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DEVELOPMENT OF A TRASH HANDLING SUBSYSTEM FOR A MANNED SPACECRAFT

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ABSTRACT

A prototype laboratory system to shred and transport trash material within a spacecraft has been designed and demonstrated. In addition to handling the normal trash materials, the system demonstrated the ability to handle or reject (if it is too tough) glass, metal and ceramics without damaging the system. The system is not dependent on liquids for the shredding and transportation and can transport slurried, damp or dry material. The resulting system offers a greater system flexibility with operational reliability.

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SUMMARY

The primary objective of this program was to demonstrate techniques for shredding a variety of nonmetallic materials and transporting the shredded waste to a reactor. The reactor design was not a part of this effort. Power and weight were not seriously considered, and manual assistance by crew members was allowed. The shredder is pictured in Figure 1. The final system schematic configuration is shown in Figure 2.

The conventional problems of tangling, bridging, and jamming in shredding were overcome by the use of a unique cutting system and by not trying to shred to a uniform and very small size. This cutting system is a very significant improvement over previous shredder designs and is the most important point determined during this program. It prevents an accidental inclusion from destroying and shutting down the shredder. For instance, it would operate despite the introduction, through human error, of materials outside the design specification. This could include almost anything not listed in the Statement of Work (SOW), including such materials as metal pens and clips, needles from syringes, and possibly food cans and lids. Any one of these metallic materials could damage or destroy a system designed only for the material specified in the SOW.

The reduced material is manually transported in batches through a tube by a series of drag pistons which clears the waste from the tubing sides and does not allow the accumulation of refuse by sticking or blocking. Whether the waste is moist or dry does not affect this technique. Each batch is swept through the tube together and the separation of the particles and moisture within the batch does not affect the transport of the solids. The waste can be transported through a moderate 90 deg bend with this method.

The hardware developed under this contract successfully demonstrated these two techniques. The concepts for closing off the transfer tubing and transport device and the inlet to the reactor, and the location of the waste within the hypothetical reactor, were not hardware development requirements. The reactor and the reactor inlet valve were considered in the transport mechanism and designed only in a general way. An inlet segment to close off the reactor and transfer tubing was conceived of as a ball valve and the reactor as providing a set of wiper blades that can be positioned within the reactor to clear the transport device before it is returned to the shredder.

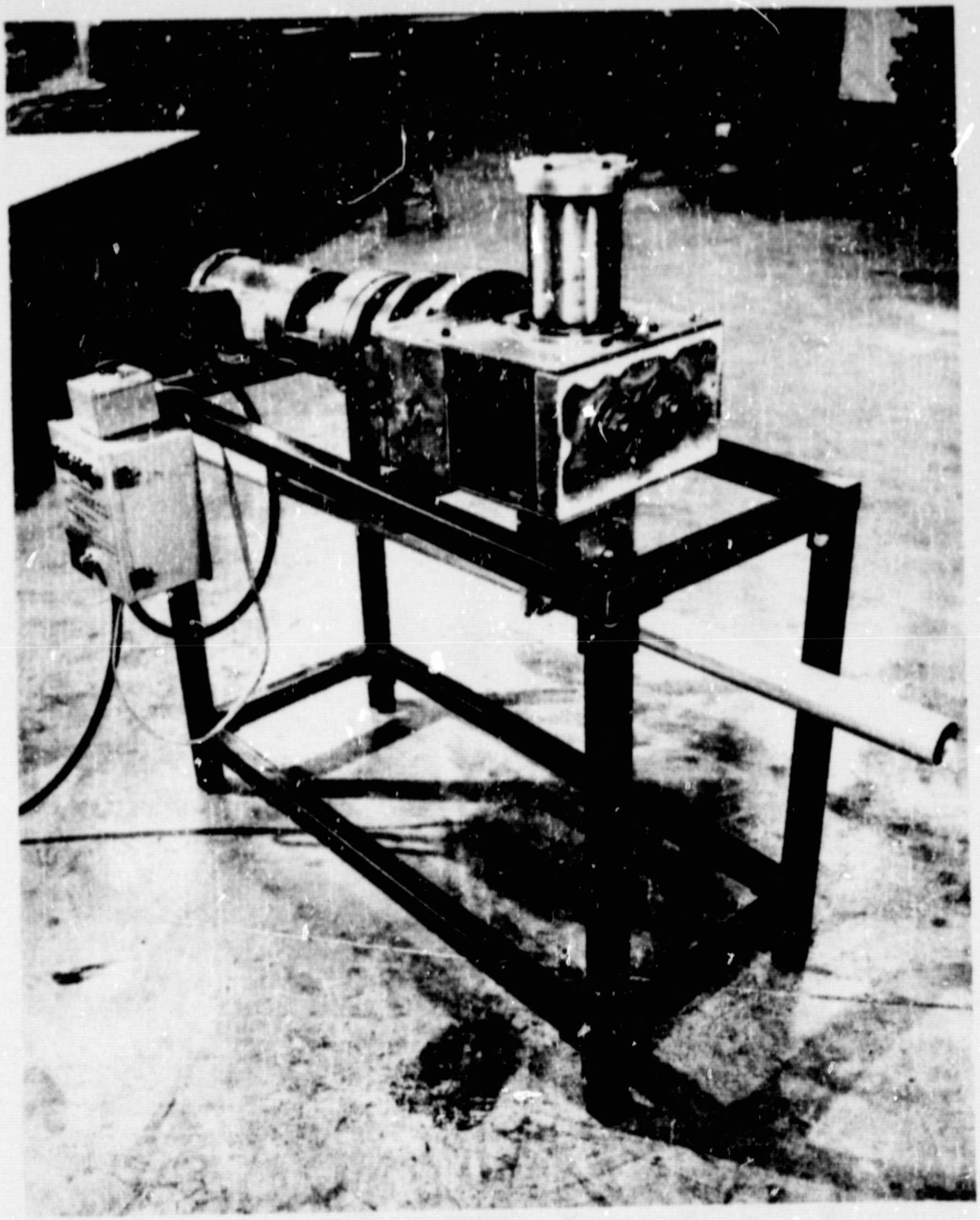

Figure 1. - Shredder system.

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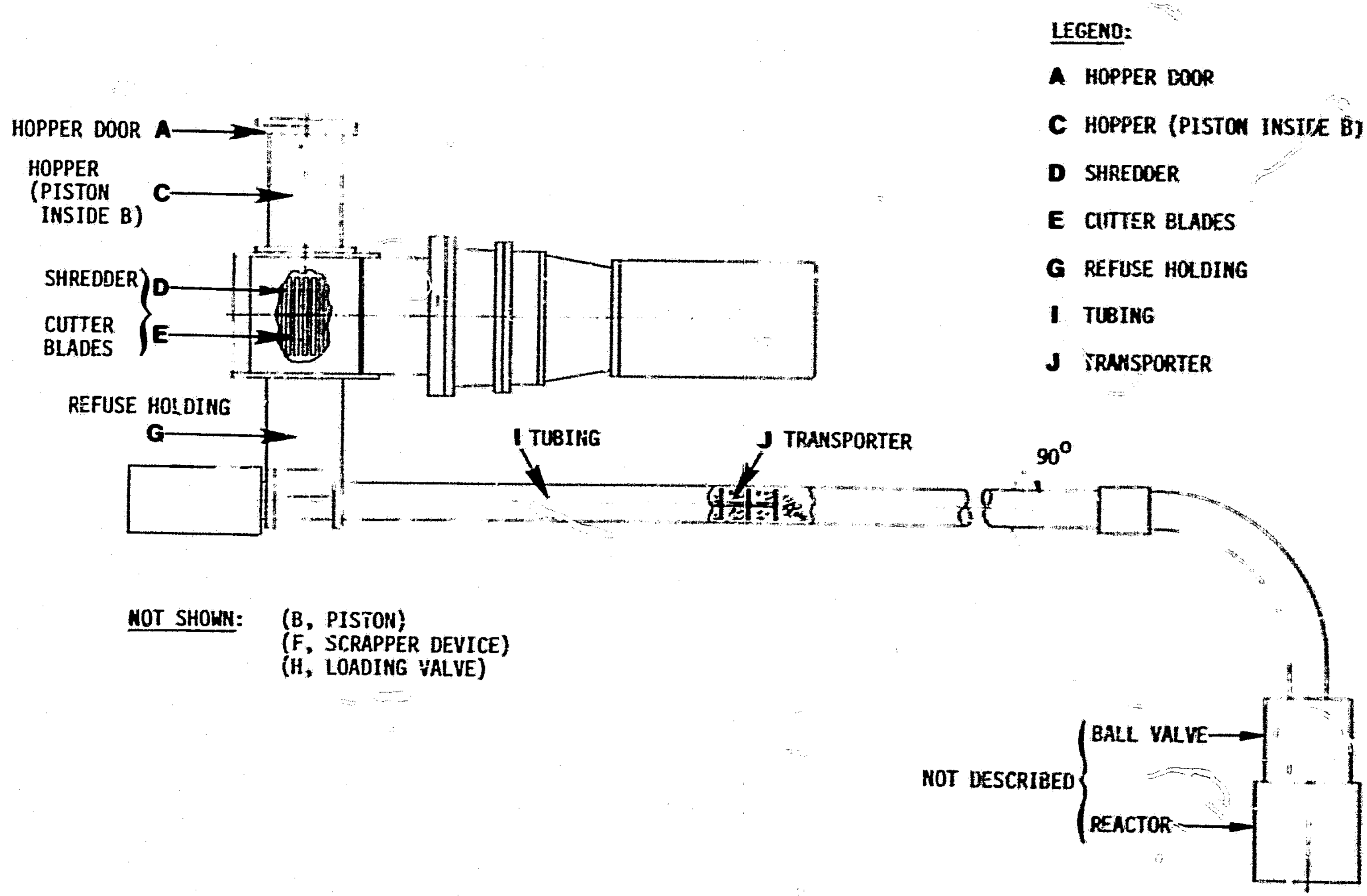
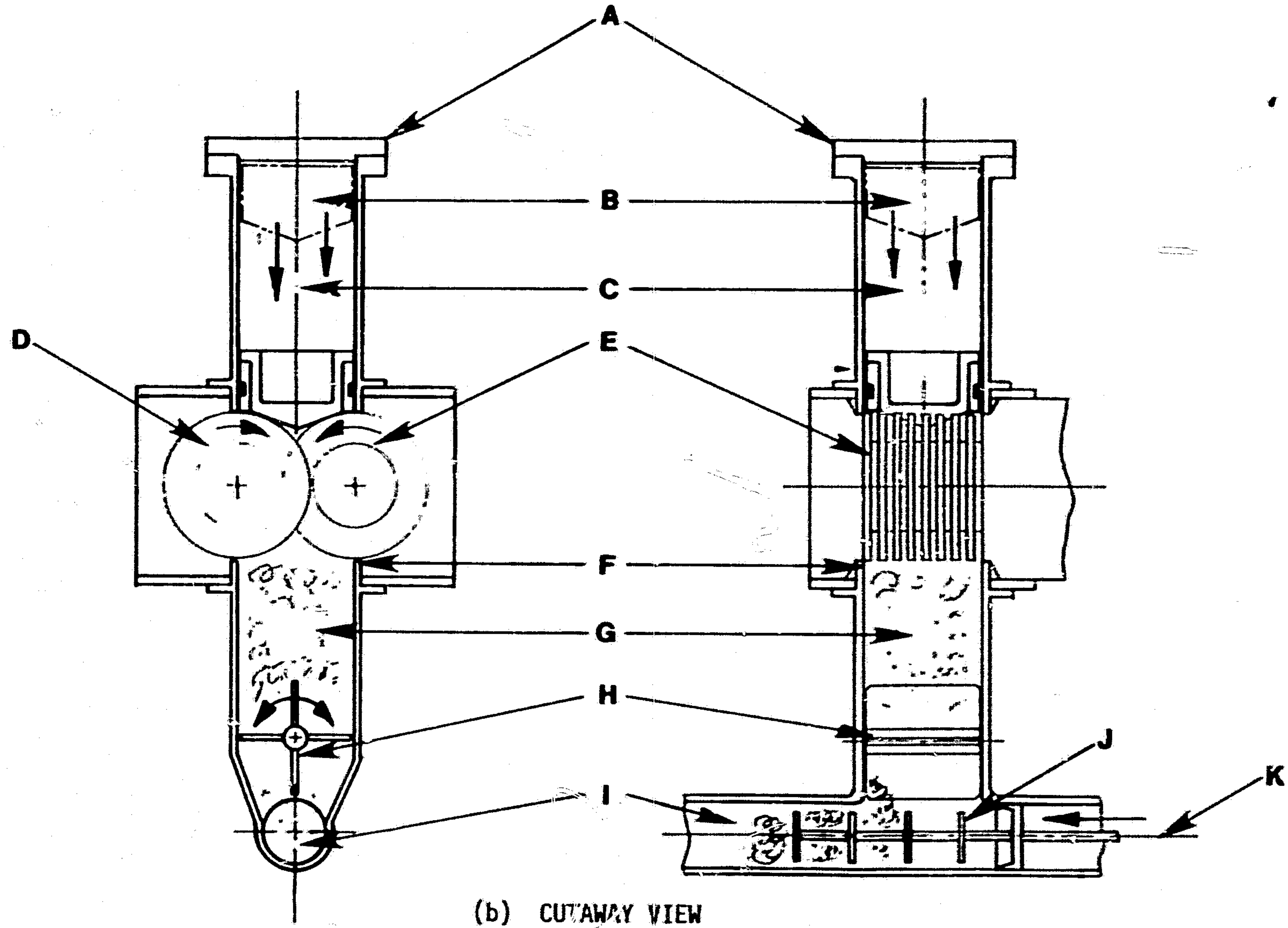


(a) SIDE VIEW

Figure 2. - Complete system configuration.



(b) CUTAWAY VIEW

Figure 2. - Concluded.

RESULTS AND CONCLUSIONS

Results

The results of this program are shown in Table 1. Once the machine has been loaded, the normal running current is 0.95 kW. With a full load (cotton cloth, plastic bags, cans and cardboard) the motor loading can be as high as 5.4 kW.

Conclusions

The prototype trash handling system demonstrated the ability to handle the normal trash expected in a spacecraft. In addition, material such as metal cans and glass was also handled. The shredder was able to handle stringy material which has defeated most if not all other trash reducing mechanisms. The transport system, a series of disks on a flexible shaft which moves within a tube, was able to carry the shredded refuse without plugging.

The prototype system has demonstrated the concept as viable. To be used in actual spacecraft operation, development of the entire system is required. Specific problem areas are:

- Cutter tooth hardness and life
- Weight and strength of shredder components
- Valve and seals
- Ejection method in the reactor
- Transport disk wear
- Automation
- Power and weight reduction.

All of the above areas are soluble problems, and, when solved, will result in a reliable system.

TABLE 1. - RESULTS

Tests	Power (kW)
Start-up current	3
Running current	0.9
Soda cans	2.2 - 2.5
Cotton cloth	1.65 - 1.85
Polyethylene bags	1.35 - 1.65
Cardboard	0.95

INTRODUCTION

This program was intended to be one of the front-end development tasks in life support that is required to allow realistic planning of future manned spacecraft missions that could have long periods between resupply. This type of mission would require efficient housekeeping practices, and the use of a closed-type life-support system. A closed-type life-support system might require the processing of many kinds of trash to allow ultimately the recovery of water and O_2, and perhaps other useful substances, and to alleviate storage problems of bulky, sometimes noxious substances which may serve as a growth medium for microorganisms.

The objective of this particular contract was to design, develop, and test a working engineering model of a trash handling subsystem suitable for a manned spacecraft mission requiring reclamation-type life-support systems. The contract required Foster-Miller Associates, Inc. (FMA) to demonstrate the design of the trash handling subsystem with a full-scale working model, but not to integrate it with a reactor or reaction process during this program.

The primary problems in processing trash for the above purposes are:

- Preparing or shredding the trash so that it can be pumped through tubing and into a closed space or reactor
- Pumping the prepared trash through connecting tubing including bends, through valve(s) and into a reactor for processing
- Accomplishing the preparation and transfer reliably and with a minimum of power, weight, complexity and manual help.

Prior to this program, the shredding, pulverizing, and transferring of trash materials had been unsuccessful. The trash pulverizer component of the trash handling subsystem had not performed satisfactorily for several reasons. The main reason is that several different types of systems are needed to grind a variety of materials. Table 2 indicates the physical characteristics of common materials and a potential method for size reduction.

TABLE 2. - PHYSICAL CHARACTERISTICS OF WASTE

Type of refuse	Shape	Material type	Possible method of disintegration
Paper	Flat, thin sheets boxes	Short fibers pulpable	Shearing, tearing, preferably at high velocity, wet
Wood	Rods, flats	Fibrous	Shearing, tearing, crushing
Cloth	Thin sheets	Long fibers	Shearing, tearing
Plastics	Thin sheets or hollow containers, foam	Very ductile	Shearing, tearing
Plastics	Utensils	Brittle	Shearing, crushing, impact
Metals	Hollow containers, continuous flat thin sheets	Ductile	Shearing, tearing
Ceramic and glass	Hollow bottle, flats	Brittle	Fracture by crushing, impact, no shearing
Wire	Rods	Ductile	Shearing

The physical characteristics of each of these types of waste require a specific reduction technique (that is, plastics require shearing, crushing or impact); even differing configurations of the same material necessitate system changes. A major problem was that a system capable of shearing or tearing was usually not capable of fracturing or crushing. Therefore, the solution for the reduction of one material has resulted in system jamming by another material. Grinding tests conducted at FMA showed that heavy or brittle materials like plastic, wood and metal are fractured quickly and tend to bridge or jam cutters designed for the softer components of refuse. The brittle materials would tend to settle to the bottom of the refuse chamber.

FMA was contracted by NASA to develop techniques for shredding trash and transporting the shredded trash through tubing and into a reactor, and to demonstrate the concepts with an engineering model. This program involved the following steps:

- Develop detailed problem description

- Analyze concepts which have a high probability of successfully delivering pulverized wastes to the disposal reactor

- Develop design specifications which include a functional description of material handling requirements; also specify power requirements, flow rates, material size, wet/dry handling problems

- Conceptual design and analyses which will show system configuration

- Design concept testing

- Demonstrate model waste handling system.

Commercial applications have only had a limited success in shredding a heterogeneous mixture of trash until recently. The first part of this problem involves material reduction. Each material outlined in the SOW had to be reduced by a specific process (see Table 2) whether it be cutting, shredding, grinding, shearing, fracturing, or some sort of nipping or jointer action. When the material to be reduced is a mixture of materials and fed to any of these processes, the reduction system has usually proved to be ineffectual. Often the power required to operate is excessive, or material binding and clogging literally defeats the shredding device.

The second part of the problem is material transport, and this, in many ways, is an equally difficult problem. The major difficulty was the transport of the reduced waste from the shredder through tubing, bend(s), valve(s), and into a reactor. Since the reactor may process the waste at an elevated temperature and pressure, the inlet to the reactor may have to be sealed after the waste is injected into the reactor. NASA has awarded several previous contracts to address the material reduction and transport problem. The previous work done for NASA indicated that mixed refuse tended to form plugs at bends or projections inside a tube even when extreme methods of material reduction were employed such as micro-pulverization which may reduce refuse to 0.1 mm, but requires heavy equipment and a great deal of power. Very dry waste has not been as big a problem as very wet or moist waste is.

A further complication arises when very small quantities of waste have to be transported any significant distance. This distance can be anything greater than five times the diameter of the transport tube. Only in very special cases has refuse transport been successful.

Acknowledgements

Mr. Mackenzie Burnett was the Division Manager, Mr. Robert W. George was the Program Manager, and Dr. James Hannoosh and Mr. Andrew Harvey were the Technical Advisors. Mr. Michael Lima was Project Manager, Technical Contributor, Creative Consultant, and the prime moving force throughout the program with Tom Gardner and Paul Tremblay, Jr., as technicians. Mr. Rex Martin was the Technical Monitor for NASA, Johnson Space Center, on this program.

CUTTER-SHREDDER CONCEPTS

A number of grinder concepts were evaluated with respect to grinder performance over a range of refuse materials using the following criteria: primarily, it must work reliably. Secondarily, it should be low in power consumption, compact and be simple in method of operation. For this contract, FMA conducted a survey of existing grinding techniques in available systems (see Table 3), and selected three grinding concepts for further study:

- Hydropulpers; this high speed impact unit depends upon high clearance and dull appendages to break and tear wet refuse; rinse to prevent plugging

- Disk mills depend upon low speed, high clearance with dull appendages to crush and tear material; rinse necessary to clear plugging

- Disposers vary in approach with sharp or dull blades rotating at high speeds with high clearance for shearing and tearing; rinsing to clear plugging is also necessary.

Dry grinding concepts were initially eliminated because of increased power requirements, noise, dust, and more importantly because they could not handle the range of materials. Of the three concepts originally selected for further evaluation each was discarded because of individual limitations:

- Hydropulpers cannot handle ductile plastics and textiles, because they blind over and plug with ductile materials

- Disk mills are blinded and plugged by textiles primarily because the fibrous material cannot be shredded in small pieces but tends to form long strings

- Disposers, because sharp blades work on soft refuse, but aluminum or heavy plastic dull the blades and then the disposers will not comminute soft material very well.

The physical characteristics of the waste materials that were required to be shredded by the SOW and some materials that could accidentally be included in a waste batch are described in Table 3.

TABLE 3. - CLASSIFICATION OF SIZE REDUCTION METHODS

Type of grinding equipment	Basic grinding process	Type of size reduction operation	Type of refuse processable	Size of grinds	Typical manufacturers	Comments
Hammermills	Tension Compression Shear	High-speed impact and high clearance shearing (tearing), dull hammers	Almost all types of mixed refuse, very ductile (plastic) items are difficult, as are textiles	1/2 to 4 in. depending on equipment size, junk rejection possible	Williams Co. CF and I Engineers Eagle Crusher Co. Link Belt/FMC Corp. Jeffrey Mfg. Co. Taylor Stiles Div. Envirotech Gruendler Co.	Massive equipment, noisy and dusty, high initial and operating cost, feed-rate sensitive, high power consumption, sizing by attrition
Shears	Shear	Low-speed, relatively sharp, low clearance	All but hard brittle feeds	All sizes possible but generally used for bulk reduction, ductile materials	Lindemann Von Roll	Massive equipment, low throughput, high initial cost, damaged by hard objects, accurate feed required
Shredders, Cutters	Shear Tension	High-speed, low clearance, sharp blades	All but hard brittle feeds, can do light gauge metals	Generally in 1/8 to 1-1/2 in. range	Taylor Stiles Div. Envirotech Entoleter, Inc. Hescor Ind., Inc. Young Industries Dorr-Oliver Co.	Very prone to jams and damage, high maintenance costs, accurate feed rate usually required
Crushers	Compression	Low-speed crushing, high speed impact, dull members	Brittle, friable feeds	Widely variable, depends on sizing screens	Eagle Crusher Co. Bradley Pulverizer Co. Hescor Ind., Inc.	Very massive, high forces, crushes but does not comminute ductile feeds, chokes on fibrous feeds, high power consumption, sizing by attrition
Cage Disintegrators	Compression	High-speed impact, dull members	Brittle, friable feeds	Usually fines and powders	Eagle Crusher Co. Entoleter, Inc.	Will not process ductile or fibrous feeds, axial inlet restricts feed size, sizing by attrition
Drum Pulverizers	Compression Tension	Low-speed tumbling, impact and bending, dull members	Virtually all types of mixed refuse	Variable, 1 to 6 in. with junk rejection possible	J. Thompson Co., Ltd.	Very large relative to capacity, low power, jam free, less effective on ductile and fibrous feeds, coarse grinds, usually used for primary size reduction, can be batch fed and liquid flushed, sizing by attrition
Rasp mills	Tension Compression Shear	Low-speed crushing, tearing, high clearance, relatively dull members	Virtually all types of mixed refuse	Variable, 1/2 to 3 in. with junk rejection possible	Dorr-Oliver Co.	Fairly large, jam free, low power, better than drum pulverizer for ductile and fibrous feeds, can be batch fed and liquid flushed, axial inlet limits feed size, sizing by attrition
Wet pulpers	Compression Tension Shear	High-speed impact and tearing, high clearance, dull members	Most types of mixed refuse, except heavy metal and heavy textiles	1/2 to 2 in. junk rejection possible	Somat Corp. Black-Clawson Co. Jones Div. Beloit Corp. Wascon Systems, Inc.	Wet process, not dusty, can be batch fed and liquid flushed, difficult to do ductile metal and plastic and heavy textiles, excellent for brittle and pulpable feeds, sizing by attrition
Sewage grinders	Shearing	High-speed, high or low clearance, sharp blades	Soft shearable feeds only, no hard feeds	Variable from fines to 1 in.	Engineered Products BIF Sanitrol Mil-Pac Systems, Inc. Smith and Loveless Div. Ecodyne Worthington Corp. Can-Tex Div. Harsco	Will not tolerate glass, metal, or textiles, prone to damage and jams
Disposers, Garbage grinders	Tension Compression Shear	High-speed, high clearance, dull or sharp blades, tearing	Usually for soft feeds, some designs will take brittle feeds, inlet size limited	Variable from fines to 1/2 in.	Taylor Stiles Div. Envirotech General Electric Hotpoint Westinghouse	Sharp bladed types will work only on soft feeds, dull bladed types are most jam free but will not comminute steel or heavy aluminum and plastic, batch fed and liquid flushed, sizing by attrition

In addition, a new and novel concept was considered in which the refuse would be allowed to "freeze" to cryogenic temperatures by the use of the space heat sink which exists outside the space vehicle. Material in the refuse chamber would become brittle enough at these low temperatures so that a hard blow to the materials would fracture and reduce the refuse to a very small size, making it easily transportable. This concept could be reduced to a laboratory demonstration system.

SYSTEM DESCRIPTION

The trash handling prototype is a complete system demonstration from loading hopper to feeding into a reactor. The refuse is piston-fed from the loading hopper into the cutter-shredder to a transport hopper and then down a tube to the reactor.

The most difficult problem in the trash handling subsystem design was the reduction of the refuse by the cutter-shredder system prior to transport. Therefore the major portion of the system description focuses on the cutter-shredder. The entire system configuration is shown in Figure 2 (a and b); within Figures 2a and 2b the cutter-shredder is referenced as D and E.

The refuse is fed into the center of the counter-rotating shredder system, see Figure 3 which shows the cutaway view of the cutters. The cutters are comprised of two parallel cutting bars. Each bar has seven-tooth cutting blades with a spacer between each blade. Each cutter is opposed by a spacer rotating at half or twice the speed of its corresponding cutter. As indicated in Figure 3, one bank of cutters and alternating spacers is rotating at 50 rpm and the other overlapping bank of cutters and spacers is rotating at 25 rpm. The result is that any material which might wind around an individual spacer is wiped clean by the differing rotational speeds of the cutter and spacer.

Brittle material is fractured at the top of the cutters by the rotating cutters while being positioned and held by the slower rotating blades. All material is cut, torn, shredded, sheared, abstracted or broken as it is caught by the cutter teeth, which are 6.4 mm wide, and taken down between two abutting cutters rotating at a different speed and cut against the opposing spacer. As the material passes through the counter-rotating cutters, it is reduced to a size of 6.4 × 6.4 × 2.5 mm, which is slightly larger than the clearance dimensions of the cutters. This is a result of material compression. This prototype proved that this approach will work, and with sophistication of size, weight and power requirements, will be applicable to space applications.

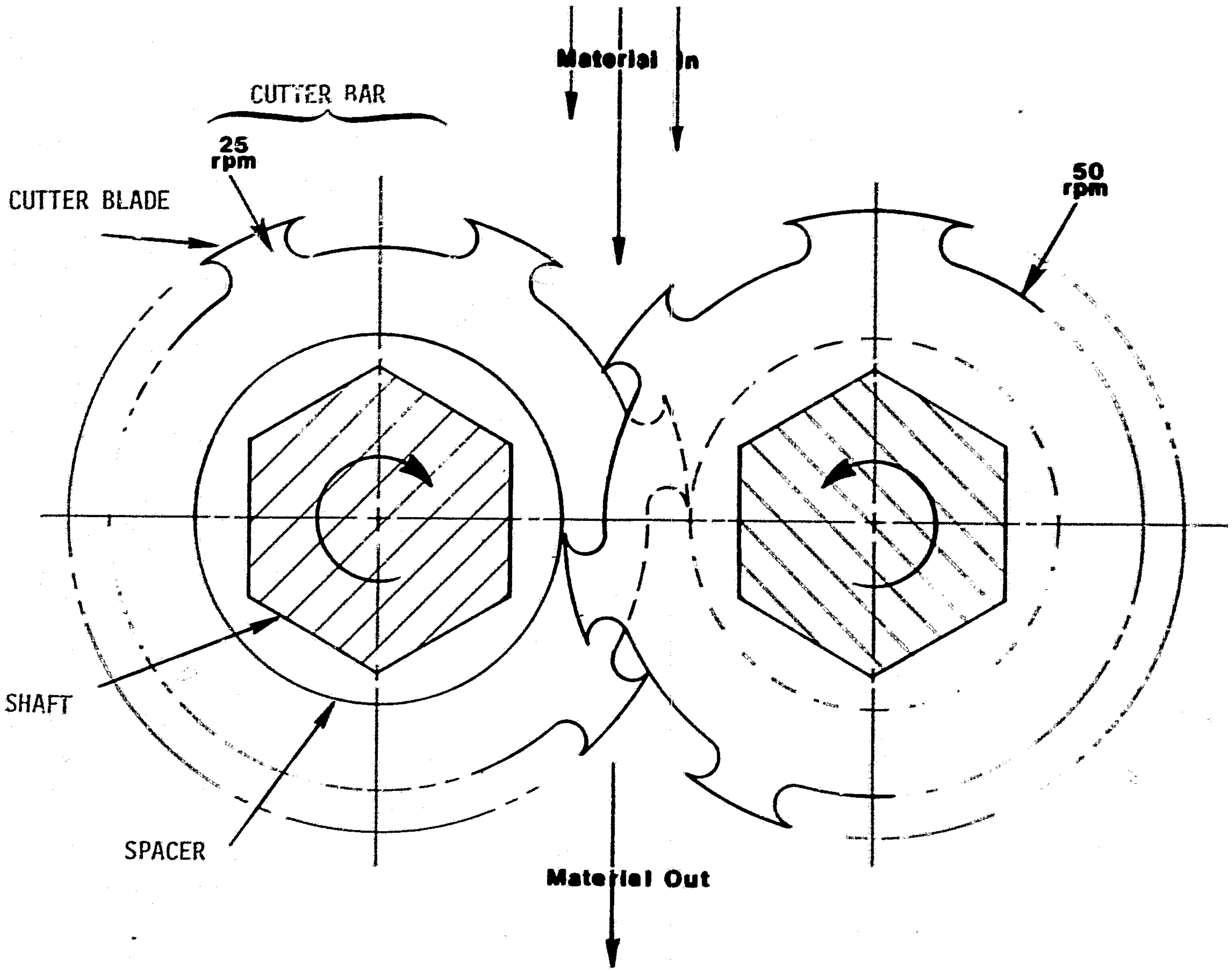


Figure 3. - Cross-section of cutter heads.

DESIGN SELECTION AND MODIFICATION

After reviewing all available systems and their respective limitations, a series of tests was conducted to determine some optimum configuration for refuse reduction. The results of these tests, plus the growing concern about some piece of ceramic or metal severely damaging the final system, led to the following conclusions discussed below.

The final design would need to be strong and self-cleaning. It would have to be able to cut, shred, break, tear and shear any and all material as it was fed in, with no water rinse. It was decided that a commercially available unit from Disposable Waste Systems, Inc. would easily accept the modifications necessary to test our initial conclusions. The unit we chose to modify was called a "Muffin Monster," because of its ability to reduce sewage.

The Muffin Monster cutter-shredder was modified primarily to provide a positive cutting action. Also, the cutter-shredder bed length was reduced by one-half. Cutting action was improved by closely matching the widths of the cutter and the opposing spacer, and by enlarging the diameter of the spacer. The cutting tooth configuration was modified slightly in our shop.

The clearance dimensions between the two rows of counter-rotating cutting disks (see Figure 4) were decreased. The spacer diameter was increased from 70 to 73 mm, which increased the amount of cutting, shredding, and shearing action and reduced the size of the material that could pass through the system from about 153 to 18.5 mm. Precisely matching the cutter width to the opposing spacer reduced the gap through which stringy material could slip, and thus entangle and bind. This careful matching of parts allowed every cutter to act like scissors and to cut more cleanly using less power. The shredding bed was shortened by 76 mm and the number of cutters was reduced by seven. The tooth configuration was modified slightly to prevent flaring and jamming of the thin edge, which has a tendency to flare when opposed by hard materials like wood or bone.

A cutter blade cleaning system was tested and worked successfully, but again was not implemented because of cost. This system consisted of a block with fingers that fit between each cutter and against the spacer at the bottom or outlet. This scraper system minimized material carryover or buildup even more than the present system. The majority of material is scraped off due to the 2 to 1 differential in cutter rotation speeds.

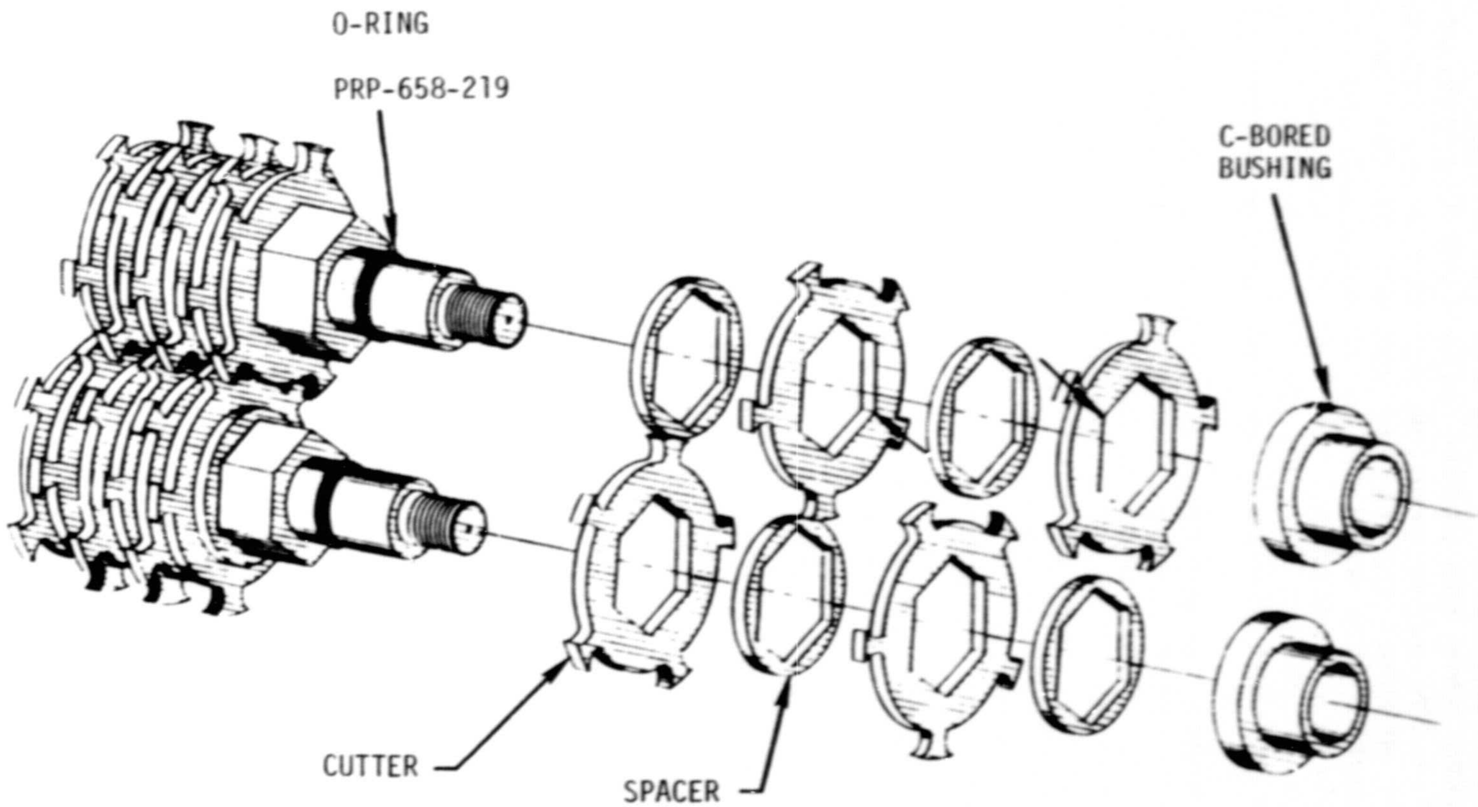


Figure 4. - Cutter-shredder bar assembly.

TRANSPORT DESIGN

The material transport system evolved through a lengthy process of tests, once the refuse size from the cutter-shredder was determined. The major problem was the small volume of the refuse, and not whether the refuse was wet or dry, as we had originally thought. The wide range of material and the changes in characteristics of material from wet to dry led us to our first approach, which was to contain the refuse as it moved to the reactor to prevent any buildup and future transport problems.

The approaches ranged from disposable capsules to a permanent retrievable vessel to be pneumatically transferred to and from the reactor. These systems were rejected for several reasons. The pneumatic shuttle was not considered reliable enough, since if for some reason the vessel stopped between the shredder and the reactor, it could be difficult to clear. The disposable vessels were a clean and easy solution, but would create dependence on a supply of vessels.

The permanent refuse transfer vessel was discarded because of the complex mechanisms required in the doors and loading and unloading stations. The design which was selected allowed the refuse to contact the transport tube walls, but incorporated a feature to keep the walls clean. The system, as tested, was manually operated, but it could be automated. The transport assembly consisted of several rings (drag seals) spaced 75 mm apart (see Figure 2, Item J) which contact the inside wall of the transport tube.

As the shredded refuse is released into the transport tube (Figure 2) the drag seals pull the refuse into the space between the seals and carry it to the reactor. The last of the five seals has a scraping seal which cleans the inside of the transport tube and forces any liquid into the reactor (see Figure 5). The sealing rings and the scraping seal are mounted on a shaft consisting of two tightly wound springs allowing flexibility to pass around corners but rigid strength to push and retrieve the transport system.

Some of the potential problems with this design are sticking or buildup of refuse on the transport tube and on the transport system itself. The potential for material sticking to the walls of the transport tube seems to have been eliminated by the cleaning of the scraping seals, though it is possible that other material could build up, forcing the seal to ride over. This problem may be avoided by using more than one scraper seal. The potential problem of refuse not releasing from the drag seals and going into the reactor could be averted several ways. One would

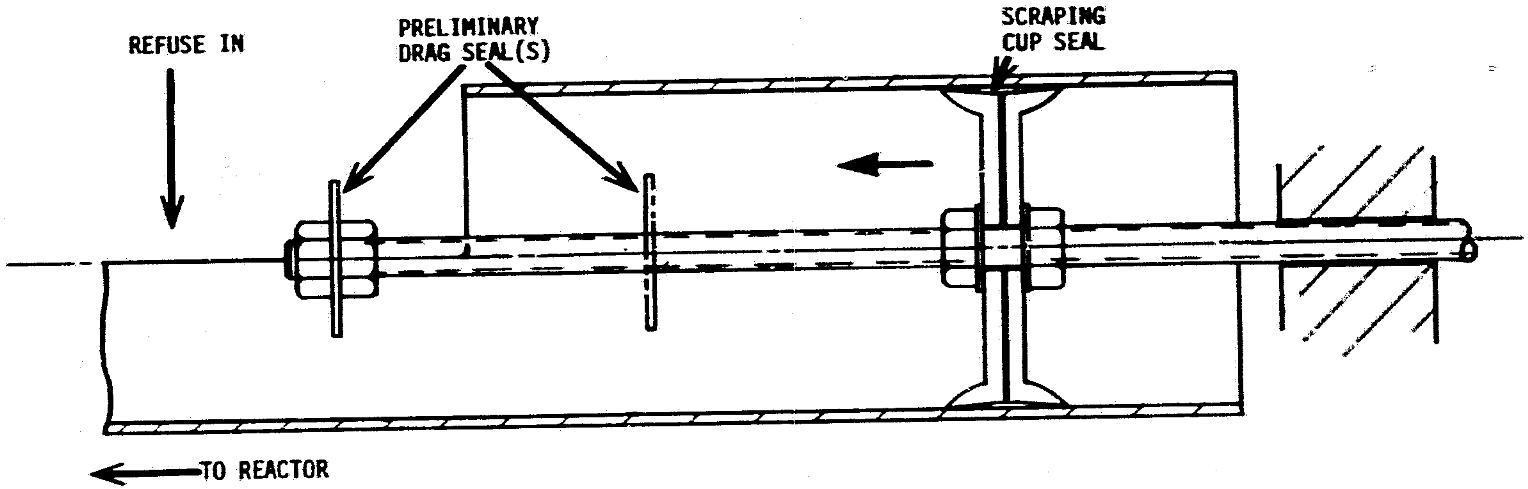


Figure 5. - Transport seal system.

be to spin the central transport shaft which would spin the material off the transport disks and into the reactor.

Another potential solution would be to have high-temperature material as the drag seals and seal the transport system into the reactor, cycle the reactor, and then retrieve the transport assembly. There was a problem with moving the refuse from the shredder to the transport in such a way as to not allow refuse to index into the transport tube behind the scraping seal and eventually hamper operation. This problem was reduced by incorporating a valve (Figure 2, Item H) which served two purposes: first, a positive displacement of refuse into the transport system, and second, to prevent refuse from falling in behind the transport seals.

TESTING

The initial testing was done with dry homogenous materials such as the polyamide and polyimides with the intention of observing the problems the shredder had with refuse of specific characteristics.

The testing continued through each material in the SOW with positive results; each material was completely cut and shredded and passed through. The next series of tests combined two and then three different dry materials together. All refuse underwent complete reduction (see Table 4).

During the next series of tests, we allowed (accidental inclusion) metal to enter with the mixed dry refuse to determine the overall capability of the cutter-shredder system. These metal inclusions consisted of ball point pens, with pocket-clips and metal barrel refills, disposable surgical needles used for blood samples, a small knife blade and a penny. The sample refuse and the metal inclusions passed through the cutter-shredder completely reduced.

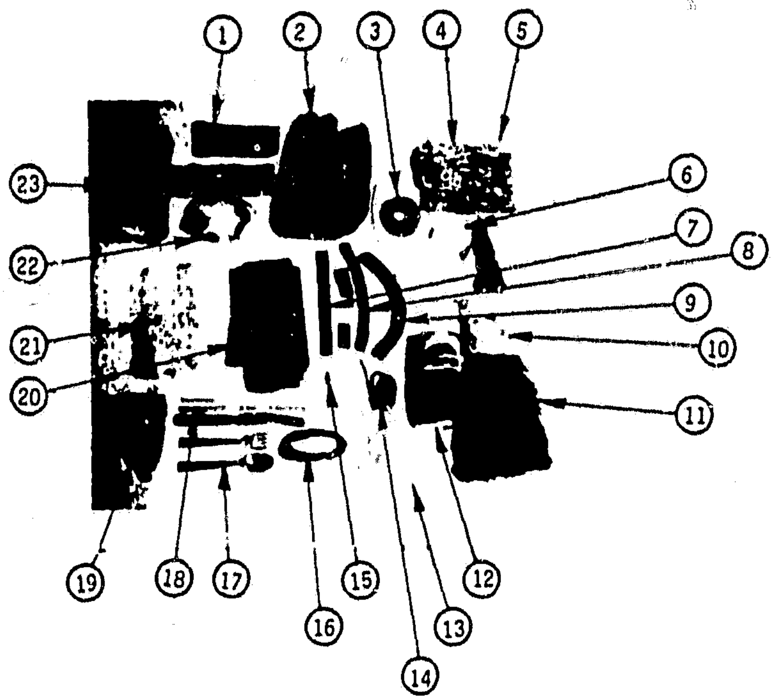
The final tests were carried out with all the materials in the SOW randomly mixed, including moist dog food. There was some residue of the wet dog food remaining on the cutter blades; however, continued operation allowed the cutters to clean themselves fairly well.

The same sequence of tests was carried out for the transport system. The results were good throughout the testing. Again, when the wet tests with dog food were done, there was some sticking of material. The solution was that if the sticking continued to be a problem, a rapid rotation of the transport rings would dislodge any remaining material. Figure 6 gives a sample of a test batch of refuse.

TABLE 4. - BREAKDOWN OF REFUSE FROM SOW

Model of test refuse*	Dry weight (grams)
Dog food - moist (80% water, 20% solids by weight)	200
Polyethylene	200
Polyester	100
Fluorocarbon	25
Polyamide	25
Polyimide	25
Silicone	25
Cellulosics	250
Cotton cloth	200
Total	1,050 grams

*This is a list of materials which were handled by a trash processing subsystem. It represents a cross-section of materials. The list is by general category or generic name only. Quantities are for a nominal crew size of three. The specific material and configuration selected in each generic category was appropriate for the particular type of material. Sheet or layered material was cut up into approximately 300 cm^2 pieces maximum.



LEGEND:

1) DUCT TAPE, 2 PIECES (ONE 105 mm LONG AND ONE 156 MM LONG), GRAY
2) SECTION OF CORDUROY PANTS LEG APPROXIMATELY 105 mm LONG, GREEN
3) PLASTIC TAPE CONTAINER APPROXIMATELY 57 mm OD BY 23 mm WIDE by 1.26 mm THICK (BLUE)
4) ALUMINUM FOIL, 105 mm^2
5) SOFT WIRE RING APPROXIMATELY 51 mm LONG BY 1.26 mm diam
6) GLASS JAR 105 mm WIDE BY 90 mm HIGH BY 2.55 mm THICK
7) STEEL STRAPPING 16.5 mm WIDE BY 0.56 mm THICK AND (1) 153 mm LONG AND (1) 105 mm LONG, BLACK
8) WIRE INSULATION (TEL.) PLASTIC, 0.8 mm THICK (1), 153 mm LONG AND (1) 105 mm LONG, GRAY
9) FOAM WEATHER STRIPPING 12.7 mm BY 6.4 mm BY 178 mm LONG, BLACK
10) CELLOPHANE 0.185 mm THICK, APPROXIMATELY 105 mm SQUARE, CLEAR
11) SHAG CARPET 165 mm, LIME GREEN
12) ALUMINUM PEPSI CAN
13) PLASTIC CONTAINER CAP 76 mm diam
14) COPPER WIRE WITH INSULATION 205 mm LONG, GRAY
15) HYPODERMIC NEEDLE, STEEL-PLATED
16) TELEPHONE WIRE (1) ROLL AND (2) 103 mm SECTIONS, BLUE AND YELLOW
17) PLASTIC KNIFE, PINK; SPOON, BLUE: AND FORK, BLUE
18) PLASTIC STRAWS
19) POLYETHYLENE STRIP 51 mm WIDE BY 51 mm LONG BY 0.065 mm THICK, GRAY FINISH
20) POLYETHYLENE 153 mm SQUARE BY 0.25 mm THICK, DARK GREEN
21) POLYETHYLENE 153 mm SQUARE BY 0.185 mm THICK, CLEAR
22) MASKING TAPE 105 mm LONG BY 51 mm WIDE
23) TIN CAN 140 mm HIGH BY 87 mm diam BY 0.64 mm THICK

Figure 6. - Dry sample prior to testing.

MODIFICATIONS

No major modifications, other than the shortening of the chassis, the modifications to the spacers, and the dimensions of the cutter blades, were undertaken. The loose bearing systems and support structures imposed additional loads but were not a factor in this program. The prototype test system used many standard components which resulted in high starting and running current due to rubbing. A considerable reduction in friction, and consequently in the power required to operate the shredder, could be achieved by refinements in the shredder configuration. However, the basic design was successfully demonstrated with all the required trash materials and with some metallics.

The cutter configuration dictates the nominal shred size. The size is controlled by the spacing between the teeth (that is, teeth per cutter) and the width of each cutter. The length and width of each shred as it passes through the cutters is controlled by those dimensions and varies only because of the stretching or compressing of the material as it is shredded. Due to the diversity of the refuse to be shredded, we required a system that could impose tearing, shearing, fracturing and crushing, as well as nibbling and cutting, without one detracting from the other. If a material bridges the cutters, this system has the capability to orient the material and draw the material into the cutting heads. The teeth have a tendency to grab and nip the refuse and draw it down into the shredder, whether it is a large plastic vessel, a metal can, or a piece of heavy fabric. Other configurations considered did not have this capability.

The entire cycle of operation, as shown in Figure 2b on the cutaway view, is as follows. Material is introduced through a sealable cap A and accumulates in a storage hopper C. When a processing cycle is started, the tapered piston B either manually or pneumatically indexes the refuse into the cutter-shredder D and E. Material is prevented from building up on the spacers by metal fingers F which also guide the shredded material into a holding area G where the indexing valve H rotates and forces the refuse into the transport tube I. The refuse is pushed into the transport tube by a series of drag seals J which are connected and driven by a flexible shaft K down the transport tube and into the reactor. The drag seals reverse direction, and then return below the indexing valve H for more refuse.

A concept was considered in which several different encapsulation systems might be used which would stay in the reactor. Each capsule would be located in the tubing, sealed, and pneumatically blown down the tube into the reactor. The desirable feature of this concept is that all the material would be sealed in the capsule, and no refuse or liquid would get on the walls of the transport tube. This concept was ruled out, however, because of dependence on the number of disposable containers that were carried and the effectiveness of lining up and sealing these capsules before they were impelled into the reactor.

Another concept, very similar to the above, is that of a reusable container which would be filled and then packed with a ram. The open end of the container would be the forward end, so that if any material were to fall out, it would be carried along by the container into the reactor.

Yet another concept was the alternating tube system, where the waste is compressed into the tube. It would then index over into the transport system and a piston would come out and force the refuse material down the tube and into the reactor. This system was ruled out because of the lack of control over the waste while it was being pushed by the ram. If it were to come apart, it could coat the walls or form a plug, and jam the system.

One concept which was fabricated, tested and modified before it was finally judged unacceptable was an auger. A close-flighted auger was specially made of teflon® to transport moist material. This device was ruled out because the material either fluidized and stayed in the auger or the wet material stuck to the auger and was not transported down the tube. There has to be friction between the auger and the tube in order to move the material down the auger.

One very interesting concept was to make the transport tube flexible and to pump through the tube by peristaltic action. The controlled contraction would push the waste down the tube and into the reactor. This concept was eliminated for two major reasons. First, because the trash mixture could be either wet or dry we found that in the case of dry material it did not roll or extrude ahead of the contraction. This is very similar to a commercial peristaltic pump, which does not readily handle dry material. The second problem was that the more brittle plastics have a tendency to tear or penetrate the flexible tube.

The *fluidized piston feeder* is, in principle of operation, close to that of a slurry pump, except that the material is dry. In this concept, dry bulk fluidized material is taken into a cylinder and pressurized with a recycled gas to a valve above the receiver. The discharge valve is opened and the material at high pressure partially discharges itself while the rest is displaced by moving the piston. The piston, with a minimum of compressive work at the end of the discharge cycle, fills the dead volume with the inert gas at low pressure. Total cylinder volume is vented before the piston moves up for a fresh charge of material. The equipment size is small and the overall costs are variable. Unfortunately, the feeder would have to transport the material over 6 to 12 ft, and possibly around bends. The wetted material, when being forced by a piston, created what we call the wine/press effect; this is where the material eventually conglomerates creating a plug. The piston behind it forces moisture through and eventually seals the tube up completely forming a solid mass which can not be moved out of the tube.

The *linear pocket feeder* consists of several solid pistons linked by a chain that are arranged to form a series of seals between the high-pressure receiver and the feed vessel. The pockets between the pistons are filled with material as they pass the feed point and enter into the receiver. Conceivably, it would be possible to transport material using this type of continuous feed system, although in this application, a sealed system is desired with isolation between the in-feed and the reactor. This transport system is typically a continuous process and would probably pose severe sealing problems if adapted to a batch loading process.

Each of the above concepts was considered, from the information available, to have deficiencies that precluded its use in this effort, or to have problems that would require more extensive development than was planned if the system were to be made fully automatic. Consequently, manual assistance by the crew was assumed to a great extent.