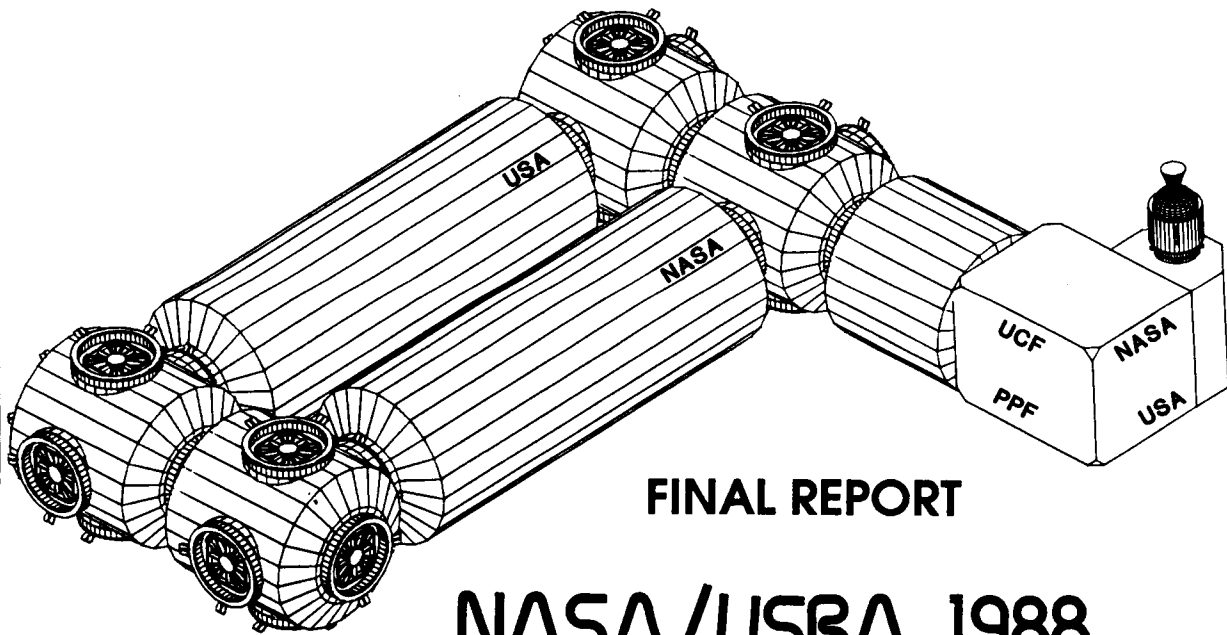


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THE SPACE STATION INTEGRATED REFUSE MANAGEMENT SYSTEM



FINAL REPORT

NASA/USRA 1988

DEPARTMENT OF MECHANICAL ENGINEERING AND AEROSPACE SCIENCES

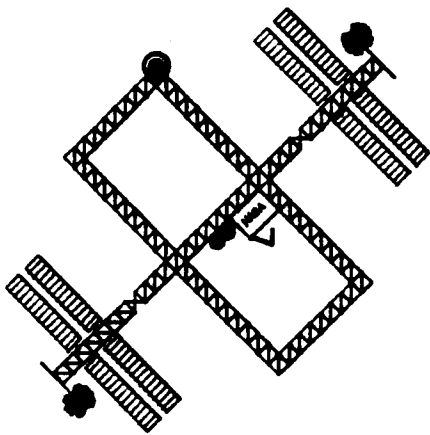
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(NASA-CR-184722) THE SPACE STATION
INTEGRATED REFUSE MANAGEMENT SYSTEM
(Universities Space Research Association)
280 P

THE
SPACE STATION INTEGRATED
REFUSE MANAGEMENT SYSTEM



MAY 1988



Submitted to:

UNIVERSITIES SPACE RESEARCH
ASSOCIATION

Foreword

The SPACE STATION INTEGRATED REFUSE MANAGEMENT SYSTEM is one of a continuing series of Senior design studies carried out by students in Mechanical and Aerospace Engineering 4505, "Engineering Design". This course caters to a variety of design interests of aerospace and mechanical engineering students at the University of Central Florida. The primary output of the course consists of (1) an oral design review, (2) a scale model of the design, and (3) the final report.

The goal of this year's project, conceived in discussions with the Space Station Office at Kennedy Space Center, is to make use of existing potential energy or material properties that space generated refuse may possess. A secondary goal is the removal and disposal of products that cannot be of benefit to the astronauts aboard the Space Station. Polyethylene bags, cylindrical polypropylene containers, and a bank shuttle network similar to those used in commercial banks, are used to collect refuse from the generation sites and transport it to the pyrolysis recycling site. The unusable products of the recycling process are removed from the Space Station environment using a jettison launch vehicle. Reentry into the earth's atmosphere then incinerates the unusable products.

The SPACE STATION INTEGRATED REFUSE MANAGEMENT SYSTEM team consisted of 29 Engineering students. Michael H. Haddock served as graduate teaching assistant during both fall and spring semesters. Twelve undergraduate students participated during the fall semester, sixteen undergraduate students participated during the spring semester, and four fall semester students performed independent studies in support of the design during the spring semester. Dana Scarbrough, one of the independent study students, had the major task of integrating the inputs from the four design groups into this final report. Assisting the documentation effort was another independent study student, Chris Rahaim, who managed and created the computer generated design drawings in this report. The scale model was created, designed, and managed by Tamyra Walters, and independent study student. Last, but not least, the final oral presentation of the design was organized by Kevin Morrison, and independent study student, and video taped by Dale Fakess, a radio-television specialist.

We gratefully acknowledge our first year of full support from the National Aeronautics and Space Administration and the Universities Space Research Association in the NASA/USRA Advanced Space Design Program. Special recognition is due Stanley R. Sadin, Assistant Director, Program Development, NASA Headquarters, Washington, D.C., and John Sevier, Director and Carolynne Hopf, Assistant Director, Advanced Design Program, USRA, Houston, TX. We are especially indebted to C. M. Giesler, Greg Opresko, Dennis Mathews, Glenn Parker, and Bruce Larsen of Kennedy Space Center, FL, for their technical support and encouragement throughout the academic year.

Professor Loren A. Anderson

May 5, 1988

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-LIST OF ACRONYMS

AmRoc - American Rocket Company
CBC - Closed Brayton Cycle
CEF - Cyclonic Entrained-Flow
CMA - Canadian Manipulator Arm
DOD - Department of Defense
dV - Change in Velocity
ELV - Expendable Launch Vehicle
EPG - Electrostatic Parametric Generator
ESA - European Space Agency
EVA - Extra-Vehicular Activity
GD - General Dynamics
GPHS - General Purpose Heat Source
HLV - Heavy Lift Vehicle
HPR - Heat Pipe Rankine Cycle
IFSM - Image Forming Solar Melter
ILV - Industrial Launch Vehicle
IOC - Initial Operating Capability
IUS - Inertial Upper Stage
KSC - Kennedy Space Center
McDD - McDonnell Douglas
MLRS - Multiple Launch Rocket System
MM - Martin Marietta
MOD-RTG - Modular Radioisotope Thermoelectric Generator
NA - Not Available
NASA - National Aeronautics and Space Administration
NASA-STD - NASA Standard
NIFSM - Non-Image Forming Solar Melter
OLV - Outside Launched Vehicle
OMV - Orbital Maneuvering Vehicle
PAM - Payload Assist Module
PMS - Planned Maintenance System
PPF - Pyrolysis Processing Facility
RJV - Rocket Jettison Vehicle
RMF - Refuse Management Facility
ROM - Rough Order of Magnitude
SCWO - Super Critical Water Oxidation
SERI - Solar Energy Research Institute
SS - Space Station
SSI - Space Services, Inc.
UCF - University of Central Florida
UHMW - Ultra High Molecular Weight
USRA - University Space Research Association
UTC - United Technology Center
UV - Ultraviolet

LIST OF SYMBOLS

ac	- Alternating Current
atm	- Atmosphere
AU	- Astronautical Unit
Btu	- British Thermal Unit
DegC	- Degrees Celsius
cf	- Cubic Feet
cm	- Centimeter
dc	- Direct Current
DegF	- Degrees Fahrenheit
g	- Gram
Hg	- Mercury
hr	- Hour
in	- Inch
J	- Joule
K	- Kelvin
kg	- Kilogram
kJ	- Kilojoule
kW	- Kilowatt
lb	- Pound
m	- Meter
mm	- Millimeter
mmHg	- Millimeters of Mercury
nM	- Nautical Mile
psi	- Pounds Per Square Inch
psig	- Pounds Per Square Inch Gage
rpm	- Revolutions Per Minute
s	- Second
W	- Watt



FALL SEMESTER PICTURE

LEFT TO RIGHT:

John Witt, Dana Scarbrough, Tamyra Walters, Tim Holttschneider, Chris Rahaim, Pat Eftekharzadeh, Michael Haddock, Mark Davda, Eldon Humphries

NOT PICTURED: Leonard Angelillo, Kevin Morrison, Jeff Battin, Rolando Cruz

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

SPRING SEMESTER PICTURE

FRONT ROW: LEFT TO RIGHT

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UCF/EML 4505 ENGINEERING DESIGN

Space Station Refuse Management

Fall '87 / Spring '88

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THE SPACE STATION INTEGRATED REFUSE MANAGEMENT SYSTEM

EXECUTIVE SUMMARY

The design and development of an Integrated Refuse Management System for the proposed International Space Station was performed by the University of Central Florida through cooperation with Kennedy Space Center. The primary goal of the yearlong study was to make use of any existing potential energy or material properties that refuse may possess. The secondary goal was based on the complete removal or disposal of those products that could not, in any way, benefit astronauts' needs aboard the Space Station. The National Aeronautics and Space Administration's design of a continuous living and experimental habitat in space has spawned the need for a highly efficient and effective refuse management system capable of managing nearly forty-thousand pounds of refuse annually. To satisfy this need, the following four integrable systems have been researched and developed:

- (1) Collection and Transfer
- (2) Recycle and Reuse
- (3) Advanced Disposal
- (4) Propulsion Assist in Disposal

For the purposes of this study, refuse is defined as all materials requiring disposal and includes both biologically active and inactive materials. It does not include metabolic/bodily wastes.

The design of a Space Station subsystem capable of collecting and transporting refuse from its generation site to its disposal and/or recycling site was accomplished. Refuse canister transport, receptacle designs, storage systems, and power supply were among the topics researched. Materials research warranted the use of high density polyethylene bags and cylindrical polypropylene canisters for refuse containment. A "bank shuttle" network, similar to those used in commercial bank applications, was recommended for canister transport exterior to a Space Station module or node. A select storage design consists of an exterior rack unit to house excess refuse generated from any of the proposed multi-disposal site arrangements. Size reduction was determined to be most effective with the use of a compaction technique capable of simultaneously removing nearly all liquids and gases while packaging takes place. System decontamination was researched in detail. General sanitization, airborne, and surface contaminant control were addressed. A combination of room arrangement, microbiological filtration, and application of germicidal vapors and gases were employed for an optimum solution. Focus was also placed on inventory control which incorporated the use of both color coding and bar coding to maximize simplicity and automation, respectively.

Several methods of recycling or reusing refuse in the space environment were researched. The optimal solution was determined to be the method of pyrolysis. Pyrolysis is described as "the destructive distillation of a carbonaceous material in the presence of heat and the absence of oxygen." The objective of producing a technically self-supporting recycle/reuse system led to the design of the Pyrolysis Processing Facility. The facility is comprised of 1) refuse size reduction, 2) pyrolysis reactor design and 3) power generation. An optimal solution for the design consists of a counter-rotating, self-cleaning shredder coincident with a cyclonic entrained-flow pyrolysis reactor and a hybrid power generating system. The combination of an electrostatic parametric generator coupled with a heat pipe Rankine cycle supply power to the shredder and reactor. Extensive research has indicated all components of the Pyrolysis Processing Facility show great promise for space applications.

The objective of removing refuse from the Space Station environment, subsequent to recycling, was fulfilled with the design of a jettison vehicle. Design goals included the safe containment of refuse while also insuring prompt destruction of the vehicle and its contents upon atmospheric reentry. The vehicle to undertake such a mission is a rigid, aluminum alloy cylinder which will be launched via an expendable rocket. The vehicle will be assembled and mated with its propulsion unit on earth. It will then be placed into low earth orbit, be retrieved by an orbital maneuvering vehicle, and placed into its desired location on the Space Station. Dimensions include a 4.5 feet diameter and a 3.5 feet length. The interior features pigeonhole storage racks that will accommodate six canisters of compacted refuse. Studies of worst case scenarios have indicated the need for a maximum of ten jettison vehicles annually. In addition to vehicle design, debris casualty risks and the environmental effects associated with atmospheric reentry were investigated.

A number of jettison vehicle launch scenarios were analyzed. Selection of a proper disposal site and the development of a system to propel the vehicle to that site were completed. Reentry into the earth's atmosphere for the purpose of refuse incineration was determined to be the most attractive solution. Interfacing a Morton Thiokol "Star 17" expendable rocket to the jettison vehicle will provide the propulsion/disposal system. The Titan 3 Commercial rocket will transport the system to the orbiting Space Station. Once filled, an orbital maneuvering vehicle will remove the assembly out of close proximity of the Space Station, initiate spin with proper attitude, and return to the Space Station. The launch of the "Star 17" rocket, which incorporates orbital mechanics and guidance controls, will deliver the refuse payload into the upper atmosphere completing destruction within one low earth orbit.

INTRODUCTION

- * Space Station Description
- * General SS Refuse Problem
- * Past Methods of Refuse Disposal in Space
- * SS Refuse Generation
- * SS Refuse Types
- * General Waste System Development
- * Microorganisms in Space
- * Space Pollution Considerations
- * General Refuse Management Solution

INTRODUCTION

Space Station Description

"Those who came before us made certain that this country rode the first waves of the industrial revolution, the first waves of modern invention, and the first wave of nuclear power. And this generation does not intend to founder in the backwash of the coming age of space. We mean to be a part of it--we mean to lead it."¹

It is in the spirit of these words by President John F. Kennedy that NASA, supported by President Ronald Reagan, has undertaken its most complex endeavor--the design and construction of an earth orbiting Space Station.

The NASA Space Station, operable in the mid-1990's, is to be a multipurpose, permanently manned space facility made up of pressurized laboratories, payload accommodations, and free-flying unmanned platforms. The station is to be the largest space system ever launched, with an initial size of approximately 300 ft. by 400 ft., and growing to an estimated 300 ft. by 550 ft. in ten years.² Its microgravity environment, potential for high solar power generation, and capabilities for extended human interaction will enable this station to benefit all of mankind in a variety of ways. The station will primarily be used for the advancement of science and technology, especially in the areas of materials research and life sciences. To enhance space exploration, the station will house specialized instruments and telescopes and will act as a servicing center for space operations. It also has the potential of being a point of departure for future missions to the Moon or Mars.³

The Space Station project symbolizes leadership in space for the United States as a necessary component of civil space policy. Opportunities for private business profits will also improve the national economy. However, the advantages are not just limited to the United States. The construction and operation of the Space Station is to be an international effort. This promotion of peaceful cooperation will ultimately benefit everyone by allowing "mankind to move beyond the confines of Earth" as never before possible.³

General Space Station Refuse Problem

As a permanently manned facility, the Space Station requires complex integrations of various subsystems to serve the needs of its human inhabitants. Among the problems that will be encountered to provide comfortable living conditions, refuse management is one of the most serious:

Introduction

"The magnitude of housekeeping (or waste management) requirements aboard an orbiting Space Station will, in a very short time, give rise to a situation that is analogous to the pollution and solid waste disposal tasks being encountered by earthbound communities, that is, cope with the waste or be inundated by it."⁴

In order to "cope" with space waste, there exists a need to address the refuse problem in a "comprehensive, long-range resource management framework".⁵ The problem compounds itself on long-term missions, and the Space Station will generate a considerable amount of waste. Therefore, the Universities Space Research Association (USRA) has provided an opportunity for preliminary research in solving the potential "space waste" problem. The overall purpose of this study is to develop a detailed design for an integrated refuse management system or facility to serve needs aboard the proposed Space Station.

Past Methods of Refuse Disposal in Space

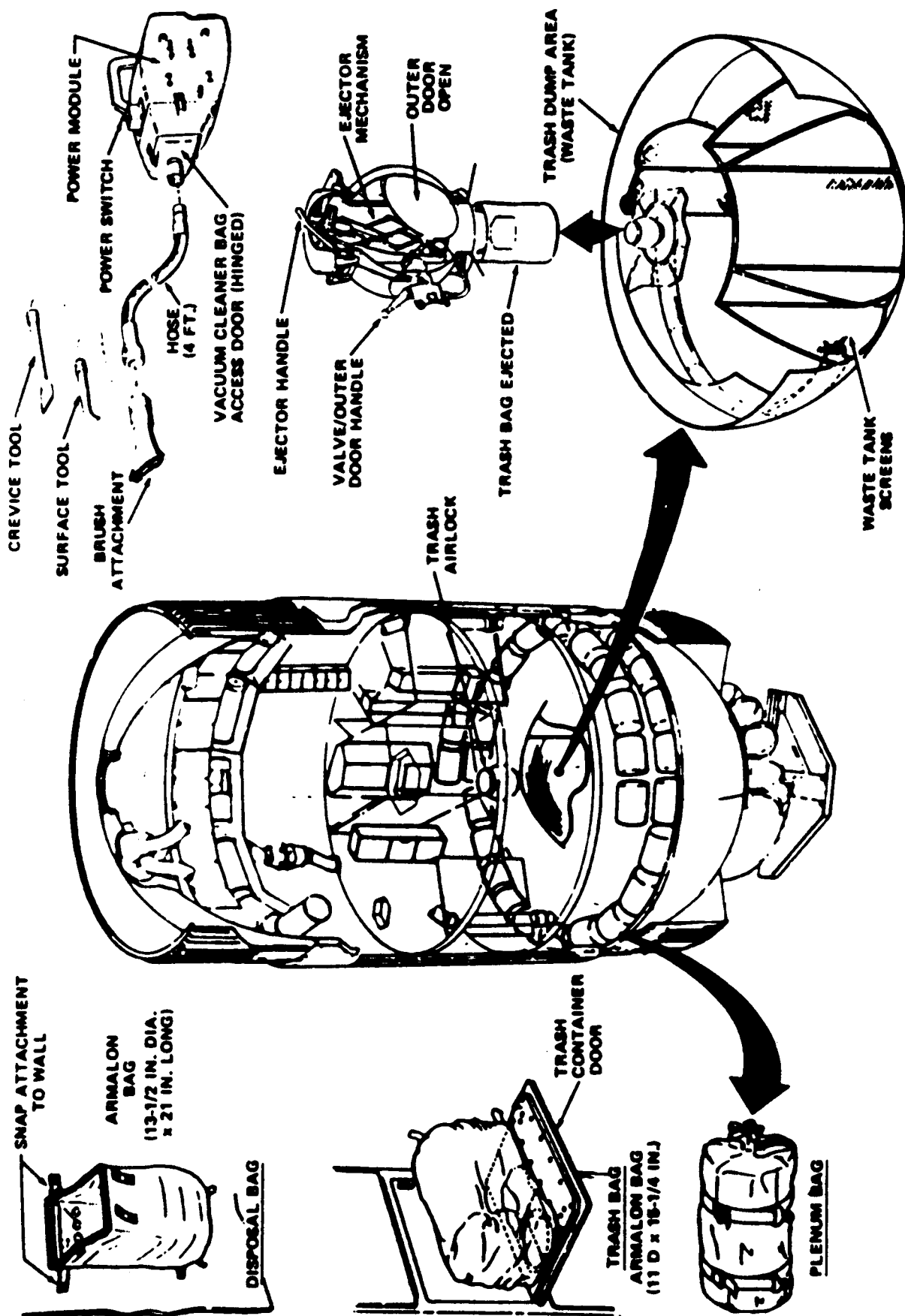
In order to establish a foundation for the Space Station refuse system study, past methods of trash management in space must be reviewed. The most educational mission to consider for this purpose is Skylab, America's first large laboratory in space. This space lab, with 12,000 ft.³ of living and working space, was utilized for three missions totaling 500 days of manned earth orbit.⁶ Thus, this project provides valuable information about habitability hardware for an extended manned mission.

In terms of refuse generation, it must be noted that by the end of the last habitation period of Skylab, all stowage items eventually became trash. Therefore, a significant amount of trash required large storage provisions. The storage area used exclusively for waste was a 2800 ft.³ S-IVB LOX tank located below the Crew Quarters (see Figure 1).⁷ This tank was vented to the vacuum of space to prevent bacterial growth. To access the tank, an airlock was used for waste transfer. A mechanical plunger was used to propel the trash from the depressurized airlock to the tank.⁶

The waste was segregated into three main categories:⁷

1. Category A - Biologically active or hazardous wastes requiring mandatory disposal through the airlock to the tank.
2. Category B - Dry, inert trash which could be returned to on-orbit storage.
3. Category C - Biologically active trash which could be processed such that it was safe for on-orbit storage.

Before it was deposited into the tank, biologically active trash was placed in trash bags or disposal bags, both made of armalon material. Trash bags were attached to the inside of various lockers throughout



Trash Management on Skylab⁶
Figure 1

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Introduction

the workshop area. The trash was inserted into trash bags by means of split diaphragms. When these bags were full, they were removed from the lockers, sealed, taped, and placed into larger disposal bags for final storage. Inert trash was placed into plenum bags (duffel bags) equipped with double draw strings for closure when filled. These bags were also stored below the Crew Quarters in the "plenum area" (see Figure 1). To control the growth of microorganisms on surfaces, biocide wipes and wet wipes were used as well.⁶

Several lessons were learned from this project about trash management in space. First, the airlock/tank system functioned fairly well, however, a urine disposal bag jammed and congested the airlock chamber. Also, operation of the airlock sometimes required excessive exertion from the crew members. Microbial wet wipes proved effective for disinfection, but areas around the food table were often difficult to clean due to limited access. Biocide wipes, although effective as well, left stains wherever used. Finally, lack of a compactor resulted in the inefficient use of trash storage space.⁶

One McDonnell Douglas study of an "Advanced Trash Management System" uses the Skylab experience to propose trash management techniques for future long-term missions in space. The following are among the recommendations presented:⁷

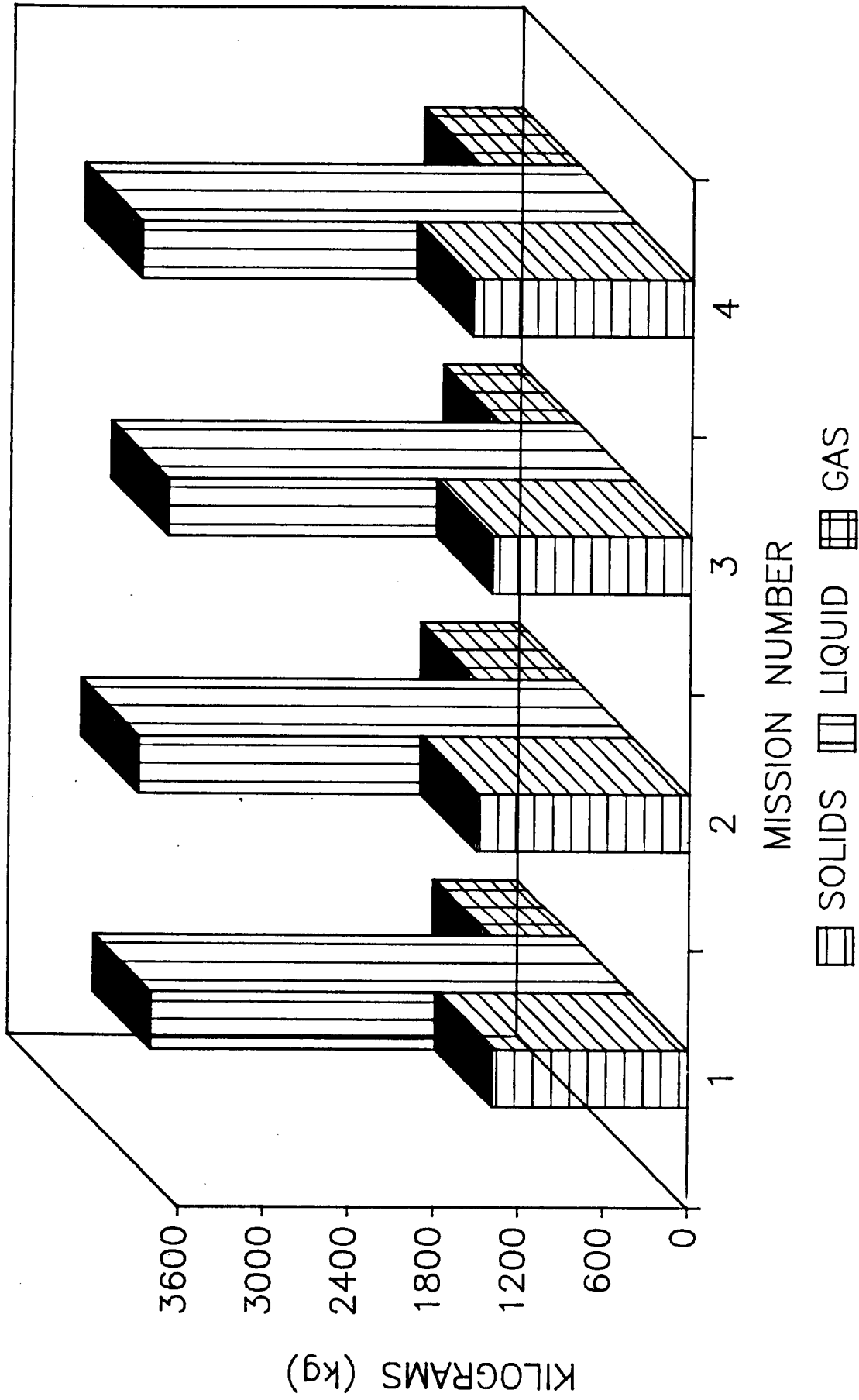
1. Sealed containers for internal storage.
2. Disposal of trash directly into space using an airlock.
3. Trash compaction.
4. Additional sterilization procedures.

The disposal of trash into space has been determined as a highly undesirable alternative (see "Space Pollution Considerations"). However, the remaining suggestions, among other ideas, are studied in detail, and various methods used to accomplish these goals are evaluated.

Space Station Refuse Generation

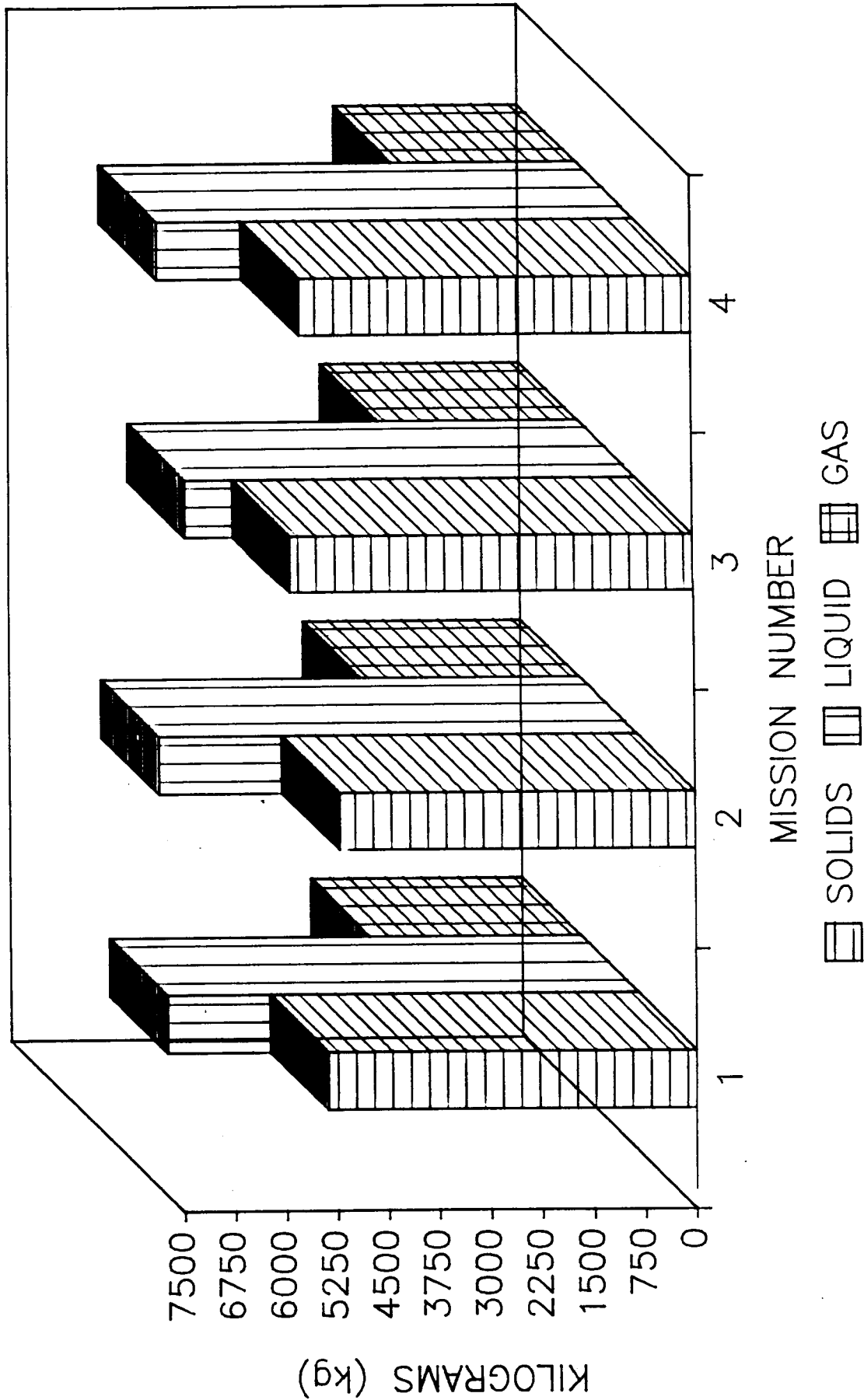
Studies have shown that in a 90 day period, the laboratory module alone will produce anywhere from 11,800 lbs.⁵ to 13,046 lbs.⁸ of refuse (see Graph 1). These waste amounts include solids, liquids and gases consisting of both toxic and nontoxic materials. Combining the refuse generations of the laboratory missions with those of externally attached payloads and free-flyer/co-orbiting platforms, Boeing Corporation estimates amounts of 136,000 lbs./yr (see Graph 2).⁹ This study also examined the capability of the Space Shuttle of returning this refuse to Earth for disposal. Consideration of four Shuttle missions per year, with a return cargo capacity of about 24,000 lbs. per mission, Boeing estimates an annual shortfall of 40,820 lbs. of refuse/yr (see Graph 3).

SPACE STATION WASTE PRODUCED BY
LABORATORY MODULE PER 90 DAY PERIOD
FOR FIRST FOUR MISSIONS

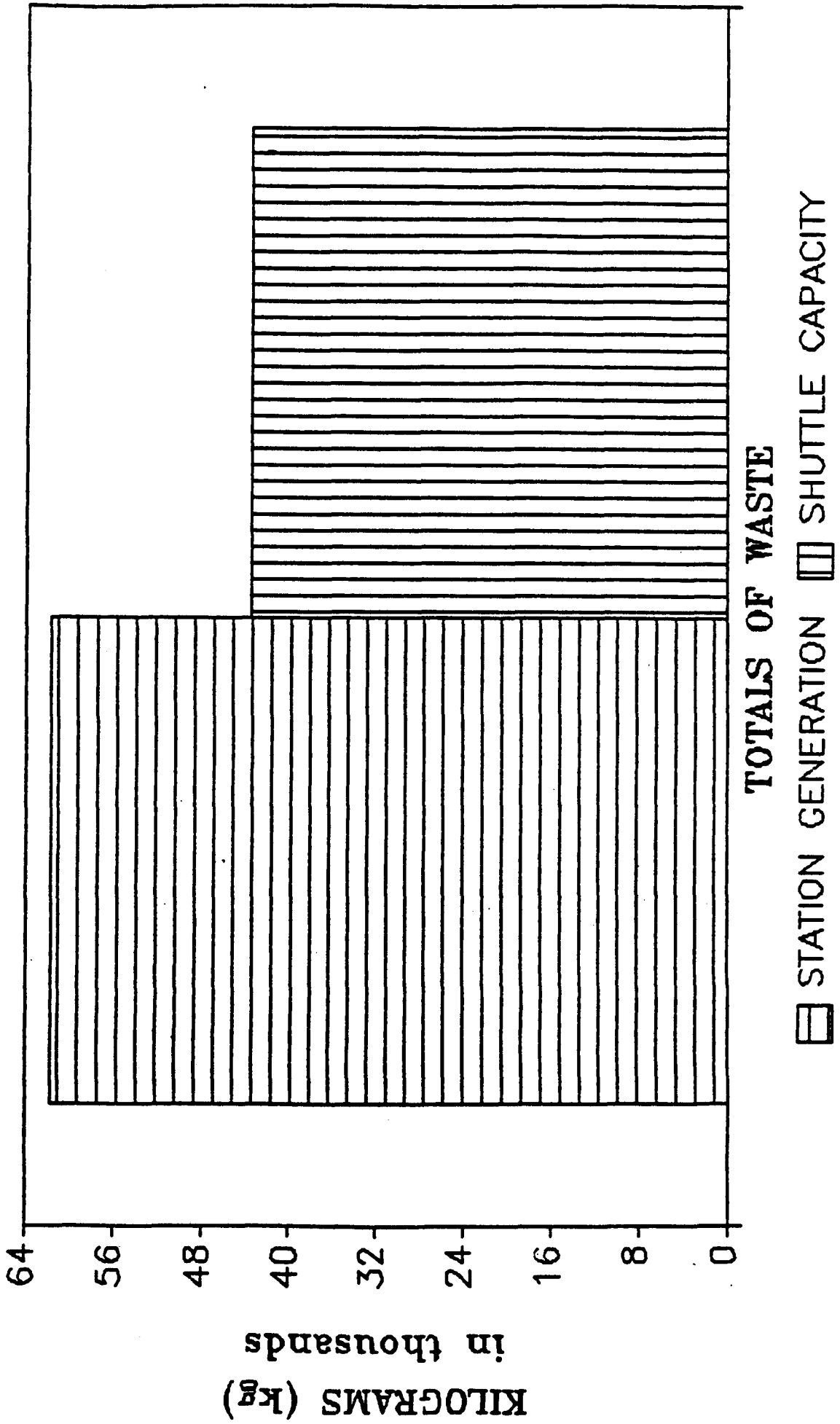


Graph 1

SPACE STATION WASTE PRODUCED BY
ALL COMPONENTS
FOR FIRST FOUR MISSIONS



**TOTAL WASTE GENERATED BY SPACE STATION
AND
SPACE SHUTTLE RETURN CAPACITY**



Introduction

Several aerospace companies (including Boeing) and NASA affiliates have conducted similar studies and have approximated the annual shortfall:

<u>Company</u>	<u>Predicted Shortfall (lbs./yr.)</u>
Boeing ⁹	40,820
Martin Marietta ⁸	28,475
OSSA ¹⁰	47,200
Marshall SFC ¹⁰	<u>35,184</u>
	avg. 37,920

It must be noted that available Space Station waste estimates are based on hypothetical conditions causing the data to be highly estimated.⁵ If the Shuttle is to be used to handle this refuse problem, then its only purpose upon return to Earth will be transporting waste with it. This consequence may be unavoidable "unless an orbit waste processing reuse/recycle⁵ and other alternatives to Shuttle deorbiting are implemented".⁵ In addition, the cost of transporting payload in the Shuttle can be as high as \$5,000/lb.¹¹ Therefore, because of its high cost and limited payload capability; use of the Space Shuttle for refuse transfer should be avoided entirely or kept to a minimum.

Space Station Refuse Types

The amount and nature of the refuse expected on the Space Station depends upon the mission and space module design. The waste model consists of refuse from four major categories:¹²

1. Crew Related
2. Food Management
3. Subsystems
4. Experiments

Waste resulting from crew activity include wipes, soap, laundry, clothing, shaving debris, dental wastes, and medical supplies. The vast amount and continuous generation of food waste, especially the bulk derived from food packaging and residual food, will contribute greatly to the refuse problem. Life Support System wastes include wicks, catalysts, and worn out, reverse osmosis membranes used in oxygen and water reclamation, air duct debris filters, bacteria filters, chemicals and odor removal beds. Paper wastes consist mainly of teletype paper. Subsystem spare part packaging and depleted hardware must also be considered in the waste model. The various wastes produced by experiments are categorized as waste gases, photographic wastes, waste water, and bioscience experiment wastes. These bioscience wastes could include deceased and sacrificed animals, animal waste, and plant types. Special treatment of experimental wastes may be required to isolate contamination.¹²

General Waste System Development

To design an effective refuse management system for these various refuse types, general waste and waste management definitions need to be established. Waste shall be defined as an item which is no longer useful in its present form.⁵ Solid waste management is defined as a "discipline associated with the control of generation, storage, collection, transfer, processing and disposal of solid wastes that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations..."¹³ The goal of this system of hardware, processes, and procedures shall be to dispose of waste or to transform it into an item useful to someone.⁵

The planning process of any effective refuse management system is complicated due to several factors:¹³

- 1) The amounts and varieties of waste.
- 2) Technological impacts.
- 3) Energy and resource limitations.
- 4) Funding limitations.

For the Space Station specifically, the unique microgravity environment, confined living conditions and energy constraints demand modifications of earth-modeled waste systems. The absence of gravity leads to significant alterations in fluid convection, buoyancy, and hydrostatic pressure.¹⁴ Also, the absence of sedimentation could make separation procedures difficult. Because the station is a facility of limited space and many functions, minimal equipment volume is desired, and automation is needed wherever possible to allow the crew to perform tasks restricted to human ability.¹⁵ The system must also use minimal power due to limited energy resources available. Also, experimental wastes will constantly differ in nature and amounts posing unique challenges for the refuse systems. A final consideration is the importance of controlling contamination due to pathogens, chemicals, particulates, and radiation in space.¹⁵ Studies have proven that under conditions of restricted space and microgravity, microorganisms breed very rapidly resulting in the potential spread of disease to crew members.¹⁵ The degree of possible station contamination due to pathogens, in particular, and the significance of microbial control is explained in the following paragraphs.

Microorganisms in Space

Microorganisms will, without a doubt be an active part of the Space Station environment. The only abundant forms expected are bacteria and fungi; the primary source of which are human crew members. However, not all microorganisms are harmful. Some microbes, in fact, are beneficial to human life and their elimination would not be in the best interest of the Space Station. Therefore, microbial control should be limited to those organisms considered harmful to humans and/or potential contaminants to station operations.¹⁶

Introduction

One important class of harmful microorganisms which have existed on all NASA missions are pathogens. Pathogens are organisms which are genetically capable of causing disease. Under many conditions, these microbes are not considered harmful. Yet, the ability of pathogens to cause disease can be activated when they are transferred to body sites not usually encountered, when they experience a dramatic increase in their population, or when there is a decrease in human resistance due to circumstances such as stress and skin lesions.¹⁶

The factors which promote the pathogenicity of organisms are enhanced by the unique conditions of the Space Station environment. First, potential areas of microbial accumulation are many on the station. These areas include mostly wet and moist surfaces as water is necessary for nutrient absorption and growth in organisms. If certain microbes are allowed to multiply, they can excrete significant amounts of toxic and/or gaseous metabolic material which also present a potential hazard for the Space Station.¹⁶

Second, the small, restrictive nature of the station can lower human resistance to pathogens. In confined places, the human exchange of microorganisms is greatly facilitated. Although the diversity of microbes is significantly less in a closed system, conditions are optimal for the growth of more rare forms of potentially pathogenic microorganisms. In addition, the increased surface to volume ratio of such a compact environment increases the likelihood of microbial colonization and this confinement magnifies any associated hazardous effects.¹⁶

Finally, the microgravity environment of the Space Station can greatly enhance contamination. Under microgravity conditions, natural control mechanisms such as aquatic and atmospheric dilution of microorganisms do not exist. Also, the long term effects of weightlessness, radiation, and confinement on pathogens in space is unknown:

"In such a 'drastically altered environment, biological change is likely to be abrupt, dramatic and unpredictable.'"¹⁶

These factors could lead to increased rates of genetic mutation resulting in microorganisms with disease causing capabilities never encountered before.¹⁶

Having achieved an understanding of the potential hazards associated with certain microorganisms, it is easily concluded that they must be eliminated or stabilized in minimum amounts. Therefore, microbial control mechanisms should be a part of all applicable engineering designs of station subsystems. This, of course, includes the refuse management system, which can be a major source of potential contamination. Some design goals to discourage microbial growth are listed as follows:¹⁶

1. Control of surface moisture accumulation.
2. Provision of maximum cleaning access.
3. Selection of materials which inhibit microbial growth.

In addition, various methods of cleaning and disinfection feasible for space use are studied. The efficient use of filterization, sterilization, disinfection, and cleaning can safely control populations of microorganisms in spite of the favorable conditions which encourage their survival and vitality on the Space Station.¹⁶

Space Pollution Considerations

In addition to the general refuse management system considerations discussed above, the hazards of waste processing and disposal in the space environment must be studied. Waste processing techniques often produce exhausts which can contaminate any environment. The impacts of this type of "space pollution" are the following:¹²

- 1) Degradation of thermal coatings on the station exterior.
- 2) Contamination of experiments.
- 3) Degradation of signal transmission.
- 4) Residue on telescope lenses.
- 5) Degradation in the performance of solar panels.
- 6) Possible interference with the logistics vehicle.
- 7) Possible guidance interference.

Therefore, refuse processing must be capable of producing minimal exhaust products and effectively collecting and disposing of them in an efficient, sanitary manner.

Effectively disposing of refuse and/or processing products does not include littering the lower earth orbit environment. Society's social and ecological conscience as well as safety factors do not permit the ejection of this refuse into the vacuum of space. This would constitute simply moving the problem to a new location without solving it. "'Out of sight, out of mind' has been a large part of the attitude toward space debris."¹⁷

Current thoughts toward space operations have focused a renewed interest in keeping orbital trajectories free of debris:

"The issue was brought into focus in November (1986) when an Ariane third stage, launched several months before, broke into around 200 radar-trackable pieces 1/2 inch across or larger and perhaps hundreds of smaller bits. Designers must think about debris two ways, as a hazard to protect spacecraft and astronauts, and as a menace not to add to..."¹⁷

Introduction

These particles in space, small and large, can travel at speeds up to 17,500 mi./hr. and if they collide with an object, it would cause serious damage. As an example, during the Shuttle project STS-7, a particle of debris collided with the outer windshield causing a crater of 2-2.4 mm. across and 0.63 mm. deep, resulting in cracks in the glass out to 4 mm. Even something as small as a salt grain (0.2 mm. diameter) could puncture a standard extravehicular space suit. The probability of an astronaut being hit by one of these particles is only about 1 in 10,000 considering an exposure of 1000 days. However, for an object as large as the Space Station, these odds increase to 1 in 10.

The following summarizes the consequences of littering the space environment:¹⁸

- 1) Once deposited into space, debris is extremely difficult to remove. Constant disposal will invariably lead to collision risk for spacecraft in near-earth orbit.
- 2) Orbital decay and earth reentry are the only natural decomposition processes, but their effects may not be significant for many years.
- 3) Any disturbances in the orbital path of particles tend to randomly disperse the debris.
- 4) Because colliding objects have high speeds relative to each other, even very small particles can cause great damage.
- 5) The collisions of orbital debris will most likely result in large numbers of tiny broken pieces with uncontrollable orbits.

Studies have revealed that the collision risks to spacecraft due to debris left in space will increase significantly; possibly to the point of restricting certain areas of space from travel or exploration.¹⁸

Various estimates concerning the amount and types of waste projectiles have been produced from studies by private and government sources:

"The amount of useless and potentially dangerous debris in outer space is rapidly becoming a major international problem. Between 10,000 and 15,000 objects have already been discarded in orbit, including dead satellites, spent fuel boosters, and garbage jettisoned from spacecraft."¹⁹

Reports have revealed that the Soviets are largely responsible for dumping some of this garbage into space during their recent space station program.¹⁸ Thus, space pollution already exists and must be prevented in future missions:

"Effective policies and procedures are required to eliminate these debris sources...(It is recommended) that the U.S. act immediately to control orbital debris from U.S. space program activities."¹⁸

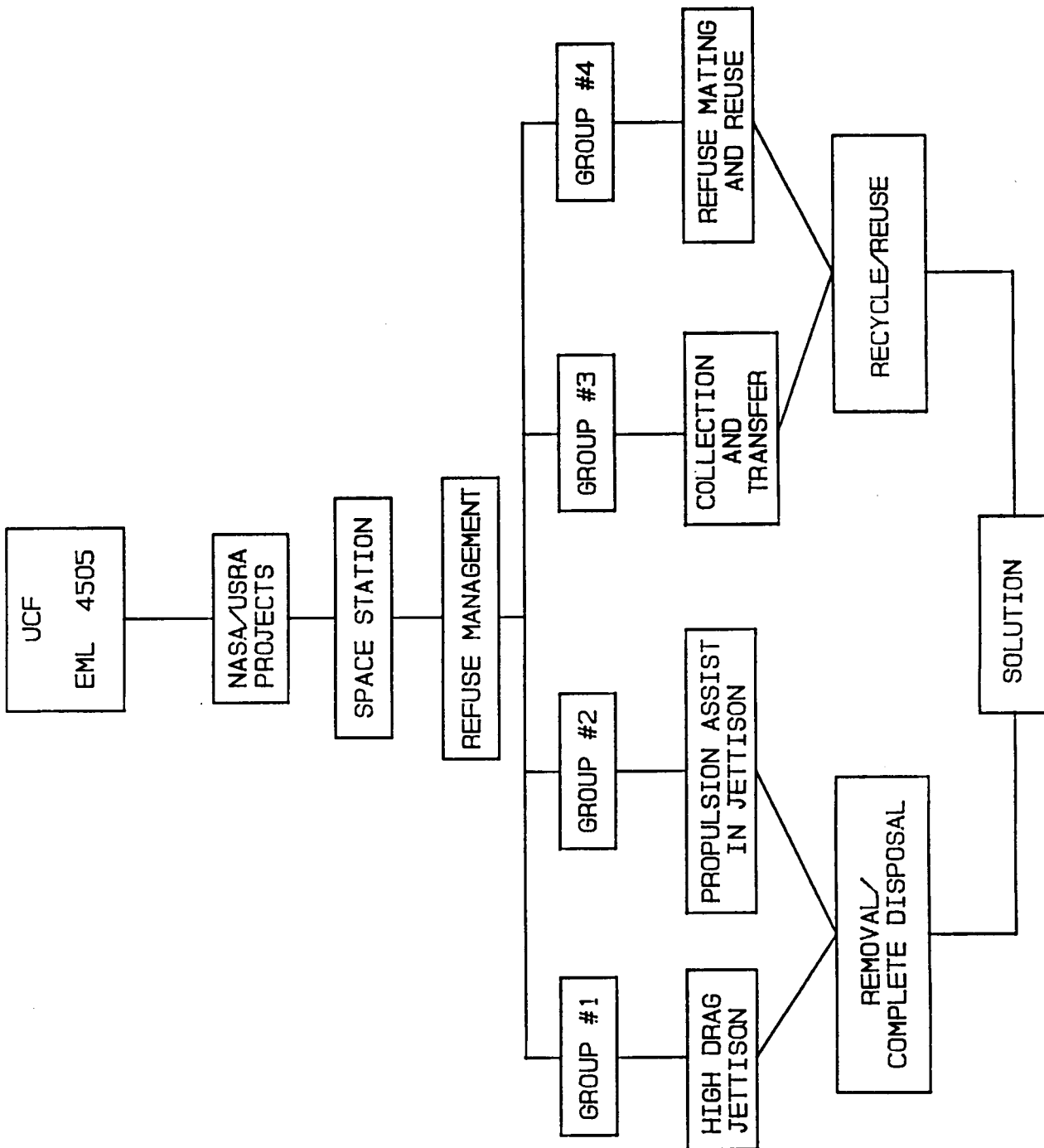
General Refuse Management Solution

Considering the unique and innovational needs of the Space Station and its environment, the following four major refuse management subsystems are proposed (see Figure 2):

- 1) Collection and transfer system.
- 2) Recycle/reuse system.
- 3) High drag, expendable jettison vehicle for refuse transfer to a disposal site.
- 4) Propulsion system for the jettison vehicle.

It must be noted that the designs of these subsystems were based on current knowledge of Space Station parameters, which are either hypothetical or unknown until the Space Station is truly operable.

As long as there is human interaction and activity, there will be accumulations of waste. The basic problem lies in the inability of nature to "dilute, dispense, degrade, (and) absorb" waste in any known environment.¹³ Because of this, there also exists a need for a human solution to the human problem of refuse no matter the environment.



Proposed Refuse Management Subsystems for the SS

Figure 2

SECTION I. REFUSE COLLECTION AND TRANSFER

- PART I.
- * Collection
 - * Transfer
 - * Material Reduction
 - * Storage

- PART II.
- * Material Types for Hardware
 - * Canister Shape
 - * Canister Transfer Forces
 - * Canister Deposit Sites
 - * Compactor Design
 - * Contamination Control
 - * Power Supplies

SECTION I. REFUSE COLLECTION AND TRANSFER SUBSYSTEM

INTRODUCTION

The collection and transfer subsystem can be thought of as the heart of the refuse management system as it represents the entire cohesive factor between all phases of waste handling. Without an efficient collection and transfer subsystem, other refuse subsystems could not function effectively. To further understand the importance of this management phase, system definitions need to be established.

Collection includes the compiling and transporting of wastes to an emptying site (which may be a transfer, processing station, or disposal site).¹³ Transfer is the relocation of wastes from smaller areas/vehicles to larger areas/vehicles. Transport is the moving of wastes to various emptying sites.¹³ Processing goals include:¹³

1. The improvement of solid waste management effectiveness.
2. The retrieval of reusable materials and those containing potential energy.
3. To prepare those materials which cannot be reused for disposal.

The integration of these systems involves the process of choosing the destiny of materials--separating them for recycling and disposal. Although the former is the most desirable, recycling and reuse of materials has, in the past, been neglected in the design of waste handling systems.²¹

Specific factors which affect the design of a collection subsystem directly relate to onsite storage. These sites are likely to be scattered and experience various waste generation patterns.¹³ Because of limited storage space, refuse with a high degree of biodegradability must be collected quickly and continually, as it cannot be tolerated for long periods of time.¹³ Factors which also affect transfer and processing subsystems include:¹³

1. Capacity requirements.
2. Sanitation requirements.
3. Accessory and equipment requirements.
4. Safety requirements.

Safety is of extreme importance when dealing with hazardous wastes in particular. These wastes require specialized handling according to the amounts generated, where they are generated, and in what form they exist.¹³

The planning process of any effective waste management system is complicated due to several factors:¹³

1. The amounts and varieties of waste.
2. Technological impacts.
3. Energy and resource limitations.
4. Funding limitations.

For the Space Station specifically, these factors are further complicated due to the unique microgravity environment, confined living conditions, and energy constraints which demand significant modifications of earth-modeled waste systems.

However complicated the design process might become, the basic operation of the collection and transfer subsystem can be simplified by the cooperation of those who generate the refuse, as modeled by the Japanese culture:

"Like most of Japan's 3255 municipalities, Machida residents separate their waste into seven general categories: newspapers, combustibles (including organic kitchen waste, light plastics, and soiled paper), non-combustibles (hard plastics, broken glass, and scrap metal), glass bottles, aluminum and steel cans, hazardous material (including batteries and other items containing mercury or cadmium), and bulky wastes such as furniture. . . Such an ambitious program is extraordinary by any standards."⁴⁴

Like the Japanese society, the Space Station is an isolated island in which material and energy resources are scarce and means of disposal is limited. Therefore, this idealistic approach of user participation is the basis for all ideas which lead to the most efficient refuse collection and transfer subsystem for the Space Station.

The contents of this section describe various alternatives to fulfill the collection and transfer needs of the Space Station refuse management system. Design Phase I presents general alternatives for the collection, transfer, material reduction, and storage system components while Design Phase II elaborates on these alternatives for a more detailed solution.

PART I. REFUSE COLLECTION AND TRANSFER - DESIGN PHASE I

For this study, possible solutions are proposed according to the following system divisions:

1. collection
2. transfer
3. material reduction
4. storage

Chapter 1. COLLECTION

For the collection process, the following methods have been considered:

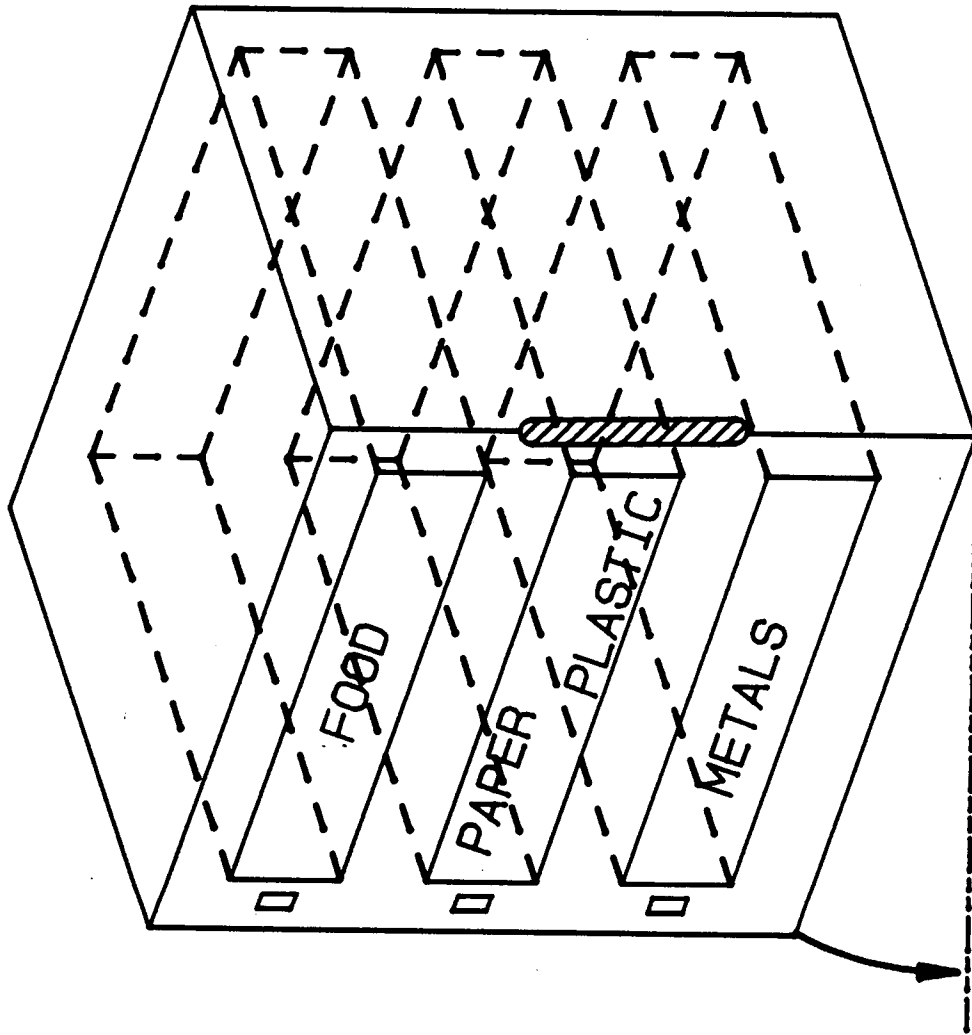
1. labeled receptacles
2. labeled bags
3. waste specific containers

1.1 Labeled Receptacles

Receptacles are containers used to temporarily hold refuse until it is ready for transfer. Receptacles can be centralized or decentralized. Centralized receptacles are highly organized "dimpster dumpsters" as shown in Figure 1.1. These receptacles are to contain all or most of the wastes in a common area. The large container can be operated by pushing a button to open (or close) sealed doors to segregated waste deposit areas. These segregated areas may also be accessed from the rear of the receptacle by various transfer and cleaning operations. Also included may be a large hinged door for overall maintenance access. Decentralized receptacles are mini versions of the centralized receptacles distributed in convenient areas of the module. The container may have segregated waste deposit areas or may be responsible for containing only certain types of waste. A noteworthy disadvantage of a multi-site waste container system is that it requires a more complex transfer operation system.

1.2 Bags

Bags are presently used for waste management on the Space Shuttle. These plastic bags are distributed throughout a module in convenient areas of waste generation. To overcome zero gravity effects, the bags are tacked down, and to prevent contamination, they are sealable. Bags are most advantageous because they are conveniently located, disposable, and require minimal volume (they assume the volume of the contained refuse). However, bags are susceptible to punctures and tearing presenting a contamination risk for the habitat area.



Centralized Receptacle

Figure 1.1

1.3 Waste Specific Containers

Waste specific containers are to be used for specific wastes such as toxic materials and volatile gases and liquids generated in such areas as experimental lab modules. These containers, sealed for maximum contamination control are to be made of nonreactive materials and labeled for waste separation. Although these containers will most likely be necessary, they are likely to be expensive due to the customized design according to waste type. Also, collection procedures associated with more hazardous wastes may be difficult.

Chapter 2. TRANSFER

For the transfer process, the following methods have been considered:

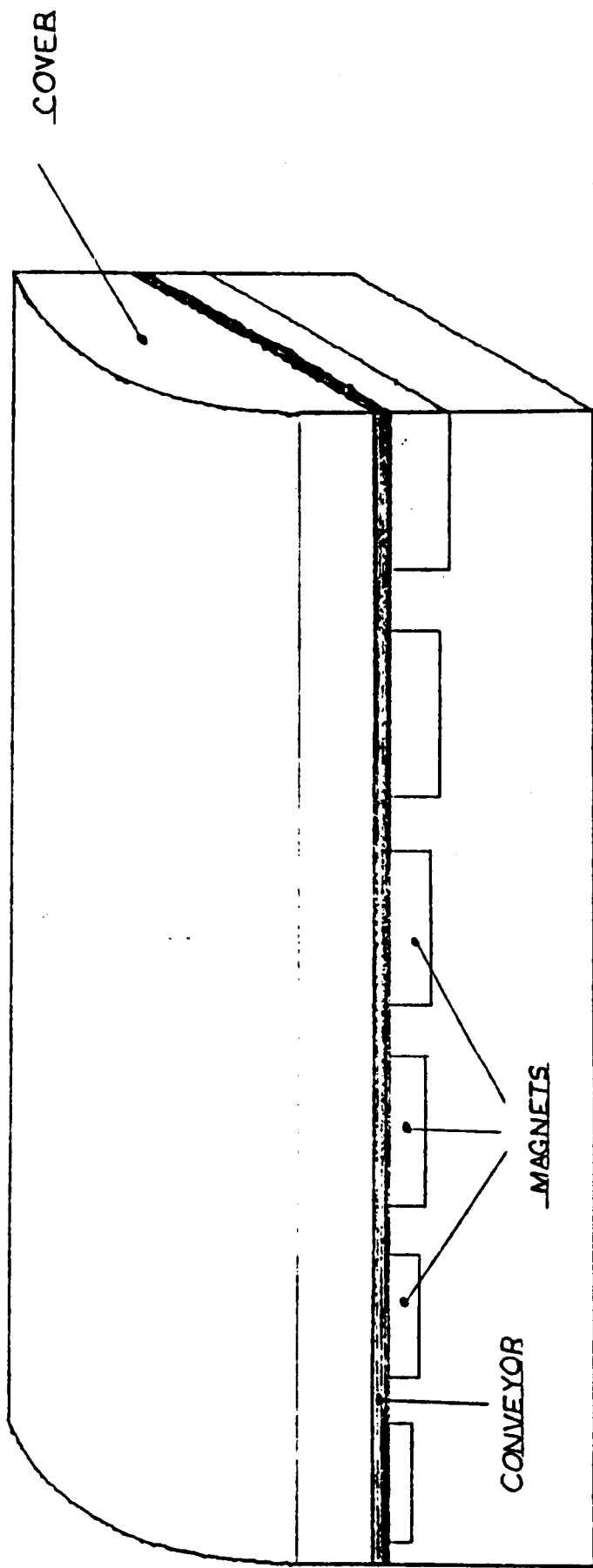
1. magnetic conveyor belt
2. retainer hook conveyor system
3. tubes
4. "bank shuttle"
5. robotics
6. manual

2.1 Magnetic Conveyor Belt

The magnetic conveyor belt, as illustrated in Figure 1.2, is a conveyor belt with a cover and varying degrees of magnetism.²² As waste is transported by the belt, the cover restricts the waste from the effects of zero gravity. The varying degree of pulsating magnetism assists in the separation of nonmagnetic materials from magnetic ones. As certain metals are moved with the aid of magnetism, the nonmetallic materials are aided by air flow. These two systems together would contribute to both the transportation and separation of refuse materials. The major disadvantages of a conveyor system for the Space Station is that it could induce significant vibration, could require a lot of maintenance and power, and it will most likely be relatively too expensive and too large for space use.

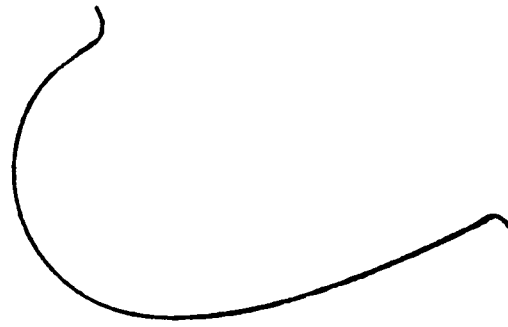
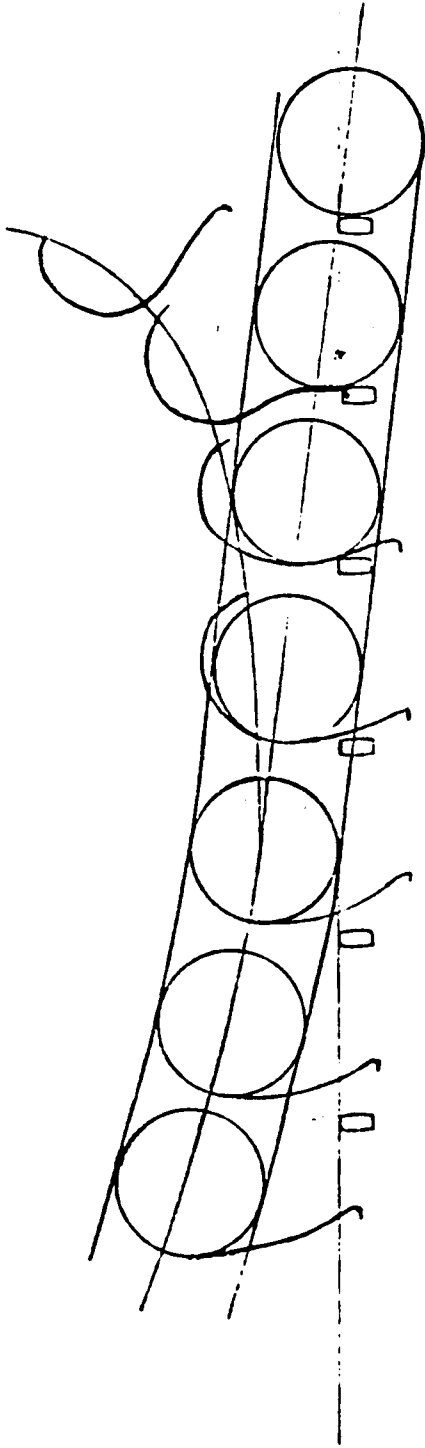
2.2 Retainer Hook Conveyor System

The retainer hook conveyor system (shown in Figure 1.3) incorporates the use of a hook, similar to a fish hook, and cylinders.²³ The hooks hold the waste containing cylinders while they are transferred along a conveyor system. These hooks help to separate and control waste containing cylinders within the zero gravity environment. As the cylinders are secured by the hooks on the conveyor belt, accuracy of cylinder spacing and constant velocity of the conveyor is essential to prevent any damage to the system components. The disadvantages presented in Chapter 2.1 are applicable for this system as well.



Magnetic Conveyor System 22

Figure 1.2



Conveyor With Retainer Hooks 23

Figure 1.3

2.3 Tubes

Tubes, with their flexibility and varying sizes, could assist in the transferring of liquid and gaseous materials anywhere. A liquid transfer experiment on Apollo 14 with baffled tanks proved tubes to be an efficient transfer method of liquids for a zero gravity environment (see Figure 1.4).²⁴ The tubular transfer system requires some sort of storage and receiving tanks so that the pump or air flow transport system is not exhausted. In addition, the tubes must be of material which is nonreactive with the materials transferred through them. The major disadvantages of using a tubular fluid transfer system is that clogging is possible, and periodic maintenance and cleaning is required. Also, if waste amounts are such that a large pumping system is needed, this system could contribute harmful vibrational effects to the Space Station.

2.4 Bank Shuttle

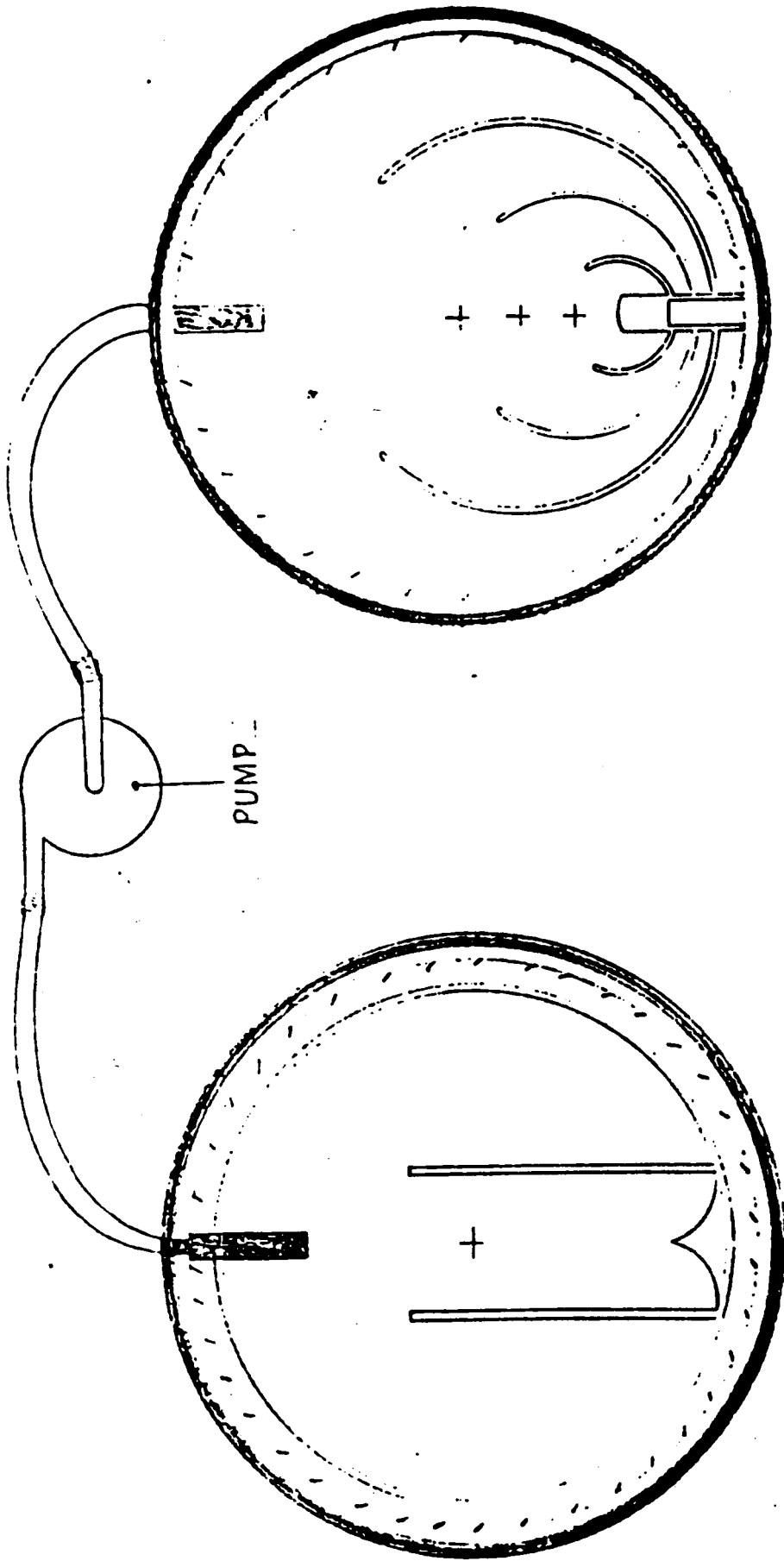
The "bank shuttle" transfer system is similar to the transaction transfer system used by banks here on Earth (see Figure 1.5).³³ The waste is collected in a cylinder which is then placed in a receptacle. The cylinder is transferred from the receptacle, pending a push-button signal, through a tubing system by means of a pulling force. This force could be created using pressurized gases, compressed air flow, or magnetic fields. If any mechanical difficulties are incurred, hinges allow the panel to be opened for easy cleaning and maintenance. Furthermore, this system may reuse the cylinders which would avoid their resupply and storage.

2.5 Robotic Transfer

Robotics is a reliable transfer method which automatically transports an item to a desired location. One robotic technique involves a single mechanical arm picking up containers from conveyor belts, for example, and placing them into storage. Also, an entire robotic system can be used to transfer containers to reduction sites. The only major disadvantage associated with the use of robotic transfer is the possibility of high cost.

2.6 Manual Transfer

In manual transfer, an individual must pick up the waste containers and physically transfer the waste to some designated area. If not selected as the primary method of refuse transfer, it remains as the secondary or back-up method in case of system failure. The major disadvantages associated with manual interaction in the refuse management system is that it presents a contamination risk for crew members and it distracts them from other important tasks.

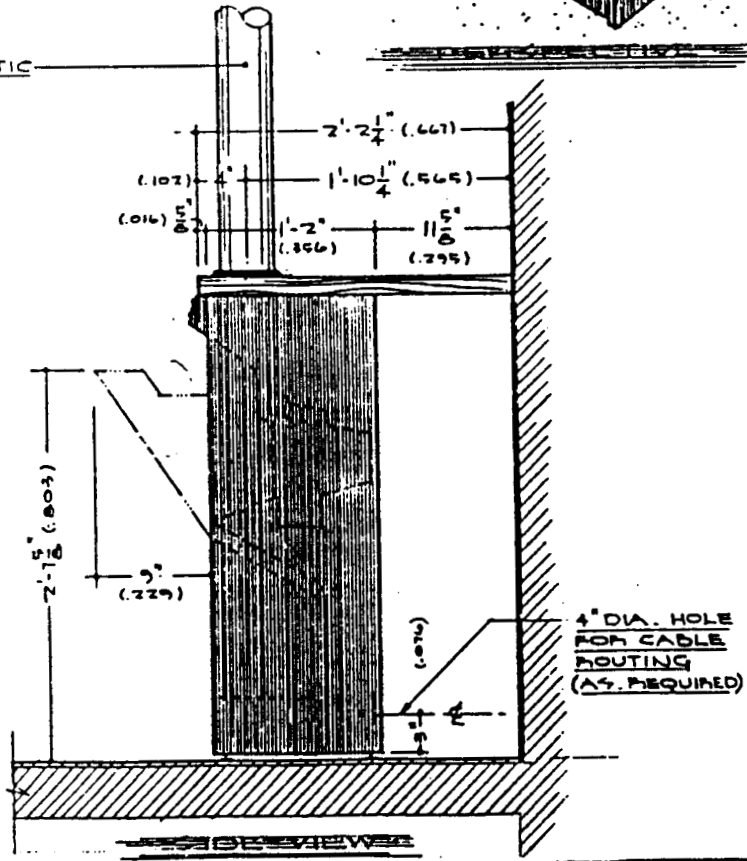
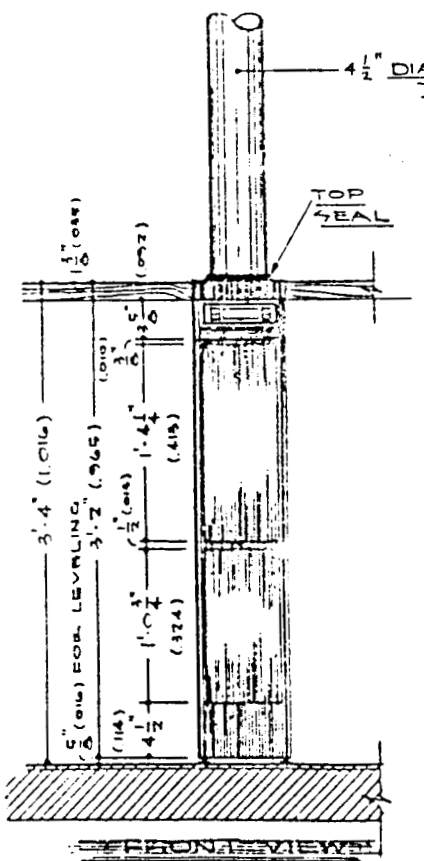
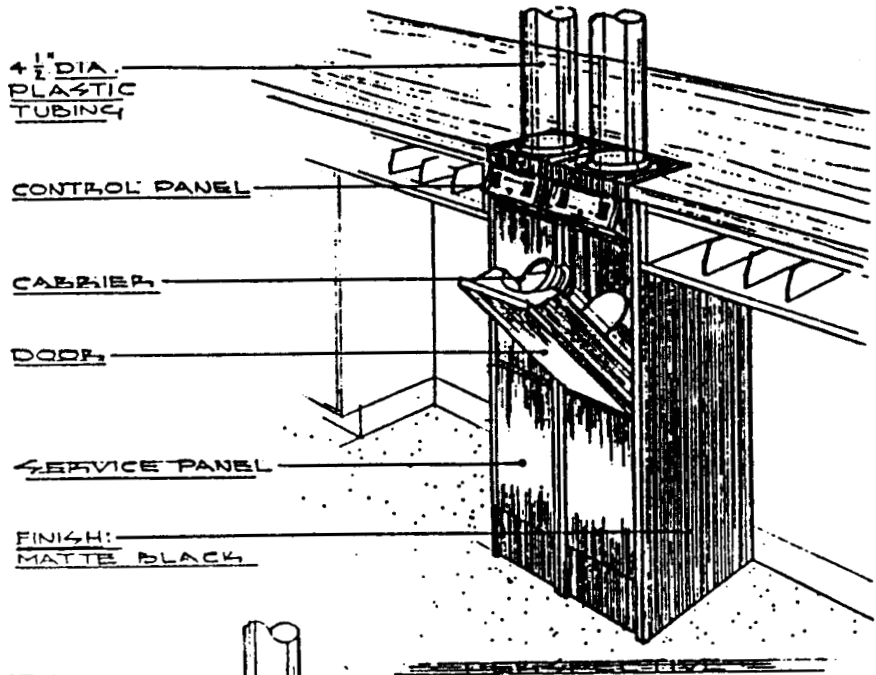
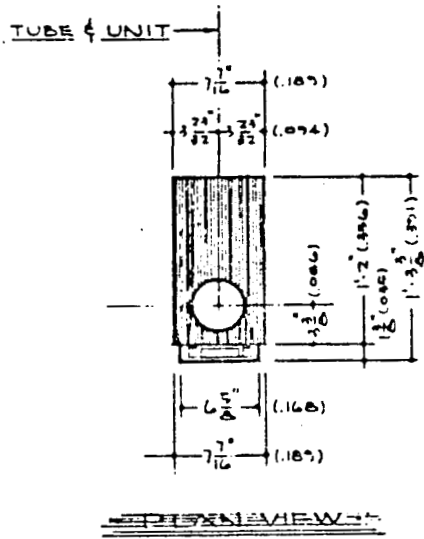


Baffled Tank Tubular Transfer (Apollo 14 Study)²⁴

Figure 1.4

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"Bank Shuttle" Concept³³
Figure 1.5

Chapter 3. REDUCTION

The reduction methods can be divided into two major categories:

1. primary reduction
2. secondary reduction

Primary reduction refers to the methods of basic reduction used at or near the generation sites. Secondary reduction refers to the methods used for further reduction or methods that cannot be employed at or near the generation sites. Some methods are used in both categories.

For primary reduction, the following methods have been considered:

1. compaction
2. shredding
3. bar coding
4. manual

For secondary reduction, the following methods have been considered:

1. wire mesh
2. centrifuge
3. magnetic separation (see Chpt. 2.1, Magnetic Conveyor Belt)
4. bar coding

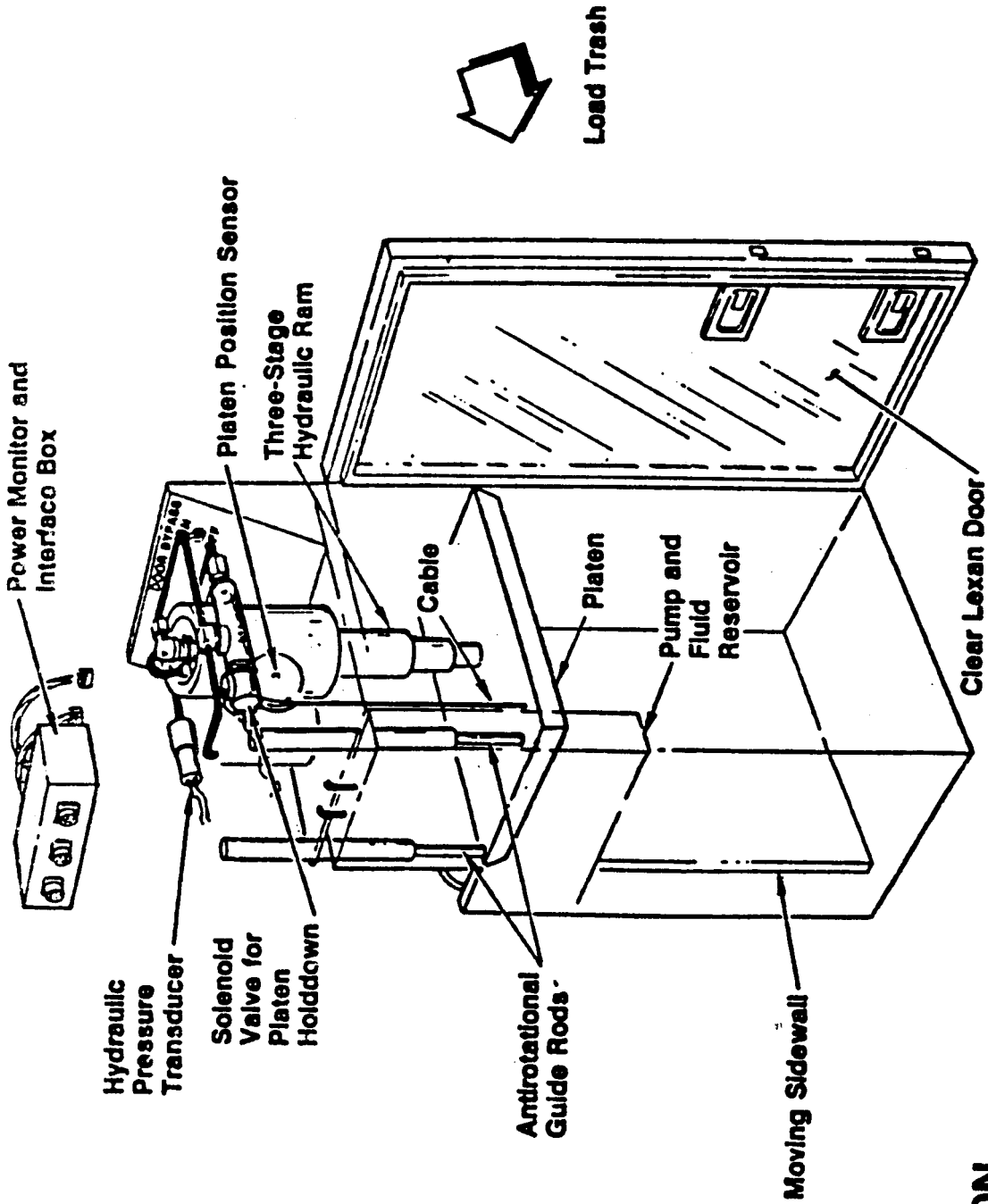
3.1 Compaction

A compactor is a device which compresses refuse into smaller volumes for easy transfer and disposal. The Space Pac Trash Compactor has already been designed and approved for space application (see Figure 1.6). This compaction method uses existing technology to not only reduce material size and volume, but also to extract fluids.²⁵ Disadvantages of a compaction device include significant power consumption and cleaning and/or resupply of liner bags.

3.2 Shredding

A shredder is a device which reduces the volume of waste by cutting it into fragments. A multi-blade system can be employed to shred most materials and is most effective for the processing of nonmetallic materials. For metallic materials, a single-blade system can be used.²⁶ The major disadvantages associated with a shredding system are high maintenance, periodic blade replacement, high power consumption, high cost, and possible vibrational effects which could threaten the stability of the station.

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McDonnell Douglas • Honeywell • IBM • Lockheed • RCA

Space Pac Trash Compactor 25

Figure 1.6

**SPACE
STATION**

3.3 Bar Coding

Bar coding, a computerized identification technique, can be used in any phase of the waste management system to identify and separate different wastes. Types of bar codes are illustrated in Figure 1.7.²⁷ Wherever used, bar coding enables a computer to identify packages for their content resulting in automated waste handling. A computerized bar coding system can also be used in storage areas to detect which containers are to be recycled or removed for disposal. In addition, this type of coding can be used to keep an accurate inventory of waste on hand which can assist in planning future modifications of the refuse management system. The only disadvantage associated with the use of bar coding is the possibility of human error. It must be noted that initial logging of the codes into the computer is manual and the smallest error may have a great impact on the safety of the module.

3.4 Manual Separation

Manual separation is the most basic method of refuse separation. The individual can separate the waste simply by placing each type into designated containers. This technique is effective if proper labeling of containers is used. Some materials, such as radioactive or toxic wastes, cannot be separated using this method. The disadvantages are identical to those listed in Chapter 2.6, Manual Transfer.

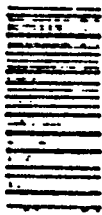
3.5 Wire Mesh Separation


Wire mesh is a method of separating liquids from gases. As a liquid and gas is fed into this system, they are adjoined. As they contact the wire mesh, liquid is extruded by absorption into the mesh while the gas is allowed to pass.²⁸ The pad with the absorbed liquid is removed and the liquid is extracted via some method. The separated gas is placed into containers and deposited into storage areas to await disposal or recycling. A major disadvantage of wire mesh separation techniques include possible manual interaction for mesh removal and cleaning. Also, space application of mesh separation was not verified during the research process.


3.6 Centrifuge Separation


The centrifuge method (see Figure 1.8) is currently used on Earth to separate gases from liquids.²⁹ As the adjoined fluid enters the centrifuge via the intake, it is forced through a screw inducer. This inducer transitions the flow into a centrifuge area where the rotating motion forces the heavier liquid to the outside walls of the device. The separated fluids are then forced through a flow divider after which, they are placed in appropriate holding containers for transfer and storage. Some disadvantages of using centrifuge separation include high maintenance (cleaning), significant power consumption, possible vibrational effects, and possible high cost.

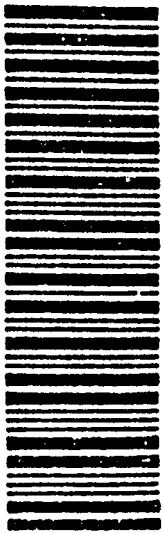
Assorted barcode symbols



 1910016839A
CODE 11



 APT-038414
CODE 39

LOT NO. **831E**

CODABAR


 200101911254
UPC Symbol


 0 0 2 2 1 4 9
Two of Five

6491032456789098765432100000378300975

 8032 8 8 3 0 DM 3783.00
Nixdorf Code

4158963641

Plessey Code


 .515-64-6238:
Ames Code

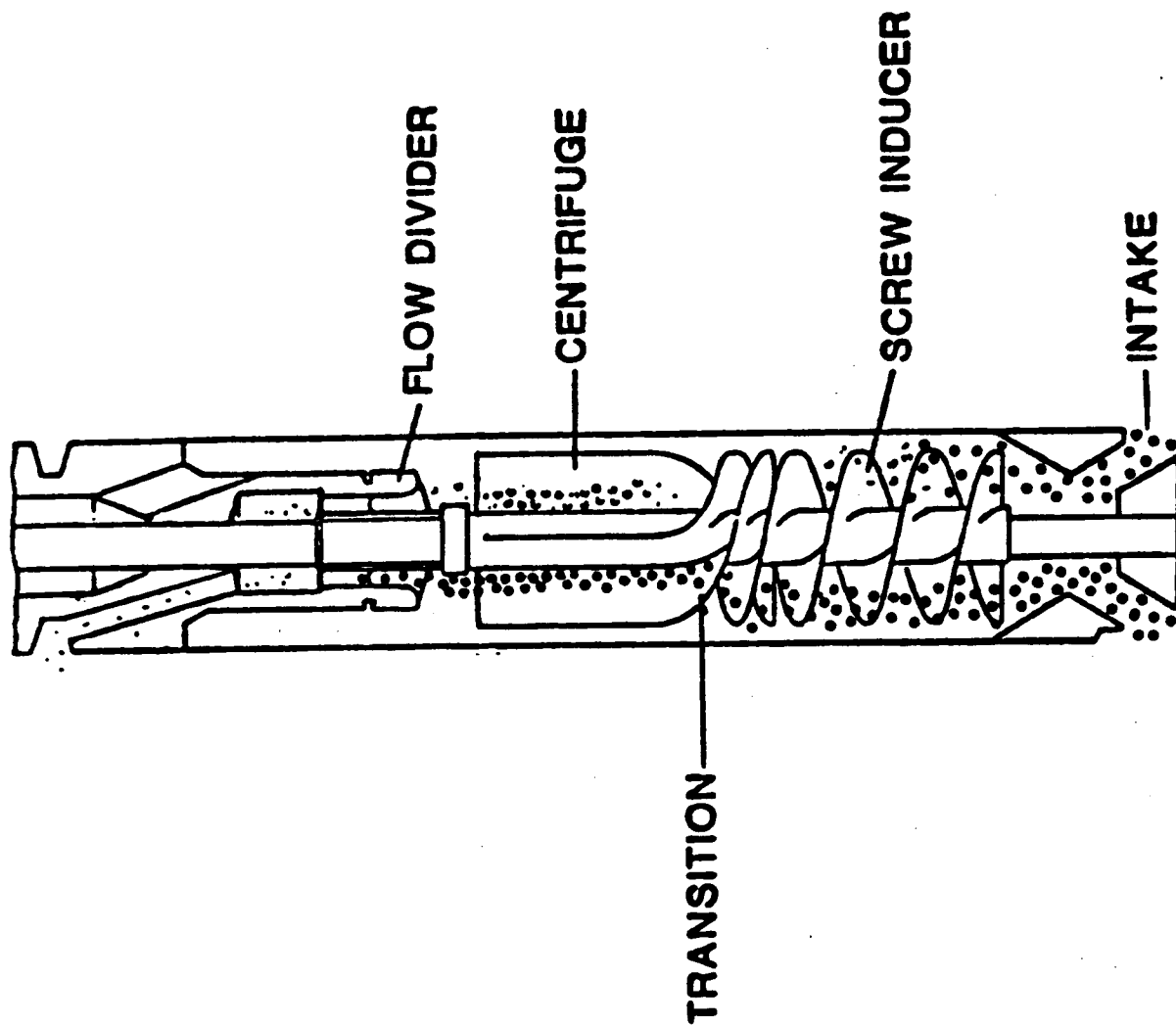

 0161A237A4CR4234560
CODE 93


 590076179
**Interleaved
Two of Five**

Source: Intermec

Examples of Bar Codes 27

Figure 1.7



Gas flow through centrifugal gas separator.
Centrifuge Gas Separator 29

Figure 1.8

Chapter 4. STORAGE

For the storage process, the following ideas have been considered:

1. "honeycomb" stacking
2. "soda machine" stacking
3. separate storage containers

It must be noted that due to the nature of some potentially useful waste materials to be stored, certain portions of storage devices must be environmentally controlled to preserve their vitality. In case of failure, it is recommended that a refrigerated storage area (which may be primarily used for other purposes) be available as a possible backup system.

4.1 "Honeycomb" Stacking

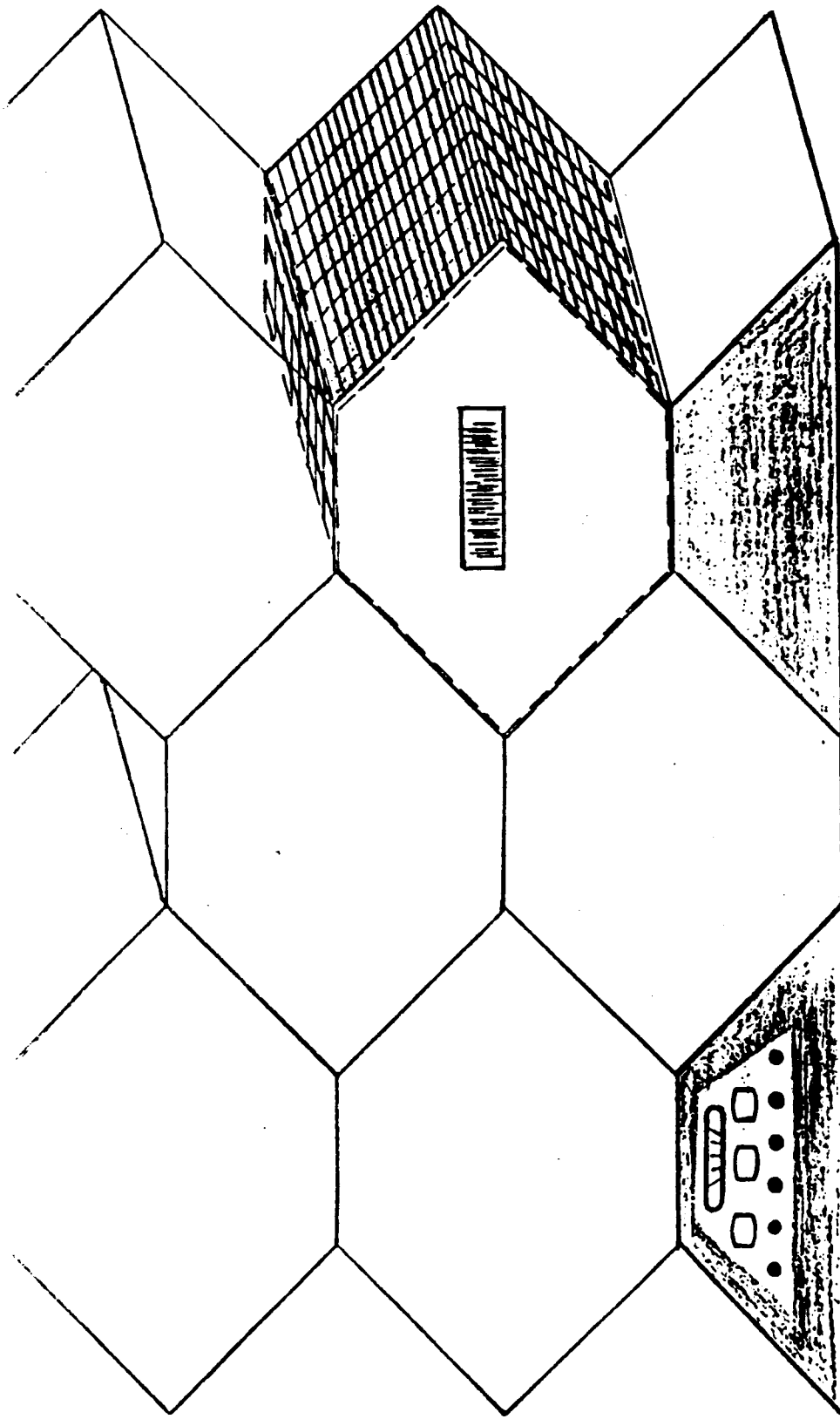
The "honeycomb" stacking (see Figure 1.9) is an efficient way to use the limited amount of storage space available on the Space Station. This method can be applied almost anywhere storage is needed. A smaller scaled version can be used within the living module or a larger one can be used for materials waiting to be recycled or disposed. The efficient use of this type of stacking requires certain shaped containers. These containers and the storage cells can vary in shape somewhat and still be effective (e.g. square cells can also be used). The placement of the containers into the grid can be manual or robotic if some coding procedure is used.

4.2 "Soda Machine" Stacking

The "soda machine" stacking, as its name implies, is based upon the method of storage used in soda machines on Earth (see Figure 1.10). Cans are placed in segregated columns from the top and removed from the bottom on a "first in/first out" basis. The same concept is used in the "soda machine" stacking; however, a mechanical system is needed to direct the containers to the bottom in a microgravity environment. This method of storage, as in "honeycomb" stacking, can hold units of varying sizes. The containers can be stacked manually or with the help of robotics. A container coding system can also be used to make this storage process fully automated.

4.3 Separate Storage Containers

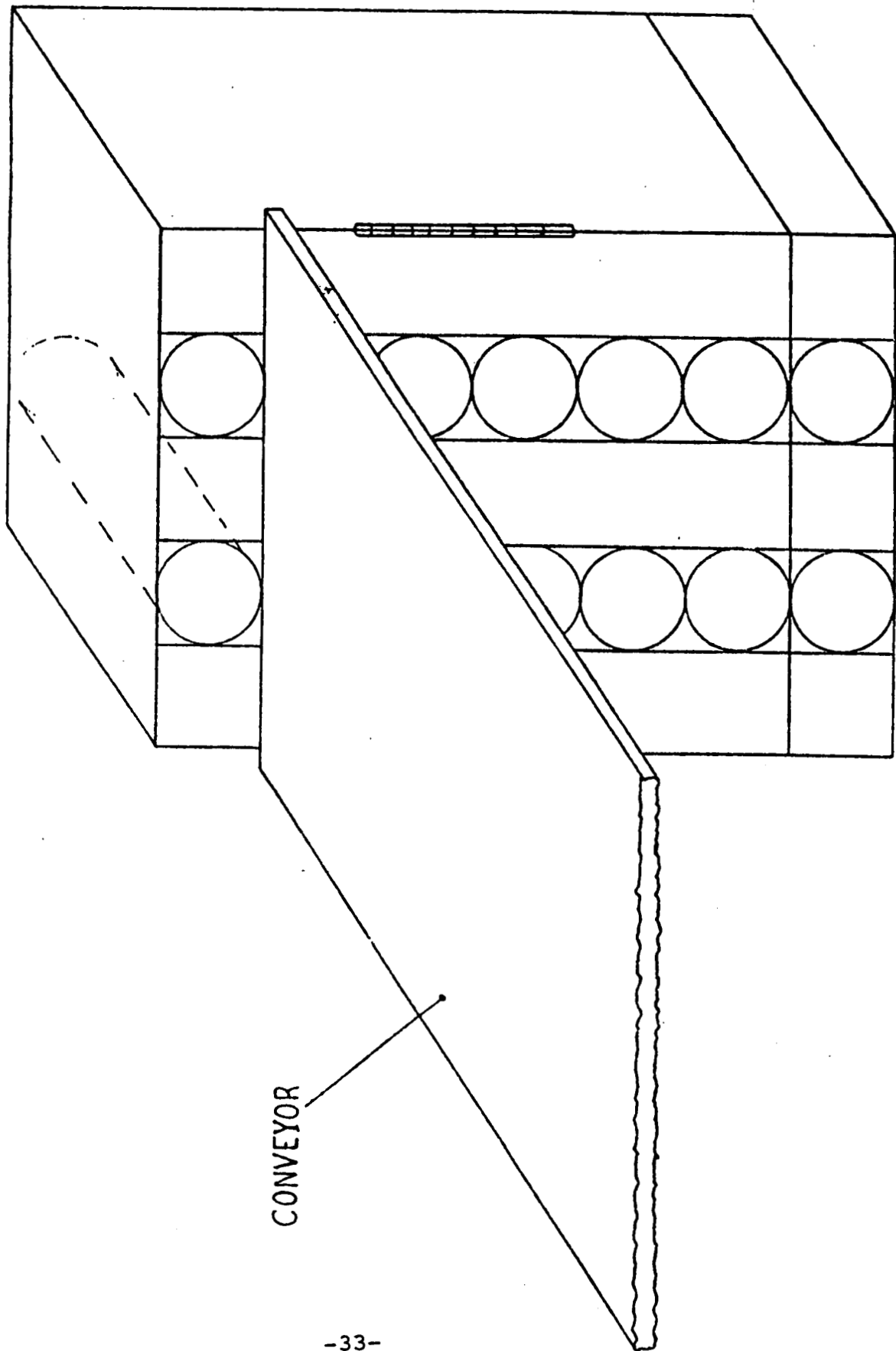
Separate storage containers are basically smaller areas set aside for isolated storage of special wastes, such as toxic or volatile materials. These containers can incorporate either type of stacking to make the most efficient use of the provided storage space. Advantages and disadvantages depend upon the design of the storage facility.



"Honeycomb" Storage

Figure 1.9

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CONVEYOR

"Soda Machine" Storage

Figure 1.10

Chapter 5. COLLECTION AND TRANSFER OPTIMAL SOLUTION - PHASE I

5.1 Integration Possibilities

The integration between the subsystems of collection, transfer, material reduction and storage must be considered when handling various types of wastes. The integration possibilities are shown in the flow chart of Figures 1.11-15. Due to the size of the chart, it is broken into five parts. Figure 1.11 shows the process of collection to primary reduction. Figure 1.12 shows the process of primary reduction. Figure 1.13 shows the transfer process from primary to secondary reduction. Figure 1.14 shows transfer from secondary reduction to storage. Figure 1.15 shows transfer from storage to disposal or reuse/recycle. This flowchart was an important tool in determining the optimal refuse collection and transfer subsystem solution.

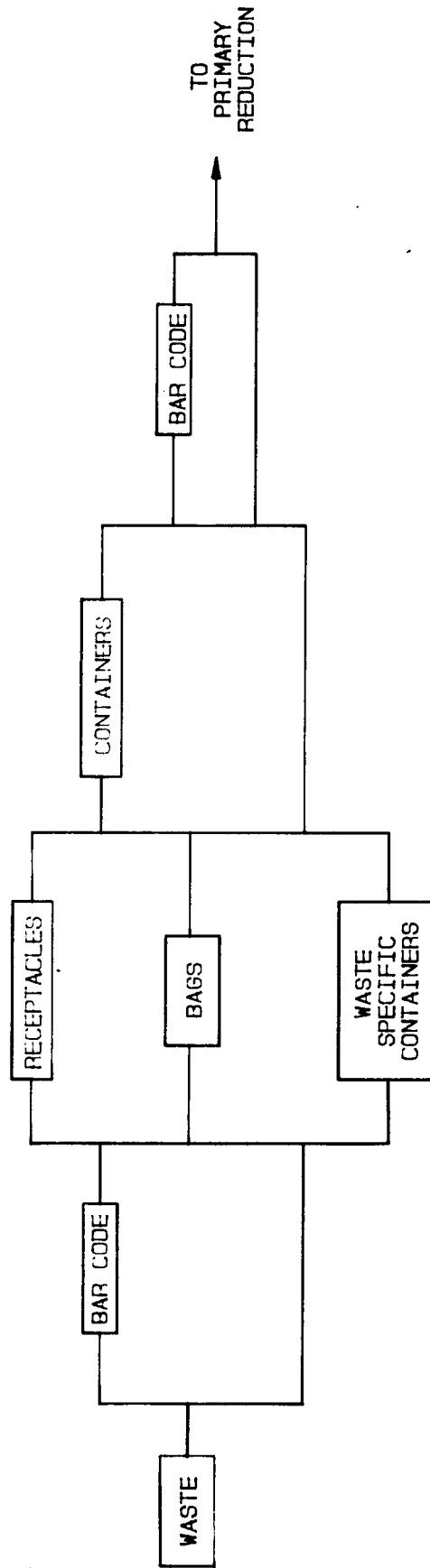
5.2 Solution Discussion

Considering the collection subsystem, plastic bags were selected as the most optimal solution. Although labeled receptacles rated higher than bags in Solution Matrix 1.1 of Appendix A, bags were chosen because of their direct transfer capability into the compactor. Bags can be distributed in convenient refuse generation sites. When they are full, they can be sealed with velcro or a draw string closure and then placed directly into the compactor for waste volume reduction.

An alternative solution for waste collection is waste specific containers. These containers, made especially for waste types with certain handling needs (such as hazardous and volatile chemicals), are sealable and constructed of nonreactive, durable material. The cost of specific containers can be higher than just utilizing receptacle space mainly because of the customization required. One such custom design could involve using inlet/outlet ducts to allow for fluid removal or deposit via some suction force. When dealing with hazardous materials, however, reducing the risk of contamination is a much more important consideration than cost, especially for the confined living conditions of the Space Station.

Both the optimal and alternative collection solutions will require some manual interaction to properly dispose of the waste. Both methods and their interaction with the transfer subsystem is shown in Figures 1.16 and 1.17.

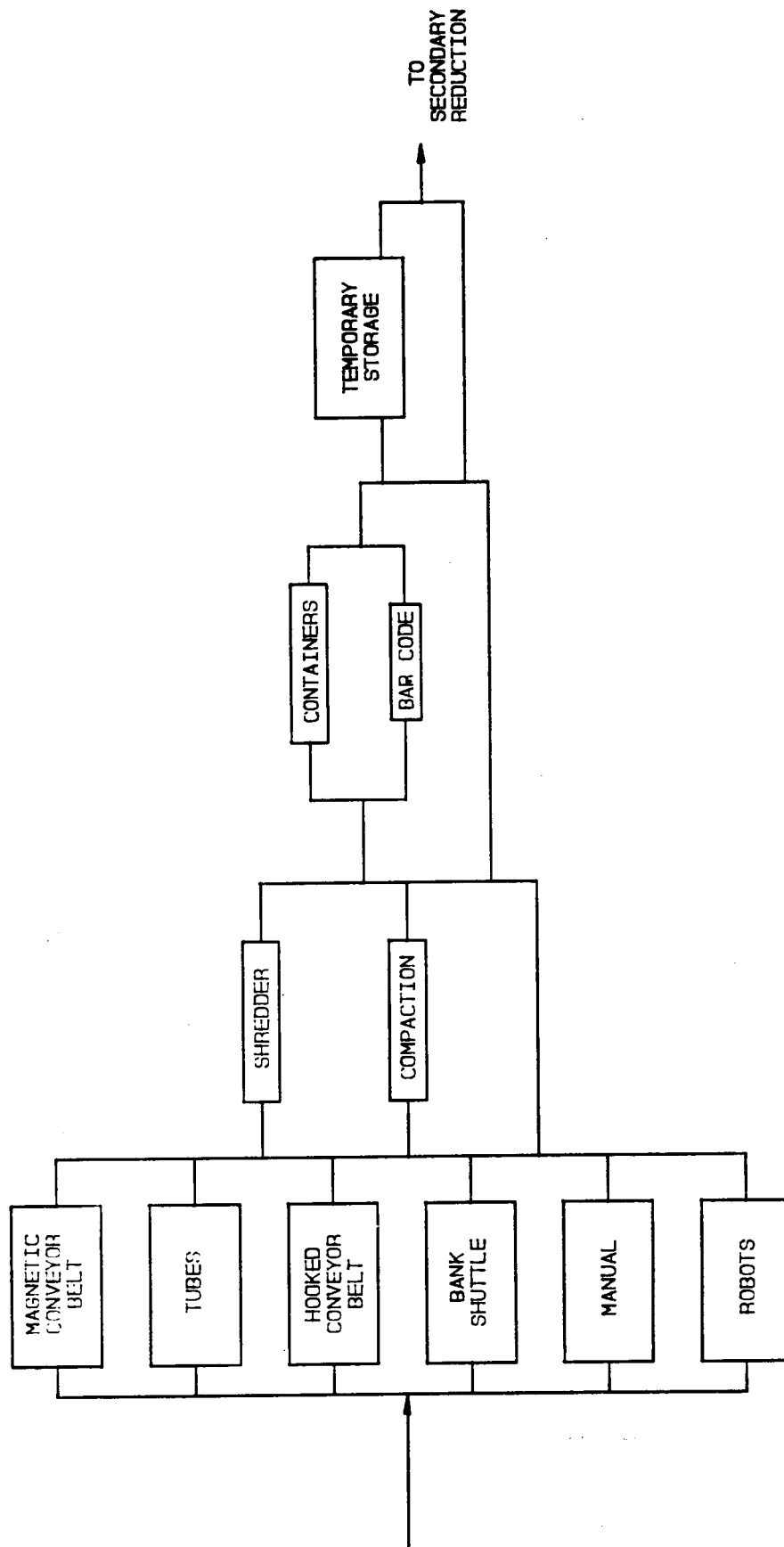
Considering the transfer subsystem, the "bank shuttle" method, a similar system to that used by bank transaction systems on Earth, proved to be the most optimal method of transfer according to Solution Matrix 1.1. The "bank shuttle" system cost is low relative to most of the other automated transfer systems considered due to the simplicity of the mechanical components involved (see Figure 1.5).³³ Most of the cost relies on how much tubing is required, where it is located, how many containers are needed, and how the suction transfer



INTEGRATION POSSIBILITIES: COLLECTION

Figure 1.11

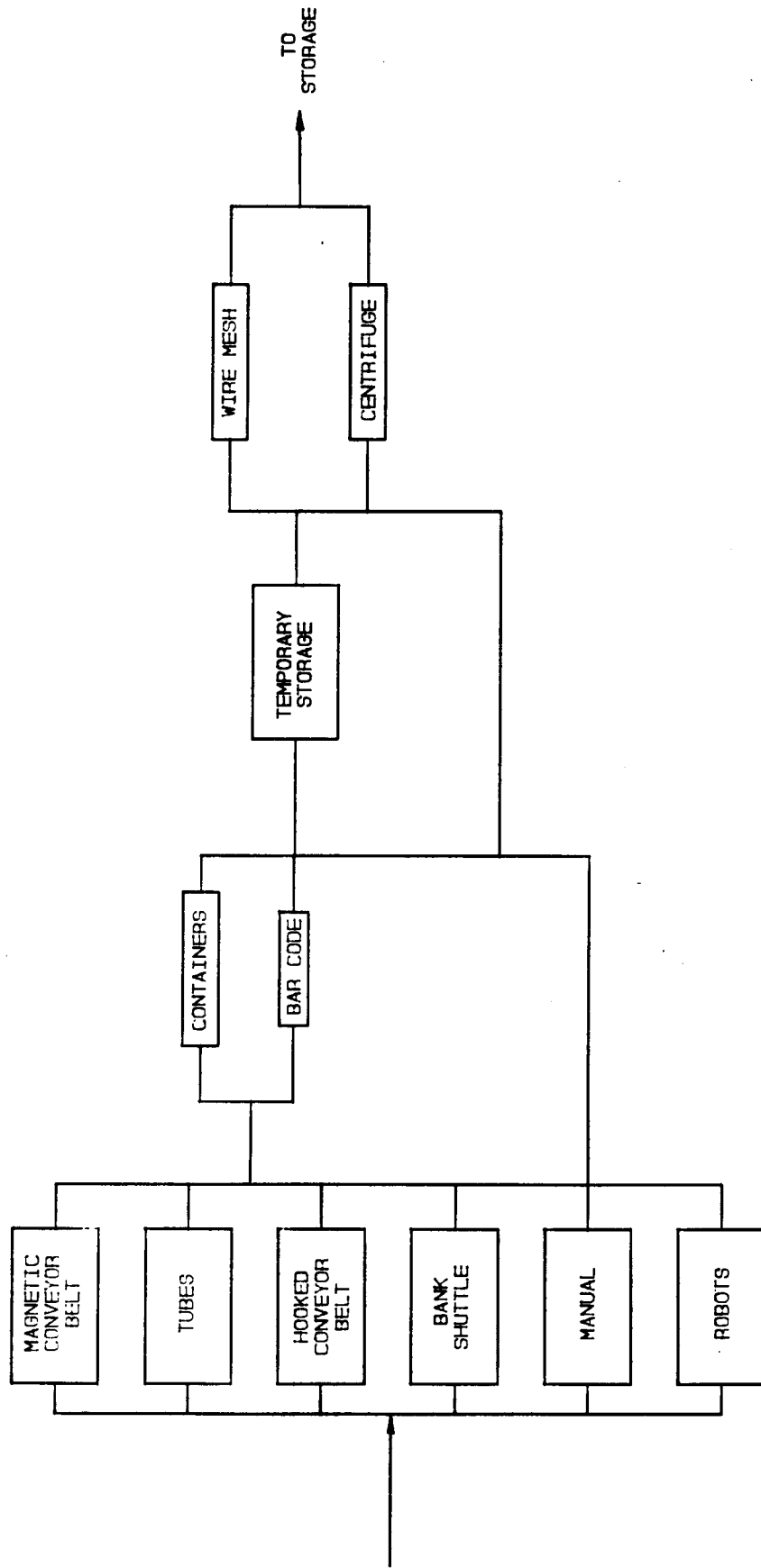
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Integration Possibilities: Primary Reduction

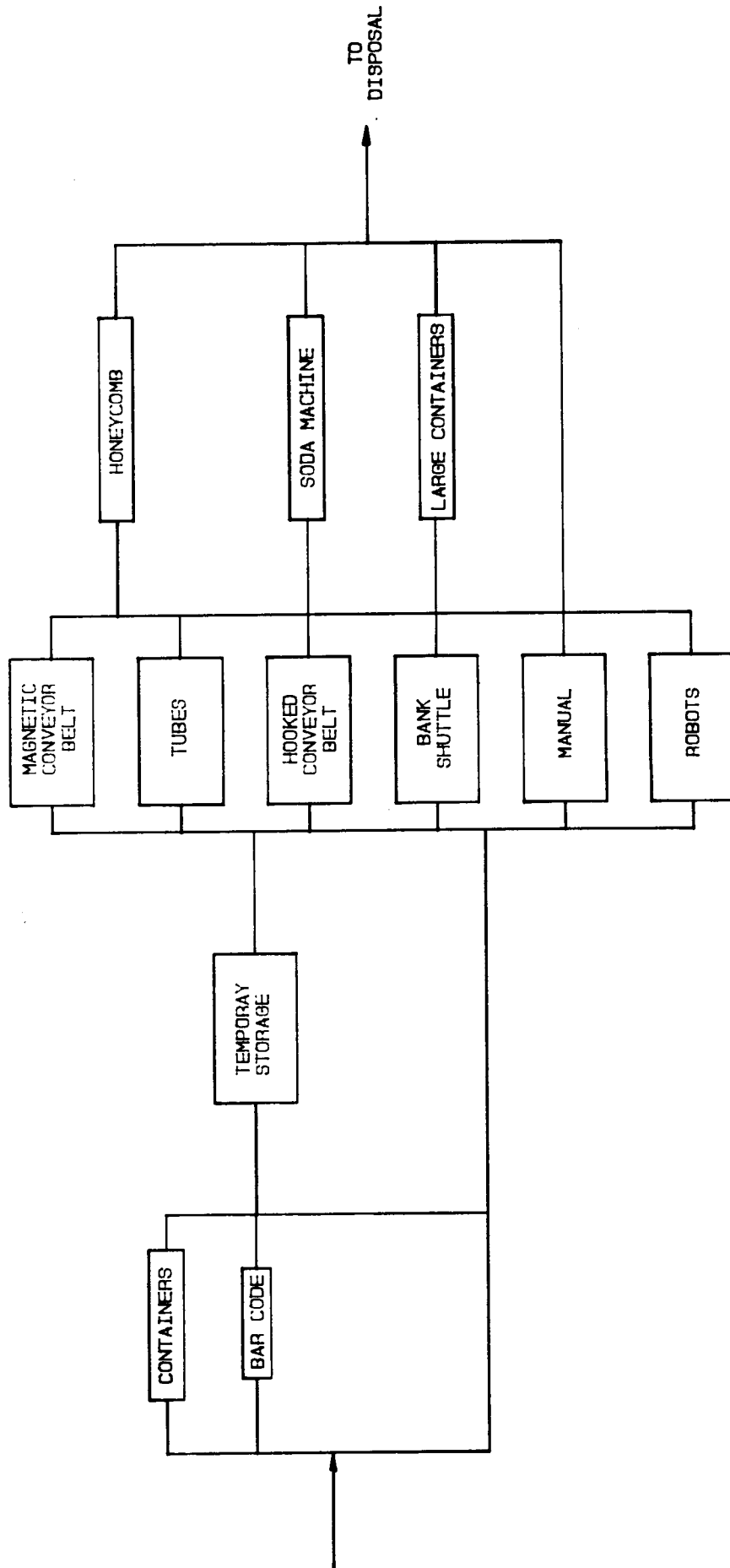
Figure 1.12

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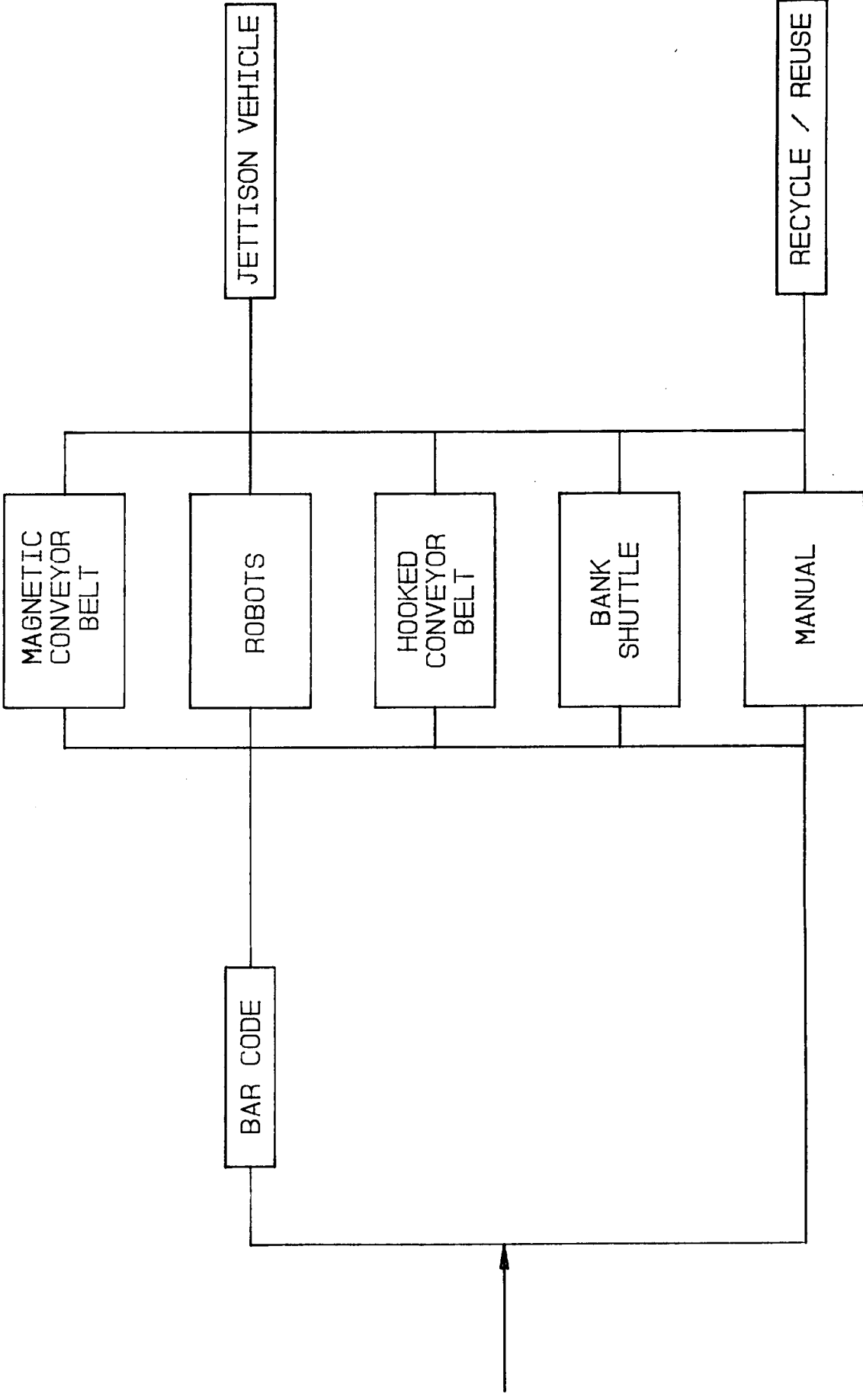
Integration Possibilities: Secondary Reduction

Figure 1.13



INTEGRATION POSSIBILITIES: STORAGE

Figure 1.14



INTEGRATION POSSIBILITIES: DISPOSAL

Figure 1.15

Collection and Transfer I

force is incorporated. Because the system is operationally simple and dry containers prevent tube clogging, there is little mechanical maintenance expected and thus little cost required in that area as well. The location of the receptacles for the shuttle containers are to be convenient areas of waste generation. The transfer containers are to be made of durable material which may or may not be reusable. Also, the design of the waste specific collection containers discussed above should permit direct transfer through the "bank shuttle" transfer system.

For fluid wastes, another tubular method of transfer also rated well in the optimization matrix. For liquid transfer specifically, baffled holding tanks with tubular transfer via pumping action proved to be an efficient method for microgravity conditions on Apollo 14 (see Figure 1.4).²⁴ Like the "bank shuttle" system, this type of transfer is mechanically simple resulting in easier workmanship and lower production cost. Contamination risks are low due to the continuous containment of waste in tanks and tubes. The amounts of fluid wastes, excluding water, will most probably be significantly less than those of solids, therefore this system need not require as much room as any of the other automated systems suggested. Both the "bank shuttle" and the fluid tubular transfer system are not expected to generate significant vibrational problems.

Manual transfer also rated fairly well as a possible alternative. This method is, of course, the most reliable as well as cheapest solution. Manual transfer can be used in any phase of the transfer subsystem and will be required where automation is not feasible. Also, manual interaction in all systems of refuse management is suggested as a backup alternative in case of failure. All three methods and their interaction with the collection and transfer subsystem are shown in the flowchart of Figures 1.16 and 1.17.

Considering the primary reduction subsystem, the bar coding method of computer identification proved to be the optimal solution according to Solution Matrix 1.2. The effective use of bar coding to identify and separate wastes in any phase of refuse management results in lower manual handling and thus lower contamination risk. However, bar coding must be coupled with other reduction methods in order to be effectively used. For example, bar coding can be coupled with manual separation at the collection receptacle to insure against human error. If someone deposits a waste type into an incorrect area, a bar code scanner could identify the mistake and reject the waste. This type of computerized coding, as an inventory tracking system, can also assist in the disposal priority of waste which has lost its usefulness through time. The versatility of bar coding extends its usefulness to an infinite number of purposes, for other Space Station systems as well as waste management, which helps justify its cost.

The co-optimal method for primary reduction is found to be compaction. The Space Pac Trash Compactor uses existing technology to not only reduce material size and volume, but to also extract fluids for the Space Station water recovery system (see Figure 1.6).²⁵ The

cost of the compactor is relatively lower than most other reduction methods, since this customized unit has already been designed and developed. However, some minor modifications to the compactor could facilitate the integration of the reduced waste with the "bank shuttle transfer system. If the "pressing plate" and bottom surface contour were curved such that the trash could be pressed into a cylindrical-like shape, it could then be directly transferred through the "bank shuttle" system.

Considering the secondary reduction subsystem, bar coding, as in primary reduction, proved to be the optimal solution. For co-optimal and alternative reduction methods, wire mesh and centrifuge rated well if there is a need for liquid and gas separation. Wire mesh is a method of separating liquids from gases by trapping moisture in the mesh as gaseous fluid travels through.²⁸ This method is inexpensive, but possibly requires manual involvement to remove the trapped liquids, thereby increasing contamination risks. The centrifuge method is used to separate gases from liquids using centrifugal force theory (see Figure 1.8).²⁹ The centrifuge separation device has already been developed for use on Earth, but the modification for space use could be expensive. Due to the mechanical system involved, maintenance and the need for disinfection is higher than many other reduction methods. Also, the centrifuge requires a significant amount of power and possibly space. However, the device generates its own artificial gravity for separation purposes and seems feasible for the specific separation of gases from liquids in space.

Primary reduction is achieved most effectively if bar coding, compaction, and manual methods are integrated together. The secondary methods of wire mesh and centrifuge are used only if there is a need for further liquid-gas separation than what can be accomplished manually.

Considering the storage subsystem, "honeycomb" stacking (see Figure 1.9), is the optimal solution for the storage of refuse. The advantage of the "honeycomb" over the "soda machine" is that it requires no mechanical system to overcome the zero gravity environment. "Honeycomb" stacking requires less maintenance, is easier to assemble, and is expected to be more reliable. This concept of storage is beneficial due to its efficient use of space, and can be applied almost anywhere storage is needed. The "honeycomb" idea is not restricted to hexagonal shapes; square or circular shapes could be incorporated and still provide efficient use of storage space. The cost of storage may be significantly high no matter the method since all storage areas containing potentially reusable waste materials with limited shelf life must be environmentally controlled. In case of failure, a refrigerated storage area, possibly used primarily for other purposes, is proposed as a storage backup. The storage areas could be automated using robotics so that the sorting, inventory and handling of waste is performed with little or no manual involvement.

Collection and Transfer I

The optimal integration involving all components of the collection and transfer subsystem is shown in Figures 1.16 and 1.17. If the waste is solid, mainly paper and used food packaging, it is manually placed in labeled bags which are sealed and deposited directly into the compactor when full. After compaction, the waste is placed in pre-barcoded "bank shuttle" containers and transported to predetermined storage sites. If the waste is of laboratory origin, it is collected into pre-coded waste specific containers. If further separation of fluids is required, then the waste is processed through the wire mesh or possibly centrifuge system using the fluid tubular system. It is then transported via the "bank shuttle" system to predetermined areas of storage.

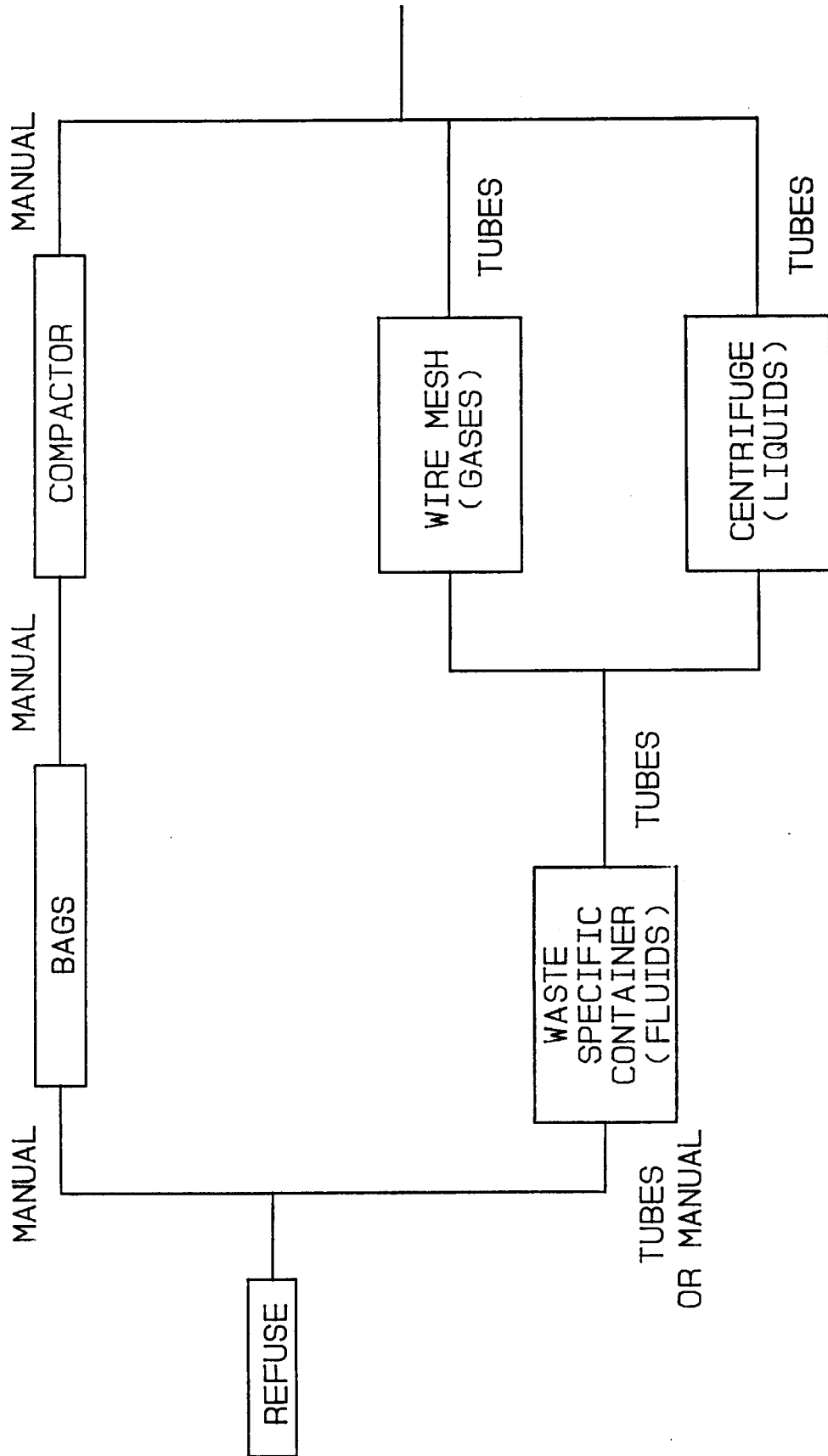
If the waste is to be recycled, the recycling subsystem can retrieve needed materials from the environmentally controlled storage area automatically via a bar code scanner and possibly robotic system. If recyclable wastes lose their vitality while in storage, a transfer mechanism (manual or "bank shuttle") must be employed to transport them to the disposal site. Bar coding can be used to determine when certain wastes need to be disposed. If the waste is to be disposed of, it can be robotically transferred from a storage site, convenient to the disposal area, directly into the jettison vehicle.

5.3 Preliminary Solution Summary

In summary, the following is a list of preliminary solutions for the collection and transfer refuse subsystem for the Space Station:

- | | |
|----------------------|---|
| Collection: | 1. Bags |
| | 2. Waste Specific Containers |
| | 3. Manual (Backup) |
| Transfer: | 1. "Bank Shuttle" |
| | 2. Fluid Tubular System (Baffled Tanks) |
| | 3. Manual (Backup) |
| Primary Reduction: | 1. Bar Coding |
| | 2. Compaction |
| | 3. Manual (Backup) |
| Secondary Reduction: | 1. Bar Coding |
| | 2. Wire Mesh - liquids from gases |
| | 3. Centrifuge - gases from liquids |
| | 4. Manual (Backup) |
| Storage: | 1. "Honeycomb" Stacking |
| | 2. Incorporation of robotics for automation |
| | 3. Refrigerated Storage (backup) |

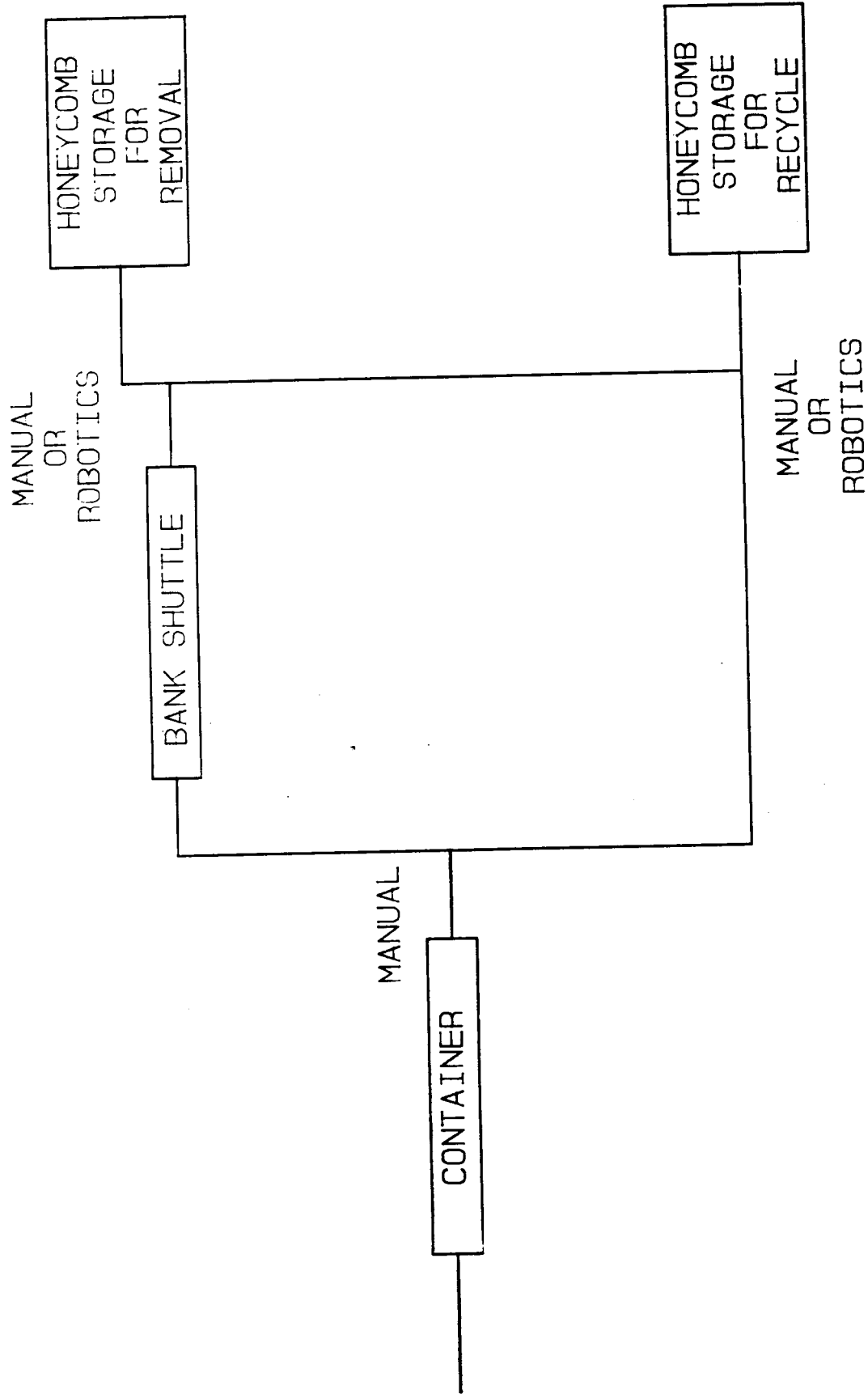
Based upon these decisions, a more detailed study is presented for the solutions in the subsequent chapters of Part II.



(ALL CONTAINERS ARE BAR CODED)

Optimal Solution Subsystem (A) (Design Phase I)

Figure 1.16



(ALL CONTAINERS ARE BAR CODED)

Optimal Solution Subsystem (B) (Design Phase I)

Figure 1.17

PART II. REFUSE COLLECTION AND TRANSFER - DESIGN PHASE II

When considering the more detailed design of a suitable network for the collection and transfer of refuse upon the Space Station, several areas must be investigated. These specific areas are:

1. Material types of canisters and "bank shuttle" hardware.
2. Canister shape.
3. Canister transfer forces.
4. Canister deposit sites (receptacles).
5. Compactor design.
6. Contamination control.
7. Power supplies.

Chapter 6. RECEPTACLE/CANISTER MATERIAL TYPES

A diversity of waste types must be considered when determining suitable materials for the waste canisters, receptacles (or "bank shuttle deposit sites"), and transfer tubing network. Alternative materials will be selected on the basis of functional acceptability and suitability, technological maturity, specific strength, cost, and chemical activity.³⁴

Various polymers being considered are as follows:

1. Lexan (polycarbonate material)
2. Polypropylene
3. Polyethylene - Ultra High Molecular Weight
4. Polyethylene - High Density

These materials are available in a diversity of forms ranging from films to foams which contribute to their easy machinability. In addition, they all possess qualities high strength, elasticity, and technological maturity.³³ The material properties of these materials are summarized in Tables 1.1 and 1.2.

6.1 Lexan

Lexan, a polycarbonate material produced by General Electric, possesses a high impact strength, high modulus of elasticity, excellent resistance to creep and cold flow, and a brittleness temperature below -200 degF. Lexan is resistant to electron beam radiation, self extinguishing, resistant to weak acids, slightly affected by strong acids, resistant to weak alkalis to a limited extent, and attacked by strong alkalis. It is soluble in hydrocarbons, ketones, and esters.³⁹

6.2 Polypropylene

Polypropylene, a fairly inexpensive polymer, is extremely resistant to weak acids, attacked slowly by oxidizing, or strong acids, very resistant to weak and strong alkalies, and resistant to organic solvents below 80 degC. This material possesses a slow burning rate and a brittleness temperature of -20 to 32 degF.

6.3 Polyethylene (Ultra-High Molecular Weight)

Ultra-High Molecular Weight (UHMW) polyethylene is a somewhat new material, hence, it fails to possess necessary technological maturity. However, this polymer is extremely resistant to weak acids, fairly resistant to strong acids, very resistant to both weak and strong alkalies, and resistant to organic solvents below 80 degC.

6.4 High Density Polyethylene

High density polyethylene is older, stronger and less expensive than UHMW polyethylene. Presently, commercial garbage bags are made of this type of polyethylene material. Because of its strength, durability, and low chemical reactivity with acids, alkalies and organic matter, this plastic can accommodate most refuse types.

Chapter 7. CANISTER SHAPE

The different types of canister shapes considered are listed as follows:

1. Cylindrical
2. Hexagonal
3. Cubical

The shape of the transfer tube system will determine the corresponding shape of the transfer canister.

7.1 Cylindrical Canisters

The cylindrical canisters would be similar to those used by bank tellers. The transfer tube system would therefore be a cylindrically shaped network. Because of its standard shape, the round tubing would require no special manufacturing process. A typical industrial trash compactor would require a simple modification to compact the refuse into a cylindrically shaped mass, rather than a rectangular one.

Table 1.1

Mechanical Properties of Selected Materials 39

MATERIAL	TENSILE STRENGTH (PSI)	COMPRESSIVE STRENGTH (PSI)	WATER ABSORPTION	HARDNESS	IMPACT STRENGTH (FT-LB/IN)	SPECIFIC GRAVITY	BRITTLENESS	MODULUS OF ELASTICITY (PSI)
ASTM	D638, D651	D695	D570	D785	D256	D792	-	D747
LEXAN (POLYCARB)	9000	12,500	.15	70	13-18	1.2	-	1.14×10^5
UHMW (POLYETHYL)	2500	2400	.01	80	NO BREAK	.94-.942	.09-.12	1.02×10^5
POLYPROPYL	3200-5300	8500-10000	<.01	85-110	.6-6.0	.900-.915	-	$1.3-2 \times 10^5$
HIGH DENS. POLYETHYL	3100-5500	2400	<.01	60-70	1.5-12.0	.941-.965	-	$80-15 \times 10^5$

Table 1.2

Chemical Reactivity of Selected Materials 39

MATERIAL	EFFECT OF STRONG ACIDS	EFFECT OF WEAK ACIDS	EFFECT OF STRONG ALKALIES	EFFECT OF WEAK ALKALIES	EFFECT OF ORGANIC SOLVENTS	BRITTLENESS TEMPERATURE	BURNING RATE
ASTM	D543	D543	D543	D543	D543	D746	D635
LEXAN (EXTRUDED)	ATTACKED BY OXIDIZING ACIDS	NONE	NONE	NONE	SOLUBLE IN AROMATIC AND CEOR HYDROCARBONS	< -200	SLOW
UHMW (POLYETHYL)	ATTACK SLOWLY BY OXIDIZING ACIDS	VERY RESISTANT	VERY RESISTANT	VERY RESISTANT	RESISTANT BELOW 80 °C	< -200	VERY SLOW
POLYPROPYL	ATTACK SLOWLY BY OXIDIZING ACIDS	VERY RESISTANT	VERY RESISTANT	VERY RESISTANT	RESISTANT BELOW 80 °C	-20 -32	SLOW
HIGH DENS. POLYETHYL	ATTACK SLOWLY BY OXIDIZING ACIDS	VERY RESISTANT	VERY RESISTANT	VERY RESISTANT	RESISTANT BELOW 80 °C	—	VERY SLOW

7.2 Hexagonal Canisters

The hexagonal shaped canister would require a hexagonal shaped tubing system which would be quite difficult to manufacture. An advantage to this design would be the efficient use of space due to the capability of staggered storage.

7.3 Cubical Canisters

The cubical transfer canister would require a rectangular shaped tube system. Because of the geometry of this model, a direct path may be required involving no curves and bends. Most compacting devices transform waste into cubical shapes; hence, no geometric modification would be needed in the compactor design.

7.4 Canister Access Considerations

In addition to shape determination, options of placing the openings on the ends of the capsules or on the side of the capsules are suitable for use in the network. If rectangular or hexagonal containers are employed, it seems more plausible to use side openings, rectangular in nature, to insert the waste. However, if cylindrical shapes are chosen, end openings seem preferable for easy insertion of the contents.

7.5 Canister Shape and Storage

Each canister design possesses its own unique storage site capability. The canisters are to be stored in racks, or shelves, where each individual bin must take the shape of the canister employed. This coordination of geometric shapes effectively reduces the area required to temporarily store the waste until it can be processed, jettisoned, or returned to Earth.

The following storage arrangements are considered applicable to the given canister designs:

1. Pigeon-Hole Storage
2. Rack Storage
3. Honeycomb or Hexagonal Storage

Pigeon-Hole storage applies to cylindrical containers only. In this method, an automated device, such as a pick-and-place robotic arm, inserts the individual canisters into a circular slot for storage. The process involved with rack and honey-comb arrangements is similar to the pigeon-hole; however, rack storage accommodates both cubical and cylindrical canisters. Honeycomb storage, although it uses space efficiently, applies to hexagonal canisters only and is complex and expensive to machine.

This temporary storage site may be built within existing modules or may require the construction of a specific facility to be located outside along the Space Station structure. By constructing a facility for this specific use, precious space in the modules would not be "wasted on waste". Utilizing this external site, though, would require additional material for construction and higher costs.

Chapter 8. CANISTER TRANSFER

To transfer the containers to the storage facility, a flow path or tubing network is needed. This transfer path may employ the following methods of force:

1. Vacuum
2. Blow Motor
3. Manual Hand Pump Backup

8.1 Vacuum Transfer

Any vacuum system must contain basic parts which are common to all systems regardless of the pumping methods employed. They are as follows:

1. A gas-tight vacuum vessel with gas-tight closures where entrance can be made at any phase of the operating cycle.
2. A rough pumping system which will reduce the pressure from atmospheric to a level where low pressures can be used.
3. A fine-pumping system which is capable of reaching the ultimate pressure the system must attain with sufficient pumping speed to handle the outgassing which results from work carried out within the vessel.
4. A system of vacuum gages and readouts to enable the pressure to be measured both during the roughing stage and during the fine vacuum stage.

In the applicable system, one or more openings are essential and arranged so that they can be opened or closed relatively easily. This allows insertion of materials for operations in the vacuum or permits adjustment of internal parts.

The transfer system incorporates the use of low pressure to propel the canister to its final destination. Once the canister arrives, it triggers a switch to deactivate the propelling force and release any low pressure still remaining within the chute.

8.2 Blower Motor Transfer

Another method of canister transportation is similar to the blower motor transfer system used by drive-in bank tellers. A tubing system is constructed to run from one disposal site to the storage facility. For simplicity, the route should be as direct as possible to reduce the risk of jamming the system and to simplify the fabrication, or construction. The motion of the canister is initiated by a blower motor which has a typical power requirement of 120 volts and 15 amps on Earth.³³ These numbers are based on a maximum of sixty foot lengths from the panel to the customer units.³³ Since the Space Station has a microgravity environment, it would require less power to put the canister into motion than here on Earth.³³

8.3 Manual Backup for Canister Transfer

In the case of a power outage or a system component failure, a manually operated hand pump should be available to act as a means of motion initiation for the canister. This would eliminate the risk of refuse accumulation at the transfer initiation point.

Chapter 9. CANISTER DEPOSIT SITE DESIGN

The design of a "bank shuttle" canister deposit site for the collection process must consider the minimization of crew involvement while simultaneously allowing for safety, simplicity, and reliability. Two network designs can satisfy the basic requirements of a suitable collection system:

1. Single canister deposit site.
2. Multiple canister deposit site.

It must be noted that selection of the deposit site type directly affects the design of the flow path as well.

9.1 Single Canister Deposit Site

The single canister deposit site would most likely be located in the lab module because of the volatile wastes generated from the experimental environment. This would prevent the spreading of toxins to other modules by the transfer network.

The advantages of a single canister deposit site are summarized as follows:

1. Minimizes the requirement for bends and turns in the canister transport tubes.
2. Lower transport failure rate due to the limitation of one path only, which also increases the system reliability.

Collection and Transfer II

3. Reduces contamination accumulation by isolating the waste in one area.
4. Provides a more efficient and effective system for cleansing and sanitizing.
5. Requires less materials for construction, hence less use of the precious shuttle cargo bay.
6. Consumes less space on the station.
7. Lower relative cost.

The disadvantages of the single deposit site are summarized as follows:

1. Requires a higher degree of crew involvement.
2. Increases the probability of spills and accidents during manual transport of refuse.
3. Does not allow for the implementation of a backup canister transport system in the event that the path becomes blocked.
4. Causes possible accumulation of trash in temporary receptacles (local trash receptacles) within the modules.

9.2 Multiple Canister Deposit Sites

The multiple site concept involves placing an access to the flow path and temporary storage facility in two or all four of the modules.

The advantages of multiple canister deposit sites are summarized as follows:

1. Isolates each specific waste type belonging to each habitat to that habitat alone. Thus, possible contamination could be confined with the environment in which it is produced.
2. Requires less manual involvement because the crew would simply transfer waste to the central receptacle/compactor in their own module.
3. Decreases the possibility of spills and accidents during manual transport of refuse since the travel time and distance are reduced.
4. Allows for possible back-up to the system in the event that one of the sites fails.
5. Prevents the possible accumulation of waste within one of the temporary receptacles by providing multiple temporary sites.

The disadvantages of the multiple site system are summarized as follows:

1. Requires a more complex transport design, such as multiple pathways, turns, and bends, which can increase the chance of a canister becoming lodged within the passageway.

2. Possesses a higher potential for system failure because of the multiple pathways, thus reducing reliability.
3. Increases the possibility of network contamination since there are many passageways which have access to the four modules.
4. Provides a complex system for cleansing and sanitizing.
5. Consumes more valuable space.
6. Requires more materials for construction, thus requiring more space in the shuttle cargo bay.
7. Higher relative cost.

Chapter 10. COMPACTOR DESIGN

10.1 Compactor Description

Regardless of the quantity of disposal sites employed, a compacting device is needed to reduce the waste volume. Two compacting devices are considered for this subsystem application:

1. Space Pac Trash Compactor
2. Rampack 100XL

The Space Pac Trash Compactor (see Figure 1.6) has been developed for space use by McDonnell Douglas, a NASA contractor.²⁵

Another compactor design which can be adapted for use in space is the Rampack 100XL developed by the Oneirus Aerospace Corporation. The Rampack 100XL yields a compact ratio of 15:1 and requires no sorting because it accepts both wet and dry refuse. Its compression ratio was used to determine the final canister dimensions and quantity required to accommodate the 40,000 pounds of refuse per year. It completes one cycle every 15 seconds. It offers safety features, such as failing to operate if the door is ajar, and an access to the compression chamber for easy cleaning. Specifications include a 110 volt, 60 cycle electrical system which consumes 13 amps. Presently, the device weighs 850 lbs. and is 28.75 inches wide, 78.25 inches high, and 22.0 inches deep.³⁶ The size and shape may be adapted for space station application.

Numerous processes take place to prepare the refuse for transfer to the storage facility or to the jettison vehicle. After the refuse is loaded into the compactor and the door is securely latched, the two inch thick ram begins the compaction process. While the ram is moving, a vacuum pump is activated to remove any excess water and air from the refuse. The air and water that are removed can be sent to the reclamation/purification facility to be used in the Life Support System. In addition, the pressure level of the refuse must be reduced as much as possible because its destination, either the pyrolysis

facility or the jettison vehicle, both operate under a vacuum environment. Finally, the refuse must be wrapped and hermetically sealed after the compaction process to prevent contamination.

10.2 Compactor Design Modifications

Various modifications to the present compactor design could adapt the device for efficient use within the refuse collection and transfer system for the Space Station. The compactor can be designed to compact the waste into cylindrical or rectangular shapes to be inserted into the transfer containers. This choice depends upon the selection of the capsule and flow path geometry. The present design offers the option of utilizing bags or cubes within the device to store the compacted mass. These bags, cubes, or newly designed cylinders can be made of the selected material to contain the diversity of wastes. An option with the compactor design is that of a rear access door and an automatic device, or motor to expel the container of compacted waste into the capsule or directly into the flow canal. However, these modifications would require extra power and design expenses. Alternative methods to this direct removal of the refuse into the flow path could involve intermediate robotic removal or manual removal.

Chapter 11. CONTAMINATION CONTROL

11.1 General Control Methods

The importance of the control of microorganisms cannot be over-emphasized, especially for the confined, microgravity conditions of the Space Station. Modern design criteria applied in the construction of the facilities can do much to control microbial contamination. The following are some approaches to microbial control:³⁷

1. Use of ventilated cabinets, chambers, cages, etc., to achieve an absolute or partial barrier to contain microorganisms at their point of origin or exclude them from a specific work area.
2. Use of laminar air flow devices to exclude microorganisms from an environment.
3. Use of appropriately effective microbiological filtration or other treatment for air supplied to and/or exhausted from cabinets, chambers, etc.
4. Use of germicidal ultraviolet air-locks and door barriers to separate areas of unequal microbiological loading or risk.
5. Use of room arrangement or layout to achieve traffic control within the facility along a clean-contaminated axis.
6. Use of an effective intercommunication system to avoid unnecessary movement of personnel from area to area.

The most secure type of containment and isolation device is the gas-tight absolute barrier enclosure. This equipment fulfills the most severe control criteria. A second type of enclosure utilizes a partial barrier concept in which controlling the direction of the air flow into or out of an open panel prevents contamination. Microbial contamination can exist and yet not be readily detectable in the usual sense; the contamination may be odorless, tasteless and invisible.³⁷

Prototype laminar air flow units were first designed in 1961. These units are valuable for controlled environmental work in the aerospace industry, particularly in the manufacture and assembly of high precision electronic components where the slightest trace of dust or particulate contamination could cause malfunction.³⁷

Careful planning for the placement of equipment and supplies and control of the movement of people and objects in the laminar air stream is necessary. Equipment and objects closest to the supply filter wall will have the greatest degree of biological protection. Laminar air flow provides control over airborne particulate contamination only and will not remove surface contamination.³⁷

11.2 Sanitization Procedures

There are many methods available to decontaminate surfaces. Those that are most widely applicable can be classified under one of four main types:³⁷

1. Heat
2. Vapors and gases
3. Liquid decontaminants
4. Radiation

11.2.1 Heat Decontamination

Heat is generally accepted as the most effective method of inactivating microorganisms. The exposure temperatures and times required for sterility are generally known and controlled. Recent research on the kinetics of dry heat inactivation of microbial spores has emphasized longer exposure times at lower temperatures for the sterilization of spacecraft and spacecraft components. Though heat is the most reliable means of decontamination, its direct application to thermolabile materials and certain areas where the contaminants exist is not always possible.³⁷

11.2.2 Vapor and Gas Decontamination

A variety of vapors and gases possess germicidal properties. Among these are ethylene oxide, formaldehyde and beta-propiolactone. When these agents are employed in closed system and under controlled conditions of temperature and humidity, excellent decontamination can result.

Under controlled conditions, ethylene oxide is a highly penetrating and effective gas, convenient to use, versatile, noncorrosive, and effective at room temperature. The gas is slow, however, in killing microorganisms and is usually mixed with other gases to avoid explosion hazards. It is used to treat items not suitable for heat sterilization. One major limitation with ethylene oxide is that neoprene gloves, clothing, footwear, or other plastic or leather apparel must be thoroughly aired for a minimum of twenty-four hours before use to avoid the irritating action of the absorbed chemical on human tissues. Ethylene Oxide gas mixtures can be used to sterilize microbiological barriers prior to use or to treat certain materials passes into or out of the barrier.

Formaldehyde and beta-propiolactone are used primarily as decontaminants for room and building interiors. Formaldehyde has the undesirable property of condensing and polymerizing when sprayed. The polymer, once formed, requires long aeration for removal similar to ethylene oxide.

Beta-propiolactone holds great promise as a space decontaminant. In the vapor state, it acts rapidly against bacteria, rickettsiae and viruses and has no adverse effect on most material. It acts faster than formaldehyde and does not leave an undesirable residue after spraying. One serious deterrent to the use of this chemical is its toxicity and carcinogenic properties under certain conditions.

11.2.3 Liquid Decontamination

Hundreds of liquid decontaminants or germicides are available under a variety of trademarks. Most of them may be classified as halogens, acids or alkalis, heavy metal salts, quaternary ammonium compounds and aldehydic compounds. The most frequently used liquid disinfectants are chlorine, formalin, and sodium hydroxide solutions. The most significant problem with liquids when used in a microgravity environment is that liquid molecules form floating droplets. The presence of these droplets threatens the safety of the crew. For this reason, liquids must be carefully considered unless they are to be used only in a closed environment, away from possible human intervention.

11.2.4 Radiation Decontamination

The most common methods presently used for the sterilization of materials (surgical supplies, packaged foods, etc.) are high-energy electrons from a particle accelerator and gamma radiation from a radioactive source. Although microorganisms vary in their resistance to radiation, a dosage of approximately 2.5₃₇ megarads is usually sufficient to sterilize surgical materials.

In specific applications, germicidal ultraviolet (UV) radiation of 2537 angstroms is an effective means of decontaminating air and surfaces.³⁷ This type of radiation can sometimes be used for the treatment of water and other liquids. Used in airlocks, UV radiation can isolate areas of differing levels of contamination within a structure. Recirculating air conditioners can be fitted with UV lamps to decontaminate the air. UV radiation has limited penetrating power and thus is most effective on exposed surfaces or in slow moving air. Proper intensity, contact time, and maintenance are critical factors for the most effective use of UV decontamination.³⁷

Chapter 12. POWER SUPPLIES

The processes of compaction, transfer, and sterilization require power sources. To avoid modifications to existing Space Station designs, it is recommended that an independent source be used to generate the power needed for the refuse collection and transfer subsystem. A number of source options are considered:

1. Pyrolysis fuel
2. Solar power
3. Space station power sources

12.1 Pyrolysis Fuel as a Power Source

An applicable solution to the problem of limited power resources is to generate power from the recycled refuse. Recycling methods such as Pyrolysis produce valuable fuels from which significant power could be produced. For more information on Pyrolysis, see Section III. The selection of this alternative would demonstrate a more closed and self supporting refuse management system.

12.2 Solar Power

Another suitable option is to use solar power, the main power source for the Space Station. Because of the size of the Space Station structure, additional panels could be used to provide the power required to operate the equipment. This solution is feasible if there is space available on the station structure. Solar energy is a common source for power in space and has been used in many past applications.

12.3 Space Station Power

A final alternative is to utilize the power provided by the space station itself. As long as there are 5 unused kilowatts of the 125 kW provided by the main power system, the collection and transfer subsystem can be maintained. A typical compacting device requires 1.7 kW of power.³⁶

Chapter 13. COLLECTION AND TRANSFER OPTIMAL SOLUTION - PHASE II

13.1 Solution Discussion

Material choices for the construction of various collection and transfer components were selected upon careful examination of Tables 1.1 and 1.2, which summarize the material properties, and Solution Matrix 1.3 of Appendix A. The materials selected are high density polyethylene and polypropylene.

High density polyethylene can be used for garbage bags placed throughout the module and for compactor liner bags. This material was chosen due to its strength, low cost, technical maturity, and low chemical reactivity as are the reasons for its widespread commercial use on Earth.³⁹ The bags used on the Space Station will be produced by a similar manufacturing process, but made from a higher grade of polyethylene for greater reliability. The cost of using polyethylene varies with dimensions of the bag. For example, based upon a purchase order of 1000 bags:⁴⁰

<u>Dimensions</u>	<u>Price per 1000 units</u>
36in.x60in.x4mil.	\$ 975
24in.x36in.x4mil.	\$ 400
18in.x30in.x4mil.	\$ 250

Polypropylene is chosen to construct the canisters and transfer tubing network. A stronger, more durable material is required for this application because of the transfer forces, contamination prevention, and safe storage requirements. While lexan possesses the necessary strength, chemical resistance, and technical maturity,⁴¹ it is much more expensive and overqualified for this application. Polypropylene, however is fairly inexpensive, has adequate chemical resistivity, and is very strong, with a specified strength of over 4000 psi.³⁹ Price studies for lexan and polypropylene sheets of 4 ft. x 8 ft. x 1/4 in. reveal the significant cost difference:⁴⁰

<u>Material</u>	<u>Price/Sheet</u>
Lexan	\$ 126
Polypropylene	\$ 62

In addition, if toxic or bulky, tough waste such as that generated in the labs or manufacturing processes are to be reduced, more rigid polypropylene containers can be used within the compactor for additional strength and safety.

Cylindrical, cubical, and hexagonal capsules were considered in Solution Matrix 1.3 for these polypropylene waste transfer devices. Consideration of mainly technical feasibility, cost, machinability, and efficiency via the solution matrix yields the cylindrical design as the optimal solution. The cylindrical canisters will be similar to those used in bank applications (see Figure 1.18). The cylindrical shape will be best accommodated by end accesses which twist open and closed and lock with a safe, simple locking and sealing mechanism. The following assumptions were used to determine the necessary canister dimensions and yearly quantities of refuse processed:

1. 40,000 lb.₃/yr. of refuse generated.
2. 9 lb./ft.³ average uncompacted refuse density.
3. 15:1 compaction ratio.
4. 135 lb./ft.³ compacted refuse density.

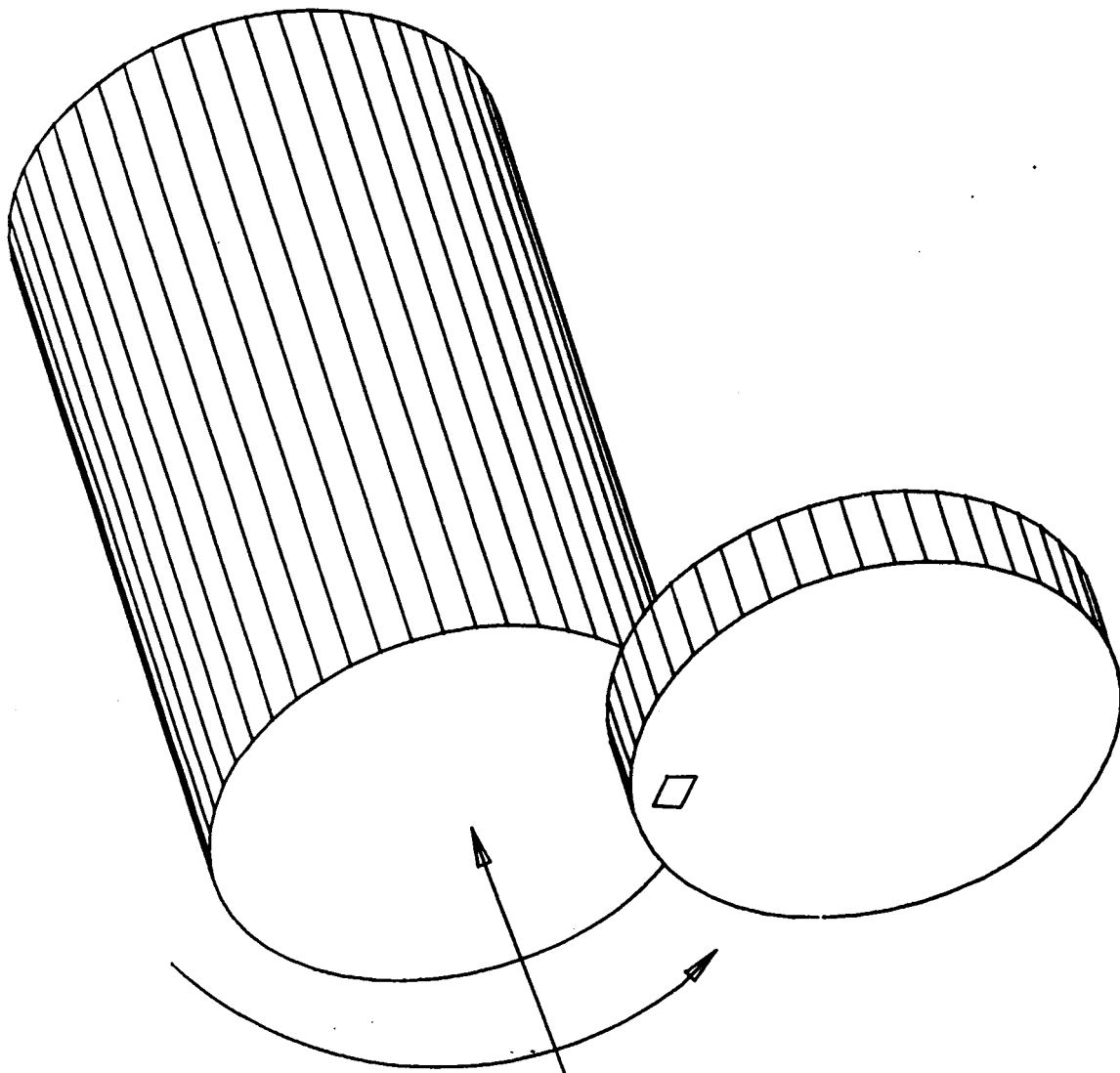
$$40,000 \text{ lb.}/135 \text{ lb./ft.}^3 = \text{approx. } 300 \text{ ft.}^3 \text{ compacted vol./yr. (1.1)}$$

<u>Can. Dimensions (ft.)</u>		<u>Can. Volume (cf.)</u>	<u>Quantity Reqmt.</u>
diam.	length		
1.0	2.0	1.57	191
1.5	3.0	5.30	57
2.0	4.0	12.57	24
2.5	5.0	24.54	13

According to this table, if a 1.5 ft. diameter canister 3 ft. in length is used, approximately 57 canisters would be needed to accommodate refuse over a period of one year. Note also that the given canister diameters do not exceed 3 ft. in diameter, which is the diameter of a Nodal Hatch.

To accommodate the cylindrical canisters, the transfer tube system must also be a cylindrically shaped network which consists of a minimum number of turns to reduce the possibility of a canister becoming lodged within the system. Because of its shape, the necessary network tubing will require no special manufacturing process and machining costs are significantly lower than cubical or hexagonal tubing design.

This cylindrical system will also require a simple modification to the design of the compactor for the greatest efficiency. The standard compacting device compacts the waste into cubical packages. However, the new design will compact the refuse into cylindrical packages which



REMOVE INSERTED

CYLINDRICAL CANISTER DESIGN

Figure 1.18

can be directly placed into the end accesses of the cylindrical capsules for transfer. The cylindrical design is an efficient use of capsule space and will be beneficial to the overall functional speed of the collection and transfer system.

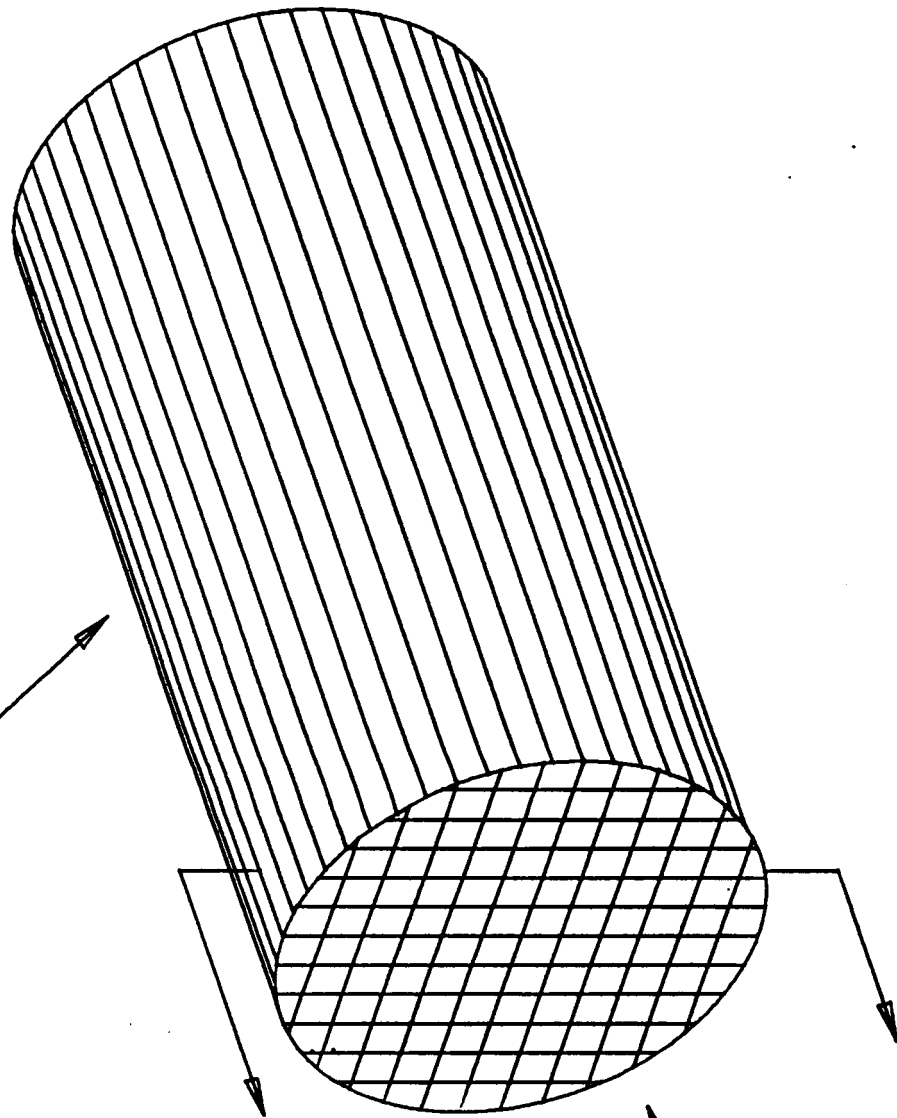
Each canister design possesses its own unique storage site capability. The canisters are to be stored in racks, or shelves where each individual bin must take the shape of the chosen canister geometry. Therefore, the optimum storage design pertains to the one which best serves the cylindrical canister. The totals established in the Solution Matrix 1.4 revealed that rack and pigeon-hole arrangements received the same rating. To provide for efficient and economical production and manufacturing of the storage facility, the individual storage sites are to possess a square cross-sectional geometry with the width being equal to the container diameter (see Figure 1.19). This provision reduces the cost of the storage arrangement, as well as allowing for the most efficient use of space. This rack must be constructed of a rigid material to effectively contain the mass held within it. Strength plays a minor role because of the microgravity environment. Polymers, such as polypropylene, can be employed for this application.

The establishment of whether this temporary storage site is to be built within or external to the modules along the Space Station structure was based upon the data of Solution Matrix 1.4. Though the construction of a specific external facility is more costly and requires more initial shuttle cargo space during the construction phase, the advantages to the external concept outweigh the disadvantages. For example, in the event that the storage site becomes contaminated, the external site would prevent the modules from becoming contaminated as well. Also, precious module space would not be wasted on refuse management. Thus, the external design best serves safety and the limited space requirements of the Space Station (see Figures 1.20 and 1.21).

In order to transfer the refuse from the internal collection sites to the external storage facilities, various transfer forces were considered. According Solution Matrix 1.5, a blow motor/vacuum pump is the desired transfer force system due to its technological maturity and effectiveness. The necessary basic components of any vacuum system are listed in Chapter 8.1. In the applicable system, one or more access openings are essential and must be arranged so that they can be opened and closed relatively easily. This addition allows for the insertion of materials for transfer and easy access for the adjustment of internal parts. As an emergency backup system in the event of power or pump failure, a hand pump can be placed at each flow access of the transfer network. These hand pumps are to be simple to use and require little expended energy from the crew to operate.

The design of the canister collection receptacles must consider minimization of crew involvement while simultaneously allowing for safety, simplicity, and reliability. According to these basic requirements, the multiple deposit site concept has been chosen as the

STORAGE FACILITY

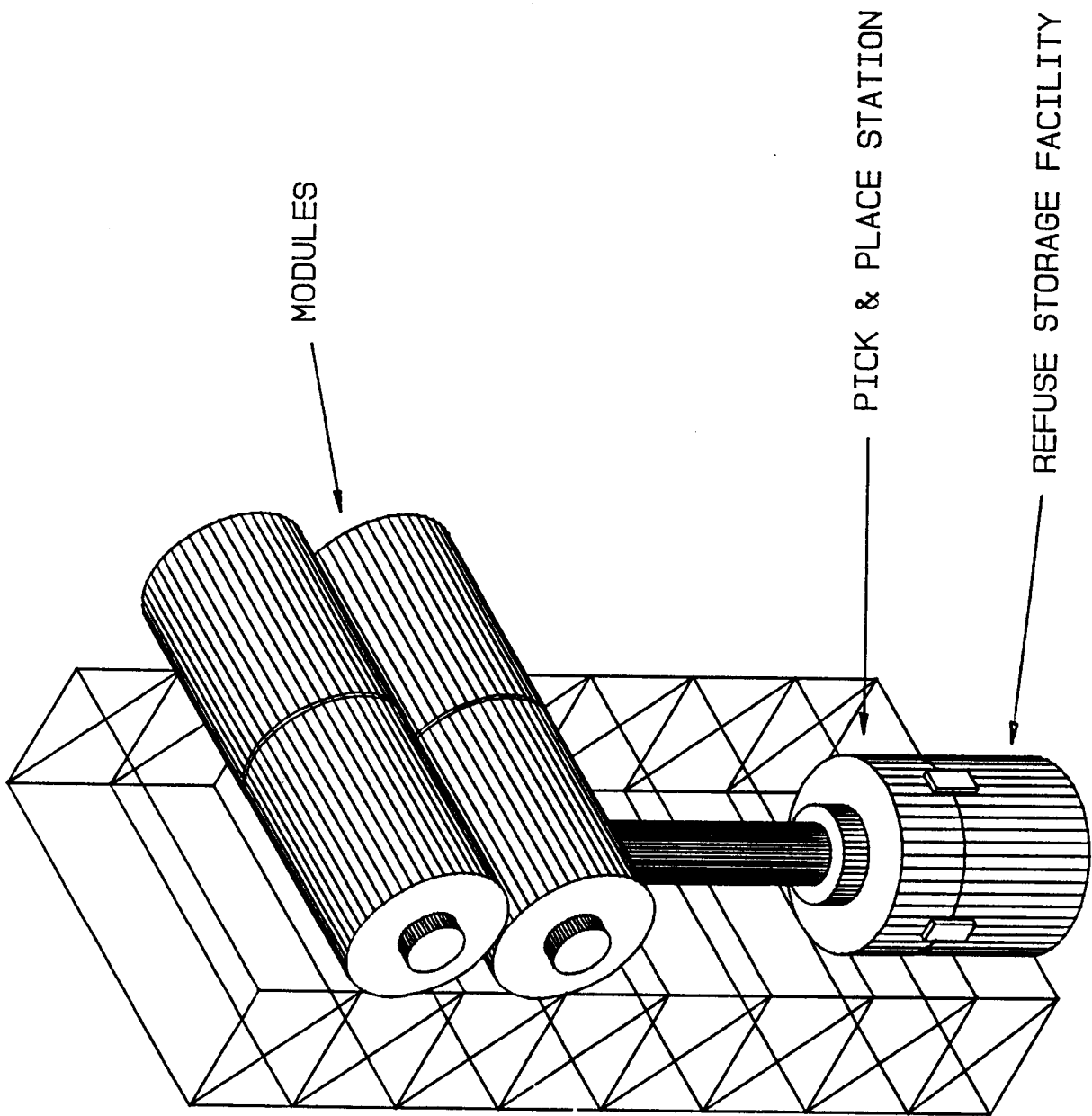


INTERFACE WITH PICK
AND PLACE ROBOTICS

CANISTER INSERTION

STORAGE FACILITY

Rack Storage³³
Figure 1.19



SPACE STATION REFUSE STORAGE FACILITY

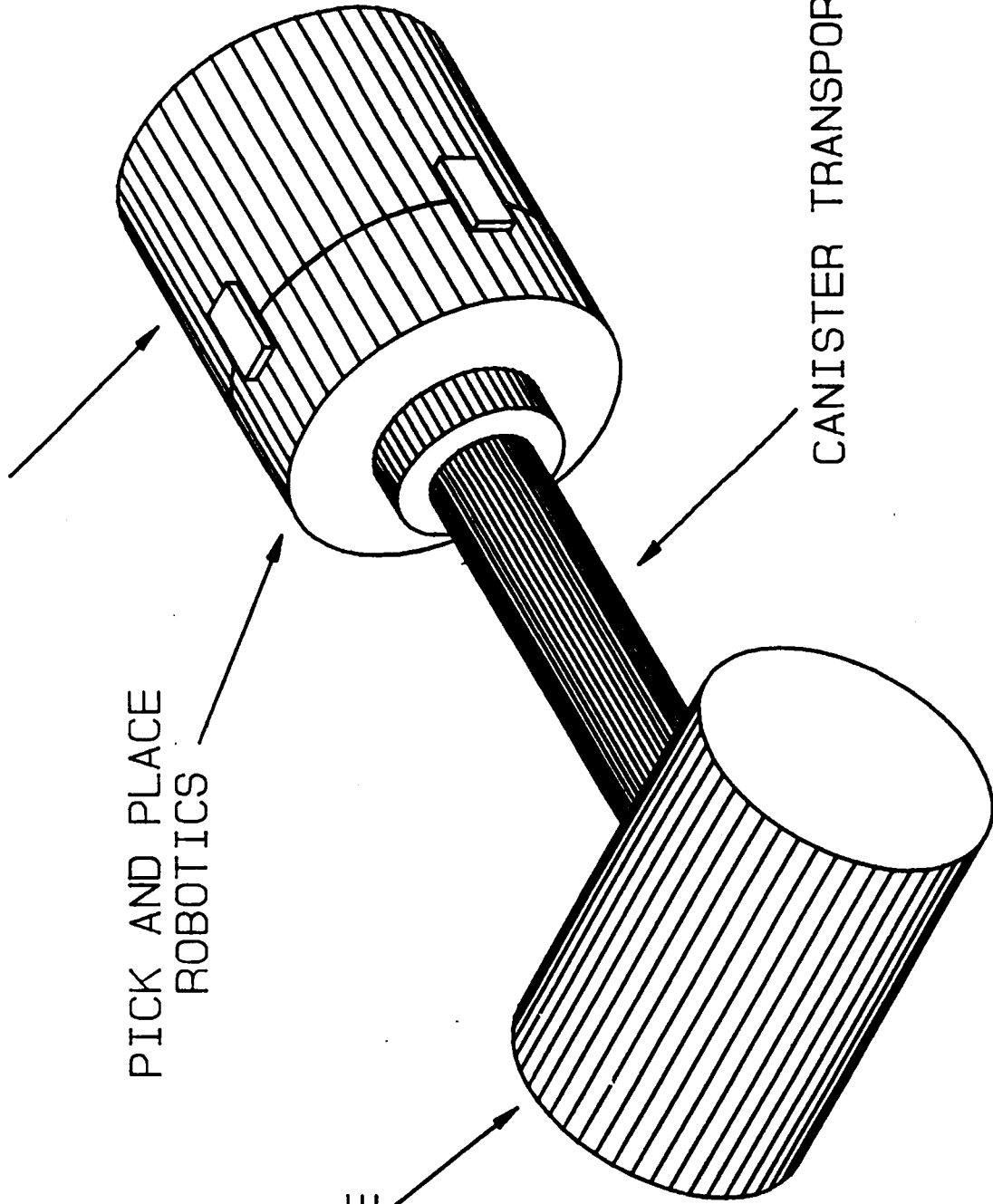
Figure 1.20

DETACHABLE REFUSE
STORAGE CONTAINER

PICK AND PLACE
ROBOTICS

MODULE

CANISTER TRANSPORT TUBE



REFUSE STORAGE DETAIL

Figure 1.21

best method (See Matrix 1.5). The advantages of this multi-collection site are summarized in Chapter 9.2. Although this configuration requires more equipment, materials, and thus higher cost, the advantages tend to overrule the disadvantages according to the solution matrix. To accommodate this design, each module must contain its own waste treatment facility consisting of a compactor, an access to the flow network, and a manual pump.

Numerous operations take place in order to prepare the refuse for transfer to the storage facility or jettison vehicle. After the refuse is loaded into the compactor and the door is securely latched, the two inch thick ram begins the compaction process. While the ram is moving, a vacuum pump is initiated to remove excess water and air from the refuse. The recovered air and water are sent to the reclamation/purification facility to be used in the Life Support System. The evacuation of air from the waste also reduces the pressure level which is advantageous for the vacuum environment of the pyrolysis facility and jettison vehicle. After the refuse has been adequately compacted and evacuated, it must be wrapped and hermetically sealed to prevent contamination.

Effective microorganism control is vital for safe operation within the confined environment of the Space Station.³⁷ Various methods of microbial control were evaluated using Solution Matrix 1.4. Ranking of the control methods according to types of contamination control, discussed in Chapter 11, from the most to least favorable are as follows:

General Sanitization:

1. Room arrangement
2. Heat
3. Ventilated cabinets, chambers, etc.

Airborne Contaminant Control

1. Microbiological filtration
2. Laminar air flow devices
3. Ultraviolet airlock radiation

Surface Contamination Control

1. Vapors and gases
2. Ultraviolet airlock radiation

The combination of methods selected for proper treatment depends upon the area of the station and the contaminants present.

The most optimal solution for general sanitization, room arrangement, is also the least complex. It simply involves strategically locating the areas of high risk to prevent the spreading of contaminants to other areas of the modules. Room arrangement isolates the contaminants rather than removing the microorganisms from

the air. Heat, on the other hand, is the most generally accepted method of inactivating microorganisms although it cannot be applied in all cases.³⁷

For atmospheric control, microbiological filtration or laminar airflow units should be employed. In terms of efficiency, cost, and power consumption, the filtration system rates higher in comparison. This system also requires less volume for storage and consequently, it would also be cheaper to shuttle it to the Space Station. The process involves various filters used to remove contaminants from the air supplied to and/or exhausted from several station locations. Although these filters remove a substantial portion of the airborne contaminants, they fail to assist with surface contamination.³⁷

For the control of surface contamination, a variety of germicidal vapors and gases may be used. Among the most effective decontamination chemicals are ethylene oxide, formaldehyde, and beta-propiolactone. When these agents are employed in closed systems, under controlled conditions of temperature and humidity, excellent decontamination can be achieved.³⁷ Ultraviolet radiation, the emission of high-energy electrons and gamma particles from a radioactive source, is also very effective. Used in airlocks, UV radiation can isolate areas of differing levels of contamination within a structure.³⁷ However, because of the complexity of the system, the costs, and the space involved, this method remains the least feasible.

One last important design consideration concerns waste handling and inventory control on the Space Station. Two methods of labeling the various capsules, bar coding and color coding, have been selected as optimal solutions. Bar coding, or the use of machine-code reading, is advantageous because of its versatility in automation and can be incorporated in any phase of the waste management system.³⁸ As previously discussed, effective use of bar coding will result in less manual handling and thus less contamination risk. Also, it can assist the crew in identifying those wastes which can be recycled or jettisoned for disposal. Color coding permits simple optical identification of refuse types. This simple system can also be considered as a backup system in case of computer failure of bar code reading. Determination of the container contents can be made from a distance rather than from contact with the capsules as is required by bar coding. Color codes are to be placed at each deposit site so that a crew member can easily place the appropriate labeled container to the designated storage facility. By employing both of these labeling techniques, the refuse can be collected and stored in an organized and safe manner.

In conclusion, high density polyethylene bags are to be placed sparsely throughout the modules for convenient waste disposal and within the compactor for sealing the waste into packages. These waste packages are then manually inserted into cylindrical capsules constructed of polypropylene and transferred via an airflow network to an external storage facility. This temporary storage site contains racks of square cross section for capsule insertion. The airflow is

generated by a blow motor/vacuum pump which receives power from solar panels placed along the Space Station structure. In case of a power shortage, a hand pump is available at each of the waste handling facilities. To prevent contamination of the subsystem and the station itself, sanitization methods such as room arrangement and microbiological filtration is employed. Finally, to insure proper handling of the refuse, color coding and bar coding can be used to assist in inventory control.

13.2 Final Solution Summary

The final refuse collection and transfer subsystem for the space station can be summarized as follows:

- Waste Collection:
1. Bags
 - a. conveniently distributed
 - b. high density polyethylene
 - d. color coded
 2. Waste specific containers / canisters
 - a. polypropylene material
 - b. cylindrical shape with end accesses
 - c. color/bar coding
 3. Polypropylene compactor liner bags
- Waste Transfer:
1. "Bank Shuttle"
 - a. cylindrical tubing design
 - b. multiple deposit sites
 - c. polypropylene material
 - d. vacuum/blower motor pump force
 - e. hand pump backup
 2. Robotic
 3. Manual transfer backup
- Processing:
1. Compaction
 - a. modification for cylindrical compaction
 2. Bar/Color coding
 3. Contamination control
 - a. General - room arrangement, heat, ventilation
 - b. Atmospheric - filtration, laminar air flow
 - c. Surface - vapors and gases
 4. Manual Separation backup
- Storage:
1. Rack Storage
 - a. square slots
 - b. environmentally controlled
 - c. refrigerated backup

This system is a general solution based upon present knowledge of Space Station parameters and on the most probable types of refuse known to be generated on the station. If these parameters change or other types of wastes are expected to be frequently generated in significant amounts, then other methods may have to be reconsidered.

Chapter 14. RECOMMENDATIONS FOR FURTHER STUDY

In order to completely integrate the Collection and Transfer Subsystem with the other proposed Space Station waste management subsystems, further study should be done in the following areas:

1. Component dimensions
2. Subsystem location
3. Alternate means of transport
4. Cost
5. Time required for construction
6. Weight of the subsystem
7. Compatibility with other existing systems
8. Environmentally controlled storage areas
9. Robotics ("pick and place")
10. Fire hazards of selected materials

SECTION II. REFUSE RECYCLE/REUSE

- PART I.
- * Super Critical Water Oxidation
 - * Incinerator
 - * Degradation of Polymers
 - * Image Forming Solar Melter
 - * Non-Image Forming Solar Melter
 - * Pyrolysis

- PART II.
- * Refuse Size Reduction
 - * Pyrolysis Reactors
 - * Power Generation

SECTION II. REFUSE RECYCLE/REUSE SUBSYSTEM

INTRODUCTION

The Space Station will definitely benefit from an efficient refuse recycle/reuse system as opposed to complete disposal for several reasons. First of all, it would be hazardous for the Space Shuttle crew to attempt reentry with a cargo bay containing refuse. Secondly, waste amounts on Earth have already caused significant disposal problems which certainly do not need to be added to. Also, the shuttle itself does not have the capabilities to return the amount of refuse that would be generated on the Space Station (see Report Introduction). Finally, waste material is very costly per pound in its unaltered form on the Space Station. Thus, the most viable long-range alternative is to recycle this waste and to reuse the end products so as to decrease the resupply needs of the station.

Methods of dealing with the reuse, recycle and energy generation from refuse materials have been studied in great detail for terrestrial waste management. From this existing technology, parallel solutions may be arrived at for refuse handling techniques aboard the Space Station. Design considerations for the station are unique compared to waste systems on Earth. Emphasis is placed on safety, minimum cost, environmental effects, reliability, maximum automation, flexibility, and system location (see Appendix B for parameter definitions). The nature of waste materials, especially those found on the Space Station, and their selection for recycling further complicate the design process:

"Waste materials as energy sources are much like conventional fuels. They vary in composition, density, heating value, and other properties. The value of a particular fuel or waste as an energy resource will depend on several factors, including the availability of large quantities near potential markets."⁴²

The Space Station is indeed a "potential market" for which available waste resources can and must be utilized to their fullest potential.

The American society's views of waste disposal historically opposes the fuel from waste concept:

"The \$25+ billion bill which this country pays annually for imported oil provides one measure of this problem. The \$6+ billion we pay for municipal waste disposal provides another measure of the problem. This is a society which is short on energy and long on rubbish, garbage, woodwaste, manure, and other residues of the production and composition processes."⁴²

On Earth, obtaining imported oil, for example, is relatively convenient and easy compared to waste-to-energy conversions. However, space shuttle supply "imports" from Earth for the Space Station are costly and inconvenient compared to employing an efficient internal recycle/reuse subsystem. This type of system would provide self-sufficiency, decreasing Earth dependence, while cutting travel and resupply expenditures.

Because the need for refuse recycling and reuse has been established and justified, the overall objective of this study is to discover alternative uses for waste materials and methods of altering them into serviceable forms for the Space Station. Design Phase I explores various alternatives for recycling refuse materials. Design Phase II studies different pyrolysis reactors, refuse reduction alternatives, and power sources for the chosen recycling process.

PART I. REFUSE RECYCLE/REUSE - DESIGN PHASE I

The following preliminary recycle/reuse processes were studied for their feasibility aboard the Space Station:

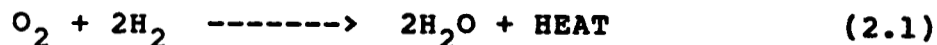
1. Super Critical Water Oxidation
2. Incinerator
3. Polymer Degradation
4. Image Forming Solar Melter
5. Non-Image Forming Solar Melter
6. Pyrolysis

Chapter 15. SUPER CRITICAL WATER OXIDATION

Technology based on super critical water oxidation (SCWO) can be applicable in the Space Station for trash and garbage reduction, as well as for carbon dioxide removal, partial humidity control, trace contaminant control, water reclamation, and nitrogen generation. This system is applicable to a wide variety of wastes such as garbage (consisting of all solids, liquids, and gases), urine, feces, dirty water, and trace contaminants. The SCWO process involves placing a mixture of waste products and oxygen (O₂) into a reactor under extreme controlled conditions to produce such outputs as carbon dioxide (CO₂), nitrogen (N₂), hydrogen (H₂), various salts, minerals, and dense carbon (see Figure 2.1). The mechanism for SCWO is as follows:

"SCWO technology is based on the physics and chemistry of water molecules (H₂O) at conditions above their supercritical pressure and temperature (250 atm., 670 degF). Under these conditions, the dielectric constant of H₂O weakens which causes two important phenomena to occur: Hydrocarbons and other normally immiscible organics become miscible in the water medium, and normally dissolved inorganic salts precipitate out of solution. Solid salts can be separated from the process stream in the same solids separator that removes any metal particles found in solution. At the high temperature, complete combustion of the organics result if sufficient oxygen is present. Complete combustion yields water, carbon dioxide, and nitrogen."

The high temperatures required for supercritical combustion can be achieved and sustained by introducing O₂ and H₂ to the feed mixture or by preheating the feed mixture electrically. If O₂ and H₂ are used, the heat would result from their 'heat of reaction' value when forming water:



The CO₂ given off by the oxidation process can be recycled to form the O₂ and H₂ being introduced into the feeding stream mixture. Maintaining the temperature for the system can be accomplished by means of

'superinsulation' utilizing the vacuum of space. The heat of combustion of the reactants is sufficient to ensure that the temperature during reaction would not fall below the lower limit required for complete combustion. Current technology exists to easily reach and maintain the desired pressure by using an in line compressor.⁴⁹

Resupply weight and volume are extremely crucial design considerations for the Space Station. The handling of wastes by the SCWO system saves significant resupply weight and volume in terms of filters, bactericides, and waste bags or containers:

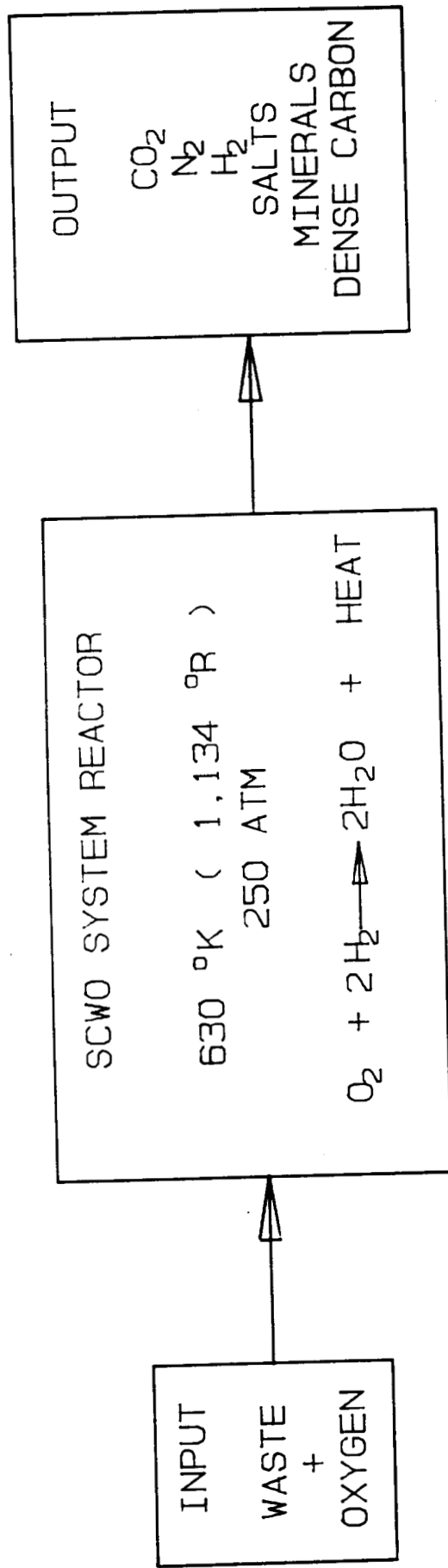
"The wastes (solid, liquid, and gaseous) would actually be broken down into harmless combustion products. Bacteria would be destroyed, so concern about masking or filtering odors, resupplying bactericides, or venting and dumping wastes would be greatly reduced. In fact, the materials derived from the SCWO system waste reduction could be incorporated back into the Space Station environmental system to help further close the system: CO₂ would go to CO₂ reduction, H₂O would go to portable water storage, and N₂ would go to the atmospheric pressure/composition control² subsystem."⁴⁹

The air management capability of the SCWO system provides a simpler, and more efficient system than is currently being considered for the Space Station:

"Essentially two and one-half Space Station Environmental /Life Support System (SS-ECLSS) air management subsystems would be replaced by the SCWO system. Having fewer unique subsystems should reduce the crew's training load and cut down on the spare parts inventory, not to mention increasing the reliability and decreasing the maintenance of the ECLSS."⁴⁹

In one package, the SCWO system would remove the CO₂, the trace contaminants, and more than half of the water vapor² from the air. Also, the water management group of the SCWO system is simpler than that of the SS-ECLSS.⁴⁹

Most disadvantages of SCWO stem from the fact that it is a new technology. The system is complex, expensive, and requires high initial energy input. In addition, there currently exist some chemical and mechanical difficulties associated with processing wastes in a SCWO reactor. Complete combustion is hard to achieve, and uncontrolled precipitation of salts has clogged experimental reactors. Furthermore, very little work has been done in the area⁴⁹ of preparation of trash and garbage for processing in the SCWO system.



SCWO System Flow Diagram⁴⁹

Figure 2.1

Chapter 16. INCINERATOR

The Space Incineration System (SIS) involves the combustion of processed (shredded) solid waste in integrated combustors equipped with mechanical strokers. The main reason for considering an incinerator for the breakdown of waste is that it can also be used to drive a steam or Brayton type cycle 'engine' which, in turn, can produce electrical energy. Two types of incinerators considered, due to their simplicity and compact size, are the Rotary Kiln Incinerator and the Augered Bed Incinerator (see Figure 2.2).⁴³

The incinerator could be supplied a steady flow of waste canisters from an automated, temporary storage facility located nearby. The canisters are emptied into a grinder prior to entering the combustion chamber. During the combustion process, the entire combustion chamber could be spun about a moment arm to achieve artificial gravity. This centrifuge effect would allow combustion gases to be liberated away⁴³ from the ash which condenses at the sides and bottom of the chamber.

Because a given charge of waste to the furnace can contain up to 35% ash, the ash must be collected continuously. The heavy ash can be concentrated and removed mechanically, while fly ash can be contained by wet or dry pollution systems. The ash collected requires disposal, but this volume and mass is considerably less than that of the original waste. Other major by-products of the process are CO₂, H₂, and N₂ which can be purified⁴³ for reuse or used to drive an 'engine' to provide mechanical power.

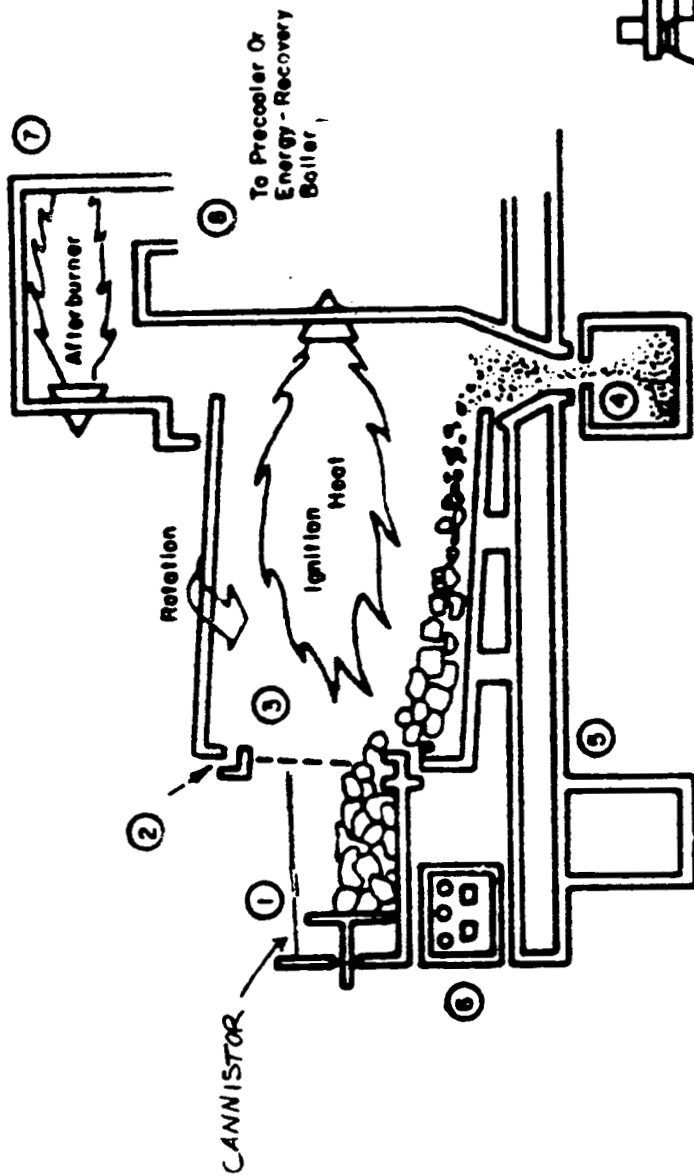
Evaluation of waste types for the incinerator involves precise identification of the following characteristics:

1. Mass generation rate of the waste.
2. Heating values.
3. Waste burning profile.
4. Ash characterization.
5. Combustion gases formed.

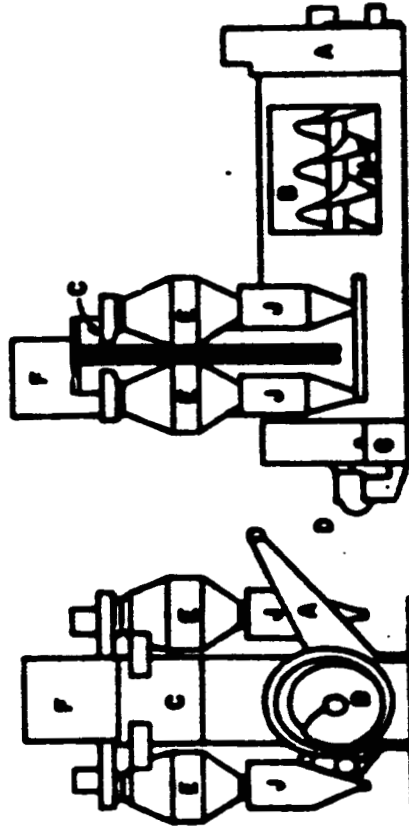
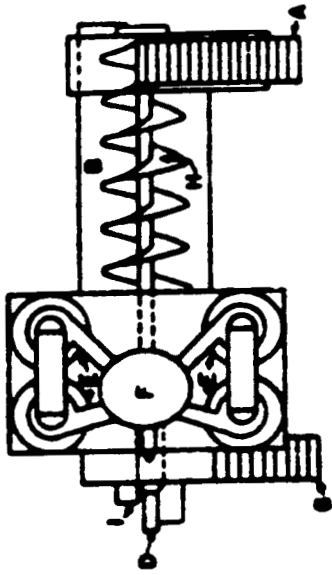
For this study, an assumption has been made that the daily generation rate and constituency of Space Station waste is random. Based on this assumption:

"...the composite heating value (mass generation times heating value) of an installation's waste system follows a normal distribution, and the actual design of energy conversion hardware can be obtained... by an average over time."⁴³

The heating value of a solid fuel is expressed as Btu./lb. or kJ./kg. of fuel on an as-received dry or moisture and ash free basis. Waste potential is evaluated by subtracting the latent heat of vaporization (heat not available for making steam because of gas content) from the heating value to give a net (lower) heating value.⁴³



- 1 Coarse RDF Auto-Feed (Hopper, Pneumatic Feed, Slide Gates)
- 2 Forced Air
- 3 Refractory-Lined Rotating Cylinder (Primary Chamber)
- 4 Ash Hopper (Incombustibles)
- 5 Support Frame And Piers
- 6 Control
- 7 Secondary Chamber
- 8 To Apertences



- A LIVE BOTTOM FEED HOPPER
- B PRIMARY COMBUSTION CHAMBER
- C COOLED HEAT EXCHANGER
- D BLOWER
- E WET CYCLONE
- F STACK
- G AUTOMATIC ASH DISCHARGE
- H WATER-COOLED AUGER
- I AUGER DRIVE
- J DUST BOX

Rotary Kiln and Augered Bed Incinerators ⁴³

Figure 2.2

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Waste materials must also be analyzed for their content of ash, fixed carbon, moisture, and volatile matter. In this case, volatile matter is defined as combustible gaseous and vaporous products which can be expelled upon heating. Undesirable, but unavoidable, constituents include sulfur, ash, and other inert material. The most favorable solid fuels are composed of carbon and hydrogen, with various amounts of nitrogen, oxygen, and mineral matter. For the major properties of materials favorable for the incinerator process, see Table 2.1.⁴³

The major disadvantages of using incineration are odor and pollution, hazardous gas production, high maintenance, high initial cost, requirement of artificial gravity procedures, and requirement of ash disposal. The most significant of these disadvantages are associated with safety and contamination risks which cannot be tolerated on such a facility as the Space Station. Thus, the incinerator will most likely not be a feasible waste breakdown solution.

Chapter 17. DEGRADATION OF POLYMERS

A large part of the packaging material used on the Space Station will be plastic bags and containers. The reuse of these kinds of containers would be very beneficial by eliminating resupply needs. One possible method of recycling is the degradation of polymers, which involves the breakdown of plastics into their basic elements by chemical, thermochemical, and/or ultraviolet light processes.⁴⁶

These degradation processes are alternatives to burning the plastics by incineration, for example, which can result in toxic by-products:

"In burning one pound of PVC, approximately 160 liters of HCl are evolved..."⁴⁶

A dangerous gas such as HCl would, in turn, require special equipment to safely break it down.⁴⁶

Unfortunately, chemical degradation is the only polymer breakdown process researched in any detail. But even for this process, information available for the reuse of their by-products is limited.⁴⁶

Chapter 18. IMAGE FORMING SOLAR MELTER

An Image Forming Solar Melter (IFSM) is a process by which materials can be melted using solar radiation (see Figure 2.3). An Image Forming Concentrator (IFC) focuses solar radiation into a black body cavity receiver which is made up of material with good thermal conductivity. The receiver collects heat by radiation, converts the

Table 2.1

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CONSTITUENT	MOISTURE CONTENT PERCENT	VOLATILE MATTER PERCENT	FIXED CARBON PERCENT	ASH PERCENT	LOWER HEATING VALUES - Btu/lb (kJ/kg)
PAPER, corrugated	4.93	71.77	9.29	14.01	6,200 (14,421)
WOOD	12.00	67.00	18.00	3.00	8,300 (19,305)
MISC.	25.00	54.00	1.00	20.00	6,000 (13,955)
TEXTILES	10.00	80.00	7.00	3.00	8,000 (18,607)
PLASTICS	1.00	95.00	2.50	1.50	14,600 (33,958)
LEATHER	4.31	62.08	8.12	25.45	9,071 (21,090)
RUBBER	2.00	83.00		15.00	11,300 (26,283)
FOOD WASTES	58.52	36.71	2.68	2.09	4,709 (10,953)
YARDS/GROUNDS WASTE	56.50	33.42	8.20	1.88	3,779 (8,790)
METALS	2.00	1.50	1.50	95.00	120 (279)

Computation of the Fuel Properties of Waste ⁴³

c-2

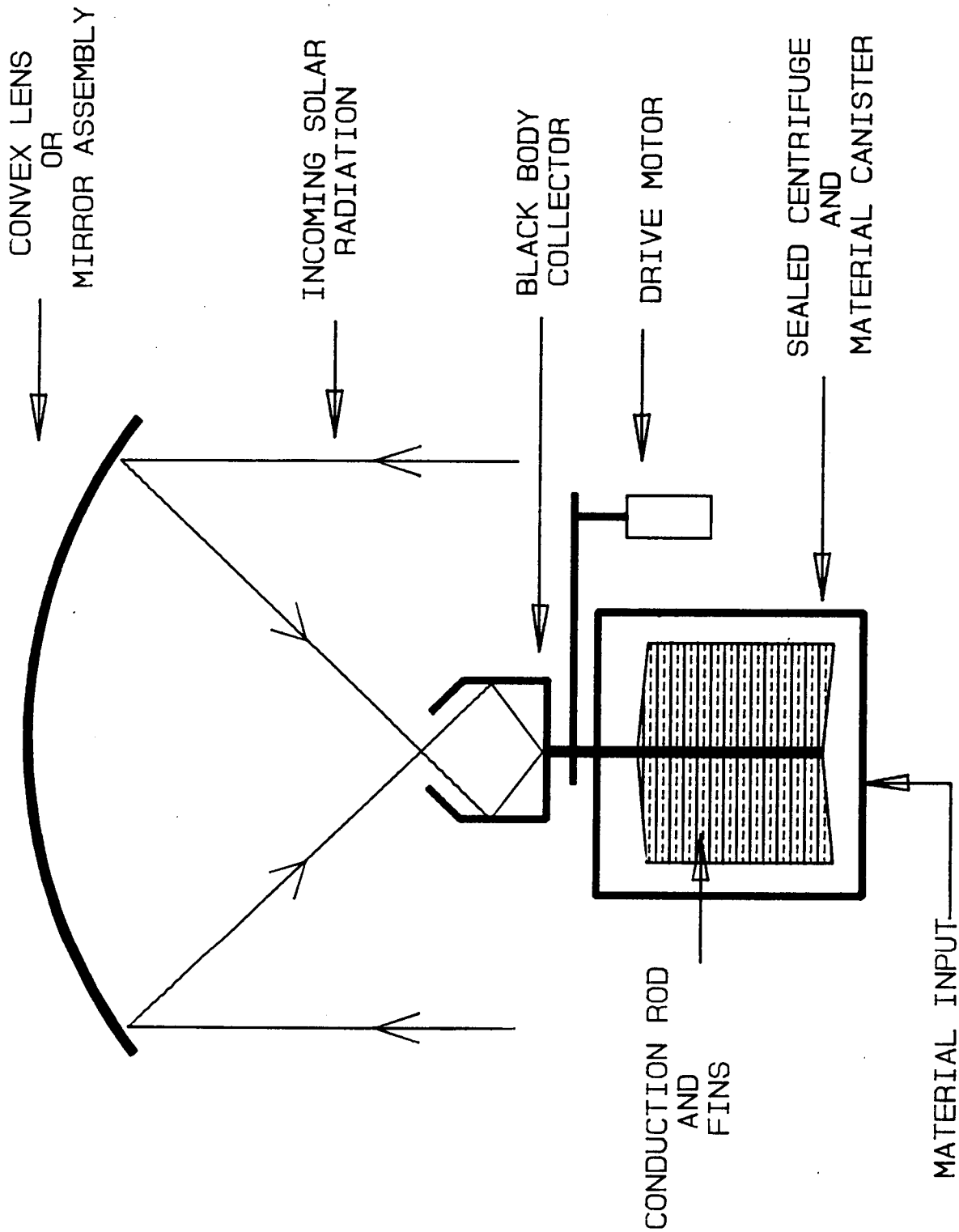


Figure 2.3
MATERIAL MELT / RESHAPE: IMAGE FORMING CONCENTRATOR

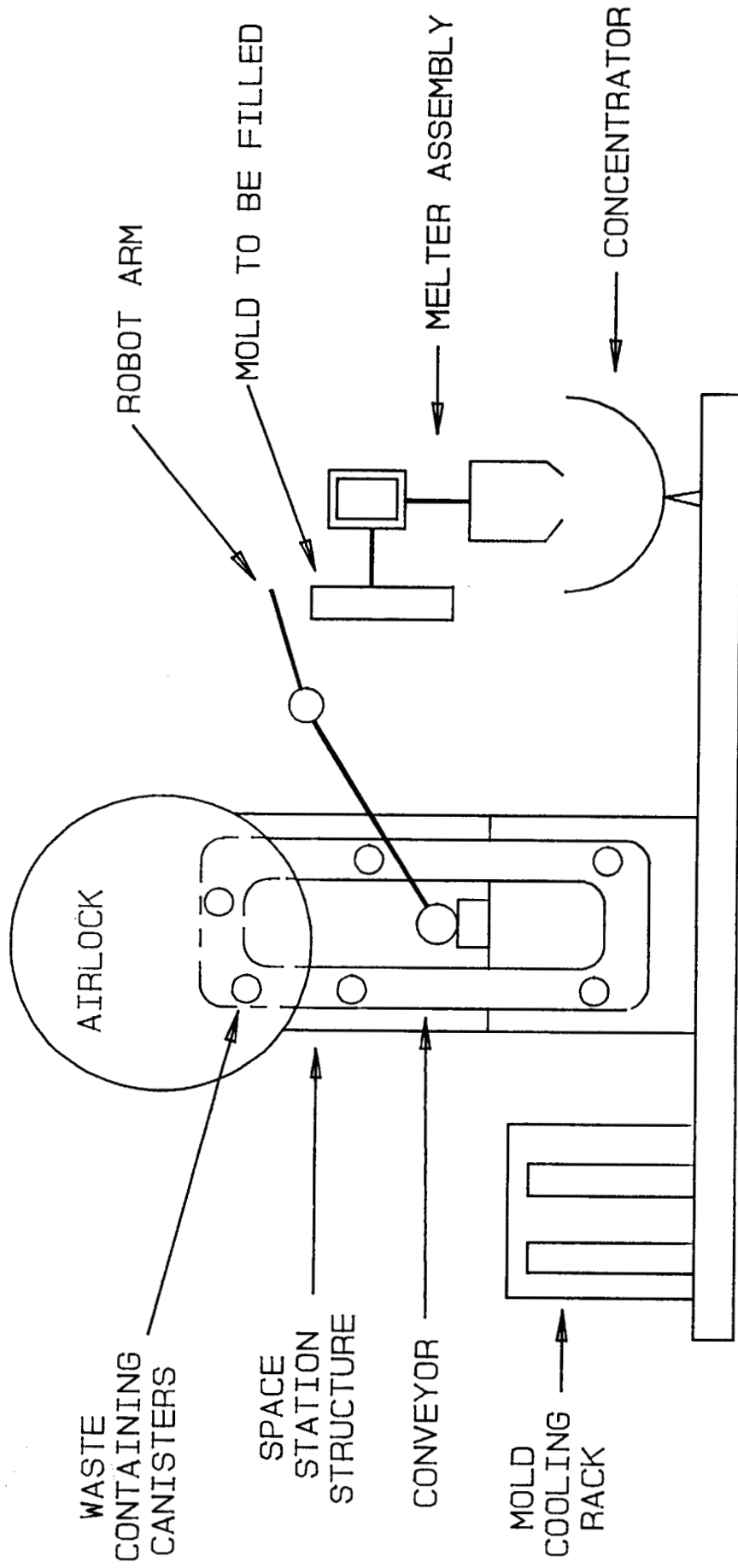
heat transfer mode to conduction, and then distributes this heat into a sealed cylindrical canister containing waste materials which have been processed to a granular form. Fins attached to a solid projection from the receiver rotate within the cylinder forming a centrifuge. The material is heated and liquified and then extruded through porous openings along the cylindrical surface. The extruded material is then collected and transported to a suitable mold for reshaping (see Figure 2.4).

The output materials from the centrifuge are in liquid form and have radial and tangential velocity components directed away from the centrifuge center. This momentum is utilized to propel the liquid through a short pipe into a mold fastened at the end. The mold remains attached to the piping system until it is sufficiently filled to form the desired product. At this time, the centrifuge stops rotating and the momentum of the fluid within the centrifuge and piping system is allowed to dissipate to prevent the discharge of materials into the surrounding space environment. A robotic manipulator arm then removes the full mold from the end of the pipe and places it onto a cooling rack for solidification via direct radiation to space. The arm then replaces the mold and places a full canister of waste into the centrifuge device where the process can begin again.

The disadvantages of the system are summarized as follows: pre-separation of waste is required, high maintenance is required, the system reliability is questionable, possible polluting of the space environment may occur, the system is complex, and the system is expensive. Significant costs include both material and maintenance costs. The configuration must be made up of material which can withstand the high operating temperatures, and the external location of the IFSM makes accessibility and thus maintenance difficult.

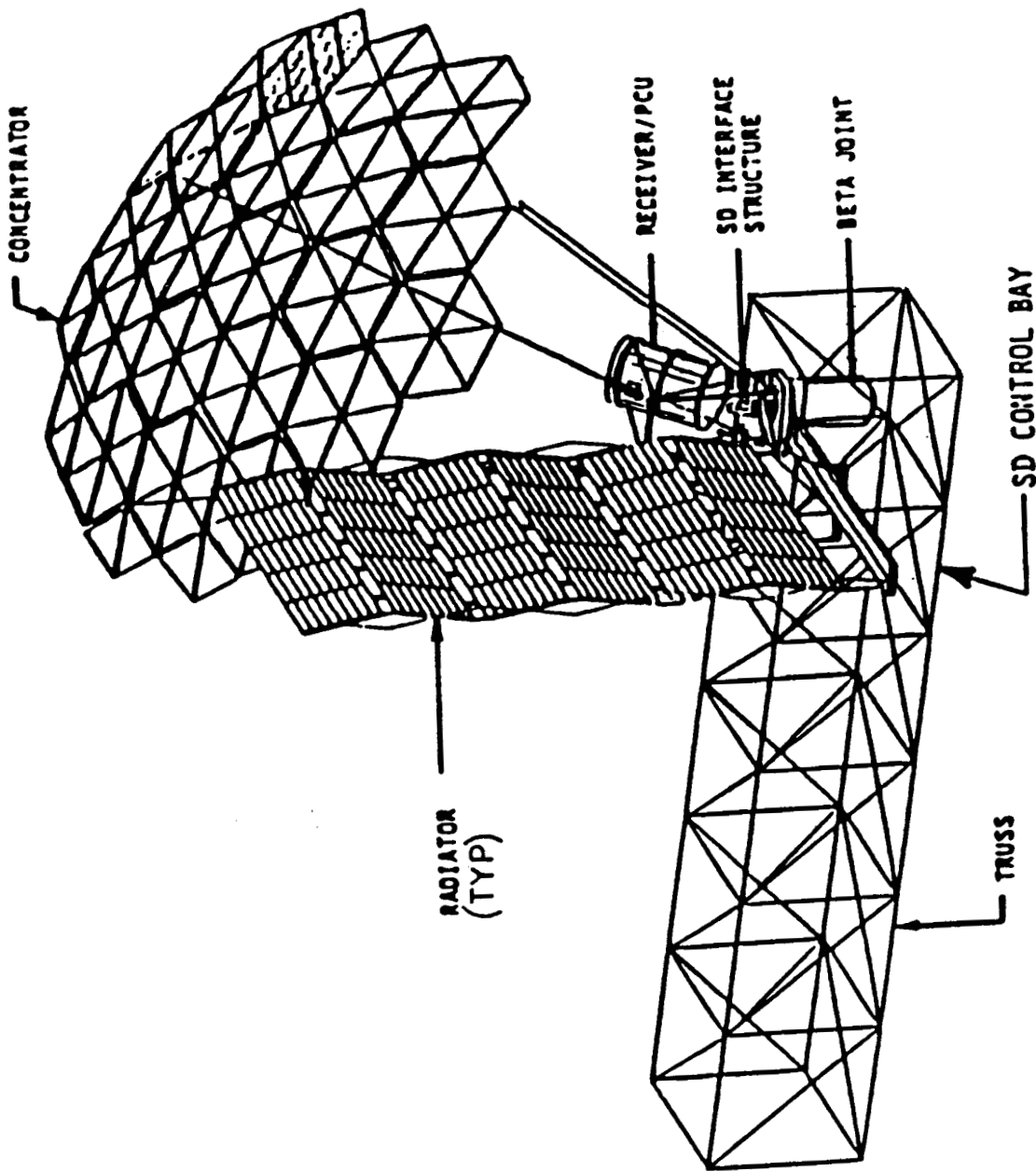
Chapter 19. NON-IMAGE FORMING SOLAR MELTER

An alternative method of melting waste materials down for recycling is the Non-Image Forming Solar Melter (NIFSM) process. This method involves collecting solar heat from a liquid convection solar panel and then transporting it into an oven located within a module or airlock. The solar panel consists of a series of parallel tubes oriented above non-image forming concentrators. These concentrators are in the shape of half cylinders with reflective material, such as aluminum, along their inner surfaces (see Figure 2.5). The concentrators are used to reflect solar radiation onto a piping system where the heat is conducted into a fluid with good convection properties. One such fluid might be a helium-xenon gas mixture, which has been proposed as the working fluid for the closed Brayton cycle (CBC) incorporated in the solar dynamic system:



Conveyor and Queuing System

Figure 2.4



Solar Dynamic Power Module

Figure 2.5

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"The CBC cycle uses an inert, single-phase gas mixture as the working fluid. The reference CBC cycle uses a mixture of helium and xenon, which has an equivalent molecular weight of 40. Xenon is a dense gas which has a high mass flow while helium is added for its heat transfer abilities. The combination of these two attributes yields a mixture which allows the equipment to be optimized in both the heat transfer and mass flow areas."⁴⁵

Using this fluid, the heat is transferred to an oven via a heat exchanger where it is used to melt and reshape materials.

The oven site within the module permits crew interaction with the system allowing versatility of product production and better accessibility for maintenance. However, the oven site within the module causes the primary disadvantages of the system as well. Because the refuse material undergoes a solid-liquid-gaseous phase change upon melting, the probability of contaminating the module is greatly increased. Thus, the oven or melting chamber must be designed to prevent the release of any foreign matter into the module environment.

Chapter 20. PYROLYSIS

Pyrolysis is defined as the destructive distillation of a carbonaceous material in the presence of heat and in the absence of oxygen:⁵¹

"Pyrolysis is destructive distillation. It is a process in which organic matter is thermally decomposed in either an oxygen-free or low oxygen atmosphere. The chief useful product of Pyrolysis is a comparatively energy rich gas or oil."⁴³

Unlike incineration, which is an exothermic combustion reaction with air, Pyrolysis is endothermic, requiring the application of heat either directly or by partial oxidation within a Pyrolysis Reactor (see Figure 2.6). The products of Pyrolysis are usually a highly complex mixture of primarily combustible gases, liquids, and solid residues which can be used as fuels and chemical raw materials. Also, the pyrolysis process is extremely efficient as many reactors can pyrolyze up to 96% of the refuse material introduced.⁴³

The following are proven results from the Pyrolysis of organic waste:

1. Biological conversion to alcohols.
2. Catalytic chemical conversion to methanol via a carbon monoxide and hydrocarbon synthesis gas.
3. Thermochemical breakdown and formation of gases.
4. Oxygenated liquids.

PYROLYSIS WASTE RECYCLING SYSTEM

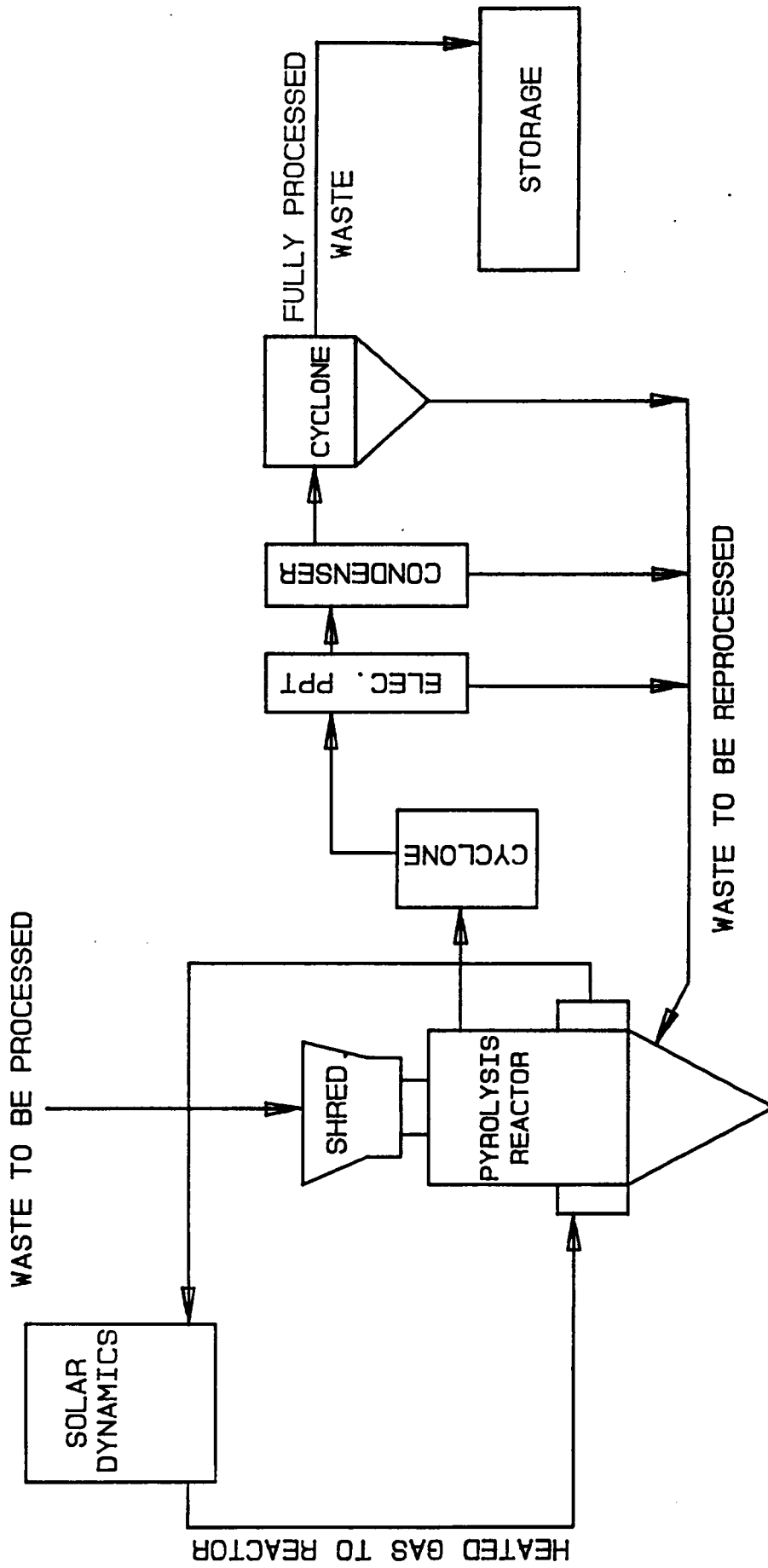


Figure 2.6

The products of one type of reactor, the Fluidized Bed Reactor, are listed in Table 2.2.⁴⁷

A major advantage of using Pyrolysis as a waste-to-fuel mechanism is that it removes the point of volatilization from the oxidation heat exchange process. Hence, there is improved control of the combustion process, a clean and predictable fuel, and easier management of ash and residue. However, a major disadvantage of Pyrolysis is that it is currently a slow break down process. Recent testing has measured the rate of mass flow through the system to be about 0.1 kg./hr., but ways of increasing the break down rate are currently being researched.⁴³

Chapter 21. RECYCLE/REUSE OPTIMAL SOLUTION - PHASE I

According to the Solution Matrix 2.1, Pyrolysis is clearly the most feasible method of recycling refuse. Pyrolysis is an endothermic destructive distillation of carbon materials which yields useful fuel by-products. This method was chosen mainly due to the fact that the process is endothermic, performed in the absence of air, and it has the ability to process almost any type of refuse with excellent efficiency.⁴³ The fuel products are not only useful for general Space Station energy purposes, but also contribute to making the refuse management system a closed system by providing its own power resource. The proposed processing facility is summarized in Figure 2.7. Based upon this decision, a more detailed study of pyrolysis reactors and associated systems is presented in the subsequent chapters of Part II (Design Phase II).

Table 2.2

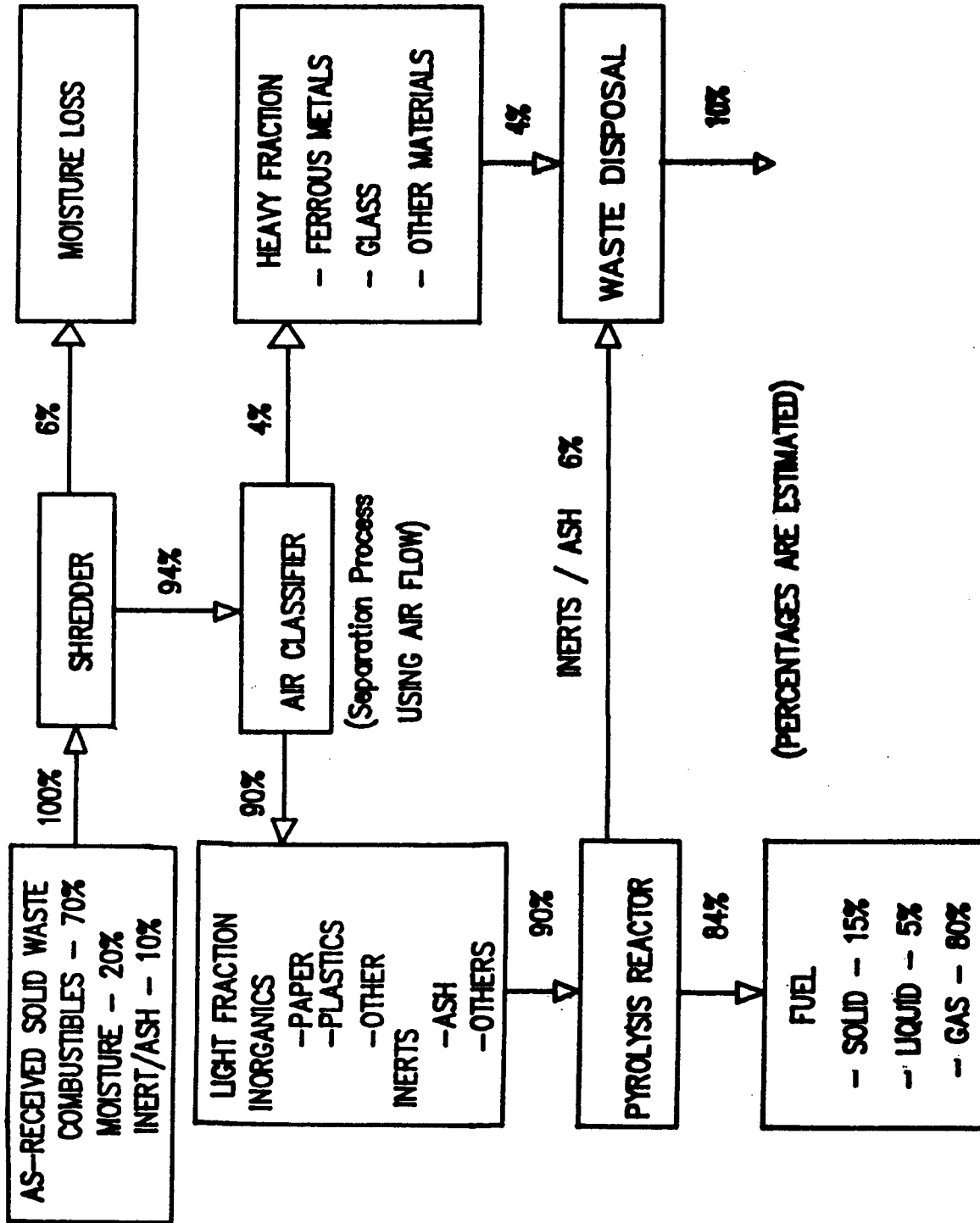
PRODUCTS OF FLUIDIZED BED PYROLYSIS OF PLASTIC WASTE
 RESULTS FROM LABORATORY SCALED REACTOR USING
 POLYETHYLENE AS FEED MATERIAL

TEMPERATURE OF REACTOR: 1013°K (1823°R)

END PRODUCT	WT - %
HYDROGEN	0.50
METHANE	16.10
ETHANE	5.30
ETHYLENE	25.40
PROPANE	+
PROPENE	9.30
BUTENE	0.50
BUTADIENE	2.80
ISOPRENE	+
CYCLOPENTADIENE	1.00
OTHER ALIPHATIC COMPOUNDS	13.30
BENZENE	12.20
TOLUENE	3.60
XYLENE	1.10
STYRENE	1.10
INDAN, INDENE	0.30
NAPHTHALENE	0.70
METHYLNAPHTHALENE	0.15
DIPHENYL	0.02
FLUORENE	0.01
PHENANTHRENE	0.02
PYRENE	+
OTHER AROMATIC COMPOUNDS	5.10
CARBON SOOT, FILLERS	0.90
 BALANCE	 99.40

+ REPRESENTS ONLY A TRACE DETECTION OF THIS MATERIAL

Products of Fluidized Bed Pyrolysis⁴⁷



Processing Facility Materials Flow Diagram

Figure 2.7

PART II. REFUSE RECYCLE/REUSE - DESIGN PHASE II

The processing of refuse into useful by-products by means of pyrolysis was chosen primarily because it's endothermic, performed in the absence of air, it has the ability to recycle almost any type of refuse, and it is an extremely efficient process no matter the reactor utilized, pyrolyzing up to 96% of the refuse material introduced.⁵¹ However, the pyrolysis process requires material reduction prior to reactor use and a power source for its operation. The combination of these processes is the basic structure of the Pyrolysis Processing Facility (PPF) (see Figure 2.8). Therefore, in researching a PPF, the following parameters were considered:

1. Refuse Size Reduction
2. Pyrolysis Reactors
3. Power Generation

Chapter 22. REFUSE SIZE REDUCTION

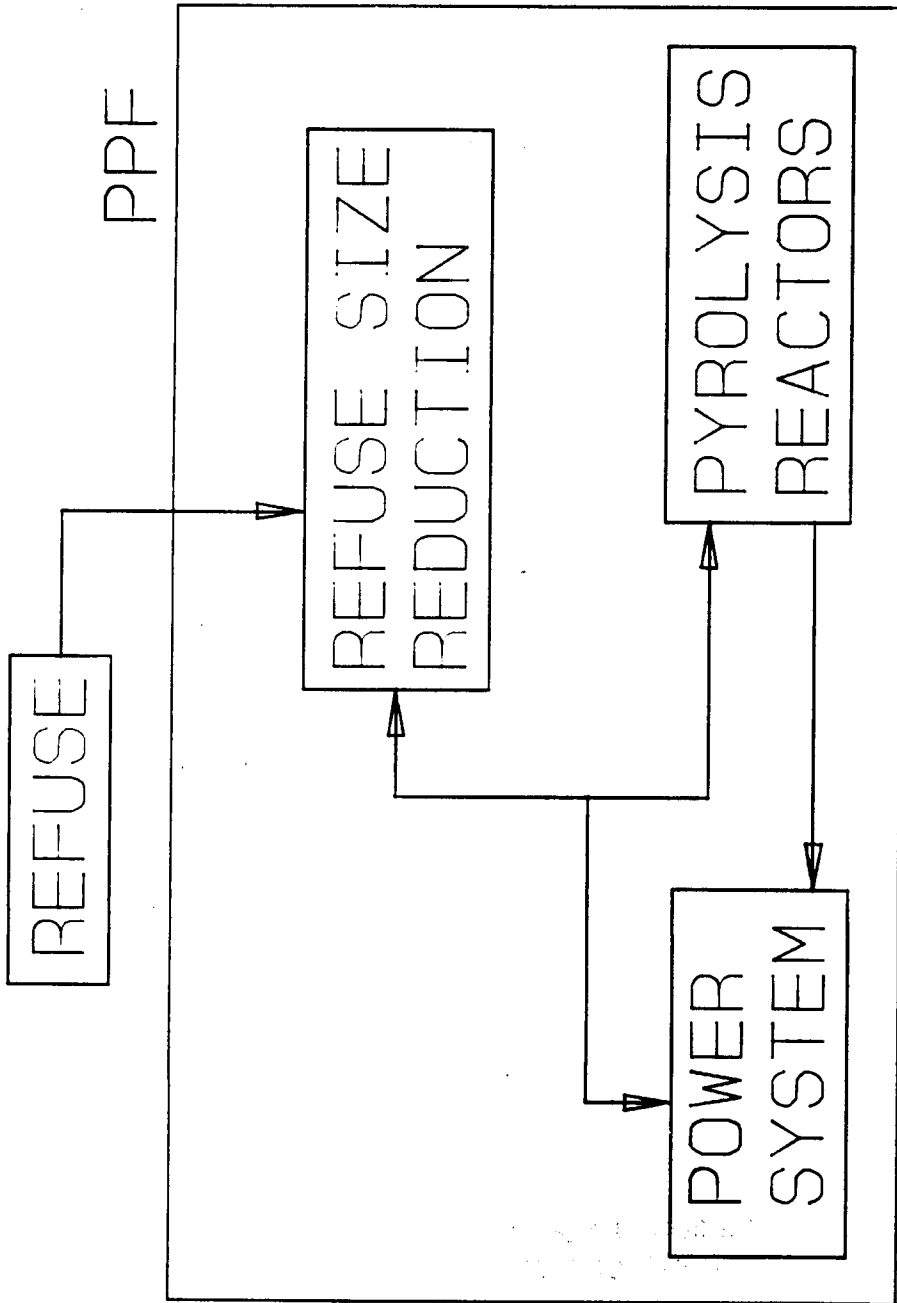
Before the pyrolysis process is implemented, it is necessary to reduce the size of the refuse in order to increase the efficiency of the system. Size reduction may be achieved using the following equipment types:

1. Hammermills
2. Wet Pulpers
3. Rasp Mills
4. Grinders
5. Shredders

22.1 Hammermills

"Hammermills are the most commonly employed equipment used for solid waste reduction."⁵² Hammermills consist basically of single or multiple rotor axles with attached hammers. Rotation of the rotor swings the hammer in an arc around the rotor axis and brings the hammer into contact with the material to be reduced (see Figure 2.9).⁵²

"Overfeeding, jamming, excessive hammer wear, fire, and explosion are just a few of the common types of problems encountered by hammermill operators."⁵² In addition to these disadvantages, the equipment is massive, noisy and dusty. The power consumption, initial cost and operating cost are all high. On the other hand, almost all types of mixed refuse is processable and junk rejection is possible.⁵²

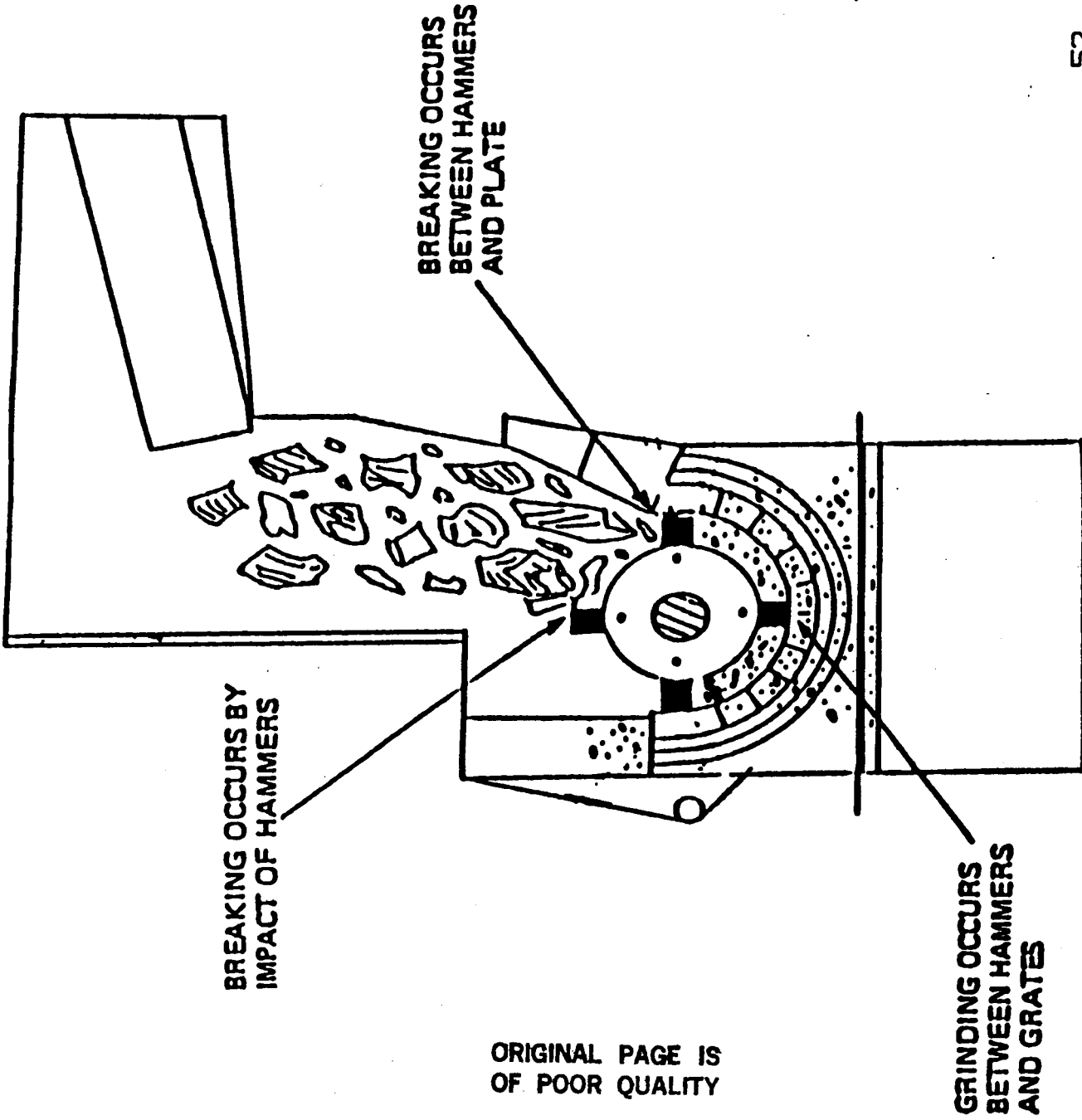


PYROLYSIS PROCESS FACILITY (PPF)

PPF Flowchart

Figure 2.8

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Hammermill 52

Figure 2.9

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22.2 Wet Pulpers

Prior to the wet pulper process, the wastes are mixed with water to produce a slurry (approximately 10% solids). This mixture is then introduced into a pulper which consists of a segmented blade rotating at an extremely high speed. The wastes are reduced rapidly to the desired size and passed out of the apparatus through openings in the bottom of the pulper for further processing. Materials which are not suitable for pulping are rejected ballistically by the rotating blades to the outer⁵³ portions of the pulper drum where they may be collected separately.

The major limitation of the wet pulper is its inability to handle ductile metals, plastics, and heavy textiles. However,²⁶ the equipment is not dusty, is liquid flushed, and can be batch fed.

22.3 Rasp Mills

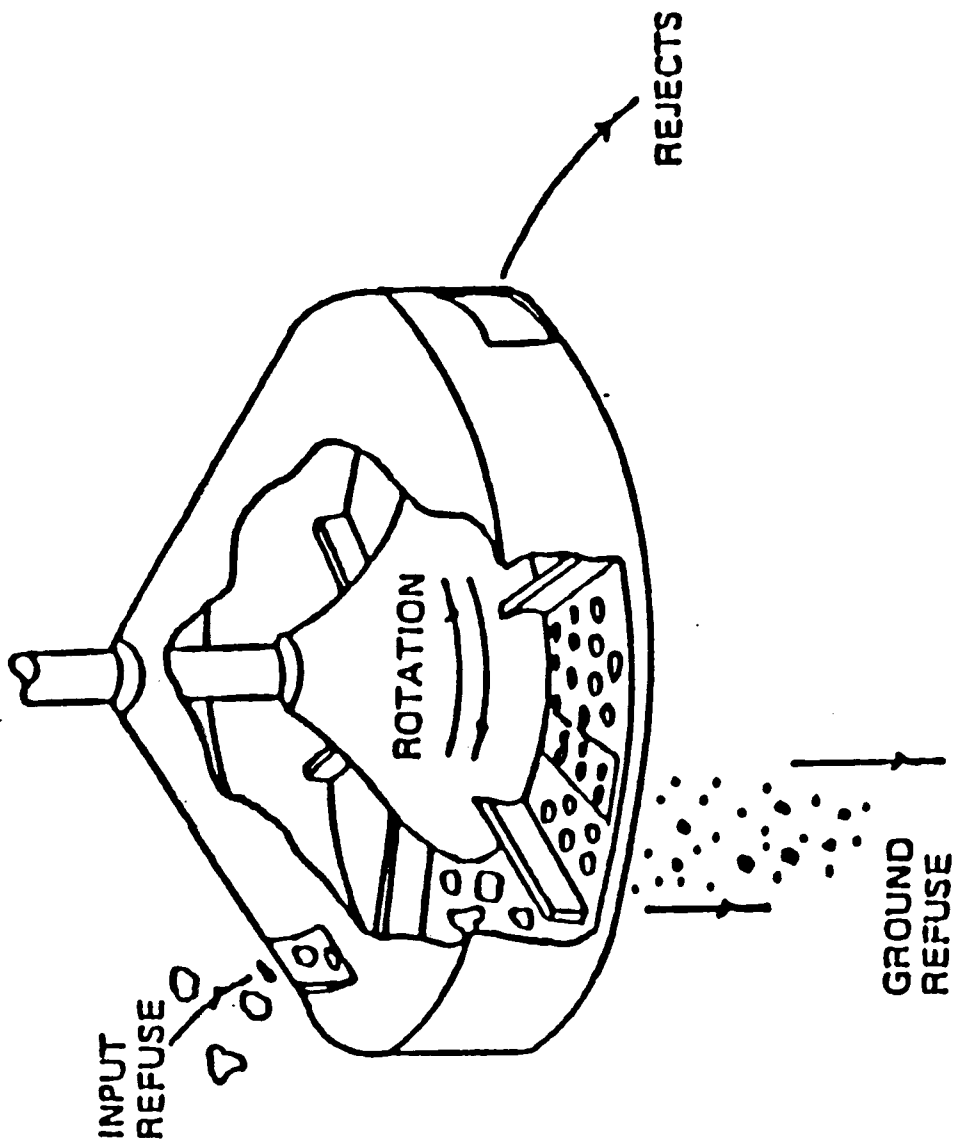
"Rasp mills and other similar size reduction equipment such as pulverizers operate in the following manner: a large rotor fitted on a vertical shaft rotates and carries heavy rasping arms around within the container drum of the mill."⁵³ The rotor turns slowly in comparison to the speed of rotation of a hammermill. The swinging arms are quite heavy and they act to push input wastes around within the external housing. As the waste is pushed around, it passes over obstructions in the bottom plate of the mill called rasping pins (see Figure 2.10). When the material has been reduced to pieces no larger than 2 inches, they fall through the bottom plate of the rasp mill and proceed for further processing.⁵³

The major drawbacks of the rasp mills are the fairly large equipment size, high costs, and the limited feed size due to the axial inlet. However, the mills require little power, are jam-free, batch fed, liquid flushed, and can process all types of mixed refuse.²⁶

22.4 Grinders

The grinder employs a high speed motor to drive a single rotor with rows of hammers. Refuse is fed into the mill at a variable distance above the rotor. As the material falls on the rotor, hard, resilient and heavy objects are propelled into a vertical trajectory to a point where⁵⁴ a deflection plate directs it into a storage compartment.

The grinder is inhibited by some major limitations in addition to consuming vast amounts of power. If the refuse is too wet, it can plug the rotor and stop the operation. If the material is too dry, the mill production is reduced because the material cannot pass through the grate. Also, sharp bladed grinders will only work on soft feeds. In contrast,⁵⁴ dull blades will not comminute steel, heavy aluminum or plastic.



Raspmill 53

Figure 2.10

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22.5 Shredders

The shredder selected for this study is called a "Muffin Monster" because of its ability to reduce waste by utilizing a counter-rotating shredder system. When utilizing the Muffin Monster, the refuse is fed into the center of the counter-rotating cutters. The cutters are comprised of two parallel cutting bars. Each bar has seven-tooth cutting blades with a spacer between each blade (see Figure 2.11). Each cutter is opposed by a spacer rotating at half or twice the speed of its corresponding cutter (see Figure 2.12). 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. (see Figures 2.12 and 2.13 for cross sectional and side views).²⁶

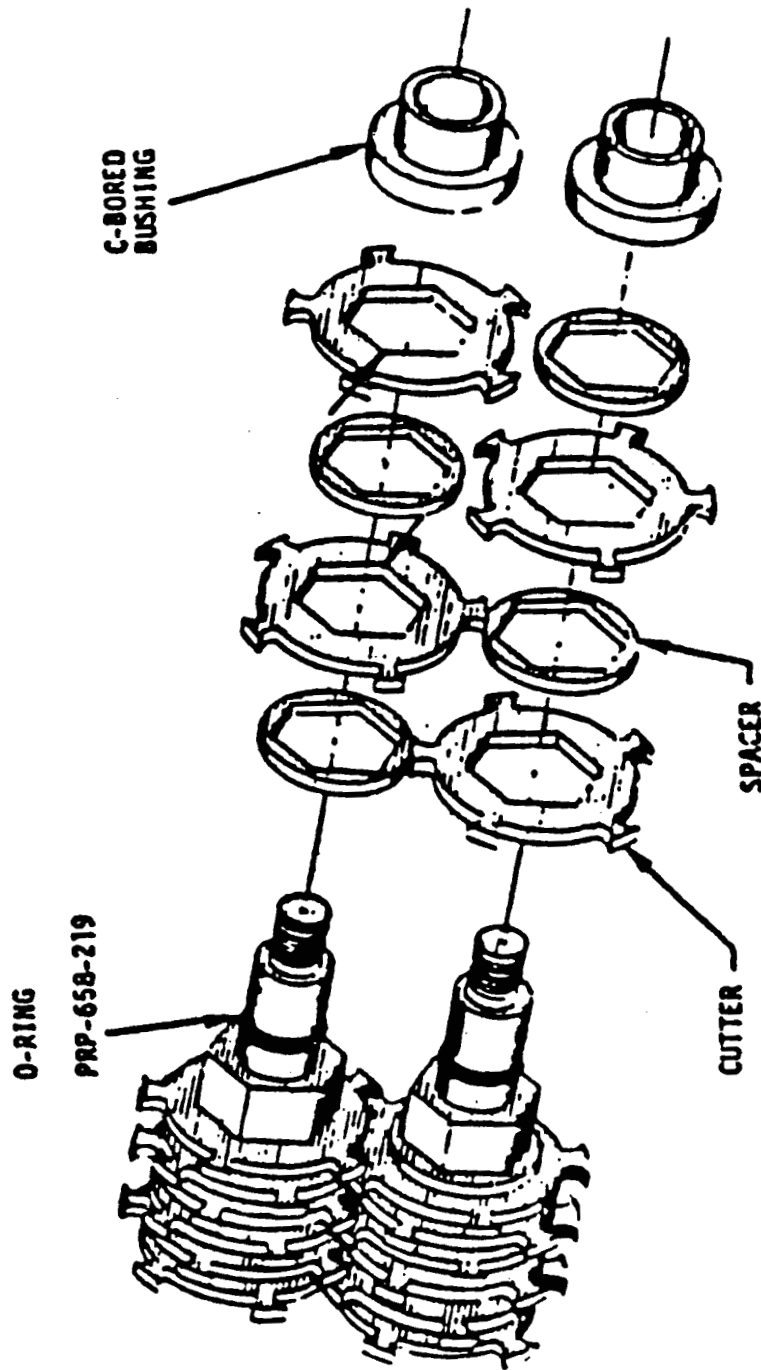
One of the major advantages of the Muffin Monster is that the system, which includes a transport system, has been designed, developed, and tested specifically for a microgravity environment (see Figure 2.14). The transport system is comprised of several rings (drag seals) spaced 75 mm. apart which contact the inside wall of the transport tube. As the shredded refuse is released into the transport tube, the drag seals pull it into the space between the seals and carry it to the pyrolysis reactor (see Figure 2.15).²⁶

The Muffin Monster has many other desirable capabilities as well. In addition to handling the normal trash materials, the system has the ability to handle or reject (if it is too tough) glass, metal and ceramics without damaging or shutting down the system. Also, the self-cleaning system is not dependent on liquids for shredding and transportation. However, the system can handle slurried, damp or dry material. Moreover, by not trying to shred the refuse to a uniform and very small size, the conventional problems of tangling, bridging and jamming are overcome.²⁶

Chapter 23. PYROLYSIS REACTORS

The pyrolysis reactors researched are listed as follows:

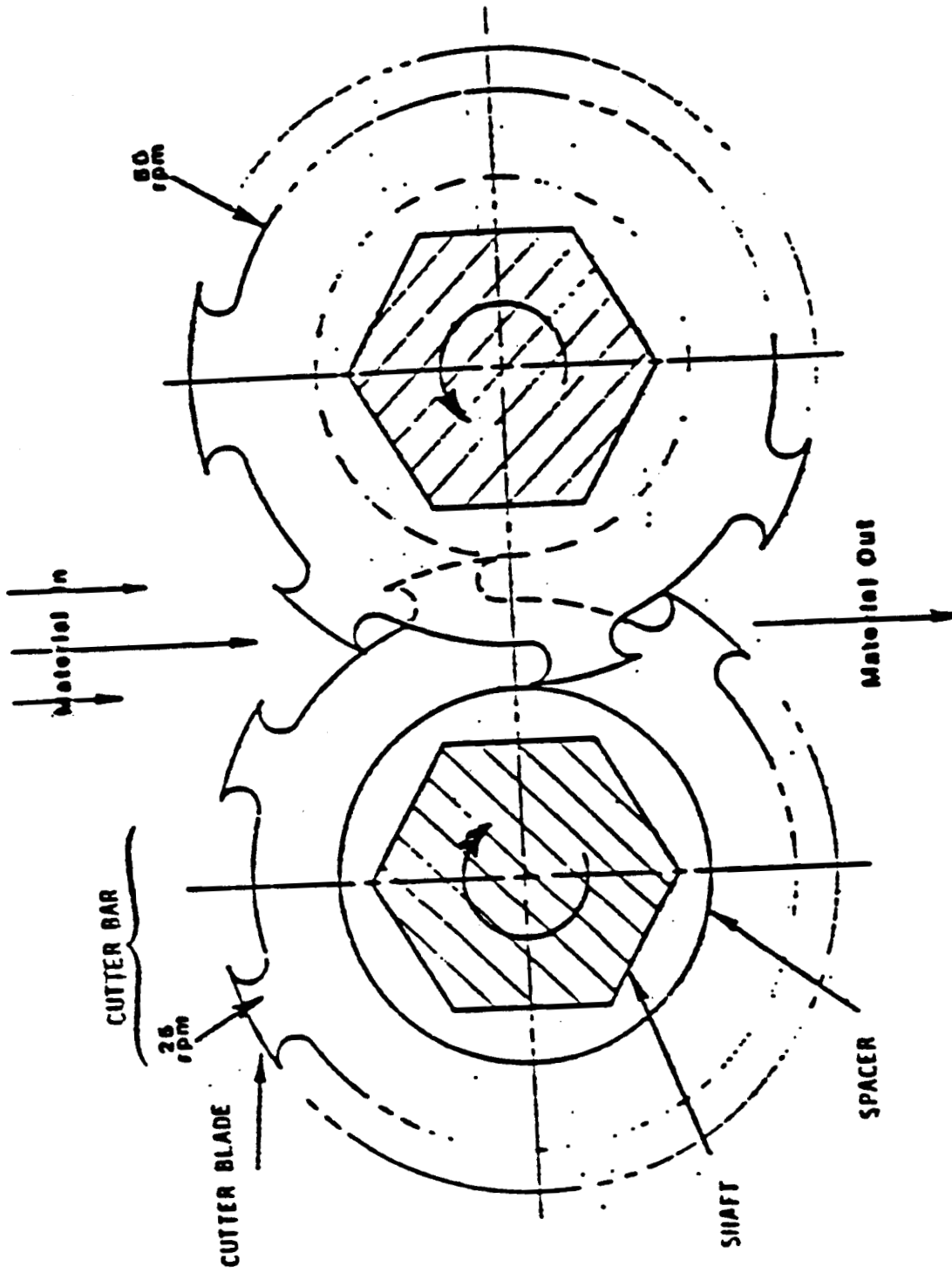
1. Fluidized Bed
2. Rotary Kiln
3. Horizontal Shaft; Fixed Bed
4. Hot Wire
5. Cyclonic Entrained-Flow



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"Muffin Monster" Cutter/Shredder Bar Assembly

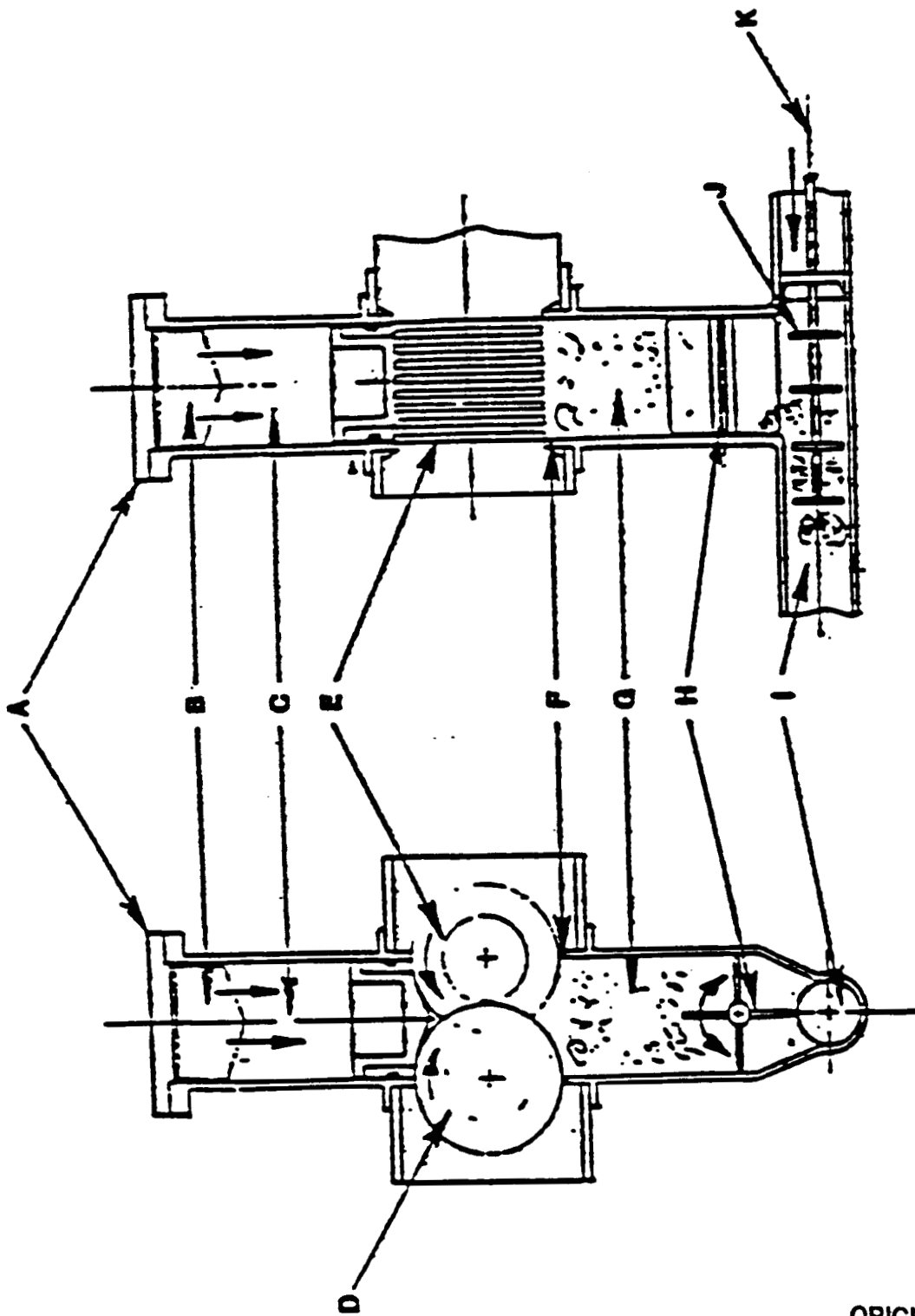
Figure 2.11



"Muffin Monster" Shredder Blades 26

Figure 2.12

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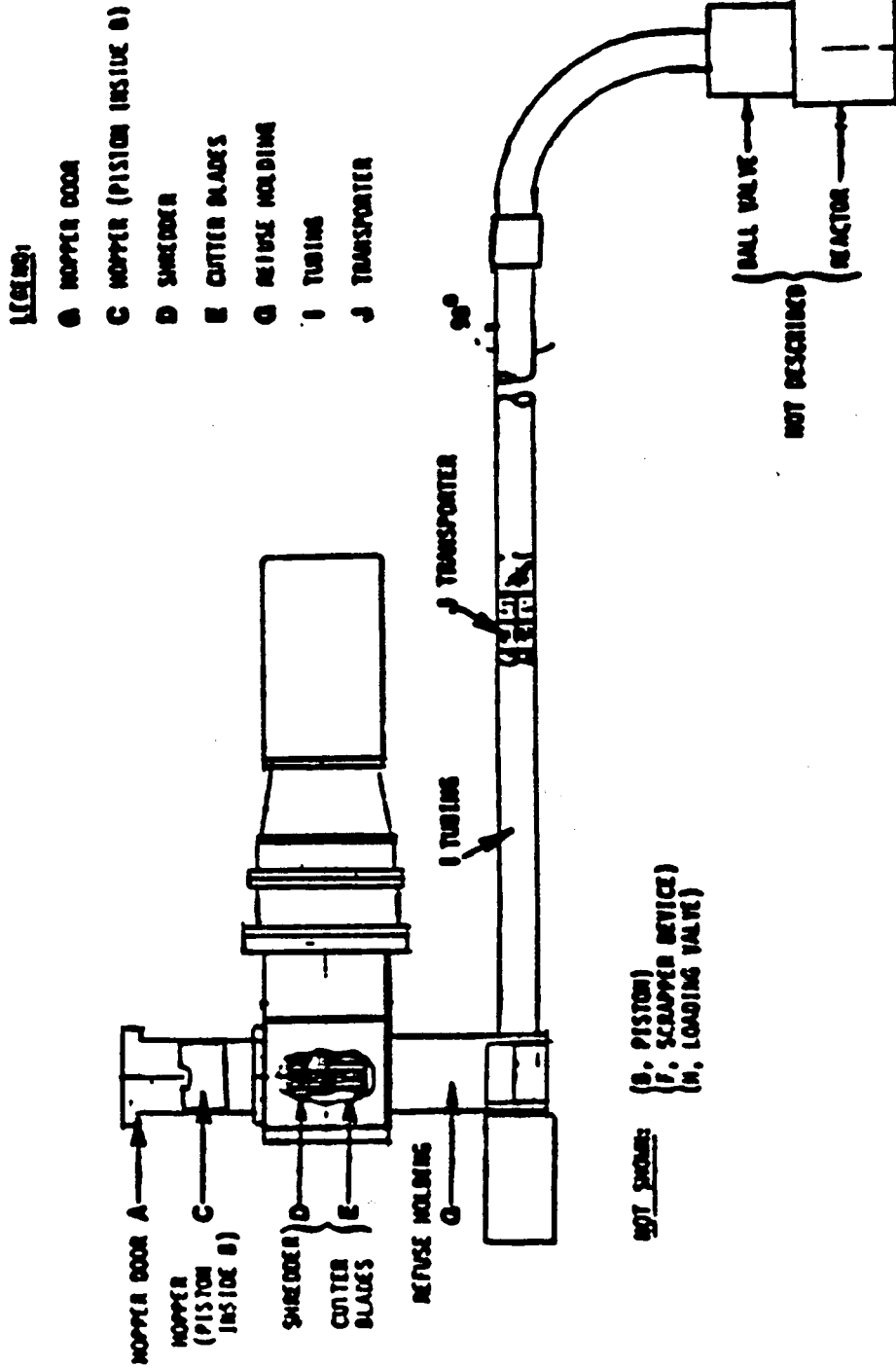


"Muffin Monster" Shredder System Detail ²⁶

Figure 2.13

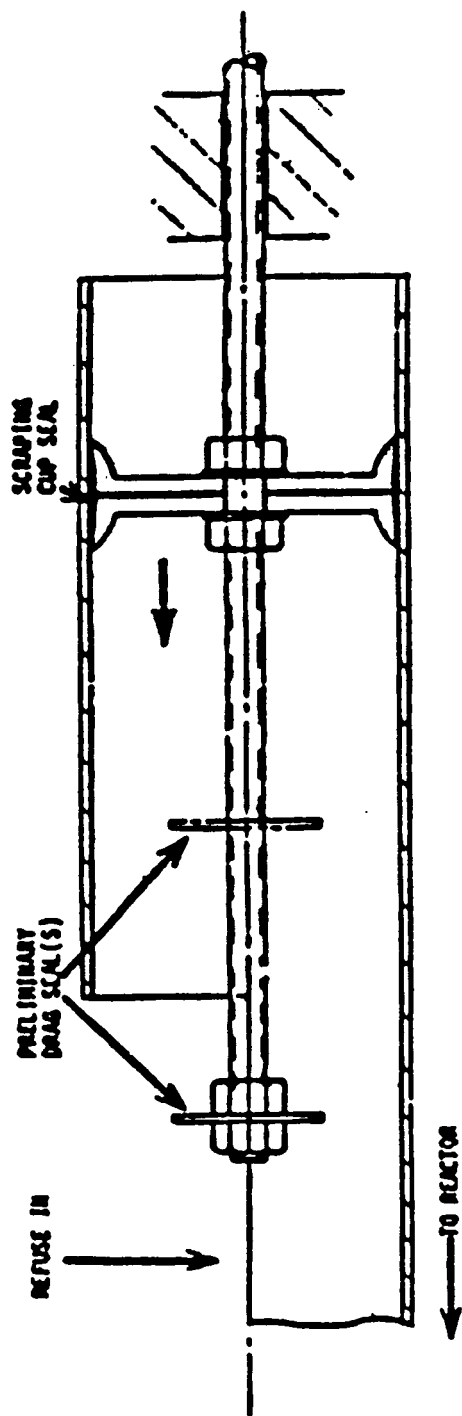
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"Muffin Monster" Transport System 26

Figure 2.14



Transport Seal System 26

Figure 2.15

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23.1 Fluidized Bed Reactor

The Fluidized Bed reactor is a cylindrical refractory lined shell with a designed plate on the surface bottom to support a sand bed (see Figure 2.16). Underneath the plate is a network of pipe configurations with several air jets on each pipe. Air (or gas) is introduced into the fluidizing air inlet at pressures of 3 to 5 psig. This fluid is then passed through the pipe network and is diffused into the sand bed thereby lifting the sand particles. This process is called "fluidizing" the bed.

This reactor is safe, cost-effective, and an extremely simple piece of equipment with no moving parts. The sand in the reactor acts as a heat sink allowing the reactor to shut down with little or no heat loss and also permitting easy start-up after shut down. It is very efficient, operating at an average temperature of 1500 degF and decomposing up to 95% of the material, depending upon the type and size of refuse introduced. However, a major concern when considering this option for space use is "fluidizing the bed", which depends upon the principle of particle drag. Therefore, adaptation for use in space would be quite complex.

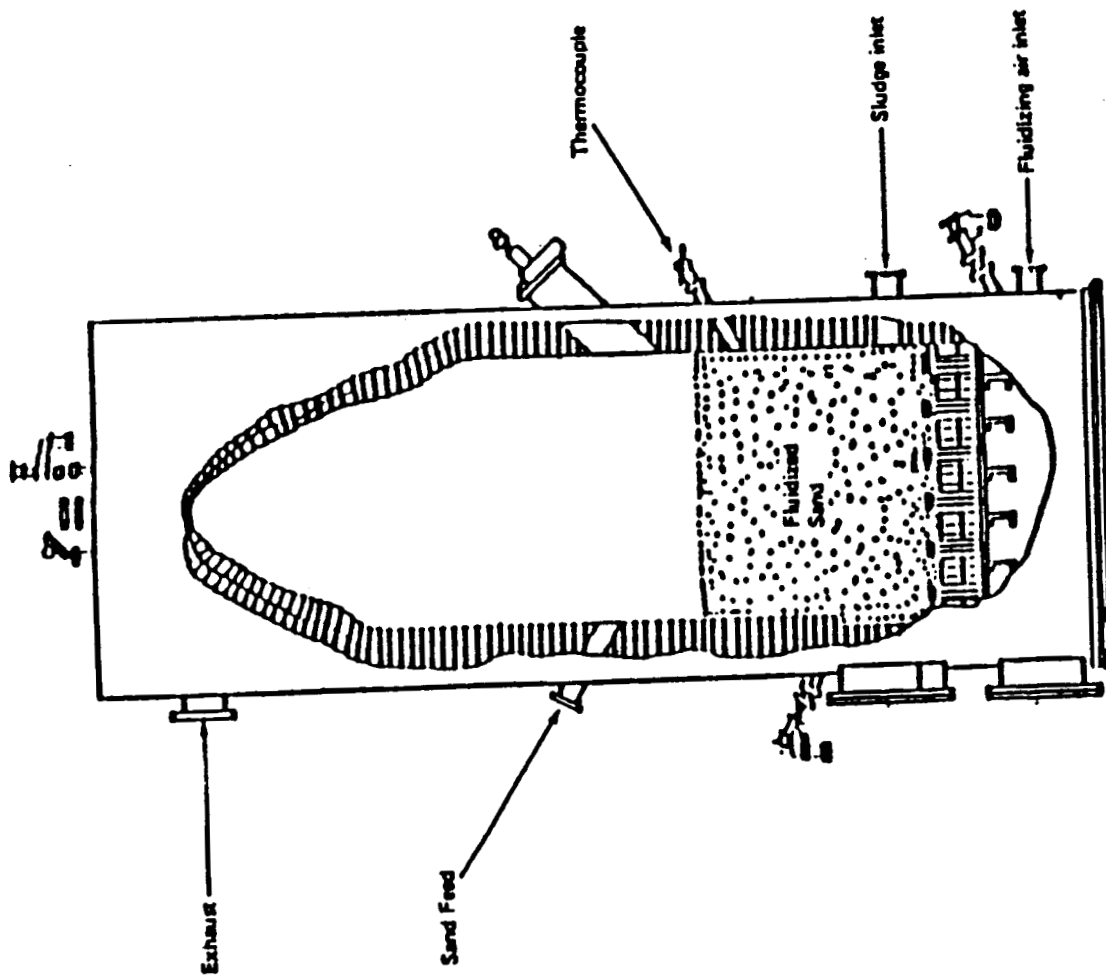
23.2 Rotary Kiln Reactor

For Rotary Kiln Reactor (see Figure 2.17), prepared refuse is introduced into a refractory-lined rotary kiln. At the opposite end of the kiln, a continuously fired fuel (oil) and air stream is fed in the opposite direction of the rotating kiln. These countercurrent flows of solids and gases constantly dry and expose the refuse to progressively higher temperatures (1000 degC maximum) as it passes through the kiln. Hot residue is then discharged from the kiln into a water filled quench tank where it is separated and stored. The gaseous by-products from the reaction are taken from the kiln and fed into an afterburner where they are mixed with air and burned before allowing the gases back into the atmosphere. This system has proven to be safe, cost-effective, and reliable. However, this system would be very difficult to implement in space from almost all aspects.

23.3 Horizontal Shaft; Fixed Bed Reactor

The Horizontal Shaft Reactor is a combination of a Kemp Waste Converter and the Barber-Coleman Horizontal Shaft process. As stated by the Kemp Corporation:

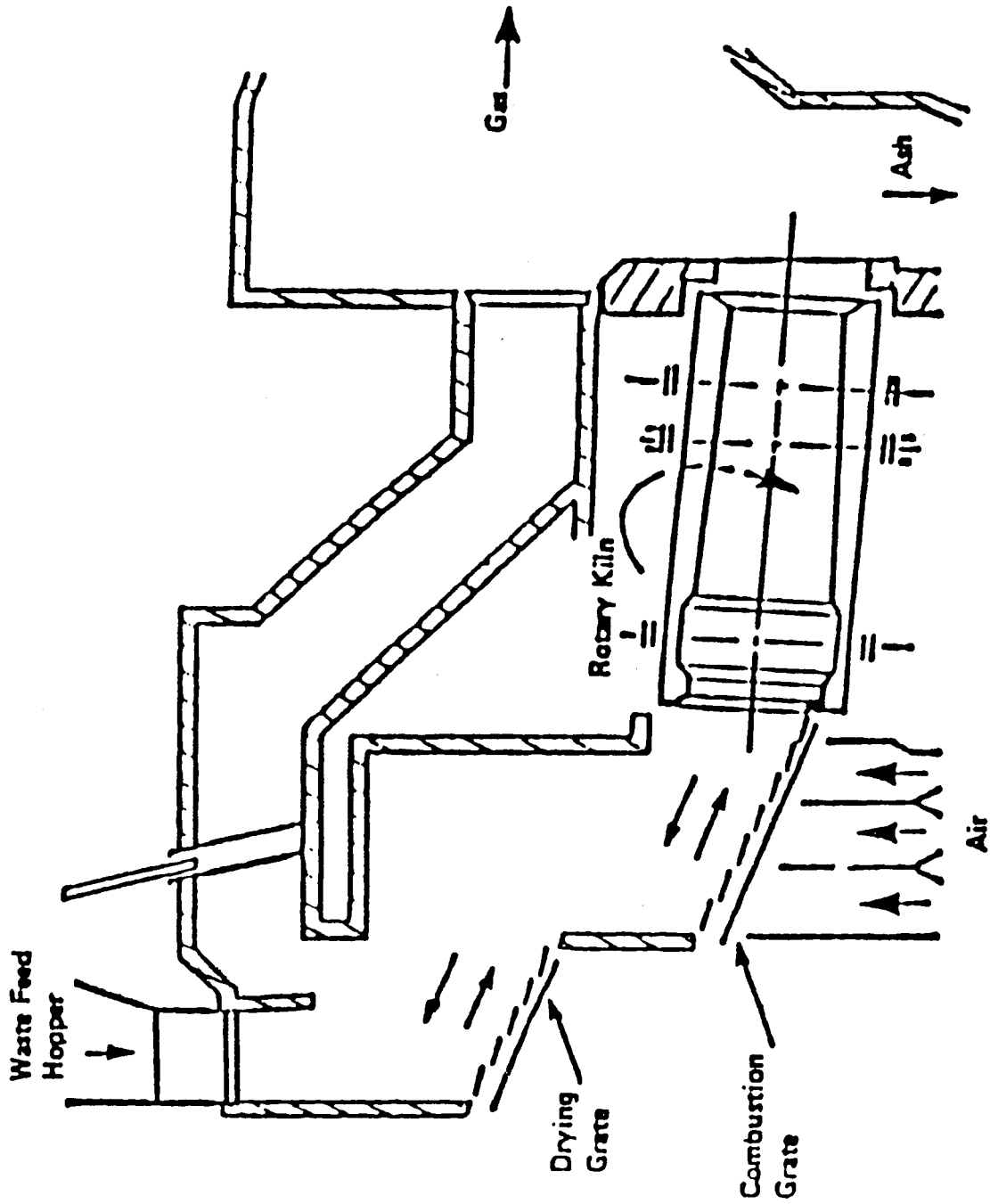
"A conveyor belt is used to carry the feed material through the reactor developed by the Kemp Corporation. Indirect heating is used to pyrolyze the organic material and produce solid, liquid, and gaseous fuels. For shredded solid waste, the pyrolysis temperature would be in the range 430 to 600 degC. If desired, metals and glass can be recovered from the char after pyrolysis at this low temperature."



Fluidized Bed Pyrolysis Reactor 51

Figure 2.16

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Rotary Kiln Pyrolysis Reactor 55

Figure 2.17

According to Barber-Coleman:

"The Barber-Coleman process reactor is a closed horizontal shaft with a circulating molten lead bed as the heat transfer media. The refuse is first fed to a metal detector where large chunks greater than 15 cm. are removed. The remaining material is then shredded to about 5 cm. before being fed to the reactor via an air lock. The pilot plant reactor has a capacity of about 700 kg./day and has dimensions of 1.8 m. length with a rectangular cross section of 25.4 cm. depth and 45.7 cm. width."⁵⁵

"The refuse floats on the molten lead surface which is circulated via a gas lift pump. The lead bath is heated from the top by standard radiant tube burners located in the vapor space. The refuse is then pyrolyzed from the lead surface at a temperature of about 650 degC, producing a gas with a target heating value of about 1.8 to 2.6 x 10⁷ J/m. About one-fourth of the gas will be used in the "gas lift" system. The remainder of the gas would be available for sale."⁵⁵

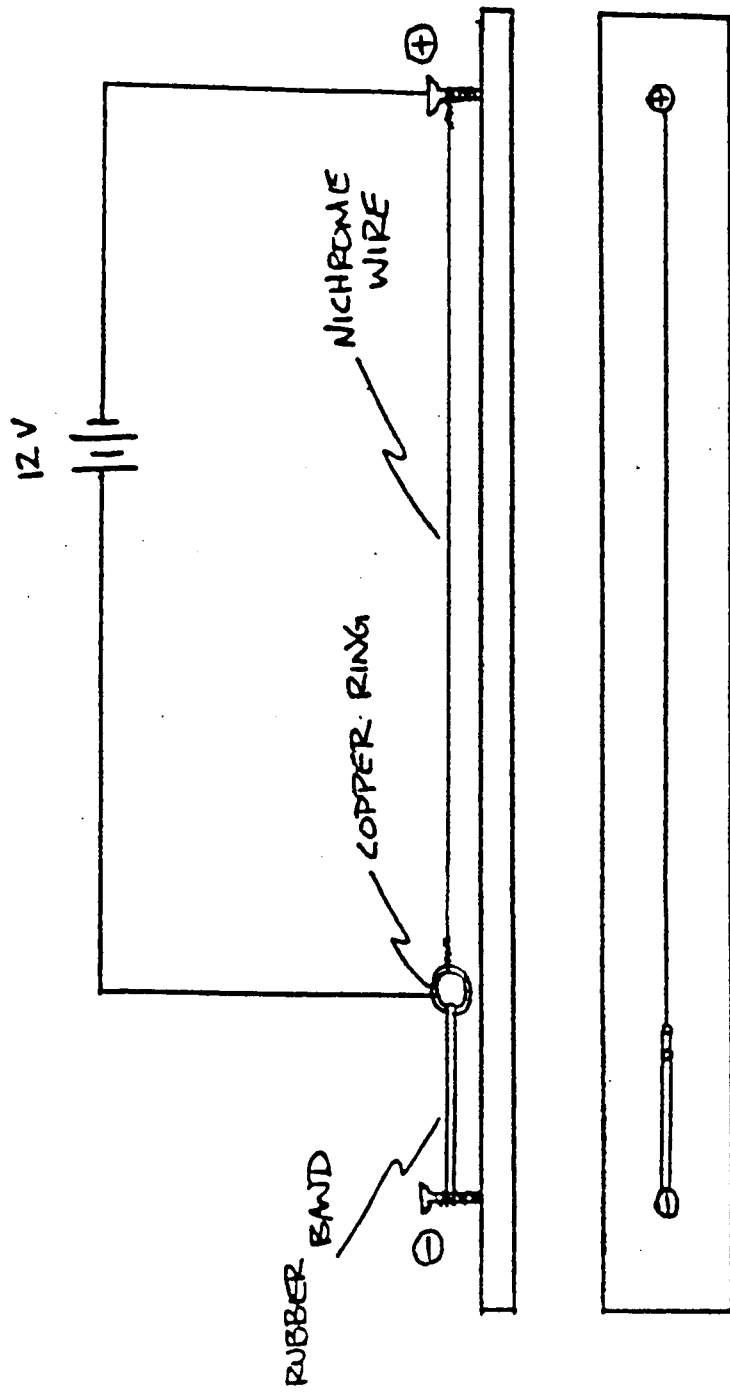
As discussed by the above, this type of reactor has a large refuse volume capacity and yet is relatively small. It is quite safe and cost-effective with little maintenance, involving the periodic removal of the lead bath for cleaning by batch processing. However, the procedures involved are not compatible for space use.⁵⁵

23.4 Hot Wire Reactor

The Hot Wire Reactor is still in the experimental stage but has excellent pyrolysis capabilities (see Figure 2.18). The research is being conducted by James Diebold and John Scahill at the Solar Energy Research Institute (SERI). Their work is cited as the best possible explanation of the process:

"...laboratory-scale heat transfer experiments have shown that when biomass is moved relatively to a red-hot Nichrome wire, the wire will cut through the biomass. The rate of cutting, or pyrolysis, can be as high as 3 cm./s. when it is a very localized surface phenomenon. With this method of heat transfer, pyrolysis appears to proceed by the depolymerization, melting, and vaporization of the biomass without observable char formation; the term 'ablative' seems to best describe this fast pyrolysis mechanism."⁵⁶

"The rate of heat transfer from the red-hot metal surface to the biomass is extraordinarily high. Based on an assumed energy of pyrolysis of 2000 J./g., the 0.025 cm. diameter wire moving across the biomass at 20 cm./s. and penetrating at a rate of 3 cm./s. was transferring 3500₂W./cm.². which is very impressive compared to the mere 15 W./cm.² radiated by a black body reactor wall at 1000 degC. Thus,



Hot Wire Pyrolysis Schematic 56

Figure 2.18

this solid convective approach to heat transfer for pyrolysis transfers energy to the biomass at rates over two orders of magnitude greater than black body radiation at similar wall temperatures. This would imply that a pyrolysis reactor relying on solid convective heat transfer could have over 100 times the throughput of a similarly sized reactor relying only on radiative heat transfer."⁵⁶

"The mechanism of this solid convective heat transfer appears to be the conduction of heat across a very thin film from a nearly isothermal metal surface at 1000 degC, while the biomass depolymerizes at about 300 to 400 degC to primary tars which are wiped away and/or vaporized. Since heat conduction is proportional to this large temperature difference by the very thin film thickness, very high heat fluxes are predicted. Because the surface regression rate is nearly the same as the thermal penetration rate, any biomass which is located more than a calculated 15×10^{-6} m from the pyrolyzing surface is still at the low initial temperature and is unaffected by the ablative pyrolysis taking place. Consequently, this charless, ablative pyrolysis will proceed in a similar manner whether the biomass is a 1 cm. chip or a fine, 50 micrometer powder. Because the pyrolysis front moves so quickly through the biomass, the temperature gradient is very steep with a calculated heating rate of about 500,000 C/s."⁵⁶

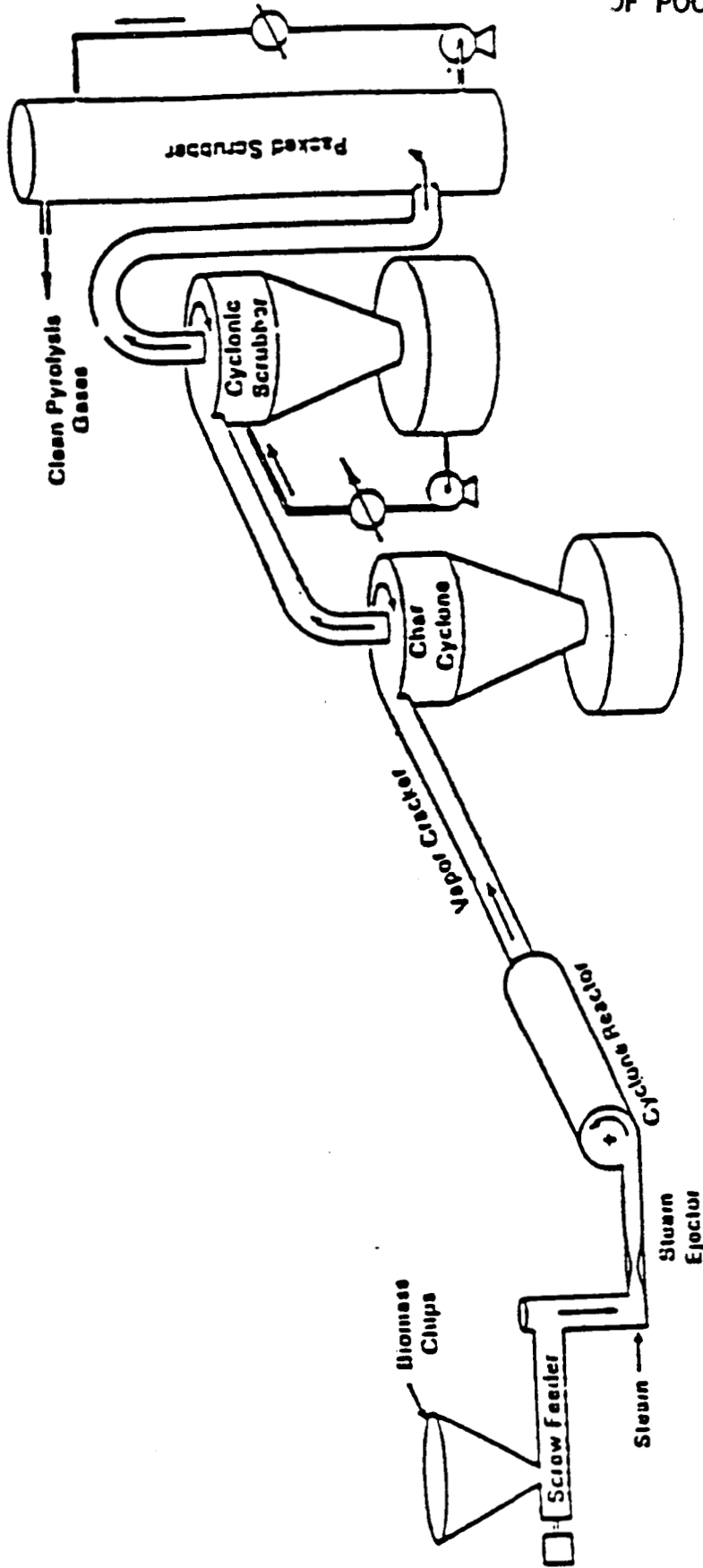
As evidenced by the findings of Mr. Diebold and Mr. Scahill at SERI, Hot Wire Pyrolysis is quite interesting and seems to have unlimited applications for the recycle/reuse PPF. However, the technical feasibility of this system is questionable until further research has been done.

23.5 Cyclonic Entrained-Flow Reactor

The concept of Cyclonic Entrained-Flow (CEF) involves a very high throughput reactor in which refuse particles are introduced at high velocity into a cyclone (or vortex tube) tangential to its X and Z axes (see Figure 2.19). The circular wall area of the cyclone is externally heated and the particles follow a spiral path through the reactor. The constant contact with the thermally activated wall combined with the high velocity of the particles make this an efficient and complete pyrolyzing process. The by-products (gaseous and char) are entrained through a vapor cracker which maximizes the gas forming process. The char is then removed in a char cyclone while the gases are cleaned and processed in the cyclonic scrubber and the packed scrubber.⁵⁶

The CEF reactor design is ideal for space application. Problems associated with the absence of gravity will not be a factor as the reactor creates its own gravitational environment. Reactor temperature requirements have been reduced (from 1500 to 600 degC) due to innovative reactor design. As particles travel through the reactor,

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Cyclonic Entrained Flow Reactor 56

Figure 2.19

friction results due to contact with the reactor walls. This frictional heat is sufficient enough such that no external heat source is required for the pyrolysis reaction. Thus, this reduction in temperature also decreases the power requirements of the reactor. In addition, this reactor has a phenomenal refuse processing rate of up to 46.2 lb./hr.⁶⁰

Another extremely important advantage is the useful by-products generated by the CEF system. Only 10 to 12% of the products is char, 15% is H₂O vapor, and the remaining 73% is a gas which can be condensed into a valuable pyrolysis oil. Using sawdust as the refuse material, this oil has a higher heating value of 8100 Btu./lb. resulting in a volumetric heating value of about 65% that of a hydrocarbon fuel oil. Pyrolysis oils made from plastic wastes have higher heating values and tend to be more viscous (see Table 2.3).⁶⁰ This becomes important when considering that the drag incurred by the Space Station photovoltaic arrays and effective areas will require subsequent reboost as atmospheric micro-drag is encountered and the orbit decays.⁶¹ As stated by Mr. James Diebold (SERI):

"A possible application for this oil would be as a rocket fuel for altitude or orbit corrections for a Space Station. Although the specific impulse value of such a fuel, when burned with oxygen, would not be as high as attainable from a kerosene/oxygen combination, it would compare well with use of hydrazine as a monopropellant. Note that since the pyrolysis oil has an empirical formula of CH_{1.300.14}, that significantly less oxygen will be required for combustion per lb. of fuel. In fact, quick calculations indicate the same higher heat of combustion per lb. of oxygen from either the wet pyrolysis oil or a hydrocarbon fuel at a stoichiometric fuel to oxygen ratio of one. Note that the flame temperature will lower when burning the pyrolysis oil."⁶⁰

"However, since rocket fuel performance is optimized with fuel-rich stoichiometries and is a strong function of the flame temperature and gaseous combustion-product molecular weight, an in-depth computer study is indicated to determine the relative merit of pyrolysis oil as a rocket fuel. It is interesting to note that the rocket performance using the pyrolysis oil should be based on seconds of thrust per lb. of oxygen (not oil plus oxygen) since the organic wastes used to make the pyrolysis oil would have been already lifted into orbit and would be on board."⁶⁰

Chapter 24. POWER GENERATION

Many power generation systems have been designed to supply the NASA Space Station. Some of these designs can be taken into consideration to supply 10 kW. of power to the PPF. The power generation systems considered are as follows:

Table 2.3

PYROLYSIS SUMMARY SHEET (MOO 4)
(without H₂O balance; R-6-405116 GC calibration)

Run R-1-1543 Date 12/22/81

-80 mesh Pine Flour used for feed

Temp. Profile	Steam	CY-1	CY-2	CY-3	VC-1	VC-2	VC-3	VC-4	VC-5	VC-6
Degrees C	780	785	855	867	779	755	761	770	770	760

Final Pyrolysis Gas Temperature: 686 C (1267 F)

Reactor Pressure 90.32 KPa (13.10 psia)

Partial Pressure of Product Gases at Reactor Exit 11.07 KPa (1.61 psia)

4.48 kg wet feed/hr .00 moisture fraction of feed

Steam Flow Rate: 22.3 kg/hr Steam/Dry Biomass = 5.0 kg/kg

5.54 MJ steam/kg wet feed at 15.60, 1 atm (104.70 scf/lb)

.92 MJ net dry gas/kg dry feed at 15.6 C, 1 atm (14.69 scf/lb)

15.00 minutes run time

Pyrolysis Products Per kg Dry Feed

Gas Phase	Yield Vol Fr	Yield G/Kg	% of Combustion Moles		Elemental Yield			G/Kg Dry Feed	
			HHV	LHV	C	H	O	S	N
H ₂	0.182	14	2017	1706	0	14	0	0	0
C ₃ H ₈	0.000	1	34	32	1	0	0	0	0
C ₃ H ₆	0.010	17	809	757	14	2	0	0	0
1-Butene	0.001	2	90	75	1	0	0	0	0
c-Butene*	0.005	11	531	497	9	2	0	0	0
c-Butene	0.000	0	19	18	0	0	0	0	0
n-Pentane	0.001	2	37	81	1	0	0	0	0
CO ₂	0.081	139	0	0	38	0	101	0	0
C ₂ H ₄	0.056	61	1060	2869	52	9	0	0	0
C ₂ H ₆	0.006	7	357	327	6	1	0	0	0
C ₂ H ₂	0.007	7	328	317	6	1	0	0	0
Y ₂	0.016	17	0	0	0	0	0	0	17
CH ₄	0.120	75	4156	3745	56	19	0	0	0
CO	0.502	545	5507	5507	234	0	311	0	0
Arom Vap	0.013	47	2017	1927	43	4	0	0	0
Char		11	177	177	4	0	0	0	0
Mass Out		954	19179	18035	466	53	412	0	17
Mass In		1000	20462	19041	505	65	425	0	1
In-Out		46	1283	1006	39	12	14	0	-16

*1,2 Butadiene is not separated from c-butene

Mol wt of dry gases = 24.33 11.38 mol CH₄/mol C₃H₆ 5.52 mol C₂H₄, mol C₂H₆
Yield per kg of dry feed: 74 g C₂'s, and 30 g C₃ - C₄'s, or a total of 153 g C₂'s.

HHV of Gases = 556 Btu/ft³ LHV of Gases = 523 Btu/ft³
Mole fraction of water vapor in final product gases was .015

Pyrolysis Summary Sheet ⁶⁰

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1. Hybrid Electrical Power Generation System
2. Modular Radioisotope Thermoelectric Generator
3. Thermionics Generator
4. Heat Pipe Rankine Cycle
5. Electrostatic Parametric Generator

24.1 Hybrid Electrical Power Generation System

The initial operational capability (IOC) calls for the space station to have 75 kW. of power. "NASA's Lewis Research Center is in charge of the power system portion of the Space Station design. A hybrid electrical power generator is to be used on the Space Station".⁴⁵ The IOC of the electrical power system of the Space Station is to be generated by four photovoltaic solar arrays. Solar dynamics are to be incorporated into the system at a later time.⁴⁵

The 75 kW. photovoltaic arrays are used to convert sunlight into d.c. power. This dc power then needs to be converted into a.c. power for transmission throughout the Space Station. "Nickel hydrogen batteries are being developed by Ford Company to supply power during the eclipse portion of the Space Station's orbit."⁴⁵

Two solar dynamic power systems are being considered by NASA Lewis: Rankine and Brayton cycle power conversion systems. Both systems use a reflecting concentrator which focuses the sun's rays onto a central receiver. A thermal energy storage unit absorbs the sun's energy and transfers it to a heat engine to be used by a turbine generator to produce power (see Figure 2.20). The design of this thermal storage unit is such that during the eclipse portion of the orbit, enough energy will remain in the unit to power the heat engine.⁴⁵

The solar concentrators and pointing control electronics associated with the solar dynamic electrical power generating system will use a large solar mirror to focus the sun's rays into the thermal storage unit. A sun sensor located on the power system unit will sense the location of the sun and feed this information to the tracking computers. Linear actuators controlled⁴⁵ by the computer will keep the solar concentrators focused on the sun.

The preliminary design of the solar concentrator includes a graphite epoxy material to keep the concentrator structure weight slightly over 1300 pounds. Hexagonal panels containing 24 triangular silver or aluminum mirrors will make the actual reflecting surface. Since the solar concentrators may range from 43 to 64 feet in diameter, the hexagonal panels can be folded and transported to the Space Station by stacking them in the cargo bay of the Space Shuttle.⁴⁵

This hybrid electrical power system could be modified to supply 10 kW of power to the PPF by reducing the size of the photovoltaic arrays and the solar dynamics modules. Of major concern to NASA, however, would be the cost involved in this modification.

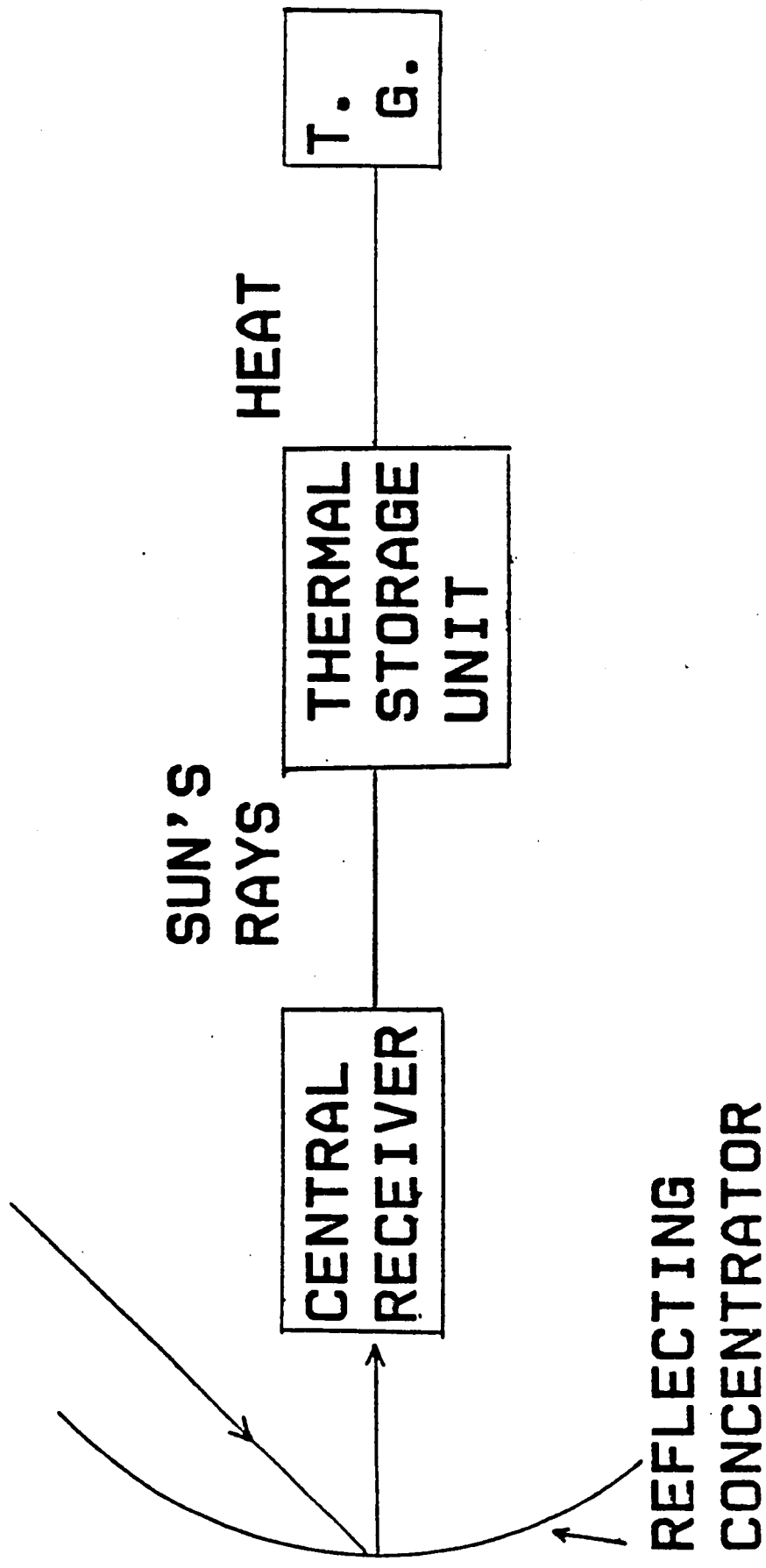


Figure 2.20

24.2 Modular Radioisotope Thermoelectric Generator (MOD-RTG)

The MOD-RTG was designed specifically with space application in mind. The generator uses up to 18 general purpose heat sources (GPHS) which provide thermal energy to be converted into electrical power by means of thermoelectric multicouples. The multicouples are made of silicon and are doped with germanium; one is the n-type, negative carrier type, the other is of the p-type, positive carrier type. Performance tests on the ground indicate a power to weight ratio of 3.8 W./lb.⁵⁷

Considering this power to weight ratio and a 6 kW power requirement for the shredder, the following equation is valid:

$$6 \text{ kW.} = 3.8 \text{ W./lb.} * X \quad (2.2)$$

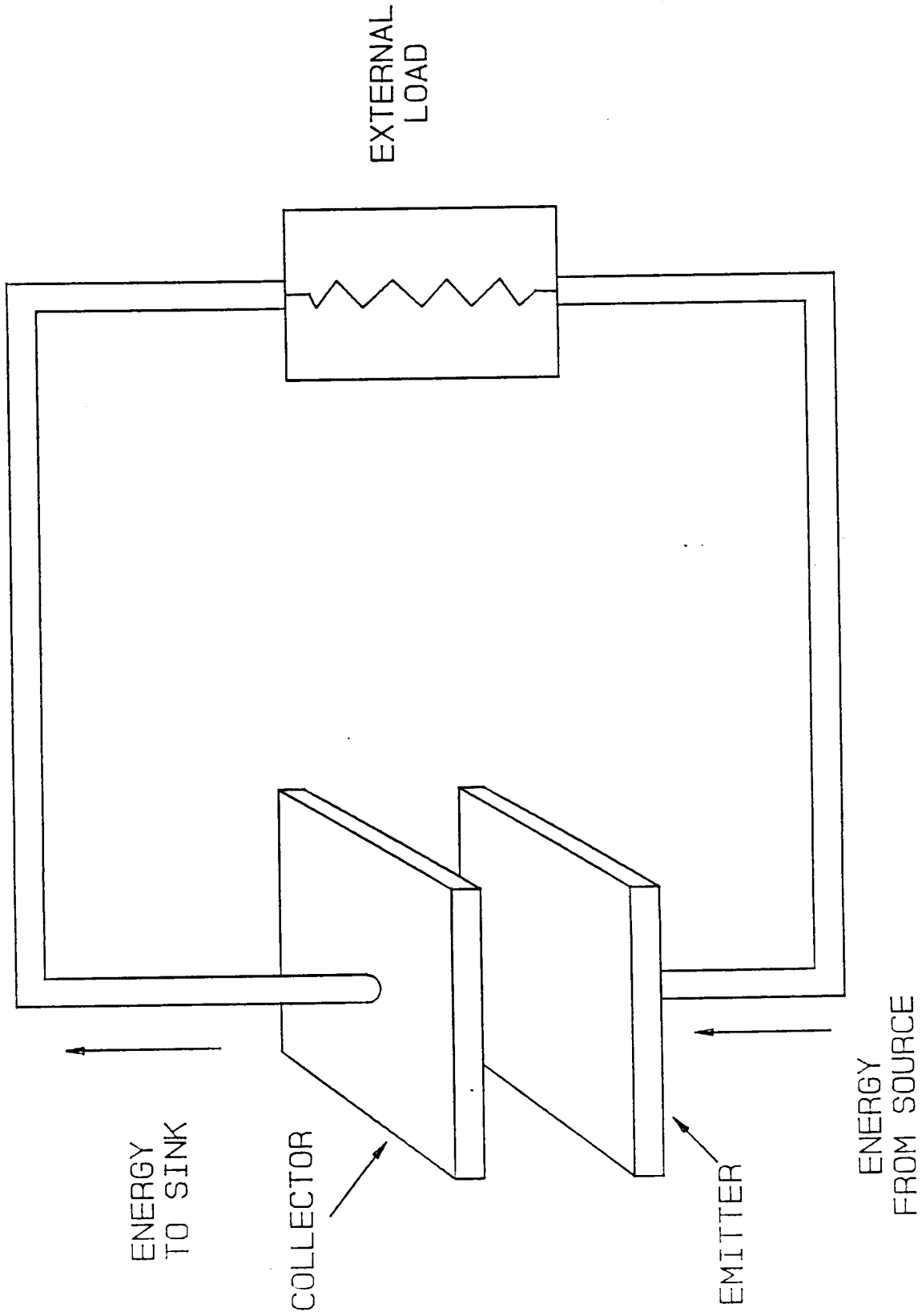
$$X = 1580 \text{ lb.}$$

Therefore, 1580 lb. of Silicon-Germanium thermoelectric multicouples will be needed to supply power to the PPF. The thermal energy for the MOD-RTG will be provided by the pyrolysis reactor.

24.3 Thermionic Generator

In its basic form for use on the Space Station, the thermionic energy converter consists of an external electrical load connected between a high temperature electrode (the emitter) and a low temperature electrode (the collector) (see Figure 2.21). The emitter and collector are separated by either a vacuum or a plasma. To overcome its own internal attractive forces, the emitter obtains a positive charge when a free electron acquires sufficient thermal energy from the heat source. The force required to overcome the internal force of the atom is called its surface work or its work function. When an atom's electron has gained energy equal to its work function, the electron will pass across the vacuum or plasma space. To enable an electron to pass from the emitter to the collector, the collector is constructed of material which has a higher work function. Therefore, the energy required to remove an electron from the emitter is less than the energy required to remove an electron from the collector. With an energy greater than the work function of the collector, electrons from the emitter pass to the collector resulting in a potential difference across the plates.⁵⁹ This potential difference is used to drive an external load.

The main problem with thermionic converters is that the electrons produce space charges in the area between the emitter and collector plates which reduce the overall efficiency. Presently, three methods of reducing⁵⁹ the space charges by introducing positive ions have proven effective:



Thermionic Generator 59

Figure 2.21

1. Low Pressure Diode
2. High Pressure Diode
3. Ignited Mode Converter

The low pressure diode method uses a gas between its plates which has a low ionization potential. It is important that the gas used has an ionization potential lower than the work function of the emitter because:

"as an atom of this gas strikes the hot emitter surface, the outermost electron of the gas becomes more strongly bound to the emitter and hence the atom leaves the emitter without its outermost electron; that is, the gas atom leaves as a positive ion."⁵⁹

If a low pressure, approximately 0.0001 mmHg, is maintained in the converter, then the electrons leaving the emitter will encounter a minimum number of collisions between electrons and ions. Cesium is the most commonly used element because it has a melting point of 301 K and a first ionization potential of 3.89 volts.

The high pressure cesium converter is similar to the low pressure diode except that the pressure has been increased from 0.0001 mmHg to 1.0 mmHg. This pressure increase causes random collisions between electrons and positive cesium atoms. Due to these collisions, the resistance in the space between the emitter and collector will increase, but the space charge is almost completely neutralized.⁵⁹

The ignited mode converter is presently the most popular method of space neutralization. This method uses an electron current to heat the cesium to a vapor:

"This method of operation is characterized by two distinct regions containing 'bright' and 'dark' plasma. In the dark region, the electrons do not have sufficient energy to ionize and excite significant numbers of cesium atoms. Neutralization occurs in this region via ion flow from the bright region. Electrons accelerated into this bright region over the emitter sheath have picked up sufficient energy to ionize and excite cesium atoms through inelastic collisions and so produce the bright discharge. Ions produced in this manner are sufficient not only to neutralize any existing negative space charge, but also to produce a strong positive space charge."⁵⁹

Due to the high operating temperatures of pyrolysis, incorporating thermionic converters is an extremely difficult technological feat. With current technology in material properties for emitters and collectors along with the advancements in additives in the cesium plasma, thermionic generators could play an important role⁵⁹ in the production of electrical power aboard the Space Station.

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24.4 Heat Pipe Rankine Cycle

The Heat Pipe Rankine (HPR) engine is a new concept for small scale power generation that uses the heat and mass transport of a heat pipe (see Figure 2.22). An HPR system consists of an evaporator section, an adiabatic section, and a condenser section (see Figure 2.23). Heat from the pyrolysis reactor is transferred into the evaporator section and removed from the condenser section. Power is generated by periodically shutting off the evaporation and condensation functions of the heat pipe by means of a mechanical thermal shutter external to the pipe. Periodic pressure variations generated by moving the thermal shutter between the evaporator and the condenser sections to block the heat transfer are used to produce the power. Vapor generated at the evaporator section flows to the condenser section due to the lower pressure in that area. The condensed liquid is returned to the evaporator section by capillary effects of the wick structure at the inner wall of the heat pipe. If a turbine is placed in the vapor flowing between the evaporator and the condenser, the pressure difference across the turbine can produce mechanical work.⁵⁸

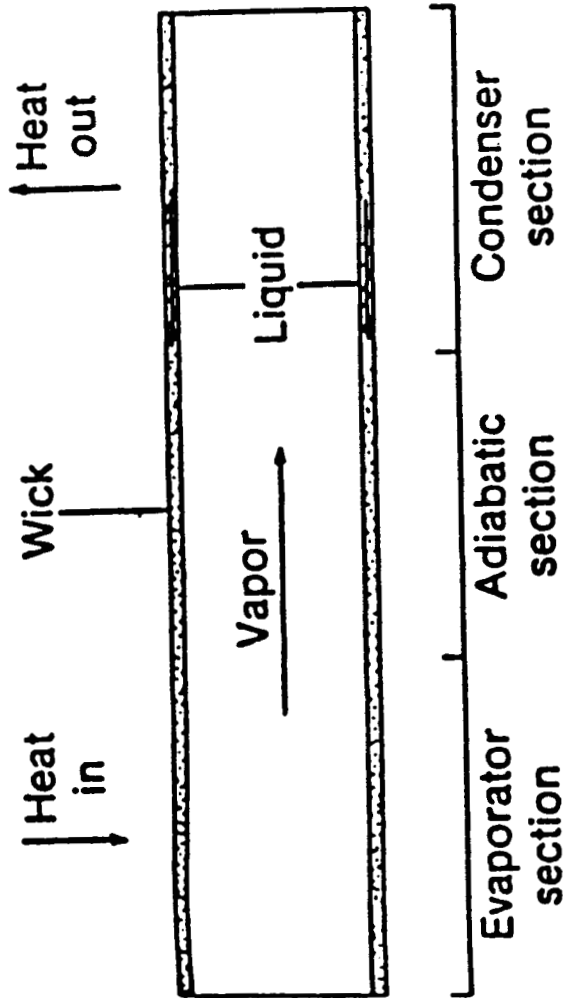
The pressure difference between the evaporator and the condenser sections is nominal when a turbine is inserted into the vapor stream. Also, the capillary effects may not be sufficient to return the working fluid to the evaporator section. Therefore, a liquid pump powered by a small part of the mechanical work delivered by the turbine shaft can be employed for this purpose.⁵⁸

24.5 Electrostatic Parametric Generator

The Electrostatic Parameter Generator (EPG) is designed for the conversion of mechanical work into electrical energy for aerospace purposes:

"A circuit containing a sinusoidally mechanically varying capacitance and an inductance converts mechanical energy into electrical energy in the form of voltage oscillations as Mathieu functions. Introduction of a nonlinearity into the circuit produces a poicare limit cycle in the form of an ellipse thus transforming the Mathieu function into sinusoidal voltage oscillations. A model has been built. It delivers 1050 volts at 400 cycles sinusoidal a.c. Calculations show that the weight of the generator is about 1/20 of that of a usual generator."⁶²

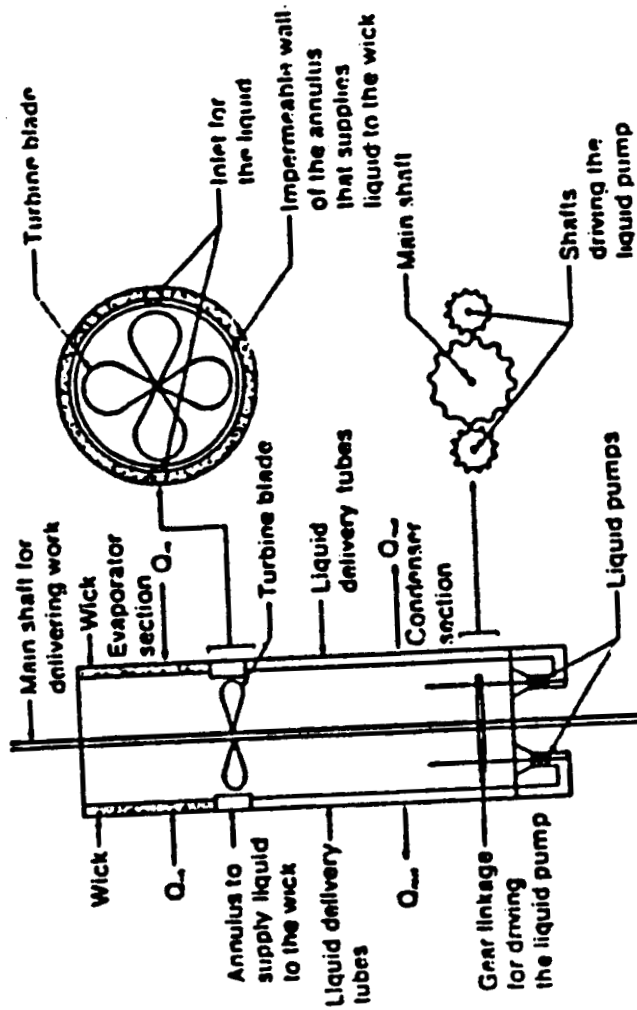
A simple laboratory model for the parametric generator is illustrated in Figure 2.24. The generator consists of a capacitor (1), with a periodically variable capacitance, and an inductance coil (2), with a core (3) of ferromagnetic material. The capacitor consists of several stator plates (5) and rotor plates (6) each containing conducting and nonconducting sectors. The rotor plates are carried by an electrically conductive material connected to the shaft (7) which is driven by a mechanical drive (8). The stator plates are held by



Heat Pipe 58

Figure 2.22

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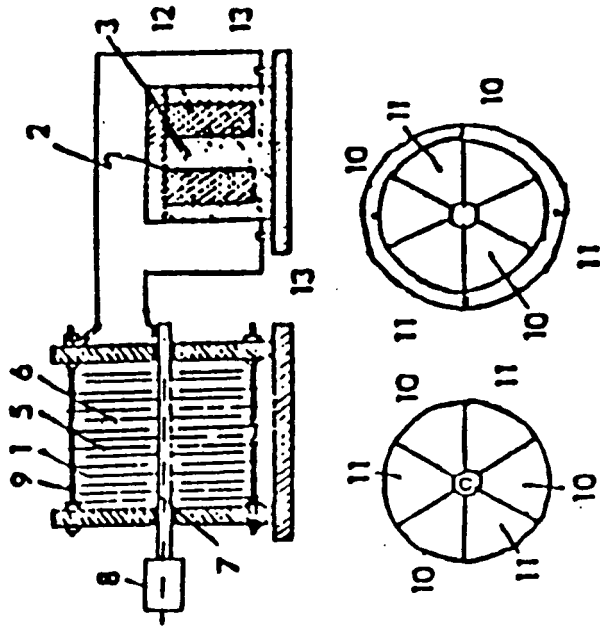


Heat Pipe Rankine Cycle Schematic 58

Figure 2.23

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1. Capacitor
2. Induction coil
3. Core; IC
5. Stator plate
6. Rotor plate
7. Shaft
8. Mechanical drive
9. Conducting rod
10. Sectors
11. Sectors



Parametric Generator Laboratory Model ⁶²

Figure 2.24

electrically conductive rods (9). The sectors (10) of the plates (5 or 6) consist of electrically conductive material such as copper or aluminum and sectors (11) are made of electrically insulative material. As the rotor plates rotate, the capacitance $C(t)$ of the capacitor varies periodically as a function of time. "The model delivers 1050 V of sinusoidal a.c. at 350 and for higher rpm even 750 cycles."⁶²

Extensive studies have involved the construction of an industrial model of the EPG for space use and comparisons to the regular electromagnetic model. The following parameters have been taken into account:⁶²

1. Viscosity, density, vapor pressure, resistivity and loss factor.
2. Efficiency of energy conversion.
3. Weight.
4. Power.

Consideration of these parameters led to the following facts:⁶²

1. The EPG is best suited for space.
2. Efficiency is decreased with power such the 0 to 150 kW is the domain for generator use.
3. The EPG is only 13.25% of the weight of a typical electromagnetic generator.
4. An EPG has a power of 2.75 times that of a typical electromagnetic generator.

Chapter 25. RECYCLE/REUSE OPTIMAL SOLUTION - PHASE II

25.1 Solution Discussion

Careful consideration of all refuse reduction systems and their feasibility for space use yielded the "Muffin Monster" as the optimal choice according to Solution Matrix 2.2 of Appendix A. The "Muffin Monster" derived its unique name from its ability to reduce waste by utilizing a counter-rotating shredder system (see Figures 2.11-15). This shredder system, which includes a transport system, has been specifically designed for space application (see Figures 2.14 and 2.15).²⁶ In contrast to the other refuse reduction systems, the "Muffin Monster" has the ability to process or reject glass, metal, and ceramics without harming or stopping the system. Also, the shredder is not dependent on liquids for processing or transport yet is able to handle both slurried and dry materials. The counter-rotating blades help minimize jamming as well as vibrational effects which is an important consideration for the sensitive orientation of the space station.²⁶

Considering the pyrolysis reactor systems, two rated relatively well in comparison to the others in Solution Matrix 2.3--the cyclonic entrained-flow reactor and the hot wire reactor. Although the hot wire

reactor possesses excellent pyrolysis capabilities for use on the Space Station, the process is still in the experimental stages and thus is not yet technically feasible.⁵⁶ Therefore, cyclonic entrained-flow remains the most optimal pyrolysis reactor system at this time. This reactor concept involves pyrolyzing waste at high velocities through an externally heated vortex tube (see Figure 2.19). Because the reactor creates its own gravitational environment, no functional problems due to lack of gravity are foreseen. The refuse particles are sufficiently heated due to the frictional heat of the high speed particles against the already heated cyclone wall such that no external heat source is required (which helps minimize power requirements). The by-products from this reaction consist of 73% gas which can be condensed into very useful fuel, 15% H₂O vapor, and only about 12% char.⁵⁶ As previously discussed, the fuel produced could possibly be used as rocket fuel to help reboost the Space Station.⁵⁶ Also, the reactor has a very high processing rate of 46.2 lb./hr.⁵⁶ Considering this rate with the PPF operating 24 hrs/day, 365 days/yr., approximately 404,712 lb./yr. could theoretically be processed. This amount of recycled refuse is more than an order of magnitude greater than the estimated 40,000 lb./yr. of refuse generation for the Space Station.⁵⁶

According to the Solution Matrix 2.4 for power generation, the most recommended system involves a combination of the HPR and EPG generating systems. The HPR system involves small scale Rankine cycle power generation via evaporator, adiabatic, and condensor sections (see Figure 2.23). A turbine can be placed within the vapor stream between the evaporator and condensor to produce mechanical work.⁵⁸ At this point, an EPG can be introduced to convert this work into electrical energy. The EPG system, specifically developed for aerospace application, is a circuit containing mechanically varying capacitance and inductance which transforms mechanical energy to electrical voltage oscillations (see Figure 2.24). This generator is advantageous for space use in that it is only 13.25% the weight of and produces 2.75 times the power of a typical electromagnetic generator.⁶² Thus, the HPR system can make use of exhausted heat from the pyrolysis reaction while the EPG system supplies the PPF system sufficient operational electrical energy.

25.2 Solution Summary

In summary, the refuse recycle/reuse system will consist of a self-supporting pyrolysis processing facility which houses a refuse size reduction station, a pyrolysis reactor, and a power generation system (see Figure 2.9). The following choices have been made for each major component of the PPF:

- I. Refuse Reduction: "Muffin Monster" Shredder
- II. Pyrolysis Reactor: Cyclonic Entrained-Flow Reactor
- III. Power Generation: Heat Pipe Rankine Cycle/Electrostatic Parametric Generator Combination

Chapter 26. RECOMMENDATIONS FOR FURTHER STUDY

In order to proceed with a more detailed study of the Space Station's PPF subsystem, the following areas of investigation are suggested:

1. A detailed cost analysis of the PPF needs to be evaluated (This task was neglected due to time restrictions).
2. Knowing that rocket performance is optimized with fuel-rich stoichiometries and is a strong function of the flame temperature and gaseous combustion-product molecular weight, an in-depth computer study is suggested to determine the relative merit of pyrolysis oil as a rocket fuel. It is interesting to note that rocket performance using the pyrolysis oil should be based on seconds of thrust per lb. of oxygen (not oil plus oxygen) since organic wastes used to make pyrolysis oil can be considered as having already⁴⁵ been lifted into orbit and on board the Space Station.

SECTION III. REFUSE JETTISON VEHICLE

- * Structural Design Alternatives
- * General Design Requirements
- * Effects of Atmospheric Reentry

SECTION III. REFUSE JETTISON VEHICLE SUBSYSTEMINTRODUCTION

The main objective of the refuse management system of the Space Station is to recycle and reuse a maximum of refuse materials. However, those materials which cannot be recycled must be disposed of efficiently. For the required station disposal system, a jettison vehicle is proposed to transport refuse to a designated disposal site (disposal sites discussed in Section IV, Part II). In order to design an effective vehicle, many factors must be considered. First, the basic structure of the vehicle, be it rigid or collapsible, must be determined. Once this has been established, various vehicle shapes, materials, structural components, and capacities must be studied. Methods of loading the vehicle with trash and vehicle transport to the Space Station must also be investigated. Finally, how the vehicle integrates with the refuse management system is important as well.

The most obvious design consideration is the vehicle's shape. For a given volume, the shape determines the surface area of the vehicle. Thus, in maximizing the volume and minimizing the amount of material needed to construct the vehicle, the surface area is minimized. Also, the construction cost, which must be minimal as well, is dependent on the complexity of shape. Certain shapes can also determine how efficiently a vehicle can be filled with refuse. Consequently, an increase in packing efficiency leads to the requirement of a smaller vehicle or fewer vehicles per given time interval.

When selecting the material used to construct the vehicle, many qualities need to be explored. Spacecraft experience significant temperature cycling while passing through the light and dark stretches of their orbit. Therefore, the material needs to retain its important properties after many thermal cycles. The space environment is also characterized by a vacuum and intense radiation. Thus, the material must also be resistant to the degradation possible from these factors.⁶⁴ Material thickness and strength are among the most important qualities to be optimized to prevent destructive punctures and tears caused by meteors and space debris. Lastly, the material must be fracture resistant in order to survive launch acceleration and vibration.⁶⁵

The vehicle's capacity is a factor that plays an important role. Its capacity is a function of the amount of garbage generated at the Space Station that needs to be destroyed. To determine the volume more directly, the extent of trash compaction must be known. How many times the vehicle will be jettisoned for atmospheric reentry and how much mass the reentry launch system can transport also need to be figured in the capacity calculation. Finally, the size of the vehicle must be designed such that it is able to be efficiently transported to the Space Station. Once at the Space Station, the vehicle must also be properly equipped with mechanisms for its transfer and attachment to the refuse loading site.

Jettison Vehicle

Therefore, the purpose of this report is to determine the general design of the jettison vehicle, how many are needed, and how it is to be transported to the Space Station. Furthermore, how it functions during atmospheric incineration is investigated. Pollution effects to the Earth's environment are determined and the possibility of human impact due to incomplete incineration is explored to evaluate the feasibility of this disposal alternative (see Section IV, Part II for more on atmospheric incineration and other alternatives).

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JETTISON VEHICLE DESIGN

In order to converge upon a final vehicle solution, this study is divided into three main parts:

1. Structural Design Alternatives
2. General Design Requirements
3. Effects of Atmospheric Reentry

Chapter 27. STRUCTURAL DESIGN ALTERNATIVES

The designs considered for the high drag jettison vehicle fall into two main categories:

1. Collapsible Design
2. Rigid Design

The flowchart of Figure 3.1 summarizes all of the proposed jettison vehicle designs of both categories.

27.1 Collapsible Vehicle Designs

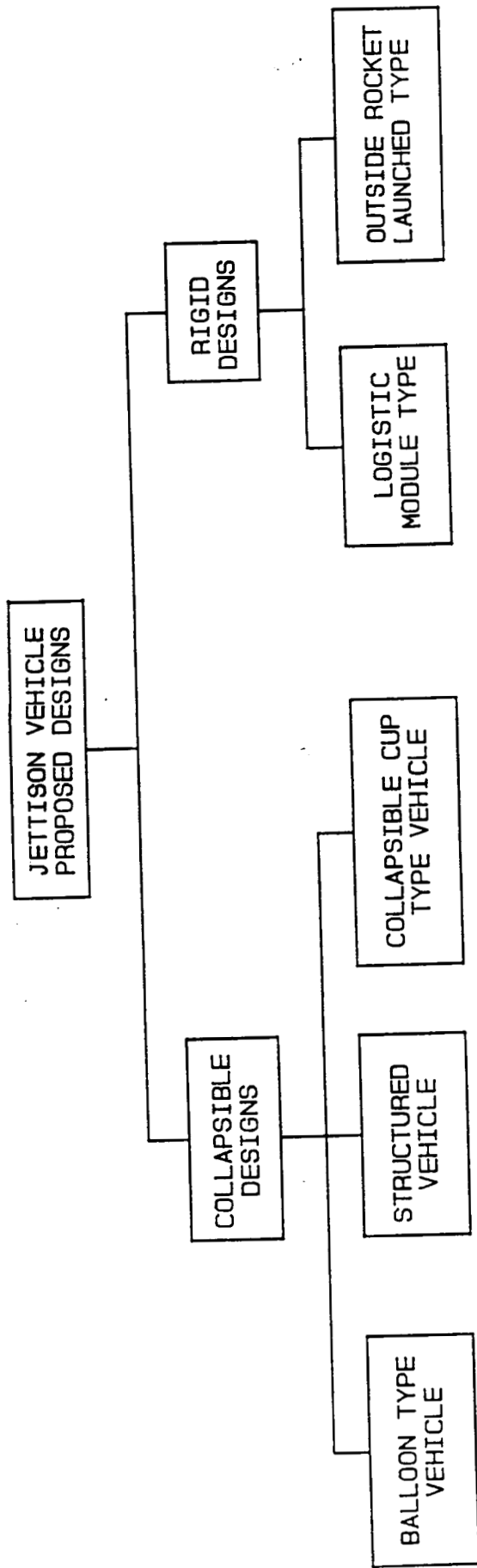
Three collapsible designs were investigated. The first design is a balloon type structure which can be deflated and packaged tightly to minimize cargo space within the Space Shuttle. Upon its arrival to the Space Station, this balloon-like jettison vehicle is removed in its deflated state by the manipulator arm. It is then placed into a desired location where it is inflated into a specified shape (see Figure 3.2).

The second collapsible design is also a balloon type vehicle, however, it possesses an internal support frame structure. This vehicle also has the capability of being deflated for shuttle transport to the Space Station. At the station, it is also removed by the manipulator arm, placed into a desired location, inflated, then its frame structure is locked into a specified shape (see Figure 3.3).

The third collapsible type is unlike the two previously discussed. It is constructed of a lightweight metal and capable of expanding and contracting into itself, similar to a collapsible drinking cup (see Figure 3.4). Similar to the other collapsible vehicles, this cup-like structure is collapsed into itself during shuttle transport, removed by the manipulator arm, placed into a desired location, and mechanically expanded and locked into a desired shape.

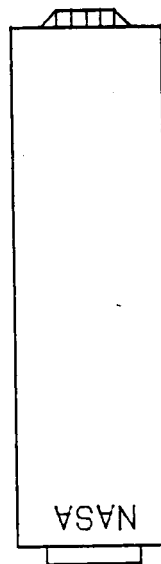
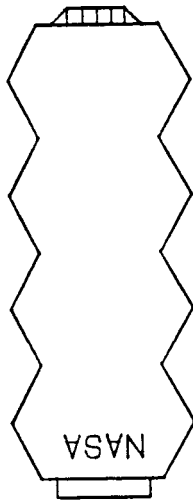
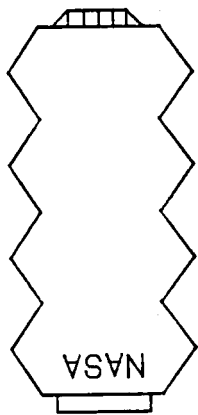
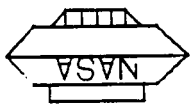
27.2 Rigid Vehicle Designs

Opposing the collapsible type vehicles are two rigid designs. These two rigid designs are similar in construction, however, they vary in how they are transported to the Space Station. The first rigid



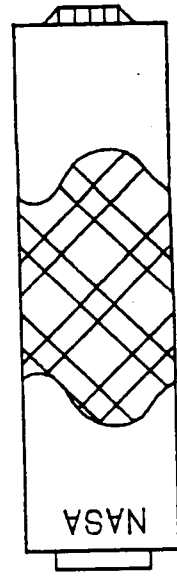
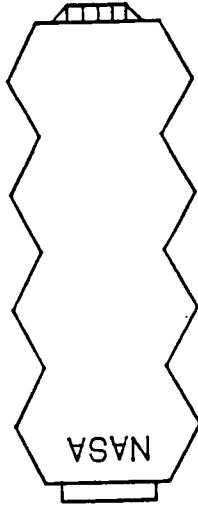
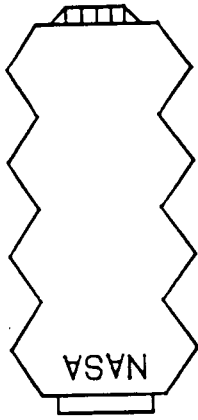
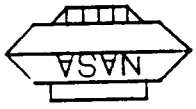
PROPOSED REFUSE JETTISON VEHICLE DESIGNS

Figure 3.1



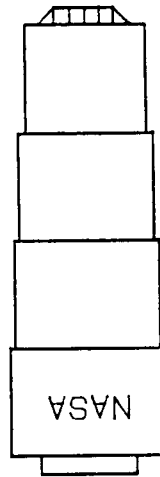
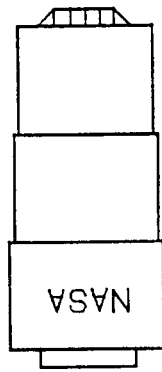
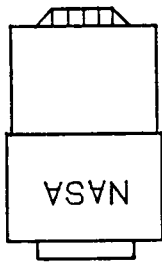
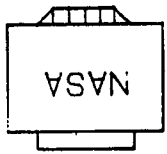
PRESSURIZATION OF BALLOON-TYPE VEHICLE

Figure 3.2



EXPANSION OF INTERNALLY STRUCTURED VEHICLE

Figure 3.3



EXPANSION OF COLLAPSIBLE-CUP TYPE VEHICLE

Figure 3.4

Jettison Vehicle

vehicle consideration is a logistics module type (see Figure 3.5). This vehicle would not replace the existing logistics module, but serve the same purpose in the shuttle's cargo bay. It is a much less sophisticated design than the logistics module, yet capable of transporting needed supplies and materials to the Space Station. At the Space Station, the manipulator arm would remove all the supplies and materials. The the arm would remove the empty vehicle and place it into a desired location for refuse deposit.

The second rigid type is similar in construction but launched by an unmanned expendable rocket, such as a Titan IV commercial rocket (see Figure 3.6). This outside launched vehicle (OLV) is completely assembled on Earth and is to contain needed support and equipment to maintain the refuse disposal system. After entering orbit, this vehicle is retrieved by the Orbital Maneuvering Vehicle (OMV) which completes its transport to the Space Station. At the station, the vehicle is emptied of its contents and placed into a desired location to serve as part of the refuse disposal system.

Chapter 28. GENERAL VEHICLE DESIGN REQUIREMENTS

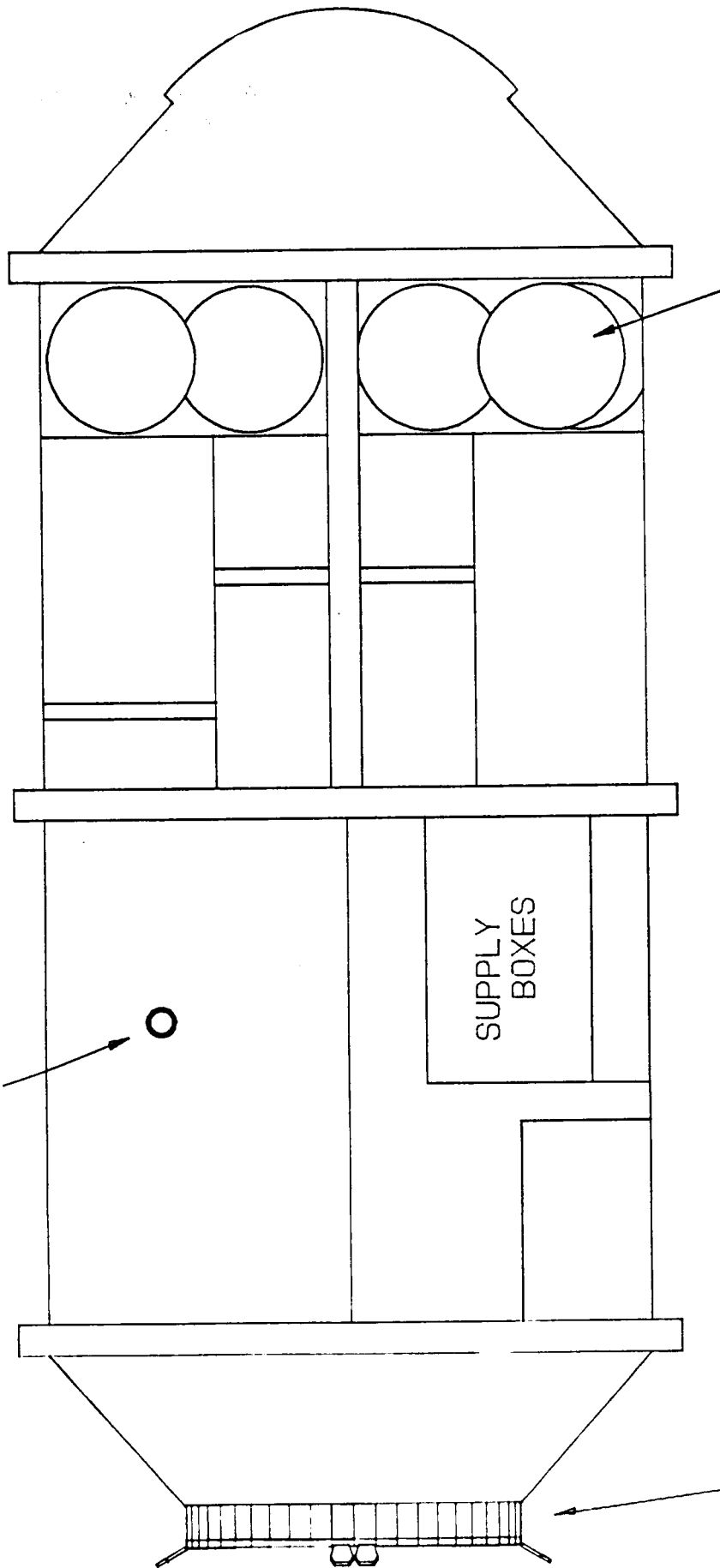
The jettison vehicle used for the atmospheric incineration of Space Station refuse must conform to many constraints. First of all, the vehicle must be as small as possible to minimize the cost of its transportation to the Space Station. However, while employed, the vehicle must have a high volume capacity to accommodate months of accumulated refuse. This is coupled with the necessity of minimizing the complexity of the vehicle and overall system. The structure of the vehicle must endure accelerations imposed by an Earth surface lift-off. Also, its material must withstand the harsh space environment imposed during orbit. This includes large fluctuations in temperature, high ultraviolet radiation, large pressure gradients, and space debris impacts. Finally, the jettison vehicle should integrate simply and efficiently with all aspects of the Space Station and the proposed refuse management systems. With these constraints in mind, the following vehicle configurations are presented:

1. Vehicle Shape
2. Vehicle Size
3. Vehicle Structural Components

28.1 Vehicle Shape

Design of the vehicle with respect to shape is of great importance. The proper shape to allow for complimentary utilization, storage, manipulation, and transportation of the jettison vehicle was investigated in detail. Another significant consideration is which shape yields the most favorable thermodynamic response during atmospheric reentry. Taking these factors into account, various

GRAPPLE
FIXTURE



BERTHING
MECHANISM

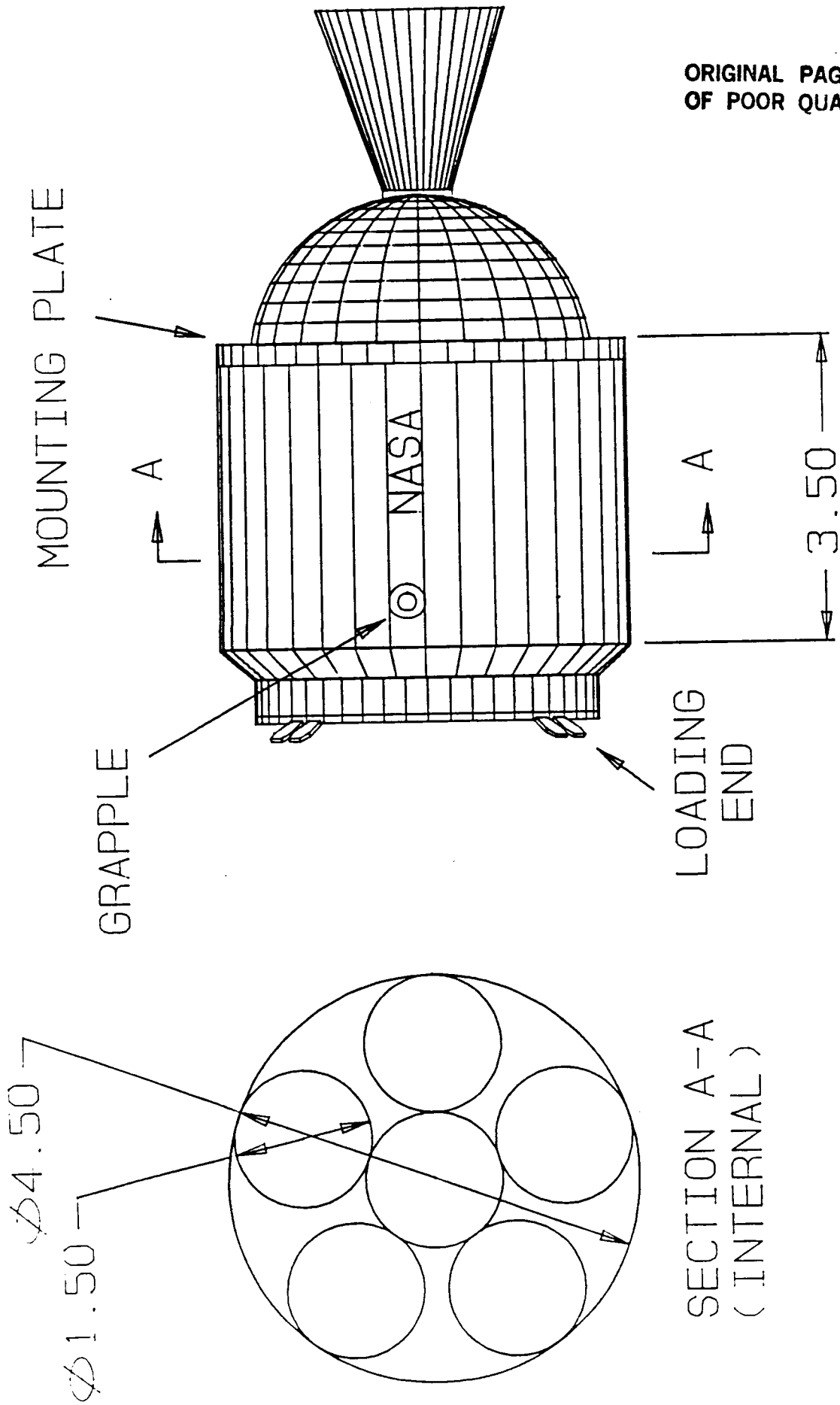
EXTERNAL
LIQUID O₂
AND N₂ TANKS

SUPPLY
BOXES

COMMON CONTAINER STRUCTURE (PRESSURIZED)

Figure 3.5

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OUTSIDE ROCKET LAUNCHED VEHICLE

Figure 3.6

shapes were subjected to two different tests: one for volumetric efficiency, and one to determine the amount of drag resistance.

In order to evaluate volumetric efficiency, each shape was assigned a volumetric efficiency coefficient. For comparison, the lower the value of the volumetric efficiency coefficient, the more favorable the shape with respect to refuse capacity. This coefficient (E_v) is calculated in the following manner:

$$\text{Total Surface Area (ft.}^2\text{)} = A_T$$

$$\text{Total Volumetric Capacity (ft.}^3\text{)} = V$$

$$A_T / V = E_v \quad (3.1)$$

Table 3.1 lists the shapes under consideration along with their approximate E_v values.⁷⁸ Note that several shapes could be eliminated due to the difficulty of design and manufacturing alone.

The next test involves how well the shape induces drag through high-speed flight. The higher the coefficient of drag (C_D), the greater the resistance during atmospheric reentry, and thus the greater the incineration rate. Each approximate value of C_D , determined with respect to vehicle velocity, shape, size, and atmospheric altitude, is also listed in Table 3.1.⁷⁹ These parameters correspond to a Reynolds Number which increases directly with the velocity of the vehicle through the atmosphere. For sample Reynolds Number calculations, see Appendix C. Note that the given drag coefficients are empirical, and should be reinforced with substantial laboratory experimentation. Given the information in Table 3.1, it is clear that either a hexahedron or a cylinder-like shape jettison vehicle would provide adequate atmospheric resistance at high speeds to ensure total refuse destruction.

Table 3.1 COEFFICIENTS FOR OPTIMIZATION OF SHAPE

<u>Shape</u>	<u>E_v</u>	<u>C_d (R > 104)</u>
Hexahedron	8.6	1.1 - 5.0
Tetrahedron	14.7	1.4 - 2.0
Octahedron	10.4	0.3 - 1.0
Dodecahedron	9.3	0.2 - 0.9
Sphere	8.1	0.1 - 1.0
Cylinder (L/D = 0.5)	51.4	1.2 - 5.0
Cylinder (L/D = 1.0)	22.0	0.9 - 4.0
Cylinder (L/D = 3.0)	30.0	0.8 - 3.9

Jettison Vehicle

28.2 Vehicle Size

The most important factor in determining the size of the jettison vehicle is the amount of refuse it is to contain. It is estimated that 40,000 pounds of refuse will accumulate on the Space Station every year. In addition to this data, the approximate density of the refuse, assuming no compaction, must be determined to accurately estimate the required volume and in turn, the dimensions of the vehicle. Subsequently, Graph 3.1 has been created, based upon an estimated average refuse density of 7 lb./ft.³, to determine the deployment frequency of a jettison vehicle as a function of various volume capacities.

28.3 Vehicle Structural Components

The structure of the jettison vehicle is separated into four necessary components:

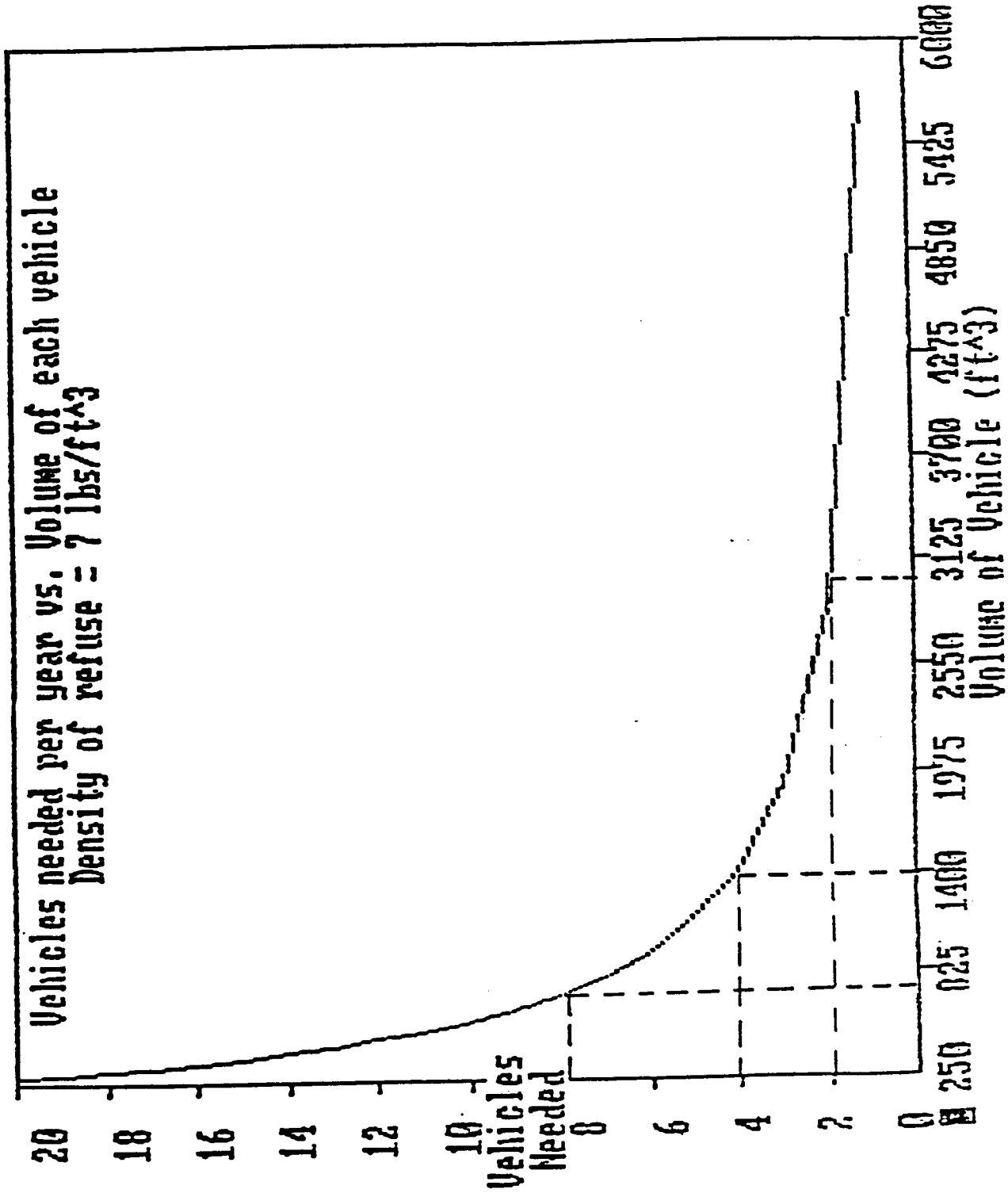
1. loading hatch
2. propulsion system mounting plate
3. handholds and grapple fixtures
4. material compositions

28.3.1 Loading Hatch

The vehicle must have a loading port, which is defined as the hatch into which refuse material is loaded. If the vehicle's design requires attachment to a Space Station node and pressurization, a flex pressurized berthing hatch is recommended (see Figure 3.7).⁶⁶ Other features include a base plate, cable/pulley structural restraints, utility transfer hatch, berthing ring, and capture guides and latches. The berthing ring and base plate are separated by rubber bellows to allow for a slight away of the vehicle with respect to the space station. For safety purposes, a pressure gauge should be mounted on the berthing mechanism to detect atmospheric leaks. If the vehicle's design requires nodal attachment but no pressurization, an unpressurized rigid berthing mechanism is recommended (see Figure 3.8).⁶⁶

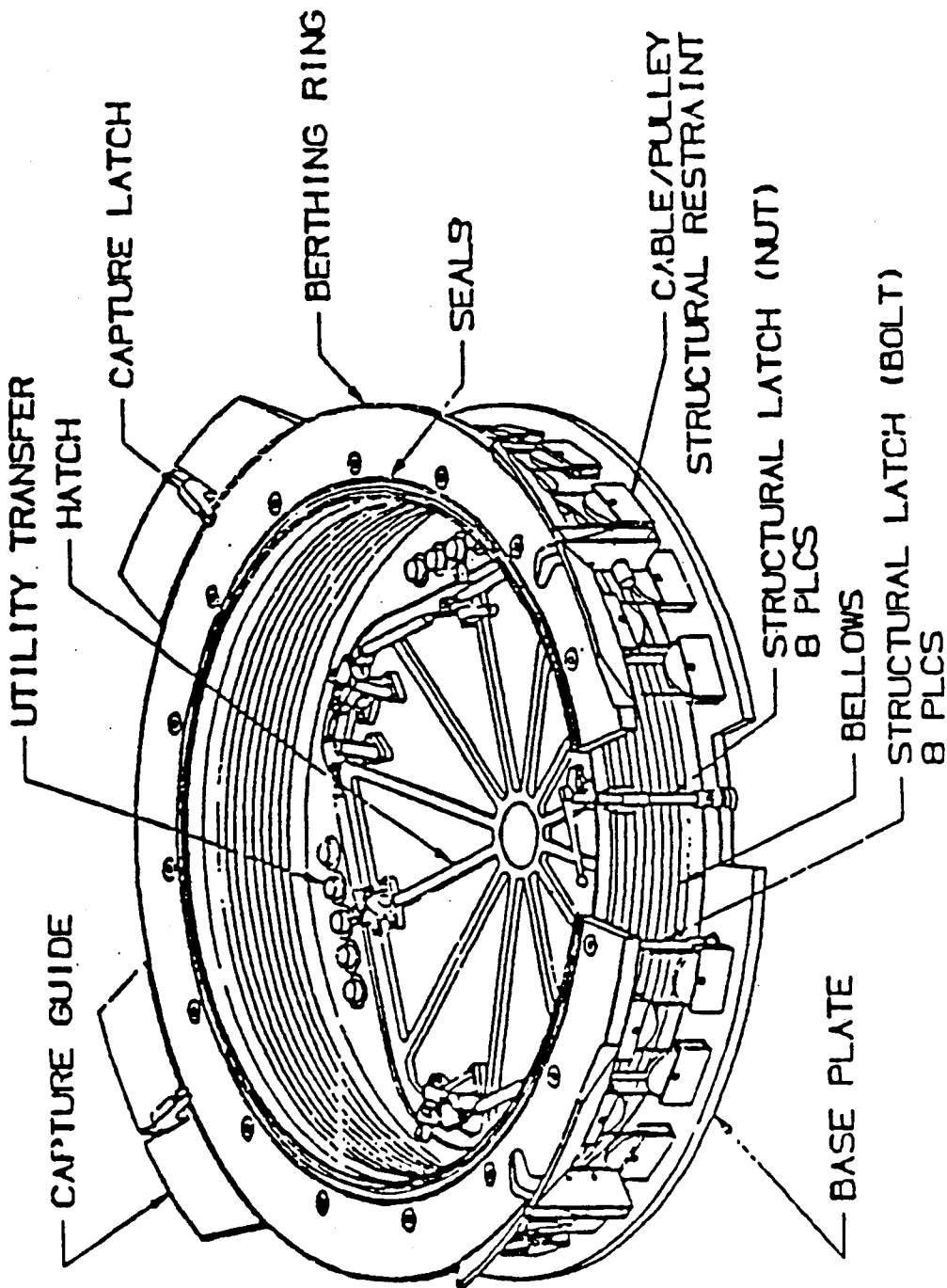
28.3.2 Propulsion System Mounting Plate

The chosen design should also include a propulsion system mounting plate. This is defined as a reinforced plate on the jettison vehicle to which the proposed propulsion system is mounted. If the propulsion system attachment is to be accomplished at the Space Station, it is recommended that the mounting plate be designed as a twist and snap assembly to eliminate unnecessary EVA.



Vehicle Deployment Frequency Per Year

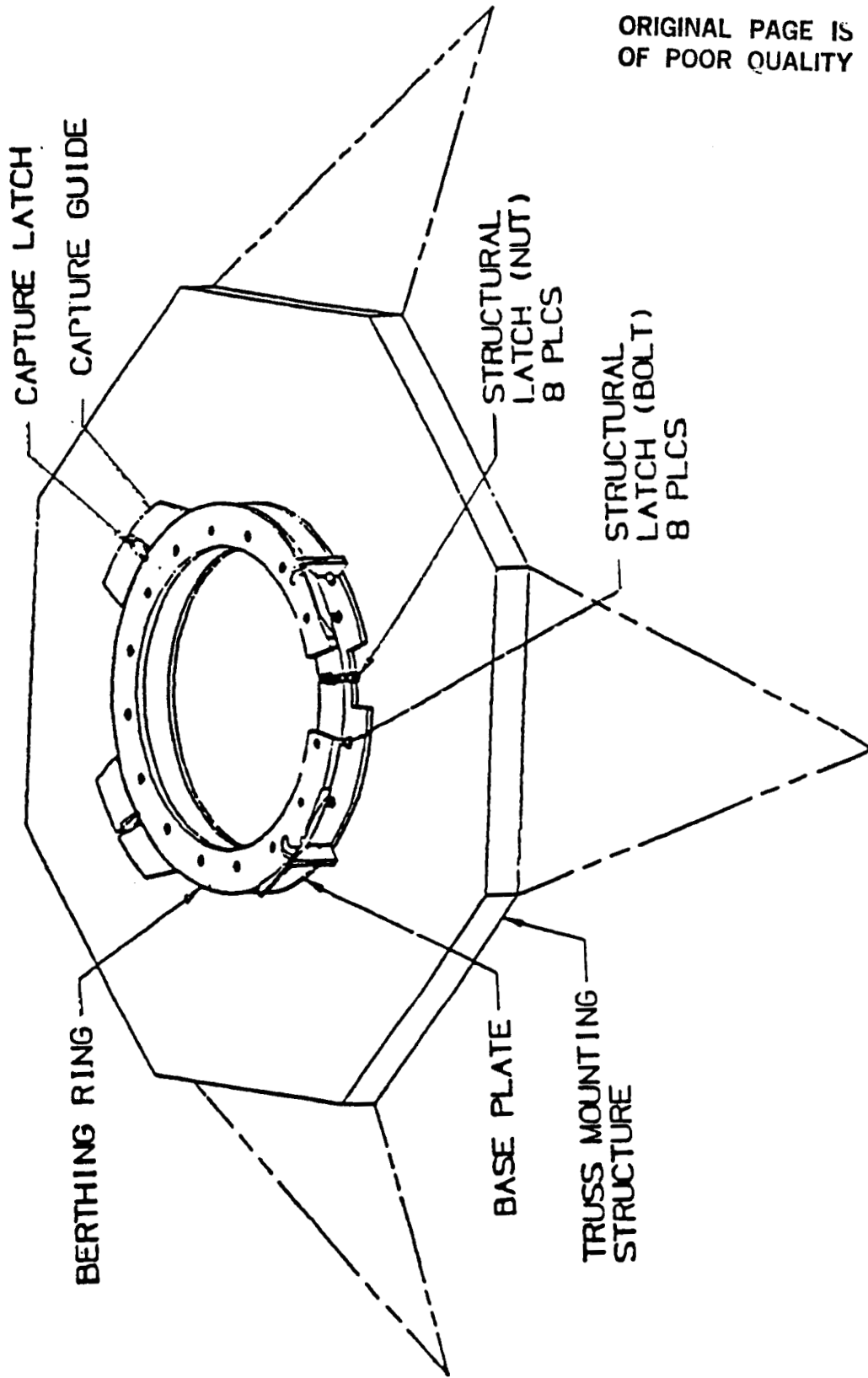
Graph 3.1



Flex Pressurized Berthing Mechanism 66

Figure 3.7

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Rigid Unpressurized Berthing Mechanism 66

Figure 3.8

Jettison Vehicle

28.3.3 Handholds and Grapple Fixtures

Also important to the design are handholds and grapple fixtures. A grapple fixture (see Figure 3.9) would be used to maneuver the jettison vehicle around the Space Station via the remote manipulator arm.⁶⁷ This fixture could be placed along the jettison vehicle's center plane of mass, or one at each end. If located at the center plane of mass, possible vehicle rotation about the fixture could be a problem. Handholds should also be placed on each end of the vehicle to allow an astronaut to maneuver the vehicle.

28.3.4 Material Compositions

The most basic component of structural design is material selection for manufacturing. This material composition includes the hardware listed above as well as the skin of the jettison vehicle. The chosen material must be able to survive the harsh, constantly changing, orbital environment. Other areas of concern include the vacuum effects upon material. A vacuum provides no pressure to keep molecules from escaping or subliming. The effects of sublimation⁶⁸ of a particular material, G , in a vacuum can be calculated by:

$$G = (P * M / T / 17.14) \text{ grams/m.}^2\text{sec} \quad (3.2)$$

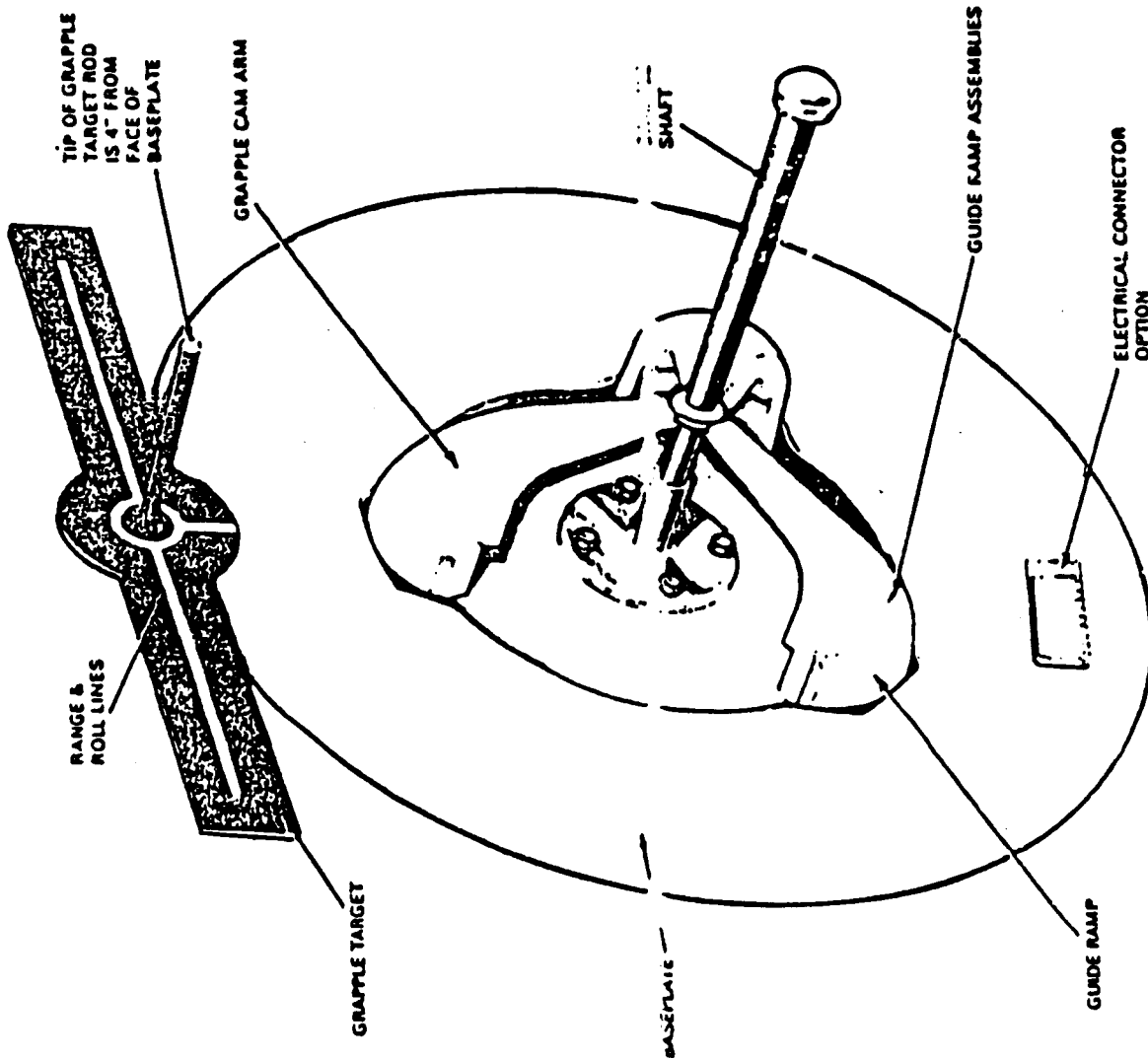
where M = molecular weight
 T = absolute temperature, K
 P = vapor pressure at T , mmHg

Studies have shown that a material's loss due to sublimation in space is insignificant provided the material's temperature does not exceed two-thirds of the material's melting point. Sublimation effects can be avoided if⁶⁸ plastics, resin or super-polymers are used to construct the vehicle.

The material must also withstand the stresses and forces imposed during launch accelerations. A material with a high strength to density ratio would be advantageous. This ratio is determined by finding the length at which a vertical column of material fails under its own weight.⁶⁹ This ratio is often referred to as the specific strength of the material.

A meteor impact protective material should be used for the outside covering of the jettison vehicle. Space debris commonly travels at speeds around 20,000 to 30,000 ft./s. Materials such as porous nickel alloys have shown success in resisting 5 milligram particle impacts traveling at speeds in excess of 25,000 ft./s. The weight of this porous nickel protective covering⁷⁰ is about 900 pounds for a sheet 1,000 square feet by 1 inch thick.

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Grapple Fixture and Target Assembly 67

Figure 3.9

To promote favorable thermodynamic response during atmospheric reentry, it is recommended that a material with a high coefficient of thermal conductivity be employed. Such values should be in the neighborhood of $k = 175 \text{ W/m-degC}$. Materials that fall into this category are copper, magnesium, and aluminum. Magnesium is a very attractive material for the construction of the internal structure of the vehicle. Magnesium is thermally responsive, strong, lightweight, and maintains rigidity during loadings. It also has a relatively high inflammation rate which would promote thorough incineration during reentry.⁶⁹ However, the cost of magnesium is about four times that of aluminum.⁷¹

Chapter 29. EFFECTS OF ATMOSPHERIC REENTRY

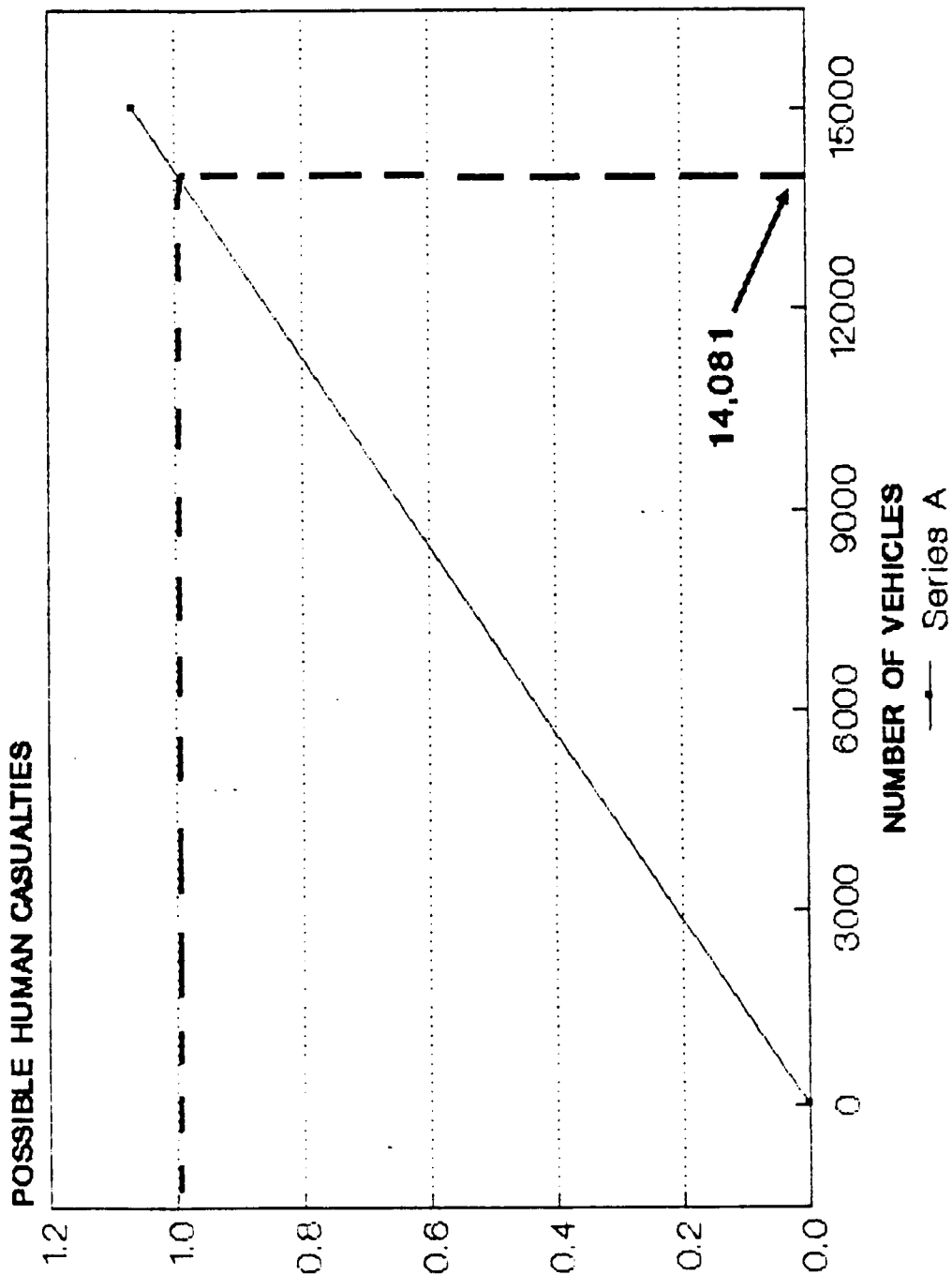
In addition to the design, the effects of atmospheric reentry were also considered. The following possible consequences of atmospheric incineration were studied (see Section IV, Part II for disposal site discussion and selection):

1. Risk of injury due to debris impact on Earth.
2. Environmental hazards.

29.1 Injury Risk Due to Debris Impact On Earth

Although the intention is for complete vaporization of the OLV and its contents upon reentry, there is always the possibility that total incineration will not occur. In consequence to incomplete combustion, solid material can plummet to the Earth's surface. The analysis for debris impact was performed as a worst case scenario--poor atmospheric incineration and human fatality as a result of any impact. The result of these two worst case assumptions allowed for the use of a simple probability calculation (see Appendix C). This calculation made use of the OLV to earth surface area ratio (OLV dimensions given in Chapter 30, Solution Discussion) and the population of the Earth.⁸⁰ The size and number of the proposed OLV's are directly proportional to the probability of human impact. Graph 3.2 was generated to serve as a quick reference to the estimated human impacts with respect to the number of OLV's launched for incineration. According to this graph, approximately 14,081 OLV's would have to be launched in order to achieve the possibility of one human impact, at worst case. Clearly, this is a very low possibility.

GRAPH OF VEHICLES .VS. CASUALTIES



Probability of Human Casualties from Reentry Incineration 80

Graph 3.2

29.2 Environmental Effects

Another important effect of atmospheric incineration is what happens to the Earth's environment. The OLV is to transport a variety of refuse materials, excluding biological wastes. These materials include paper, plastics and other polymers, metals, rubbers, ceramics, and textiles. As stated earlier, it is intended for the entire OLV and its contents to incinerate completely into a vapor form. Temperatures associated with reentry range from 5,000 degK to 13,000 degK.⁸¹ These excessive temperatures are essential for prompt and complete combustion. However, complete atmospheric combustion is accompanied by one major drawback--the emission of toxins and compounds into the air which may adversely effect the ecosystem and mankind upon the Earth's surface. Ideally, the products of complete combustion are carbon dioxide and water with small quantities of sulfur dioxide and nitrogen. Some of the nitrogen is converted to oxides, with nitric oxide as the predominant product. Small amounts of sulfur found in the refuse may become sulfur trioxide upon contact with sulfur dioxide in the atmosphere. Other non-combustibles in the refuse also partially oxidize under the influence of excessive heat. Usually, the results of this process consist of aluminum and iron oxides which are not considered hazardous to man or animal life.⁷⁶

Chemical analysis of refuse and the incineration process has established amounts of air or oxygen required for complete combustion. Any air fed to the process that is not needed for complete combustion is classified as excessive air. If the waste is packaged tightly in containers that receive insufficient amounts of oxygen, smoke is produced. This smoke contains liquids and solids in a dispersion of droplets and particles. These fine droplets or aerosols are actually vaporized liquids produced by the heating of combustible material in the refuse. The dispersion of aerosol droplets leads to harmful and unwanted deposits in the atmosphere.⁷⁷ Where combustion is incomplete, fine ash, flakes, and carbonaceous particles are released. Altogether, this particulate matter is a mixture of harmless mineral ash, carbonaceous solids, and similar materials. Over 99.9 percent of the gases from incineration are normal constituents of the atmosphere: water vapor, carbon dioxide, oxygen, and nitrogen. The combined total of the other gases would not normally exceed 0.077 percent.⁷⁷ However, there are a few noxious gases that make up that small percentage:

1. Carbon Monoxide
2. Nitrogen Oxides
3. Sulfur Oxides

A summary of these pollutants and their effects is presented in Table 3.2

SUMMARY OF POLLUTANTS AND THEIR EFFECTS

Pollutant	Cause	Effects on:			
		Human health	Plants, animals	Materials	Other
Particulates	Burning coal, crushing, grinding	Bronchitis, emphysema, cancer, etc.	Damage to leaf structure, toxic effects	Soiling, corrosion	Haze, smog
SO ₂	Burning any fuel with sulfur, processes using liquid SO ₂ or H ₂ SO ₄	Acts with particulates (synergism)	Necrosis, chlorosis	Corrosion	Forms H ₂ SO ₄ in atmosphere, haze, smog
VOC	Incomplete burning of fuels, evaporation of solvents	Small	Small	None	Reacts with NO _x to form photochemical smog
NO _x	Reaction of N ₂ with O ₂ at high temperature	Respiratory irritant	Small	Corrosion	Reacts with VOC to form photochemical smog and forms HNO ₃ in atmosphere
CO	Incomplete combustion of carbon fuels	Poisonous; reacts with blood hemoglobin	None on plants, deadly to animals	None	Eventually oxidizes to CO ₂
Photochemical oxidants; ozone	Chemical reaction of VOC, NO _x , and sunlight	Irritating and damaging to lungs, eyes, nose, and throat	Severe damage to plants	Corrosion, oxidation, bleaching	Smog formation

Summary of Pollutants and Their Effects 75

Table 3.2

29.2.1 Effects of Carbon Monoxide

Carbon monoxide (CO) is a toxic, combustible gas which is the result of incomplete combustion. Among other things, it is a component of automobile exhaust, tobacco smoke, and fire smoke. Large quantities at low concentrations are even emitted by oceans. Although CO is absorbed by microorganisms in the soil, man can tolerate only small concentrations due to its damaging effect to blood hemoglobin.⁷⁵ Fortunately, the reentry trajectory of the OLV promotes complete incineration and the levels of CO produced are considered negligible. The ultimate desired product is carbon dioxide (CO₂).

29.2.2 Effects of Nitric Oxides

Nitric Oxides are also possible hazards to the environment. Some of the nitrogen in protein and other refuse components burn to nitric oxide (NO). Also, at high temperatures, some atmospheric nitrogen is oxidized to NO. At excessive temperatures, on the order of 5,000 degK and higher, nitric oxide formation could be a serious problem. When NO enters the atmosphere, it is oxidized to brownish nitrogen dioxide (NO₂), which combines with water to produce the highly corrosive and harmful nitric acid (H₂NO₃).⁷⁵ The equilibrium nitric oxide concentration for combustion gases with 10 percent excess air is nearly 2000 parts per million at 3000 degF and 20,000 parts per million at 6000 degF.⁷⁵ However, the amount of toxins released into the atmosphere is negligible given the small size of the OLV.

29.2.3 Effects of Sulfur Oxides

Sulfur contamination is a possible threat to the atmosphere as well. Most refuse contains approximately 0.1 to 0.2 percent sulfur combined with other elements. When refuse is burned, a minor fraction of the sulfur remains with the ash, while most of the sulfur vaporizes into sulfur dioxide (SO₂). Sulfur dioxide is oxidized by sunlight in the atmosphere to SO₃ and combines with water to return to the soil and plants. Recorded effects of SO₃ and SO₂ are bronchitis, emphysema and cancer to humans, and necrosis and chlorosis to plants. Forms of sulfur compounds also combine with water to form H₂SO₄, which is responsible for atmospheric haze and smog.⁷⁵ Since the disposed refuse is expected to comprise a very small fraction sulfur, the contamination threat imposed by atmospheric incineration is negligible.

Chapter 30. REFUSE JETTISON VEHICLE DESIGN SOLUTION

30.1 Solution Discussion

The first stage in the solution optimization process was to determine whether to choose a collapsible type vehicle or a rigid type vehicle. From Solution Matrix 3.1 of Appendix A, it was determined that a rigid refuse jettison vehicle design is favored mainly due to safety risk. The solid construction of the rigid design allows for a lesser possibility of puncture or leakage through its outer shell which could lead to the contamination of the Space Station environment. Because the rigid design requires no mechanical or pressurized expansion, it was also estimated to require less crew EVA and IVA time as well as station support interaction. Overall, the rigid design has been determined to be more reliable and durable than the collapsible type and is, therefore, the superior choice.

The second stage in the solution process was to determine which rigid refuse vehicle design, logistics module type or outside rocket launched type, would be most feasible. Using Solution Matrix 3.2 the outside launched vehicle (OLV) is considerably more favorable with respect to transportation costs and minimum cargo space requirements. The OLV is far more economical considering the magnitude of the cost reduction associated with utilizing a separate transportation system other than the Space Shuttle. This use of alternative transportation avoids interference with the shuttle's transport of more critical cargo such as that needed for experimental, space exploration, and DOD projects.

The final design stage involved the determination of the shape, size, and weight and load capacity of the rigid OLV. These design requirements are subject to the estimated 40,000 pounds of generated refuse on the Space Station as well as the integration constraints of the jettison propulsion and refuse collection and transfer subsystems. Consideration of a refuse transfer canister of 3.0 ft. in length and 1.5 ft. in diameter, as recommended by the collection and transfer design study, and a compaction ratio of 15 to 1, it was determined that each canister would hold 667 pounds of refuse. In order to accommodate the gross weight constraint of 5000 pounds imposed by the jettison propulsion system study, it was determined that six canisters per vehicle are needed. This yields a refuse weight of 4002 pounds per vehicle with 998 pounds remaining as the limit for the OLV structure, propulsion system, and canister structure.

In addition to the above constraints, the OLV should perform at a minimum cost and minimum weight per cubic foot. Because the provision of adequate strength at a minimum weight is so important, it is customary to evaluate space structures and materials on the basis of weight-strength ratios. For the OLV design, other factors such as thermal stability and environmental contamination are concerns as well. Consideration of all of these variables led to the decision to incorporate conventional materials and structural shape. Although alternative composite and structural plastic materials have a higher

Jettison Vehicle

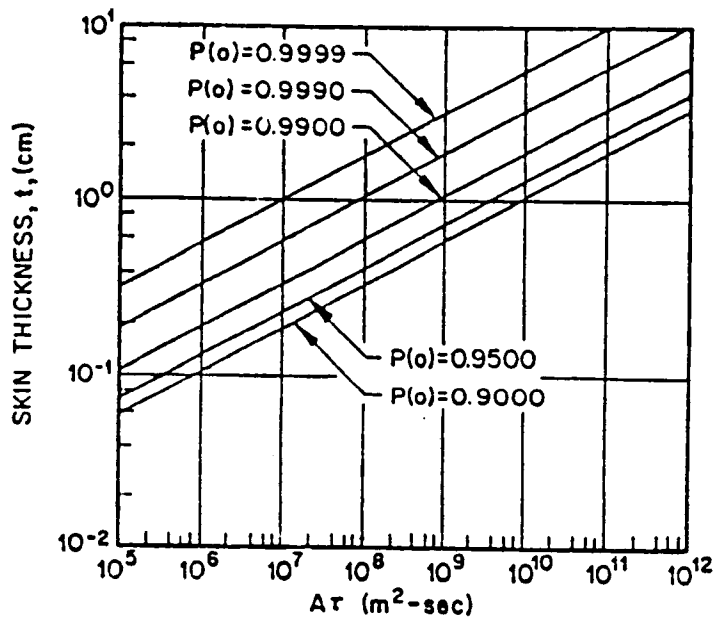
strength to weight ratio, their behavior in a microgravity environment has not yet been determined.⁷² In order to avoid the complexity involved in mass producing the OLV, simple casing methods are suggested. The avoidance of an internal beam network is also recommended for manufacturing and weight purposes. Cylindrical tubes, 1.55 ft. in diameter, are to be placed into the vehicle--one in the center and five surrounding it as shown in Figure 3.6.

The process of material selection was based on data from the space shuttle's external tank. Research of this data concluded that a combination of aluminum alloys is the best solution for the refuse jettison vehicle application. The OLV is to be made of a high strength aluminum alloy (Al 2219-temper⁷³ T-87) to provide a shield against meteor and space debris collisions. This alloy is to be simply casted into a cylindrical mold and possibly solution treated to withstand thermal cycling. From past experience, there is a slight concern about the effects of vacuum and the associated sublimation effects on materials. For most materials, these sublimation effects do not become significant until they are subjected to temperatures of about 400 degF. For aluminum specifically, extensive sublimation occurs at 810 degF,⁷⁴ which is outside the range of thermal cycling encountered in space.

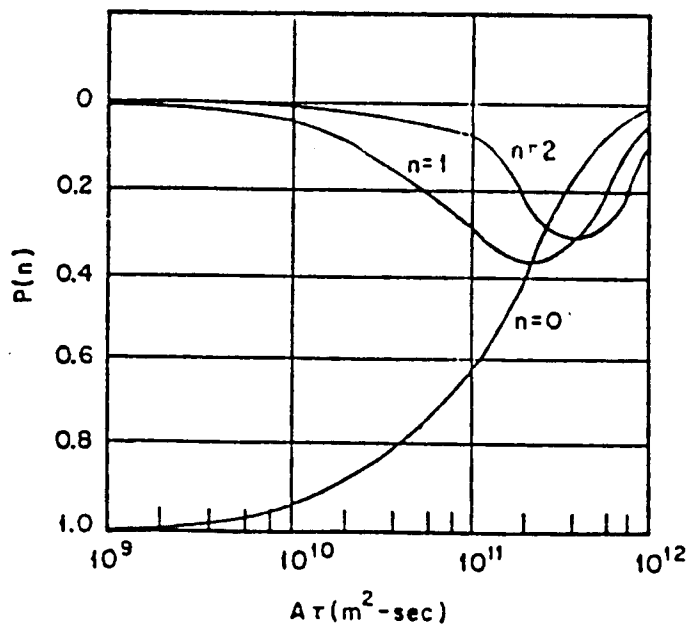
The determination of the shell thickness of the OLV is dependent upon several factors as well. This shell thickness is to be 0.5 inches, which satisfies the necessary factor of safety as stated in 3.4.2 of the military specifications. The probability of meteor punctures imposed on a 0.5 inch thick shell of aluminum is estimated in Graphs 3.3 and 3.4.⁷⁴ At this thickness, it is 99.9% certain that no punctures will occur. Another factor in determining the shell thickness is the weight limitation imposed by the rocket propulsion system. As stated above, the OLV weight (including the canisters but not the refuse) must not exceed 998 pounds. It is estimated that the overall weight of six empty canisters and the OLV, using the aluminum alloy discussed above, will be 553 pounds (see Appendix C). By adding the weight of the refuse to this value, a gross weight of approximately 4555 pounds per vehicle was determined. This value is well within the 5000 pound propulsion constraint and even allows for a slight variation of payload weight and materials used.

In regard to the aftereffects of atmospheric incineration, a few notable advantages and disadvantages have been observed. First, total incineration provides for the highest possible reduction in refuse volume. Furthermore, the high temperatures involved in the incineration process ensure complete oxidation of the unwanted refuse. However, these high temperatures are also likely to produce higher levels of pollutants into the Earth's environment. In addition, the possibility of incomplete incineration poses debris impact threats on Earth. However, given the relatively small size of the OLV, both of these aftereffects have been determined to be negligible threats for the Earth and its inhabitants (see Chapter 29).

Graph 3.3



Sheet Thickness of Al as a Function of the Surface Area-Lifetime Product Required for Various Probabilities of No Meteoroid Punctures or Spallation



Probability Function for Meteoroid Puncture or Spallation of a 1.27-cm (0.5 in.) Thick Al Sheet in Space vs Surface-Area-Lifetime Product

Graph 3.4

Jettison Vehicle

30.2 Solution Summary

In summary, the following outside launched jettison vehicle (OLV) has been determined as most feasible for the Space Station refuse disposal system (see Figure 3.6):

1. Structural Type - Rigid
2. Shape - Cylindrical
3. Material - High Strength Aluminum Alloy
4. Shell Thickness - 0.5 inches
5. Dimensions - 4.5 ft. diameter by 3.5 ft. length
6. Weight including refuse - 4555 pounds
7. Weight excluding refuse - 553 pounds
8. Method of transport to SS- Expendable Rocket

Chapter 31. RECOMMENDATIONS FOR FURTHER STUDY

In order to continue the research for the development of a refuse disposal jettison vehicle, the following areas of investigation are suggested:

1. A study of the orbital mechanics involved in achieving atmospheric incineration should be performed to determine the altitude and incineration time of the vehicle.
2. A prototype vehicle should be built and tested with the propulsion system under a simulated space environment.
3. The OLV should be examined under launch accelerations after being subjected to environmental conditions.
4. The OLV should then be evaluated for possible modifications.

The design of a suitable jettison vehicle for station refuse removal and disposal sets the foundation for the design of an efficient propulsion system, discussed in Section IV.

SECTION IV. JETTISON VEHICLE PROPULSION

- PART I.
- * General Launch Systems
 - * Mechanical Launch Force Subsystems

- PART II.
- * Physical Attachments
 - * Orbital Mechanics for Separating from SS Vicinity
 - * Disposal Sites
 - * Propulsion Options
 - * Payload Vehicles for Jettison Transport to SS

SECTION IV. REFUSE JETTISON VEHICLE PROPULSION SUBSYSTEM

INTRODUCTION

As previously stated, a disposal system is required to rid the Space Station of that refuse which cannot be recycled. As a result, a jettison vehicle has been proposed to transfer refuse to a disposal site. In order to complete the design of this disposal system, the vehicle requires a propulsion system to transport it to suggested disposal sites such as the Earth's atmosphere where incineration occurs upon reentry, the moon, sun, and libration points.

Upon selecting a final disposal site, many factors are critical. First, the amount of present technology available on achieving a voyage to any one of the disposal sites is most important in order to estimate overall cost, safety risk, and reliability. The idea of utilizing an atmospheric incineration is not new. Disposal of unwanted launch hardware, after its intended use, through the intense heating of atmospheric reentry is used today. For example, after emptied during flight, the external fuel tank of each Space Shuttle mission is discarded and purposely allowed to incinerate during its fall. This demonstrates that refuse disposal through atmospheric incineration is simple, financially feasible, and familiar to the United States Space Program. However, the safety ramifications of using atmospheric incineration warrants further consideration. Even though friction causes most objects to burn up when they reenter the upper atmosphere, larger objects may reach the Earth's surface. An example is the Skylab incident in 1979:

"The 85-ton spacecraft plummeted to Earth and scattered large chunks of debris across areas in Australia that, fortunately, were not densely populated."¹⁹

If a large object were to accidentally reenter the Earth's atmosphere, both lives and property could be endangered. Consequently, the attributes of other disposal sites must also be carefully measured to obtain the solution which is in the best interest of all concerned.

A voyage to the moon is certainly feasible as well, as demonstrated many times by past Apollo missions and others, and could be accomplished even easier by launching from the Space Station. However, future lunar missions could be hindered by refuse disposed there indefinitely. Voyages to the sun and libration points are possible, yet present technology is very limited. Second, once the feasibility of making the voyage has been determined, propulsion options must be studied to achieve the respective change in velocity (dV) requirements of attaining each destiny. For example, a voyage to

the Earth's atmosphere requires a dV of approximately 280 ft./s. while the other three sites can require a dV up to 10,000 ft./s. In addition, these changes in velocity must be achieved considering an

upper weight limit of 5000 lbs. (which is the estimated weight of the jettison vehicle including refuse, instruments, and structural design). Finally, other requirements such as fuel types, energy expenditures, fuel storage, etc. are analyzed as well.

Therefore, the overall purpose of this study is to propose the most effective launch and transportation system for this jettison vehicle in order to achieve a designated disposal site. This study is divided into two design phases. Design Phase I investigates general launch systems and support subsystems to transport the refuse vehicle from the Space Station vicinity. Design Phase II furthers the investigation by presenting various disposal site options, disposable rockets to enable travel to these different sites, and propulsion options for transporting the disposable rockets from the Earth to the Space Station.

PART I. REFUSE VEHICLE LAUNCH SYSTEM - DESIGN PHASE I

Chapter 32. GENERAL LAUNCH SYSTEMS

The following waste disposal launch systems were studied for their operational feasibility in conjunction with the Space Station:

1. Tethers
2. Disposable Rocket
3. Orbital Maneuvering Vehicle (OMV)
4. OMV Assisted Mechanical Launch
5. Mechanical Launch from the Space Station
6. Mechanical Launch from an Auxiliary Platform

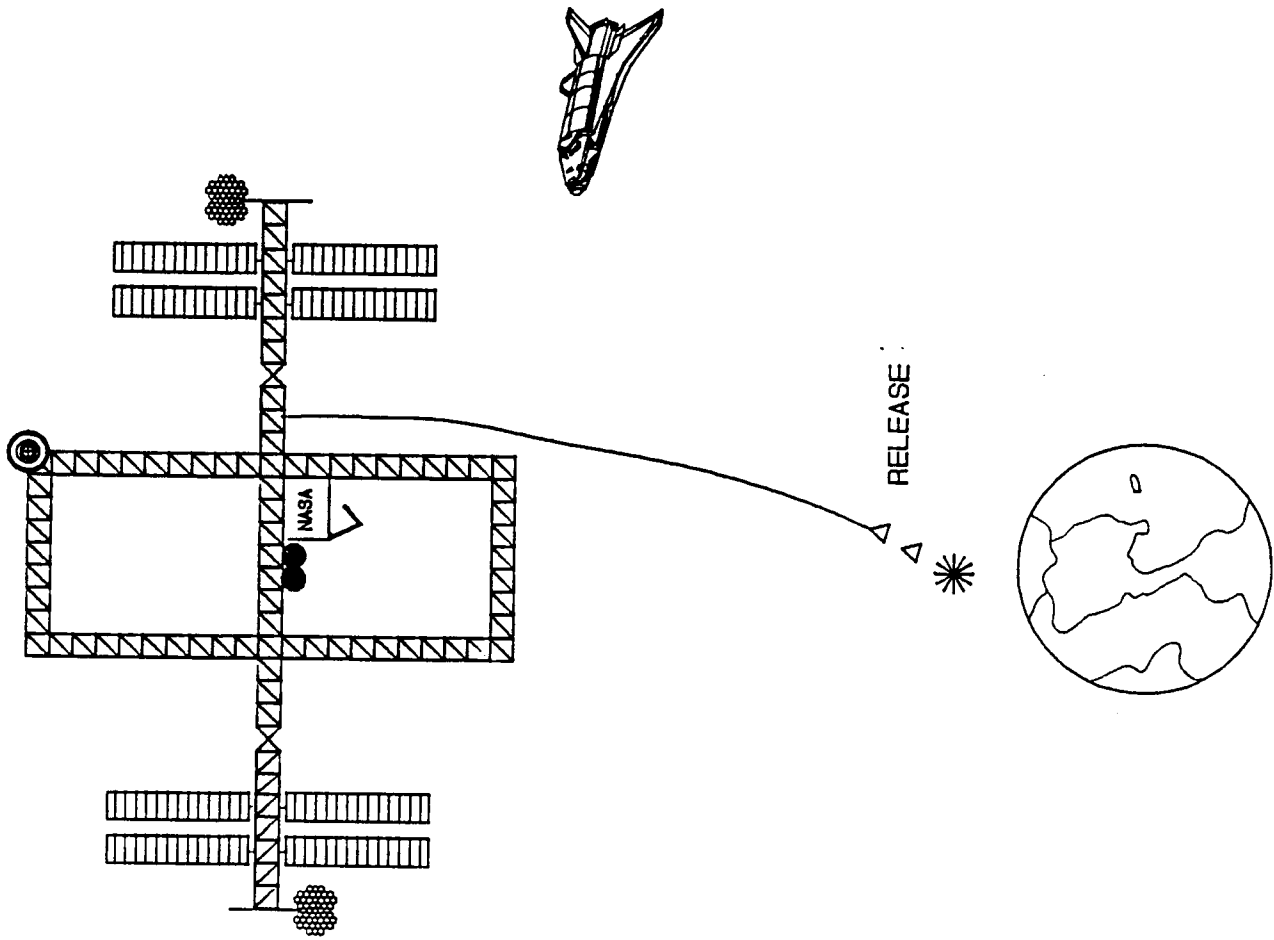
32.1 Tethers

The use of tethers has been proposed for several applications on the Space Station. This simple spooled cable system is to be used to attach objects to the station at proximal locations, while providing sufficient isolation. For example, one such application might be to attach a fuel storage facility such that it is easily accessible, yet far enough away to avoid subjecting the station to significant safety risks. For the refuse disposal system, tethers could be used to isolate a filled waste capsule and then lower and release it, with little incurred vibration, into a lesser orbit for atmospheric incineration (see Figure 4.1). Although a simple system, the incineration path using tethers is very unpredictable. Attachment of the waste module to the station during most of its decent results in little velocity change. Thus, a large number of orbits may be required to achieve the desired momentum for destruction, and this path is difficult to predict.

In general, the tether launch system provides a simple, reusable transportation system which requires no propellants and thus incurs little vibration or pollution to the Space Station and its environment. However, for this application, the spool system is estimated to contain up to 150 miles of cable which would require a large amount of storage space on the station. Also, the estimated time of human involvement required to cycle this very large system is 4 to 8 hours. Because of these undesirable characteristics, in addition to its unpredictable path of destruction, the use of the tether most likely will not be chosen as the most desirable solution.

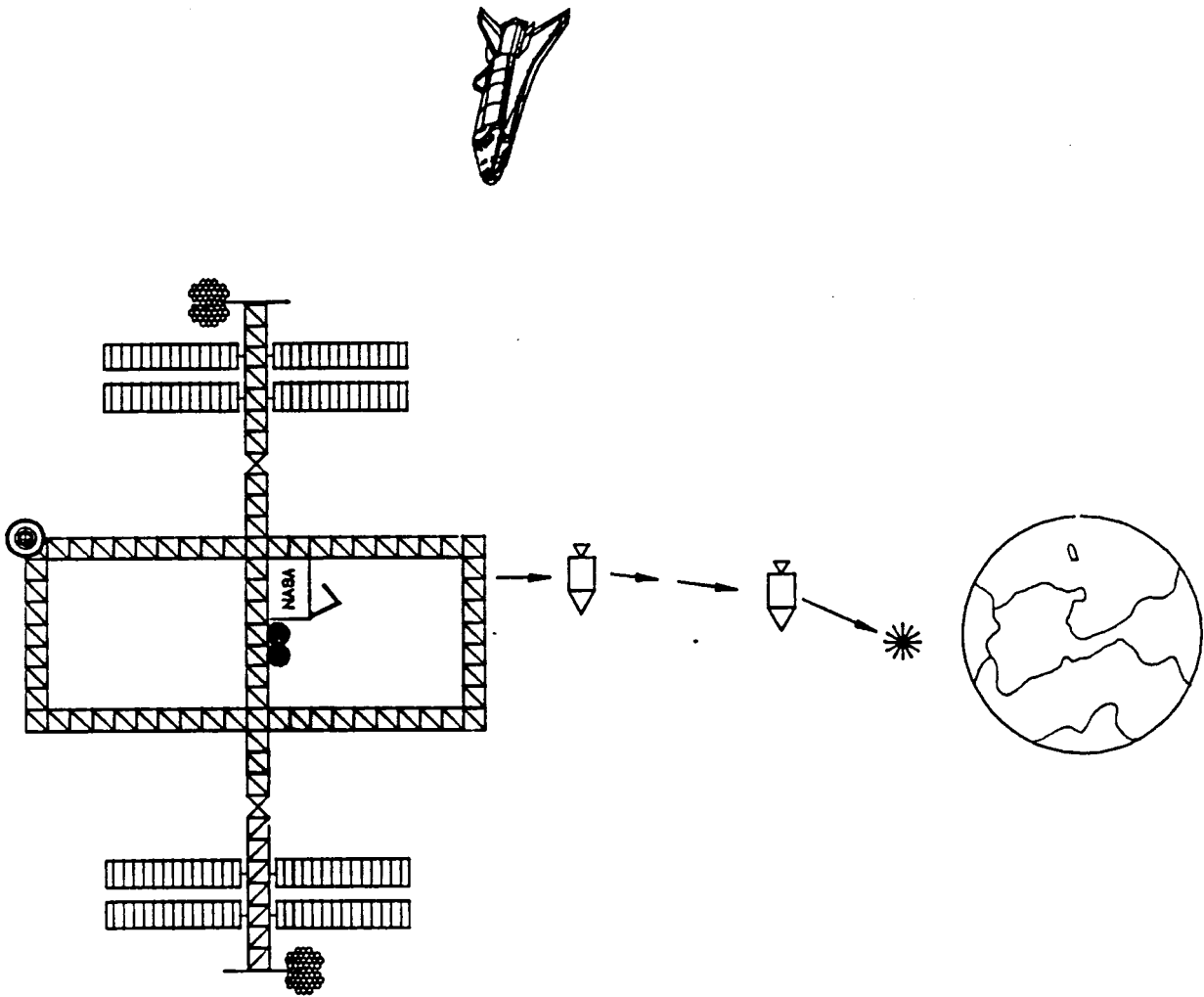
32.2 Disposable Rocket

A disposable rocket can be used to create the required 280 ft./s. decrease in velocity for atmospheric incineration. The waste module would be attached to the rocket and both will incinerate upon reentry (see Figure 4.2). The most feasible propellants for the disposable rocket could either be solid fuel or cold gas as both of these have



TETHER

Figure 4.1



DISPOSABLE ROCKET

Figure 4.2

been tested and proven efficient for space application.⁹ Cold gas propellants could be used to power the vehicle to avoid pollution, and the complete removal of the propulsion system at the time of launch would eliminate any moments or disturbances imposed on the space station. Otherwise, solid rocket fuel could be used if a removed launch, a safe distance away from the Space Station, is chosen as the best alternative.

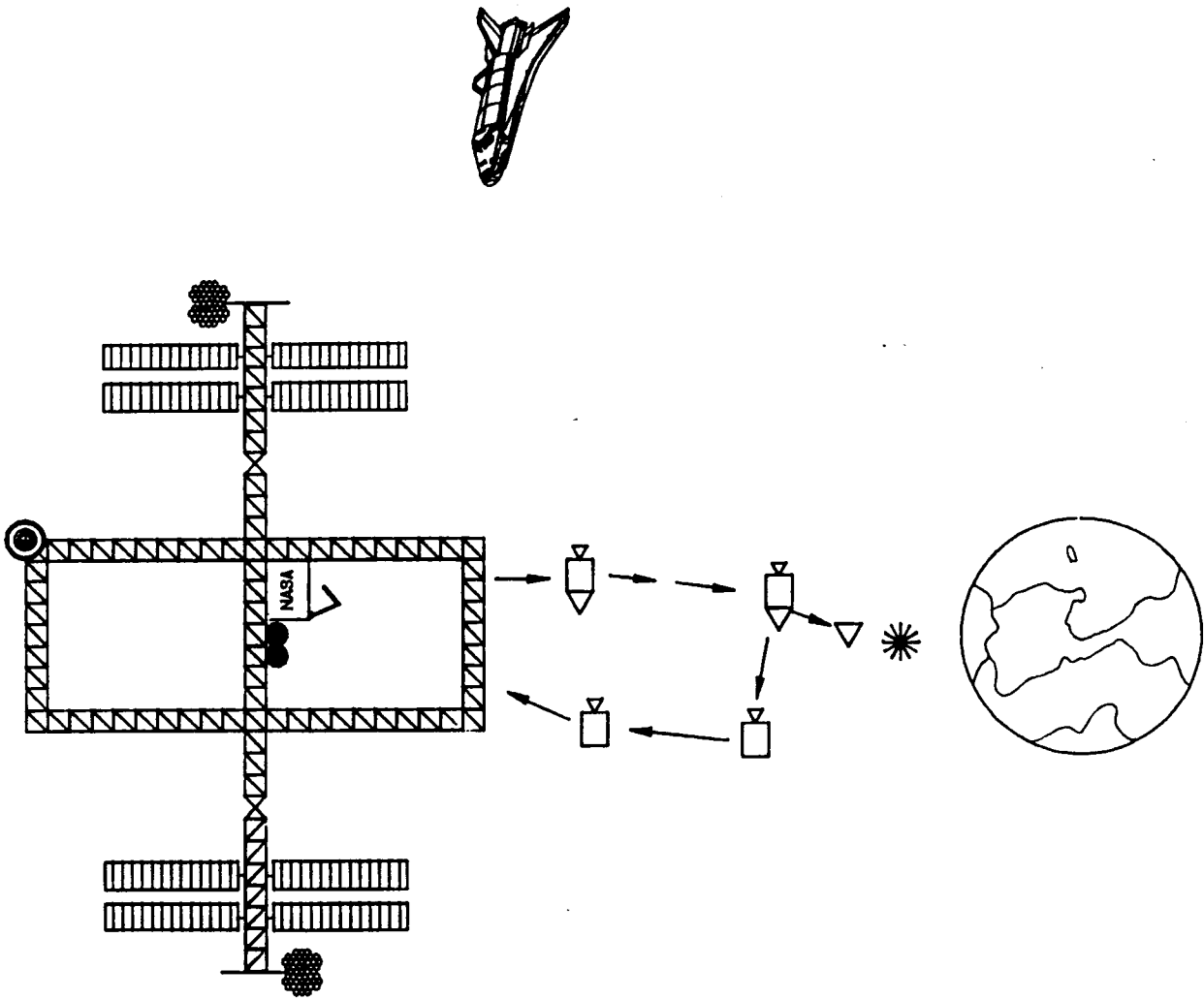
The major disadvantages associated with using a disposable rocket are safety hazards with respect to fuel handling and storage, large fuel storage requirements, and possible high costs depending on waste amounts and number of launches needed. Also, an on board guidance system may be necessary to overcome the rocket's sensitivity to the vehicle's center of mass.

32.3 Orbital Maneuvering Vehicle

The orbital maneuvering vehicle (OMV) is an unmanned vehicle which is to be one of the first operable systems on the Space Station.¹⁰ This vehicle will be used for the local transport of materials from the shuttle and about the station:

"The OMV is a stage that will be available for the IOC station, independent of the stations propulsion system. It has both bipropellant (N_2O_4/MMH) and cold gas nitrogen capability. The main propulsion (4-3830 newtons (200 lbs.) thrusters) and attitude control propulsion (24-67 newtons (15 lbs.)) share common bi-prop tanks and pressurization system...to allow for thrust level selection between a lower bound of 67 newtons (15 lbs.) (one control thruster) to an upper bound of 383 newtons (860 lbs.) (four main and four control thrusters)."

This type of vehicle could also be used to transport a waste capsule to a desired disposal site. A waste capsule could be attached to the OMV at a module dock site, after which the cold gas propulsion system would launch the vehicle toward the Earth's atmosphere. When the vehicle is sufficiently close, it will release the waste package for reentry incineration, then return to the docking facility for more payload (see Figure 4.3). The OMV is capable of providing the waste capsule with a reduction in velocity of 280 ft./s. or more to insure complete incineration within one predictable orbit. It is also capable of varying its acceleration rate to limit the stresses imposed on the waste module. The cold gas propulsion system of the OMV not only allows an unpolluted launch within close proximity of the station, but also provides sufficient thrust to reboost the Space Station.⁸³



OMV DELIVERY
Figure 4.3

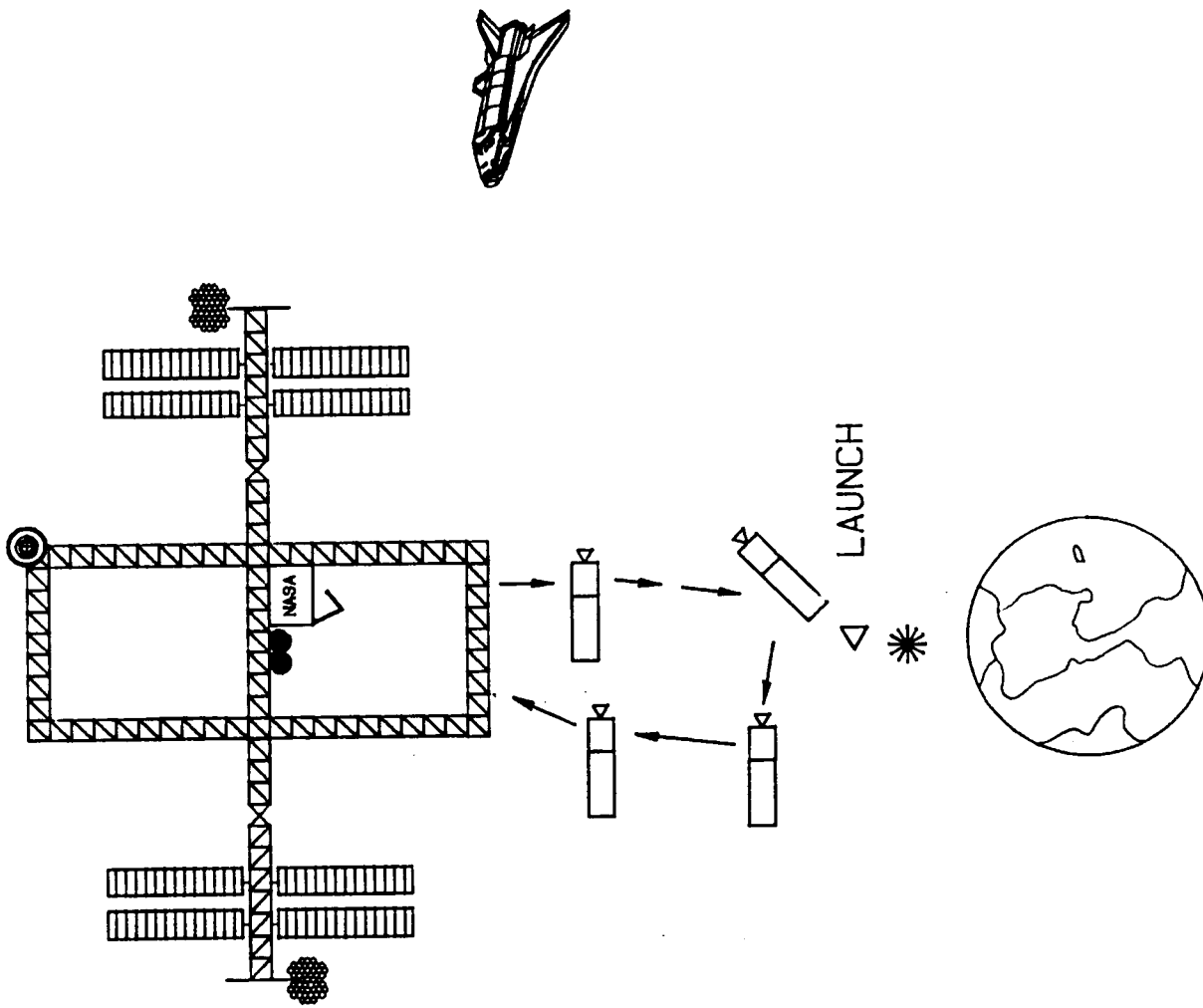
The general disadvantages of the OMV are: high man hours (complete supervision required during the cycle), high maintenance, high operational cost (expensive fuel, maintenance), docking/module attachment imposes collision risk, and no backup capability. If the OMV is inoperative or unavailable, the waste must be stored until handling is possible.

32.4 OMV Assisted Mechanical Launch

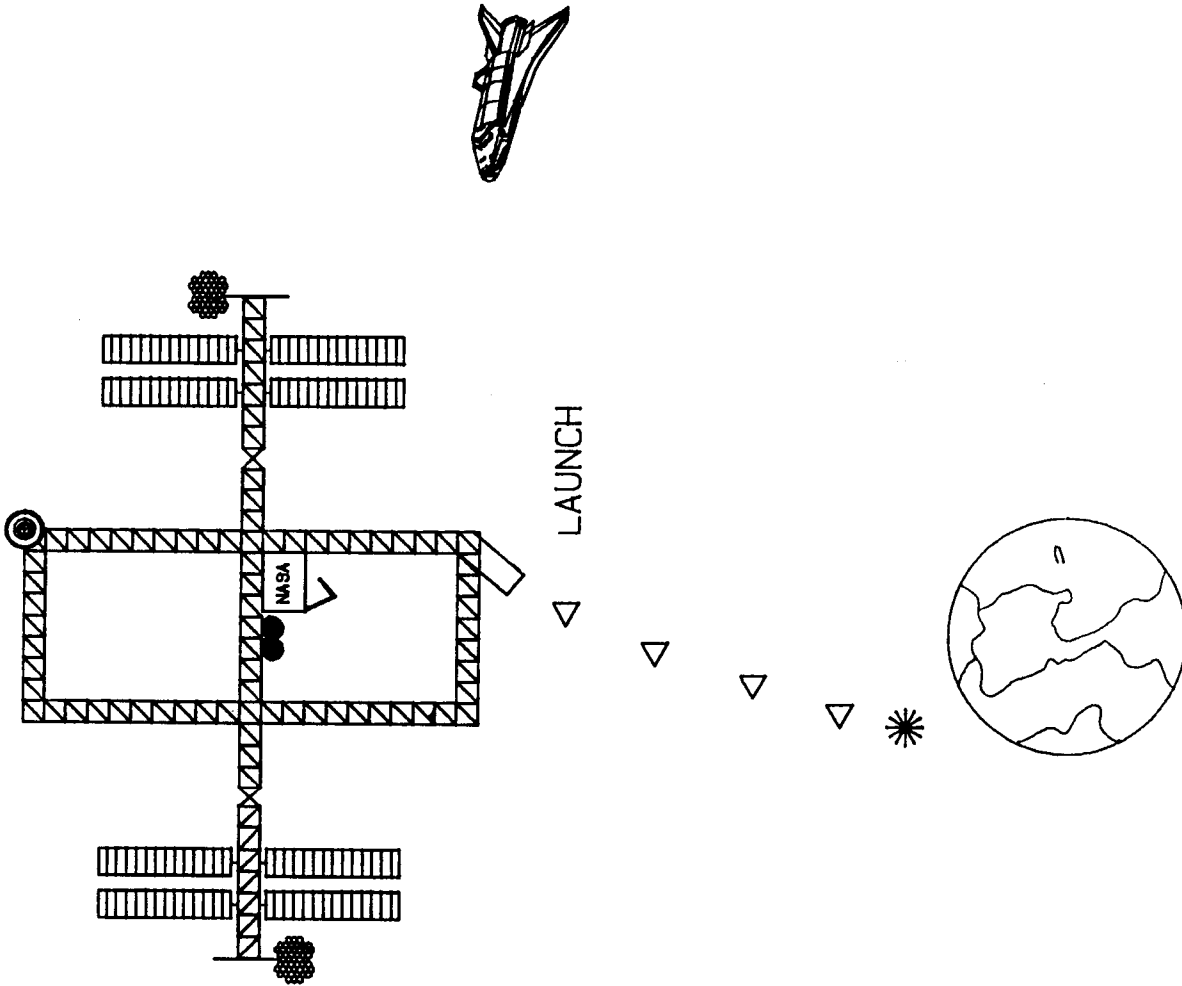
Any of the mechanical systems discussed in Chapter 33 could be attached to the OMV such that the waste module could be launched from variable positions (see Figure 4.4). The reaction forces incurred by the launch system would help propel the OMV back to a higher orbit, thus reducing the fuel requirements for its return to the space station. Also, the initial velocity established by the OMV reduces the load on the mechanical launch system. Thus, this complimentary combination allows all of the advantages of using an OMV while reducing its power requirements. Even if solid fuels are used for the mechanical launch, the OMV can move the system far enough away from the station such that the pollutants will not interfere with its normal operations. Because the OMV assisted launch is dependent upon the operation of two systems, routine maintenance requirements increase as does the possibility of failure. If either of the systems were to fail, the cycle could not be completed.

32.5 Mechanical Launch from the Space Station

Any of the mechanical systems discussed in Chapter 2 could be attached to the Space Station structure such that direct launching of the waste module is possible (see Figure 4.5). The launch system could be located within close proximity to the waste module for convenient attachment after it is filled with refuse, or the module could be filled while directly attached to the launch facility. The placement of the waste capsule onto the mechanical launch system could be performed by the Canadian manipulating arm. In general, the location of the launch facility on the station increases the accessibility of the system, as well as providing reboost capability for the Space Station. However, it would be impossible to dampen all of the unwanted forces associated with a Space Station launch. Because torques and vibrations could damage or disrupt the operation of the station, this type of launch will most likely be undesirable.



OMV ASSISTED LAUNCH
Figure 4.4



SPACE STATION LAUNCH

Figure 4.5

32.6 Mechanical Launch from an Auxiliary Platform

Any of the mechanical systems discussed in Chapter 33 can also be located on a co-orbiting platform, isolated from the Space Station (see Figure 4.6). However, the forces exerted upon the launch must be counteracted by either an additional built-in system or by the use of an OMV. This launch site prevents any Space Station disturbances from reactive forces and isolates any pollutants from the local station environment. However, a remote launch would require more man hours to operate (less accessible for loading and launching). Also, a counteraction of the launch reaction trajectory is required to maintain the proper platform position.

Chapter 33. MECHANICAL LAUNCH FORCE SUBSYSTEMS

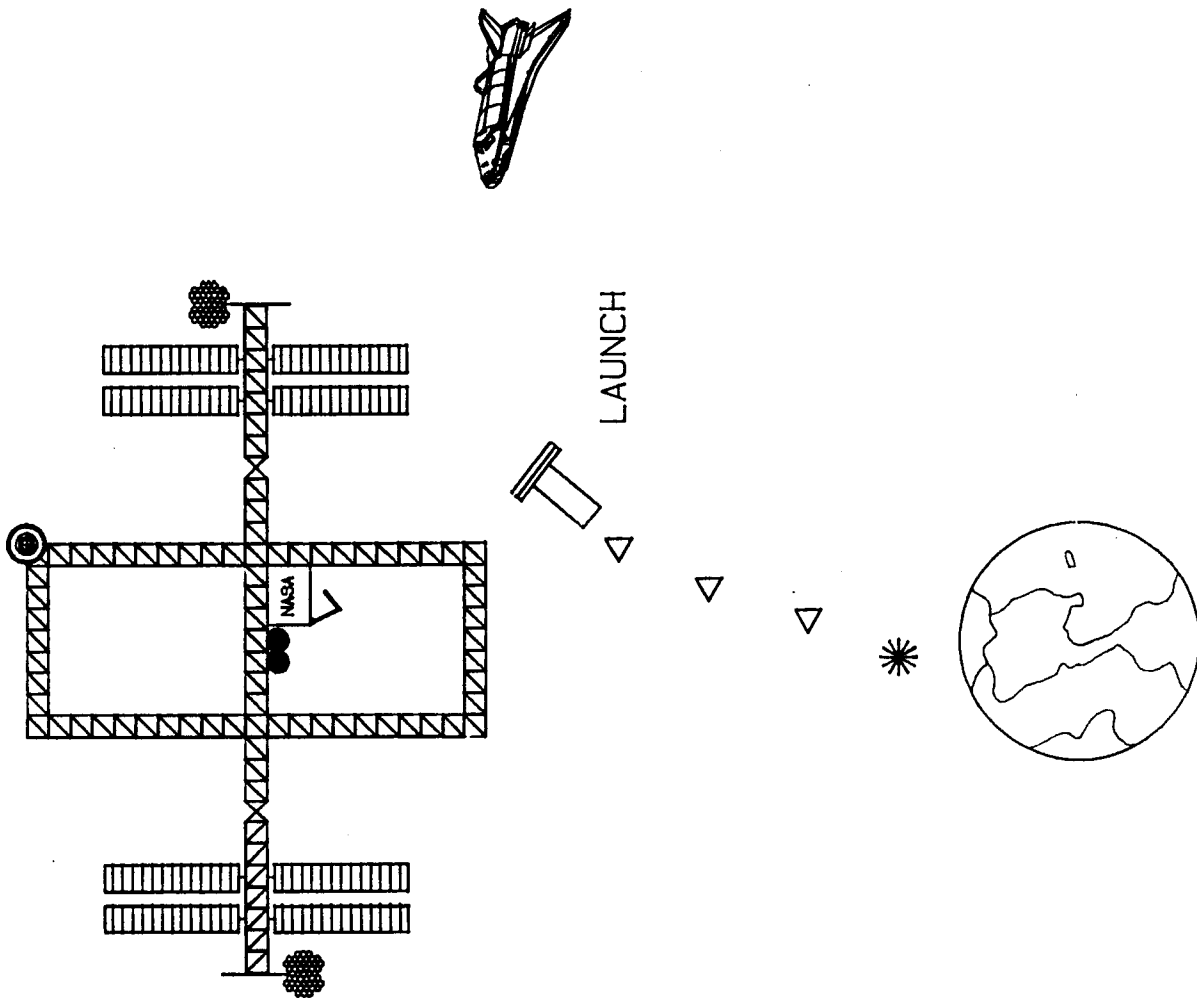
There are several mechanical launch systems which can be used to provide the waste module with transport to the disposal site and all or some of its needed decrease in velocity for atmospheric incineration. These systems can be placed in various locations on or about the space station and can receive power from either self-contained supplies or the existing station power sources. In general, the waste module will be "loaded" into the launch system and then "shot" out with the necessary velocity. The most feasible launch subsystems are listed as follows:

1. Electromagnetic
2. Spring
3. Pressurized Waste Gas
4. Solid Fuel Rocket
5. Liquid Fuel Rocket

33.1 Electromagnetic Launch

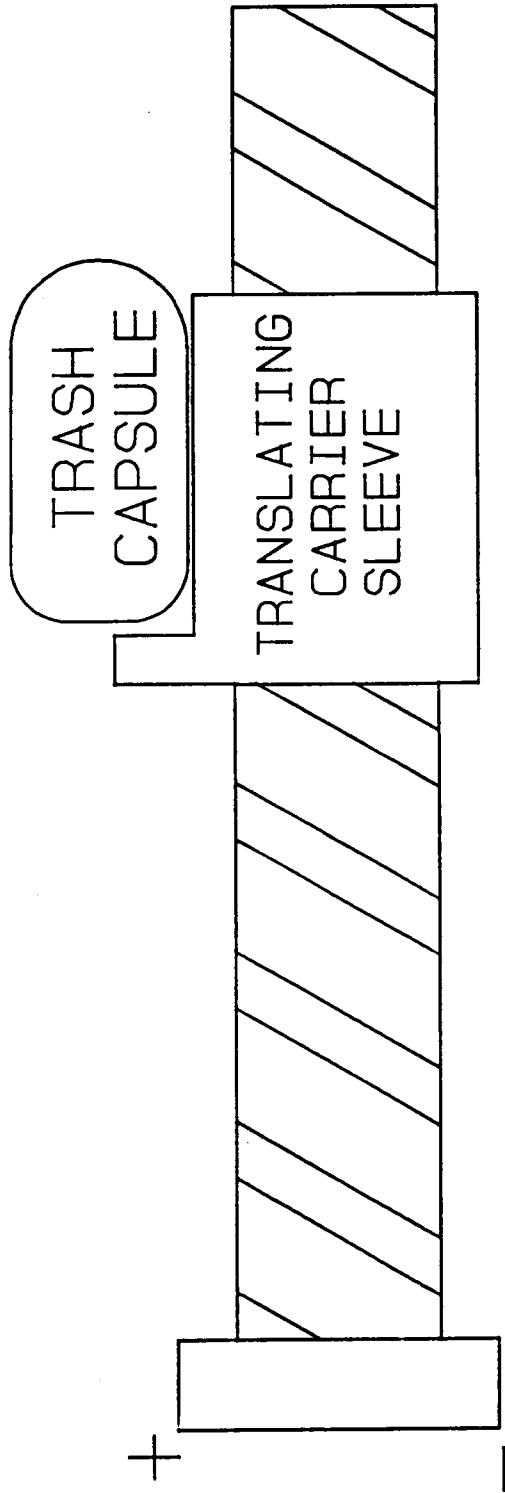
Electromagnetic propulsion is defined as motive power produced by the discharge of plasma fluid at high speeds.⁸² The behavior of the plasma, or highly ionized gases, is governed by electrical currents in the plasma interacting with the magnetic fields of the vehicle. The discharge produced by this process is electrically neutral. An accelerator is utilized to initiate speed and direction to the flow of plasma.⁸²

The concept of an electromagnetic launch involves producing an electrical field along a rail which induces a force on a carrier sleeve to which the waste module is attached (see Figure 4.7). This force translates the sleeve across the rail while creating the necessary velocities for the launch of the waste capsule.



AUXILIARY PLATFORM LAUNCH

Figure 4.6



ELECTROMAGNETIC LAUNCH

Figure 4.7

The electromagnetic launch is advantageous in that it emits no pollution, requires little maintenance, and it can generate variable acceleration forces. However, this launch has a high initial cost and requires significant power to operate.

33.2 Spring Launch

A spring can be defined as a mechanical component used for storing energy as a function of displacement.⁸² Deflection of the spring through a given displacement is initiated by the application of a force. The purpose of a spring system is to provide motive power to a mechanism.⁸²

A spring launch involves the compression of the waste module against a mechanical spring (see Figure 4.8). When released, the resulting energy can be used to achieve the necessary deceleration of the waste module for atmospheric incineration.

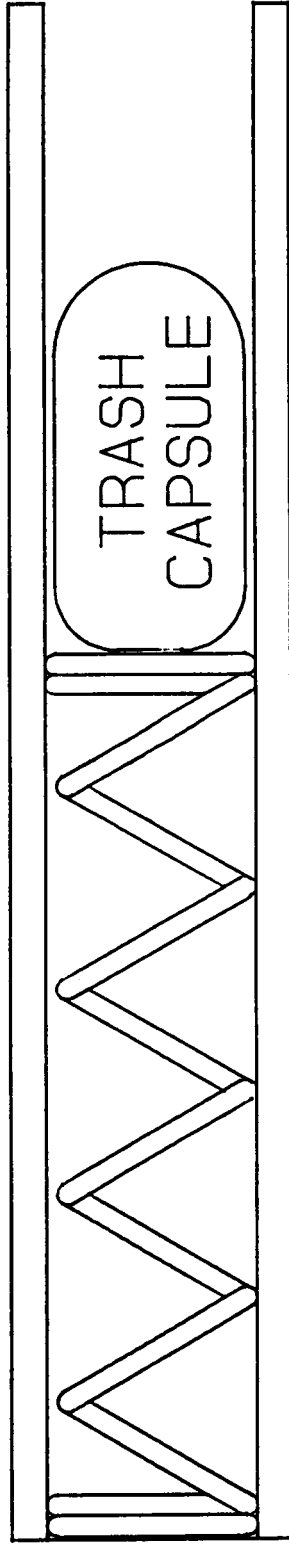
The advantages of the spring launch are: no pollution, low power requirement, and low maintenance. Nonetheless, this launch induces a high initial acceleration, has a high initial cost, and requires an additional system to compress the spring.

33.3 Compressed Gas Launch

Compression of a gas involves an increase in its pressure as a result of an increase in its density.⁸² To supply motive power, this compressed gas is delivered to an attached resistive mechanism. For the purposes of a gas launch, the resistive mechanism is connected to the discharge side of the compressed gas system.⁸²

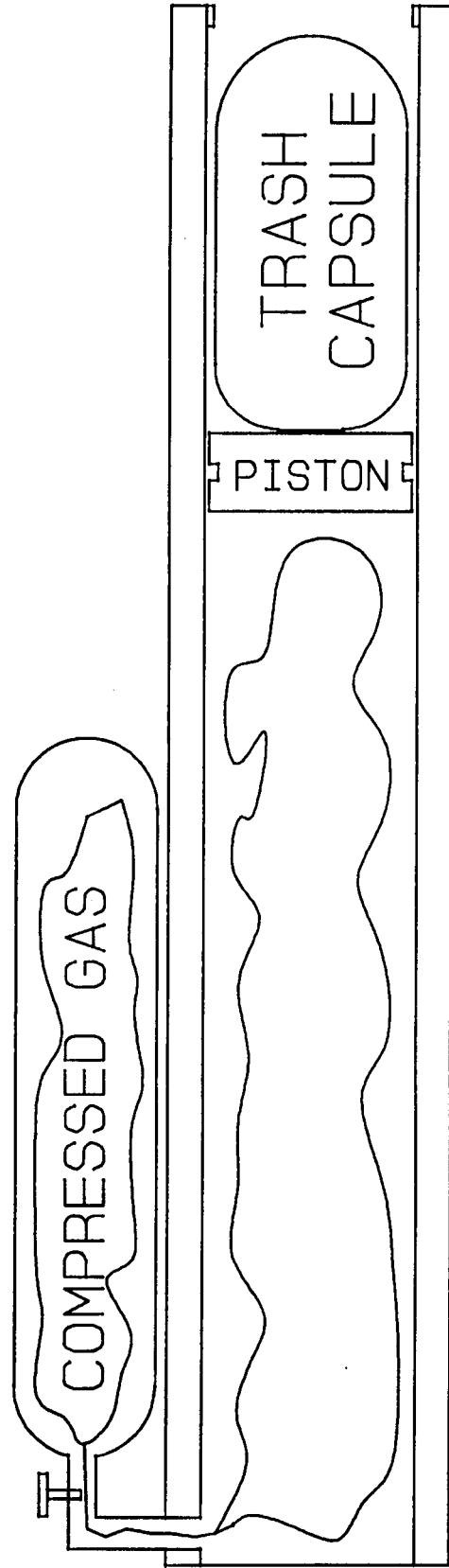
A compressed gas launch involves attachment of the waste capsule to a piston/cylinder arrangement which is connected to a container of pressurized waste gas (see Figure 4.9). The waste gas is pressurized either mechanically or thermally and then released into the piston/cylinder. The waste module is driven by the expansion of the gas and is launched toward the Earth.

A compressed gas launch produces no pollution and has a low power requirement. Furthermore, waste gases produced on the station can be used as propellant. However, this launch requires high maintenance (pressurization and seals), is dependent upon waste gas supply, and has a high initial cost.



SPRING LAUNCHER

Figure 4.8



COMPRESSED GAS LAUNCH

Figure 4.9

33.4 Solid Fuel Launch

Solid rocket fuel is defined as materials used to supply motive power for rocket propulsion. These materials involve a mixture of oxidizers, fuels, and additives which remain in a solid state at ordinary temperatures. Upon ignition, the burning solid fuel produces a hot gas which can propel an attached mechanism.

Solid fuel rockets have already been proposed for use on the station, therefore, storage facilities will already exist (see Figure 4.10). Solid fuel is also very compact with a high thrust to mass ratio. However, this fuel is very pollutive and highly explosive, presenting a storage safety hazard.

33.5 Liquid Fuel Launch

Liquid propellants supply motive power by means of chemical action and thus, leave no exhaust plume after launch. Two common types of liquid bipropellants are hypergolic and cryogenic. Hypergolic fuels, comprised of such chemicals as hydrazine and nitrogen tetroxide, are characterized by boiling points of around 236 degF and freezing points of around 35 degF. Cryogenic fuels, on the other hand, are comprised of liquid hydrogen and oxygen and are characterized by very low boiling points of around -297 degF and freezing points of around -362 degF.

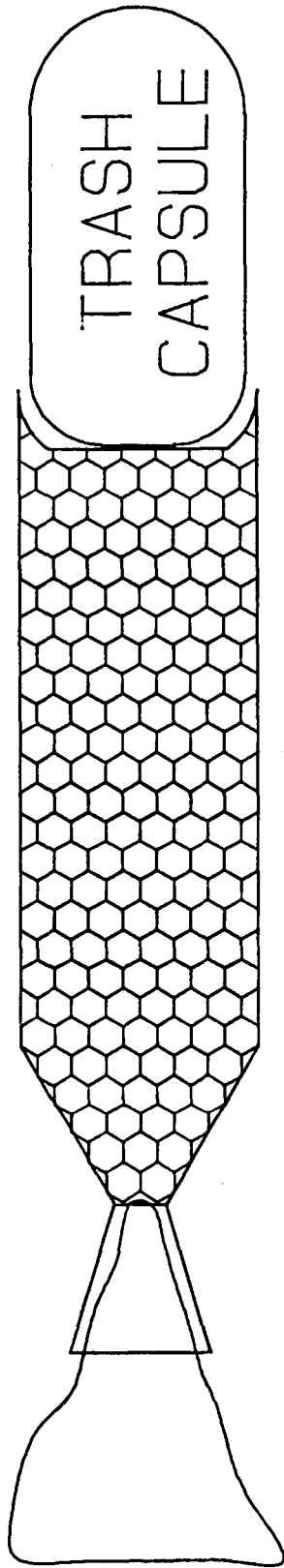
The major disadvantages of using liquid fuel is that it requires separate bulk storage containers and it requires significant maintenance due to its fluid system components (seals, electrical solenoid valves, mechanical operators, etc.).

Chapter 34. JETTISON PROPULSION OPTIMAL SOLUTION - PHASE I

34.1 Solution Discussion

Consideration of Solution Matrices 4.1 and 4.2 of Appendix A, the most optimal refuse jettison vehicle transportation system is comprised of an OMV assisted launch using either disposable cold gas or solid rocket propulsion. Use of the OMV alone would be impractical and inefficient. Therefore, an OMV assisted launch using either disposable rocket subsystem to properly "aim" and "shoot" the waste capsule would yield excellent operational performance.

One complete cycle of the refuse disposal system begins with the filling of the waste module and ends with the return of the OMV to the Space Station (see Figures 4.11-16). While the module is being filled, fuel manufactured from the recycle station (solid or cold gas) is loaded into the disposable rocket. After fueling, the rocket can be moved to a remote storage area. Once the waste module is ready for



DISPOSABLE SOLID ROCKET

Figure 4.10

Jettison Propulsion I

disposal, the rocket can be retrieved and attached. The OMV will then remove the waste assembly (module and rocket) and transport it away from the proximity of the Space Station toward the Earth's atmosphere. When near the Earth's atmosphere, the assembly is "aimed" and set into a spinning motion while the OMV detaches and begins its return to the Space Station. Once the OMV is a safe distance away, the rocket is ignited sending the waste assembly into the proper deorbit attitude (final $dV = -280$ ft./s.). The OMV then redocks with the Space Station while the waste package disintegrates within one earth orbit.

The OMV has more than the necessary thrust capability and can vary the acceleration rate during launch to reduce the inherent stresses imposed on the waste capsule. Also, with the increase in controllability provided by the OMV, the initial velocity of the waste assembly can be adjusted to compensate for varying payload masses to assure a predictable path of atmospheric incineration. To increase the system's overall performance efficiency, the disposable rocket is to provide most of the assembly's deorbit velocity. Also, disposal launch will occur when the Space Station altitude is at its minimum (before reboost), thus requiring the least amount of fuel expended by the OMV (expected cost of OMV fuel = \$1235/lb.).¹⁰

During the launch of the waste assembly from the vicinity of the Space Station, many unfavorable conditions can be avoided. The OMV's cold gas rockets allow removal of the assembly with minimal dynamic disturbance to the Space Station, and without inflicting harmful pollution effects to its environment. The overall safety of the system is enhanced by the use of disposable rockets as well. The replacement of the complete final propellant system for each launch eliminates failure due to part fatigue. Also, a removed launch increases overall safety by reducing the risk of collision and/or incineration of the local structures. Although the use of rockets requires the storage of some type of fuel, it can be placed in the existing storage facility for the OTV (upper earth Orbital Transfer Vehicle) and OMV propellants.

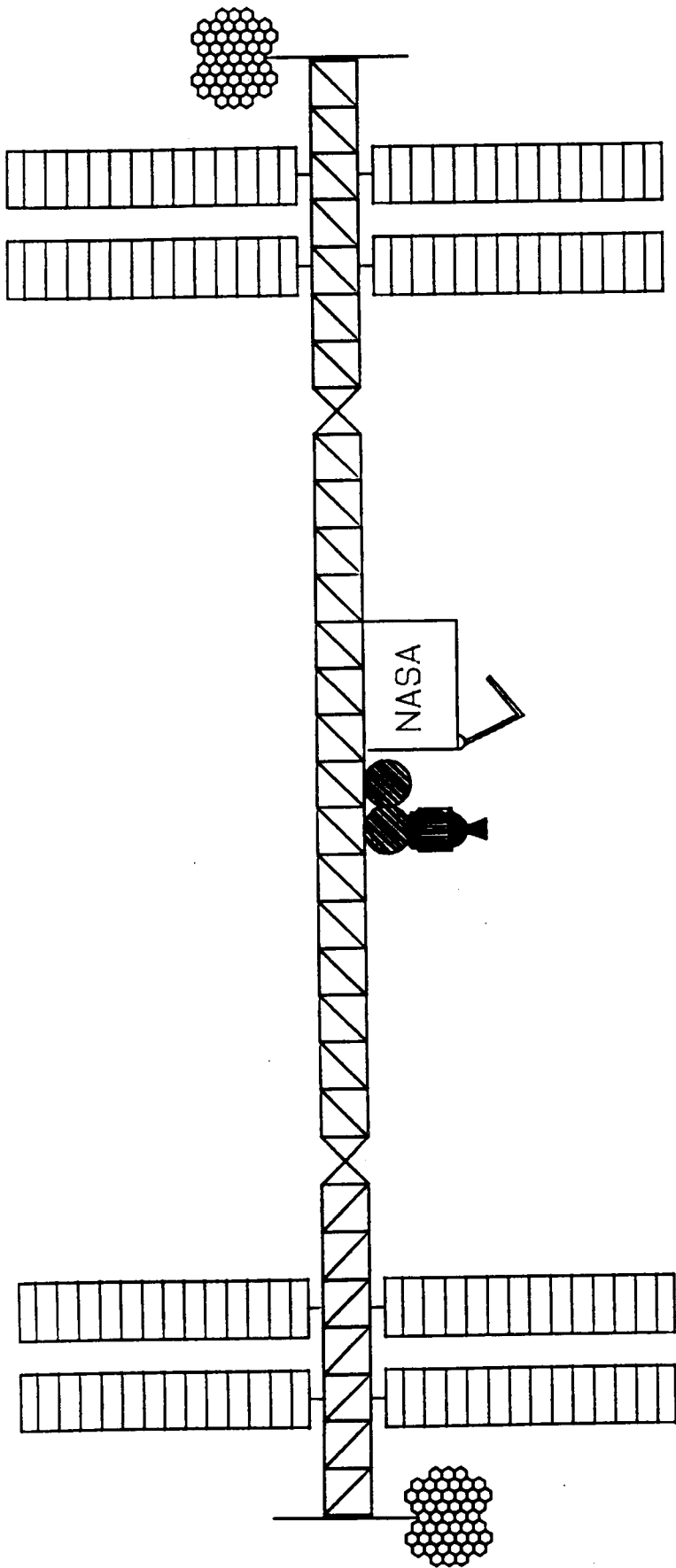
34.2 Solution Summary

In summary, the basic refuse jettison vehicle launch system is comprised of an OMV transport assisted by a disposable rocket propelled by either cold gas or solid fuel. The proposed launch cycle is as follows: (see Figures 4.11-16).

1. Rocket is fueled at the recycling facility (using pyrolyzed fuel) while the waste module is filled.
2. Fueled rocket is placed in safe storage until needed.
3. When needed, the rocket is retrieved and the waste module is attached.
4. The waste assembly is attached to the OMV and transported away from the Space Station vicinity.

5. When a safe distance away, the OMV induces a spin on the waste assembly and releases it.
6. The OMV returns to the Space Station while the rocket ignites, sending the waste assembly into the proper de-orbit attitude.

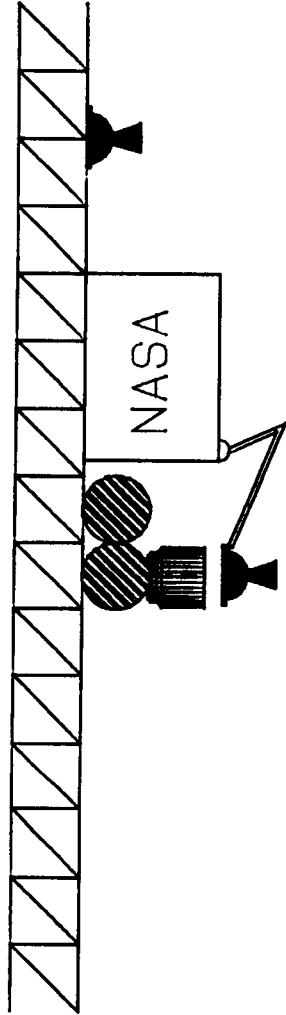
With the general launch cycle defined, it is necessary to explore various disposal sites and specific rocket motors which are applicable to this system.



ROCKET IS FUELED FROM WASTE RECYCLE FACILITY WHILE MODULE IS ACCUMULATING DISPOSABLE WASTE

Launch Cycle: Fueling of Rocket

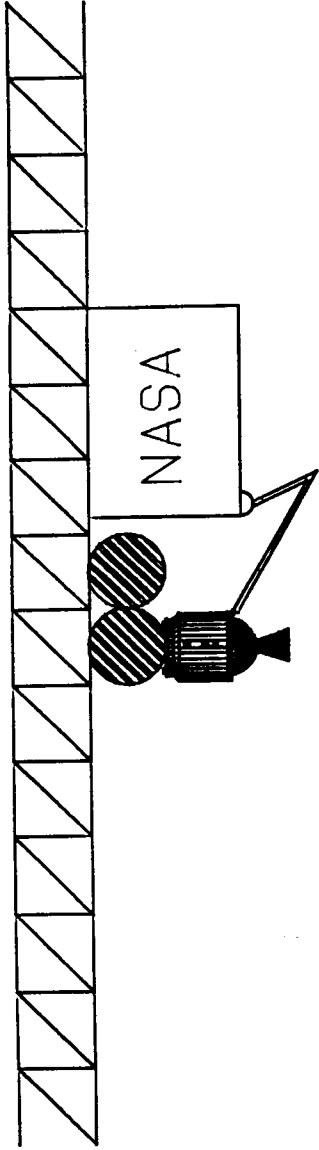
Figure 4.11



ONCE THE ROCKET HAS BEEN FILLED IT IS REMOVED FROM THE RECYCLE FACILITY AND PLACED IN SAFE STORAGE UNTIL NEEDED

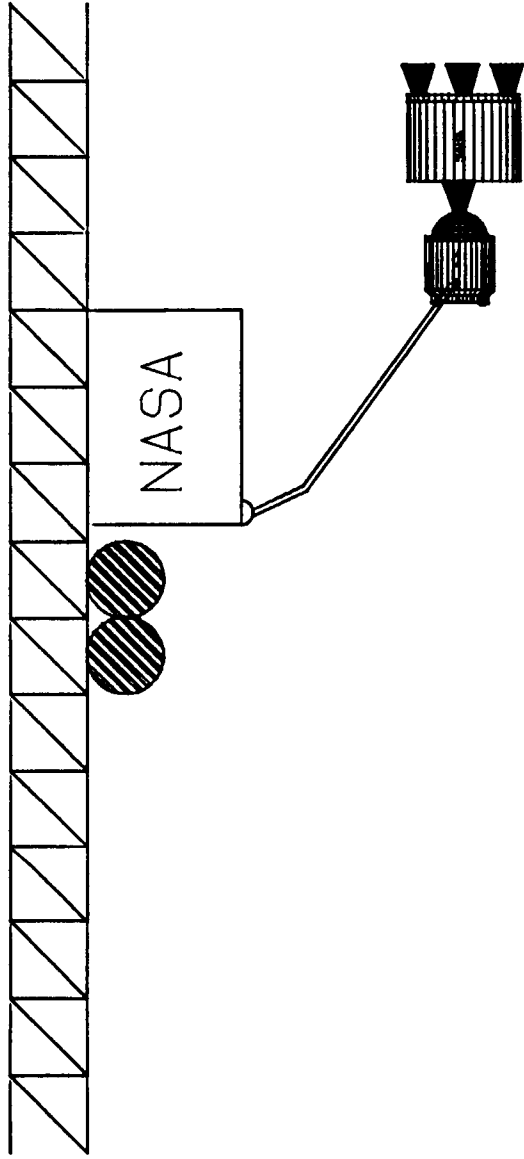
LAUNCH CYCLE: ROCKET STORAGE

Figure 4.12



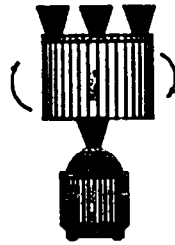
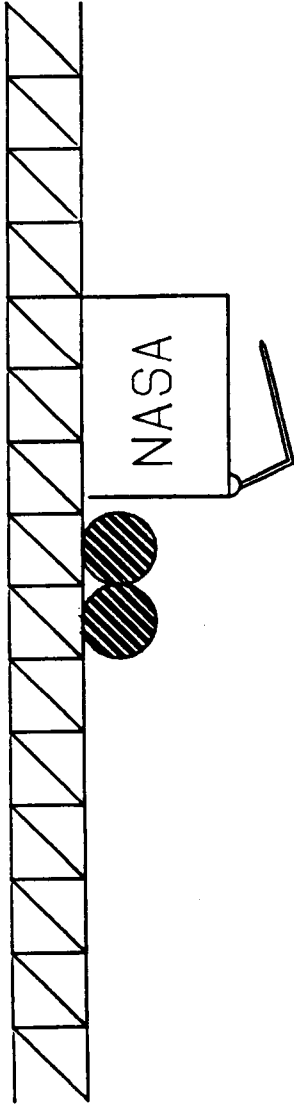
WHEN MODULE IS READY TO BE DISPOSED OF
THE FUELED ROCKET IS RETRIEVED AND
ATTACHED TO THE MODULE

LAUNCH CYCLE: ROCKET ATTACHMENT
FIGURE 4.13



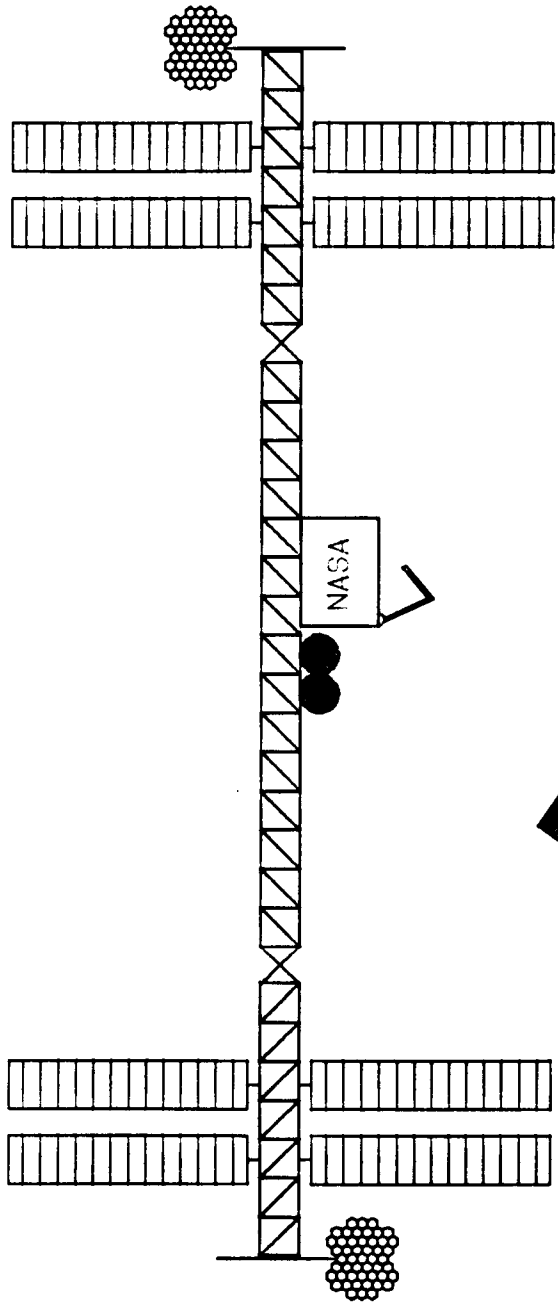
THE WASTE ASSEMBLY IS THEN ATTACHED TO
THE OMV AND TRANSPORTED OUT OF CLOSE
PROXIMITY OF THE SPACE STATION

LAUNCH CYCLE: OMV ATTACHMENT
FIGURE 4.14



THE OMV THEN INDUCES A SPIN ON THE ASSEMBLY, RELEASES, AND RETURNS TOWARD SPACE STATION

LAUNCH CYCLE: JETTISON VEHICLE RELEASE
FIGURE 4.15



AS THE OMV RETURNS TO SPACE STATION, THE
ROCKET IS IGNITED AND THE WASTE ASSEMBLY
ASSUMES PROPER DE-ORBIT ATTITUDE

Launch Cycle: Rocket Ignition Figure 4.16

PART II. REFUSE JETTISON VEHICLE PROPULSION - DESIGN PHASE II

The preliminary jettison vehicle launch system is composed of an OMV assisted by a disposable rocket which propels the refuse module, of less than 5000 lbs., to its final destination (see Part I). This Phase II study addresses the following options for this launch system:

1. Refuse vehicle physical attachments.
2. Orbital mechanics to achieve needed rocket launch distance from the Space Station vicinity.
3. Disposal sites.
4. Propulsion options to transport the refuse vehicle various disposal sites.
5. Payload launch vehicles to transport the disposable rockets from Earth to the Space Station.

Chapter 35. PHYSICAL ATTACHMENTS

The following are suggested attachments for connecting the rockets to the waste module jettison vehicle:⁸⁵

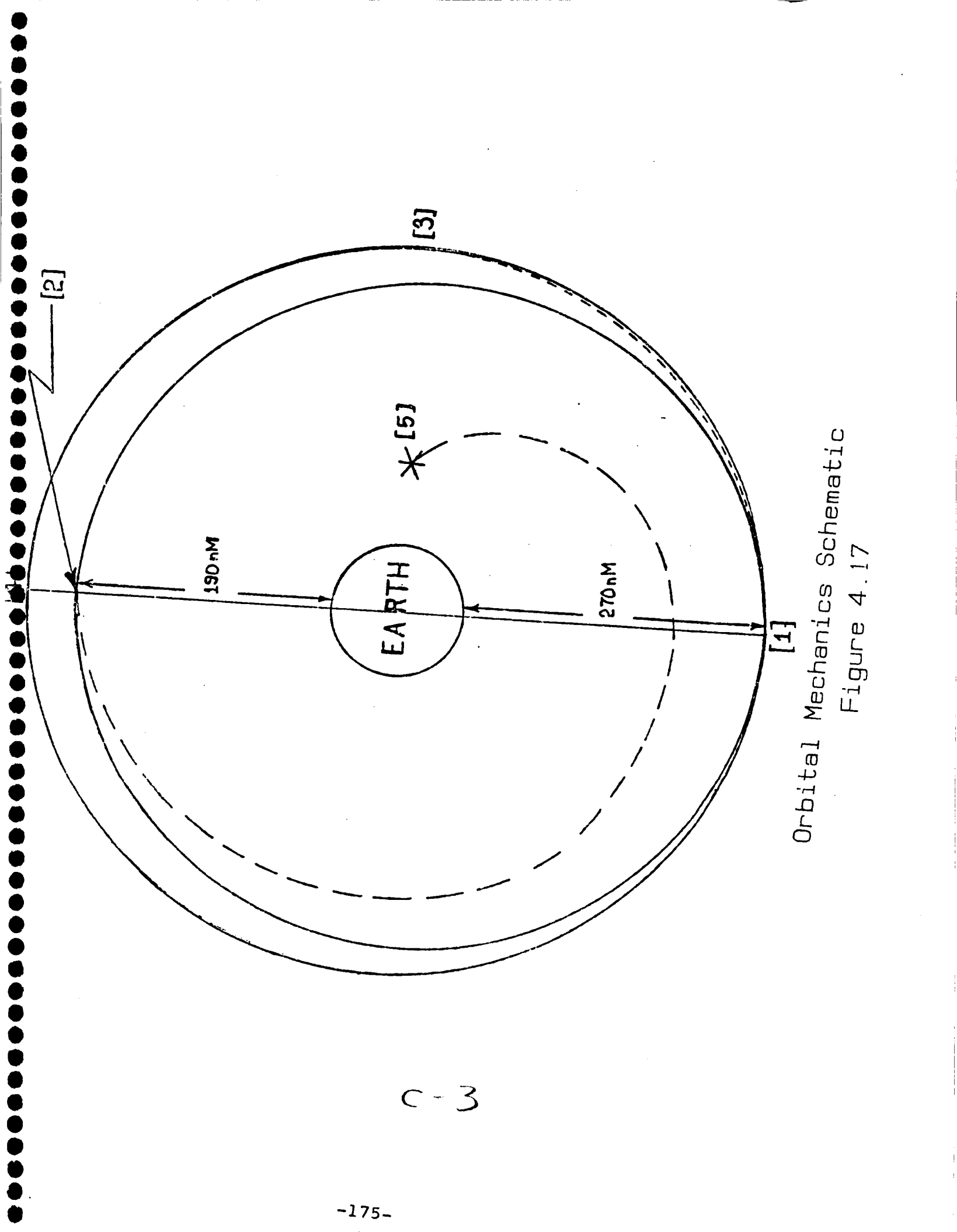
1. Bolt-on attachment.
 - a. Attached at the Space Station.
 - b. Pre-assembled on Earth.
2. Snap ring attachment much like a "camera-lens" configuration.
3. An attachment like that used to connect the waste module to the waste management node aboard the Space Station.

The attachment of the resulting rocket/jettison vehicle (RJV) to the OMV is accomplished using the OMV's grappling device. The grappling device is to connect to one of two proposed attachment locations:⁸⁵

1. A stud device attached at the center of the waste module lid. The OMV will grasp the stud after the Canadian Manipulator Arm (CMA) places the RJV alongside the Space Station.
2. The same stud device attached to the side of the structural frame. This location allows both the CMA and the OMV to manipulate the RJV.

Chapter 36. ORBITAL MECHANICS TO ACHIEVE DISTANCE FROM SS

The following is a scenario of the orbital mechanics involved to achieve at least an 80 nautical mile separation distance between the Space Station and the RJV before rocket burn is used (see Figure 4.17). In using Figure 4.17, the positions [#s] indicate proper orientation assuming a 90 minute orbit:⁸⁶



Orbital Mechanics Schematic
Figure 4.17

C-3

Jettison Propulsion II

- [1] At time(t)=0 minutes, the Space Station (SS), with the RJV on board, are in a slight elliptical orbit of 190 nautical miles (nM) perigee and 270nM apogee.
- [2] At t=45 min., separation begins.
- [3] At t=135 min., the OMV assisted separation distance is achieved.
- [4] After the rendezvous, the SS is reboosted into a 270nM near circular orbit.
- [5] At t=225 min., the RJV is at the elliptical orbit perigee of approximately 190nM or less (due to radial burn (TBD) and the OMV separation distance).
- [6] The SS is in the higher circular orbit.
- [7] At t=225 min., ignition is initiated to the rocket creating, with smart capabilities, the deorbit path to fire-ball incineration without detrimental effects to the SS.

Chapter 37. DISPOSAL SITE OPTIONS

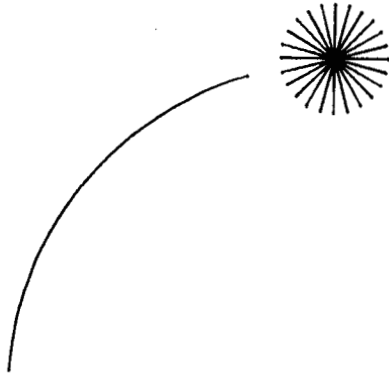
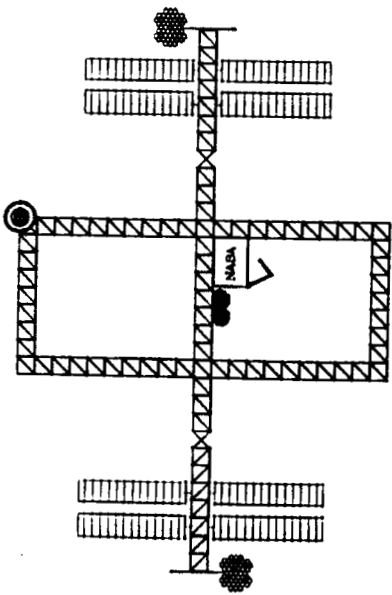
The following disposal sites were studied for their feasibility for the refuse disposal system:

1. Atmospheric incineration via Earth reentry.
2. Voyage to the moon.
3. Voyage to libration points.
4. Voyage to the sun.

37.1 Atmospheric Incineration Disposal Site

The use of the OMV assisted by an expendable rocket as a transport system is definitely the best solution for the incineration of disposable refuse via reentry into the Earth's atmosphere (see Figure 4.18). In order to achieve incineration within one earth orbit, certain parameters are critical. The jettison vehicle assembly must achieve a total change in velocity (ΔV) of 280 ft./s. and must have an upper weight limit of 5000 lbs. This limit is the weight of the RJV less that of the rocket and includes the weight of the refuse, guidance systems, and structural design. Rocket specifications for interface with these parameters are presented in Chapter 38, Propulsions Options of this section. The size and weight of the required rocket when compared to that of the entire jettison vehicle assembly is relatively small if a solid or liquid propellant is used. The use of a solid propellant would result in a more simple design requiring less maintenance. However, if a liquid propellant is used, there would be no plume effects.⁹²

Because the RJV is launched in an orbit out of close proximity of the Space Station, the plume from a solid propellant would not interfere with station operations. As previously discussed, this safe separation distance is achieved with the proper utilization of orbital



EARTH

Atmospheric Incineration

Figure 4.18

Jettison Propulsion II

mechanics after Space Station reboost.⁸⁶ In any event, available stowage at station dock points should be equipped with proper shielding to protect propulsion devices (especially from solar radiation).⁹² The maneuverability and reliability of the jettison vehicle assembly could be greatly increased using certain instrumentation. A guidance control system for the RJV would ensure proper attitude. A spin table would induce a stabilized spin, augmented by cold gas ACS and Earth horizon sensors.⁸ Also, all rockets should be equipped with remotely controlled abort actuating safety devices.

The structural design of the jettison vehicle for earth incineration is relatively simple, composed of an aluminum frame mated to the rocket and guidance systems. The use of inexpensive, off the shelf, bolt-on propulsion rockets, which are readily available with today's technology, would also enhance the system's simplicity. Because this transport system is not complex, manufacturing and assembly costs are low. Operating costs are also relatively low because the change in velocity requirements are easy to achieve. The use of existing Space Station components help to cut costs as well. The accessible CMA arm could transfer the rocket or RJV to the waste management module thereby eliminating extravehicular activity. Heavy Lift Vehicles (HLV's), Titans, and other upper stage vehicles can be utilized to transport the disposable rockets (possibly already attached to the jettison vehicle) from Earth to the Space Station.⁸⁶ Use of the OMV is also the incorporation of an existing multipurpose station transfer vehicle for refuse management purposes.

Although atmospheric incineration appears to be a very reasonable solution, many conditions also make this alternative appear unfavorable. The probability of less than 100% incineration poses the largest threat, possibly creating detrimental effects to Earth and its inhabitants.⁸⁶ Also, atmospheric reentry creates holes in the protective ozone layer. These holes allow harmful radiation levels to penetrate into lower layers increasing the possibility of reaching the Earth's surface.⁹³ Because of these possible effects, there a bound to be repercussions from the general public leading to the imposition of environmental laws and bureaucratic red tape. Negative publicity could in turn create international tension similar to that which occurred after the fall of Skylab into the plains of Australia in 1979.¹⁹

In addition to problems on Earth, there are possible negative effects to space operations as well. Solid propellants can leave plumes 100 miles long and 200 miles wide. This trek can last up to two years and could harm sensitive instruments and tests if launches occur too close to the Space Station.⁸⁶ Also, liquid propellants require⁹² extensive maintenance and careful, temperature controlled storage. An alternative to using solid fuel is the use of cold gas, but this propellant has a low⁸⁶ specific impulse which requires a large, heavy containment vessel. The need for such a large vessel could create logistics problems and higher cost considerations.

37.2 The Moon as a Disposal Site

Another disposal site option is the moon. As before, the OMV is used to transport the RJV far enough away from the Space Station to eliminate plume impingement concerns. The OMV will then point the waste assembly in the proper direction, induce a spin on it, separate from it, and return to the Space Station. Meanwhile, the propulsion device of the RJV ignites and propels it along a predicted path impacting the surface of the moon (see Figure 4.19).

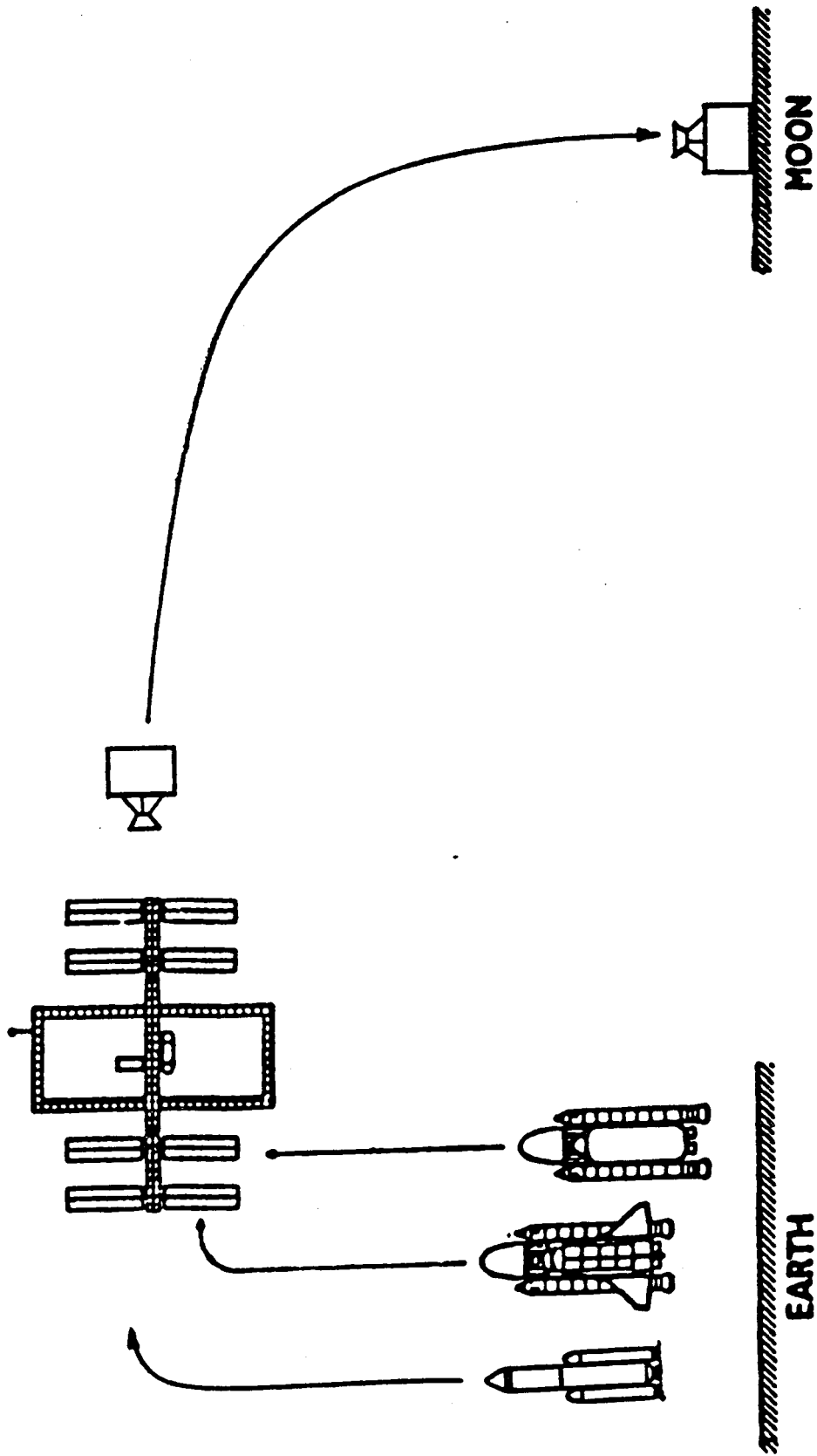
Voyage to the moon for refuse disposal is a feasible alternative for several reasons. Technology exists to propel the waste assembly to the moon's surface. Upper stages used on existing programs, such as Centaur and Transtage, have the necessary flight characteristics of a ΔV capacity equal to or greater than 9700 ft./s., restart capability, and guidance control systems. The moon is relatively nearby (235,596 miles), has frequent launch windows, and can be reached within a few days.⁸⁶ The refuse is logistically traceable such that the total load is guaranteed to contact the moon's surface at a known location.

Although the maintainability of this system is comparable to that for earth incineration, the larger ΔV requirement demands a more complicated system. Because the attainment of a larger ΔV requires a more complex vehicle and a larger supply of propellant, the cost of the system increases significantly. The delivery cost of the heavier disposable rocket from Earth also increases. Based upon the known dimensions of existing upper stages, the rocket is estimated to be about 10 ft. in diameter and 15 ft. long. In addition, the increase in needed propellant increases storage requirements, the facilities for which are very limited on the Space Station.

The disposal of refuse on the moon poses no immediate danger to humans and the Earth's environment. However, 'out of sight, out of mind' philosophies always seem to pose negative consequences later. In this case, using the moon's surface as a dumping site could cause problems for the proposed future colonization of the moon.⁸⁶

37.3 Libration Points as Disposal Sites

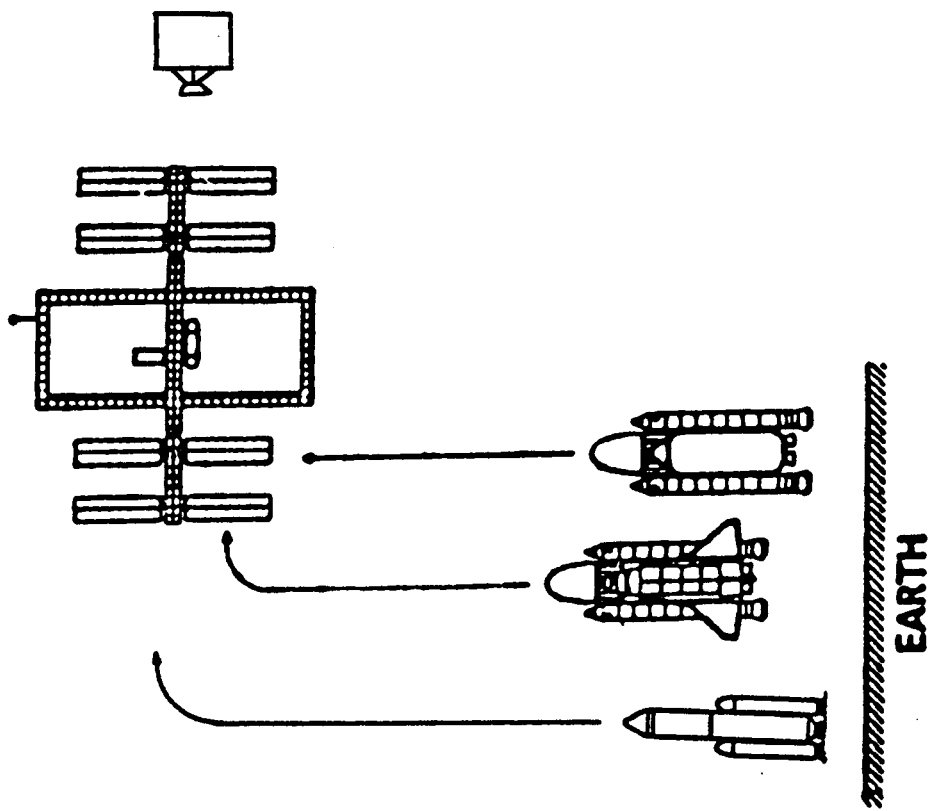
A third disposal option is an OMV assisted launch of the RJV to a libration point where the waste assembly remains indefinitely (see Figure 4.20). The existence of equilibrium positions in a rotating two-body gravity field was first demonstrated by the French mathematician J. Lagrange. He determined that there are five such "libration points" in each of these two-body systems. Three are situated on a line joining the two attracting bodies and the other two form an equilateral triangle with these bodies and the line joining them. There are seven libration points located in the vicinity of Earth. Five are members⁹⁴ of the Earth-Moon System and two are part of the Sun-Earth System.



Voyage to the Moon

Figure 4.19

L-POINT



Voyage to Libration Points

Figure 4.20

Use of libration points as disposal sites is advantageous in several ways. First, toxic wastes and other harmful Space Station by-products can be safely disposed of without risk. Possible collision with other spacecraft is minimal since the position of the waste assembly, corresponding to a particular libration point, is always a known, easily determined location. However, there is a possibility of an unpredicted collision with space debris which could disperse the refuse. Nonetheless, the use of libration points, for the most part, does not interfere with future space operations.⁹⁵ Finally, "although the three collinear points are unstable and the two triangular points are only quasi-stable, very little propulsion is needed to keep a spacecraft at or near one of these points for an extended period of time."⁹⁴

The stability of these points, although requiring "very little propulsion" for a vehicle to remain there, poses significant problems in the long run. At best, a jettison vehicle positioned at a quasi-stable libration point would require periodic (propulsive) repositioning to avoid drifting away. Because the vehicle is to remain there indefinitely, these position alterations will eventually consume the finite amount of fuel available. Even if the vehicle did not run out of fuel, other major positioning problems could develop. Also, as the number of vehicles at a libration point increased, the maintenance of their positions could become a tremendous task.

Other disadvantages arise from the large magnitude of the required ΔV , which can be as high as 10,000 ft/s. As discussed before, the larger the ΔV , the more fuel required and the larger the jettison vehicle. In turn, the amount of fuel and size of the vehicle are proportional to the amount of storage needed and the cost of the system. Another significant cost is that of the on-board attitude control provision necessary for libration point maintenance.

37.4 The Sun as a Disposal Site

A final disposal option involves sending refuse toward the sun. Although interplanetary missions are complex, current and future technology provide the means for this type of journey. The final destination points for a trip toward the sun might include:

1. A solar effective burn-up.
2. A "tight" solar orbit.
3. A relative solar orbit.

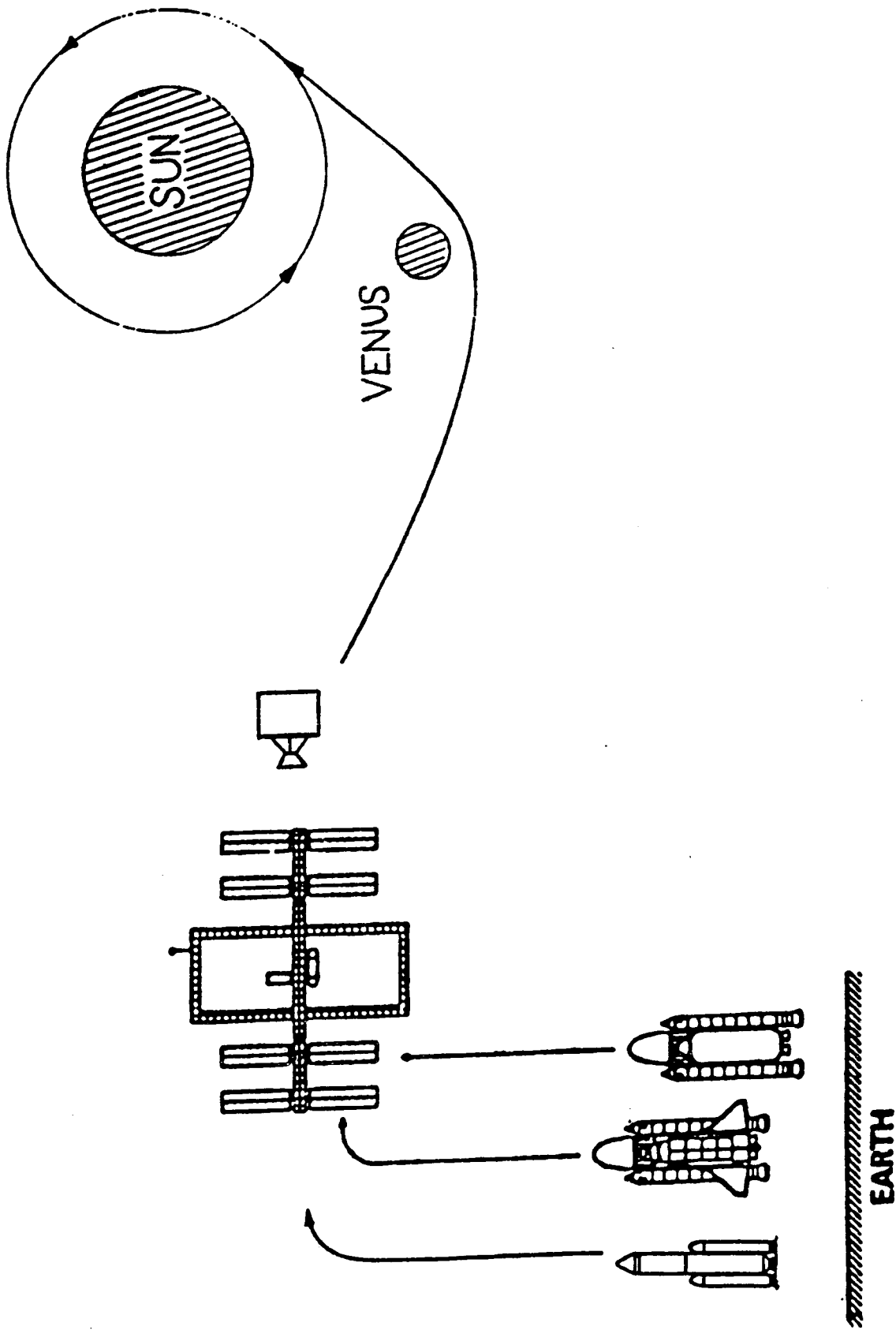
A solar effective burn-up involves strategies for targeting the RJV into the sun, providing incineration. The tight solar orbit would deliver the RJV to 0.1 AU (1 astronomical unit is equivalent to the distance from the Earth to the sun). The relative solar orbit is any heliocentric orbit relative to the Earth.⁹⁶

The distance of travel to the sun is approximately 93 million miles.⁹⁶ For comparison, Mercury lies 36 million miles (.38 AU) from the sun.⁹⁶ A solar orbit of .1 AU has been described as "...one of the most difficult missions within the solar system".⁹⁷ However, several unmanned probes have already obtained solar orbit with frequent success. They include the Pioneer (U.S.) (Pioneer 6 - 12 attained solar orbits on the order of .814 to .985 AU)⁹⁸, Solarmax (E.S.A.), and Helios (U.S.S.R) projects.⁹⁸ A "mere boost" is all that is required from the Space Station to deliver a solar orbit. To attain a tighter orbit about the sun, an⁹⁹ additional impulse of about 0.2 to 0.6 kg. of added thrust is needed.

The following scenario describes a possible journey from the space station to the sun. The RJV launches far from the Space Station's surrounding environment following the OMV attitude adjustment as previously discussed. This launch attains the proper Δv in a direction opposite the Earth's⁹⁷ rotation to take advantage of the sun's gravitational pull.⁹⁷ Travel along this course enables an encounter with the planet Venus, the target planet for "gravity assist".⁹⁷ Due to the gravitational effects of this planet, the trajectory's velocity reduces to the required solar orbit (see Figure 4.21).

The gravity assist of the planet Venus aids the transportation of the RJV significantly. The gravitational effects of this planet are strong enough such that propellant needs are minimized. This lower propellant requirement enables the use of mid-size (Delta or Centaur) rockets. This gravity assist is also strong enough to change the speed and direction⁹⁷ of the RJV for proper orbit, as demonstrated by the Mariner 10.⁹⁷ Other advantages of the sun disposal option include the removal of hazardous waste and material difficult to incinerate without any safety risk to Earth, the Space Station, or to future space exploration.

Although the sun appears to be an ideal disposal site for many reasons, its selection is hindered by many factors. First, a flight to the sun using current technology is a very expensive endeavor. The solar orbit destination has a long flight time (6 months to many years) and a large Δv requirement resulting in higher energy expenditure.¹⁰⁰ Second, the need to use the gravity assist of the planet Venus presents problems as well. A high precision guidance mechanism and additional propulsion units, similar to the "signaled time pulse thrusts" on-board the Pioneer, are required for a successful rendezvous with Venus.⁹⁷ Also, the proper interception of this target planet requires the attainment of a critical trajectory. Because this trajectory is achieved via an iterative process, the overall reliability of success is decreased.¹⁰⁰ Finally, very little is known about solar wind effects and the sun's magnetosphere and until these factors are predictable, the sun cannot be considered as a refuse disposal site option. However, near future space endeavors include the placement of orbiting solar observatories, which may be able to provide more insight into such effects.¹⁰¹



Voyage to the Sun

Figure 4.21

Chapter 38. PROPULSION OPTIONS FOR DISPOSAL SITE TRANSPORTATION

The disposable rockets considered to propel the refuse to its final destination are divided into two types:

1. Rockets for atmospheric incineration.
2. Rockets for alternative disposal voyages.

38.1 Rockets for Atmospheric Incineration

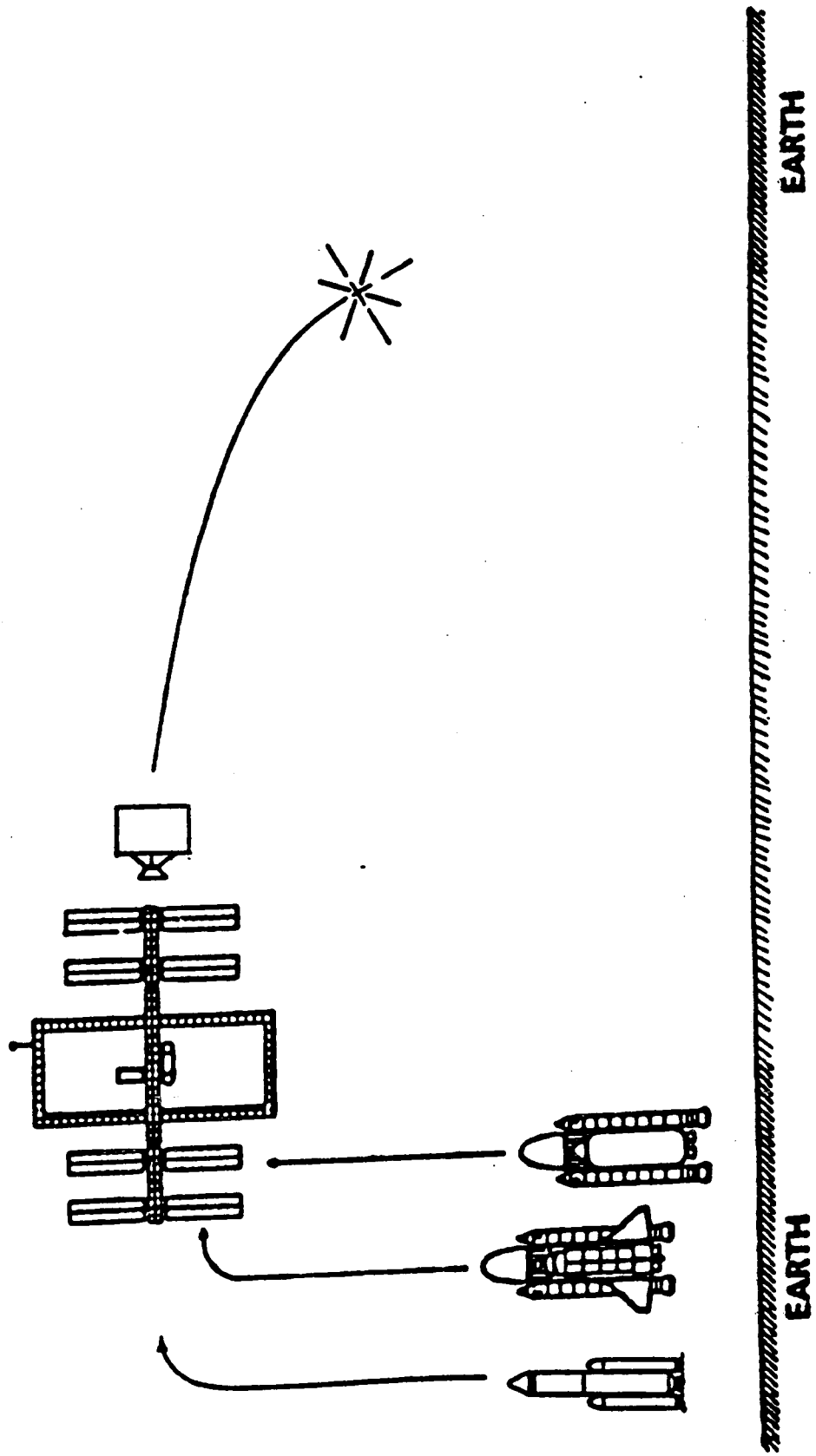
Three general types of rockets were considered to propel the jettison vehicle toward the Earth's atmosphere (see Figure 4.22). These rockets utilized either solid, liquid, or gas propulsion systems. Gas rocket designs were discarded because they require a huge containment vessel, and cryogenic and other liquid systems were eliminated due to their complexity, limited availability, and higher cost. Therefore, solid propulsion systems proved to be the most feasible for this application due to a relatively simple design, high availability, and less maintenance. The following bolt-on, off-the-shelf, solid rockets have the capability of achieving the required dV of 280 ft/s at the weight limit of 5000 lb. needed for atmospheric incineration:

1. STAR 17 (Morton Thiokol)
2. SKY FLASH/SPARROW (Aerojet)
3. MLRS (Atlantic Research)
4. UA-3KS5000 (United Technology Center)

A comparison of these expendable rockets is summarized in Table 4.1.

38.1.1 STAR 17 Rocket

The STAR 17 is a rocket motor which has been used as the apogee kick motor for the Radio Astronomy Explorer satellite, the SOLRAD Satellite, and an S-3 satellite (see Figures 4.23 and 4.24). It has been a very reliable rocket with a history of ten flight-worthy missions. The total weight with propellant is 174.3 lb, which makes this rocket the lightest of all solid rockets considered for this application. In addition to being the lightest rocket, its overall dimensions are also the smallest. The burn time of the STAR 17 is also longer providing better accuracy, stability, and maintainability into the Earth's upper atmosphere. The dV capability of 281 ft/s does not overly exceed the minimum design requirement of 280 ft/s; thus, this rocket is not overqualified for this purpose. Although this rocket seems to be the obvious propulsion solution given the data thus far, its off-the-shelf production cost of approximately \$40,000 is by far the most expensive of the four considered.



Expendable Rocket Incineration

Figure 4.22

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EXPENDABLE ROCKETS

Rockets	Propellant	I_{sp} (sec)	weight with Propellant (pound) _m	weight w/o Propellant (pound) _m	Total Impulse (lb _f -sec)	Propellant mass fraction	Max. Thrust (pound) _f
STAR 17 quantity: one	Solid TP-II 3062	290.0	174.3	20.8	44,500	0.881	2,775
SKY FLASH/SPARROW quantity: cluster of 2	Solid CTBD	•••	306.0	126.0	45,000	0.588	•
MLRS quantity: one	Solid Arcadene 360B HTPB	257.0	325.0	190.0	50,950	0.665	40,660
UA-3KS5000 quantity: cluster of 3	Solid UTP-1090	•	246.0	81.6	15,442	0.668	•

Pockets	Burn time average thrust (pound) _f	Operation temperature range	Case Material	Cost	Dimensions (inches)	Purn time/Action time (sec)	dV (ft/s)
STAR 17 quantity: one	2,460	0°-120°F	6A1-4V Titanium	≈ 40,000 each	27L x 17.4D	17.6/18.6	281
SKY FLASH/SPARROW quantity: cluster of 2	24,000	-66°-160°F	•	≈ 20,000 for both	51.7L x 8D	1.88/•	•
MLRS quantity: one	30,000	-25°-140°F	4130 Steel	1,500-2,000 each	77.6L x 9.3D	1.51/2.61	342
UA-3KS5000 quantity: cluster of 3	5,109	10°-130°F	6061-T6 Aluminum	≈ 30,000 each	45L x 6D	2.81/3.32	•

• Unknown

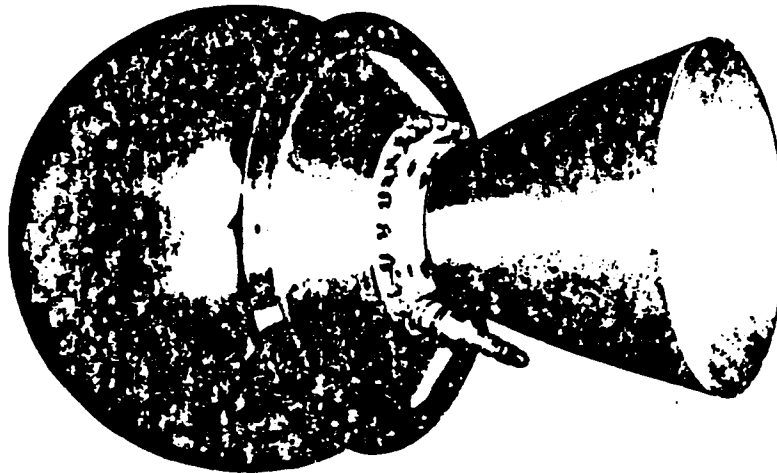
•• Action time total impulse

••• Classified

$dV = g I_{sp} \ln (m_1/m_f)$

Comparison of Expendable Rockets

Table 4.1



The STAR 17 motor has been used as the apogee kick motor for the Radio Astronomy Explorer satellite, the SOLRAD satellite, and an S-3 satellite.

MOTOR PERFORMANCE (70°F Vacuum)

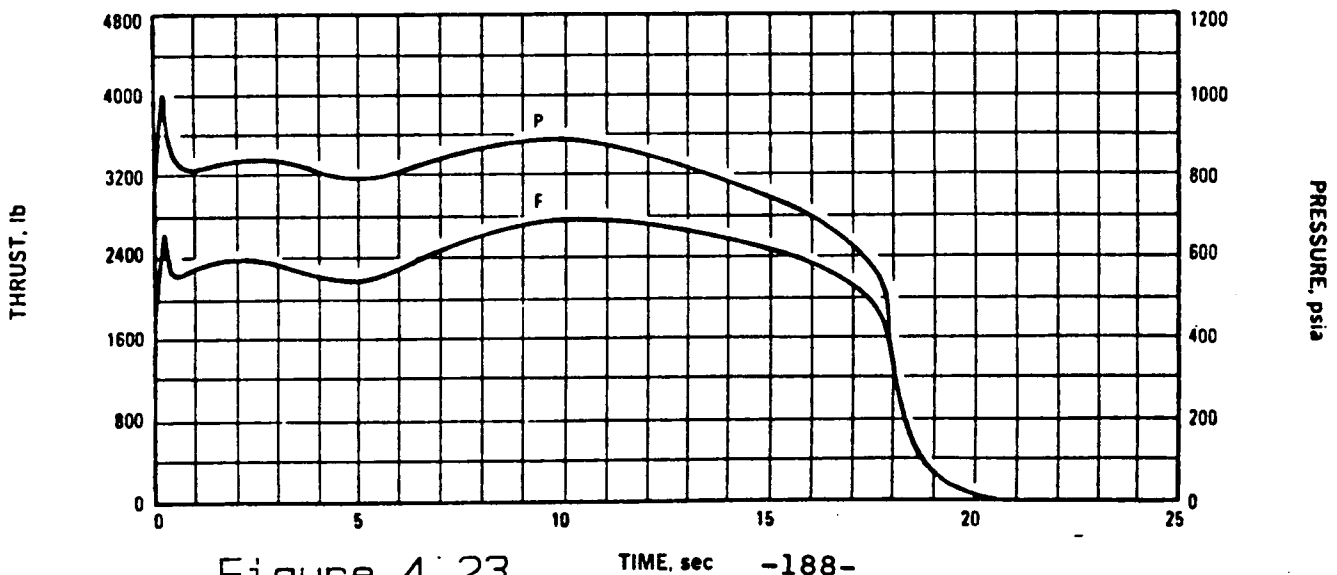
Burn Time/Action Time, sec	17.6/18.6
Ignition Delay Time, sec	0.060
Burn Time Average Chamber Pressure, psia	803
Action Time Average Chamber Pressure, psia	788
Maximum Chamber Pressure, psia	1,000
Total Impulse, lbf-sec	44,500
Burn Time Impulse, lbf-sec	43,300
Propellant Specific Impulse, lbf-sec/lbm	290.0
Effective Specific Impulse, lbf-sec/lbm	286.2
Burn Time Average Thrust, lbf	2,460
Action Time Average Thrust, lbf	2,380
Maximum Thrust, lbf	2,775

WEIGHTS, lbm

Total Loaded	174.3
Propellant	153.50
Case Assembly	8.80
Nozzle Assembly	7.0
Igniter Assembly	0.8
Internal Insulation	3.5
Liner	0.3
Miscellaneous	0.4
Total Inert	20.8
Burnout	18.8
Propellant Mass Fraction	0.881

TEMPERATURE LIMITS

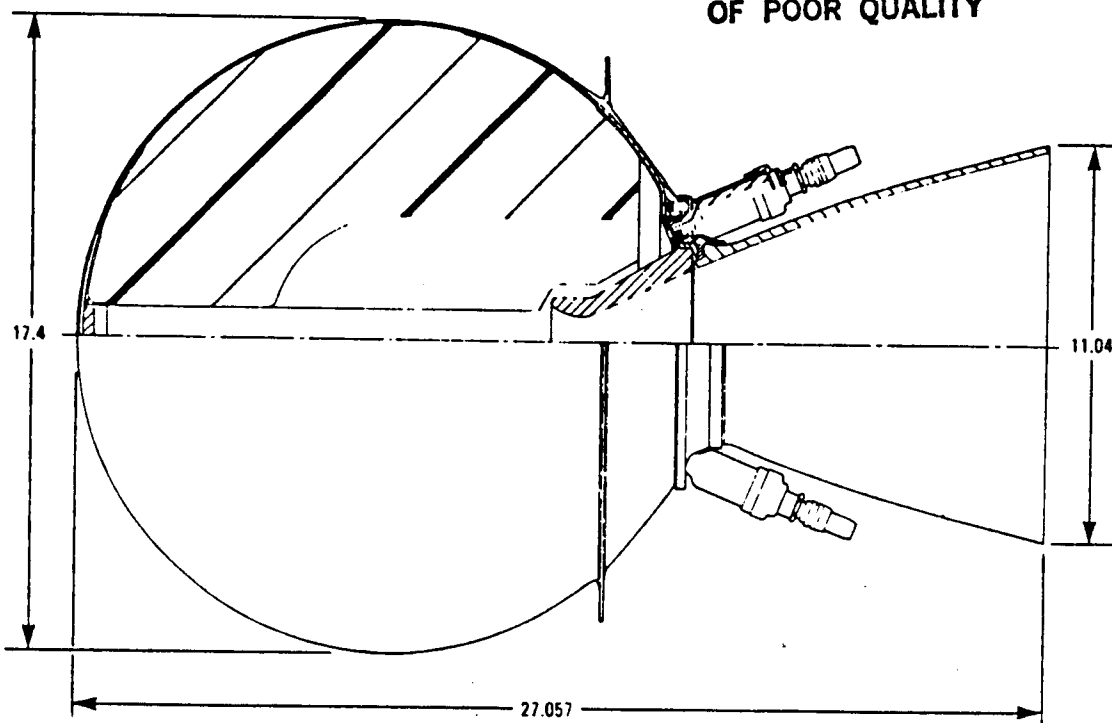
Operation	0 to 120°F
Storage	0 to 120°F



★ STAR 17
 TE-M-479
 17.6-KS-2,460
 ORBIT INSERTION MOTOR

MORTON THIOKOL INC.
 Elkton Division

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CASE

Material	6Al-4V Titanium
Minimum Ultimate Strength, psi	165,000
Minimum Yield Strength, psi	155,000
Hydrostatic Test Pressure, psi	1,267
Minimum Burst Pressure, psi	1,417
Hydrostatic Test Pressure/Maximum Pressure	1.1
Burst Pressure/Maximum Pressure	1.25
Nominal Thickness, in.	0.041

NOZZLE

Body Material	Vitreous Silica Phenolic
Throat Insert Material	Graph-I-Tite G-90
Initial Throat Diameter, in.	1.372
Exit Diameter, in.	10.69
Expansion Ratio, Initial/Average	60.7/56.0
Expansion Cone Half Angles, Exit/Eff, deg	14.5/16.2
Type	Fixed
Number of Nozzles	1

LINER

Type	TL-H-304
Density, lbm/in. ³	0.046

IGNITER

Morton Thiokol Designation	TE-P-386
Type	Pyrogen
Minimum Firing Current, amperes	3.95
Squib Circuit Resistance, ohms	1.0 +0.2
Squib or TBI Compatible	2

PROPELLANT

Propellant Designation and Formulation	TP-H-3062
AP—70%	
Al—16%	
CTPB Binder—14%	

PROPELLANT CONFIGURATION

Type	Internal-Burning, 8-Point Star
Web, in.	5.225
Web Fraction, %	0.60
Sliver Fraction, %	2.7
Propellant Volume, in. ³	2,448
Volumetric Loading Density, %	94.8
Web Average Burning Surface Area, in. ²	456.0
Initial Surface to Throat Area Ratio	309

PROPELLANT CHARACTERISTICS

Burn Rate at 1000 psia, in./sec	0.301
Burn Rate Exponent	0.31
Density, lbm/in. ³	0.0628
Temperature Coefficient of Pressure, %/°F	0.10
Characteristic Exhaust Velocity, ft/sec	5,025
Adiabatic Flame Temperature, °F	5,662
Effective Ratio of Specific Heats (Chamber)	1.15
(Nozzle Exit)	1.21

CURRENT STATUS

Production

MORTON THIOKOL INC.

Elkton Division

P.O. Box 241, Elkton, Maryland 21921-0241 (301) 398-3000

Figure 4.24

Jettison Propulsion II

38.1.2 SKYFLASH/SPARROW Rocket

Four surplus SKYFLASH/SPARROW production motors are currently stored at Aerojet at a current cost of less than \$20,000 per dual motor (see Figure 4.25).⁸⁵ A cluster of two rocket motors is needed for interfacial design consideration with the jettison vehicle. These rockets have been determined to perform satisfactorily after long space storage if they are sealed in a multiple Mylar bag.¹⁰² The total weight with propellant of the dual motor is 306 lb, which poses a relatively high \$/lb payload cost in comparison with the other three.¹⁰² The specific impulse is classified and therefore the calculation of its ΔV capabilities is not possible at this time.

38.1.3 MLRS Rocket

The MLRS (Multiple Launch Rocket System) is used extensively for DOD because it is a very reliable as well as available rocket (see Figure 4.26). Its production rate is 300 per day at a cost of \$1,500 to \$2,000 per rocket which makes this the most readily available as well as least expensive rocket considered.¹⁰² Although only one MLRS is needed to achieve the ΔV , it remains the heaviest of the given rockets, making it unattractive for a cost per pound of payload cost consideration. The MLRS also has the fastest burn time with the largest average thrust.¹⁰² These properties may pose serious problems for precise controllability and maintainability into the Earth's upper atmosphere.

38.1.4 UA-3KS5000 Rocket

The UA-3KS5000 rocket is currently used as the Titan's booster separation motor (see Figure 4.27). Of the approximately 700 motors manufactured by United Technology Center, 150 have been successfully static tested and 500 have been delivered.¹⁰² The total weight with propellant is 246 lb. for the cluster of 3 rockets needed to achieve the minimum ΔV requirement. The burn time is 2.81 seconds with an average thrust of 5,109 lb_f. However, the cost of this rocket motor is estimated to be \$750,000 for 24 motors (\$30,000/motor) per year if it is in production, and \$1.1 million per year if not in production.¹⁰² In addition, a cluster of 3 rockets presents a more complicated interfacial design to the jettison vehicle.

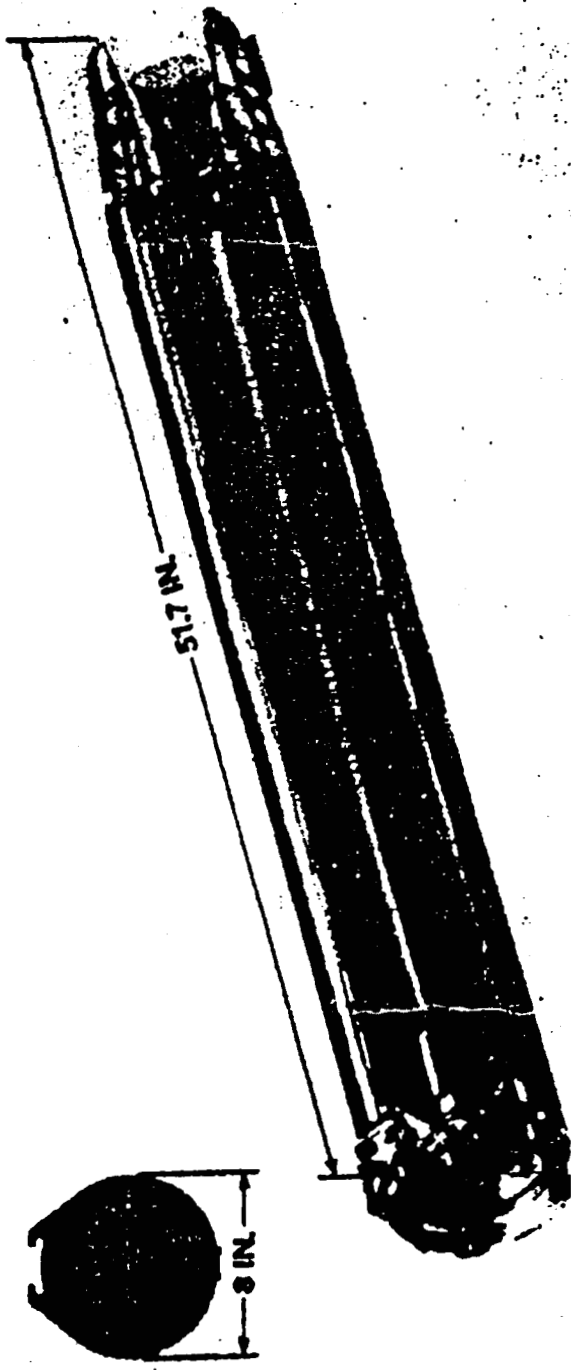
38.2 Rockets for Alternative Voyages (Upper Stages)

Upper stages, currently used to place payloads into various orbits, are characterized by several features. These stages utilize an attitude control system which is housed in a structure that attaches to the forward end of the payload. They are also equipped with a guidance

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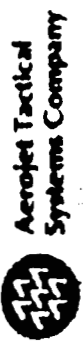
SKY FLASH/SPARROW

MK S2 MOD 2



UNITS PRODUCED _____ 11,000+	SPECIFIC IMPULSE NOMINAL SEC _____ CLASSIFIED
TEMPERATURE LIMITS, °F -- -65 TO +160	CHAMBER PRESSURE, NOMINAL PSIA _____ 1250
TOTAL WEIGHT, LBM _____ 153	TOTAL IMPULSE, LB-SEC _____ CLASSIFIED
PROPELLANT WEIGHT, LBM _____ 99	PROPELLANT _____ CTPS
THRUST NOMINAL LBF _____ CLASSIFIED	

1/78



Aerojet Tactical
Systems Company

Figure 4.25

MLRS Rocket

1.75KS-30,000

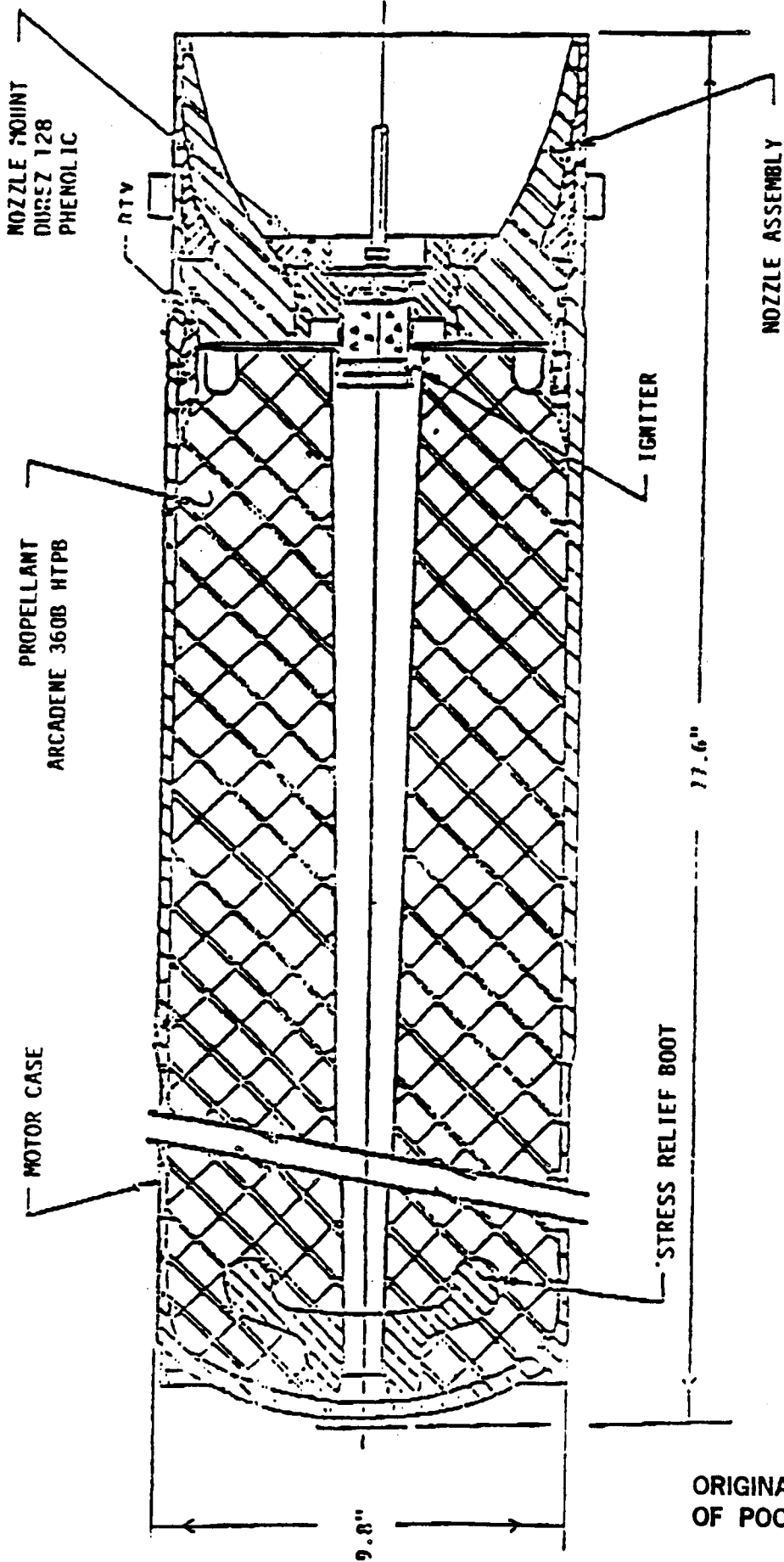


Figure 4.26

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motor mass fraction of 0.67. The propellant charge configuration is an internal-burning seven-point star, with additional burning on the aft end. The motor is hermetically sealed. Pertinent motor interface dimensions are shown in figure 3.

UA-3KS5000 Rocket Motor

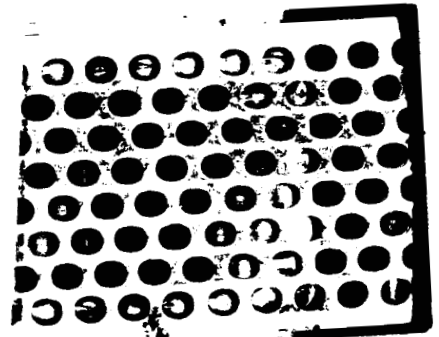
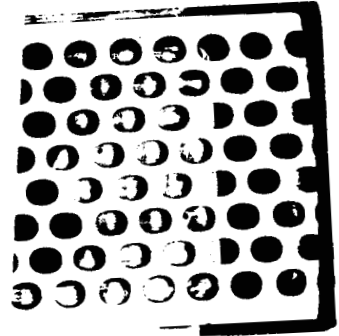
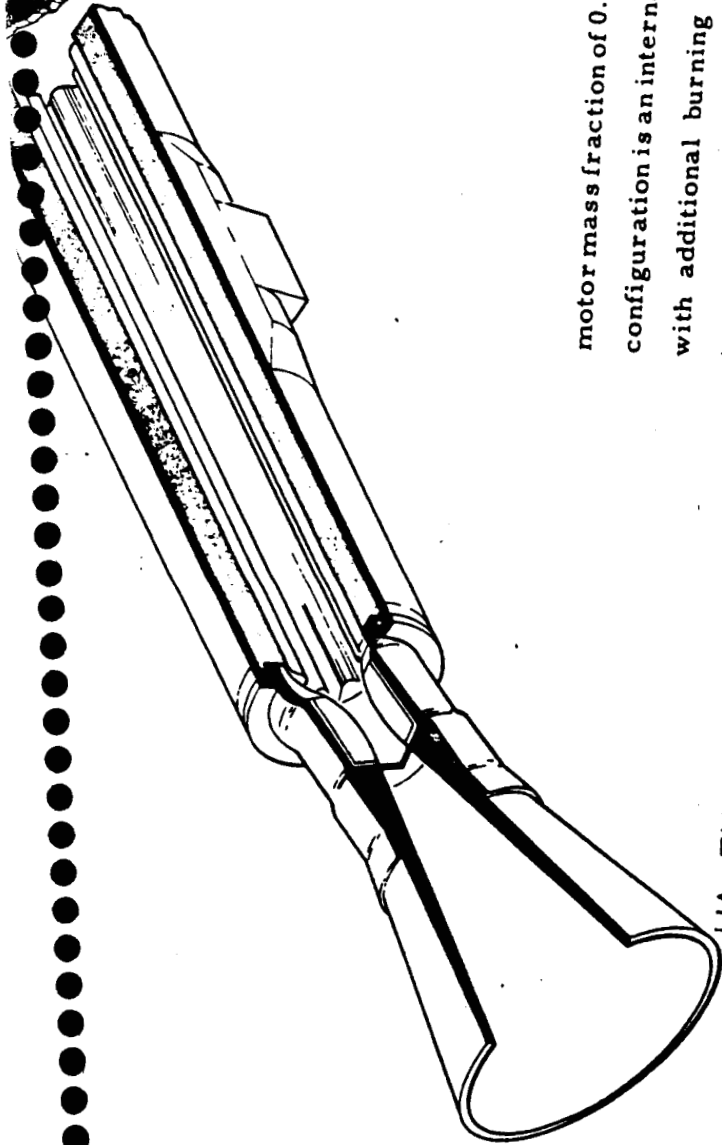


Figure 4.27 120

Jettison Propulsion II

system which provides position, velocity, and acceleration data to the control and command systems. This data enables ground control personnel to monitor flight performance and issue commands at the proper time. Finally, upper stage rockets use one of three types of propellant: solid, hypergolic, or cryogenic fuels.⁹²

Four types of upper stages were studied for their feasibility in the refuse vehicle launch system:

1. Payload Assist Module (McDonnell Douglas)
2. Inertial Upper Stage (Boeing)
3. Centaur (General Dynamics)
4. Transtage (Martin Marietta)

The capabilities of all of these rockets exceed those needed to achieve the large ΔV requirements of alternative voyages like the sun, moon, and libration points (see Figure 4.28). If necessary, these stages could even be down sized for this specific application. A comparison of these upper stages is summarized in Table 4.2.

38.2.1 Payload Assist Module

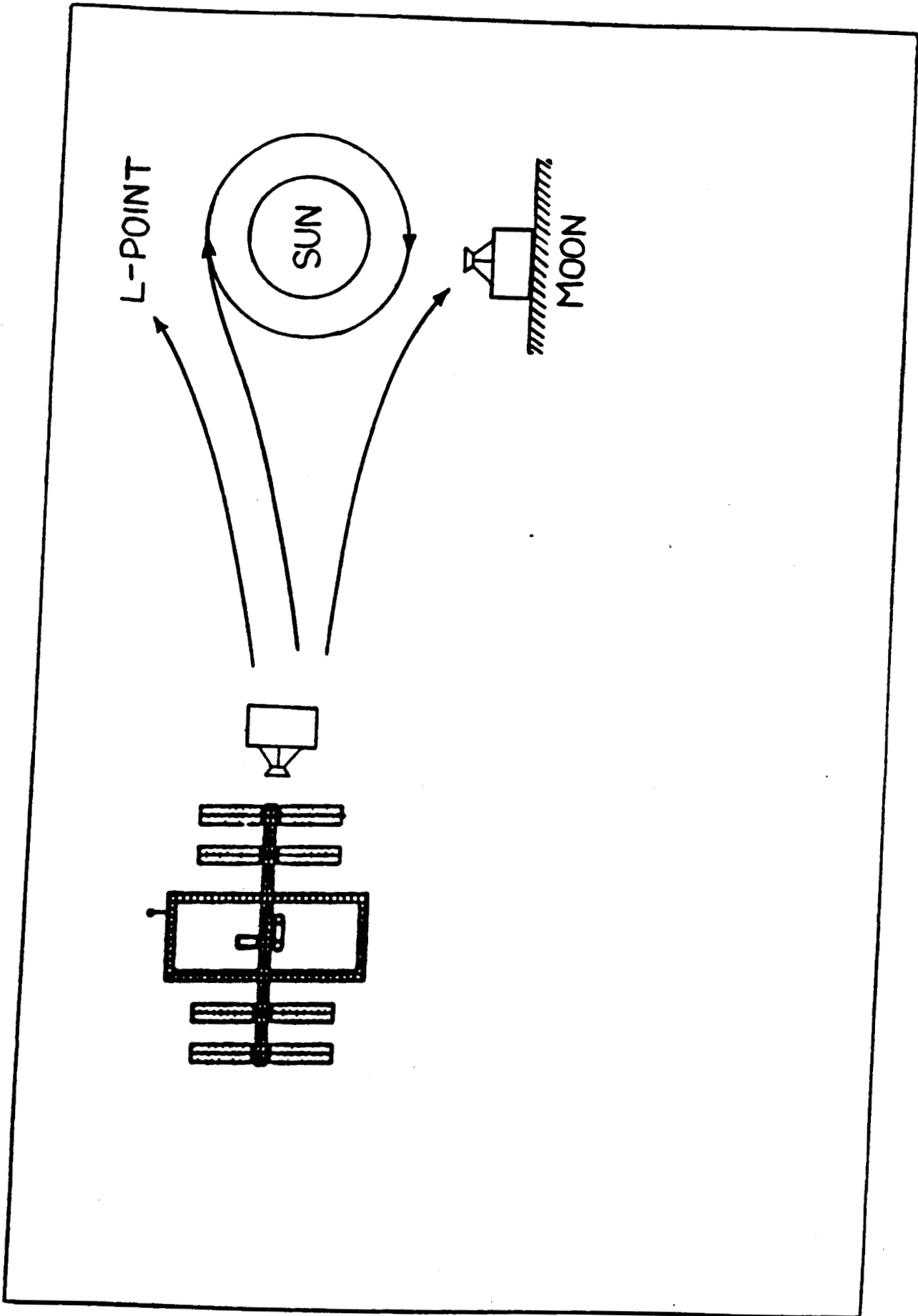
The Payload Assist Module (PAM) is a single stage solid propellant rocket which has been proven reliable on past Shuttle and Delta missions. The use of solid propellant as a fuel is, in itself, a highly reliable propulsion system which requires little maintenance. In this case, no auxiliary fuel storage is required as the solid propellant is stored in the rocket casing. Although reliable, solid rocket propellants do generate plume impingement large enough to be of concern to the Space Station. Another disadvantage of using PAM is its lack of restart capabilities essential in case of system failure.⁹²

38.2.2 Inertial Upper Stage

The Inertial Upper Stage (IUS) is a solid propellant two-stage rocket which has been proven reliable on past Shuttle and Titan missions. A major advantage of this rocket is that its two-stage design is equivalent to having restart capabilities. As previously discussed, solid rocket fuel is reliable, requires little maintenance, and can be stored within the rocket itself. However, this fuel also threatens the safety of the Space Station due to its generation of a large plume upon ignition.⁹²

38.2.3 Centaur

The Centaur is a liquid propellant rocket which has been proven reliable on Titan and Atlas missions. This rocket, like the IUS, does possess the necessary restart capabilities in case of system failure. The liquid propellant is composed of cryogenic (liquid hydrogen/oxygen) fuels which do not create an exhaust plume. However, this fuel type



Expendable Upper Stage Destinies

Figure 4.28

EXPENDABLE UPPER STAGES

UPPER STAGE	FUEL	I_{sp} (sec)	WEIGHT WITH PROPELLANT (pounds)	WEIGHT W/O PROPELLANT (pounds)	dV CAPABILITY (ft/s)	RELIABILITY	MAINTENANCE
Transtage	hypergolic	302.2	37,791	4,500	14,645	98%	high**
IUS	solid	294.3	29,334	1,693	15,495	98%	low
Centaur	cryogenic	444.0	34,200	4,200	20,723	94%	high***
PAM	solid	291.4	9,261	4,411	3,472	89%	low

* $dV = g I_{sp} \ln (m_i/m_f)$ where $g = 32.2 \text{ ft/s}^2$

I_{sp} = Specific Impulse

m_i = mass waste module + rocket + propellant

m_f = m_i w/o propellant

** Hypergolics require high maintenance due to mechanical components (seals, valves, fluid system).

*** Cryogenics require high maintenance due to mechanical components (seals, valves, fluid system) and need to be maintained at cold temperatures.

Comparison of Expendable Upper Stages

Table 4.2

requires a complex fluid system (composed of seals, electrical solenoid valves, mechanical operators, etc.) which requires significant maintenance. In addition, the hydrogen and oxygen require separate bulk storage vessels which must be maintained at low temperatures.⁹²

38.2.4 Transtage

The Transtage is a liquid propellant rocket which has been proven reliable on past Titan missions. This rocket is also equipped with unlimited restart capabilities in case of system failure. The liquid propellant is composed of hypergolic (hydrazine) fuels which require oxidizers (nitrogen tetroxide). Because combustion is so spontaneous upon contact, the fuels and oxidizers require separate bulk storage vessels at remote locations to minimize safety risks to the Space Station. Like the Centaur², significant maintenance is required for the fluid system components.

Chapter 39. PROPULSION OPTIONS FOR DISPOSABLE ROCKET TRANSPORT TO SS

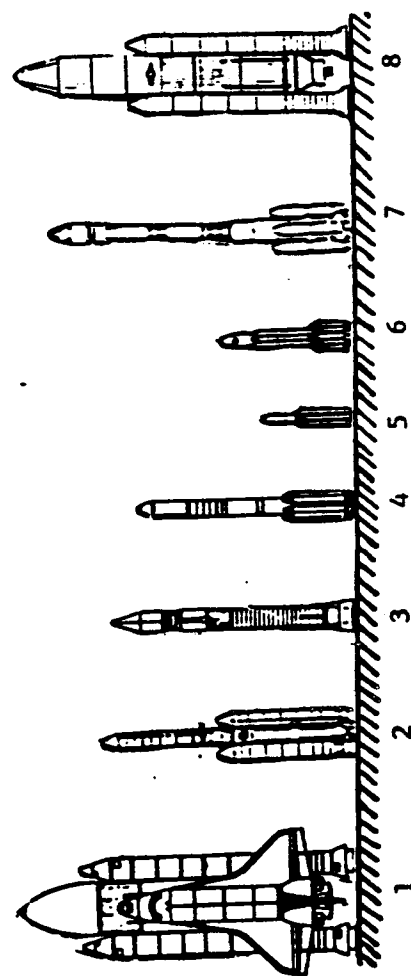
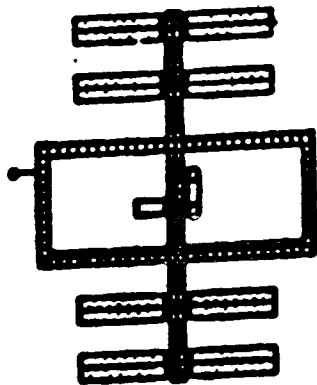
Initially, the Space Shuttle was proposed to transport the disposable rocket from the Earth to the Space Station. However, consideration of the cost of using the shuttle (nearly \$5000/lb.) and the human risk of transporting such a payload leads to further evaluation of alternative propulsion systems (see Figure 4.29).⁸⁴ Three expendable, unmanned vehicles are selected for this study:

1. Shuttle Derived Cargo Vehicle (NASA)
2. Titan 3 Commercial (Martin Marietta)
3. Delta (McDonnell Douglas/NASA)
4. Atlas/Centaur (General Dynamics)
5. Conestoga (Space Services, Inc.)
6. Industrial Launch Vehicle (AmRoc)
7. Jarvis (Hughes Aircraft)
8. Ariane 4 (European Space Agency)

A comparison of these vehicles is summarized in Table 4.3.

39.1 Shuttle Derived Cargo Vehicle

The Shuttle Derived Cargo Vehicle (HLV) is an unmanned, expendable delivery vehicle which is currently being examined as an advanced transportation system for greater payloads. It is to be designed to deliver typical payloads of 80,000 to 150,000 lb./flight to the space station.¹⁰³ Therefore, this type of vehicle is capable of transporting more disposable rockets per launch than the shuttle and without risk to human life. However, this transportation system is still in the design phase and lack of cost and performance data prohibits its consideration for the refuse disposal system.



1. Space Shuttle
2. Commercial Titan III
3. Atlas/Centaur
4. Delta
5. Connestoga
6. ILV
7. Ariane
8. Jarvis

Payload Launch Vehicles

Figure 4.29

Payload Launch Vehicles (Earth to Space Station)

Launch Vehicle	Cost (millions)	Payload Capacity (pounds)	Cost per pound	Reliability
Shuttle	\$150 - \$200	40,000	5,000	96%
Delta	\$35 - \$40	5,500	6,800	95%
Titan 3 Series	\$90 - \$150	32,000	3,750	96.3%
Heavy Lift Vehicle	\$200*	80,000 to 150,000	2,500*	96% **
Atlas-Centaur	\$70	13,500	5,200	96.5%
Conestoga	\$15	300 - 3,000	5,000	***
Industrial Launch Vehicle	\$5 - \$8	3,000	2,350	****
Jarvis	\$150	85,000	1,800	*****
Ariane 4	\$80 - \$95	17,216	5,100	81%

- * Assumed cost per flight equal to Shuttle (Shuttle derived vehicle)
- ** Assumed same reliability as Shuttle (Shuttle derived vehicle)
- *** Testing stage - successful suborbital launch 1982
- **** Testing stage
- ***** Proposed

Comparison of Payload Launch Vehicles

Table 4.3

39.2 Titan 3 Commercial

The Titan 3 Commercial, the newest member of the Titan 3 Series family of expendable space launch vehicles, is an unmanned, multistage rocket designed to meet the demands of a variety of missions. It is capable of transporting payloads of up to 31,000 pounds and placing them into a low earth orbit.¹⁰⁴ Because the Titan 3 is the largest U.S. launch vehicle in both size and payload capability, more RJV's could be transported in one flight. As a derivative of the Titan Family (in service for over 20 years), this vehicle has a proven performance record of better than 96% success rate. In addition, the Titan 3 is a commercial vehicle which has a reflight guarantee at a competitive price of \$3,750/lb.⁸⁷

39.3 Delta

The Delta is also an expendable multistage vehicle which has the capability of placing a 1300 lb. payload into a low earth orbit.⁸⁷ Like the Titan Family, the Delta Family (also in service for over 20 years) has a proven performance record and is presently a very reliable means of unmanned transportation. Although this launch vehicle system is under NASA jurisdiction, its payload capacity is limited which can result in higher cost when compared to using larger payload carriers.⁸⁷

39.4 Atlas-Centaur

The Atlas-Centaur, operational since 1966, is a multistage expendable launch vehicle used to launch government and commercial space missions.¹⁰⁵ This vehicle has the capability of placing 13,500 lb. into low earth orbit with a reliability of about 96.3%.⁸⁷ However, its cost per pound of payload of \$5,200 is greater than the Space Shuttle at \$5,000/lb.⁸⁷

39.5 Conestoga

The Conestoga is a commercial expendable launch vehicle which underwent a successful sub-orbital test in 1982.⁸⁷ However, this vehicle is still in the testing stages and lacks proven performance record to determine its reliability. Its cost per pound of payload is estimated to be about the same as the shuttle at \$5,000/lb.⁸⁷

39.6 Industrial Launch Vehicle

The Industrial Launch Vehicle (ILV) is a small commercial payload launcher capable of placing 3,000 pounds into low earth orbit. Its cost per pound of payload is significantly lower than the shuttle at \$2,350/lb. versus \$5,000/lb.⁸⁷ However, this vehicle also lacks a proven performance record to determine its reliability.

39.7 Jarvis

The Jarvis is currently a new launch vehicle proposal from Hughes Aircraft Company. It is to be capable of placing 85,000 pounds into low earth orbit at a very low cost of \$1,800/lb.⁸⁷ However, because the vehicle is not fully developed and no data exists to verify its performance, it is not considered as a likely solution for disposable rocket transport.

39.8 Ariane 4

The Ariane 4, owned by the European Space Agency, is a commercial launch vehicle. It is capable of placing 17,216 pounds into low earth orbit at an approximate cost of \$5,000/lb.⁸⁷ However, its reliability of only 81%⁸⁹ is somewhat lower than many of the other vehicles considered.

Chapter 40. JETTISON PROPULSION OPTIMAL SOLUTION - PHASE II

40.1 Solution Discussion

According to the Solution Matrix 4.3 of Appendix A, the most optimal disposal site was atmospheric incineration with the moon disposal option as a second choice. The most important factors upon choosing the disposal site were cost, time, simplicity, and safety. Atmospheric incineration has feasibility advantages in present technology and simplicity. Simple, off-the-shelf, rockets combined with OMV attitude control enable a relatively easy atmospheric burn-up voyage. On the other hand, the Moon and interplanetary travel (Sun and libration points) all require sophisticated guidance control and additional propulsive devices for larger dV requirements (10,000 ft/s vs. 280 ft/s for atmospheric incineration). Libration points also require periodic reboost due to instability. Voyages to the Sun, Moon, and libration points also require more energy consumption, larger rockets, and larger storage requirements.

Although atmospheric incineration is chosen as the most feasible disposal site, many problems remain significant with its use. First, there are potential detrimental effects to the Earth's environment from pollutant burn-up. This is especially true if hazardous waste is injected into the atmosphere. Second, the logistics of determining the exact location of the refuse after the RJV has initiated fireball is difficult. Large and/or hard-to-burn material may not achieve full incineration and the remains could fall to the Earth's surface. For these reasons, atmospheric incineration is suggested for only those materials with negligible environmental effect potential such as papers and light plastics. For heavier and hazardous refuse materials, a remote section of the moon, far from potential sites of future lunar missions, is suggested as a disposal site.

Jettison Propulsion II

Having determined atmospheric incineration as the optimal disposal site, the STAR 17 rocket motor proved the best to interface with the jettison vehicle. Solution Matrix 4.4 determines the MLRS to be the optimal choice, however, the high payload cost of launch vehicles revealed weight to be a critical factor in selecting the STAR 17 over the MLRS. Minimizing the unit weight is desirable since the Titan 3, the chosen payload launch vehicle, has a \$3,750/lb. payload transportation cost.⁸⁷ Simple calculations demonstrate this fact:

$$\begin{array}{r} 325 \text{ (lb.)} \\ -174.3 \text{ (lb.)} \\ \hline 150.7 \text{ (lb.)} \end{array} \quad \begin{array}{l} \text{(MLRS)} \\ \text{(STAR 17)} \end{array}$$

$$\$3750 \text{ (/lb.)} \times 150.7 \text{ (lb.)} = \$565,125 \quad (4.1)$$

According to Equation 4.1, the transportation cost of the MLRS would cost \$565,125 more than the STAR 17. Also, the difference between the unit cost of a STAR 17 at approximately \$40,000 and the MLRS at \$2000 is \$38,000 in favor of the MLRS. Therefore, the total difference in cost of a MLRS as compared to the STAR 17 is \$527,125 more.⁸⁵

Other important parameters used for comparison were size, operational performance, availability, and reliability. The dimensions of the STAR 17 are the most compact of all rockets considered at 27 inches in length by 17.4 inches in diameter.⁸⁵ Also, the STAR 17 requires only one rocket for this particular application as opposed to clusters (two or more rocket motors combined) required by other rockets. Therefore, these factors combined constitute a less complicated interface with the jettison vehicle. The STAR 17 is also a highly available off-the-shelf vehicle with 10 successful flights and tests as of June 2, 1986 (for more comparative information, consult Table 4.1).⁸⁵

The attachment of the rocket to the jettison vehicle is to consist of a simple bolt-on arrangement.⁸⁵ Pre-assembly of the RJV on Earth as a complete system will save valuable time and money in both transportation aboard a Titan 3 vehicle and manipulation on board the Space Station. Maneuverability of the RJV at the Space Station can be accomplished using a grappling device designed for the CMA and the OMV.

With the selection of attachment devices, a more detailed scenario of the orbital mechanics involved for deployment of the RJV for atmospheric incineration can be described (see Figure 4.17 in the Orbital Mechanics section). At time (t) = 0 min., the SS, OMV, and RJV are in a slight elliptical orbit of 190 nautical miles (nM) perigee and 270nM apogee [1]. At t = 45 min., separation begins [2]. The RJV is separated by the CMA which uses the grappling device at a predetermined location on the RJV. The CMA maneuvers the RJV by extending its arm for OMV hookup. After hookup, separation of the RJV/OMV from the SS begins after the CMA disengages with the grappling device. With cold

gas propulsion, the OMV maneuvers the RJV away from close proximity of the SS. After an adequate separation distance has been achieved, the OMV dislodges while inducing a spin on the RJV, then returns back to rendezvous with the SS. At $t = 180$ min., after the OMV rendezvous is complete, the SS is reboosted into a 270 nM near circular orbit from [1] to [3]. At $t = 225$ min., the OMV assisted separation distance is achieved; i.e., the RJV has achieved an elliptical orbit perigee less than 190 nM due to the OMV assisted launch [2], and the SS is in the higher near circular orbit [4]. Also at $t = 225$ min., ignition is initiated to the STAR 17 rocket creating, with smart capabilities, the proper deorbit attitude to fire-ball incineration [5] without detrimental effects to the SS.⁸⁶

Of the four upper stages considered for an alternative voyage to the moon, the IUS proved to be most optimal according to Solution Matrix 4.5. All four upper stages (PAM, IUS, Transtage, and Centaur) are equipped with the necessary guidance control, however PAM lacks the ability to achieve the necessary Δv of 10,000 ft/s required to escape the Earth's gravitational pull.⁹⁰ In addition, PAM is estimated to have the lowest reliability (89%), while Transtage and IUS have the highest reliability (98%) (see Table 4.2).⁹² The largest difference between the four stages is the type of fuel system they use. The Transtage uses hypergolics which require high maintenance due to fluid system mechanical components. The Centaur uses cryogenics which require even higher maintenance because in addition to being a liquid system, its fuel must be maintained at cold temperatures. The IUS and PAM are both solid rockets which require lower maintenance, but generate large plumes upon ignition. Another difference between the rockets is stowage requirements. The IUS and PAM require no fuel auxiliary stowage, while the Centaur and Transtage require separate bulk storage vessels. A final consideration was the existence of a restart system in case of failure. Of the four stages, PAM was the only rocket which did not fulfill this requirement. Therefore, because of its high reliability, low maintenance, easy stowage, sufficient Δv and restart capabilities, the IUS is proposed as the propulsion system solution for a voyage to the moon disposal site.⁹¹

Evaluation of eight unmanned expendable launch vehicles (ELV's) to transport the disposable rocket (possibly pre-attached to the jettison vehicle) to the Space Station led to a Titan 3 Series as an optimal solution (see Solution Matrix 4.6, Appendix A). Alternatives to the shuttle were studied to decrease dependence on its already demanding mission workload and to decrease human risk involved with transporting such a payload. The cost of the eight ELV's range from \$5 to \$20 million. Since the payload varies from each vehicle, a cost per pound of payload was calculated to make a comparison (see Table 4.3). The Jarvis rated the highest (\$1800/lb.) while the Delta rated the lowest (\$6800/lb.). The shuttle was found to be slightly above average and the Titan 3 Series was below average (\$3750/lb.).⁸⁷ Another factor for comparison is reliability. Considering the shuttle's success rate of 1 failure out of 25 missions, it has a high reliability (96%).⁸⁸ The Delta, Titan 3 Series and Atlas-Centaur also have high reliability (95% to 96.5%).⁸⁹ The HLV is a proposed vehicle; however, since it is

Jettison Propulsion II

derived from the shuttle, it is safe to assume that its reliability will be comparable to the shuttle. Other ELV's have lower reliabilities or insufficient data prevents prediction of their reliabilities. Taking all of these factors into account, the Titan 3 Series, with its high reliability, relatively low operational cost, and absence of human risk, is proposed to transport the disposable rocket to the Space Station.

40.2 Solution Summary

In summary, the proposed refuse disposal system consists of a RJV, an assembly made up of a refuse jettison vehicle connected to a disposable rocket, assisted by an OMV. The OMV is to transport the RJV away from the Space Station environment, release it, and then return to the Space Station. Meanwhile, the disposable rocket ignites sending the refuse vehicle to its final destination (see Solution Discussion/Summary--Phase I). The proposed refuse disposal sites, disposable rocket choices, and preferred payload vehicle to transport the rocket to the Space Station are as follows:

1. Disposal Site
 - a. Atmospheric Incineration - light plastics/paper
 - b. Moon - heavier/hazardous materials
2. Disposable Rocket
 - a. STAR 17 - Atmospheric Incineration
 - b. IUS - Moon Disposal
3. Payload Vehicle for Rocket Transport to SS
 - a. Titan 3 Series

Chapter 41. RECOMMENDATIONS FOR FURTHER STUDY

Beyond the scope of this study lie intriguing possibilities for Space Station refuse management. The following are areas of recommended study for a more detailed design:

1. An environment impact study should be performed to predict the advent of sending refuse to Earth or any alternative site.
2. Pending the by-product results of the station's refuse pyrolysis facility, a compatible rocket could be designed for RJV propulsion.
3. Future space manufacturing capabilities may make possible the assembly of a total RJV system, thereby eliminating the costly transportation of rockets.
4. Guidance controls, smart capabilities, and spin tables should be identified and incorporated in the overall design of the RJV. Furthermore, because of the possibility of refuse reaching the Earth's surface, these controls should be designed to coordinate fireball initiation to a point above an area of minimum population density.
5. The availability of additional off-the-shelf rockets to

interface with the required performance parameters should be further researched.

6. A rocket manufacturing company should be contracted to complete the design of the RJV to allow for mass production, simplicity, and cost reduction. This design should minimize RJV volume such that several RJV system can be transported (which helps to justify the \$/lb. cost of the payload launch vehicle cost).

SECTION V. GENERAL REFUSE SYSTEM INTEGRATION

SECTION V. GENERAL REFUSE SYSTEM INTEGRATION

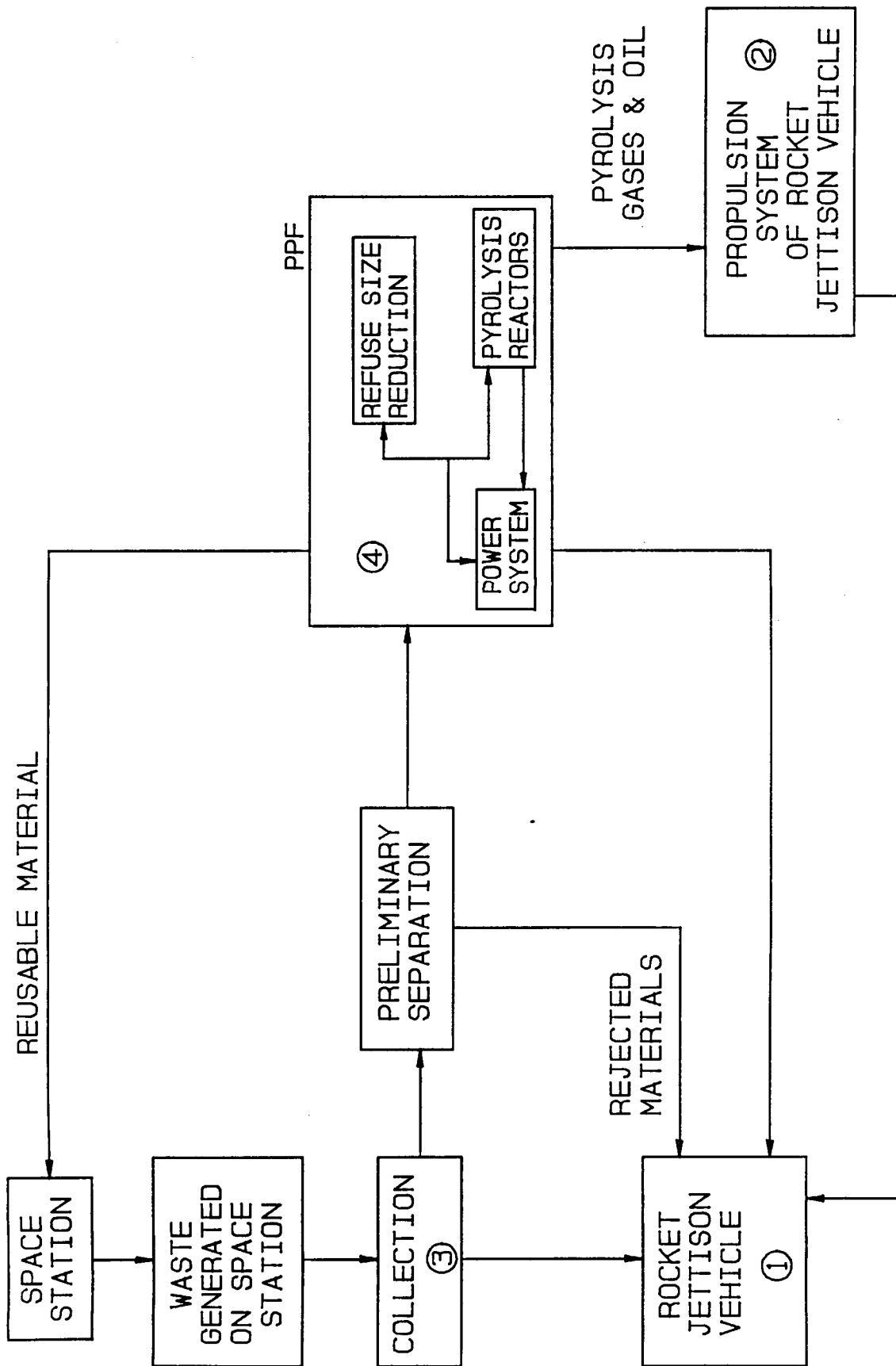
The purpose of this section is to describe the overall integration of the Space Station Refuse Management System. The general refuse system schematic is shown in Figure 5.1.

General waste types (paper, light plastics, used food packages) are collected in color coded plastic bags distributed throughout the modules. When full, these bags are sealed via a velcro or draw string closure and deposited directly into a compactor. This compactor reduces the waste volume such that its compacted shape is cylindrical. The reduced waste is then placed into bar coded canisters for deposit into multi-site "bank shuttle" receptacles located in various locations. Special refuse such as chemical, volatile, and/or toxic wastes may be collected into coded waste specific containers designed for direct transport through the "bank shuttle" system.

After collection, the refuse is transported through the "bank shuttle" network via a vacuum/blower motor force system. If requiring disposal, the appropriately bar coded trash canister is transferred either directly into the jettison vehicle or to an area convenient to its docking site. If the refuse can be recycled, it is transported to the PPF (see Figure 5.2 for PPF location). At the PPF, refuse is reduced further in the "Muffin Monster" shredder and transported directly into the Cyclonic Entrained-Flow Pyrolysis Reactor for processing. Any useless pyrolysis by-products are transferred to the jettison vehicle for disposal. Most of the fuel products are returned to Space Station storage facilities to be utilized later by various systems. However, some of this fuel is reserved as propellants for the jettison propulsion system.

When the rocket jettison vehicle (RJV) is filled to capacity, it is attached to an OMV (via the CMA) which transports the waste assembly out of the close vicinity of the Space Station. When a safe distance away, the OMV induces a stabilizing spin in the RJV while detaching to return to the station. The STAR 17 rocket then ignites, sending the waste assembly into the proper deorbit attitude for atmospheric incineration. This incineration is proposed only for paper and light plastics refuse types. It is suggested that any potentially dangerous materials be transported via and IUS Rocket/Jettison Vehicle assembly to the moon for remote disposal.

The expended jettison vehicle is replaced by transporting one from Earth as payload on a Titan 3 Series Rocket. To help justify the cost of transporting the vehicle as payload, the empty jettison container can be filled with Space Station logistics equipment and supplies. Once the vehicle is docked at the station ready for loading, the refuse management process can repeat its cycle.



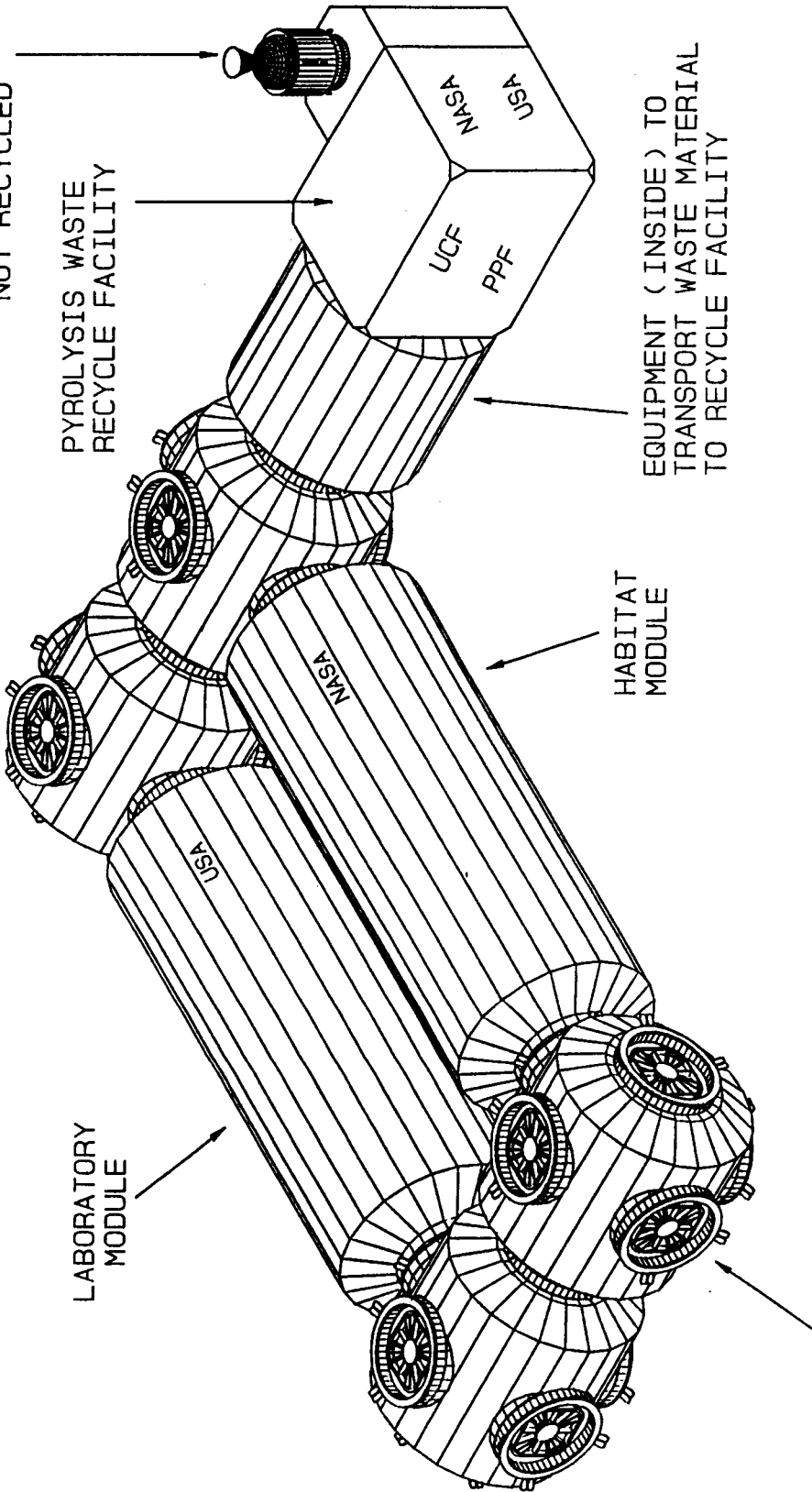
Refuse System Integration Flow Chart

Figure 5.1

JETTISON ROCKET
BEING FILLED WITH
WASTE MATERIAL
NOT RECYCLED

PYROLYSIS WASTE
RECYCLE FACILITY

EQUIPMENT (INSIDE) TO
TRANSPORT WASTE MATERIAL
TO RECYCLE FACILITY



LABORATORY
MODULE

HABITAT
MODULE

PRIMARY SHUTTLE
DOCKING PORT

SPACE STATION (PARTIAL VIEW) WITH PROPOSED
WASTE RECYCLE FACILITY AND JETTISON VEHICLE

Pyrolysis Processing Facility Location

Figure 5.2

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APPENDIX A

EXPLANATION OF SOLUTION MATRIX OPERATION

In general, the solutions of this report were selected by means of a Solution Optimization Matrix analysis. These matrices provide a concrete method of justifying the relative worth of various systems and components. Within these matrices, various methods of accomplishing a given goal are weighed against applicable performance parameters. The method which performs most positively with respect to its constraints is chosen as the best solution. In all cases, this evaluation was performed by using a numerical scale in order to rate the various methods and performance parameters. However, each design group assigned and manipulated the numerical values differently, and therefore, an explanation of each matrix set is given for reference. The definitions of the performance parameters considered are presented in the dictionary of Appendix B.

A.1 Matrix 1.1-2 Collection and Transfer: Design Phase I

These matrices contain numbers from 0 to 10 in which 0 is the least applicable to the desired objective, or performance parameter, and 10 is the most applicable. Some parameters were not applicable to a method and are indicated as so instead of a number. The parameters were also weighted from 1 to 3 with 1 being of lesser importance and 3 the most important. These numbers are shown in parentheses located in the title boxes of the performance parameters. The number used for the final evaluation of a given method was calculated by summing the applicability number times the weight of the parameter then dividing by the number of parameters applicable. These numbers are shown in the final average column. For each section of the subsystem, the highest number refers to the most optimal method.

A.2 Matrix 1.3-5 Collection and Transfer: Design Phase II

A weight factor was assigned to each performance parameter on a scale from 1 to 10 indicating an increase in the degree of importance with an increase in number. Each design proposal was then rated on a scale from 1 to 20 for each parameter, 20 representing the highest optimal ranking. Next, each ranking was multiplied by the designated weight factor and added successively for each of the design concepts. The ratings were collaborated and the averages were placed in the matrix for final analysis. Those parameters which were not applicable for certain designs were given a ranking of 10. The proposal with the highest score is the optimal design.

A.3 Matrix 2.1 Recycle/Reuse: Design Phase I

The number assignments used for each method were based upon a scale from 1 to 10. The following clarifies the significance of the highest, middle, and lowest rating with respect to the given performance parameter:

- 1 - Process meets desired objective excellently.
- 2 - Process meets desired objective fairly.
- 3 - Process meets desired objective poorly.

Once these values were determined, they were multiplied by a weighing factor which ranged from 1 to 5 as defined below:

- 1 - Performance Parameter is least important.
- 5 - Performance Parameter is most important.

For example, the most important parameter was safety while one of the least parameters was system flexibility. The final values for each method were added and the final value placed in the totals column. The smallest total value indicates the most optimal solution.

A.4 Matrix 2.2-4 Recycle/Reuse: Design Phase II

The categories to be evaluated were assigned numbers on a scale from 1 to 20, with 20 being the highest (best) score with respect to the given performance parameters. The parameters were also assigned a weight factor from 1 to 5 with 5 having the most significant weight, i.e. safety was weighted a 5. The scale factor of each method was then multiplied by the weight factor of the corresponding parameter. These resulting numbers were summed to calculate a score for each method. Each method was then rated by dividing the score by the total possible for that matrix, which in the case of the Pyrolysis Reactor Matrix is 1040. For instance, the Fluidized Bed Pyrolysis Reactor scored a 695. Therefore, its rating is:

$$(695/1040) \times 100\% = 66.8\%$$

The method with the highest rating is the optimal solution.

A.5 Matrix 3.1-2 Jettison Vehicle

Each proposal to be evaluated was assigned a numerical value between 1 and 10 according to how positively it responded to the given performance parameter (10 being most positive). The parameters were also weighted from 1 to 5 according to their importance as a design goal (1 being the least significant design goal). A proposed idea was evaluated by multiplying each assigned number to the weight of its respective parameter, and then summing these totals for a final score. The method with the highest score is considered the best solution.

A.6 Matrix 4.1-2 Jettison Propulsion - Design Phase I

Each of the launch systems and subsystems were rated against various performance parameter on a scale from 1 to 10. The higher the number, the more excellent the performance of the system with respect to the given constraint. The performance parameters were weighted on a scale from 1 to 4, with 4 signifying the most important parameter. These weighted numbers were multiplied with the ratings of a particular system and summed together. The system with the highest total is the optimal solution.

A.7 Matrix 4.3-6 Jettison Propulsion - Design Phase II

In these matrices, the rows contain the various options under investigation, while the columns list applicable performance parameters. A numerical value between 1 and 10 was assigned to each parameter, denoting quality (the best quality receiving a 10). A weight factor between 1 and 5 signifies a given parameter's relative significance. The products of the weight factor and the quality number are entered in corresponding matrix squares. The sum of the rows are compared, and options receiving the largest numerical value are selected as the optimal solution.

COLLECTION AND TRANSFER

METHOD	COLLECTION										TRANSFER										TOTAL	TOTAL APPLICABLE	AVERAGE
	(3)	(3)	(3)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)			
RECEPTACLE	5	7	4	9	9	8	8	9	6	5	7	8	8	N/A	5	7	N/A	180	15	12			
BAGS	9	4	6	N/A	N/A	6	9	5	2	3	9	9	4	N/A	8	4	N/A	136	13	10.5			
WASTE SPEC. CONTAINERS	2	8	5	8	8	9	5	9	5	8	9	5	7	N/A	9	8	N/A	174	15	11.6			
MAG. CONV. BELT	3	5	3	2	2	4	3	6	8	N/A	3	5	3	6	5	5	3	105	16	6.6			
TUBES BAFFLE TANK	7	8	8	5	5	5	7	5	8	N/A	6	5	4	4	6	8	6	170	16	10.6			
CONV. W/ HOOKS	5	5	3	3	2	6	7	6	8	5	8	6	2	2	5	5	3	125	17	7.4			
"BANK SHUTTLE"	7	8	6	5	5	8	4	7	9	5	8	9	8	5	8	8	5	188	17	11.1			
MANUAL	9	4	N/A	N/A	N/A	9	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A	2	4	N/A	72	7	10.3			
ROBOTICS	2	5	5	4	4	8	8	N/A	8	N/A	8	7	7	8	2	5	5	149	16	9.3			

10 MOST APPLICABLE N/A NOT APPLICABLE 0 LEAST APPLICABLE

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METHOD	REDUCTION										STORAGE								
	(3)	(3)	(2)	(2)	(2)	(2)	(2)	(2)	(1)	(1)	(1)	(1)	TOTAL	TOTAL APPLICABLE AVERAGE					
	LOW COST	CONTAM. RISK	SMALL VOLUME	ENERGY EFFICIENCY	LOW MECH. MAINTENANCE	RELIABILITY	SIMPLE WORKMANSHIP	DURABILITY	LOW MANUAL INVOLVEMENT	LOW RESUPPLY NEEDED	LITTLE/NO DISINF. REQ.	OPERATIONAL SIMPLICITY	APPEARANCE	INTERFACE (STANDARD)	CONVENIENCE	LOW LEGAL RISK	LOW VIBRATION	TOTAL	TOTAL APPLICABLE AVERAGE
COMPACTOR	8	6	7	4	6	8	5	8	6	4	5	8	8	8	8	6	5	183	17 10.8
SHREDDER	5	4	5	3	3	6	4	4	6	5	3	7	6	7	7	4	4	129	17 7.6
MAGNETIC	3	5	3	2	2	4	3	6	8	N/A	3	6	3	6	5	5	3	102	16 6.4
WIRE MESH	7	4	7	5	5	5	6	5	5	5	4	6	4	3	5	4	7	149	17 8.8
CENTRIFUGE	5	5	5	4	5	6	5	5	5	N/A	5	6	6	3	5	5	3	133	16 8.3
BAR CODE	8	9	N/A	8	N/A	9	7	N/A	9	N/A	N/A	N/A	N/A	8	9	9	N/A	134	9 14.9
MANUAL	9	3	N/A	N/A	N/A	8	N/A	N/A	0	N/A	N/A	N/A	N/A	9	2	3	N/A	66	7 9.4
HONEY-COMB	8	8	4	8	9	9	8	9	8	7	8	7	8	N/A	7	8	N/A	199	15 13.3
"COKE MACHINE"	5	7	4	6	7	8	7	9	8	7	8	8	7	N/A	7	7	N/A	174	15 11.6

10 MOST APPLICABLE N/A NOT APPLICABLE 0 LEAST APPLICABLE

RECEPTACLE AND TRANSFER DESIGN

	COST	SAFETY	HUMAN INTF	TIME	EVA/IVA	MAINTAINABILITY	MAINTENANCE	RELIABILITY	CONTAMINATION	SIZE	EFFICIENCY	SIMPLICITY	DURABILITY	APPEARANCE	DISTURBANCE	ENV EFFECT	PERFORMANCE	MASS	STORAGE REQ	POWER REQ	TECH MATURITY	TECH FEAS	TOTAL
	8	10	8	8	6	7	7	7	10	9	8	9	8	3	9	4	10	7	8	8	9	10	
SHAPES	Cubic	12	10	4	10	10	13	13	15	10	15	15	10	10	10	10	13	10	14	10	17	16	2146
	Cylindrical	13	10	13	10	10	16	17	17	10	16	17	15	10	13	10	16	10	13	10	18	17	2308
	Hexagonal	8	10	8	10	7	11	10	11	10	15	11	12	10	11	10	10	11	10	13	10	8	1774
MATERIALS	Polyethylene	13	15	10	10	10	13	13	15	15	10	10	10	18	17	10	10	16	10	10	18	18	2290
	HDN P-Ethyl	15	15	10	10	10	13	13	13	14	10	10	10	12	13	10	10	16	15	10	10	14	2083
	Polypropylene	17	15	10	10	10	13	13	15	15	10	10	10	18	13	10	10	18	17	10	10	17	2308
	H.D. P-Ethyl	17	15	10	10	10	13	13	15	16	10	10	10	18	15	10	10	18	17	10	10	16	2315
LABELING	Bar Coding	15	18	8	15	12	15	11	14	15	16	17	17	15	11	16	17	18	16	12	17	17	2623
	Color Coding	19	18	17	13	12	20	20	17	17	18	17	20	19	17	18	18	15	18	17	10	19	2930
	Disposal	9	17	15	18	13	13	13	14	10	18	12	11	14	10	18	12	15	18	12	15	19	2125
	Reusable	15	9	9	10	10	10	10	13	8	18	10	9	14	10	18	10	15	18	10	7	19	1732

STORAGE AND SANITIZATION

	COST	SAFETY	HUMAN INTF	TIME	EVA/IVA	MAINTAINABILITY	MAINTENANCE	RELIABILITY	CONTAMINATION	SIZE	EFFICIENCY	SIMPLICITY	DURABILITY	APPEARANCE	DISTURBANCE	ENV EFFECT	PERFORMANCE	MASS	STORAGE REQ	POWER REQ	TECH MATURTY	TECH FEAS	TOTAL
	8	10	8	8	6	7	7	7	10	9	8	9	8	3	9	4	10	7	8	8	9	10	
STORAGE SITES	9	16	15	12	11	11	10	11	16	16	15	11	12	15	15	14	13	12	13	12	11	12	2226
	12	13	15	13	16	12	10	11	8	10	14	13	13	15	12	13	11	13	11	16	13	15	2169
	12	10	10	10	10	16	14	15	10	13	13	15	11	10	11	12	8	9	10	10	14	13	2005
	10	11	10	10	10	15	14	10	8	10	11	13	11	10	11	12	8	11	9	10	14	12	1878
	14	10	10	10	10	15	15	10	8	10	11	16	11	10	11	13	8	8	8	10	13	12	2005
SANITIZATION	8	15	16	15	15	16	15	8	5	15	10	13	16	16	16	18	15	15	12	11	15	15	2323
	10	18	10	14	14	15	14	9	7	10	12	12	15	16	16	18	15	15	11	11	15	15	2276
	14	18	14	18	16	18	13	12	11	16	15	12	18	16	16	16	18	16	10	11	16	17	2601
	8	10	8	15	10	9	8	12	15	8	17	11	16	17	17	14	17	16	9	9	16	17	2196
	18	20	18	20	20	20	20	20	10	10	17	20	10	17	20	20	15	10	18	20	10	10	2799
	10	16	10	16	10	10	10	19	18	16	19	12	15	15	17	19	19	16	12	10	17	16	2580
	10	10	6	15	8	8	8	17	10	15	18	10	14	14	17	12	17	16	11	11	17	16	2232
	10	10	6	15	8	6	6	16	10	15	15	10	15	14	17	12	17	16	10	12	17	16	2129
	8	8	5	17	5	5	5	18	15	10	19	5	14	14	17	10	18	13	9	11	18	17	2093

NETWORK AND COMPACTOR MATRIX

	COST	SAFETY	HUMAN INTF	TIME	EVA/IVA	MAINTAINABILITY	MAINTENANCE	RELIABILITY	CONTAMINATION	SIZE	EFFICIENCY	SIMPLICITY	DURABILITY	APPEARANCE	DISTUBANCE	ENV EFFECT	PERFORMANCE	MASS	STORAGE REQ	POWER REQ	TECH MATURITY	TECH FEAS	TOTAL
NETWORK	8	10	8	8	6	7	7	7	10	9	8	9	8	3	9	4	10	7	8	8	9	10	
	17	11	8	7	9	15	14	16	16	16	10	13	13	10	13	14	13	15	14	16	13	15	2285
	13	14	15	14	15	11	11	14	15	13	16	14	14	12	13	13	16	11	12	14	13	16	2378
	CAPSULE																						
	14	15	12	12	13	12	13	14	15	12	14	13	15	10	12	13	13	10	11	10	16	17	2117
	13	14	11	14	13	13	13	15	16	13	15	15	16	17	12	13	14	11	11	10	17	15	2284
	11	14	9	10	13	11	11	13	14	12	14	11	14	10	12	13	13	10	11	10	15	15	2438
	NO CAPSULE																						
COMPACTOR DESIGN	17	15	14	13	13	15	14	14	12	12	12	13	15	10	11	12	9	11	12	11	14	16	2148
	15	14	15	13	13	15	13	14	11	13	12	13	15	10	12	12	13	11	12	11	16	14	2277
	14	14	13	13	13	14	13	14	10	12	12	12	14	10	11	12	10	11	12	11	13	13	2238
	13	16	14	16	16	14	13	15	14	13	15	15	15	10	11	10	14	15	13	12	16	16	2444
	16	17	8	9	8	14	16	17	14	14	17	14	16	10	11	9	12	17	15	17	17	18	2460
POWER SOURCE	15	17	10	10	14	15	13	14	10	15	16	13	15	10	12	14	15	13	11	17	17	16	2400

SOLUTION OPTIMIZATION MATRIX

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	⑤ SAFETY	④ COST	② AUTOMATION	③ POLLUTION	② EFFICIENCY (X 10%)	① POWER REQUIREMENTS	③ RELIABILITY	③ COMPLEXITY	① FLEXIBILITY	③ USEFUL BY-PRODUCTS	② MAINTENANCE	① RESOURCE INPUT	① COMPATIBILITY W/ EXISTING EQUIP.	① RATE OF BREAKDOWN OR REFORMATION	③ USER FRIENDLINESS	TOTALS	WT. TOTALS
INCINERATOR	9	5	3	9	5	3	4	3	2	9	6	6	7	2	2	84	199
SCWO	8	9	2	1	2	5	6	3	8	4	4	1	3	1	1	60	160
PYROLYSIS	4	5	3	2	5	2	4	2	4	8	3	4	2	7	2	55	117
POLYMER DEGRADATION	4	6	4	2	4	2	4	2	4	8	3	4	2	9	9	69	154
IMAGE FORMING SOLAR MELTER	2	4	5	2	6	4	5	6	4	6	2	4	4	5	8	74	169
NON-IMAGE FORM. SOLAR MELTER	8	6	9	7	7	4	8	7	4	5	6	2	8	6	8	102	246

○ DESIGNATE WEIGHTING FACTORS

SOLUTION OPTIMIZATION
MATRIX
SHREDDERS

	SAFETY	COST	POWER	RELIABILITY	VOLUME	MASS	DURABILITY	EFFICIENCY	AUTOMATION	VERSATILITY	ENVIRONMENTAL EFFECTS	PERFORMANCE	SIMPLICITY	MAINTAINABILITY	SCORE	RATING
WET PULPERS	11	10	6	7	5	2	9	5	7	2	4	8	3	7	309	32.0%
RASP MILLS	6	2	10	8	6	3	14	4	8	4	8	10	9	4	357	37.0%
GRINDERS	3	6	1	10	5	3	6	2	4	6	1	5	7	12	201	21.0%
"MUFFIN MONSTER"	18	12	8	17	10	5	10	18	11	19	20	16	5	13	647	67.0%
HAMMER-MILLS	1	4	3	12	2	1	8	7	6	20	2	9	12	8	297	31.0%

SOLUTION OPTIMIZATION
MATRIX
POWER SYSTEMS

	WT. FACTOR [1-5]	SAFTEY	COST	TECHNICAL FEASIBILITY	RELIABILITY	VOLUME	MASS	DURABILITY	EFFICIENCY	AUTOMATION	SIMPLICITY	ENVIRONMENTAL EFFECTS	PERFORMANCE	MAINTAINABILITY	SCORE	RATING
RADIOISOTOPE THERMOELECTRIC	10	10	10	8	8	5	5	10	8	10	8	8	4	10	354	40.2%
THERMIONICS	16	10	10	2	12	13	10	8	2	18	7	20	2	15	474	53.8%
HPR-EPG	15	15	18	18	18	20	20	20	18	18	17	15	18	18	719	81.7%
HYBRID	12	8	8	10	10	5	5	8	14	10	10	15	12	15	463	52.6%

SOLUTION OPTIMIZATION MATRIX

Rigid or Collapsible Design of the RJV

	Crew Safety	Min. Risk of S.S. Contamination	Manufacturer Costs	Transportation Costs	Min. EVA Required	Min. IVA Required	Space Station Support Required	Cargo Space Required	Maintainability	Reliability	Durability	Simplicity	Flexibility	Destroyability	Performance	TOTAL
WEIGHT	5	5	3	4	4	2	4	4	2	4	2	1	3	2	3	3
Rigid	7	9	4	2	9	8	8	2	7	9	9	7	8	6	6	321
Collapsible	5	4	6	8	4	4	2	7	3	4	5	4	5	9	4	236

Weight Factor 1 to 5, 5 being best

Scale Factor 1 to 10, 10 being best

SOLUTION OPTIMIZATION MATRIX

Logistics Module or Outside Launched RJV.

WEIGHT	Crew Safety	Mir. Risk of S.S. Contamination	Manufacturing Costs	Transportation Costs	Mir. EVA Required	Mir. IVA Required	Space Station Support Required	Cargo Space Required	Maneuverability	Reliability	Durability	Sampleability	Feasibility	Structurability	Performance	TOTAL
5	5	3	4	4	2	4	4	2	4	2	1	3	2	3	3	213
Logistics Module	6	NA	8	3	5	6	7	1	8	7	6	6	7	NA	NA	273
Outside Launched	4	NA	6	9	6	6	5	10	7	7	9	5	6	NA	NA	253

Weight Factor 1 to 5, 5 being best

Scale Factor 1 to 10, 10 being best

SYSTEMS' PERFORMANCE MATRIX

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SYSTEM	HUMAN INTERFACE	INITIAL COST	OPERATIONAL COST	RELIABILITY	MAINTENANCE	ENERGY EFFICIENCY	SPACE STATION DISTURBANCES	SAFETY	DURABILITY	SPACE STATION POLLUTION	INTERFACE ABILITY	SIMPLICITY	OPERATIONAL PERFORMANCE	WEIGHTED TOTAL
WT. FACTOR	3	4	3	1	2	2	4	4	1	2	1	1	3	170
TETHERS	1	1	9	0	8	8	5	2	7	10	9	9	3	191
OMV	1	8	2	6	5	1	9	7	6	9	8	2	6	195
OMV ASS.	6	6	7	6	1	6	9	7	5	9	8	1	9	174
S.S. LAUNCH	8	6	7	7	6	8	1	1	6	8	1	5	6	187
PLATFORM	7	4	7	7	5	1	9	5	5	9	3	4	6	

~~1 2 3 4 5 6 7 8 9 10~~
 POOR EXCELLENT

SUBSYSTEMS' PERFORMANCE MATRIX

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SYSTEM	INITIAL COST	OPERATIONAL COST	RELIABILITY	MAINTENANCE	ENERGY EFFICIENCY	SPACE STATION DISTURBANCES	SAFETY	DURABILITY	SPACE STATION POLLUTION	SIMPLICITY	OPERATIONAL PERFORMANCE	WEIGHTED TOTAL
WT. FACTOR	4	3	1	2	2	4	4	1	2	1	3	150
ELECTROMAG	3	3	7	7	3	5	7	7	10	6	7	221
COLD GAS	9	5	9	9	9	8	8	10	9	9	8	213
SOLID ROCKET	9	6	9	9	10	8	6	10	5	9	9	170
SPRING	5	7	8	6	9	3	7	6	10	7	6	

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 POOR EXCELLENT

DISPOSAL SITE OPTIONS MATRIX

	Safety	Human Risk	Cost	Environment	Time	Maintainability (Logistics)	Reliability	Hazardous Waste	Size of System	Energy Consumption	Simplicity	Durability	Space Station Disturbance	Storage Requirement	Technical Feasibility	Political	TOTAL
Weight Factor	5	5	5	5	1	3	4	3	2	2	4	1	5	1	4	1	
Atmospheric Incineration	6	7	10	4	10	5	9	1	10	10	10	10	10	9	10	5	393
Moon	9	9	5	7	7	10	7	9	7	8	6	10	8	6	8	6	390
Libration Points	2	10	2	9	5	6	5	7	5	5	4	5	8	5	3	8	291
Sun	8	10	2	8	4	9	6	8	6	7	4	10	8	4	5	8	343

Weight Factor 1 2 3 4 5
 Least Important Most Important

Scale 1 2 3 4 5 6 7 8 9 10
 Poor Excellent

EXPENDABLE UPPER STAGES MATRIX

UPPER STAGE	Safety	Reliability	Space Station Disturbance	Size Requirement	Storage	dV Requirement	Maintenance	Simplicity	Durability	Mass	
WEIGHT FACTOR	5	4	5	1	1	5	2	3	2	2	TOTAL
Transtage	5	9	9	7	4	8	4	6	6	5	205
Centaur	4	8	9	6	2	9	2	5	5	9	197
IUS	9	9	2	8	9	10	9	9	9	6	233
PAM	9	6	2	8	9	1	9	9	9	9	173

Weight Factor 1 2 3 4 5
Least Important Most Important

Scale 1 2 3 4 5 6 7 8 9 10
Poor Excellent

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APPENDIX B

PERFORMANCE PARAMETER DEFINITIONS,

The following performance parameters were used in the Solution Matrices of Appendix A:

1. Appearance - A rating assigned to the device on the basis of attractiveness.
2. Automation - Measure of how much human interface is needed for normal system operation.
3. Availability - Degree of difficulty in obtaining hardware.
4. Cargo Space Requirement - Refers to the payload capacity requirement of a vehicle which needs transportation from the Earth to the SS.
5. Compatibility With Existing Equipment - See "Interface Ability".
6. Complexity - Measures how many parts must be integrated together for the process to work efficiently.
7. Contamination - The level and/or likelihood of unwanted contaminants being released into the environment.
8. Cost - The total expenditures required for designing, implementing, operating, and maintaining the device.
9. Cost Per lb./Payload - Expenditure of launch vehicle per pound of payload.
10. Destructibility - Refers to how well a jettison vehicle will incinerate upon atmospheric reentry.
11. Disturbance - The level of vibration, sound effects, and general commotion imparted upon the Space Station as a result of the device being operated.
12. Durability - The relative amount of abuse which can be imparted upon the device without detrimental effects.
13. dV Requirement - Change in velocity requirement.
14. Efficiency - The ratio of the performance level of the device to the energy required.
15. Environmental Effects - The impact the device will have on the environment.
16. EVA/IVA - The level of external and internal activity about the Space Station.
17. Flexibility - How applicable a system is to other tasks aside from refuse management.
18. Human Interface - The level of time and effort required of humans in conjunction with the use of the device.
19. Hazardous Waste - Toxics, radioactive materials, or heavy metals.
20. Human Risk - Degree of danger to human life.
21. Interface Ability - A measure of how easily a system can interface with others.
22. Location - Where the system or device can reside.
23. Maintainability - The level of servicing required to keep the device in proper operating condition.
24. Maintenance - The level of difficulty involved in the repair or servicing of the device.
25. Mass - The bulk of the device.
26. Performance - A relative measure of how well the device carries out its intended function.

27. Political - Social/bureaucratic friction.
28. Pollution - Measure of contaminants liberated by a process.
29. Power Requirement - The amount of electrical power required by the device during normal operation.
30. Rate of Breakdown - Measure of how quickly the process reforms waste materials.
31. Reliability - The number of failures per unit time.
32. Resource Input - How dependent a process is on outside resources other than the refuse.
33. Safety - The level of risk to the inhabitants and/or the other components of the Space Station as a result of the operation of the device.
34. Simplicity - The relative ease with which the device can be fabricated, installed, and used.
35. Size - The volume of space occupied by the device.
36. Space Station Support Required - Measures to what degree the system must rely on SS supplies, manpower, etc.
37. Storage Requirement - The volume of space required to accommodate a device, or the holding requirements of a rocket.
38. Technical Feasibility - The capability of being accomplished technically.
39. Technical Maturity - The measure of degree of technical development.
40. Time - The amount of time required for the device to perform its required function.
41. Useful By-Products - A measure of what percentage of the products of the process are usable.
42. User Friendliness - Measures the ease of operating a system.
43. Versatility - How well the system responds to a related input or environmental change.
44. Volume (Payload) - The space required for system components in the transportation vehicle.

APPENDIX C

SAMPLE CALCULATIONS FOR REYNOLDS NUMBER

at 120 miles above the Earth's Surface:
density = 1.3×10^{-9} lbm/ft³
kinematic viscosity = 641 ft²/s
characteristic dimension = 4.5 ft
reference velocity = 10,000 ft/s

$$R = \frac{(10,000 \text{ ft/s}) \cdot (4.5 \text{ ft})}{(641 \text{ ft}^2/\text{s})} = 70$$

at 60 miles above the Earth's Surface:
density = 1.5×10^{-9} lbm/ft³
kinematic viscosity = 5.6 ft²/s
characteristic dimension = 4.5 ft
reference velocity = 10,000 ft/s

$$R = \frac{(10,000 \text{ ft/s}) \cdot (4.5 \text{ ft})}{(5.6 \text{ ft}^2/\text{s})} = 8,035$$

WEIGHT ANALYSIS

$$\text{Weight} = 0.0769 \times T \times (\text{OD}^2 - \text{ID}^2)$$

T = length

OD = outside diameter

ID = inside diameter

RJV

$$\begin{aligned} W &= 0.0769(36\text{in})(54^2 - 53.5^2) + 2(0.0769)(0.5)(54)^2 \\ &= 148.8 + 224.2 = 373 \text{ lbs} \end{aligned}$$

CANISTERS

$$\begin{aligned} W &= 0.0769(36\text{in})(18^2 - 17.8^2) + 2(0.0769)(0.2)(18)^2 \\ &= 19.8 + 10.0 = 30 \times 6 = 180 \text{ lbs} \end{aligned}$$

$$\text{TOTAL WEIGHT} = 373 + 180 = 553 \text{ lbs}$$

REENTRY DEBRIS RISK ANALYSIS

THE ANALYSIS WAS DONE AS A WORST CASE SCENARIO, AS FOLLOWS:

1. MINIMUM INCINERATION/DESTRUCTION
2. ANY HUMAN IMPACT IS FATAL
(POP) * (SURF)

$$\text{CAS} = \text{-----} \\ \text{(ATOT)}$$

CAS = NO. OF HUMAN CASUALTIES

SURF = TOTAL SURFACE AREA OF RJV

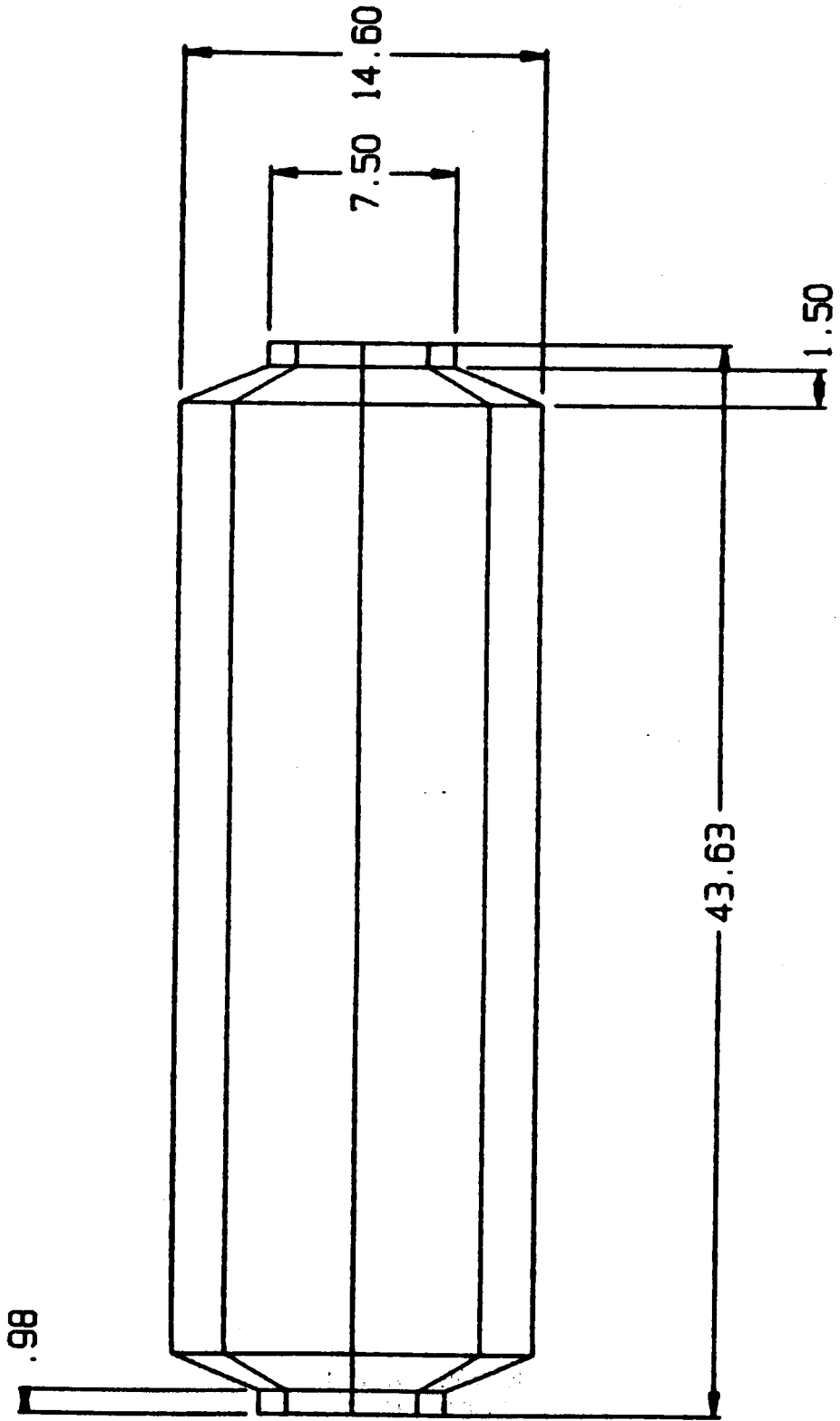
ATOT = TOTAL SURFACE AREA OF EARTH
(4.8×10^9) * (81.23FT^2)

$$\text{CAS} = \text{-----} = 0.000071 \\ (5.49034 \times 10^{15} \text{FT}^2)$$

PROB. OF ONE DEATH = 0.000071 (100%)
= 0.0071%

FOR PROB = 100% WE NEED 14,081 RJV'S (18)

APPENDIX D



All Dimensions In Feet & Tenths Of Inches

TYPICAL MODULE SIZE
SHOWING FULL SIZE DIMENSIONS

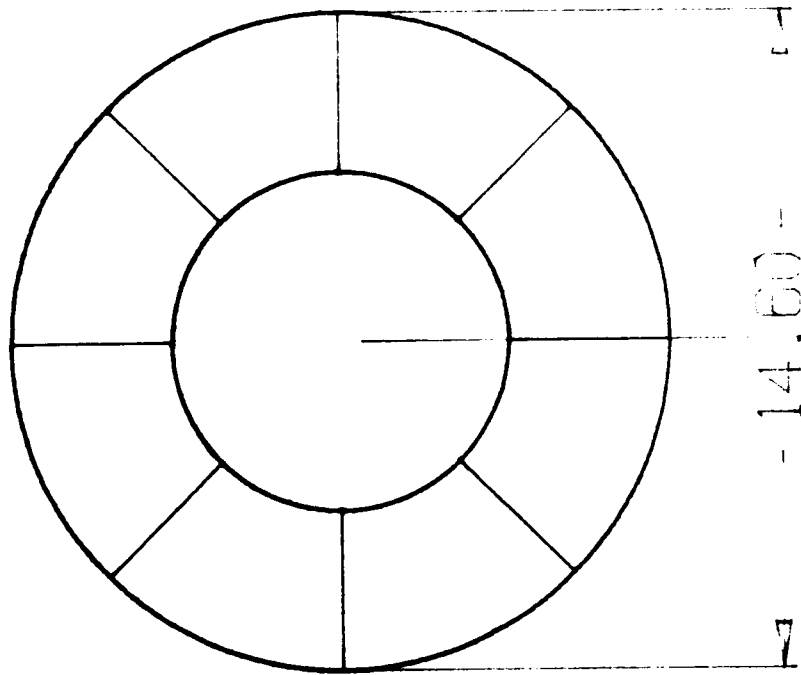
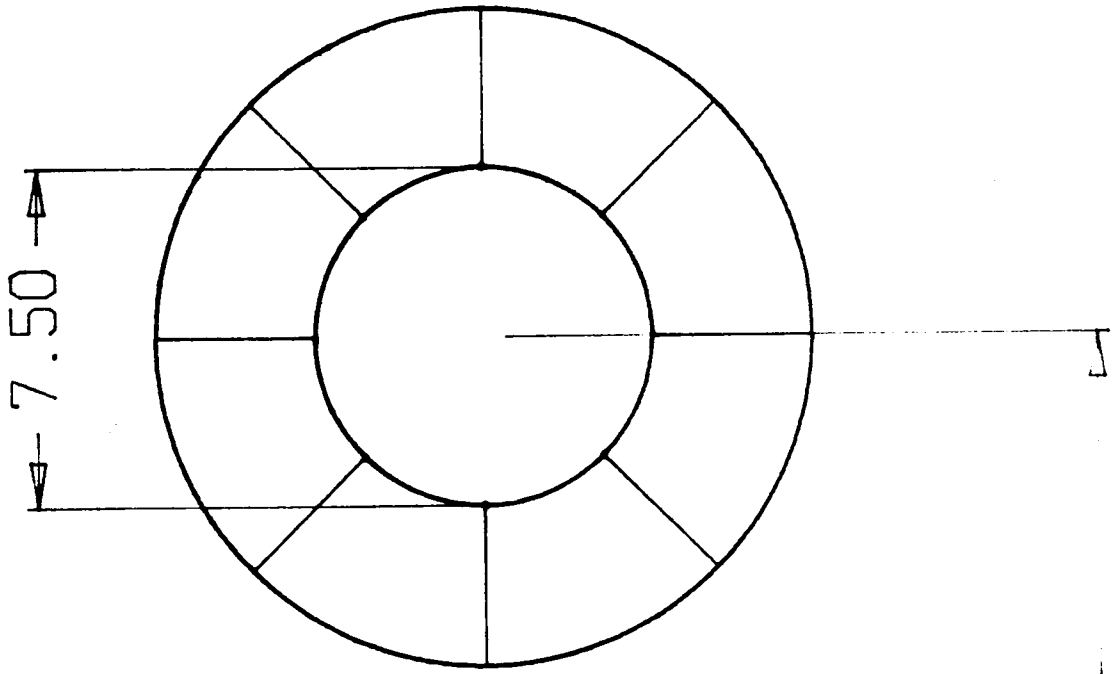
DRAWN BY: C. RAHAIM
DATE: 2/10/88

SPACE STATION MODEL - AN END VIEW

ALL DIMENSIONS FEET & INCHES

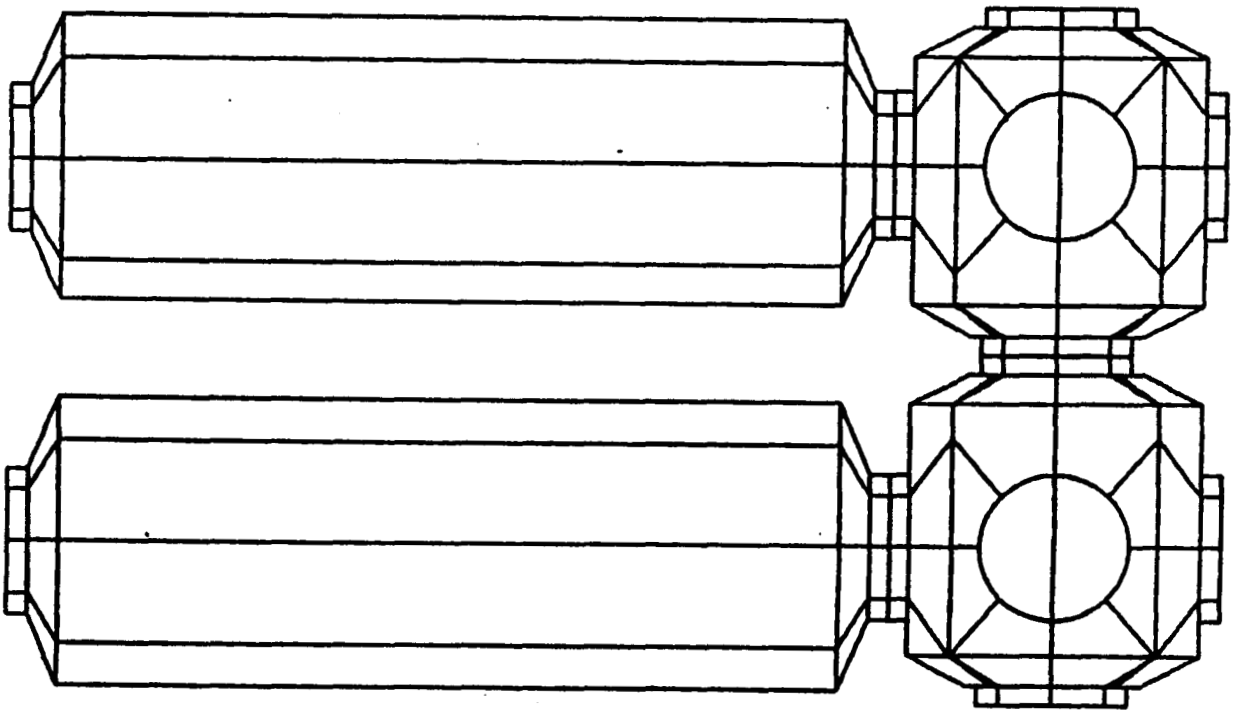
DRAWN BY: C. RAHAIM

DATE: 2/15/88

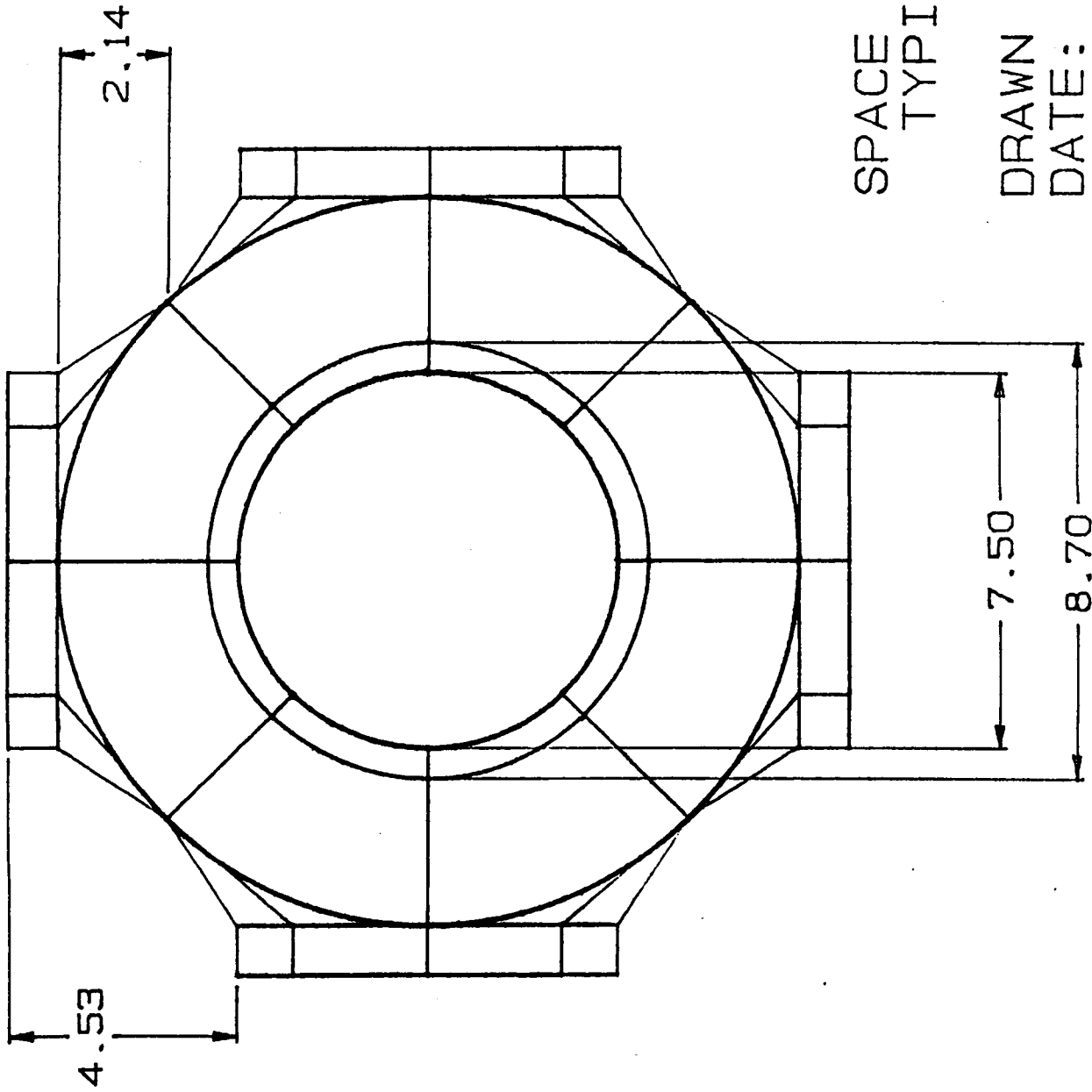


- 19.52 -

ORIGINAL PAGE IS
OF POOR QUALITY

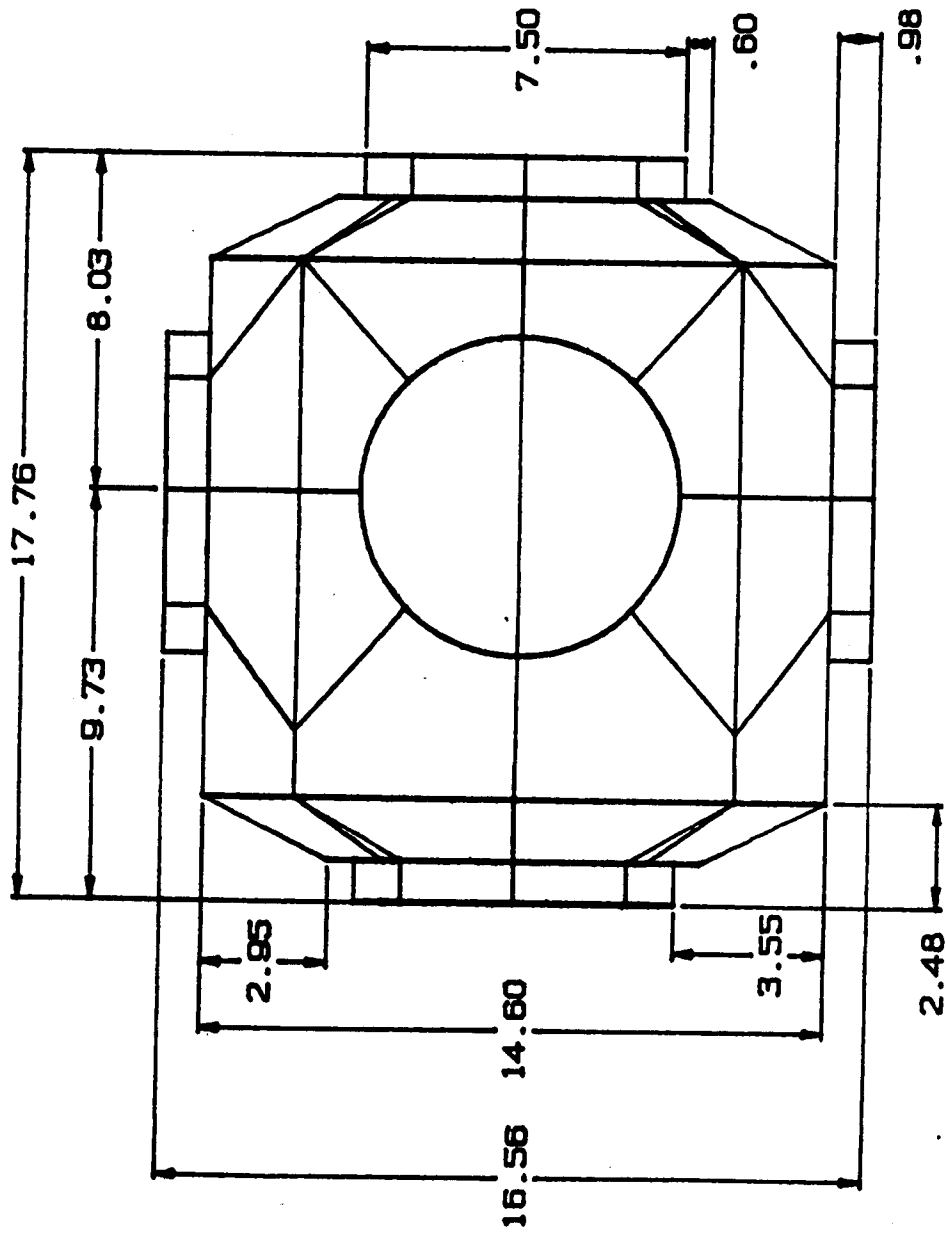


SPACE STATION MODEL
TOP VIEW
DRAWN BY: C. RAHAIM
DATE: 2/17/68



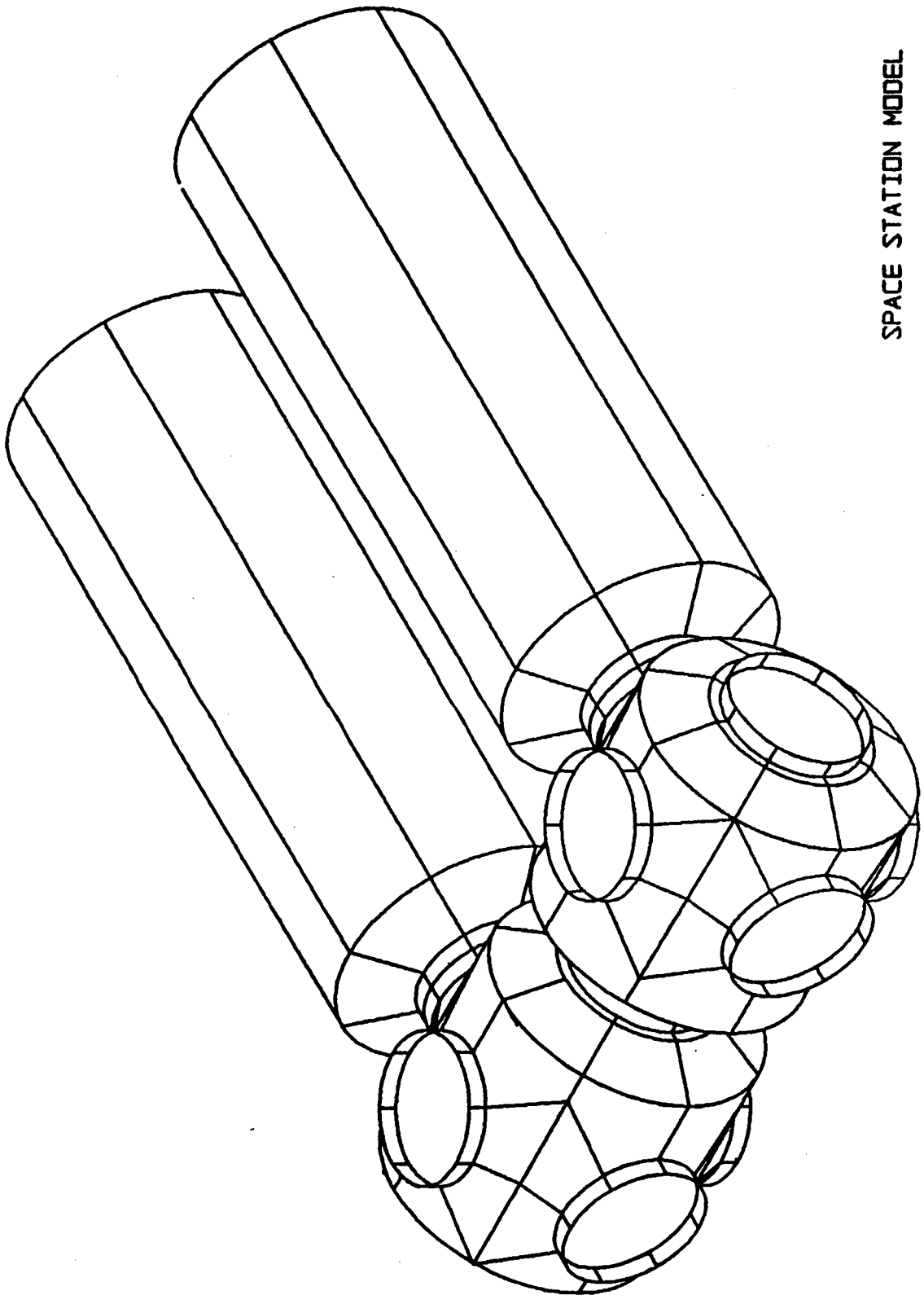
SPACE STATION MODEL
TYPICAL NODE

DRAWN BY: C. RAHAIM
DATE: 2/22/88



SPACE STATION MODEL - TYPICAL NODE

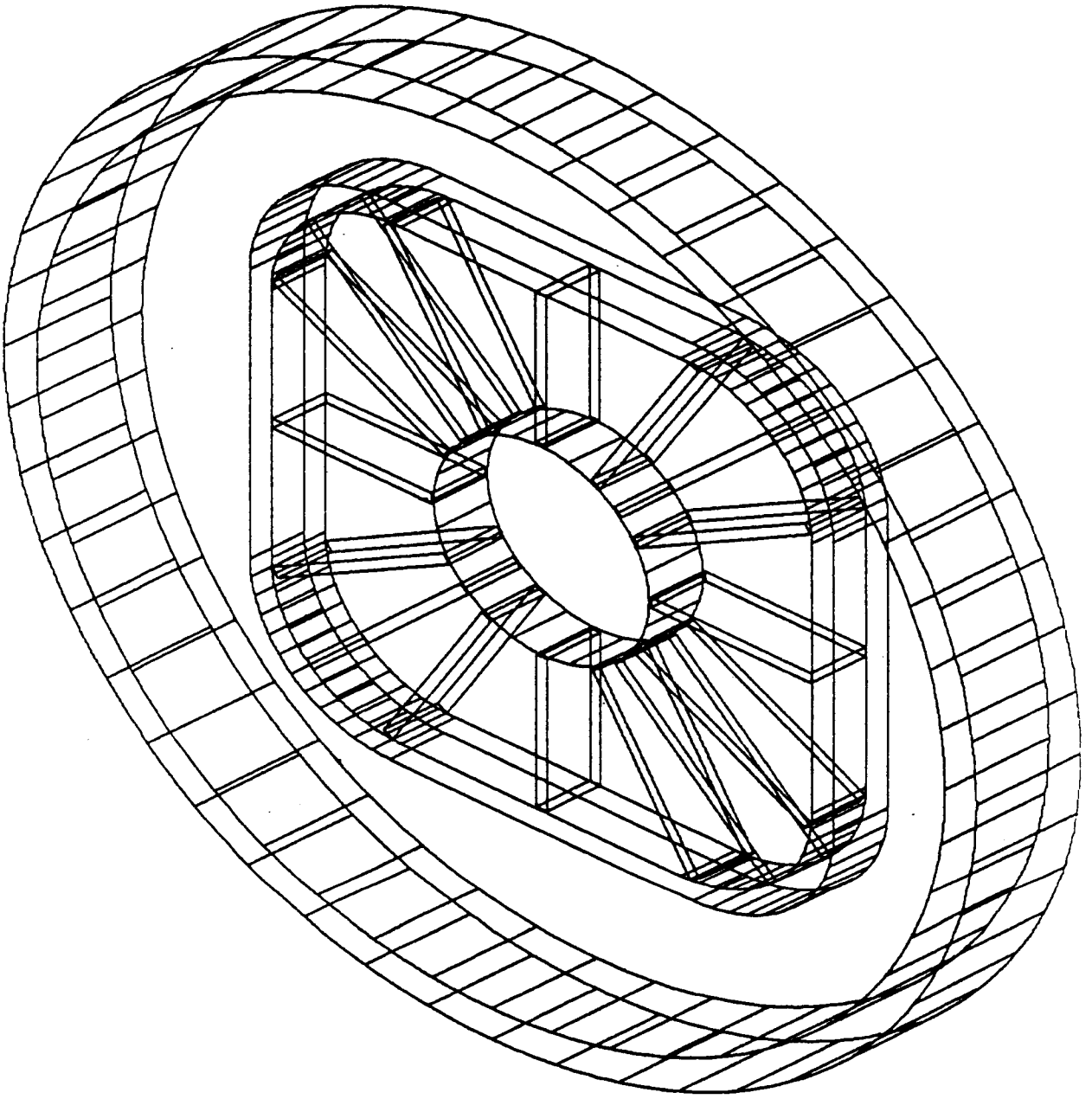
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 DATE: 2/22/88

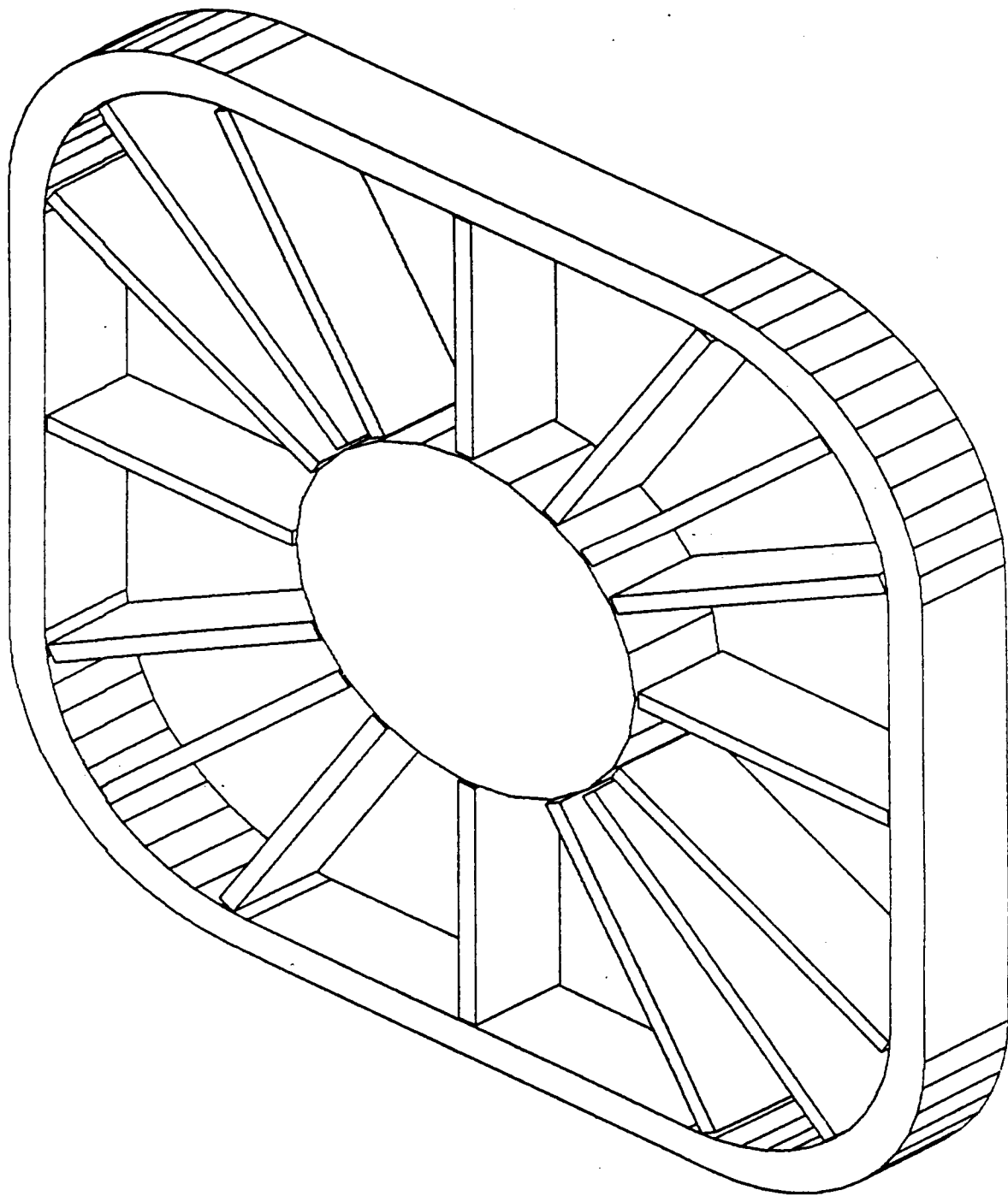


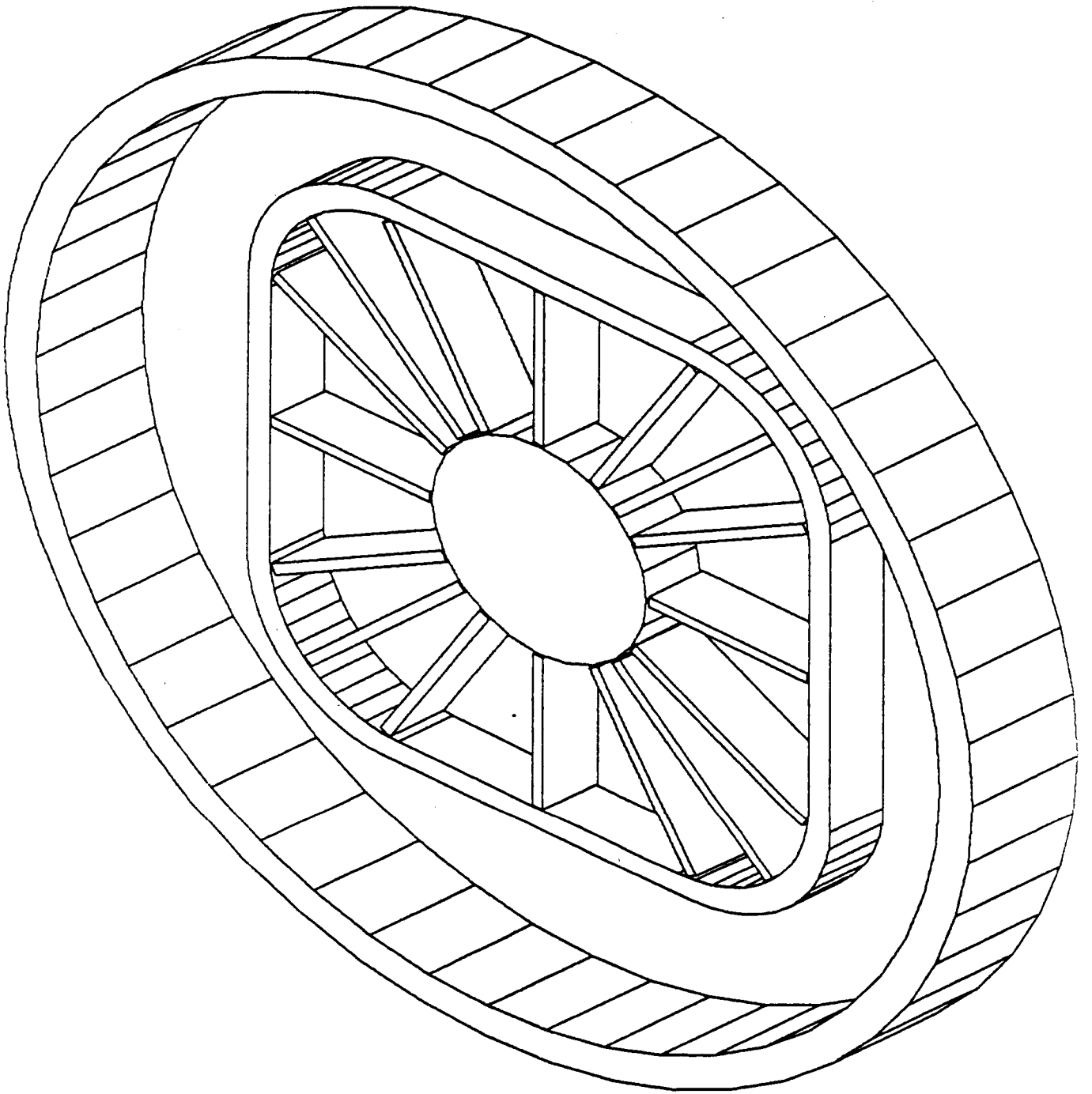
SPACE STATION MODEL

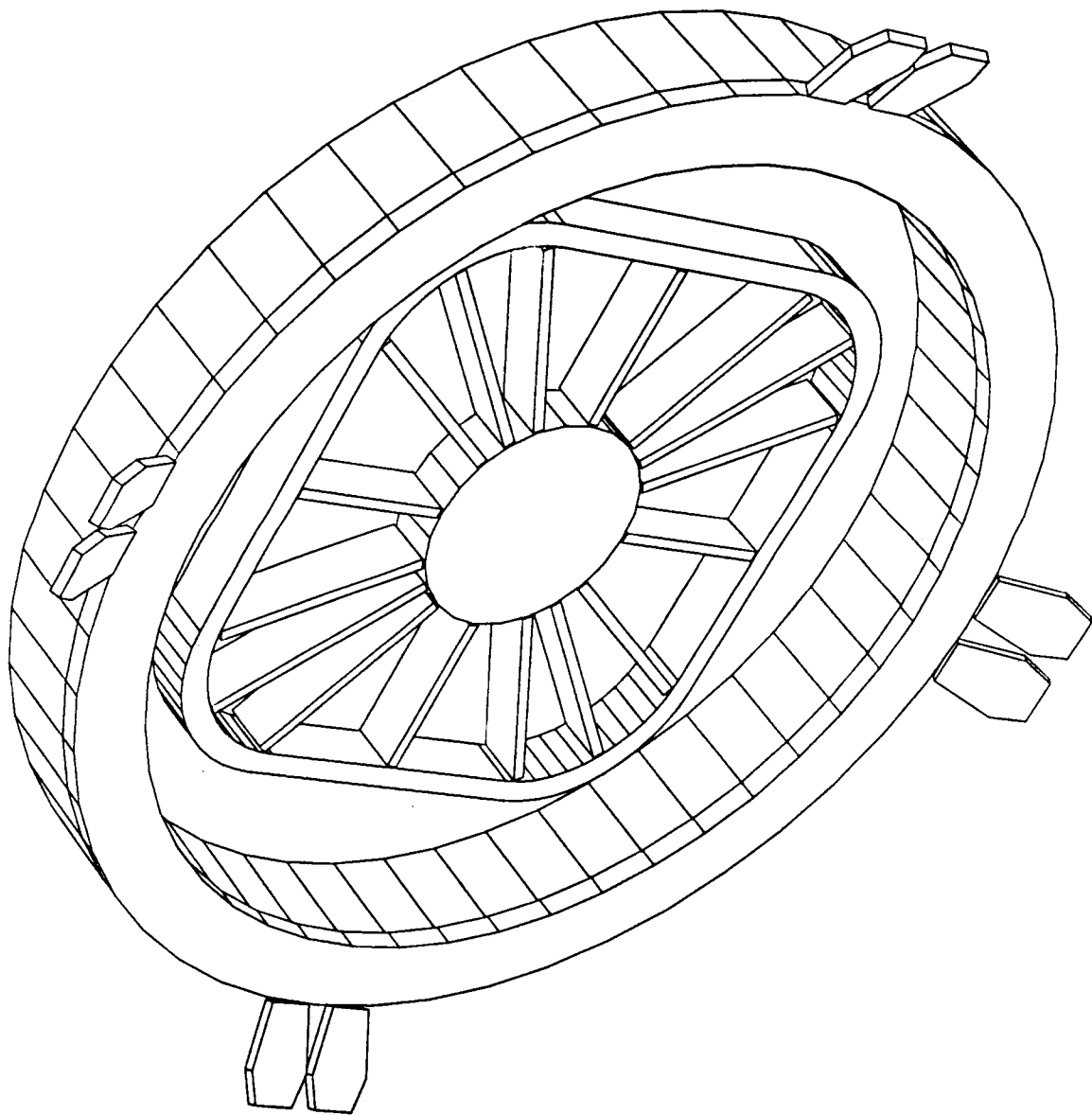
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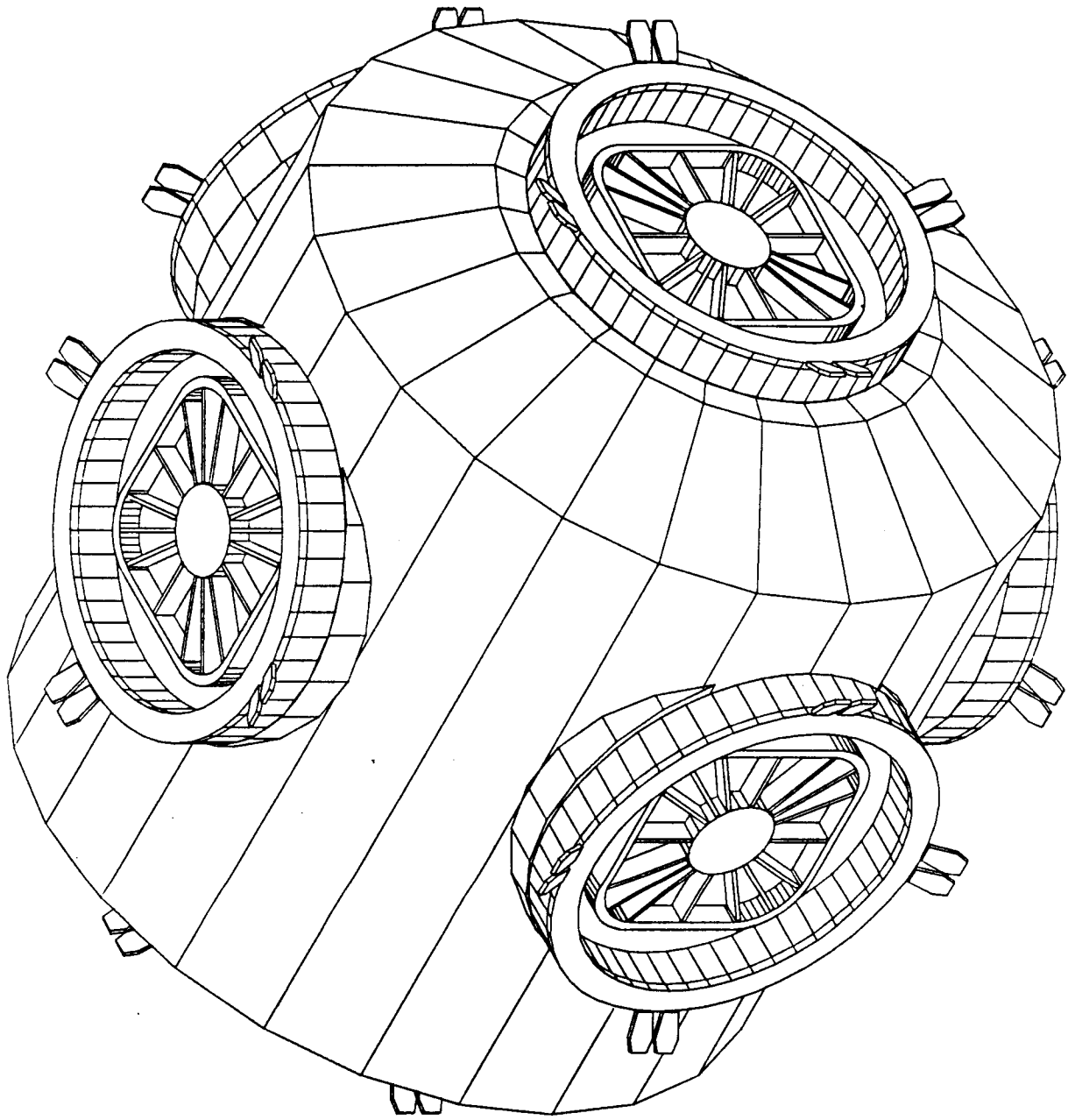
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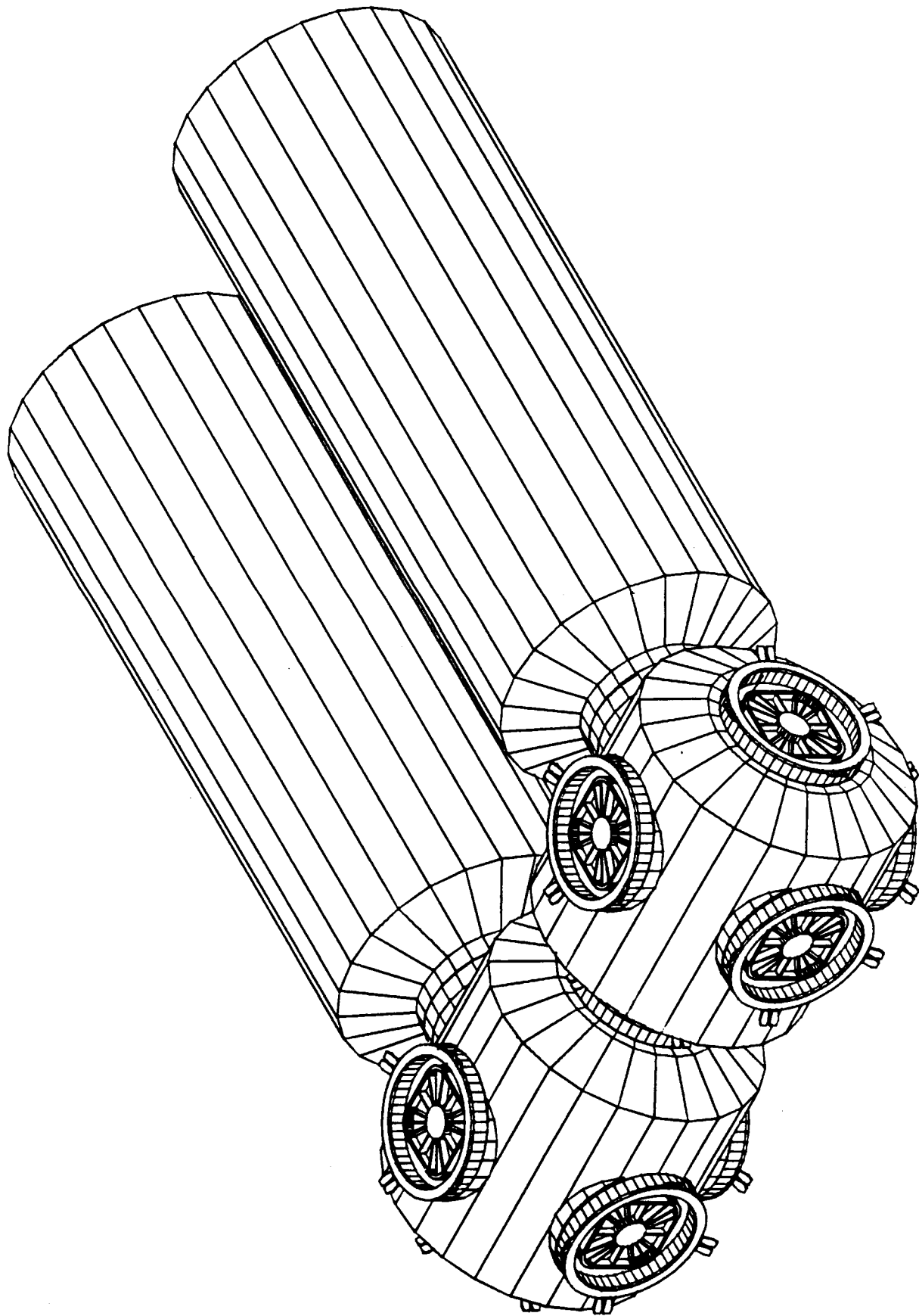


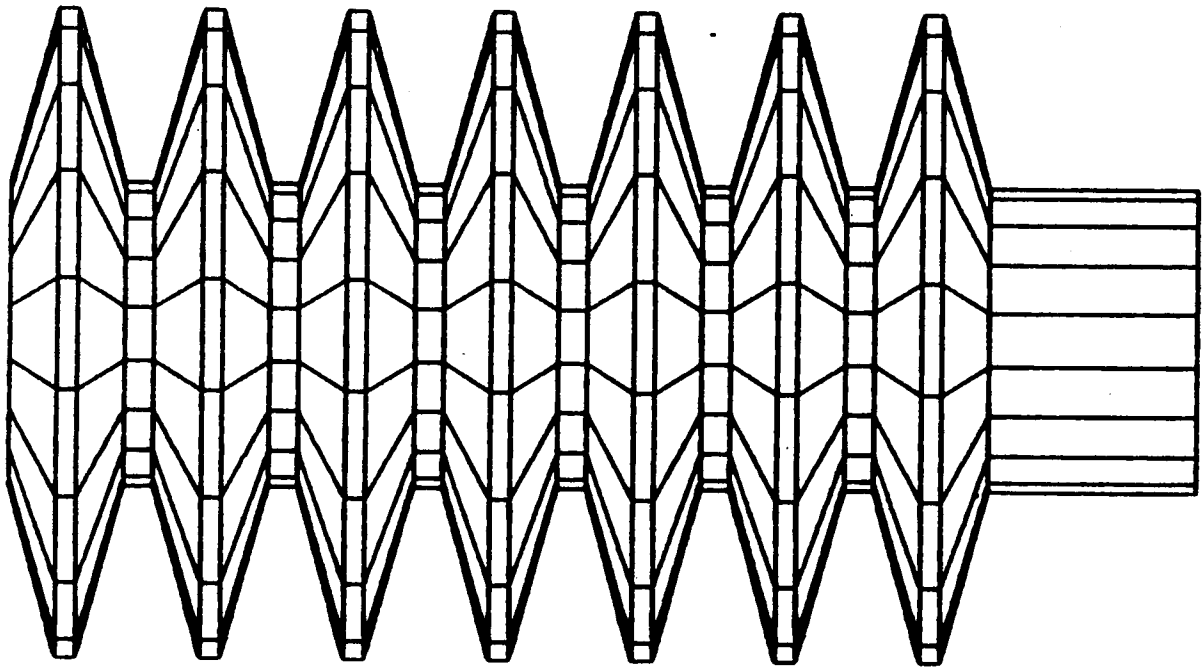




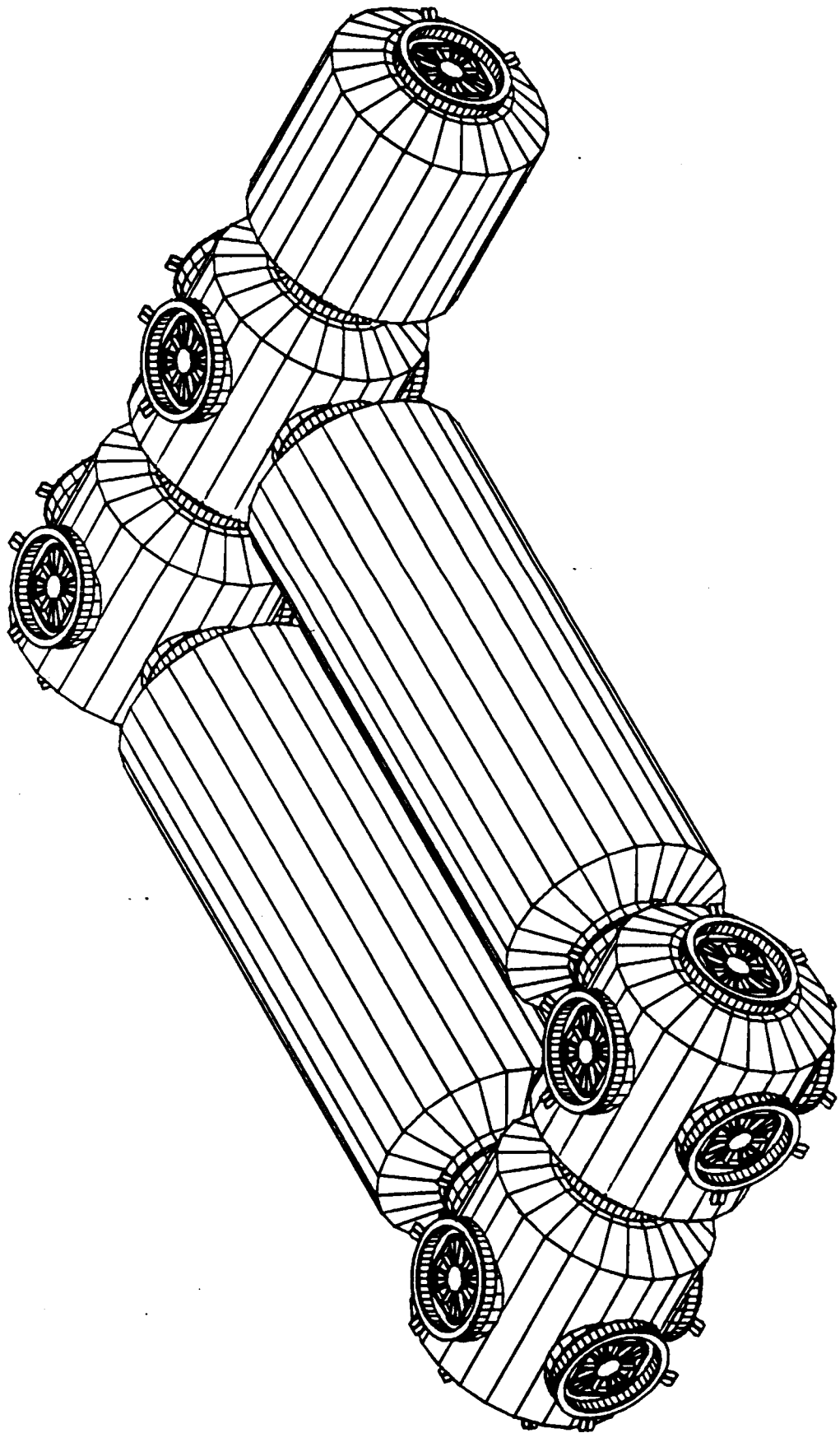




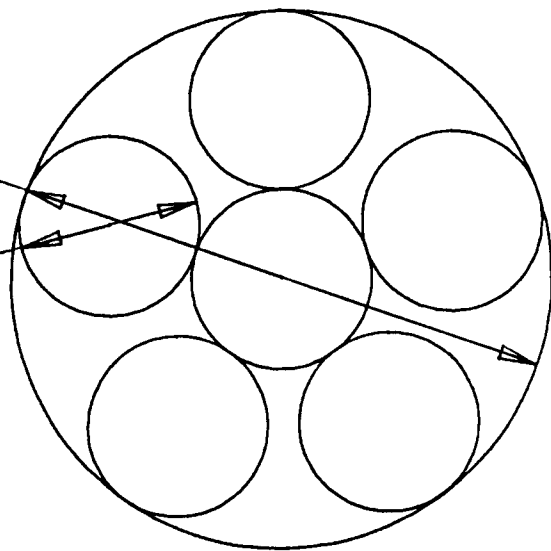




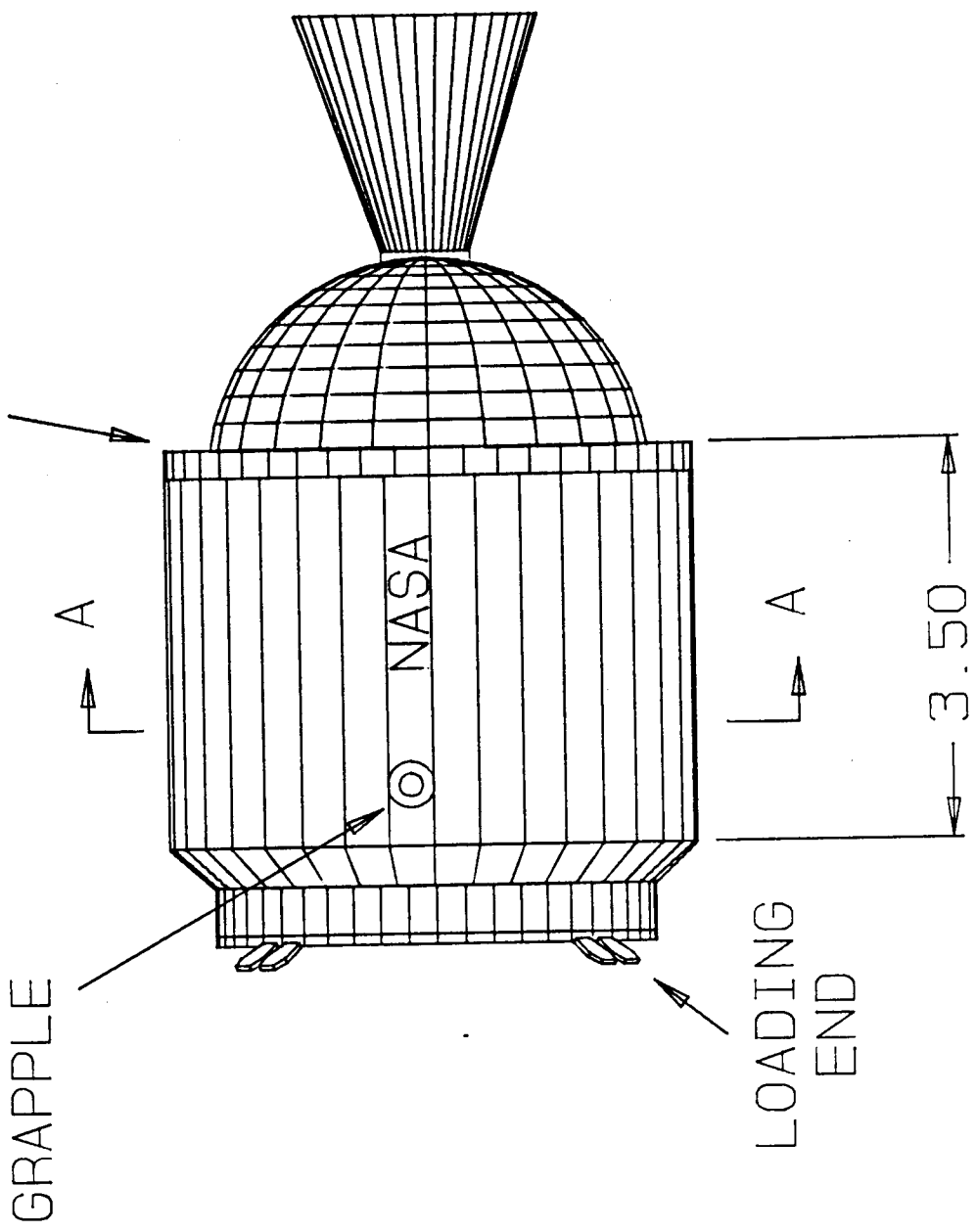
COLLAPSIBLE VEHICLE
3/20/88
C. RAHAIM



$\phi 4.50$
 $\phi 1.50$



MOUNTING PLATE



SECTION A-A
(INTERNAL)

OUTSIDE ROCKET LAUNCHED VEHICLE