94.234	483.593	441.981	395.505	150.415	10	0.380
4.776	201.843	292.807	456.204	504.012	527.078	532.526	520.599	103.502	492.804	458.818	409.019	153.536	10	0.375
5.210	228.755	292.807	465.062	521.097	541.925	552.434	543.483	107.011	512.322	476.989	424.188	157.132	10	0.370
5.644	228.755	292.807	474.271	539.381	541.925	562.956	555.696	110.766	522.671	496.659	432.589	161.288	10	0.373
6.078	263.949	318.268	474.271	558.995	557.633	573.887	568.470	114.794	533.448	507.115	447.083	159.133	10	0.356
6.512	263.949	318.268	483.852	580.089	574.278	585.251	595.866	119.125	556.392	518.020	459.509	166.524	10	0.362
6.946	263.949	318.268	483.852	580.089	574.278	597.075	610.579	123.797	556.392	529.405	463.769	168.337	10	0.363
7.381	311.939	348.580	493.829	602.838	591.949	609.386	626.037	128.850	568.621	529.405	481.143	164.986	10	0.343
7.815	311.939	348.580	493.829	602.838	591.949	609.386	626.037	134.333	581.399	541.302	484.159	164.907	10	0.341
8.249	311.939	348.580	504.225	627.443	610.741	622.215	626.037	134.333	581.399	553.746	492.066	170.045	10	0.346
8.683	311.939	348.580	504.225	627.443	610.741	622.215	642.298	140.303	594.764	553.746	495.625	170.965	10	0.345
8.683	311.939	348.580	515.069	654.143	630.765	635.596	659.426	146.829	608.758	566.775	507.788	177.512	10	0.350
SPRINGBACK	152.504	252.420	405.944	468.194	475.020	503.067	526.137	110.766	451.917	439.962	378.593	150.277	10	0.397
												Average CV:		0.435

TABLE 2
FRESH REFUSE CORRUGATED CARDBOARD PACKAGING EXPERIMENTS

PSI	SAMPLE NUMBER 1 (POUNDS PER CUBIC YARD)	2	3	4	5	6	7	8	9	10	11	AVERAGE	STANDARD DEVIATION	N	CV
bin vol1	21.227	29.624	47.484	37.534	89.426	36.841	26.072	22.545	31.740	30.102		37.259	19.902	10	0.534
com1	22.590	22.123	65.334	32.155	75.193	30.977	28.873	17.650	29.715	26.800		35.141	19.187	10	0.546
com2	25.817	25.283	70.545	42.874	76.162	36.119	34.128	22.940	40.242	27.032		40.114	18.784	10	0.468
0.174	24.504	21.625	61.821	31.057	73.994	32.880	32.103	21.839	37.072	26.866		36.376	17.582	10	0.483
0.434	29.266	25.572	74.667	34.869	86.622	35.686	40.998	26.333	43.838	29.159		42.701	21.058	10	0.493
0.868	38.656	33.130	84.966	36.357	99.337	44.166	46.653	39.563	48.240	37.066		50.813	22.544	10	0.444
1.302	43.285	33.796	93.233	51.840	116.427	53.316	51.751	52.162	53.625	45.751		59.519	25.247	10	0.424
1.737	53:546	53.803	100.866	58.016	140.620	54.179	66.227	66.581	69.038	57.855		72.073	27.885	10	0.387
2.171	60.745	77.304	114.226	59.536	194.511	55.528	75.764	81.084	76.353	68.770		86.382	41.407	10	0.479
2.605	63.971	110.253	118.953	67.830	292.642	60.010	91.946	98.668	81.768	83.470		106.951	68.066	10	0.636
3.039	67.558	149.454	122.327	72.137	349.282	67.247	106.410	101.104	84.155	93.457		121.313	84.183	10	0.694
3.473	83.088	164.034	125.899	74.502	391.365	73.127	116.919	103.664	86.686	100.317		131.960	95.211	10	0.722
3.907	101.812	172.446	131.665	85.747	421.861	99.127	129.733	122.230	92.234	104.138		146.099	100.142	10	0.685
4.342	111.210	181.768	135.812	94.026	457.511	129.924	141.350	148.899	157.935	110.450		166.889	105.233	10	0.631
4.776	122.520	203.800	149.984	99.517	484.825	137.961	145.700	167.131	235.291	117.575		186.430	112.456	10	0.603
5.210	131.430	216.949	161.198	104.075	515.607	140.865	155.254	181.988	268.123	122.860		199.835	120.977	10	0.605
5.644	153.802	231.911	174.224	107.353	532.513	153.818	201.499	199.743	281.202	128.641		216.470	122.053	10	0.564
6.078	168.109	249.089	177.816	112.676	569.882	199.734	220.244	209.986	295.622	134.994		233.815	129.444	10	0.554
6.512	176.309	249.089	181.560	149.822	590.605	212.416	230.987	221.336	295.622	142.007		244.975	130.064	10	0.531
6.946	185.351	249.089	189.540	156.711	636.927	219.380	242.833	233.984	311.602	149.788		257.520	141.723	10	0.550
7.381	185.351	249.089	198.255	160.398	662.924	226.817	255.959	248.165	311.602	154.007		265.257	147.818	10	0.557
7.815	206.533	269.016	207.809	168.319	691.133	234.775	270.585	264.176	311.602	163.202		278.715	152.476	10	0.547
8.249	206.533	269.016	218.331	177.063	721.850	243.313	270.585	264.176	329.408	168.223		286.850	160.312	10	0.559
8.683	206.533	269.016	224.002	181.784	755.425	243.313	286.984	282.395	329.408	173.564		295.242	169.042	10	0.573
8.683	219.051	292.409	236.276	197.592	792.275	262.396	305.499	303.313	349.372	191.833		315.002	175.384	10	0.557
SPRINGBACK	150.597	188.563	185.464	183.415	523.924	181.659	220.244	209.986	256.206	151.868		225.192	109.524	10	0.486
														AVG. CV=	0.551

TABLE 3
FRESH REFUSE PAPERBOARD BOXES

	SAMPLE NUMBER												STANDARD		
PSI	1	2	3	4	5	6	7	8	9	10	11	AVERAGE	DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)														
in vol1	22.293	26.072	32.370	23.805	27.080	15.181	34.564	30.606	36.274	37.156	33.503	28.991	6.781	11	0.234
com1	23.817	25.187	32.302	25.432	29.275	14.049	36.783	39.146	37.433	34.785	34.971	30.289	7.577	11	0.250
com2	27.266	27.813	37.092	31.501	32.679	14.792	42.451	41.329	40.920	40.409	38.031	34.026	8.369	11	0.246
0.174	24.764	28.962	32.752	29.312	30.835	14.401	41.632	42.272	38.415	37.595	37.216	32.560	8.216	11	0.252
0.434		32.103	42.143	40.218	45.751	15.810	49.230	51.709	50.100	45.751	43.619	41.644	10.691	10	0.257
0.868	53.629	44.049	52.727	51.778	65.142	19.657	70.752	77.745	72.002	62.775	61.155	57.401	16.058	11	0.280
1.302	65.837	59.563	65.687	66.007	73.959	24.046	95.908	91.880	97.602	84.884	69.542	72.265	20.894	11	0.289
1.737	77.123	70.152	75.858	80.813	91.930	34.238	116.645	117.026	138.698	103.027	80.595	89.646	28.330	11	0.316
2.171	85.241	78.268	83.390	95.021	108.093	44.955	142.281	144.383	158.751	123.822	87.552	104.705	34.314	11	0.328
2.605	90.988	91.946	97.174	104.180	131.153	52.221	168.150	182.254	175.684	117.361	100.577	119.244	40.977	11	0.344
3.039	97.566	106.410	109.888	121.788	151.330	59.424	182.360	202.137	196.661	142.069	109.638	134.479	44.994	11	0.335
3.473	107.973	119.879	132.113	151.701	166.720	70.820	205.517	226.888	216.005	179.954	120.493	154.369	49.451	11	0.320
3.907	120.865	129.733	145.161	169.548	185.594	77.162	219.450	258.547	239.569	162.609	133.734	167.452	54.717	11	0.327
4.342	132.753	166.149	161.069	183.978	209.287	84.752	235.410	285.064	258.359	221.255	154.048	190.193	58.489	11	0.308
4.776	147.235	185.696	175.493	192.155	218.588	90.700	253.874	317.643	280.347	221.255	171.405	204.945	63.357	11	0.309
5.210	172.297	201.499	199.289	210.901	239.914	97.545	264.236	336.894	306.426	245.392	181.639	223.276	66.038	11	0.296
5.644	188.324	210.455	206.281	221.717	265.851	105.508	287.723	358.629	337.854	264.639	199.505	240.590	72.069	11	0.300
6.078	207.640	220.244	230.550	233.701	298.075	109.997	301.106	383.362		299.924	213.505	249.810	74.130	10	0.297
6.512	218.863	230.987	250.171	247.056	317.306	120.230	315.794	411.760	376.466	329.185	221.269	276.281	82.884	11	0.300
6.946	231.370	242.833	261.290	262.029	339.189	126.094	349.934	444.700	399.282	346.066	229.619	293.855	90.910	11	0.309
7.381	245.392	255.959	286.781	278.934	364.314	132.561	369.930	444.700	425.042	385.616	248.363	312.508	93.516	11	0.299
7.815	261.224	270.585	301.488	298.171	393.459	139.726	417.663	483.370	488.012	385.616	258.932	336.204	106.870	11	0.318
8.249	279.239	286.984	317.785	298.171	393.459	147.711	417.663	483.370	488.012	408.987	270.440	344.711	103.163	11	0.299
8.683	299.924	305.499	335.944	320.258	393.459	156.663	446.467	483.370	488.012	435.373	283.018	358.908	100.936	11	0.281
8.683	323.918	326.568	356.304	345.878	427.673	166.770	479.539	529.405	527.052	465.399	312.046	387.323	109.837	11	0.284
[NGBACK	192.808	217.712	232.832	227.551	252.217	106.963	343.740	366.511	411.760	329.185	208.031	262.665	89.651	11	0.341
														AVG. CV=	0.297

TABLE 4
FRESH REFUSE OTHER PACKAGING PAPER AND PAPERBOARD EXPERIMENTS

PSI	SAMPLE NUMBER 1	2	3	4	5	6	7	8	9	10	11	AVERAGE	STANDARD DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)														
bin vol1	21.630	21.160	17.759	21.412	25.442	20.908	35.644	34.637	29.068	21.764	22.545	24.725	5.888	11	0.238
com1	23.915	23.013	21.503	21.847	25.671	25.316	42.038	34.565	30.586	28.506	22.498	27.224	6.364	11	0.234
com2	33.866	29.966	28.671	27.483	36.529	33.679	55.096	46.859	43.295	40.501	30.388	36.939	8.664	11	0.235
0.174	28.007	29.225	24.528	26.365	35.140	32.877	52.419	42.649	41.402	38.805	29.353	34.616	8.477	11	0.245
0.434	37.015	38.624	47.784	33.670	55.340	45.477	70.752	54.466	54.717	47.817	44.751	48.219	10.435	11	0.216
0.868	54.562	60.521	62.630	57.612	77.661	63.821	125.704	83.322	80.657	54.901	73.779	72.288	20.522	11	0.284
1.302	66.360	92.605	75.893	81.870	93.351	78.296	205.517	127.086	98.097	60.258	103.664	98.454	40.061	11	0.407
1.737	80.944	122.003	90.858	103.702	111.346	91.502	253.874	163.397	137.832	78.018	134.253	124.339	50.412	11	0.405
2.171	100.903	150.709	105.752	119.657	130.165	104.037	301.106	193.562	178.504	117.646	160.577	151.147	58.722	11	0.389
2.605	120.753	170.804	117.289	131.825	146.694	128.723	331.989	213.247	205.448	172.365	190.452	175.417	61.949	11	0.353
3.039	129.227	187.468	131.651	141.412	162.135	148.915	369.930	228.755	241.972	200.316	221.336	196.647	70.078	11	0.356
3.473	138.980	207.735	143.353	146.749	196.632	185.236	392.350	256.766	265.579	239.086	248.165	220.057	73.485	11	0.334
3.907	144.430	247.941	157.339	158.728	214.924	205.262	417.663	279.590	294.291	274.506	264.176	241.714	78.925	11	0.327
4.342	150.325	265.041	165.408	165.483	236.967	244.990	446.467	292.594	329.962	296.467	282.395	261.463	85.572	11	0.327
4.776	237.610	265.041	184.311	180.876	264.049	261.885	479.539	306.867	351.250	322.247	303.313	286.999	83.059	11	0.289
5.210	253.997	284.673	195.482	199.428	280.052	281.284	479.539	340.042	375.474	322.247	303.313	301.412	80.098	11	0.266
5.644	272.812	334.182	208.094	210.208	298.120	303.787	517.902	359.473	403.287	352.937	327.578	326.216	87.249	11	0.267
6.078	237.610	334.182	222.445	235.687	318.680	303.787	517.902	381.259	403.287	352.937	356.063	333.076	86.162	11	0.259
6.512	253.997	334.182	222.445	250.893	342.286	330.203	562.937	405.856	435.550	390.088	356.063	353.136	96.606	11	0.274
6.946	272.812	366.009	238.922	268.196	369.669	330.203	562.937	433.846	473.424	390.088	389.973	372.371	95.566	11	0.257
7.381	294.637	366.009	258.036	288.062	369.669	330.203	562.937	433.846	473.424	435.981	389.973	382.071	90.375	11	0.237
7.815	320.258	404.536	258.036	288.062	401.814	361.651	562.937	465.983	473.424	435.981	431.023	400.337	88.931	11	0.222
8.249	320.258	404.536	258.036	311.107	401.814	361.651	562.937	465.983	473.424	435.981	431.023	402.432	86.252	11	0.214
8.683	320.258	404.536	280.474	311.107	401.814	361.651	616.550	465.983	518.512	494.112	431.023	418.729	100.646	11	0.240
8.683	350.758	452.128	280.474	338.160	401.814	399.720	616.550	503.262	518.512	494.112	481.732	439.748	96.445	11	0.219
SPRINGBACK	219.878	269.691	157.339	243.053	253.198	244.990	438.900	354.410	382.062	380.086	346.033	299.058	85.826	11	0.287
														AVG. CV=	0.284

TABLE 5
FRESH REFUSE PLASTIC FILM PACKAGING EXPERIMENTS

PSI	SAMPLE NUMBER 1 (POUNDS PER CUBIC YARD)	2	3	4	5	6	7	8	9	10	AVERAGE	STANDARD DEVIATION	N	CV
n vol1	37.785	22.923	28.751	22.033	20.282	28.213	28.087	20.152	10.832	13.981	23.304	7.815	10	0.335
com1	37.297	33.042	34.967	29.309	24.112	32.584	39.240	28.594	20.074	18.949	29.817	6.965	10	0.234
com2	59.034	56.072	54.242	64.683	46.801	47.097	95.798	57.669	50.443	39.215	57.105	15.415	10	0.270
0.174	55.568	49.860	53.501	63.052	39.001	45.381	75.574	57.669	45.225	37.618	52.245	11.521	10	0.221
0.434	75.002	87.649	82.275	105.679	82.036	61.251	117.270	86.869	91.502	49.305	83.884	19.618	10	0.234
0.868	115.339	151.394	155.408	242.038	145.657	108.825	200.049	221.376	207.084	163.818	171.099	44.740	10	0.261
1.302	193.314	203.090	227.691	300.127	183.004	157.873	217.074	298.377	262.306	241.827	228.469	47.617	10	0.208
1.737	240.795	268.603	279.735	326.225	246.109	219.785	226.722	361.193	262.306	298.728	273.020	44.951	10	0.165
2.171	292.028	333.068	315.830	357.294	285.487	260.675	237.267	361.193	262.306	338.558	304.371	43.261	10	0.142
2.605	334.764	362.030	362.620	394.904	339.865	302.946	237.267	403.686	302.661	338.558	337.930	48.734	10	0.144
3.039	351.931	396.509	391.629	394.904	375.640	339.667	237.267	403.686	302.661	390.644	358.454	53.176	10	0.148
3.473	442.752	396.509	425.684	394.904	375.640	361.581	248.841	457.511	357.690	461.670	392.278	63.024	10	0.161
3.907	473.287	396.509	425.684	441.363	419.833	386.518	248.841	527.897	357.690	461.670	413.929	75.416	10	0.182
4.342	508.345	438.247	466.225	441.363	475.811	415.149	248.841	527.897	357.690	461.670	434.124	80.575	10	0.186
4.776	508.345	489.806	466.225	500.212	475.811	448.361	248.841	623.878	357.690	461.670	458.084	98.401	10	0.215
5.210	549.013	489.806	515.302	500.212	475.811	448.361	248.841	623.878	437.177	564.263	485.266	100.180	10	0.206
5.644	549.013	555.113	515.302	500.212	549.013	487.348	248.841	623.878	437.177	564.263	503.016	102.550	10	0.204
6.078	596.753	555.113	575.925	500.212	549.013	487.348	248.841	623.878	437.177	564.263	513.852	108.172	10	0.211
6.512	596.753	555.113	575.925	500.212	549.013	487.348	248.841	623.878	437.177	564.263	513.852	108.172	10	0.211
6.946	596.753	640.515	575.925	577.167	549.013	533.763	248.841	623.878	437.177	564.263	534.730	114.896	10	0.215
7.381	653.587	640.515	575.925	577.167	549.013	533.763	248.841	623.878	437.177	564.263	540.413	119.613	10	0.221
7.815	653.587	640.515	575.925	577.167	648.834	533.763	261.602	623.878	437.177	564.263	551.671	121.061	10	0.219
8.249	653.587	640.515	652.715	577.167	648.834	533.763	261.602	623.878	437.177	564.263	559.350	125.137	10	0.224
8.683	653.587	640.515	652.715	577.167	648.834	589.948	261.602	623.878	562.085	725.481	593.581	125.677	10	0.212
8.683	653.587	756.972	652.715	577.167	648.834	589.948	261.602	762.518	562.085	725.481	619.091	144.438	10	0.233
NGBACK	249.551	264.340	241.746	230.867	254.899	221.961	237.267	392.152	262.306	236.203	259.129	48.680	10	0.188
													AVG. CV=	0.210

TABLE 6
FRESH REFUSE PLASTIC RIGID PACKAGING CONTAINERS EXPERIMENTS

PSI	SAMPLE NUMBER 1 (POUNDS PER CUBIC YARD)	2	3	4	5	6	7	8	9	10	AVERAGE	STANDARD DEVIATION	N	CV
bin vol1	41.438	43.358	41.186	36.778	45.972	43.969	44.209	103.658	35.896	45.469	48.193	19.782	10	0.410
com1	40.032	40.202	34.001	35.156	43.487	40.369	38.602	93.201	33.263	40.481	43.879	17.636	10	0.402
com2	42.580	42.911	36.713	39.120	45.194	43.343	39.602	103.018	35.772	43.179	47.143	19.872	10	0.422
0.174	40.139	41.539	36.050	35.625	42.709	40.468	37.964	96.300	34.045	40.580	44.542	18.403	10	0.413
0.434	48.399	47.352	46.898	45.286	48.686	43.921	46.818	109.776	39.875	48.152	52.516	20.292	10	0.386
0.868	60.940	58.214	53.622	59.907	59.854	52.959	61.059	147.659	52.790	55.987	66.299	28.773	10	0.434
1.302	70.010	69.113	62.597	70.684	67.608	66.682	69.518	175.131	65.523	62.799	77.966	34.258	10	0.439
1.737	78.807	76.975	74.431	82.977	72.291	82.766	79.107	201.354	72.844	71.498	89.305	39.585	10	0.443
2.171	87.006	85.935	81.752	94.747	91.252	90.002	84.077	220.194	77.154	79.788	99.191	42.853	10	0.432
2.605	97.110	94.980	87.489	105.191	96.527	98.625	89.713	239.829	82.007	87.387	107.886	46.845	10	0.434
3.039	105.259	102.149	90.670	110.408	102.449	107.650	95.021	259.677	87.510	92.269	115.306	51.301	10	0.445
3.473	111.497	110.487	100.407	120.354	110.590	116.811	102.284	274.840	92.476	96.586	123.633	53.861	10	0.436
3.907	122.375	115.189	104.620	129.702	118.434	123.838	107.776	291.885	99.535	100.098	131.345	57.347	10	0.437
4.342	133.204	122.118	112.486	137.725	123.697	129.688	113.891	301.225	102.670	109.378	138.608	58.202	10	0.420
4.776	140.674	127.887	121.631	146.806	129.451	136.119	118.953	316.413	107.761	115.497	146.119	60.998	10	0.417
5.210	149.031	136.484	130.092	153.555	135.765	145.756	130.558	333.214	115.390	122.342	155.219	63.639	10	0.410
5.644	158.443	141.232	154.233	160.956	145.210	151.104	139.640	351.898	124.182	130.048	165.695	66.485	10	0.401
6.078	165.408	151.791	176.007	169.105	153.203	159.907	147.327	372.803	129.100	134.278	175.893	70.725	10	0.402
6.512	173.013	157.686	189.375	178.124	159.039	166.368	152.939	396.349	137.253	141.164	185.131	75.920	10	0.410
6.946	181.351	164.057	194.294	188.159	168.678	173.373	158.996	413.771	140.205	148.794	193.168	79.311	10	0.411
7.381	185.828	170.965	199.475	199.393	175.780	180.993	172.673	423.069	146.506	160.351	201.503	79.519	10	0.395
7.815	195.482	178.479	210.713	205.528	187.631	189.315	180.434	442.978	149.874	163.526	210.396	83.719	10	0.398
8.249	200.695	182.490	230.163	212.053	191.944	198.438	188.925	464.854	153.401	170.269	219.323	88.833	10	0.405
8.683	206.193	195.682	237.470	226.429	211.382	208.486	193.477	476.622	157.097	177.593	229.043	89.957	10	0.393
8.683	224.658	205.590	245.256	242.897	235.199	225.622	208.554	515.796	169.338	194.308	246.722	97.392	10	0.395
SPRINGBACK	118.056	132.585	137.253	135.628	128.455	124.305	119.395	262.391	96.586	108.659	136.331	46.043	10	0.338
													AVG. CV=	0.413

TABLE 7
FRESH REFUSE OTHER PLASTIC PACKAGING EXPERIMENTS

PSI	SAMPLE NUMBER 1 (POUNDS PER CUBIC YARD)	2	3	4	5	6	AVERAGE	STANDARD DEVIATION	N	CV
n vol1	14.107	20.274	19.019	21.790	27.138	11.210	18.923	5.661	6	0.299
com1	15.397	21.576	22.430	22.233	20.629	13.051	19.219	3.990	6	0.208
com2	18.584	24.303	29.088	27.968	25.743	17.145	23.805	4.917	6	0.207
0.174	17.218	23.225	26.268	24.205	23.220	16.485	21.770	3.976	6	0.183
0.434	24.140	27.221	37.751	28.369	30.602	22.251	28.389	5.471	6	0.193
0.868	40.369	41.501	50.426	43.251	58.492	33.104	44.524	8.813	6	0.198
1.302	46.639	59.801	58.054	58.629	75.752	41.130	56.667	12.015	6	0.212
1.737	57.878	68.421	65.794	73.971	81.068	45.751	65.480	12.417	6	0.190
2.171	76.252	72.330	75.917	85.107	90.605	52.881	75.515	12.983	6	0.172
2.605	84.278	83.458	85.289	93.117	102.686	59.012	84.640	14.534	6	0.172
3.039	90.639	96.135	92.112	102.791	107.462	64.632	92.295	14.986	6	0.162
3.473	98.038	106.967	100.122	111.478	118.484	69.014	100.684	17.223	6	0.171
3.907	106.753	120.550	106.283	118.133	124.888	71.436	108.007	19.426	6	0.180
4.342	111.718	128.723	117.092	129.753	132.025	79.840	116.525	19.663	6	0.169
4.776	117.167	138.085	121.200	134.151	140.026	86.635	122.878	20.007	6	0.163
5.210	123.176	148.915	130.347	143.908	149.060	94.694	131.683	20.932	6	0.159
5.644	137.253	154.993	140.988	149.338	159.340	99.313	140.204	21.678	6	0.155
6.078	137.253	168.771	146.988	155.195	159.340	104.406	145.325	22.741	6	0.156
6.512	145.572	176.620	153.520	168.403	171.143	110.050	154.218	24.559	6	0.159
6.946	145.572	185.236	160.661	175.887	184.834	116.338	161.421	26.866	6	0.166
7.381	154.963	194.735	160.661	175.887	184.834	123.389	165.745	25.471	6	0.154
7.815	154.963	194.735	168.498	184.068	200.907	123.389	171.094	28.840	6	0.169
8.249	165.650	205.262	177.139	184.068	200.907	131.350	177.396	26.952	6	0.152
8.683	165.650	205.262	177.139	193.047	200.907	131.350	178.892	27.637	6	0.154
8.683	177.921	216.991	186.714	202.947	220.041	140.408	190.837	29.700	6	0.156
NGBACK	95.126	127.642	97.302	127.660	102.686	79.065	104.913	19.292	6	0.184
									AVG. CV=	0.178

TABLE 8
FRESH REFUSE NON-PACKAGING PLASTIC EXPERIMENTS

	SAMPLE NUMBER				STANDARD		
PSI	1	2	3	AVERAGE	DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)						
bin vol1	68.249	39.767	59.953	55.990	14.649	3	0.262
com1	68.357	42.320	52.350	54.342	13.133	3	0.242
com2	71.955	48.108	59.828	59.964	11.924	3	0.199
0.174	67.760	45.906	58.073	57.246	10.950	3	0.191
0.434	78.785	58.625	70.024	69.145	10.109	3	0.146
0.868	94.095	74.002	88.168	85.422	10.324	3	0.121
1.302	105.165	94.702	91.888	97.252	6.996	3	0.072
1.737	115.630	111.920	109.435	112.328	3.118	3	0.028
2.171	125.630	124.241	119.003	122.958	3.495	3	0.028
2.605	134.344	145.616	127.354	135.771	9.215	3	0.068
3.039	139.171	155.659	128.861	141.230	13.517	3	0.096
3.473	148.035	171.422	130.404	149.954	20.576	3	0.137
3.907	155.984	180.564	131.985	156.178	24.290	3	0.156
4.342	162.528	190.737	131.985	161.750	29.384	3	0.182
4.776	167.205	202.124	133.604	167.645	34.262	3	0.204
5.210	174.748	214.957	133.604	174.437	40.677	3	0.233
5.644	180.167	222.005	135.264	179.145	43.380	3	0.242
6.078	188.956	229.531	142.337	186.941	43.632	3	0.233
6.512	195.307	237.585	207.405	213.432	21.774	3	0.102
6.946	202.100	246.224	211.432	219.919	23.254	3	0.106
7.381	209.383		224.510	216.947	10.696	2	0.049
7.815	213.225	276.374	229.237	239.612	32.828	3	0.137
8.249	213.225	276.374	239.313	242.971	31.733	3	0.131
8.683	221.348	288.134	250.316	253.266	33.491	3	0.132
8.683	230.114	288.134	262.380	260.209	29.071	3	0.112
SPRINGBACK	139.171	134.749	166.241	146.720	17.049	3	0.116
						AVG. CV=	0.143

TABLE 9
FRESH REFUSE COMPOSITE/MIXTURES EXPERIMENTS

	SAMPLE NUMBER						STANDARD		
PSI	1	2	3	4	5	AVERAGE	DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)								
in vol1	130.318	68.942	173.022	179.919	130.990	136.638	44.305	5	0.324
com1	147.928	70.137	180.897	182.351	154.886	147.240	45.742	5	0.311
com2	177.870	78.672	216.082	203.015	185.285	172.185	54.373	5	0.316
0.174	159.063	69.159	186.416	194.138	196.942	161.143	53.559	5	0.332
0.434	206.412	89.037	238.064	237.480	241.774	202.553	65.039	5	0.321
0.868	242.506	98.471	276.346	279.007	283.221	235.910	78.523	5	0.333
1.302	290.056	129.297	294.079	313.241	313.034	267.941	78.230	5	0.292
1.737	314.741	141.610	310.694	347.335	349.861	292.848	86.443	5	0.295
2.171	338.768	150.193	325.401	378.209	386.210	315.756	96.044	5	0.304
2.605	366.765	159.883	345.867	408.466	396.509	335.498	101.208	5	0.302
3.039	392.731	170.909	359.430	429.061	418.848	354.196	105.937	5	0.299
3.473	414.753	193.105	384.565	459.984	443.854	379.252	107.970	5	0.285
3.907	430.860	203.686	407.354	486.269	457.511	397.136	112.087	5	0.282
4.342	439.392	215.494	470.024	505.527	457.511	417.589	115.536	5	0.277
4.776	467.143	228.755	504.521	537.455	487.512	445.077	123.642	5	0.278
5.210	487.676	236.017	533.911	573.688	504.037	467.066	133.240	5	0.285
5.644	498.635	243.756	566.936	615.159	521.723	489.242	144.307	5	0.295
6.078	534.681	252.019	591.320	630.348	540.695	509.813	149.334	5	0.293
6.512	547.883	270.347	632.101	663.094	561.098	534.905	155.503	5	0.291
6.946	561.754	280.549	646.974	680.776	561.098	546.230	157.560	5	0.288
7.381	576.345	280.549	662.564	699.427	583.102	560.397	164.964	5	0.294
7.815	607.925	280.549	678.923	719.130	583.102	573.926	172.785	5	0.301
8.249	625.050	303.451	696.111	739.974	606.902	594.298	171.234	5	0.288
8.683	643.167	303.451	733.237	762.063	606.902	609.764	182.614	5	0.299
8.683	662.366	330.424	774.546	837.020	632.728	647.417	195.598	5	0.302
NGBACK	467.143	223.596	541.801	573.688	457.511	452.748	137.202	5	0.303
								AVG. CV=	0.300

TABLE 10
FRESH REFUSE ALUMINUM CAN EXPERIMENTS

PSI	SAMPLE NUMBER 1	2	3	AVERAGE	STANDARD DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)						
bin vol1	49.625	51.262	54.106	51.664	2.267	3	0.044
com1	44.619	46.552	49.676	46.949	2.552	3	0.054
com2	47.625	48.428	50.860	48.971	1.685	3	0.034
0.174	48.069	48.115	49.798	48.661	0.985	3	0.020
0.434	52.554	53.050	56.456	54.020	2.124	3	0.039
0.868	55.808	55.584	59.090	56.827	1.962	3	0.035
1.302	57.961	58.372	62.362	59.565	2.431	3	0.041
1.737	61.105	61.051	64.753	62.303	2.122	3	0.034
2.171	62.808	63.552	68.242	64.867	2.946	3	0.045
2.605	65.549	66.741	70.131	67.473	2.377	3	0.035
3.039	68.540	69.740	72.127	70.136	1.826	3	0.026
3.473	70.690	72.454	74.241	72.462	1.775	3	0.025
3.907	72.979	74.782	76.482	74.748	1.752	3	0.023
4.342	75.422	76.628	78.863	76.971	1.746	3	0.023
4.776	77.364	77.911	80.748	78.674	1.816	3	0.023
5.210	80.834	80.609	82.725	81.389	1.162	3	0.014
5.644	83.842	83.501	85.518	84.287	1.080	3	0.013
6.078	85.431	85.026	86.986	85.814	1.035	3	0.012
6.512	87.931	86.608	89.285	87.941	1.339	3	0.015
6.946	89.681	88.250	90.887	89.606	1.320	3	0.015
7.381	92.441	89.955	92.547	91.647	1.467	3	0.016
7.815	95.375	92.640	95.154	94.390	1.519	3	0.016
8.249	96.395	94.521	96.975	95.964	1.282	3	0.013
8.683	98.502	96.480	98.867	97.950	1.286	3	0.013
8.683	99.591	97.491	98.867	98.649	1.067	3	0.011
SPRINGBACK	91.271	89.094	91.502	90.622	1.328	3	0.015
						AVG. CV=	0.025

TABLE 11
LANDFILL REFUSE NON-PACKAGING PAPER EXPERIMENTS

SAMPLE NUMBER (POUNDS PER CUBIC YARD)

PSI	1	2	3	4	5	6	7	8	9	10	11	AVERAGE	STANDARD DEVIATION	N	CV
in vol1	229.870	211.076	167.129	195.963	223.755	207.568	186.660	242.709	304.803	198.500	318.245	226.025	45.098	11	0.200
com1	305.782	278.845	215.585	230.389	333.634	314.157	292.255	386.677	384.436	305.524	364.164	310.132	53.609	11	0.173
com2	362.408	321.052	267.203	272.765	391.729	337.350	299.351	445.264	403.343	368.817	399.613	351.718	54.850	11	0.156
0.174	316.923	306.597	246.382	245.281	359.532	338.107	283.695	381.655	396.837	312.137	390.964	325.283	51.344	11	0.158
0.434	370.996	417.368	311.007	324.166	471.483	430.844	362.583	503.785	505.560	402.814	504.540	418.650	68.385	11	0.163
0.868	401.436	472.205	340.804	421.628	514.625	499.323	406.007	561.544	556.370	465.185	540.794	470.902	68.541	11	0.146
1.302	427.760	517.536	371.989	464.094	543.018	534.736	449.027	599.744	592.073	504.222	575.240	507.222	69.089	11	0.136
1.737	457.778	543.630	403.648	477.845	558.423	550.349	467.608	634.261	618.534	550.410	590.279	532.070	68.771	11	0.129
2.171	492.328	562.539	434.461	485.030	574.727	575.556	480.873	662.875	632.672	595.898	606.125	554.826	68.610	11	0.124
2.605	532.518	582.811	478.272	507.945	601.050	593.683	502.245	694.192	662.980	626.989	631.557	583.113	66.921	11	0.115
3.039	571.388	604.598	503.667	542.093	619.981	612.990	542.425	716.767	679.249	661.502	640.515	608.652	61.754	11	0.101
3.473	597.558	616.115	531.910	560.948	640.143	623.122	569.774	728.614	687.687	686.702	649.731	626.573	57.211	11	0.091
3.907	626.241	628.078	542.041	591.826	640.143	633.595	589.592	753.524	705.208	700.036	659.216	642.682	57.148	11	0.089
4.342	657.816	628.078	563.508	626.301	650.724	644.425	622.047	766.629	723.645	713.898	668.982	660.550	53.676	11	0.081
4.776	680.697	653.455	586.746	638.703	661.661	655.633	633.674	794.255	733.229	728.320	679.042	676.856	54.229	11	0.080
5.210	692.744	666.928	599.098	651.606	672.971	667.237	658.283	794.255	753.181	743.337	689.409	689.914	52.086	11	0.075
5.644	718.166	666.928	625.432	665.041	672.971	679.259	684.880	808.829	763.570	758.986	700.098	704.015	51.190	11	0.073
6.078	731.590	680.969	639.487	665.041	684.675	691.723	699.001	823.947	774.249	775.309	711.123	716.101	52.580	11	0.073
6.512	745.525	680.969	654.188	679.042	696.793	704.652	713.717	823.947	785.231	792.348	722.501	727.174	51.143	11	0.070
6.946	760.001	695.613	669.581	693.645	709.348	704.652	729.066	839.641	796.530	810.154	722.501	739.157	52.373	11	0.071
7.381	775.050	695.613	669.581	693.645	709.348	718.074	729.066	855.945	808.158	810.154	734.249	745.353	56.102	11	0.075
7.815	790.708	710.901	685.715	708.890	722.363	718.074	745.089	855.945	820.130	828.778	734.249	756.440	54.773	11	0.072
8.249	807.011	710.901	685.715	724.820	722.363	732.017	761.833	872.894	832.463	828.778	746.385	765.926	57.329	11	0.075
8.683	807.011	726.877	702.646	724.820	735.866	732.017	761.833	890.529	845.173	848.279	746.385	774.676	59.663	11	0.077
8.683	841.721	743.587	720.435	741.483	749.882	761.594	779.346	908.890	871.792	890.169	771.903	798.255	63.994	11	0.080
INGBACK	674.828	569.974	555.262	597.306	610.369	605.605	627.806	740.860	735.665	717.450	627.171	642.027	62.407	11	0.097
													Average CV:		0.107

TABLE 13
LANDFILL REFUSE PAPERBOARD BOXES EXPERIMENTS

PSI	SAMPLE NUMBER 1 (POUNDS PER CUBIC YARD)	2	3	4	5	6	7	AVERAGE	STANDARD DEVIATION	N	CV
bin vol1	155.695	219.660	118.227	255.329	206.449			191.072	54.177	5	0.284
com1	183.532	296.837	128.103	315.036	251.086	149.750	148.691	210.434	76.438	7	0.363
com2	198.827	330.256	158.776	349.196	301.304	184.834	189.635	244.690	79.106	7	0.323
0.174	193.192	284.964	147.553	316.757	272.145	172.973	185.600	224.741	65.200	7	0.290
0.434	272.676	398.949	202.753	456.430	426.086	271.815	281.394	330.015	95.914	7	0.291
0.868	343.298	493.749	245.067	552.063	533.956	347.807	339.865	407.972	117.595	7	0.288
1.302	381.747	514.110	284.673	623.297	577.842	371.793	368.586	446.007	125.903	7	0.282
1.737	429.895	560.322	309.700	666.283	594.120	399.334	415.391	482.149	126.714	7	0.263
2.171	454.461	615.663	323.939	715.637	629.589	420.078	459.116	516.926	138.922	7	0.269
2.605	502.299	664.916	347.934	752.813	669.563	443.096	475.811	550.919	146.439	7	0.266
3.039	536.162	702.376	366.009	772.888	691.516	468.783	513.130	578.695	146.720	7	0.254
3.473	548.487	744.309	396.939	794.063	714.958	497.631	534.074	604.351	147.355	7	0.244
3.907	561.393	767.210	420.637	816.431	740.044	513.429	556.800	625.135	148.893	7	0.238
4.342	589.116	791.566	433.579	840.096	766.954	530.263	556.800	644.054	154.476	7	0.240
4.776	604.030	817.519	447.344	865.173	766.954	530.263	581.547	658.976	157.946	7	0.240
5.210	619.719	845.232	462.011	920.105	795.896	548.238	581.547	681.821	171.546	7	0.252
5.644	636.245	874.889	477.672	950.272	795.896	567.474	608.596	701.578	174.075	7	0.248
6.078	653.676	906.703	494.433	950.272	827.108	567.474	608.596	715.466	178.029	7	0.249
6.512	672.090	906.703	512.412	982.485	827.108	588.109	608.596	728.215	177.928	7	0.244
6.946	672.090	940.918	531.748	982.485	827.108	588.109	638.283	740.106	177.084	7	0.239
7.381	691.571	940.918	531.748	1016.958	860.867	610.302	638.283	755.807	183.855	7	0.243
7.815	712.215	977.817	552.601	1016.958	860.867	610.302	671.016	771.682	181.804	7	0.236
8.249	712.215	977.817	575.156	1016.958	860.867	634.236	671.016	778.324	173.916	7	0.223
8.683	734.129	977.817	575.156	1053.939	897.500	634.236	671.016	791.970	184.466	7	0.233
8.683	757.435	1017.728	599.631	1093.710	897.500	660.123	707.287	819.059	187.419	7	0.229
SPRINGBACK	564.715	744.389	402.610	799.540	644.008	465.410	471.525	584.588	150.412	7	0.257
									Average CV:		0.261

TABLE 14
LANDFILL REFUSE OTHER PACKAGING PAPER AND PAPERBOARD EXPERIMENTS

	SAMPLE NUMBER						STANDARD		
PSI	1	2	3	4	5	AVERAGE	DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)								
n vol1	104.308	119.785	128.974	66.502		104.893	27.543	4	0.263
com1	105.718	134.893	172.646	82.854	91.045	117.431	36.683	5	0.312
com2	137.359	157.740	199.460	121.322	122.208	147.618	32.529	5	0.220
0.174	131.560	152.435	195.727	114.185	104.649	139.711	36.218	5	0.259
0.434	212.956	237.714	283.728	230.306	185.805	230.102	36.020	5	0.157
0.868	287.388	317.692	411.246	289.108	260.128	313.112	58.516	5	0.187
1.302	374.696	373.550	463.302	331.416	293.692	367.331	63.277	5	0.172
1.737	416.915	419.667	530.447	367.245	313.947	409.644	80.160	5	0.196
2.171	469.856	465.658	580.966	411.760	337.202	453.089	89.344	5	0.197
2.605	519.315	507.359	620.354	438.325	364.179	489.906	95.726	5	0.195
3.039	558.508	539.572	665.470	468.554	395.846	525.590	101.158	5	0.192
3.473	580.411	557.263	690.582	503.262	395.846	545.473	107.919	5	0.198
3.907	604.101	596.369	717.664	503.262	395.846	563.449	120.656	5	0.214
4.342	629.807	618.056	746.956	543.523	433.546	594.378	115.704	5	0.195
4.776	657.799	829.099	778.742	543.523	433.546	648.542	163.471	5	0.252
5.210	657.799	666.530	813.353	543.523	433.546	622.950	142.784	5	0.229
5.644	688.394	693.736	813.353	543.523	433.546	634.510	147.531	5	0.233
6.078	721.974	693.736	851.183	543.523	433.546	648.792	162.596	5	0.251
6.512	721.974	693.736	851.183	590.786	433.546	658.245	156.194	5	0.237
6.946	758.999	723.256	851.183	590.786	479.182	680.681	146.373	5	0.215
7.381	758.999	723.256	892.704	590.786	479.182	688.985	159.090	5	0.231
7.815	800.026	755.401	892.704	590.786	479.182	703.620	166.457	5	0.237
8.249	800.026	755.401	938.484	590.786	479.182	712.776	180.153	5	0.253
8.683	845.741	755.401	938.484	647.051	479.182	733.172	178.358	5	0.243
8.683	845.741	790.536	938.484	647.051	479.182	740.199	180.136	5	0.243
NGBACK	592.019	581.078	653.587	476.774	387.424	538.176	105.541	5	0.196
							Average CV:		0.222

TABLE 15
LANDFILL REFUSE PLASTIC FILM PACKAGING EXPERIMENTS

	SAMPLE NUMBER												STANDARD		
PSI	1	2	3	4	5	6	7	8	9	10	11	AVERAGE	DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)														
bin vol1	57.877	38.021	43.290	28.213	25.795	27.283	35.871	23.242	38.827	54.736	28.348	36.500	11.637	11	0.319
com1	63.172	42.591	62.584	45.527	39.928	29.175	44.910	31.408	50.084	72.959	32.178	46.774	14.296	11	0.306
com2	97.476	65.891	107.432	106.753	79.137	59.646	87.254	75.741	99.789	111.336	75.714	87.833	17.820	11	0.203
0.174	85.993	60.221	98.280	80.761	73.817	59.646	90.485	62.322	95.123	105.252	71.507	80.310	16.045	11	0.200
0.434	153.501	108.803	224.878	157.415	204.284	141.266	172.050	184.068	209.874	221.393	110.960	171.681	41.323	11	0.241
0.868		193.247	340.200	189.540	283.362	230.063	284.082	239.847	281.320	337.916	205.393	258.497	55.543	10	0.215
1.302	260.709	235.410	379.080	343.980	325.341	277.662	349.015	293.146	307.490	393.086	275.814	312.794	50.000	11	0.160
1.737	400.601	287.723	457.511	371.499	351.368	322.088	394.050	316.597	339.027	447.935	311.403	363.618	56.087	11	0.154
2.171	443.909	331.989	491.400	403.803	381.922	350.095	421.225	344.128	357.353	493.877	332.879	395.689	60.203	11	0.152
2.605	497.716	369.930	530.713	442.260	418.296	383.438	488.622	376.902	400.669	550.320	357.536	437.855	68.526	11	0.157
3.039	529.827	417.663	530.713	488.814	418.296	383.438	531.110	416.576	377.773	583.673	386.139	460.366	73.860	11	0.160
3.473	566.367	446.467	576.861	488.814	418.296	383.438	531.110	416.576	426.518	621.329	386.139	478.356	83.321	11	0.174
3.907	566.367	479.539	576.861	488.814	462.327	423.799	531.110	465.585	455.933	621.329	419.716	499.216	65.830	11	0.132
4.342	608.320	479.539	576.861	488.814	462.327	423.799	581.692	465.585	455.933	664.179	419.716	511.524	81.945	11	0.160
4.776	608.320	517.902	576.861	488.814	462.327	423.799	581.692	465.585	489.706	713.378	419.716	522.555	89.250	11	0.171
5.210	656.986	517.902	631.801	546.322	516.718	473.658	581.692	527.662	489.706	713.378	459.689	555.956	81.064	11	0.146
5.644	656.986	562.937	631.801	546.322	516.718	473.658	581.692	527.662	489.706	770.448	459.689	565.238	91.974	11	0.163
6.078	714.115	562.937	631.801	546.322	585.614	473.658	642.923	527.662	528.882	770.448	459.689	585.823	96.498	11	0.165
6.512	714.115	562.937	698.306	546.322	585.614	536.813	642.923	608.841	528.882	770.448	459.689	604.990	93.051	11	0.154
6.946	714.115	562.937	698.306	546.322	585.614	536.813	642.923	608.841	528.882	837.444	459.689	611.081	106.224	11	0.174
7.381	714.115	616.550	698.306	619.165	585.614	536.813	642.923	608.841	574.872	837.444	459.689	626.757	99.131	11	0.158
7.815	714.115	616.550	698.306	619.165	585.614	536.813	718.561	608.841	574.872	837.444	459.689	633.634	102.916	11	0.162
8.249	714.115	616.550	698.306	619.165	585.614	619.399	718.561	608.841	574.872	837.444	508.078	645.540	89.829	11	0.139
8.683	782.126	616.550	698.306	619.165	585.614	619.399	718.561	608.841	574.872	837.444	508.078	651.723	97.070	11	0.149
8.683	782.126	616.550	698.306	619.165	675.708	619.399	718.561	608.841	574.872	917.200	508.078	667.164	111.263	11	0.167
SPRINGBACK	335.197	215.793	331.695	327.793	247.442	203.853	287.424	239.847	251.849	343.950	238.357	274.836	51.937	11	0.189
													Average CV:		0.180

TABLE 16
LANDFILL REFUSE PLASTIC RIGID PACKAGING CONTAINERS EXPERIMENTS

PSI	SAMPLE NUMBER 1	2	3	4	5	6	7	8	9	10	11	AVERAGE	STANDARD DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)														
in vol1	108.192	117.005	76.579	88.992	89.637	91.733	96.086	93.540	109.523	97.958	125.589	99.530	14.163	11	0.142
com1	121.297	116.568	93.671	98.651	99.366	108.468	103.287	102.755	115.300	112.170	148.500	110.912	15.117	11	0.136
com2	129.490	123.290	102.267	109.327	106.657	116.476	108.205	121.349	118.649	127.555	162.369	120.512	16.468	11	0.137
0.174	120.184	115.645	87.983	96.025	91.174	107.129	105.280	114.275	102.489	118.953	154.286	110.311	18.209	11	0.165
0.434	159.110	140.931	118.753	138.003	114.070	140.715	131.728	152.595	132.997	149.561	194.755	143.020	21.817	11	0.153
0.868	184.508	160.548	140.205	167.249	131.801	155.882	147.393	168.764	167.219	167.156	218.651	164.489	23.270	11	0.141
1.302	195.523	170.543	154.126	187.071	137.501	165.811	159.460	178.205	189.367	178.845	236.027	177.498	25.772	11	0.145
1.737	203.628	177.448	171.116	202.037	145.358	172.400	171.495	183.333	208.718	198.255	245.794	189.053	26.563	11	0.141
2.171	212.433	184.935	182.620	212.223	166.259	182.045	178.220	188.766	221.662	211.362	256.404	199.721	25.833	11	0.129
2.605	219.554	193.082	192.316	223.492	175.432	190.017	185.494	210.606	240.289	222.390	264.001	210.607	26.553	11	0.126
3.039	232.545	201.979	203.101	236.024	177.885	195.732	193.388	221.594	248.647	230.404	276.280	219.780	28.625	11	0.130
3.473	241.105	207.723	215.166	245.190	185.676	204.979	201.983	233.792	262.334	239.017	294.546	230.137	31.230	11	0.136
3.907	250.320	215.909	228.755	255.097	188.427	215.144	208.150	238.162	277.616	248.300	309.914	239.617	34.215	11	0.143
4.342	260.266	222.485	238.811	260.357	200.296	230.375	218.141	242.699	288.833	263.658	321.082	249.727	34.300	11	0.137
4.776	267.348	229.474	244.177	265.838	206.810	243.293	225.352	221.594	300.994	274.998	326.973	255.168	36.315	11	0.142
5.210	274.826	234.383	249.790	277.523	213.761	252.741	233.057	257.408	314.224	287.358	339.429	266.773	37.019	11	0.139
5.644	278.725	244.858	261.828	283.760	225.112	257.746	241.307	262.715	328.672	293.964	346.020	274.973	36.782	11	0.134
6.078	286.863	250.454	268.293	290.283	233.372	268.375	245.654	274.015	344.511	300.881	352.872	283.234	38.053	11	0.134
6.512	300.001	259.346	282.231	297.113	242.263	279.918	254.838	280.037	353.018	308.131	360.001	292.445	37.418	11	0.128
6.946	309.450	268.893	289.757	311.785	246.967	286.070	259.692	292.912	361.955	323.732	375.159	302.397	39.962	11	0.132
7.381	319.514	275.657	297.695	319.678	251.857	292.498	264.734	299.804	371.356	332.141	383.227	309.833	41.196	11	0.133
7.815	330.254	282.771	306.081	327.982	262.243	299.223	275.431	307.028	381.259	340.998	391.649	318.629	41.204	11	0.129
8.249	341.741	290.262	306.081	336.728	267.764	306.263	281.110	314.609	391.704	350.340	400.450	326.096	42.913	11	0.132
8.683	347.789	294.158	314.953	336.728	273.523	313.643	287.028	322.574	402.738	360.209	409.656	333.000	44.364	11	0.133
8.683	381.555	315.320	334.335	366.009	285.816	338.083	313.421	339.778	414.412	381.714	429.399	354.531	44.314	11	0.125
INGBACK	238.907	215.909	185.742	209.582	183.665	201.022	186.765	199.089	209.483	219.527	260.147	209.985	23.448	11	0.112
													Average CV:		0.136

TABLE 17
LANDFILL REFUSE OTHER PLASTIC PACKAGING EXPERIMENTS

PSI	SAMPLE NUMBER 1	2	3	4	AVERAGE	STANDARD DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)							
bin vol1	31.599	39.927	45.343	50.549	41.854	8.096	4	0.193
com1	35.028	38.987	49.810	61.478	46.326	11.877	4	0.256
com2	41.805	39.844	57.057	69.904	52.152	14.115	4	0.271
0.174	40.212	38.675	55.895	62.882	49.416	11.880	4	0.240
0.434	50.096	46.634	79.695	102.008	69.608	26.205	4	0.376
0.868	54.347	55.145	97.266	119.748	81.627	32.369	4	0.397
1.302	57.853	61.715	102.089	131.153	88.203	34.930	4	0.396
1.737	61.001	65.625	113.328	139.102	94.764	37.857	4	0.399
2.171	63.597	70.063	119.930	148.076	100.417	40.535	4	0.404
2.605	66.424	72.880	127.348	154.731	105.346	42.786	4	0.406
3.039	68.452	76.736	135.745	162.013	110.736	45.456	4	0.410
3.473	70.608	77.557	141.986	170.013	115.041	48.742	4	0.424
3.907	72.904	80.128	148.829	174.317	119.044	50.285	4	0.422
4.342	75.355	82.875	152.504	183.614	123.587	52.988	4	0.429
4.776	77.976	83.833	156.364	188.645	126.704	54.555	4	0.431
5.210	79.356	85.817	164.704	193.959	130.959	57.179	4	0.437
5.644	82.268	87.898	169.216	199.581	134.741	58.710	4	0.436
6.078	83.806	88.976	173.983	205.538	138.076	61.092	4	0.442
6.512	87.060	92.376	179.026	211.863	142.581	62.533	4	0.439
6.946	90.578	93.568	179.026	218.588	145.440	63.716	4	0.438
7.381	92.445	96.047	184.370	218.588	147.863	63.485	4	0.429
7.815	94.392	97.336	190.043	225.755	151.882	66.317	4	0.437
8.249	94.392	98.660	196.076	225.755	153.721	67.168	4	0.437
8.683	96.422	100.021	196.076	233.408	156.482	68.994	4	0.441
8.683	100.755	107.430	209.369	241.598	164.788	71.361	4	0.433
SPRINGBACK	73.202	83.351	126.695	146.501	107.437	34.876	4	0.325
						Average CV:		0.390

TABLE 18
LANDFILL REFUSE NON-PACKAGING PLASTIC EXPERIMENTS

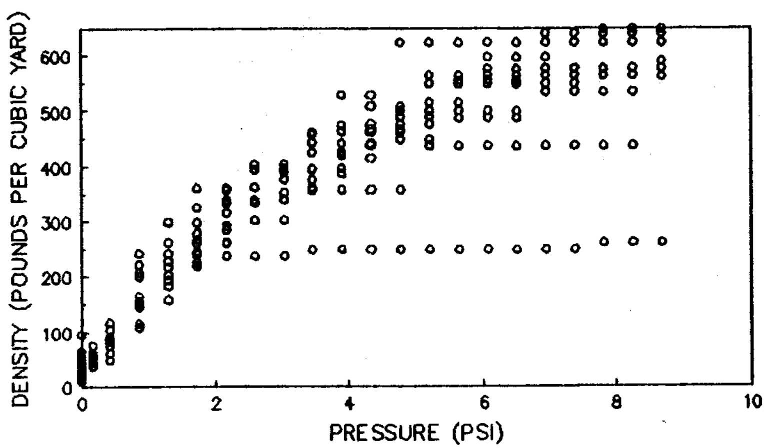
PSI	SAMPLE NUMBER 1	2	3	4	AVERAGE	STANDARD DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)							
in vol1	109.326	107.694	122.013	96.443	108.869	10.468	4	0.096
com1	119.614	136.436	107.290	109.476	118.204	13.288	4	0.112
com2	123.713	126.288	107.669	115.238	118.227	8.475	4	0.072
0.174	115.778	116.204	103.289	109.868	111.285	6.064	4	0.054
0.434	146.539	123.732	131.906	132.698	133.718	9.459	4	0.071
0.868	179.692	132.302	170.225	167.504	162.431	20.754	4	0.128
1.302	203.651	144.842	186.934	179.259	178.671	24.745	4	0.138
1.737	217.005	163.432	196.582	203.001	195.005	22.711	4	0.116
2.171	221.854	172.665	204.498	217.399	204.104	22.214	4	0.109
2.605	229.549	174.638	216.101	237.622	214.477	28.004	4	0.131
3.039	237.796	183.004	222.410	245.226	222.109	27.747	4	0.125
3.473	243.632	205.112	232.597	253.332	233.668	20.837	4	0.089
3.907	252.942	210.770	236.203	266.550	241.616	24.019	4	0.099
4.342	259.555	213.718	243.762	276.155	248.298	26.577	4	0.107
4.776	266.523	213.718	247.725	281.222	252.297	29.145	4	0.116
5.210	270.149	219.869	251.820	286.479	257.079	28.563	4	0.111
5.644	277.706	226.383	256.052	291.935	263.019	28.534	4	0.108
6.078	285.697	233.296	260.429	297.604	269.257	28.548	4	0.106
6.512	294.163	240.643	264.958	303.497	275.815	28.623	4	0.104
6.946	298.586	240.643	269.648	309.629	279.626	30.978	4	0.111
7.381	307.844	244.494	274.506	316.013	285.714	32.825	4	0.115
7.815	317.696	248.469	274.506	322.666	290.834	35.572	4	0.122
8.249	322.861	256.821	279.543	322.666	295.473	32.849	4	0.111
8.683	328.198	261.211	284.768	329.605	300.946	33.687	4	0.112
8.683	351.433	275.331	290.193	336.849	313.451	36.443	4	0.116
INGBACK	229.549	223.078	194.698	197.127	211.113	17.777	4	0.084
						Average CV:		0.106

TABLE 19
LANDFILL REFUSE COMPOSITE/MIXTURES EXPERIMENTS

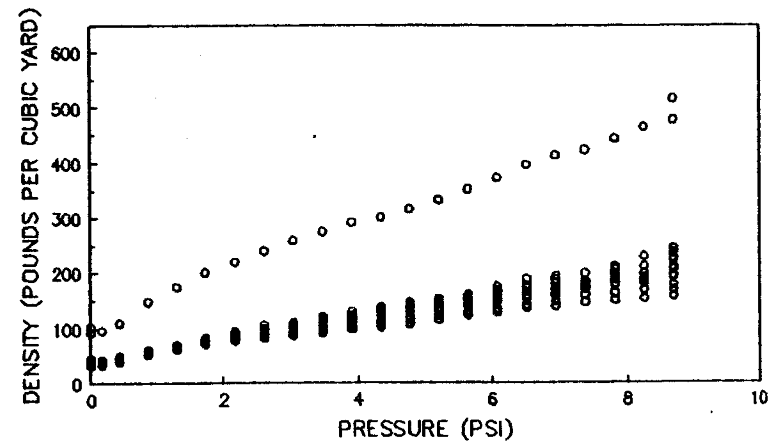
PSI	SAMPLE NUMBER 1	2	3	AVERAGE	STANDARD DEVIATION	N	CV
	(POUNDS PER CUBIC YARD)						
bin vol1	257.747	282.833	302.732	281.104	22.542	3	0.080
com1	261.230	401.317	271.296	311.281	78.135	3	0.251
com2	330.597	455.816	345.561	377.325	68.386	3	0.181
0.174	282.684	403.510	310.831	332.342	63.220	3	0.190
0.434	446.684	489.021	409.639	448.448	39.721	3	0.089
0.868	527.168	572.420	502.890	534.159	35.289	3	0.066
1.302	568.113	610.266	557.256	578.545	28.003	3	0.048
1.737	603.254	653.471	600.538	619.088	29.808	3	0.048
2.171	643.029	690.114	637.685	656.943	28.851	3	0.044
2.605	672.593	716.915	665.112	684.874	28.000	3	0.041
3.039	705.008	745.881	695.005	715.298	26.954	3	0.038
3.473	740.704	794.003	727.711	754.139	35.129	3	0.047
3.907	759.943	829.688	745.247	778.293	45.112	3	0.058
4.342	780.208	848.761	763.648	797.539	45.126	3	0.057
4.776	801.584	889.666	782.981	824.743	56.989	3	0.069
5.210	801.584	911.633	803.318	838.845	63.042	3	0.075
5.644	824.164	934.712	847.335	868.737	58.299	3	0.067
6.078	824.164	934.712	847.335	868.737	58.299	3	0.067
6.512	848.053	958.990	871.204	892.749	58.523	3	0.066
6.946	873.368	984.563	896.456	918.129	58.681	3	0.064
7.381	873.368	984.563	951.622	936.518	57.116	3	0.061
7.815	900.240	1011.538	981.833	964.537	57.629	3	0.060
8.249	900.240	1040.032	981.833	974.035	70.221	3	0.072
8.683	900.240	1040.032	981.833	974.035	70.221	3	0.072
8.683	959.273	1070.177	1014.024	1014.491	55.454	3	0.055
SPRINGBACK	700.786	798.295	710.982	736.688	53.596	3	0.073
					Average CV:		0.078

FIGURES 5 TO 8
FRESH REFUSE COMPACTION EXPERIMENTS

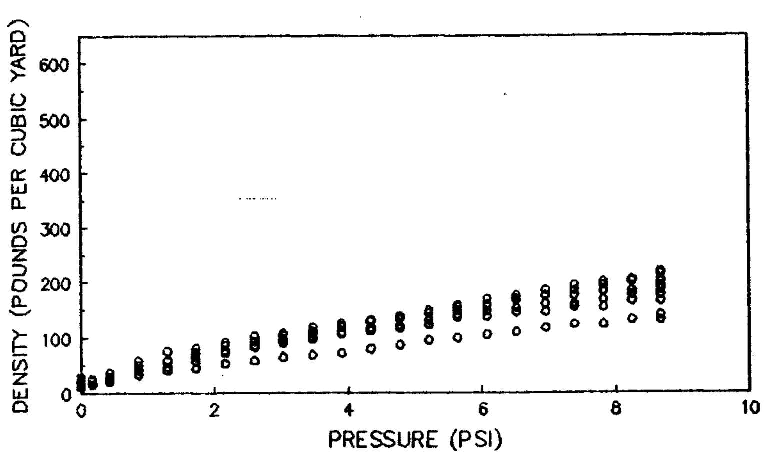
PLASTIC FILM PACKAGING



PLASTIC RIGID PACKAGING CONTAINERS



OTHER PLASTIC PACKAGING



NON-PACKAGING PLASTIC

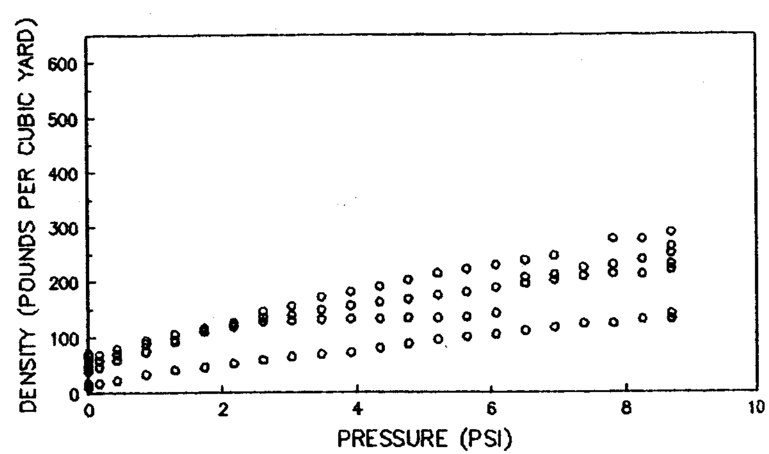


TABLE 20
AVERAGE TRASH-CAN AND LANDFILL DENSITIES
WITH 95 PERCENT CONFIDENCE INTERVALS

	TRASH-CAN DENSITY		LANDFILL DENSITY	
	Pounds per cubic yard			
REFUSE TYPE	AVERAGE	95 % c.i.	AVERAGE	95% c.i.
Non-packaging Paper	170.484	+/- 60.559	798.255	+/- 37.818
Corrugated	42.701	+/- 13.052	750.218	+/- 44.632
Paperboard Boxes	41.644	+/- 6.626	819.059	+/-138.842
Other Packaging Paper	48.219	+/- 6.167	740.199	+/-157.896
Plastic Film Packaging	83.884	+/- 12.159	667.164	+/- 65.752
Plastic Rigid Pack. Cont.	52.516	+/- 12.577	354.531	+/- 26.188
Other Plastic Packaging	28.389	+/- 4.378	164.788	+/- 69.934
Non-packaging Plastic	69.145	+/- 11.439	313.451	+/- 35.714
Composite/Mixtures	202.553	+/- 57.009	1014.491	+/- 62.752

TABLE 21
AVERAGE AND MEDIAN DENSITIES FOR REFUSE CATEGORIES AS EXCAVATED FROM FIVE STUDY LANDFILLS

TYPE		NON-ZERO CASES	*DENSITY (Lbs/cu yd)* *MEAN*	*MEDIAN*	SKEWNESS	COMPACTION STUDY AVERAGE (BIN VOL.1)
Glass		110	2581.7	1199.8	10.4	N
Metal	Aluminum	101	108.7	90.5	1.39	N
	Steel	111	557.4	486.5	3.58	N
Plastic	Clear/Rigid	30	228.6	207.6	5.17	99.5 [1]
	Colored/Rig.	36	189.7	202.0	3.61	99.5 [1]
	Foam	34	184.3	170.2	4.98	41.8 [2]
	Film	36	127.2	102.9	0.00	36.5 [3]
	Total	111	154.3	113.9	7.36	N
Paper	Corrugated	80	243.7	216.0	0.88	116.6 [4]
	Glossy Mags	56	619.9	460.6	7.27	N
	Newsprint	109	321.5	253.1	6.52	226 [5]
	Non-Package	107	257.2	214.6	1.29	226 [5]
	Packaging	109	217.6	206.3	0.51	191 [6]
Organics	Food	95	422.2	426.7	-1.63	N
	Wood	105	354.0	323.2	0.54	N
	Yard	105	212.8	162.6	1.33	N
Other						
	QSR Pack.	39	66.4	49.8	1.37	N
	Diapers	66	176.4	121.4	1.84	281.1 [7]
	Rubber	65	343.2	343.2	0.87	N
	Textiles	105	201.4	180.8	0.69	N
	Dirt	22	1598.6	1625.4	0.41	N
	Fines	106	1708.2	1424.2	9.64	N
	Rocks	46	1780.2	1845.7	0.28	N

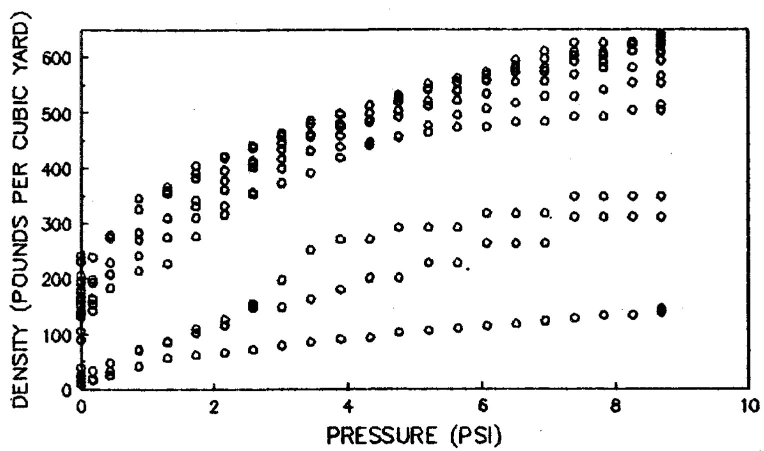
Notes:
N = not studied.
1 = rigid plastic containers
2 = non-packaging plastic
3 = plastic film packaging
4 = corrugated cardboard packaging
5 = non-packaging paper
6 = paperboard boxes
7 = composite/mixtures

Trace volumes of materials measured in the field were assigned volumes based on those samples having non-trace volume measurements for a material category.

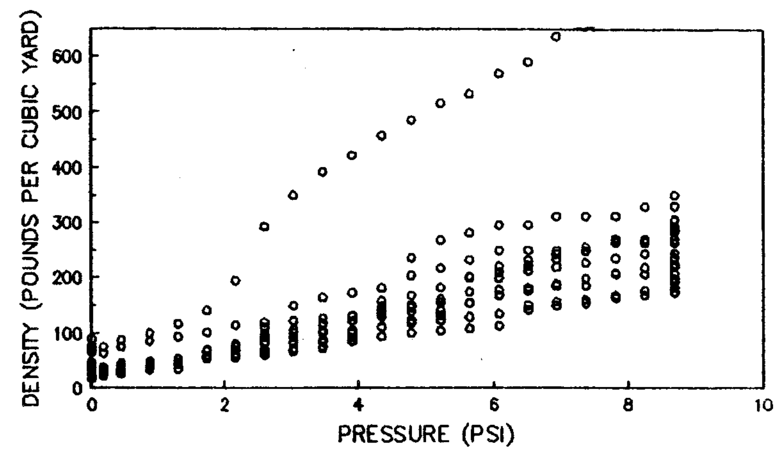
FIGURES 1 TO 4

FRESH REFUSE COMPACTION EXPERIMENTS

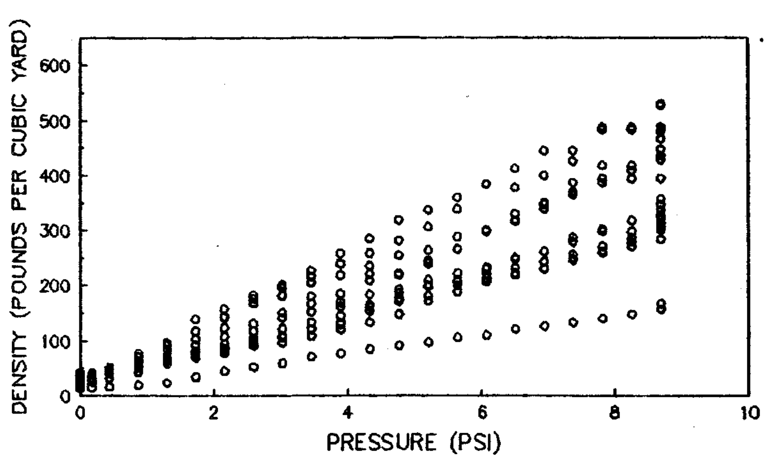
NON-PACKAGING PAPER



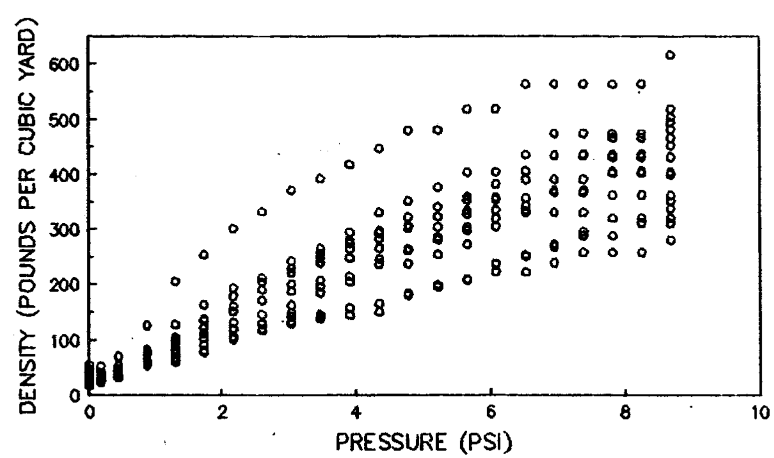
CORREGATED CARDBOARD PACKAGING



PAPERBOARD BOXES

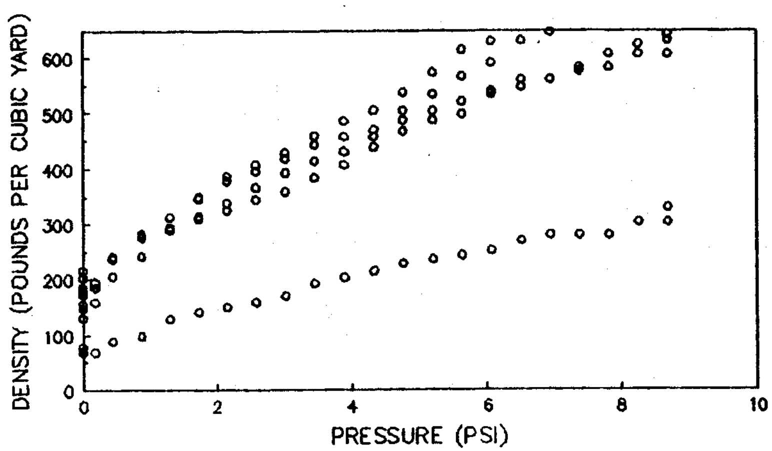


OTHER PACKAGING PAPER AND PAPERBOARD

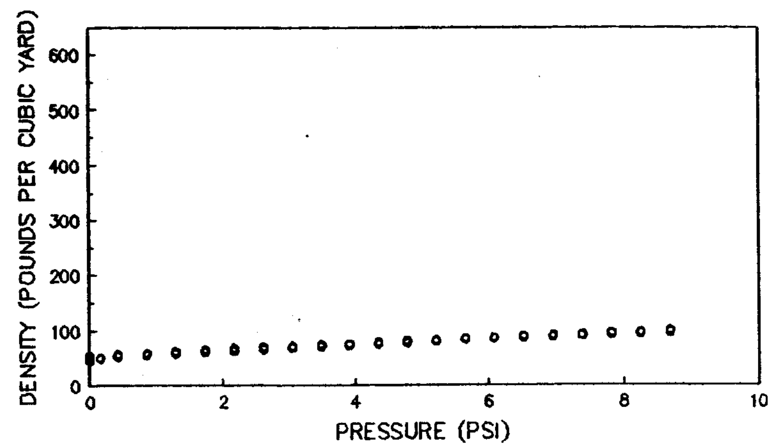


FIGURES 9 AND 10
FRESH REFUSE COMPACTION EXPERIMENTS

COMPOSITE/MIXTURES

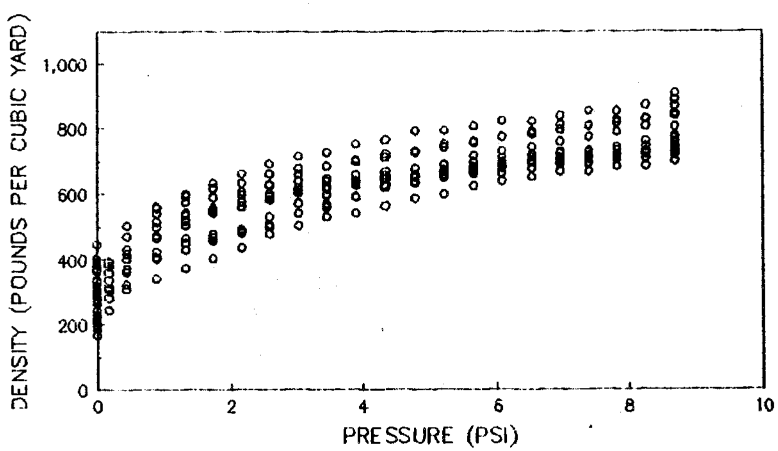


ALUMINUM CANS

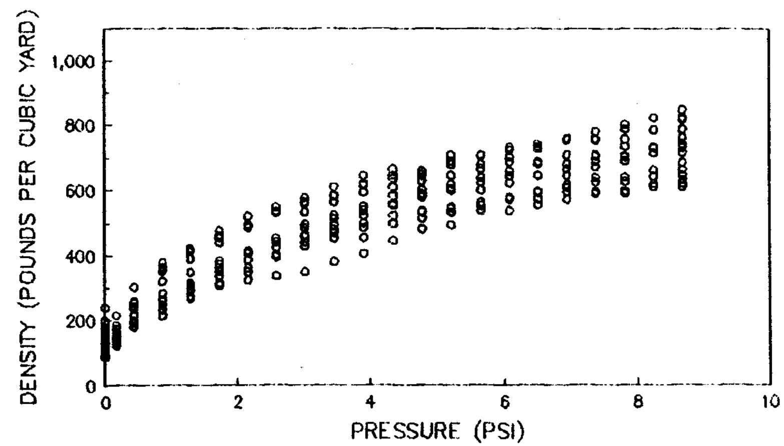


FIGURES 11 TO 14
LANDFILL REFUSE COMPACTION EXPERIMENTS

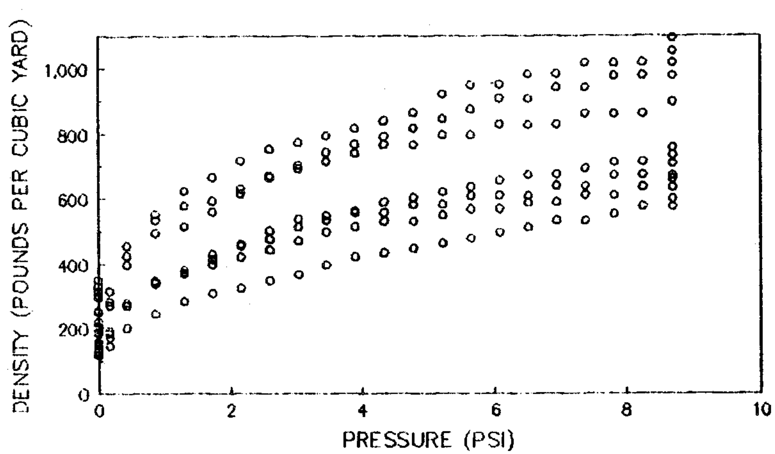
NON-PACKAGING PAPER



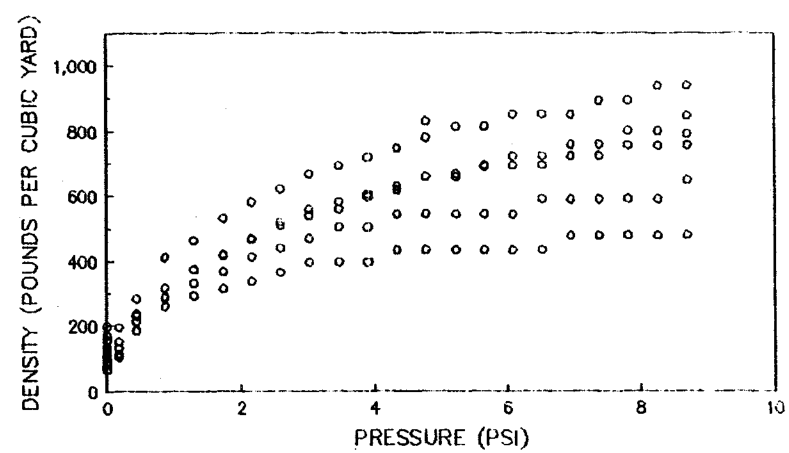
CORRUGATED CARDBOARD PACKAGING



PAPERBOARD BOXES

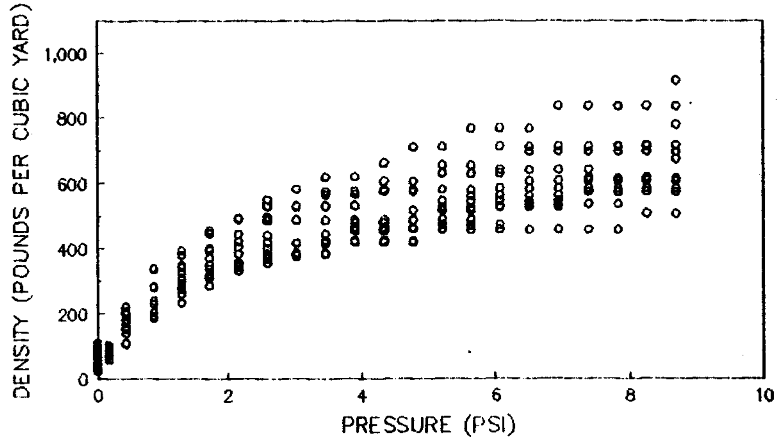


OTHER PACKAGING AND PAPERBOARD

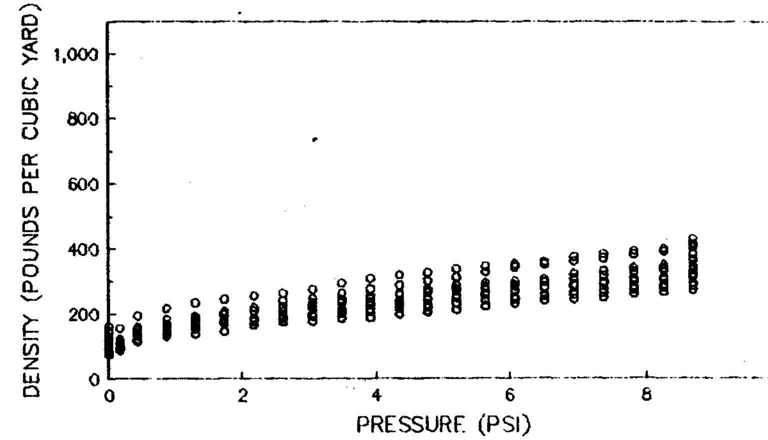


FIGURES 15 TO 18
LANDFILL REFUSE COMPACTION EXPERIMENTS

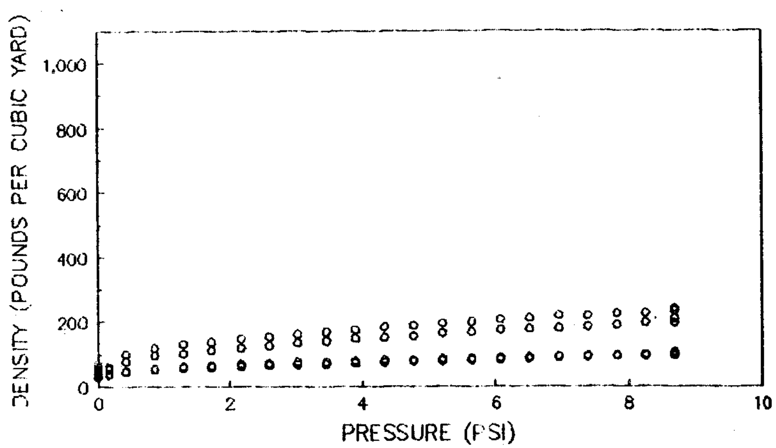
PLASTIC FILM PACKAGING



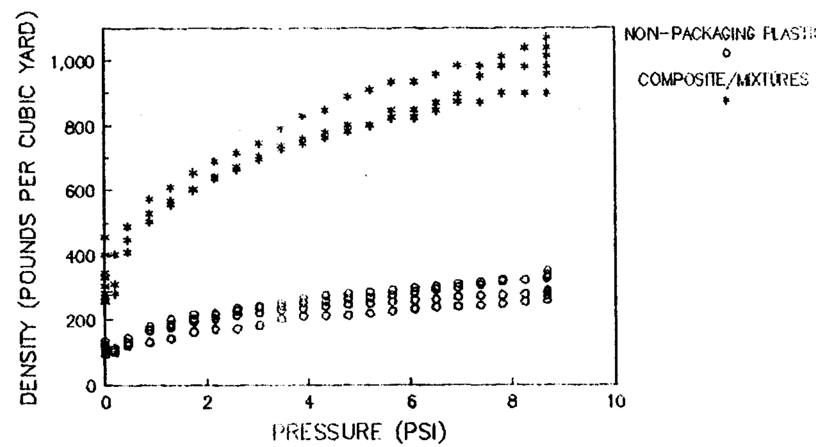
PLASTIC RIGID PACKAGING CONTAINERS



OTHER PLASTIC PACKAGING



NON-PACKAGING PLASTIC AND COMPOSITE/MIXTURES



FORM 1

GARBAGE PROJECT CRUSH STUDY CODE LIST (S-89)

A NON-PACKAGING PAPER

- paper plates, tissues, mail, stationary, magazines, newsprint

B CORREGATED CARDBOARD PACKAGING

C PAPERBOARD BOXES

- food boxes (cereals, etc.), detergent boxes, milk cartons

D OTHER PACKAGING PAPER & PAPERBOARD

- paper bags and wrapping papers, paper towel rolls, moulded pulp egg cartons, bottle/can holders, butcher paper

E PLASTIC FILM PACKAGING

- bags and wrappers (trash, food, etc.), baggies, food wrap films

F PLASTIC RIGID PACKAGING CONTAINERS

- bottles, jars, tubs and lids, microwave trays, hard cosmetic cases

G OTHER PLASTIC PACKAGING

- cookie trays, six-pack rings and holders, flexible tubes, all polystyrene foam

H NON-PACKAGING PLASTIC

- plastic cups and utensils, pens, razors, toys, etc.

I COMPOSITE/MIXTURES (papers & plastics)

- blister packs, juice concentrate containers, spiral wound dought containers, diapers

ATERIALS VOLUME MEASURING AND COMPACTION RECORDING FORM

D.WILSON 5-16-89 FRK

NUMBER B-5 WEIGHT 14.20 MATERIAL CORC
YEAR(S) 1989 TYPE FR PLATE OPEN
SAMPLE(S) ~~~~
BIN VOL1 32 ~~BIN VOL2~~

NUMBER	PSI	INCHES	EIGHTHS
COM1,#1	0	27	Ø
COM1,#2	0	28	Ø
COM1,#3	0	27	Ø
COM1,#4	0	26	Ø
COM2,#1		29	1
COM2,#2		30	Ø
COM2,#3		27	3
COM2,#4		26	3
CONTACT	2	29	Ø
1	5	25	Ø
2	10	22	Ø
3	15	19	Ø
4	20	16	Ø
5	25	12	Ø
6	30	8	4
7	35	7	3
8	40	6	6
9	45	6	3
10	50	6	Ø
11	55	5	6
12	60	5	4
13	65	5	3
14	70	5	1
15	75	5	Ø
16	80	4	6
17	85	4	5
18	90	4	4
19	95	4	3
20	100	4	2
30 SEC	100	4	1
OM3,#1		5	Ø
OM3,#2		5	4
OM3,#3		5	6
OM3,#4		5	4

NOTES

TYPE = LANDFILL(LF)
FRESH(FR)
PLATE = OPEN(OP)
CLOSED(CL)
BIN VOL1 = UNCOMPACTED
BIN VOL2 = COMPACTED
COM1 = NO PLATE
COM2 = WITH PLATE
COM3 = FINAL

3

APPENDIX C

Appendix C

IDENTIFICATION OF HIGH-INTEREST SEGMENTS OF SOLID WASTE

The composition of the nation's household and commercial solid waste stream in 1986 is summarized in Table C-1. On a weight basis, manufactured products account for 69.1 percent of all wastes, with packaging being the single largest component, accounting for 30.3 percent of all waste by weight. People are most familiar, however, with what ends up in their own trash cans at home, and what is discarded at food service establishments, parks, and other public places, as well as what they see in litter. They are also aware, but to a lesser extent, of what is visible in the trash cans where they work.

Table C-1

MUNICIPAL SOLID WASTE -
HOUSEHOLD AND COMMERCIAL SOLID WASTE COMPOSITION - 1986
(In percent by weight)

Durable goods (major appliances, tires, etc.)	13.6
Nondurable goods (printed paper, etc.)	25.2
Packaging	30.3
Product Subtotal	69.1
Food wastes	8.9
Yard wastes	20.1
Miscellaneous inorganics	1.8
Total	100.0

Source: Franklin Associates, Ltd.

The two primary areas of highly visible solid waste identified are packaging and living area wastes. Packaging includes all packaging materials whether discarded at or away from home. Table C-2 summarizes the weight data of packaging for 1986, as reported in Reference 15 and repeated in Appendix Table A-2.

The second highly visible category of MSW is the living area wastes, which are those materials discarded to trash cans inside homes, primarily kitchen and bedroom trash cans.

Three broad categories of trash were selected from Table C-1 for the initial definition of living area trash. These are (1) nondurable goods, (2) packaging, and (3) food wastes. Excluded are durable goods (major appliances, etc.), yard wastes, and miscellaneous inorganics. These items are stored outside living areas or set out for trash pickup separate from the living area trash.

The values for the living area trash categories shown in Table C-3 were derived by reducing total MSW categories to reflect discards at businesses and other sites away from home, as detailed in Appendix Table A-2. For example, office papers are discarded primarily in businesses, as are corrugated containers,

Table C-2

NET DISCARDS OF PACKAGING MATERIALS, 1986
(Million tons per year)

	Million Tons
Glass Containers	
Beer and soft drink	4.4
Other containers	6.3
Subtotal	10.7
Steel Containers	
Beer and soft drink	0.1
Food cans	1.7
Other packaging	0.9
Subtotal	2.7
Aluminum	
Beer and soft drink	0.7
Other packaging	0.4
Subtotal	1.1
Paper and Paperboard	
Corrugated	11.4
Other paperboard	5.1
Paper packaging	3.9
Subtotal	20.4
Plastics	
Film	2.0
Rigid containers	2.8
Other packaging	0.8
Subtotal	5.6
Wood Packaging	2.1
Other Miscellaneous Packaging	0.2
Total	42.8

Source: Franklin Associates, Ltd.

so amounts were subtracted from total MSW to reflect this. In a similar fashion, each of the 30 MSW categories was adjusted to develop estimates of quantities discarded in household living areas.

The second fractional component of MSW selected for detailed study was packaging. This category was much easier to derive from the MSW database, as it is already detailed sufficiently. The amounts are summarized in Table C-4.

Table C-4 also shows that the packaging portion of the waste stream is about 31 percent of the total waste stream (by weight). Living area trash is 36 percent of the MSW waste stream, with living area consumer packaging being 16 percent of the MSW total, nondurable goods being 16 percent, and food waste, 4 percent.

DESCRIPTION OF PACKAGING AND LIVING AREA WASTES

Packaging

This category of waste includes items that are used to surround, protect, and label other products or materials bought

Table C-3

NET DISCARDS TO LIVING AREA TRASH CANS, 1986
(Million tons per year)

Packaging	
Glass	8.9
Metal	2.5
Paper	6.8
Plastics	4.4
Other	0.1
Subtotal	22.7
Nondurable Goods	
Paper	17.9
Plastic	1.6
Other	2.6
Subtotal	22.1
Food	6.3
Total	51.1

Source: Franklin Associates, Ltd.

Table C-4

TWO HIGHLY VISIBLE COMPONENTS OF MUNICIPAL SOLID WASTE, 1986

	Weight (million tons/year)	Percent of Total Waste Stream*
Packaging Discarded at All Locations	42.8	31
Living Area Trash		
Packaging**	22.7	16
Nondurable goods	22.1	16
Food	6.3	4
Subtotal	51.1	36

* Total net discards of MSW for 1986 was 141 million tons (after recovery for recycling).
** Note that packaging and living area trash overlap to some degree, with some packaging discarded in living areas.

Source: Franklin Associates, Ltd.

by individual consumers or businesses. The items included in this category either end up at home, are used for very short times and discarded elsewhere, or are discarded by commercial or small manufacturing businesses. Included are disposable food and beverage service either carried out or consumed on premises and discarded there. Listed below are the material and major subdivisions of package types.

Glass Containers

Beer and soft drink bottles
Wine and liquor bottles
Food and other bottles and jars

Steel Containers

Beer and soft drink cans
Food cans
Pails and other

Aluminum Packaging

Beer and soft drink cans
Food cans, foil, trays, closures, and other

Paper and Paperboard Packaging

Corrugated containers (pizza boxes, mail order or delivery boxes, etc.)
Other paperboard boxes, separators, and other paperboard packaging
Paper bags and sacks, wrapping paper, and other paper packaging

Plastics Packaging

Bottles, jars, closures, and other rigid containers
Bags, sacks, and other film
Foam, rigid containers, and other

Other Packaging

Miscellaneous (textiles, leather, string, tape, etc.)
Composites or mixtures of materials

Living Area Trash

About one-half of living area wastes are packaging and the other half is nondurable goods. Nondurable goods are primarily paper and plastic products, which are produced, used, and discarded in a relatively short period of time ranging from a few minutes to a few years. This is in contrast to durable goods, which include major appliances, tires, furniture, and other items intended to last many years. Examination of discarded household wastes shows the following as being the major subdivisions of this category:

Newspapers
Books and magazines
Mail
Tissues and towels
Plates, cups, tableware, coverings and other nonpackaging paper and plastic film
Clothing and footwear
Toys, games, and other miscellaneous nondurables.