N71-26806

FACILITY FORM 602

(ACCESSION NUMBER)	(THRU)
140	G3
(PAGES)	(CODE)
CR-115044	05
(NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

[illegible] INCORPORATED

[illegible]

NOTICE TO USERS

Portions of this document have been judged by the Clearinghouse to be of poor reproduction quality and not fully legible. However, in an effort to make as much information as possible available to the public, the Clearinghouse sells this document with the understanding that if the user is not satisfied, the document may be returned for refund.

If you return this document, please include this notice together with the IBM order card (label) to:

Clearinghouse
Attn: 152.12
Springfield, Va. 22151

CR-110… 7

HABITABILITY: GARMENT CONCEPTS AND ENGINEERING DATA

CONTRACT NAS 9-10407

FINAL REPORT

Prepared for the

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

by

WELSON & CO., INC.

HARTFORD, CT.

DECEMBER 4, 1970

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

1.0 INTRODUCTION

This report presents data obtained during the conduct of the study program "HABITABILITY-GARMENT CONCEPTS AND ENGINEERING DATA", NAS 9-10407. This study is a continuation of the original contract - NAS 9-9563 - which defined the basic garment to be used in Space Station applications. The current study is concerned with the broader aspects of Habitability Technology investigating such areas as wardrobe definition, fabric usage, laundry system concepts, wardrobe packaging, candidate fabric testing, and crewman sizing.

These areas were considered of minor importance during the earlier phases of space flight due to the relatively short mission durations and small crew numbers resulting in negligible total system penalties. However, with increasing vehicle size, mission profiles and number of crewmen, Habitability Technology is emerging as a major design consideration and as such, must be investigated thoroughly.

The "Handbook of Garment Selection Criteria for a Space Station" presented at the completion of contract NAS 9-9563 has been updated to include the results of the current effort and has been retitled to reflect the broader scope of this study.

2.0 SUMMARY

The study program "HABITABILITY-GARMENT CONCEPTS AND ENGINEERING DATA" NAS 9-10407 has been completed and the results of this study effort are contained herein. The tasks investigated under this contract were:

Task 1 ------	Wardrobe Definition
Task 2 ------	Fabric Usage
Task 3 ------	Laundry Systems
Task 4 ------	Garment Packaging
Task 5 ------	Fabric Testing
Task 6 ------	Crew Sizing
Task 7 ------	Hand Laundry Concepts

In addition to the study outputs associated with the listed tasks, mockup items were fabricated and delivered to NASA. These items were as follows:

(a) Representative wardrobe consisting of:

Duty Garment	Sleep Garment
Leisure Garment	Special Duty Garment
Exercise Garment	Transfer Container

(b) Waste storage container.

(c) Laundry container.

(d) Crewman sleep restraint.

(e) Hand laundry systems (2).

The study was conducted in accordance with the study plan (BW-165) prepared at the start of the program. All study results are summarized in the task descriptions contained in this report and pertinent data obtained during the conduct of this study effort has been incorporated into the revised handbook. The laundering testing effort was successfully completed and the Mechanical Test Plan and Mechanical Test Procedure were both delivered to NASA along with the necessary fabric items required to perform the mechanical test portion of this program.

3.0 STUDY TASKS

Six basic study areas were defined in the study plan and are discussed in detail in this section of the report. A seventh study area, Hand Laundry Concepts, was added during the latter part of the program and, for continuity the data resulting from this effort will be contained in the Task 3 - Laundry system portion of this report rather than in a separate section.

Task 1 is concerned with the determination of the total wardrobe requirement of a space station crew. Wardrobe systems are defined as well as the rationale for their selection. The total system impact in the areas of wardrobe weight and volume is assessed as well as the impact on the space station of the wardrobe ancillary items.

Task 2 presents the investigation of the use of fabric in the design of space station accommodations and accessory items. Typical fabric items required to support the space station and their weight and volume impact on the system are discussed .

In Task 3, laundry systems were evaluated for use in a space station. Conceptual designs of typical laundry systems are presented along with their weight, volume, and power impact on the total space station complex. Alternate methods of water reclamation are discussed with an assessment of their relative applicability for use in a space station environment. This section also contains the task 7 effort- Hand Laundry Concepts.

Task 4 was an evaluation of garment and wardrobe packaging. Garment folding techniques, rolled versus flat folded, are compared and standard versus vacuum packaging are discussed. Modular packaging techniques are discussed and the wardrobe transfer volumes outlined. In addition, an assessment of the space station wardrobe storage volume is made based on the results of the Task 1 effort.

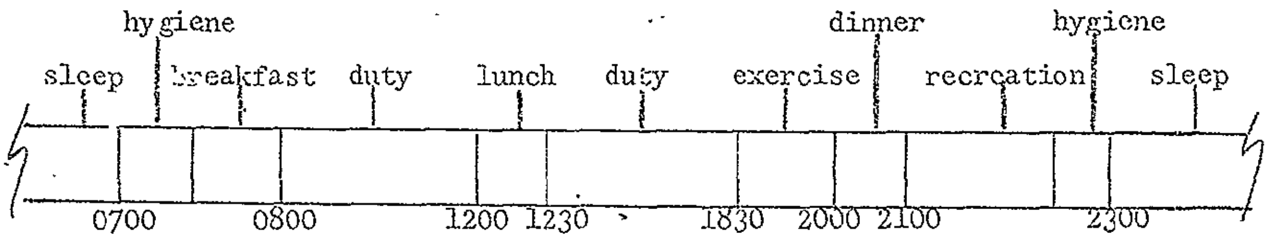
Task 5 was a testing effort that investigated the effect of laundering on the physical characteristics of candidate materials and the response of certain select materials when exposed to thermal testing. The data obtained from the testing effort supplements the analytical data contained in the original handbook.

Task 6 is an evaluation of a garment sizing program for use in space station applications. Basically, it is an updating of a study program conducted in the 1950's for personnel on flying status and was undertaken to be more representative of the current astronaut/scientist population. This effort also outlines the major bodily measurements essential to the sizing of clothing.

Task 7 evaluated various hand laundry concepts and resulted in the fabrication of two such concepts. Hand laundry systems are of importance when considering small laundry loads, on the order of five pounds or less, due to their relative small impact on the space vehicle design. The results of this study effort are contained in Task 3 - Laundry System to maintain continuity.

3.1 WARDROBE DEFINITION

During the Mercury, Gemini, and Apollo flights, wardrobe systems were relatively meager with garments serving a multiple function. With the increase in space vehicle size, mission durations, and crewmember numbers, a need arises to provide a more diversified wardrobe for the crewman. This task effort was concerned with the definition of a typical wardrobe system and was based on the following duty cycle:



With the duty cycle defined, the wardrobe system was determined based on the various functions to be performed during the duty cycle. Design justification sheets were generated to summarize the particular garment items, function, candidate materials, selected configuration, and the rationale behind the selection. These sheets are contained in Appendix A of this report.

The resultant wardrobe was comprised of the following items:

(a) Duty garment - uniform dress for on-duty crewmen.

(b) Leisure garment - non-uniform dress for off-duty and recreational periods.

(c) Exercise garment - loose fitting clothing designed for comfort during exercise periods.

(d) Sleep garment - added insulation for comfort during sleep periods.

(e) Special duty garment - special garment worn during performance of critical functions.

Figures 3.1.1 through 3.1.5 are a representation of the garments to be used in a space station application.

3.1.1 GARMENT IMPACT ON SYSTEM DESIGN

The impact of garment weight and volume on the space station system was evaluated and an example of the analysis technique is presented herein. To arrive at the wardrobe total weight and volume requirements, certain ground rules or baselines were established. The first determination made was to use washable garments as opposed to disposable garments. The rationale for this selection is contained in the tradeoff study

FIGURE 3.1.1

DUTY GARMENT

ITEMS

- . JACKET
- . PANTS
- . SHIRT
- . SHOES
- (. SOCKS
- * (
- (. BRIEFS

* COMMON ITEMS

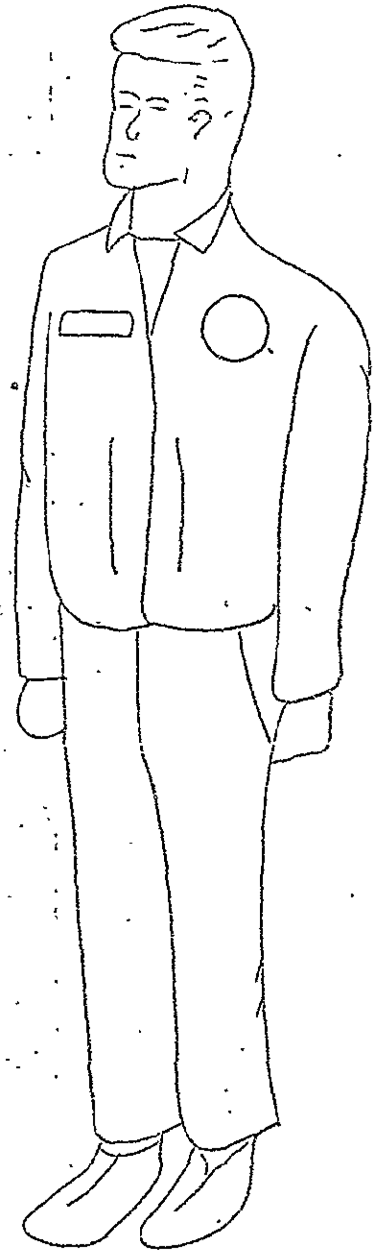
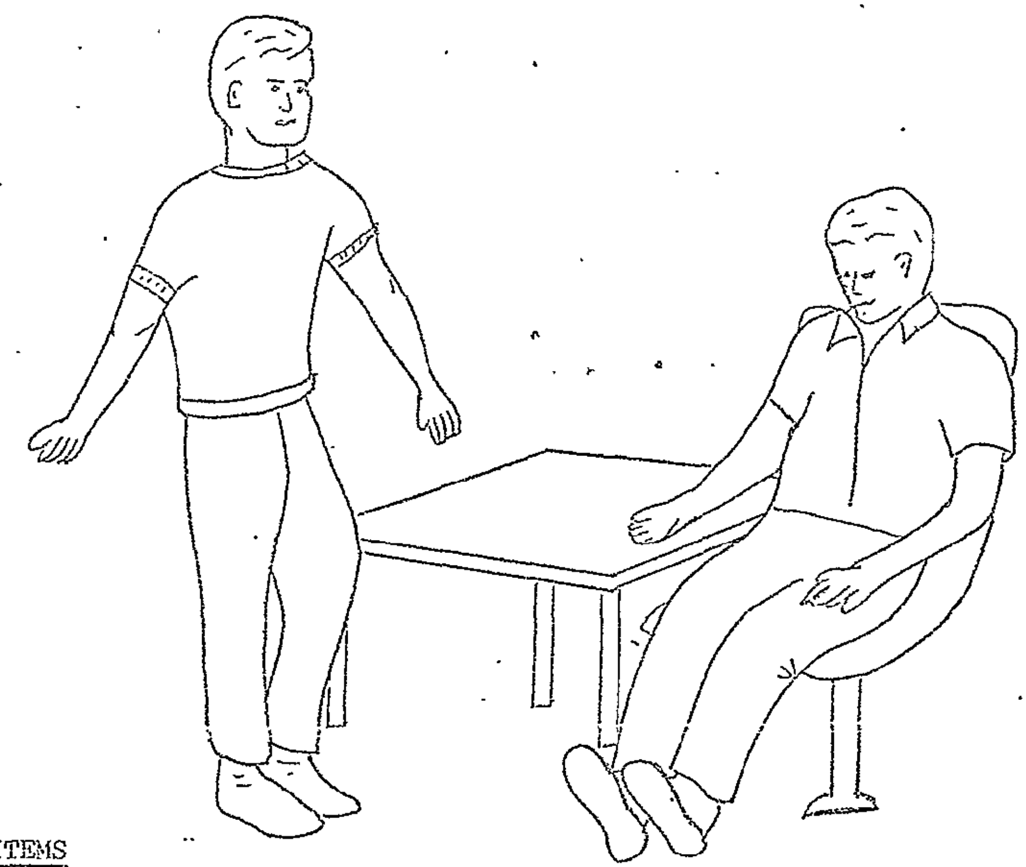


FIGURE 3.1.2

LEISURE GARMENT



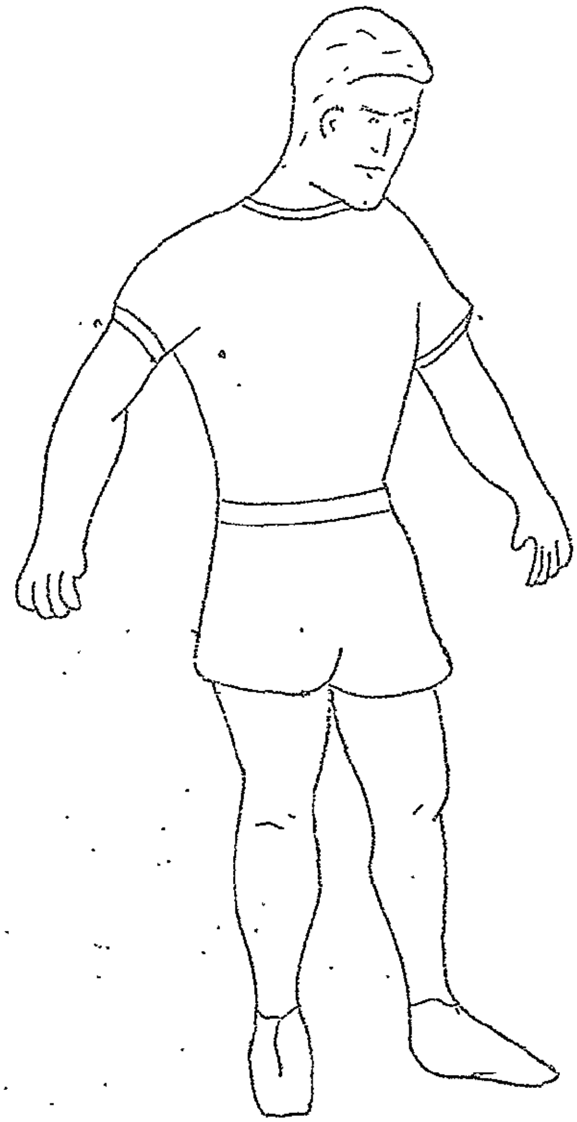
ITEMS

- SHIRT (2 TYPES)
- PANTS
- SHOES
- * SOCKS
- * BRIEFS

* COMMON ITEMS

FIGURE 3.1.3

EXERCISE GARMENT



ITEMS

- SHIRT
- SHORTS
- SUPPORT
- SOCKS

FIGURE 3.1.4

SLEEPING GARMENT

ITEMS

. PAJAMAS

. ROBE

. SLIPPERS

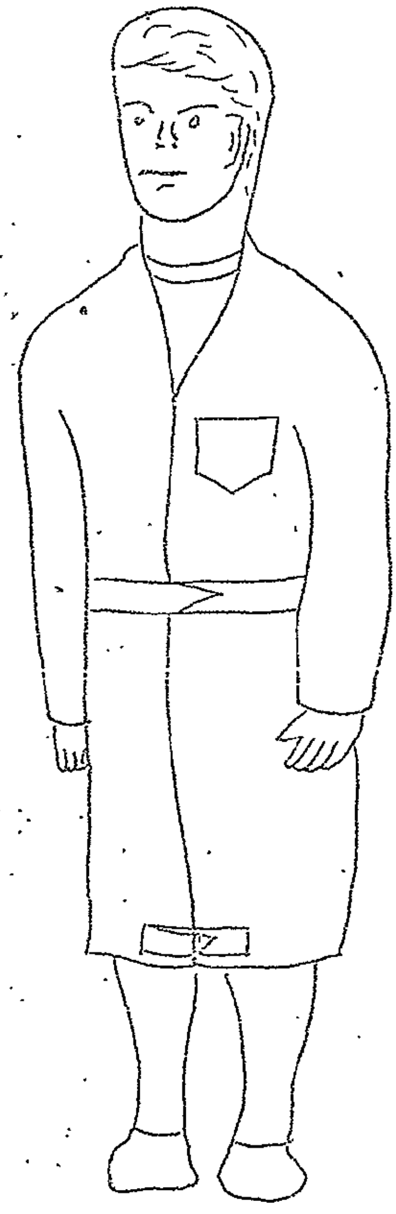
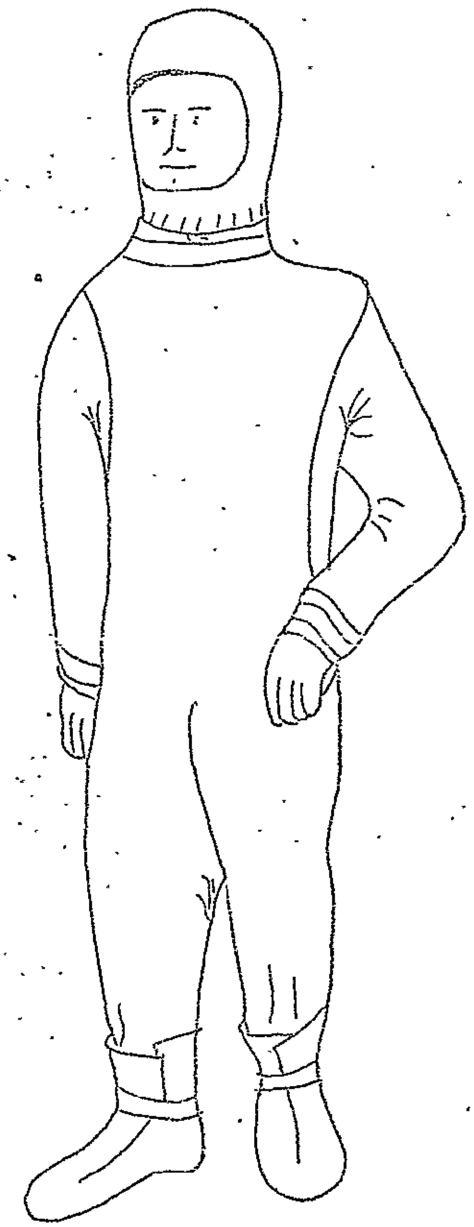


FIGURE 3 .1.5

SPECIAL DUTY GARMENT

ITEMS

- COVERALL
- BOOTIES
- GLOVES
- HAT



of Appendix B. The crew compliment was established at 12 with mission durations of 180 days. The garment change rate was set according to the following arbitrary schedule:

Garment	Change Interval (days)
Jacket	3
Trouser	3
Shirt	1
Briefs	1
Socks	1

The wardrobe quantity for a duty garment system was then determined based on a 7 day wash cycle and the results are as follows:

ITEM	CHANGE RATE(Days)	QUANTITY REQ'D
Jacket	3	3
Trousers	3	3
Shirts	1	8
Briefs	1	8
Socks	1	8

Referencing the Design Justification Sheets of Appendix A, a cotton or cotton blend material was selected for use in the fabrication of the duty garment items. Based on the measurements of the garment mockup wardrobe (medium-regular) presented under this contract, the weight of this material for the particular duty garments listed above were:

ITEM	MAT'L	MAT'L WT. (OZ/YDS)	MAT'L REQ'D (YDS)	GARMENT UNIT WT. (Lbs)	GARMENT TOTAL WT. (Lbs)
Jacket	Cotton-Dacron	4	2.7	0.8	2.4
Trousers	Cotton-Dacron	6	2.3	1.031	3.1
Shirt	Cotton	4	1.7	0.4	3.2
Brief	Cotton	2	0.2	0.2	1.6
Socks	Cotton	6	0.2	0.1	0.8
Shoes	Soft Leather	-		0.3	0.3

Total duty garment system weight= 11.2 pounds

Adding the weights of the leisure garment, exercise garment, sleep garment, and special duty garment results in a system weight (per crewman) impact of 25 pounds, occupying a volume of 838 IN^3. Wardrobe transfer envelopes and storage volumes are presented in the Task 4 - Packaging Study portion of this report.

3.1.2 GARMENT SUPPORT ITEMS

The ancillary items required to support a wardrobe system consists of such items as hangers, garment restraints, clothing organizers and garment laundry/storage containers. Depending on the concept selected for wardrobe storage and maintenance, the impact of ancillary item weight and volume can range from a minimum of 20 pounds using a hand laundry and a 10 pound laundry load, to a maximum of 800 pounds utilizing an automatic laundry system with water recovery capabilities and a 20 pound laundry load. The selection of the optimum system is dependent upon the particular mission requirement and can be made only at the time of mission definition.

Figure 3.1.6 depicts typical garment restraint devices for Space Station use. Schematics of typical laundry systems are presented in section 3.3 of this report.

Figure 3.1.7 is a representation of a typical garment flow cycle from garment fabrication to final usage. Each step of the cycle is defined as follows:

Fabricate Garment - The basic raw material is fabricated into a particular garment according to the size requirements of a particular crew, and in enough quantity to supply the crew and have spares as backup items.

FIGURE 3.1.6 GARMENT RESTRAINT DEVICES

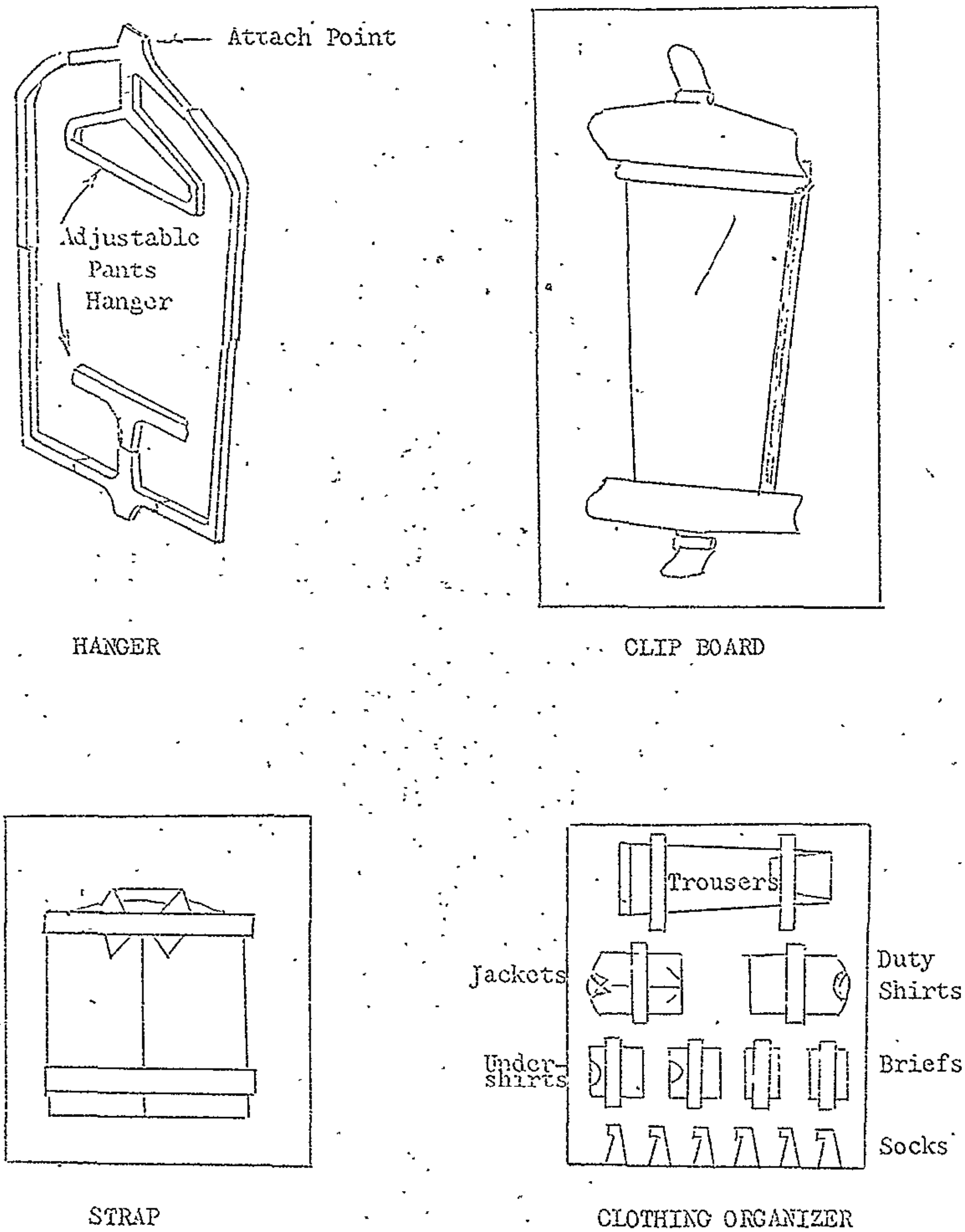
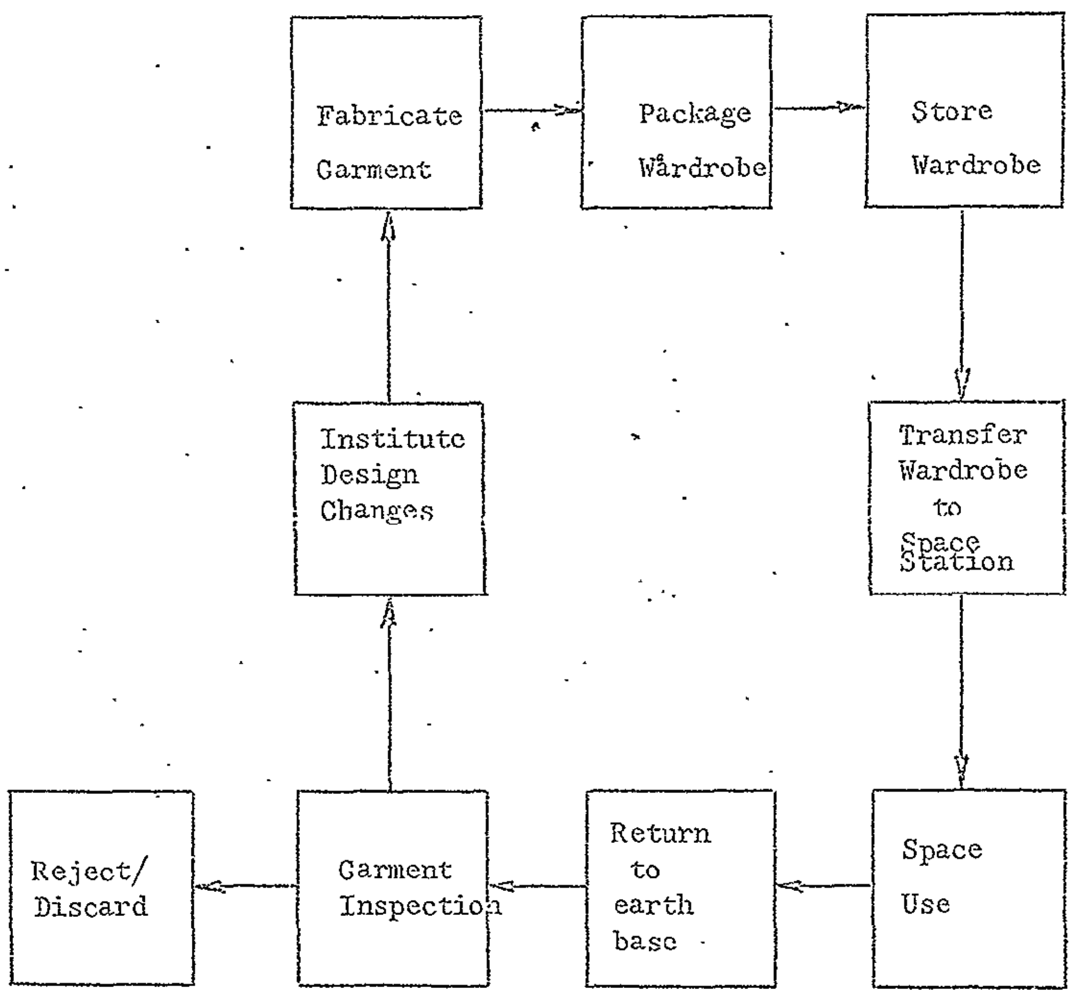


FIGURE 3.1.7 GARMENT CYCLE FLOW DIAGRAM



Package Wardrobe - The wardrobe will be packaged in accordance with functional groupings, that is, duty garments will be packaged as a group, leisure garments as a group, etc. This will allow select garment re-supply as demand dictates rather than having to ship a complete wardrobe when only one garment type is required.

Store Wardrobe - Garment items will be stored in functional groupings ready for transfer as required to the using facility.

Transfer Wardrobe - When needed the garment items will be transferred to the Space Station or the using facility as required to fulfill mission requirements.

Space Use - garment items are received and used in the space station complex.

Garment Inspection - After return to Earth base, each garment is inspected to determine condition for reuse. If considered reusable, the particular garments will undergo a design change cycle and be cycled back into the garment flow sequence. If the garment is deemed not reusable, it is discarded.

3.1.3 WARDROBE STYLING

Wardrobe styling has been mainly predicated on personal preference in the earlier space flights, however, with extended missions and larger crews, garments can serve a more functional role in providing ease of recognition through select color coding or styling. This particular coding pattern can be established on a duty basis or a rank basis or a combination of both which would then allow a much easier method of identification of personnel.

In summary, the wardrobe required for a Space Station application has been defined, material of construction selected, wardrobe weight and volume impact on the Space Station system assessed, and wardrobe support systems have been outlined. Once a mission profile has been defined, the data presented herein and in the revised handbook, will be useful in assisting in the selection of a crewman wardrobe system.

3.2 FABRIC USAGE

The previous section of this report was concerned with a wardrobe system designed to be worn by the crewman, however, with the increase in the physical size of space vehicles, there will be a need for fabric items to satisfy additional requirements outside the personal wardrobe. This task investigated the Space Station fabric requirements and the results of this study are contained herein.

The use of fabric in Space Station accommodations and accessory items have a major weight advantage over their contemporary non-fabric (plastic, ferrous, non-ferrous metals,etc.) counterparts. The flexibility of fabric items also enhances their applicability to Space Station use as well as providing secondary benefits in the areas of sound absorbency, ease of fabrication, maintenance and compactness.

The stringent flammability requirements imposed on current space related fabric items will be somewhat lessened for Space Station use due to the change from a more hazardous environment to a more earth-like environment within the space vehicle. This results in the consideration of more types of fabrics (woven and non-woven) other than the accepted costly fire-crit cria materials. Design factors such as fabric toxicity, flame propagation rates, and ignition points will not be neglected but rather, factors such as material wear, utility, availability, ease of fabrication and cost will take on greater significance in the fabric selection process.

For the purposes of this study a four-level space vehicle, with a 12- man compliment was assumed. The physical layout of the space vehicle was assumed to be:

Level 1 - Wardroom and medical section.

Levels 2 and 3 - Staterooms and hygienic section.

Level 4 - Experiment and controls section.

The fabric items contained in the mess section of the wardroom will include a compartment separator to isolate the wardroom from the medical section; chair coverings used to support the crewmen during recreational and/or eating activities; restraint devices to immobilize men and equipment when required, and napkins and wipes used by crewman. The medical section will contain a couch cover and an examining table cover; chair covers, and a lavatory separator. The individual fabric items used in a medical laboratory (swabs, compresses, slings, etc.) requires a detailed study effort and was considered beyond the scope of this task effort.

The stateroom sections of level's 2 and 3 will require couch and chair coverings; a compartment separator; individual bedding;laundry container; waste storage container, toiletry kit; towels, and individual crewman handkerchiefs.

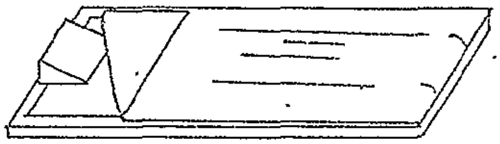
Level 4 - experiments and controls section will require chair coverings; restraint devices and section separators. Individual experiment packages have not been considered in this study.

Figure 3.2.1 is a pictorial representation of the various fabric items that were considered for space station use. The material weight and areas are based on single unit quantities.

The fabric to be considered for Space Station use must be evaluated on the basis of availability, wear resistance, comfort, ease of fabrication, and cost. Fabric item construction is dependent on the particular application but generally in the

FIGURE 3.2.1 FABRIC USAGE

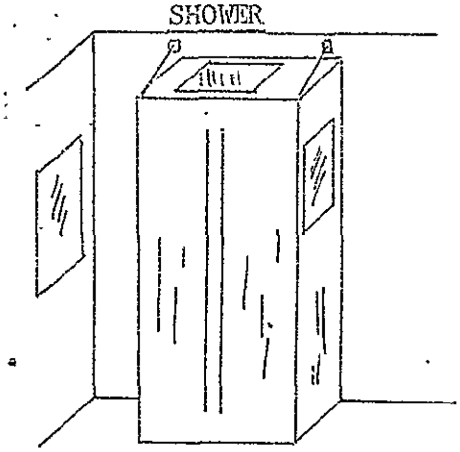
BEDDING



DESIGN CONSIDERATIONS

- Comfort
- Warmth
- Absorbency
- Strength
- Ease of Operation

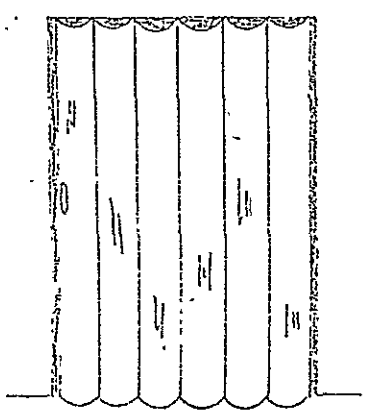
SHOWER



DESIGN CONSIDERATIONS

- Strength
- Endurance
- Ease of operation
- Water Compatible

SEPARATOR

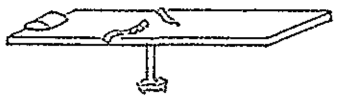


DESIGN CONSIDERATIONS

- Strength
- Ease of Operation
- Light Weight
- Close Weave

FIGURE 3.2.1 FABRIC USAGE (Cont'd)

MEDICAL COUCH



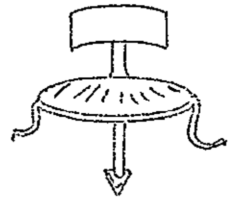
DESIGN CONSIDERATIONS

Strength

Endurance

Absorbency

CHAIR



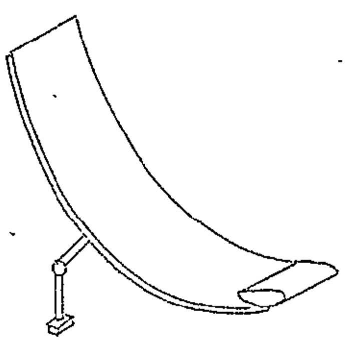
DESIGN CONSIDERATIONS

Strength

Endurance

Comfort

COUCH



DESIGN CONSIDERATIONS

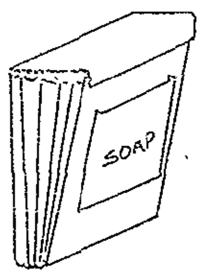
Strength

Endurance

Comfort

FIGURE 3.2.1 FABRIC USAGE (CONT'D)

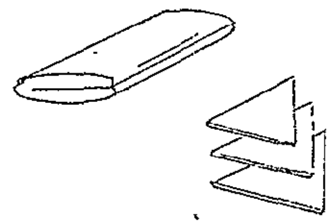
LAUNDRY KIT/BAG



DESIGN CONSIDERATIONS

Strength
Endurance
Tight Weave
Ease of cleaning

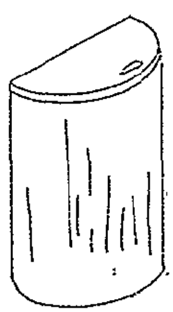
TOWELS, NAPKINS



DESIGN CONSIDERATIONS

Absorbency
Comfort
Soft Hand
Washable

WASTE STORAGE CONTAINER



DESIGN CONSIDERATIONS

Strength
Endurance
Ease of Operations
Ease of Cleaning

case of space vehicle accessory items, fabric strength as indicated by the fabrics performance under similar conditions, takes on a major importance.

Fabric color will be dependent on the general decor of the space vehicle or may be considered in functional grouping for ease of identification and/or for aesthetic reasons. For example, chair colorings may be varied in a grouping to break up the monotony of monochromatic styling and napkins may be assigned a red hue while wipes may be green. Space vehicle interior coloring must consider psychological as well as functional reasons and was beyond the scope of this task effort.

3.3. LAUNDRY SYSTEMS

The earlier manned space flights - Mercury, Gemini, Apollo - were relatively short duration missions requiring a minimal personal wardrobe for the crewman. The garment items provided served a multiple function and were discarded at the completion of the mission. With the extension of mission timelines and the increase in crew number, the penalties imposed, mainly weight and volume, on the Space Station system become prohibitive if the current techniques are maintained. To minimize the impact of larger crew wardrobes, a laundry system must be developed for Space Station use.

This task effort investigated laundry systems which, although considered state-of-the-act systems, have applicability for use in a space environment.

In the evaluation of a laundry system the impact of weight, volume, power usage, and interface requirements between the space vehicle and selected system must be considered in conjunction with the actual laundry hardware design. This results in the design of an optimum system with minimal impace on the entire Space Station complex. In this study, laundry concepts that result in the least impact on the entire system were investigated.

Current cleaning methods were evaluated to determine their applicability to Space Station use. Present day laundering systems require a gravity field within which to operate effectively, therefore, a standard washing machine cannot be used in a Space Station application that is operating in a near zero-gravity field. Major modifications would be required to use an existing design. The theory of cleaning and the mechanics of soil removal were studied in conjunction with determining the types of soils anticipated in a Space Station environment. These factors have a direct bearing on the design of the laundry water recovery and storage systems. This task evaluated laundry systems varying from hand operated to completely automatic with closed-loop water recovery capabilities.

3.3.1 SYSTEM DESIGN GROUND RULES

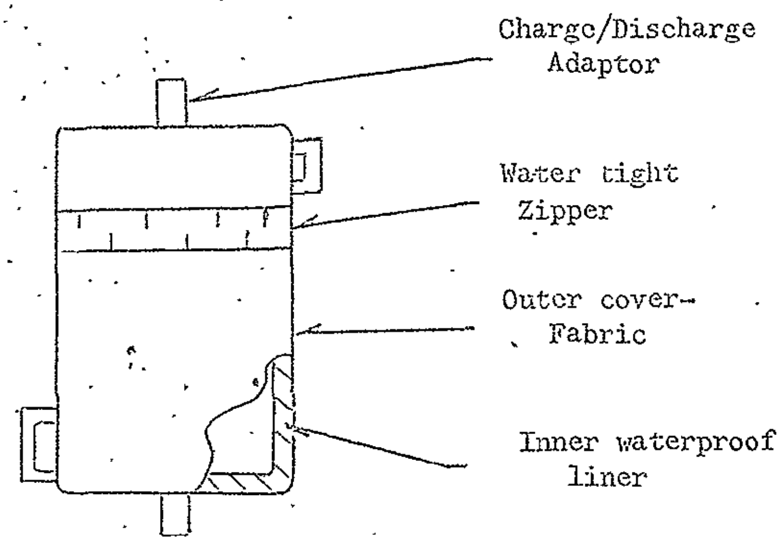
For this study effort certain ground rules were made that established the baseline design. In the case of a hand laundry system, the laundry load was considered to be less than 5 pounds per man on a seven day laundering cycle. The composition of the laundry load was considered to be shirts, socks, and briefs with jackets and trousers excluded. For the automatic laundry system the laundry load was considered to be 20 pounds/man on a weekly laundering cycle. This laundry load was composed of jacket, trouser, shirt, briefs and socks. Other washable fabric items, such as sheets, towels and washcloths can also be laundered by either the automatic laundry system at the same time as the garment items, or with the hand laundry system separate from the garment items, for both concepts the solvent considered for use was water. The selection of the detergent to aid the water in soil removal has not been determined and requires an in depth evaluation, beyond the scope of this task effort, to determine the optimum detergent to be used in a Space Station application.

3.3.2 HAND LAUNDRY CONCEPTS

Hand laundry concepts were evaluated for use with small laundry loads, on the order of 5 lbs/man or less. This type system is adequate for cleaning such items as shirts, briefs, and socks but would be limited in its ability to launder the larger items such as jackets and trousers. A laundry system of this type relies on the crewman to provide the agitation required to assist in soil removal. This imposes a burden on the crewman that, depending on the laundering cycle, can prove to be prohibitive. For this reason, hand laundry systems must be considered as a limited use item and a higher degree of sophistication is required in a laundry system for use in a Space Station.

Figure 3.3.1 depicts two hand laundry concepts considered for Space Station use. Alternate systems such as vibratory agitators, chemical/physical effervesing tablets, rotary hand-crank and pneumatic-vacuum systems were investigated but found not applicable for this particular use due to complexity of design, low reliability, and/or ineffective cleaning action.

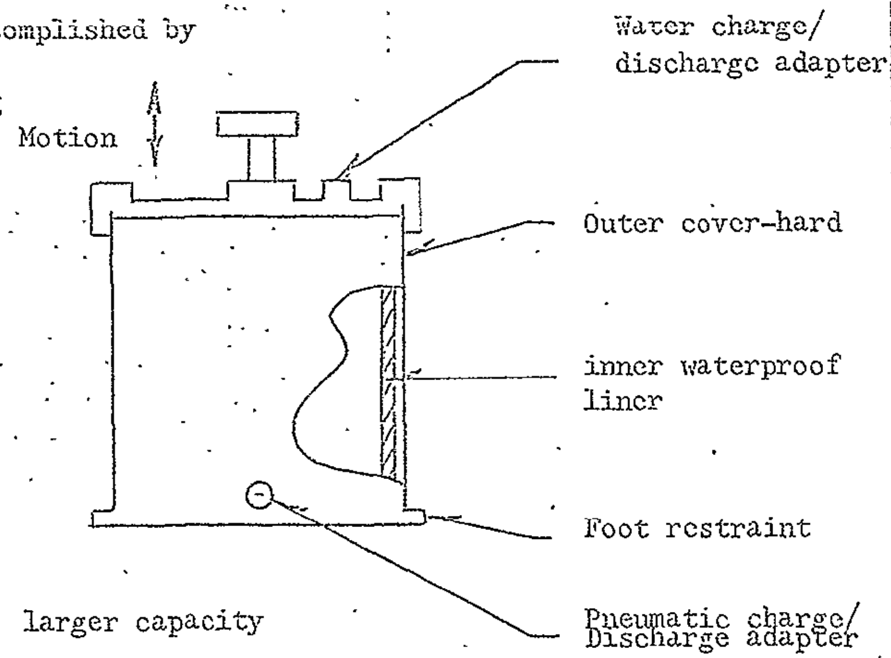
FIGURE 3.3.1 HAND LAUNDRY CONCEPTS



A. Flexible-Water Bag

Features:

- Simple design, easy operation
- Small volume, light weight
- Agitation accomplished by hand kneading



B. "Churn" T ub

Features:

- Simple design, larger capacity
- Positive water discharge after laundering cycle
- Can be bulkhead mounted or operated from seated position

3.3.3 AUTOMATIC LAUNDRY SYSTEMS

The need for a laundry system to support a long duration, multiple crew Space Station has been presented and this task effort investigated various concepts that are applicable for use in a Space Station environment.

A trade study was conducted at the beginning of this task evaluating the solvent to be used in a laundry system. Due to the toxicity and flammability hazards present when using standard cleaning solvent like Stoddard solvent and perchloroethylene, water was selected for use in this application.

Water can be considered the most important single component in the system and, through its solvent action, water alone is an effective and complete detergent for a large percentage of the soils that are anticipated in a Space Station. Water functions as a wetting agent that penetrates the soil-fiber interfaces, and carries away the separated soil. Water also aids in transmitting the mechanical energy developed by the washer agitator to the fabric-soil interface and assist in reducing the soil particle globule size for stable dispersion. Lastly, water is the oldest and only self-sufficient detergent, soaps, synthetic detergents, and builders have been developed primarily for the purpose of improving the actions that water and mechanical agitation, for the most part, are capable of doing alone. From a system standpoint, water imposes the least penalty on the space craft environmental control system.

The selection of soaps and/or synthetic detergents for use in a Space Station laundry system has been investigated in a cursory analysis, however it forms a basis for a complete study of its own. Current water recovery systems are being evaluated with a detergent Miranol (Miranol Chemical Co.) for possible space application.

3.3.3.1 SYSTEMS GROUND RULES

The ground rules established for the laundry system were as follows:

- Typical load size ..... 20 pounds per crewman based on task 1 evaluation.
- Crew size .... 12 men/laundry system.
- Max. laundry cycles/day. 2 to minimize impact on spacecraft water reclamation system.
- Wash cycle time .... 40 minutes - based on recommendation of the American Institute of Laundering and initial estimates.

3.3.3.2 WASHER SELECTION

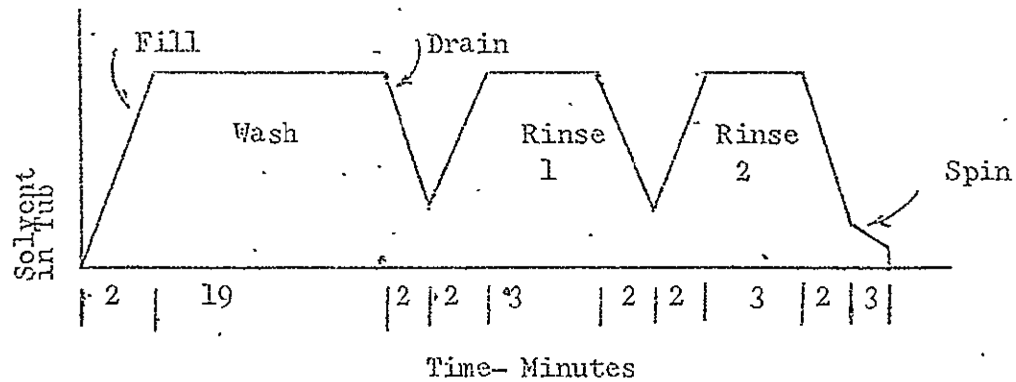
In the design of a laundry washer, the impact on the spacecraft water reclamation system is of primary concern. From this baseline, various concepts can be evaluated. In this study, the following washer concepts were evaluated. These concepts were considered primarily to investigate the system impact on the Space Station more than to arrive at a final system design.

- Rotary washer.
- Oscillatory washer.
- Ultrasonic washer.
- Vibratory washer.
- Water jet.
- Drycleaning

From the preliminary evaluation, the vibratory and ultrasonic concepts were eliminated from further study due to the high power requirements for this type system and the lack of success in this application due to the dampening action of fabric items. Drycleaning was discarded due to the hazardous cleaning solvents required for this system. The rotary type system, although imposing the least penalty on water usage rate, would require analysis that, according to the task ground rules, was considered beyond the scope of this study. A system of this type can be developed for use in a zero gravity environment and can be the basis for a future study effort. The water jet concept requires select positioning of clothing to effectively remove soils and demands high water usage rates which impose undue penalty on the water recovery system. The remaining concept, the oscillatory washer, is the recommended system for use in the Space Station based on present washer technology. For zero gravity operation, the washer tub is filled completely with water and the mechanical agitation is imparted to the water in an oscillatory manner or can be combined with other types of motion (corkscrew, transverse, etc) to effect the cleaning action. This task considered only the oscillatory motion, alternative methods can be evaluated in a future study to optimize the system.

The wash cycle was determined based on an evaluation of data prepared by the American Institute of Laundering concerning the proper cycle to use for the cleaning operation of fabric items in this particular application.

This cycle considers the anticipated soiling characteristics of a Space Station Environment.



An evaluation of single cycle washing should be made during the conduct of a future study effort concerned with obtaining basic laundering data. A single wash cycle will have obvious advantages over the dual cycle in water usage rates and in reducing laundry times.

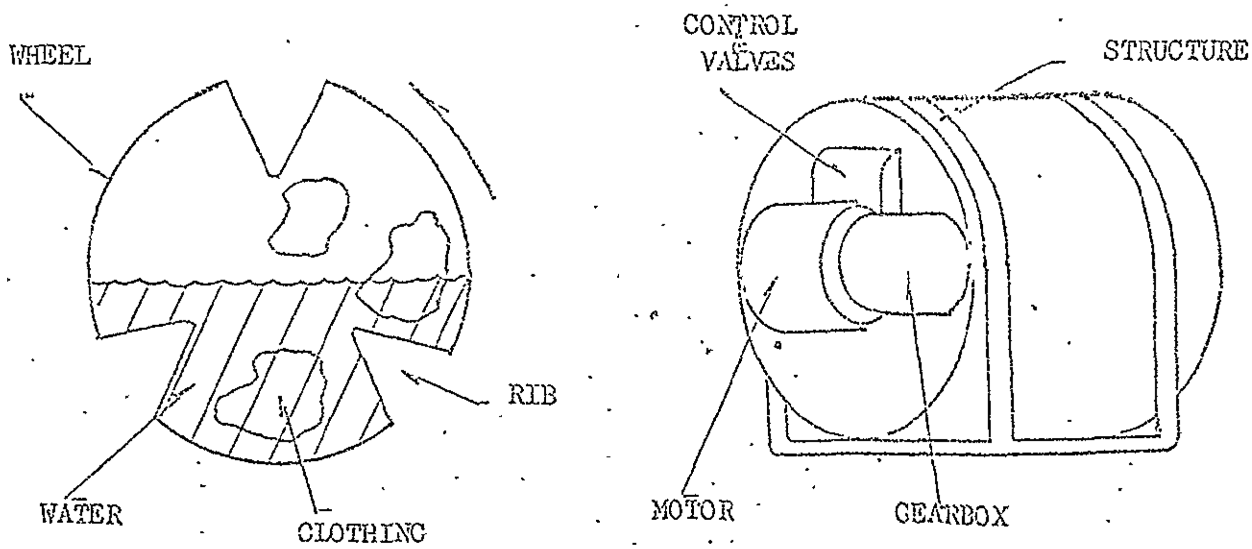
Figure 3.3.2 is a representative drawing of a rotary washer concept.

Figure 3.3.3 depicts an oscillatory type washer system.

Figure 3.3.4 represents an ultrasonic system.

Table 3.3.1 compares the various systems evaluated in this study effort.

FIGURE 3.3.2 ROTARY SYSTEM - WATER SOLVENT



FEATURES

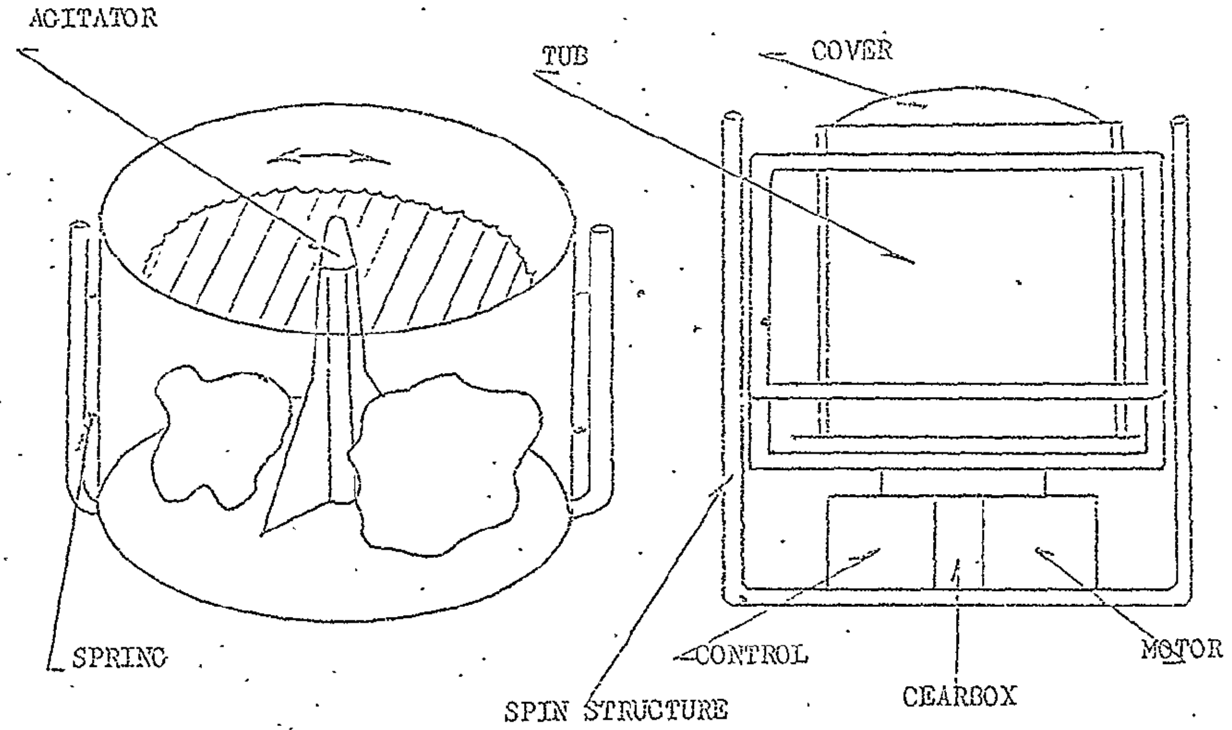
LOAD FACTOR	-	2.5 LB/FT^3
WEIGHT	-	50 LBS.
TUB VOLUME	-	8 FT^3
POWER	-	345 WATTS
WATER		
SUDS	-	190 LBS.
RINSE	-	140 LBS/CYCLE

PROBLEM AREAS

Requires a gravity field to operate properly.

Revision for space use would be costly.

FIGURE 3.3.3 OSCILLATORY WASHER SYSTEM



FEATURES

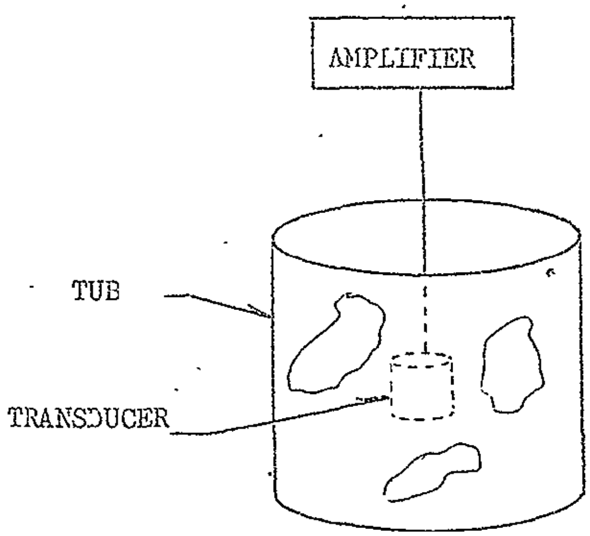
LOAD FACTOR	$3.3\ LB/FT^3$
WEIGHT	44 LBS
TUB VOLUME	$6\ FT^3$
POWER	535 WATTS
WATER	
SUDS	300 LBS
RINSE	250 LBS.

DOES NOT REQUIRE GRAVITY

PROBLEM AREAS

Relatively high water usage.

FIGURE 3.3.4 ULTRASONIC SYSTEM



. Agitation provided by cavitation of solvent

. Presently used to clean rigid items.

FEATURES

LOAD FACTOR -	2.5 lb/ft.^{3}*
WEIGHT -	55 lbs.
TUB VOLUME -	8 ft^{3}
POWER -	5500 Watts
WATER:	
SUDS -	425 lbs.
RINSE -	375 lbs.

PROBLEM AREAS

- No successful application made for clothing.
- High power requirement.
- Sound interference

*Estimated - for comparison only .

TABLE 3.3.1 WASHER SYSTEMS COMPARISON

SYSTEM / CRITERIA	ROTARY-WATER	*OSCILLATORY-WATER	ULTRASONIC WATER	DRY CLEANING
WEIGHT (POUNDS)	50	44	55	62
POWER (WATTS)	345	535	5500	640
VOLUME (FT^3)	8	6	8	10
WATER SOLVENT PER CYCLE (POUNDS)	330	550	800	790

* A DRAWING OF A TYPICAL OSCILLATORY WASHER SYSTEM IS SHOWN ON WELSON DRAWING BW-2006-001 WHICH WAS SUBMITTED AT THE MIDTERN PRESENTATION.

3.3.3.3. DRYER SELECTION

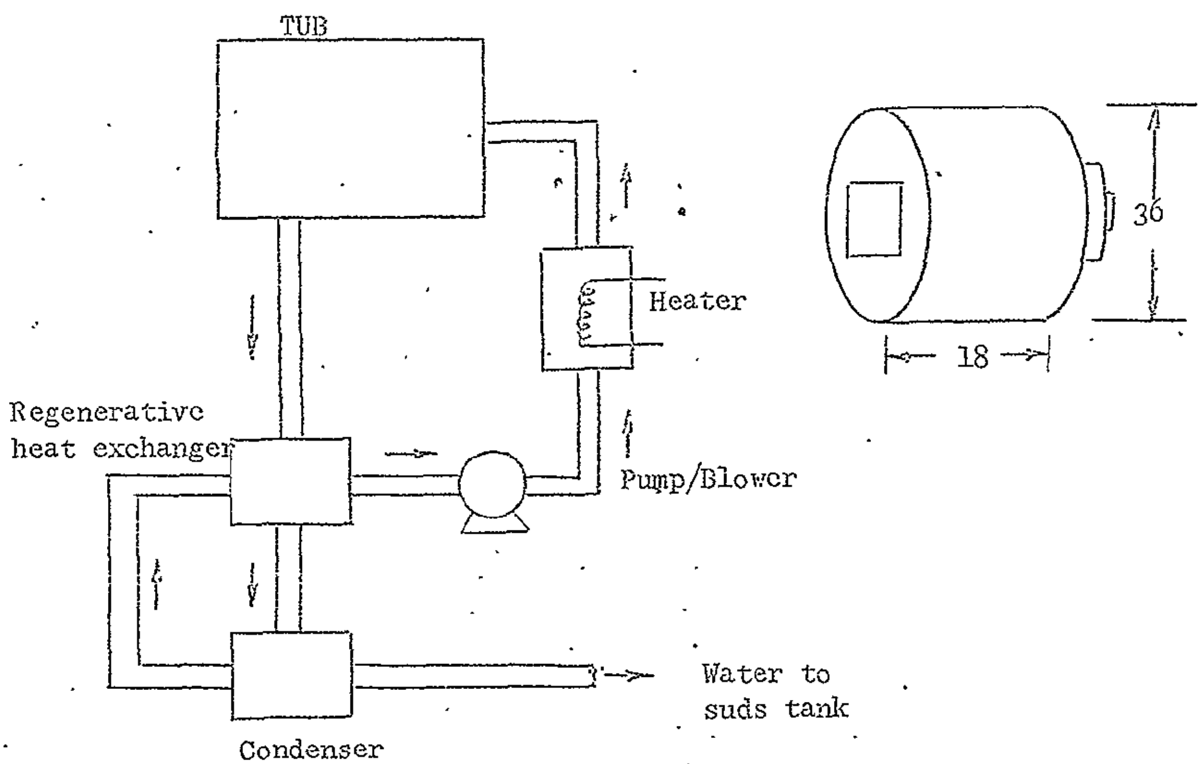
The laundry system dryer concepts investigated were:

- Heated gas with tumbling action.
- Vacuum desorption.
- Drip dry.

The candidate system recommended for use in a Space Station application is the heated gas-tumbling concept, with the tumbling action imparted by strategically placed, sequencing hot air nozzles. The vacuum desorption technique is not applicable for this use due to high water wastage, on the order of 1/4 to 1/2 pound per pound of clothing and to water sublimation when exposed to high vacuum causing ice formation on the fabric material and on the equipment. To prevent this, a highly sophisticated system would have to be developed. Drip drying was discarded based on the penalty imposed on the Space Station ECS to either remove the moisture directly from the fabric material which may result in unduly high cabin humidity levels or by having to provide a separate compartment and associated equipment to effect drying of the fabric items which results in a higher degree of sophistication than is justified.

Figure 3.3.5 depicts the candidate laundry system dryer concept.

FIGURE 3.3.5 HEATED GAS DRYER SYSTEM



FEATURES:

WEIGHT .... 70 pounds

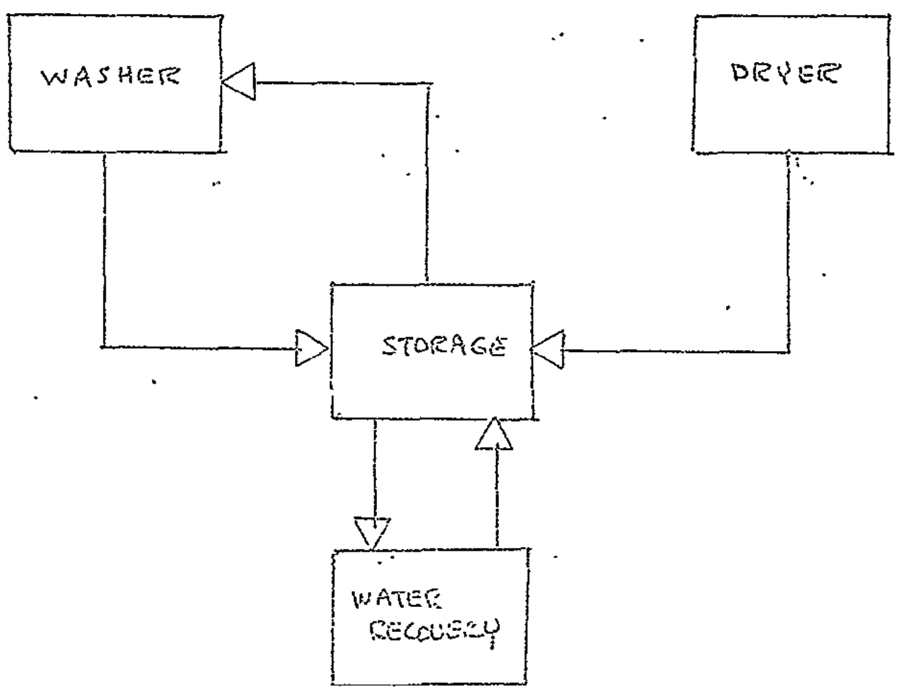
POWER .... 220 Watts (20,000 BTU Thermal)

VOLUME .... 10 Cubic feet.

3.3.3.4 WATER PROCESSING

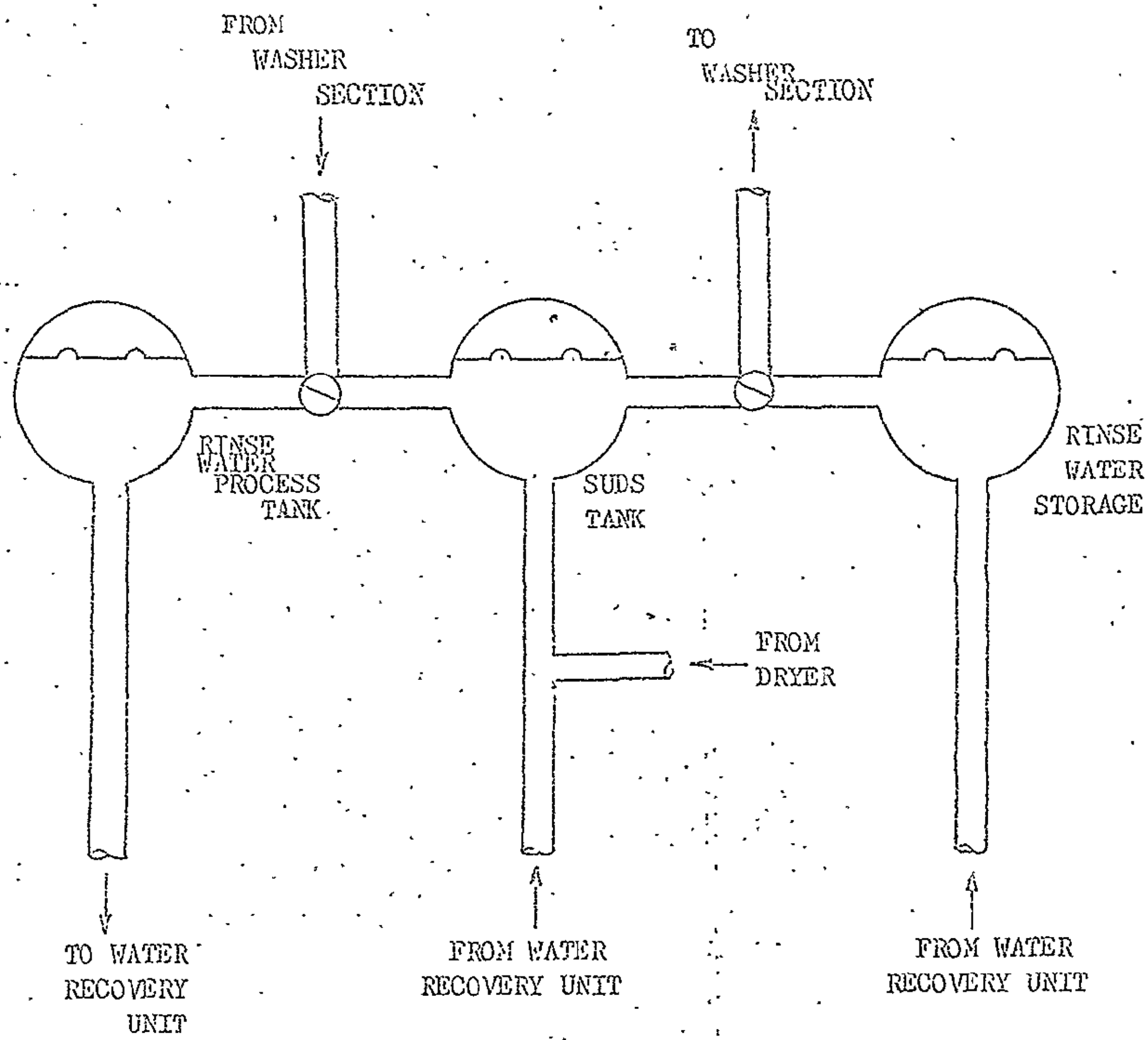
The water processing system required to support the laundering concepts can be designed to interface with the Space Station water management system or be a closed loop, self contained unit. This decision must await a systems analysis based on the final configuration of the Space Station and associated support equipment. In either case, the water used in this laundering cycle must be processed for reuse to minimize the weight penalties imposed on the Space Station.

The laundering proccess water flow diagram is as follows:



Water is transferred from the laundry system holding tank to the washer where it is used in the wash cycle. At the end of the cycle, dirty water is returned to the storage tanks and retained until it is processed through the water recovery system where impurities are removed and clean water returned to the holding tanks for future use. To minimize the impact on the spacecraft water recovery system, the wash water suds can be filtered out and only the rinse water processed through the water recovery system. Water extracted during the drying cycle is also returned to the storage unit for future use. Figure 3.3.6 depicts a typical laundry water storage system. To minimize the impact of laundry water processing on the Space Station water management system, the laundry system will incorporate holding tanks, as depicted in Figure 3.3.6, to limit and control the quantity of "dirty" water to be processed and to provide an adequate supply of water to perform the washing task. This unit will allow simultaneous operation of the laundry system while water used in an earlier wash cycle is being processed to remove impurities such as detergent, soils, and lint. Make up water to replace that lost in the drying cycle will be provided by the Space Station water supply.

FIGURE 3.3.6 LAUNDRY WATER STORAGE SYSTEM



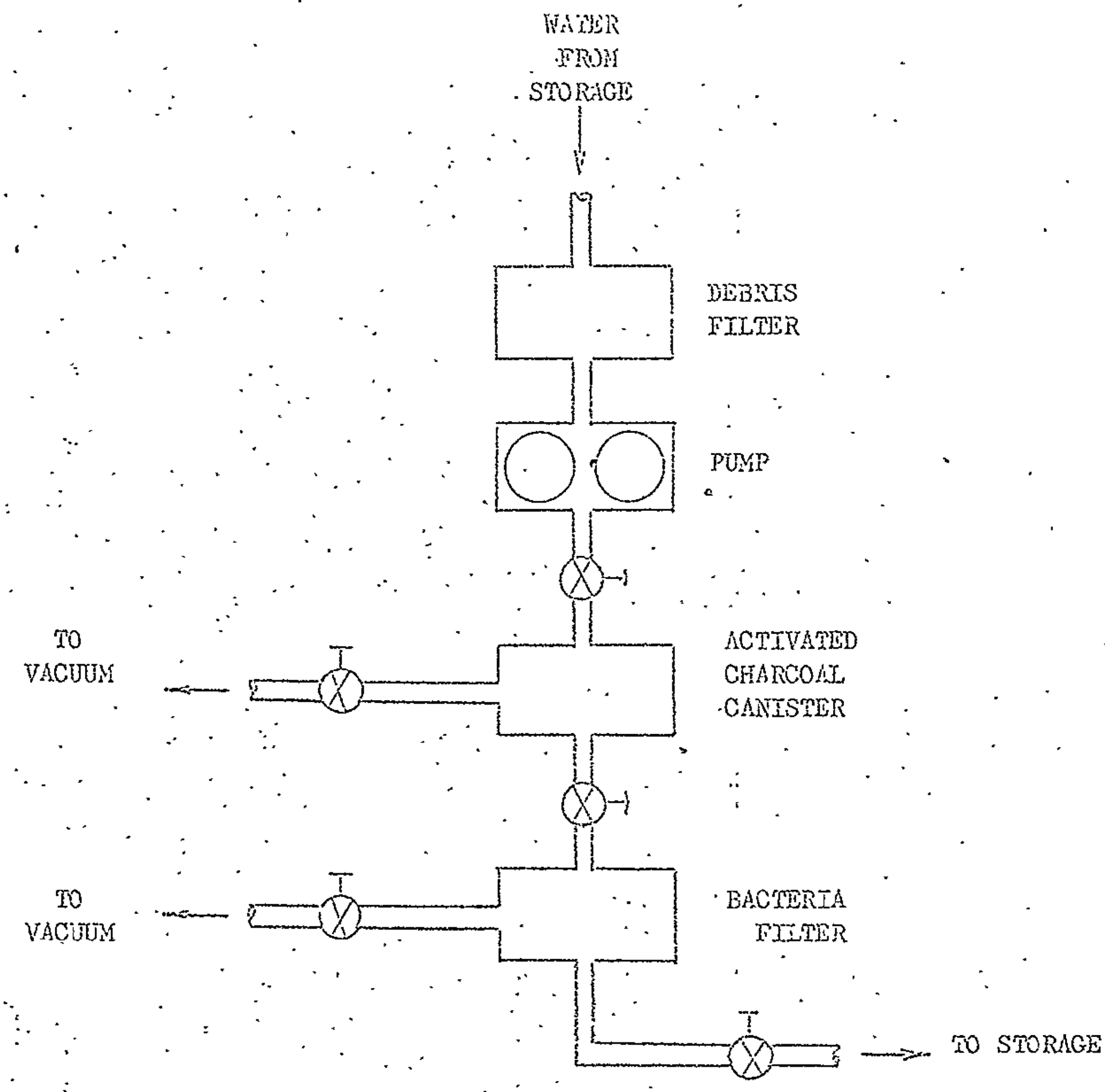
The water reclamation systems investigated for possible use in the Space Station are shown in Figures 3.3.7, 3.3.8 and 3.3.9. Table 3.3.2 is a system comparison and Figure 3.3.10 depicts the complete candidate laundry systems.

WATER FILTRATION SYSTEM DESCRIPTION

Water is removed from the washer/dryer unit and pumped through a filter that traps the solids entrained in the wash water. As shown in figure 3.3.7, the wash water is then passed through an activated charcoal canister where sour odors are removed and then passed through a bacteria filter that is used to keep the bacterial growth within acceptable limits by use of additives or ultraviolet light techniques. The water is then returned to the laundry storage tank for future use. The activated charcoal canister and bacteria filter can be vacuum purged for long life usage.

This system is limited to the removal of solid particulates in wash water only, and will not perform satisfactorily with ionic detergents.

FIGURE 3.3.7 WATER FILTRATION CONCEPT



FEATURES

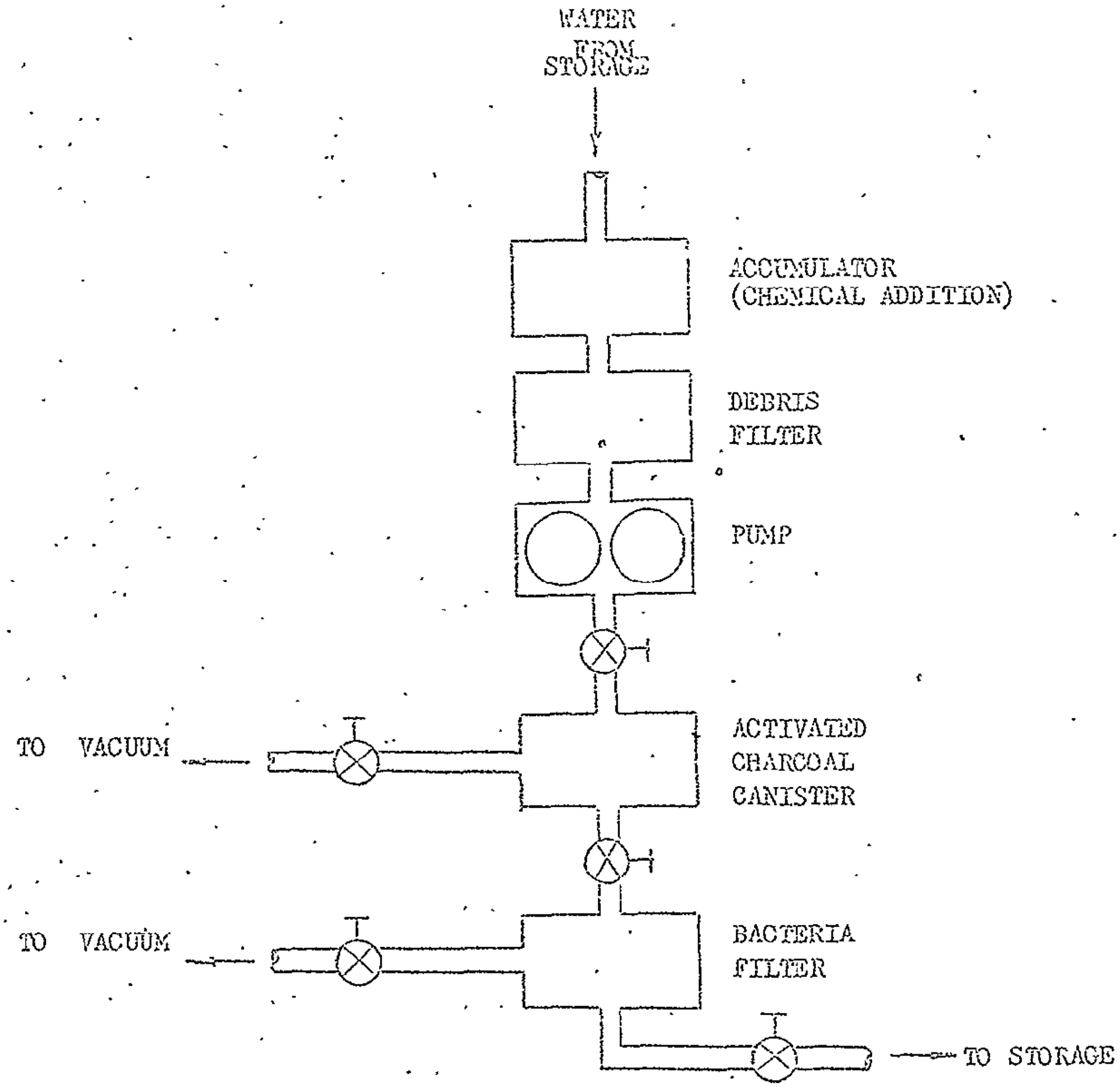
- FILTRATION OF SOLIDS (ONLY) IN RINSE WATER.
- WEIGHT PENALTY:
  BASIC SYSTEM . . . 30 LBS.
  EXPENDABLES . . . 33.6 LBS.
  Per 180 days
- POWER . . . 20 – 30 WATTS
- REQUIRES SPECIAL DETERGENT SELECTION (OR NONE AT ALL).

PRECIPITATION-FILTRATION CONCEPT (REF. FIG. 3.3.8)

The wash water is pumped through an accumulator containing a chemical additive used to precipitate electrolytes, then through a filter where solid particles are collected. The "clean" water then passes through a canister containing activated charcoal where the odors are removed, then through a bacterial filter and returned to the laundry system storage tank for re-use. The activated charcoal canister and the bacteria filter can both be vacuum purged for long life usage.

This system is designed to remove certain electrolytes as well as solids in wash water and can be recommended only for predictable soils and detergents.

FIGURE 3.3.8 PRECIPITATION - FILTRATION CONCEPT



FEATURES:

- REMOVAL OF CERTAIN ELECTROLYTES - COMPATIBLE WITH SOAP (BUILT OR UN-BUILT)

- WEIGHT PENALTY:
  - BASIC SYSTEM . . . . 35 LBS.
  - EXPENDABLES . . . . 53.6 LBS. Per 180 Days

- POWER . . . . . 20 - 30 WATTS

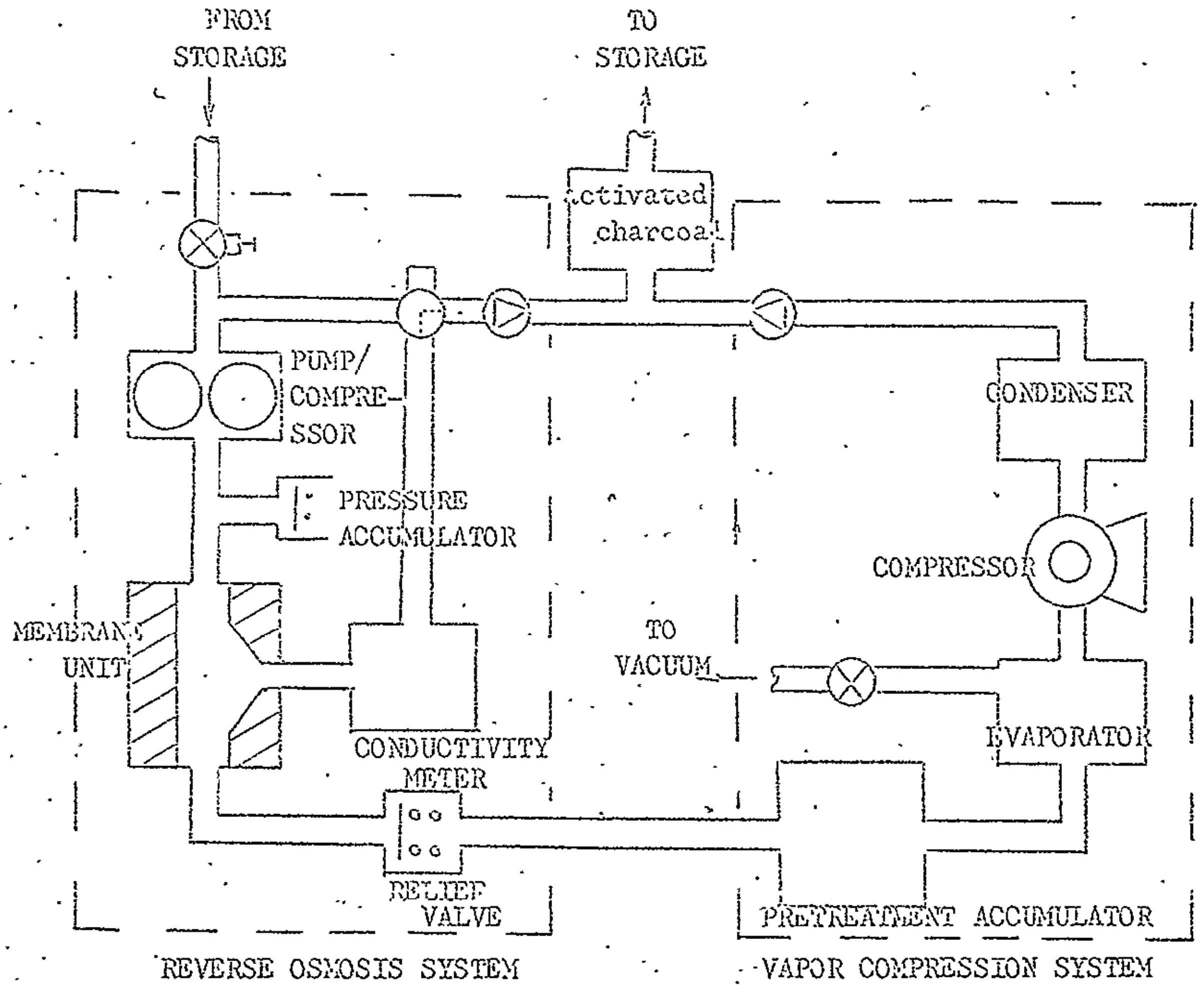
- WILL REMOVE PREDETERMINED ELECTROLYTES (QUANTITY AND TYPE).

REVERSE OSMOSIS - VAPOR COMPRESSION (REF. FIG. 3.3.9)

The most feasible method of water processing is shown in figure 3.3.9. The wash water is pumped into the reverse osmosis unit where the contaminants are trapped and the "clean" water passes on through the membrane to storage. The remaining water is directed to the vapor compression system where the balance of contaminants in the wash water are removed. The processed water then passes through a canister containing activated charcoal for odor control and into the laundry system water storage unit. The reverse osmosis system is designed to process 80% of the water and the vapor compression system, 20%.

This system is designed to remove all of the contaminants from the wash water with a residue of approximately 1%.

FIGURE 3.3.9 REVERSE OSMOSIS - VAPOR COMPRESSION



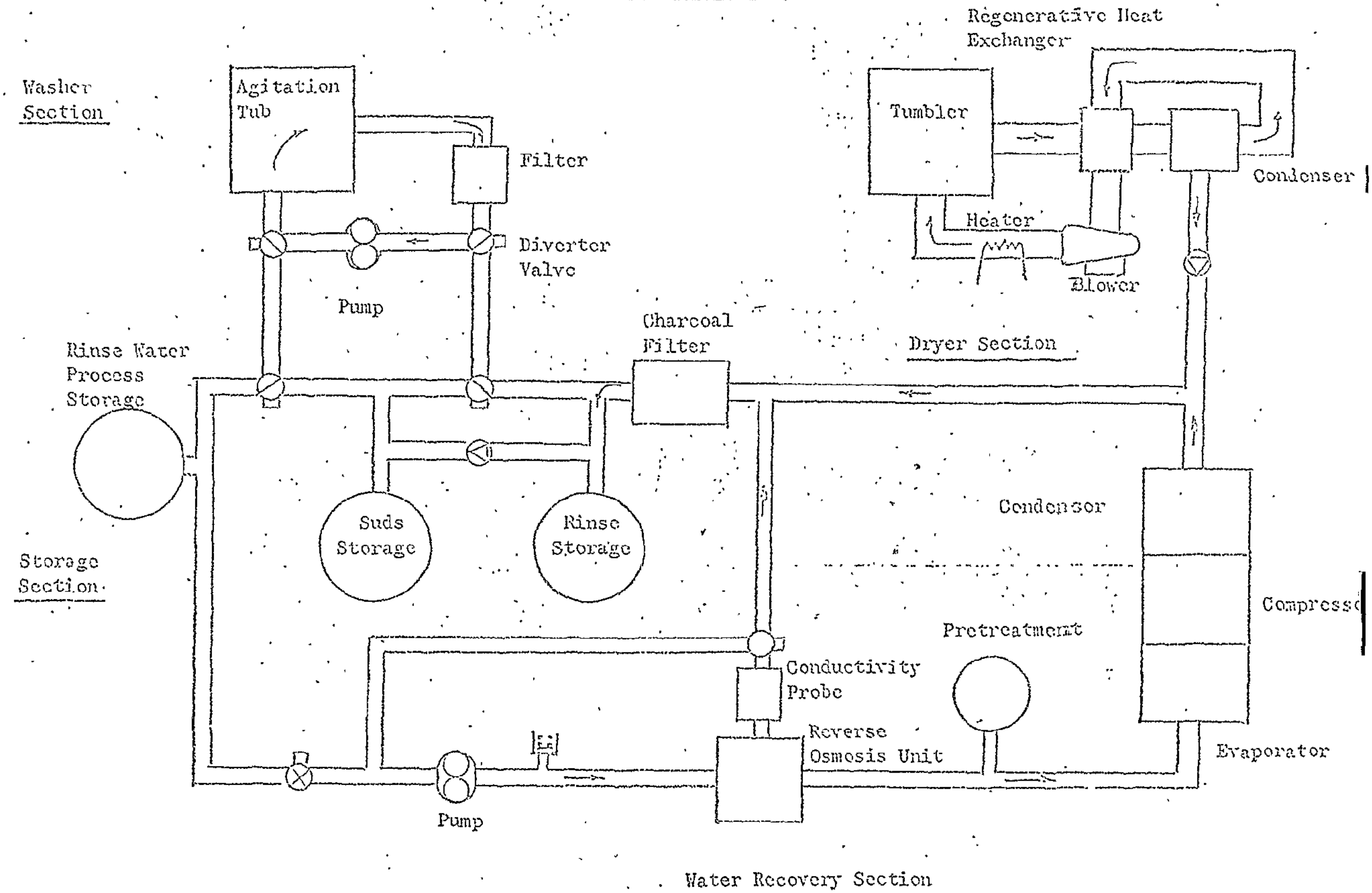
- WILL REMOVE MOST CONTAMINANTS FROM RINSE WATER
- HIGH (200 - 600 PSIA) PRESSURE WATER
- ACTIVATED CHARCOAL REQUIREMENTS = 33.6 LBS PER 180 DAYS
- OSMOSIS SYSTEM MEMBRANES = 2 REQUIRED - 1 ON LINE AND ONE SPARE

TABLE 3.3.2 WATER RECOVERY SYSTEMS COMPARISON

DESCRIPTION	FIXED WT.(LBS)	STORAGE WATER (LBS)	EXPENDABLES (LBS)	TOTAL WT.(LBS)	POWER (WATTS)	REMARKS
Filtration System	30	250	33.6	313.6	20/30	Can be used with non-electrolytes only. Dependent on concentration. Use non-ionic detergent
Precipitation Filtration System	35	250	53.6	338.6	20/30	Can be used with certain electrolytes. Weight dependent upon concentration. Can use soap, built soap and ionic detergents.
Reverse osmosis vapor compression system (80/20)	318	250	20	588	634	Weight penalty can be improved with higher reverse osmosis unit recoveries Can be used with any electrolyte. Can use soap, built soap, and ionic detergent.
Vapor Compression	570	500	20	1090	1375	Least desirable from a weight and power standpoint. Can use soap, built soap and ionic detergents.

The complete laundry system is shown in Figure 3.3.10. Water and suds from the water storage section is transferred to the washer where it is used for the cleaning cycle. At the completion of this cycle, the dirty water is transferred back to the water storage section, and, held until cycled through the water recovery unit. When the dirty water is scheduled for processing it is transferred from the storage area to the two-stage water recovery section when all contaminants are removed. The "clean" water is then returned to the storage section and held for future use. Excess water extracted from the clothing during the drying cycle is also returned to the water storage section for re-use.

FIGURE 3.3.10 - LAUNDRY SYSTEM



EXPENDABLE USAGE

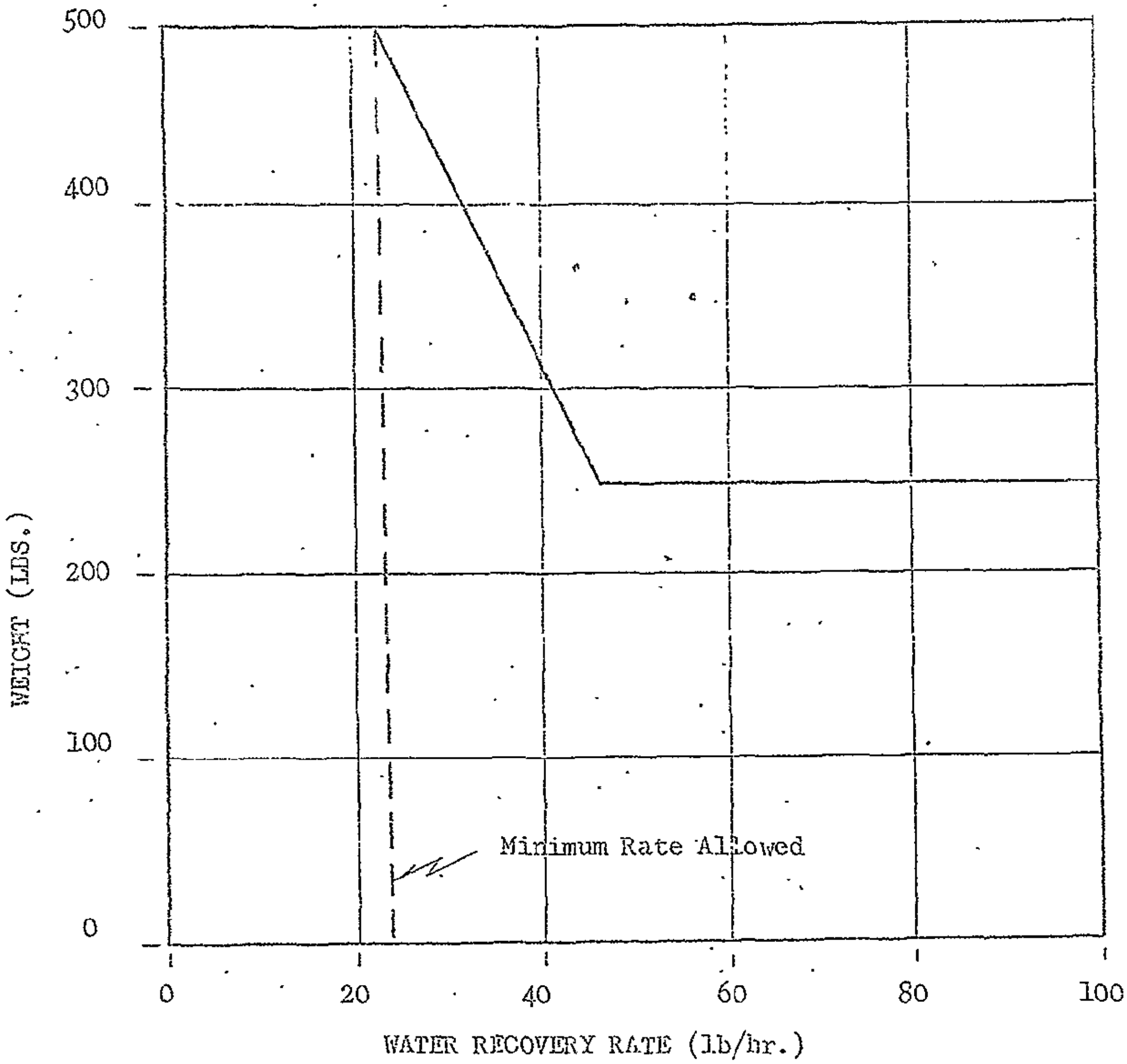
Activated Charcoal = 33.6 lbs. per 180 days
Osmosis System = 1 on line and 1 spare Membranes

3.3.6 WATER USAGE

The quantity of water to be stored in a Space Station for laundry use is dependent upon the water recovery process rate. With a low recovery rate more water must be made available to satisfy the wash cycle requirements. The process rate, in turn, is dependent upon the amount of clothing being laundered and the type of detergents to be removed from the wash water. A systems analysis is required to arrive at the optimum configuration for Space Station use.

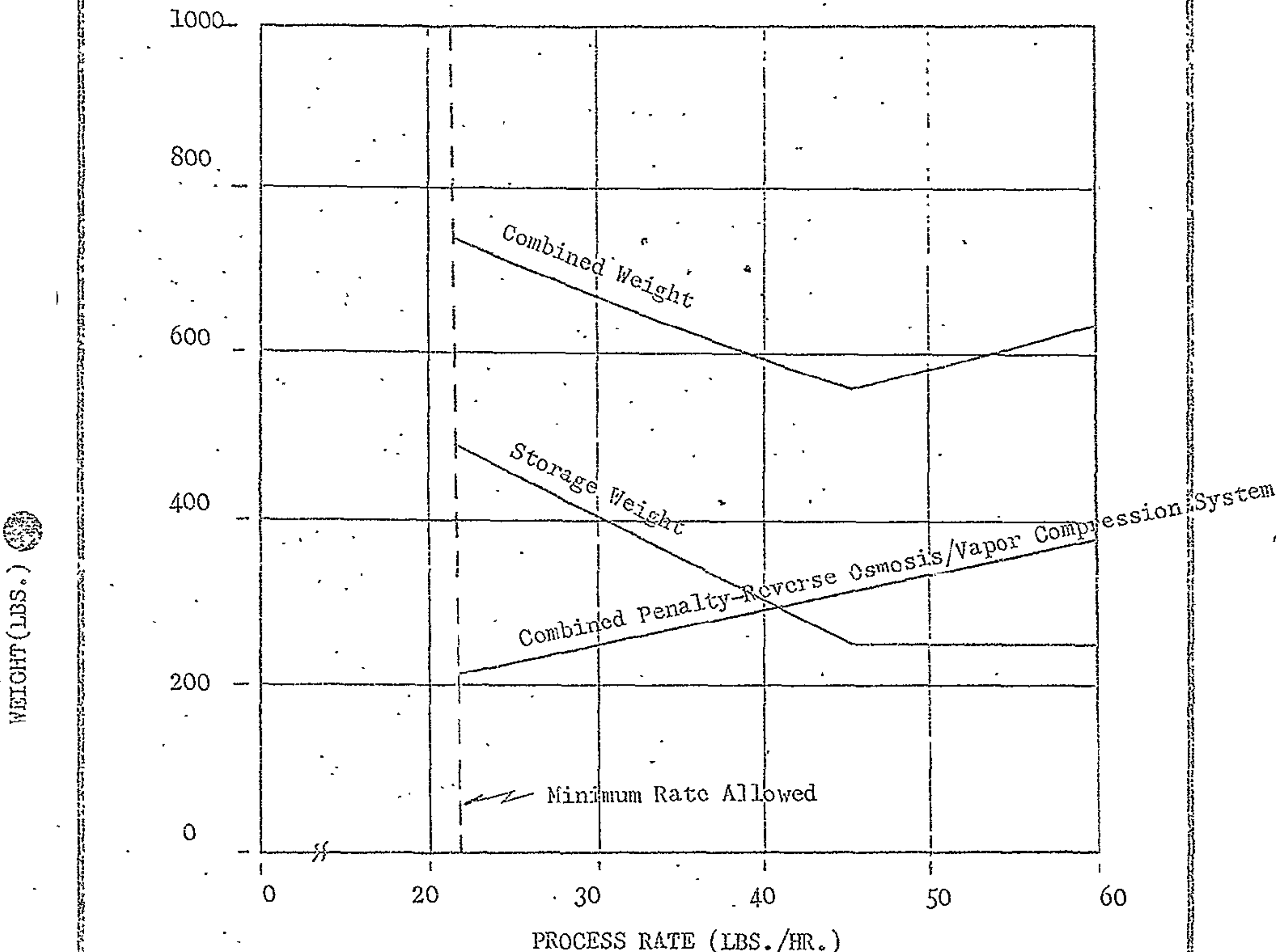
For the purposes of this study, a 20 pound laundry load was assumed, using a water solvent. It was determined that a minimum water recovery rate of 22 lbs/hr. would be required to support a 12 man laundry system with a two cycle recovery sequence. Figure 3.3.11 outlines the stored water requirement for these conditions and Figure 3.3.12 depicts the water recovery rate for the candidate system.

FIGURE 3.3.11 RINSE WATER STORAGE QUANTITY



- 12 man laundry system
- Minimum cycle sequence - Two (separated by 12 hours).
- 20 pound load

FIGURE 3.3.12 WATER RECOVERY RATE



Reverse Osmosis/Vapor Compression Recovery System

– 80% Recovery from Reverse Osmosis System

–	System Weight –	318
–	Water Weight –	250
	Total –	568

3.3.3.6 The laundry system concept presented is representative of state-of-the-act hardware presently undergoing evaluation. Other concepts are certain to be developed that equal or possibly surpass current systems, however, to develop these concepts requires a systems analysis to define such factors as proper detergent to be used, water usage rates, definition of acceptable cleanliness levels, mechanics of soiling and the detergent action and optimization of the selected design. There is a definite need to explore this area in greater depth before an adequate laundry system can be developed.

3.4 GARMENT PACKAGING

In the logistics of Space Station supply garment items one must consider the method of packaging to achieve the maximum quantity delivery in the minimum transfer envelope, while maintaining the garment appearance. This task effort was concerned with garment packaging and investigated various folding techniques and packaging concepts. This effort was concerned with packaging for a Skylab type mission and a Space Station mission.

Two folding techniques investigated in this study were the flat fold configuration and the rolled configuration. Figure 3.4.1 depicts a typical flat fold configuration for a duty jacket. Figure 3.4.2 is a comparison of the resulting folded vs. rolled volumes of flight items fabricated for use in the Skylab program.

To minimize the garment packaged envelope, vacuum packaging of garment systems can be employed. This method reduces the total packaged volume which in turn provides more available transfer space. When vacuum packaging garment items, consideration must be given to the method of garment stackup to minimize the effect of local increased garment thicknesses due to the

FIGURE 3.4.1 SAMPLE FOLDING TECHNIQUE

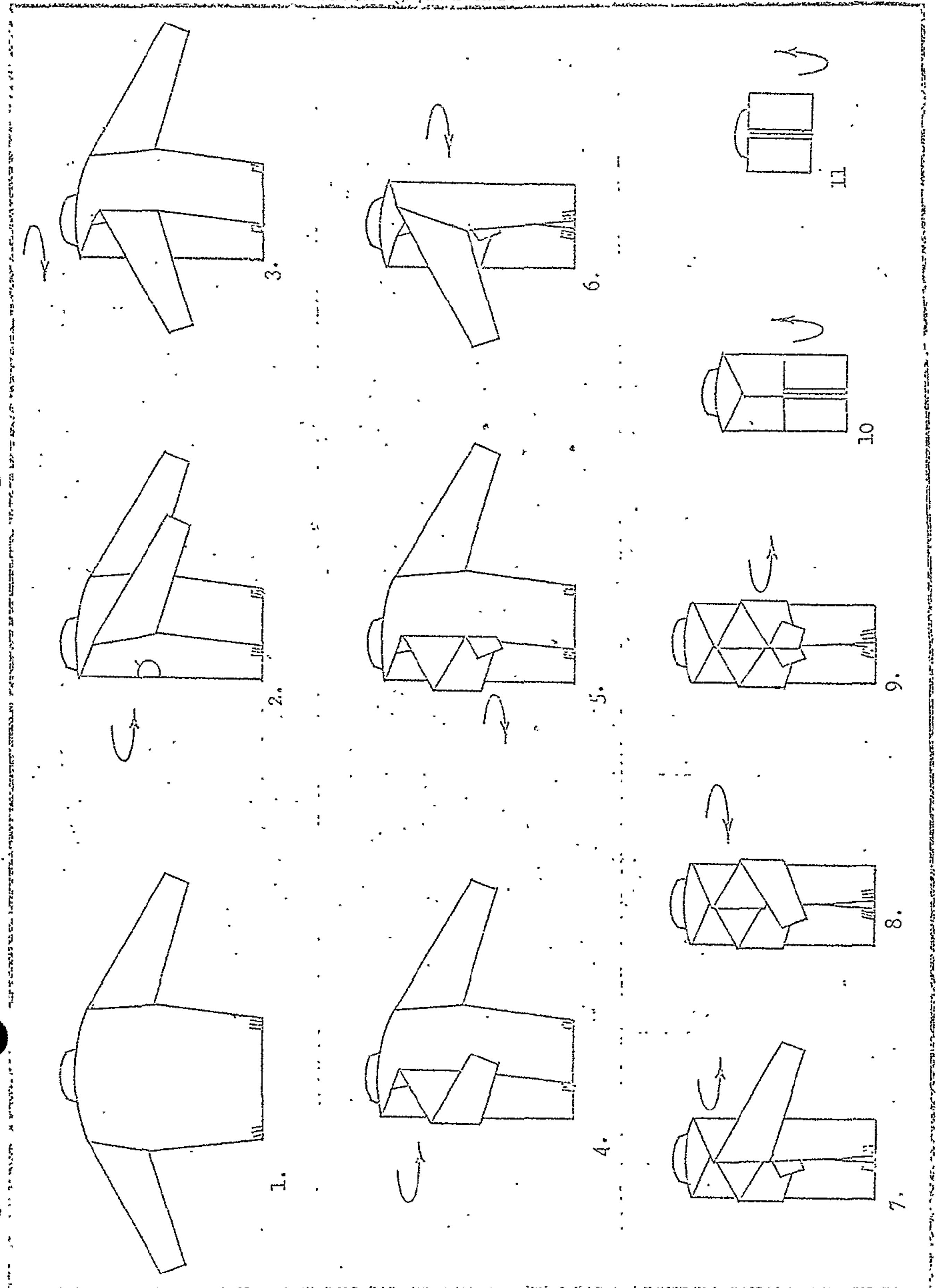
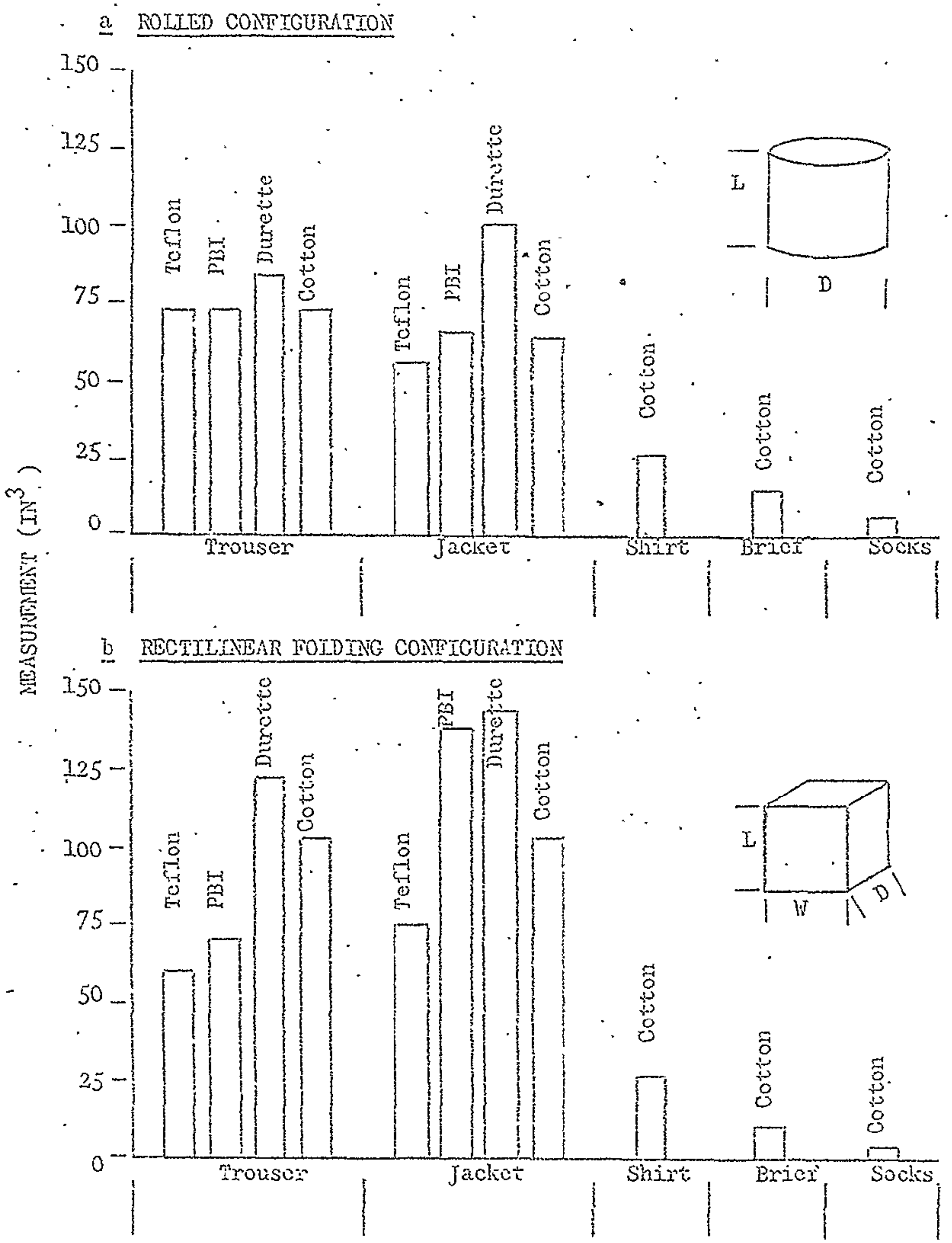


FIGURE 3.4.2 FLIGHT GARMENT ENVELOPE

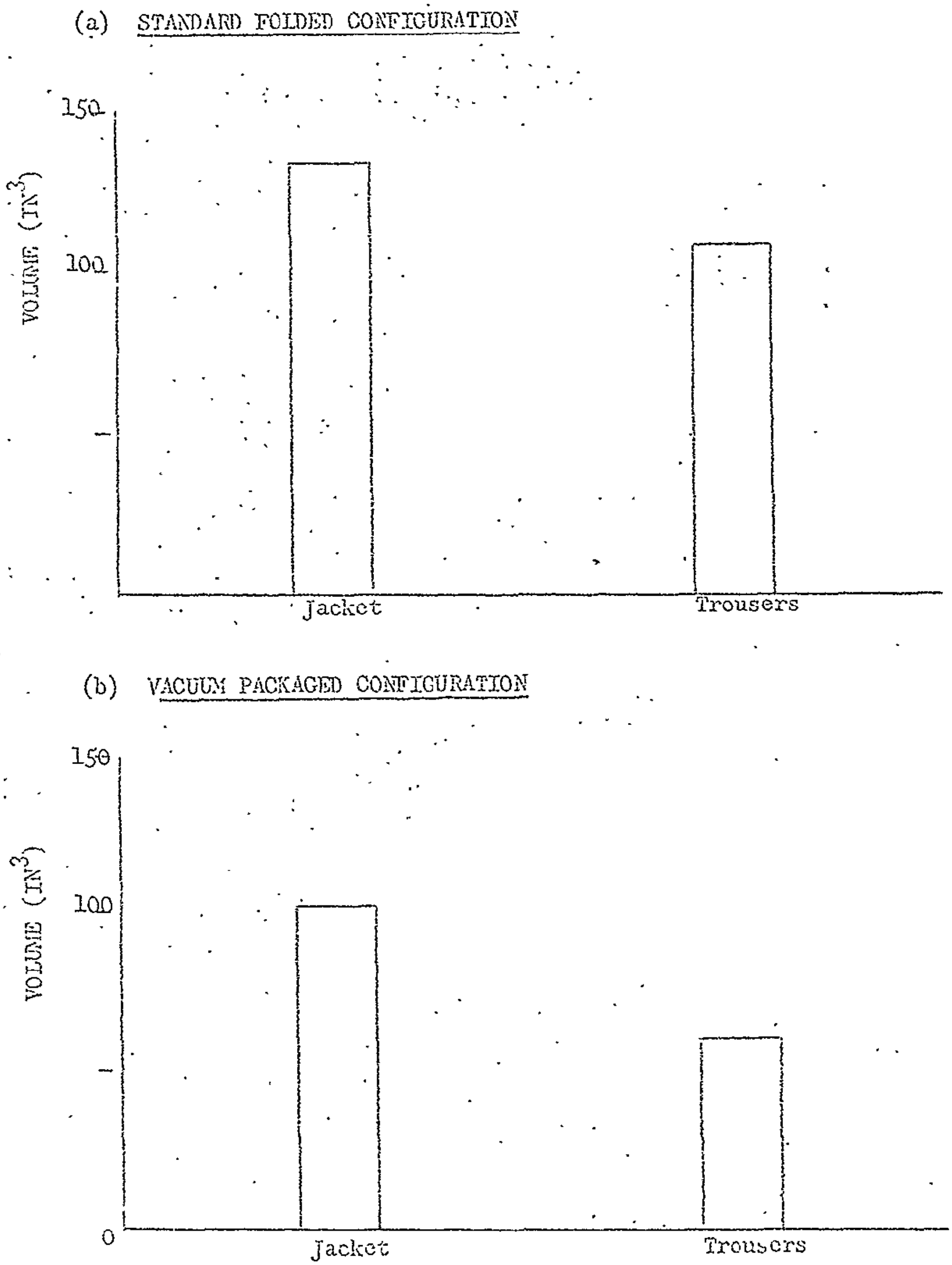
(Dimensions in Inches)



presence of padding, cuffs, collars, fasteners, belts, or ribbing on the garment items. By proper superpositioning of garment items, this effect can be reduced. Figure 3.4.3 is a comparison between a standard folded configuration and a vacuum packaged configuration for a typical duty jacket and duty trouser item.

Garment transfer from earth base to Space Station and return must be considered. Adopting a modular packaging technique within a minimized transfer envelope, the garment items can be packaged in functional groups, that is, a duty garment ensemble, consisting of jackets, trousers, shirts, hat, and shoes, can be packaged in one module and readied for transfer to the Space Station, and a leisure garment ensemble, consisting of trousers, shirts, and shoes can be contained in a separate module. This method allows selective re-supply of garment ensembles as the individual needs arise. The technique is presently envisioned for the Skylab program in the form of wardrobe rucksacks for each crew member.

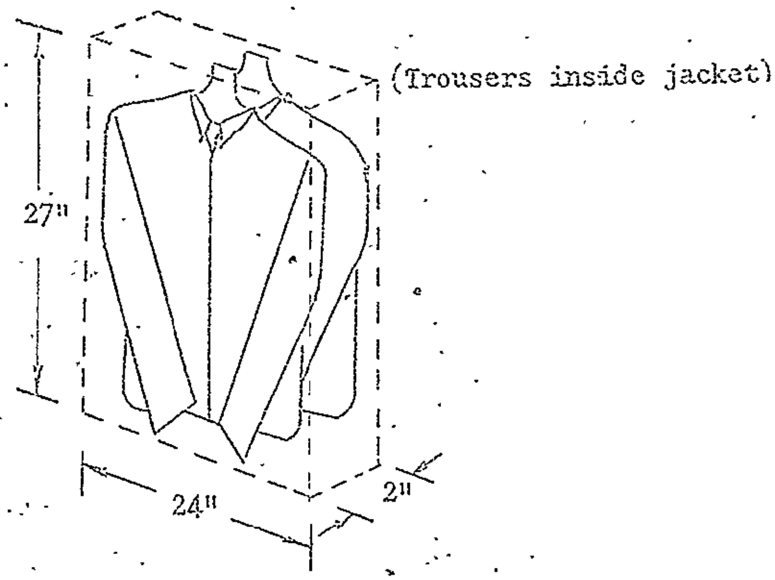
FIGURE 3.4.3 STANDARD vs. VACUUM PACKAGING
(Cotton Flight Garment)



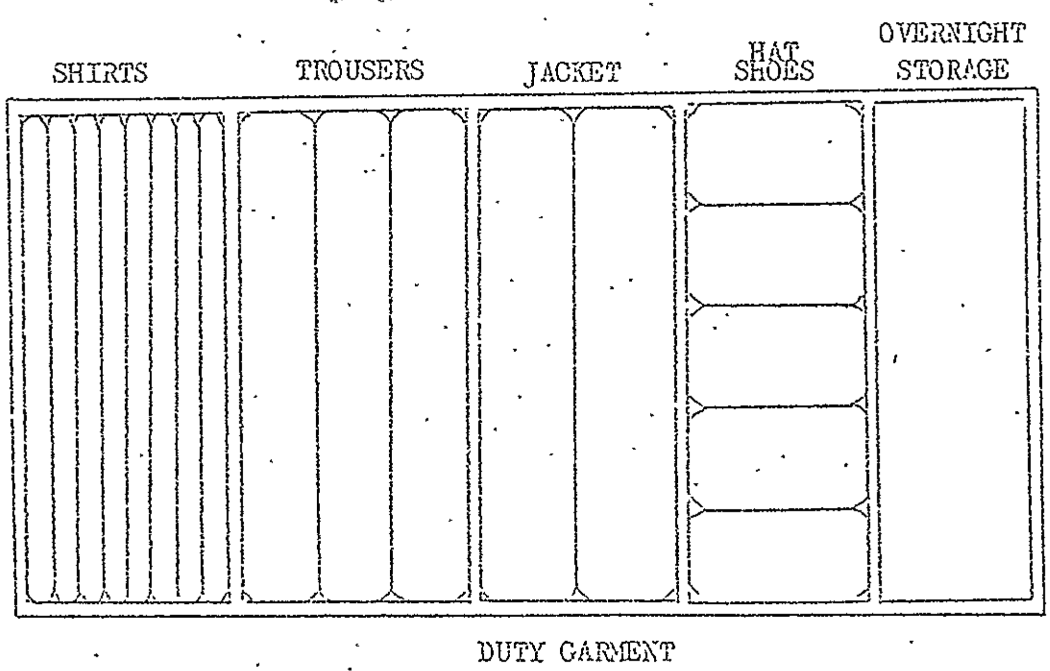
Once a garment ensemble has been transferred to a Space Station there is a need for on-board storage. This can be accomplished by providing closet space for major garment items (trousers, jackets) or by utilizing the modular container as a transfer device and as a storage drawer. Figure 3.4.4. is a representation of the required closet volume for hanging a trouser-jacket combination, and shows a typical modular packaged garment ensembled.

FIGURE 3.4.4 GARMENT STORAGE

a. JACKET AND TROUSER HANGING STORAGE VOLUME



b. Modular Packaging



3.5 FABRIC TESTING

A test program was performed on candidate materials presently considered for use in Space Station applications. The test effort, consisting of a laundering test series and a mechanical test series, was conducted to evaluate the effect on certain material physical properties of continuous laundry cycles and to evaluate the response of various materials when subjected to thermal testing. The results of this test effort will aid the system designer in selecting materials for use in a Space Station environment.

3.5.1 LAUNDERING TESTS

Laundering tests were conducted on test fabric swatches of candidate materials and on three representative flight jacket items. Prior to initiating the laundry cycle effort, various wash cycle schemes were evaluated to determine the optimum technique to be used. This was required because new materials, such as Durette, PBI, and Teflon were not laundered previously, therefore, there was not data available to indicate the effect of laundering on these items. The baseline wash method established for swatch testing was a standard family white wash technique using a wash water temperature ranging from 100 to 160°F and a commercial drying method utilizing a hot-air, tumbling technique with air temperatures reaching a maximum of 250°F when the load was completely dried. For the representative flight garment testing, a wash method used for wool fabrics was used. In this process the wash water temperature was maintained at 95°F and the tumble drying air temperature was a maximum of 160°F.

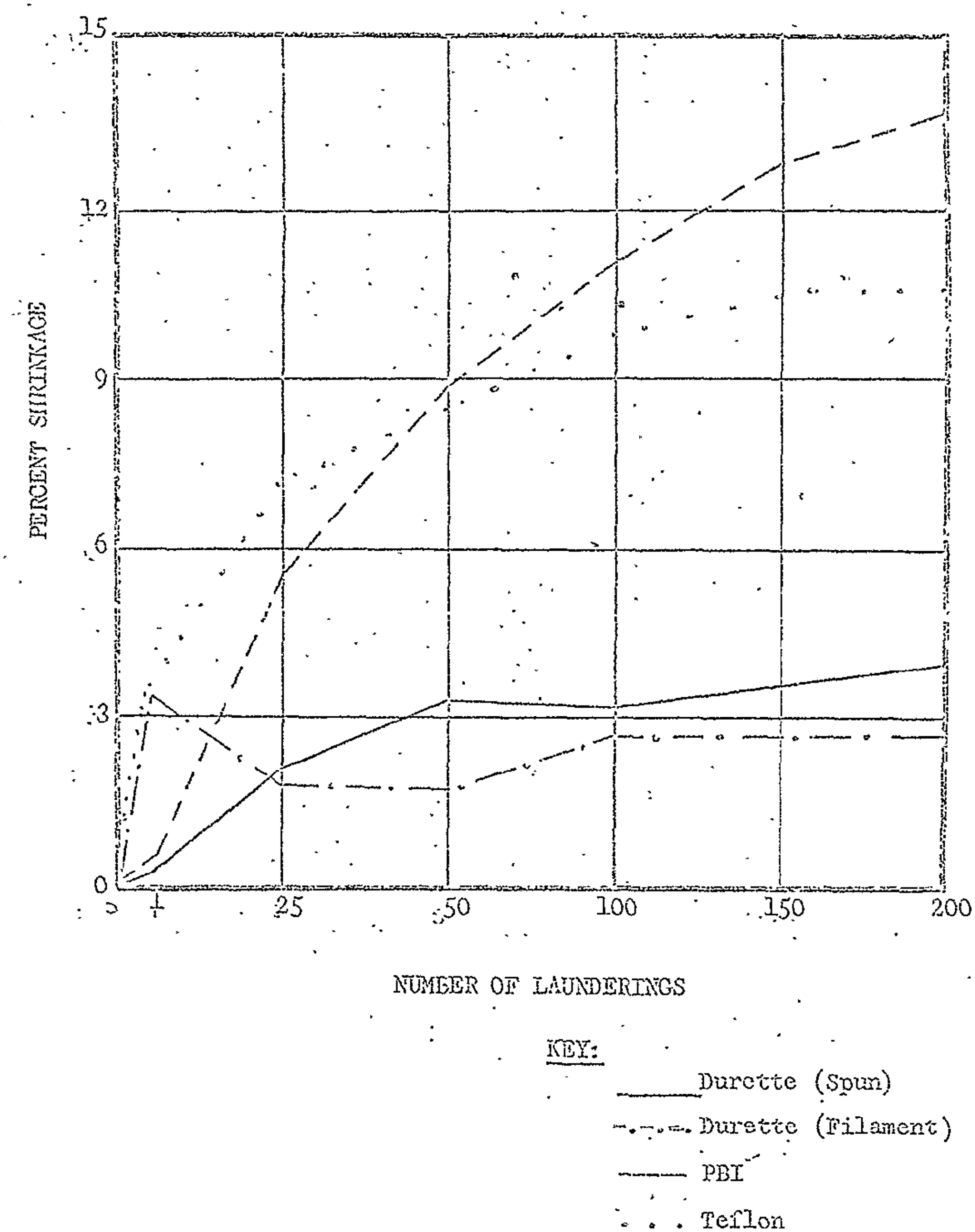
The following figures presents the results of the laundering test effort. The paragraphs preceeding the figures describe the test method and the parameter measured.

3.5.1.1 <u>FABRIC SHRINKAGE TEST - SWATCHES</u>

Swatches of candidate fabric materials were subjected to shrinkage tests to determine the effect of repeated wash cycles on the shrinkage characteristics of the various fabrics. The test specimens were washed by a standard white wash method and shrinkage measurements made periodically in the cycle until the last measurement at the 200th cycle.

Referencing Figure 3.5.1, the Durette (Monsanto) filament indicates the least percent of shrinkage and Polybenzimidazole (PBI) the greatest. If shrinkage was the main selection criteria, garments would be made from Durette filament or if a smoother hand is desired, a spun Durette which exhibits the second least percentage of shrinkage.

FIGURE 3.5.1 FABRIC SHRINKAGE TEST
MATERIAL CONFIGURATION - SWATCHES



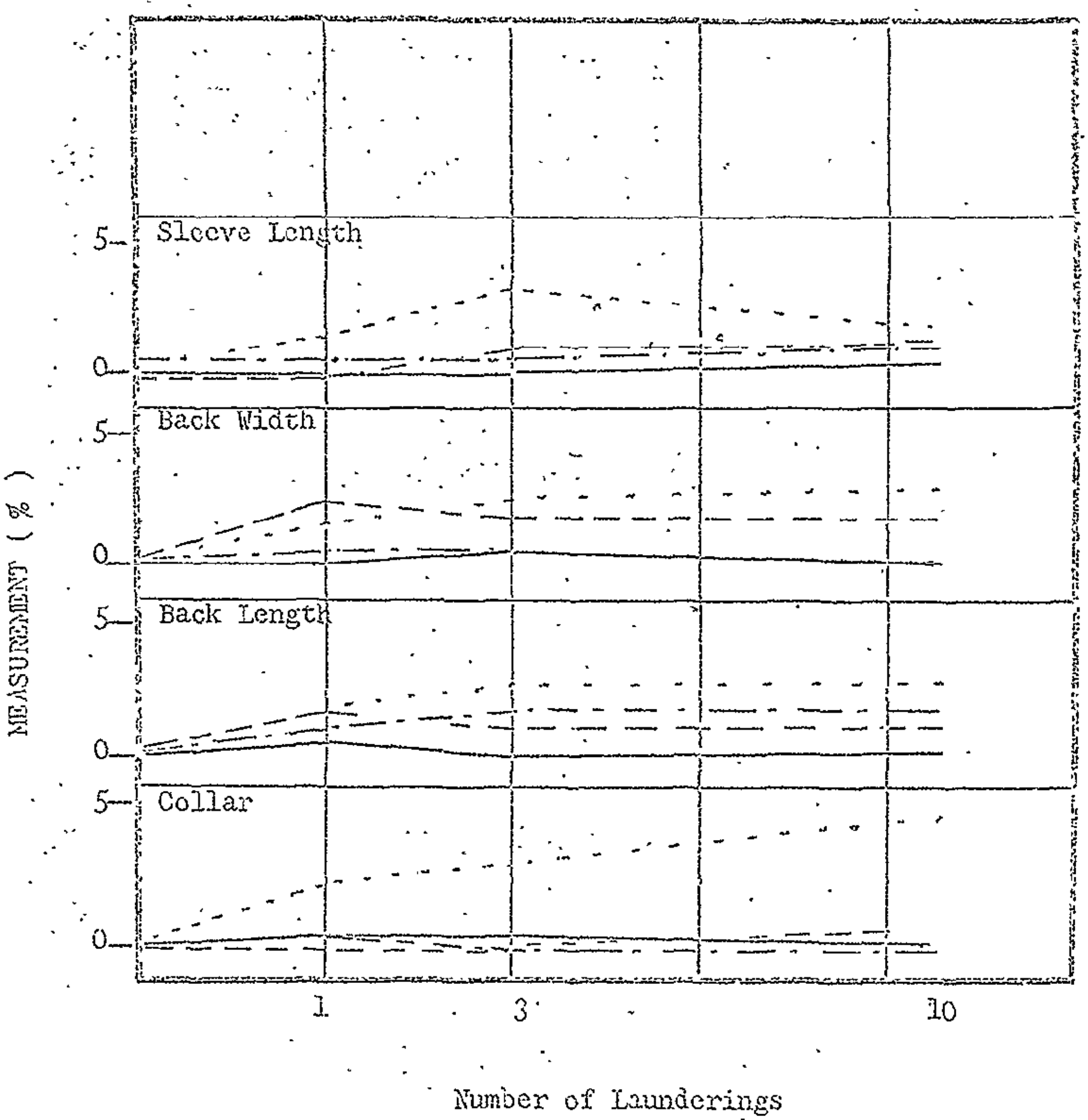
3.5.1.2 FABRIC SHRINKAGE TEST-GARMENTS

Flight configured jackets, fabricated from Durette, PBI, and Teflon were subjected to ten wool wash procedures, and select measurements made periodically in the cycle. Four measurement points were evaluated, sleeve length, back width, back length, and collar dimensions, to determine the percent shrinkage at these points.

Referencing Figure 3.5.2, Durette has again exhibited the least percent of shrinkage in all categories. Spun Durette tended to perform better than the Durette filament but both bested the remaining two materials. Durette would be selected for garment fabrication for space use based on this test result.

FIGURE 3.5.2 GARMENT SHRINKAGE

MATERIAL CONFIGURATION - JACKETS



Key:

______ Durette (Spun)

-.-.-.-.Durette (Filament)

-------- PBI

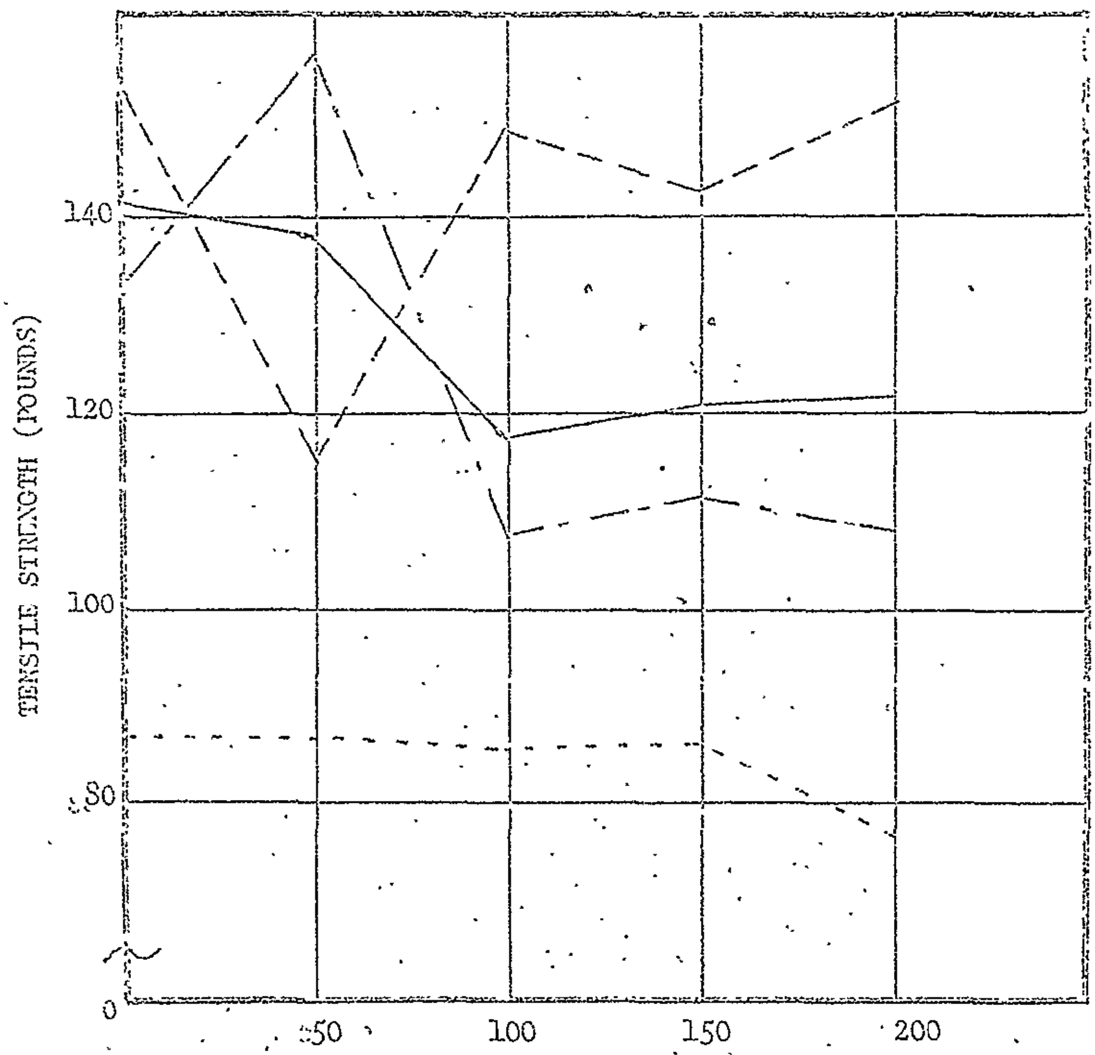
.... Teflon

3.5.1.3 FABRIC TENSILE STRENGTH

Fabric swatches were subjected to tensile strength tests periodically during the conduct of a 200 cycle wash program. This test was accomplished by laundering the swatch by a standard white wash procedure for a number of cycles, then removing the swatch from the wash, placing it between two mechanical jaws, making three breaks in the fabric warp direction, then applying a pulling force until material failure. This test was conducted to evaluate the laundering effect on candidate materials strength properties. This is important for long life requirements.

Referencing Figure 3.5.3, PBI exhibits the most strength retention of the materials tested, and would be the selected fabric based on this criteria alone. The interesting initial decrease in PBI strength characteristics cannot be explained other than the fact that PBI is still being evaluated and is presently considered an experimental fabric.

FIGURE 3.5.3 FABRIC TENSILE STRENGTH



Key:

———— Durette (Spun)
-.-.-. Durette (Filament)
- - - - - PBI
.... Teflon

3.5.1.4 FABRIC ABRASION TEST

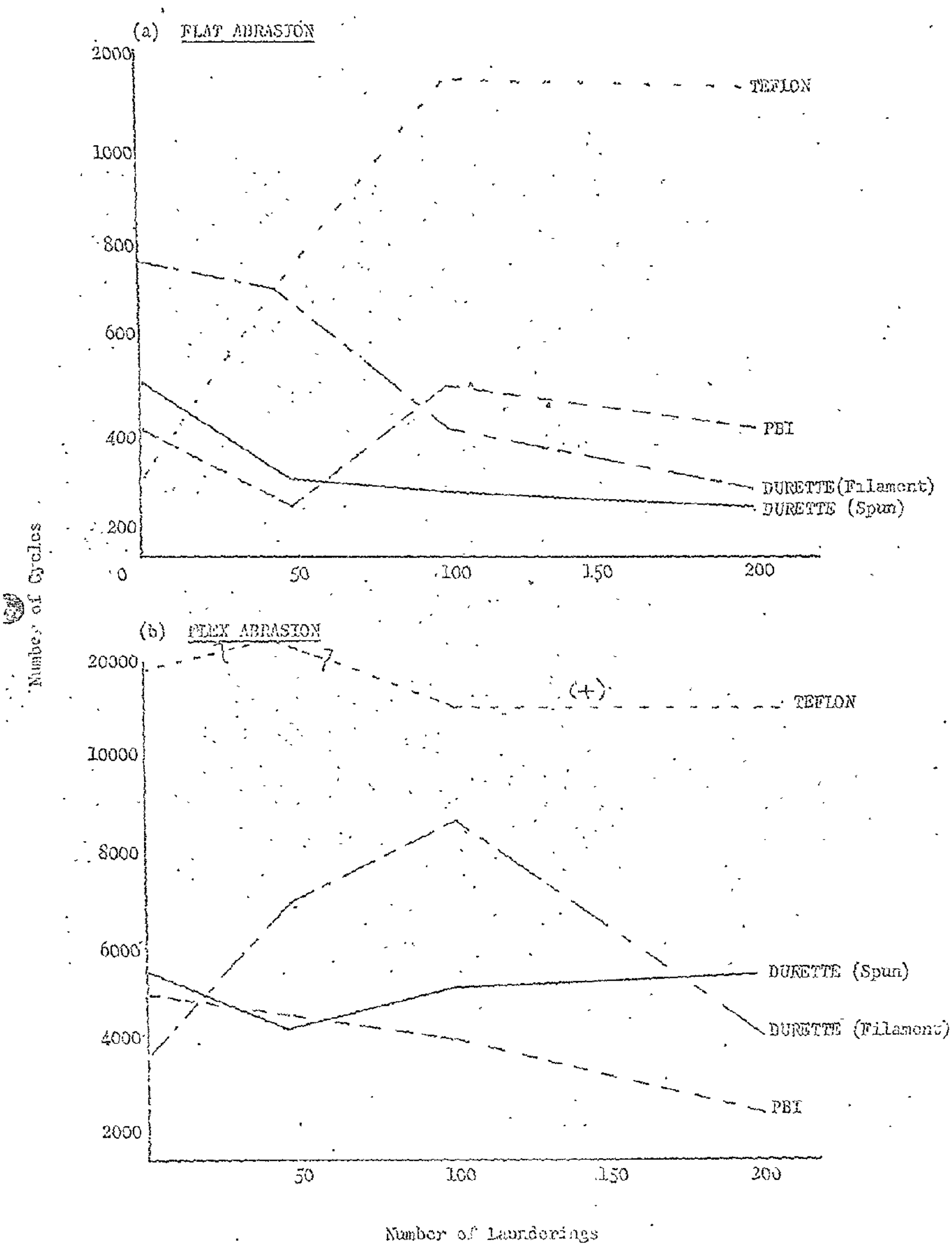
The resistance of garment damage by flat and flex abrasive forces is of concern and tests were conducted to evaluate various fabric test swatches.

The flat abrasion test was conducted by subjecting the test specimen to the abrasive forces applied by a very fine sandpaper until material failure.

The flex abrasion test was performed by bending the test specimen repeatedly over a sharp edge until material failure.

Referencing figure 3.5.4 Teflon far exceeds the other materials in its resistance to flat abrasion and is a runaway candidate in terms of its resistence to flex abrasion. In fact, the flex abrasion test of Teflon had to be terminated at 122,000 cycles because the material did not even indicate any visible wear due to the test. This would, of course, be the candidate material when considering the abrasive stresses experienced by garment items in normal use.

FIGURE 3.5.2 FABRIC ABRASION TEST



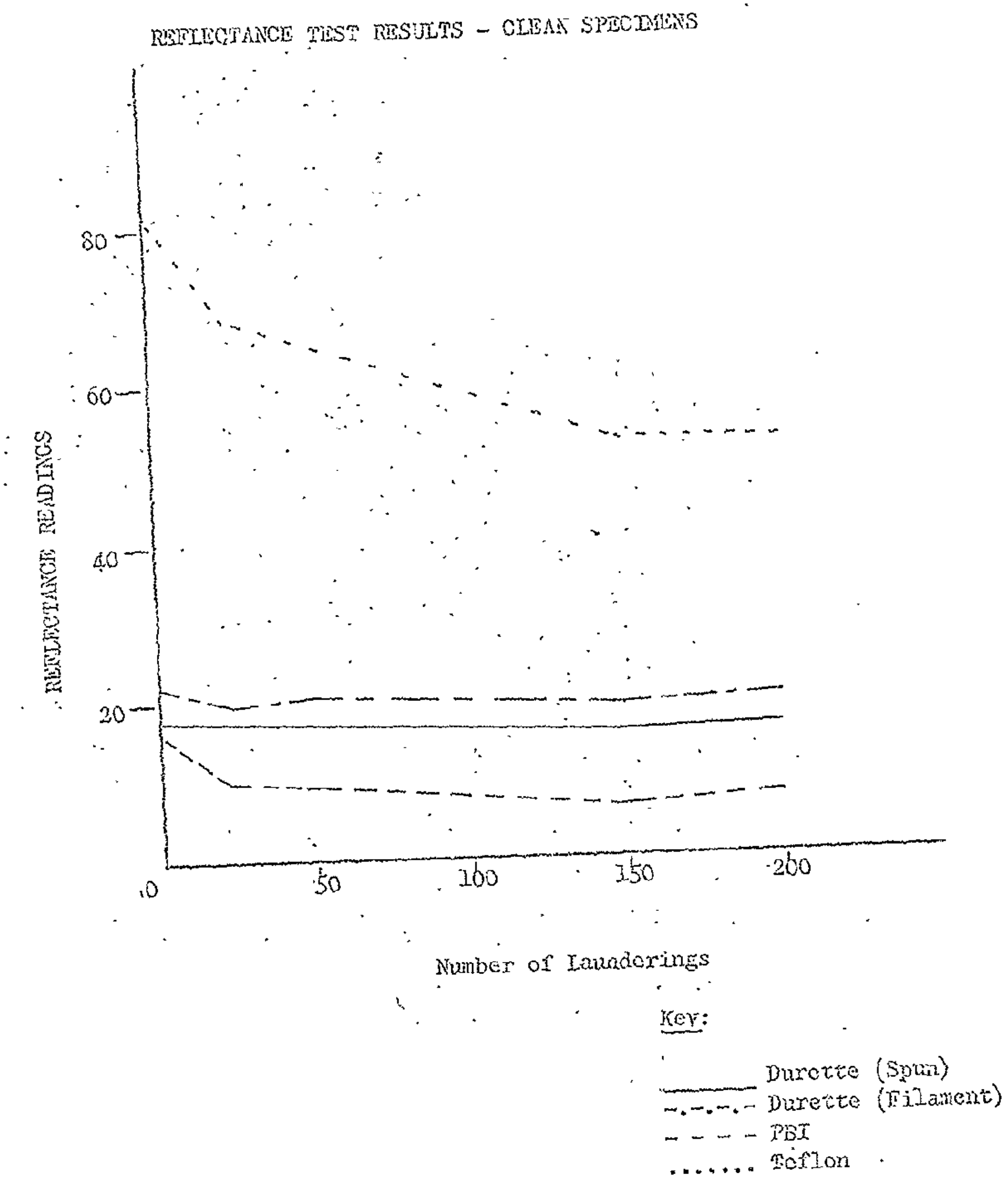
3.5.1.5 FABRIC REFLECTANCE MEASUREMENTS -- FADING

Over extended periods of usage and washing, garments have a tendency to lose their original color and could cause problems from an aesthetic standpoint in a Space Station application. Therefore, a material exhibiting a high degree of color fastness should be selected for this use.

Test swatches were subjected to 200 wash cycles and reflectance measurements, ie. the measurement of the amount of light reflected back from a surface to the light source, were made. The higher the measurement reading, the greater the amount of light reflected back, and, hence, the greater the color fastness of a material. In this test, each test specimen was measured prior to initiating the wash cycle and this value was used as the baseline against which subsequent measurements were compared.

Referencing Figure 3.5.5 Durette exhibited the least amount of fading, or loss of color, than the other candidate materials and would be the recommended fabric for Space Station use if considering this parameter alone.

FIGURE 3.5.5 FABRIC REFLECTANCE MEASUREMENTS– FADING



3.5.1.6 FABRIC REFLECTANCE MEASUREMENTS - SOIL TRANSFER

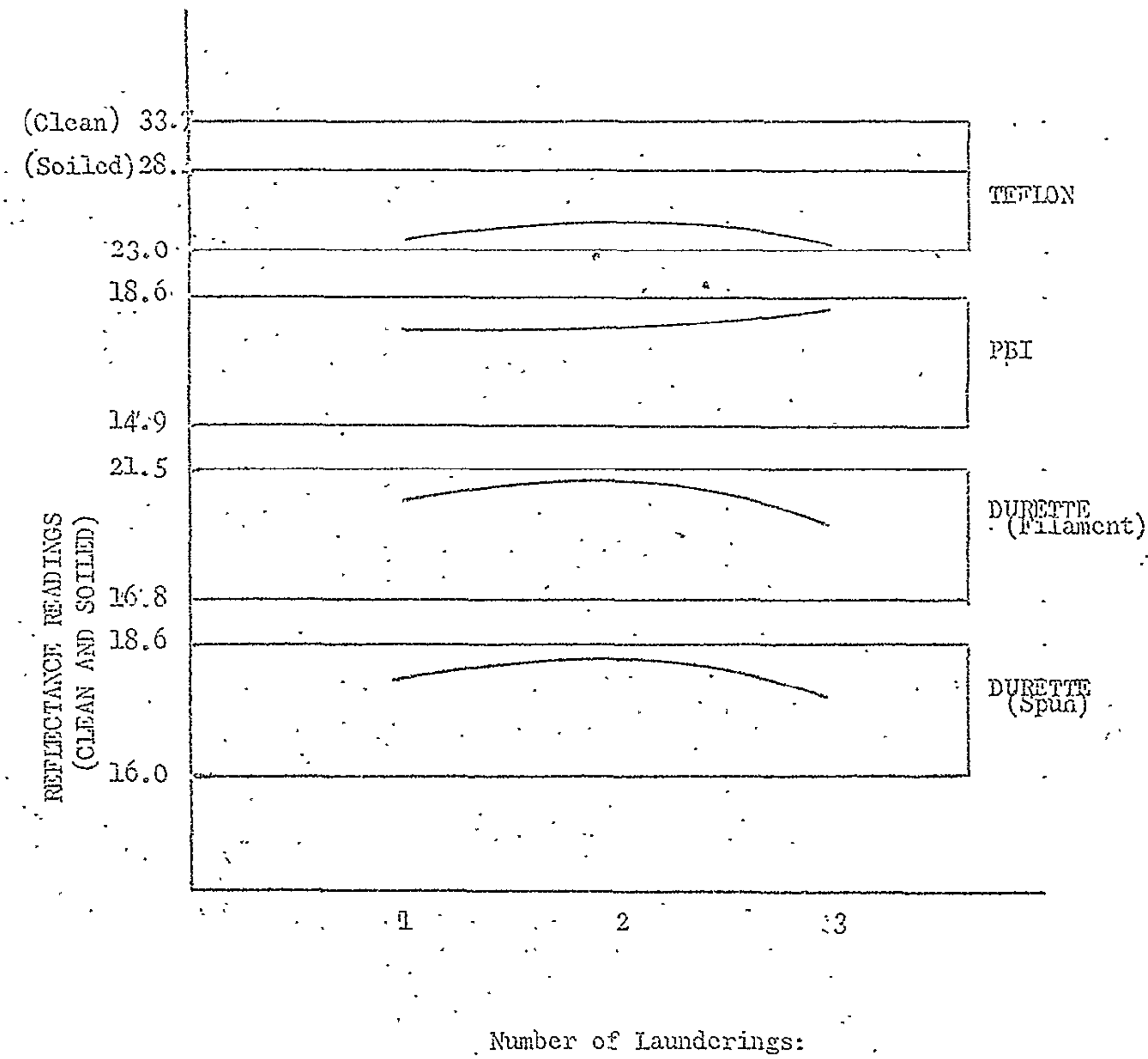
The fabric reflectance test was repeated in a similar wash procedure, but this time clean swatches were laundered in the same wash water as swatches soiled with a solution of 4 grams of Oildag* (graphite in mineral oil), and 4 grams of Wesson oil made up to 1 liter with perchlorethylene. The clean swatches were contained in a net bag as was the soiled swatches to prevent physical contact between specimens. This test was performed to evaluate the soil absorption and soil retention characteristics of fabric materials. Measurements were made on the clean swatches prior to the start of laundering and periodically during the wash cycle. Three cycles were accomplished during this test effort.

Referencing Figure 3.5.6 PBI indicated an increase in the reflectance measurement. This cannot be explained at this point, more testing must be conducted to be able to evaluate this material more adequately. Of the remaining materials, spun Durette exhibited the least amount of soil transfer and would be recommended on the basis of this selection criteria.

* Trademark of Acheson Colloids Company.

FIGURE 3.5.6 FABRIC REFLECTANCE -MEASUREMENTS -SOIL TRANSFER

REFLECTANCE TEST RESULTS - CLEAN AND SOILED SWATCHES



Note: Upper reading is the original measurement and the lower reading is the soiled measurements.

3.5.2 MECHANICAL TESTING

Three mechanical tests were defined as part of this study effort:

(a) Crease resistance test.

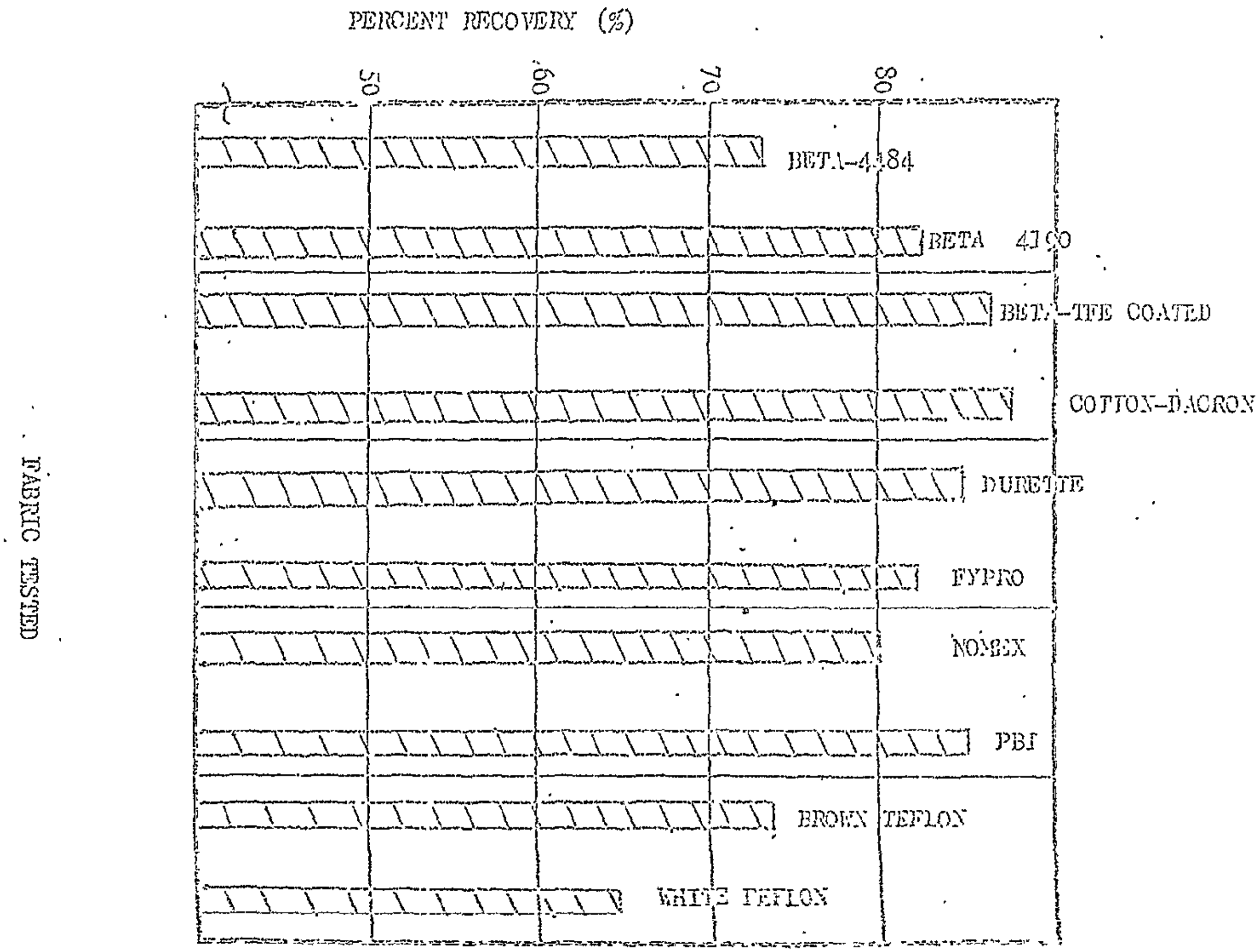
(b) Fabric weave effect test.

(c) Garment drape test.

3.5.2.1 CREASE RESISTANCE TEST

A crease resistance test was performed on various fabric materials. This test was conducted to measure the ability of a material to regain its original shape after being creased. The results of this test effort is indicative of a materials response to the creasing action occurring during normal wear and is representative of a materials ability to maintain a relatively wrinkle-free appearance.

Referencing figure 3.5.7, a blend of cotton and dacron exhibited the highest percentage of crease recovery of the ten fabrics evaluated. For this selection criteria a cotton-dacron wardrobe would be recommended.


PERCENT RECOVERY (%)
50
60
70
80
BETA-4484
BETA 4190
BETA-TFE COATED
COTTON-DACRON
DURETTE
FYPRO
NOMEX
PBI
BROWN TEFLON
WHITE TEFLON
FABRIC TESTED

3.5.2.2 FABRIC WEAVE EFFECT TEST

The weave effect upon material insulation properties was the first of two thermal tests. This test evaluated the effect of weave on the insulation characteristics of fabric material when exposed to a gas stream of varying velocity. Test specimens of various pick and end densities were placed in an air stream directly over a heat sink maintained at a constant temperature. The air velocity was then increased and the amount of heat flux required to maintain the heat sink temperature constant was measured and recorded. The air stream temperature was also measured and recorded. Data points were obtained for air velocities of 10, 20, 30, and 40 cfm. From this basic data and the relationship:

$$I = \frac{0.88 \Delta T \ (A)}{Q}$$

where I = fabric insulation value.

ΔT = temp.difference between air stream and heat sink.

A = material area.

Q = heat flux.

the insulation values for each case were determined.

The conclusions derived from this test were:

(a) The weave effect upon material insulation is most pronounced at low ventilation velocities.

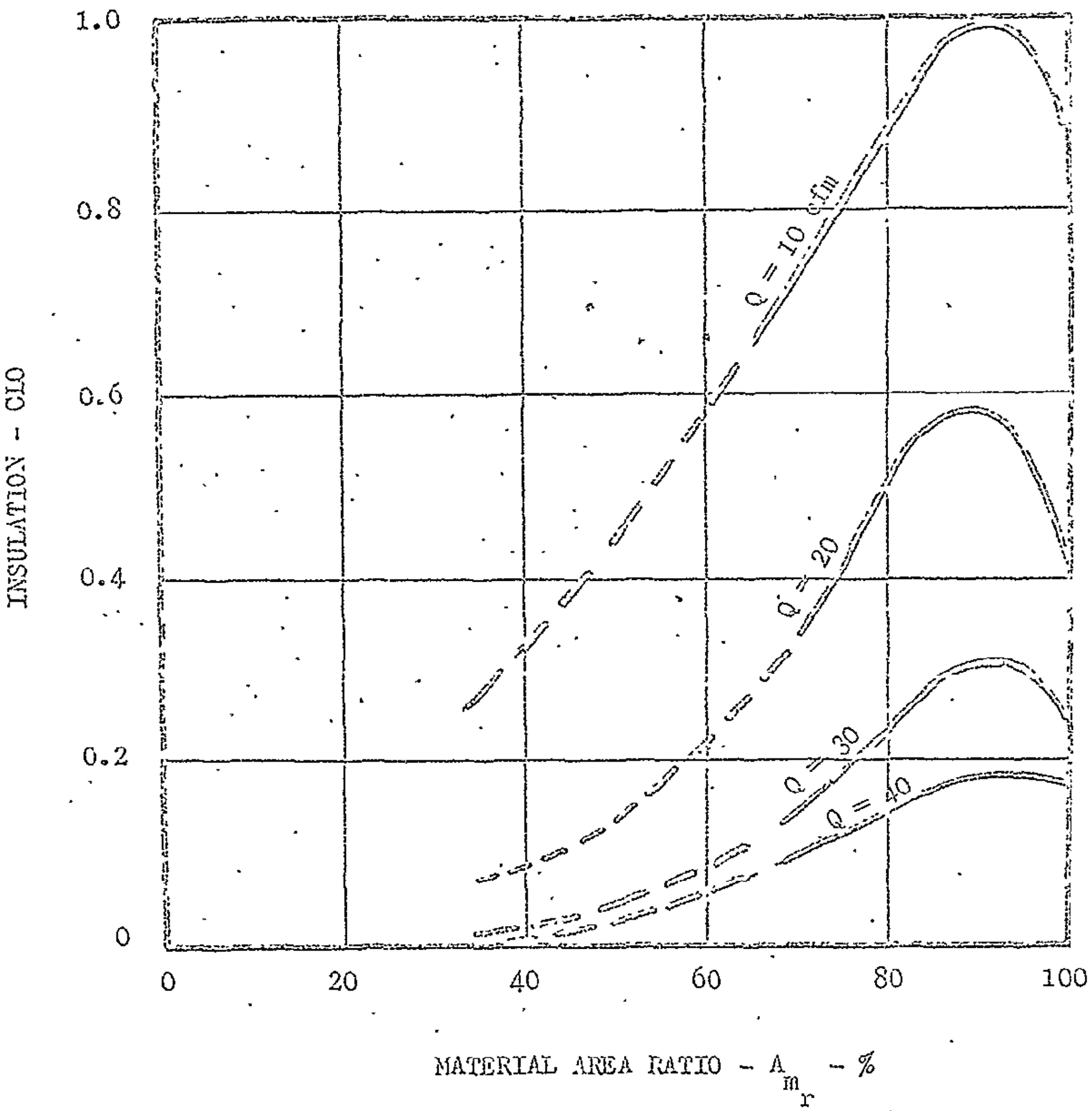
(b) As the ventilation velocity may vary, the insulation value corresponding to a material area ratio of 100% should be used. This is also based upon the fact that the material area ratio is greater than 90% for clothing.

Figure 3.5.8 depicts the results of the weave effect test conducted on four sample swatches at NASA-MSC. The curves substantiate the original analysis performed in the <u>Handbook of Garment Selection Criteria for a Space Station</u> which was prepared under contract number NAS 9-9563 and revised under this contract.

3.5.2.3 GARMENT DRAPE TEST

Three representative flight garments, one conformed, one normal, and one loose fitting were fabricated to be used on a thermal manikin for the evaluation of garment drape effect on the insulation characteristics of clothing systems. The fabricated garments consisted of a shirt, jacket and trousers ensemble. A

FIGURE 3.5.8 WEAVE EFFECT UPON MATERIAL INSULATION



$$A_{m_r} = \frac{A \text{ material}}{A \text{ total}}$$

garment system was to have been placed on the manikin and the manikin temperature raised and maintained at a constant level. The distance between the jacket and manikin in the chest area was to be measured, then the air velocity impinging on this chest area varied over a range of 15 to 90 feet per minute. The change in heat flux to maintain the manikin temperature constant was to have been measured and recorded. This test was to be repeated using the three different size flight garments and the resulting data used to evaluate the drape effect on the insulation characteristics of garment systems. This test was to have been performed at NASA-MSC.

Due to scheduling conflicts the drape effect test has not been completed in time for inclusion into this final report or into the revised HANDBOOK OF GARMENTS AND ACCESSORY SYSTEMS SELECTION CRITERIA FOR A SPACE STATION. A Test Plan (BW-187) and Test Procedure (BW-190) have been approved and delivered to NASA-MSC as contracturally required. Upon completion of the manikin testing and use of these documents and handbook, the test data may be reduced and conclusions derived.

3.5.2.4 CONCLUSIONS

The results of the fabric testing effort have been summarized in Table 3.5.1. The actual testing performed is listed and the material exhibiting the most favorable response to the particular test, numbered 1 and the material responding least faborably numbered 4. Based on the test results, Durette exhibited the most favorable response to the majority of tests conducted, therefore, this is the material recommended for use in Space Station applications.

TABLE 3.5.1 FABRIC TEST RESULT MATRIX

Material / Test	Durette (spun)	Durette (filament)	PBI	Teflon
Shrinkage test (swatches)	2	1	4	3
Shrinkage test (garments)	1	2	3	4
Tensile strength	2	3	1	4
Abrasion Test Flat	4	3	2	1
Abrasion Test Flex	2	3	4	1
Reflectance Test (Fading)	3	2	4	1
Reflectance Test (Soil-Transfer)	1	2	4	3
Crease Resistance	2	–	1	4
Total	17	16	23	21

3.6 CREW SIZING

The data used in the habitability study performed under contract NAS 9-9563 for computing the size distribution among a spacecraft crew was applicable to personnel on flying status surveyed in 1950. The crew of a Space Station will not necessarily fit the pattern established in the earlier study by virtue of changes in physical makeup and population segment. In this study effort, the anthropomorphic measurements required to determine the proper sizing of crew personnel has been determined. In addition, bodily measurements related to the current astronaut-scientist population segment have been obtained from NASA and included in the revised handbook.

In this study of crew sizing, two body dimensions-height and weight-form the basis of this sizing program due to their high correlation between these variables and the balance of the bodily measurements. The remaining measurements essential to the sizing of clothing are as follows:

(1) Weight

(2) Height

(3) Crotch height.

(4) Chest breadth.

(5) Neck Circumference.

(6) Shoulder circumference.

(7) Chest circumference.

(8) Waist circumference.

(9) Buttock circumference.

(10) Thigh circumference.

(11) Lower thigh circumference.

(12) Calf circumference.

(13) Ankle circumference.

(14) Wrist circumference.

(15) Vertical trunk circumference.

(16) Knee circumference.

(17) Axillary arm circumference.

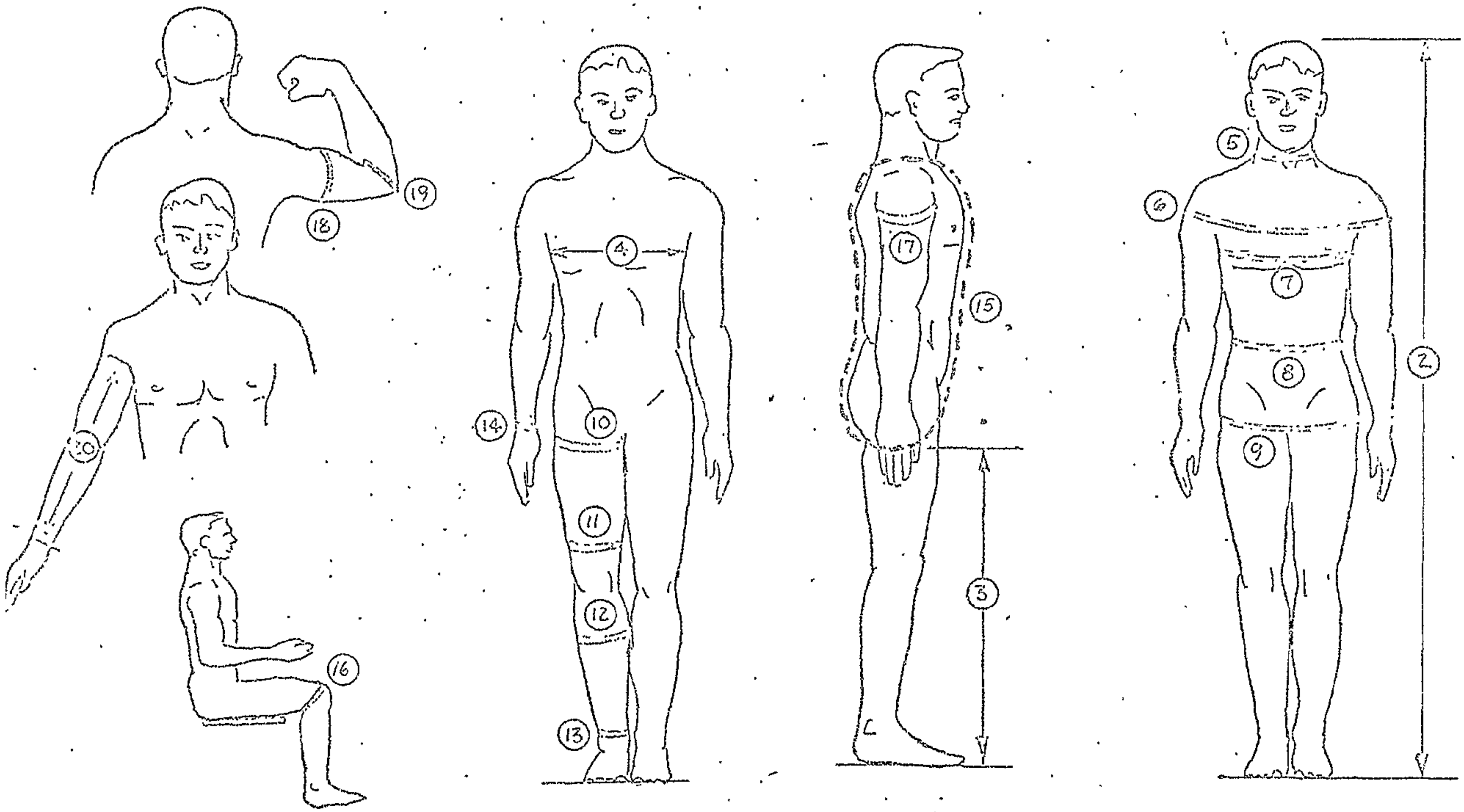
(18) Biceps circumference.

(19) Elbow circumference

(20) Sleeve inseam.

Figure 3.6.1 is a pictorial representation of the above bodily measurements. For definition of the above measurements see Appendix B of the revised handbook.

FIGURE 3.61 VISUAL INDEX OF MEASUREMENTS

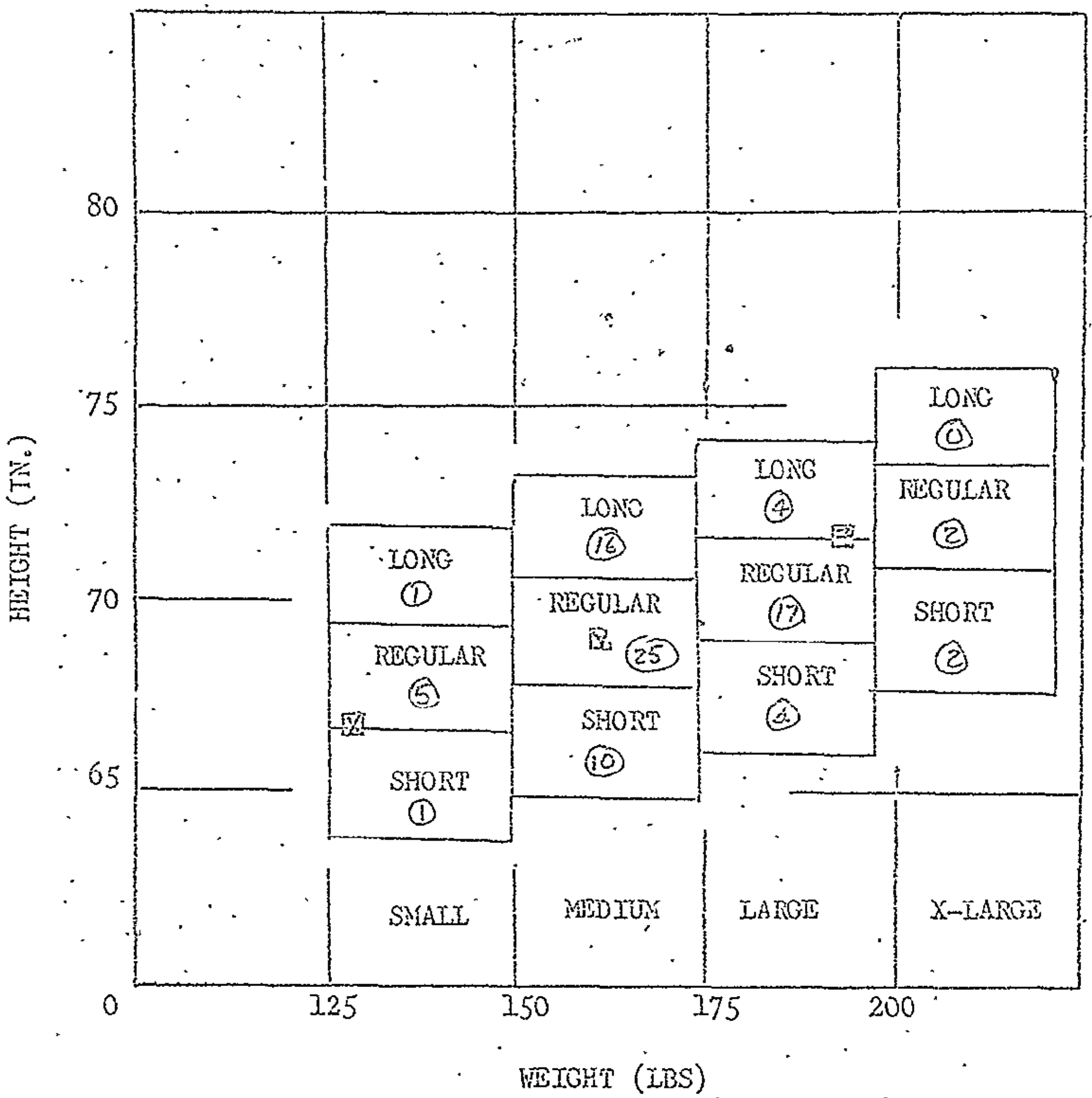


An analysis of the data received from NASA relative to the current astronaut-scientist population indicates a size shift towards the medium-long/large-regular end of the sizing schedule. As was the case with the 1950 study, the majority of the personnel measured fall into the medium-regular category.

Figure 3.6.2 represents the crew size program for the current astronaut-scientist population and Figure 3.6.3 compares this current size distribution with the original 1950 survey.

Current outfitting of crewmen for space missions requires "custom" fitting of each individual. As crew numbers increase for advanced missions, this procedure becomes prohibitive from a time and cost standpoint. With a stockpile of basic garment systems, sized in accordance with the bodily measurements outlined herein, entire crews can be outfitted with a minimum of alterations required.

FIGURE 3.6.2 CREW SIZING PROGRAM



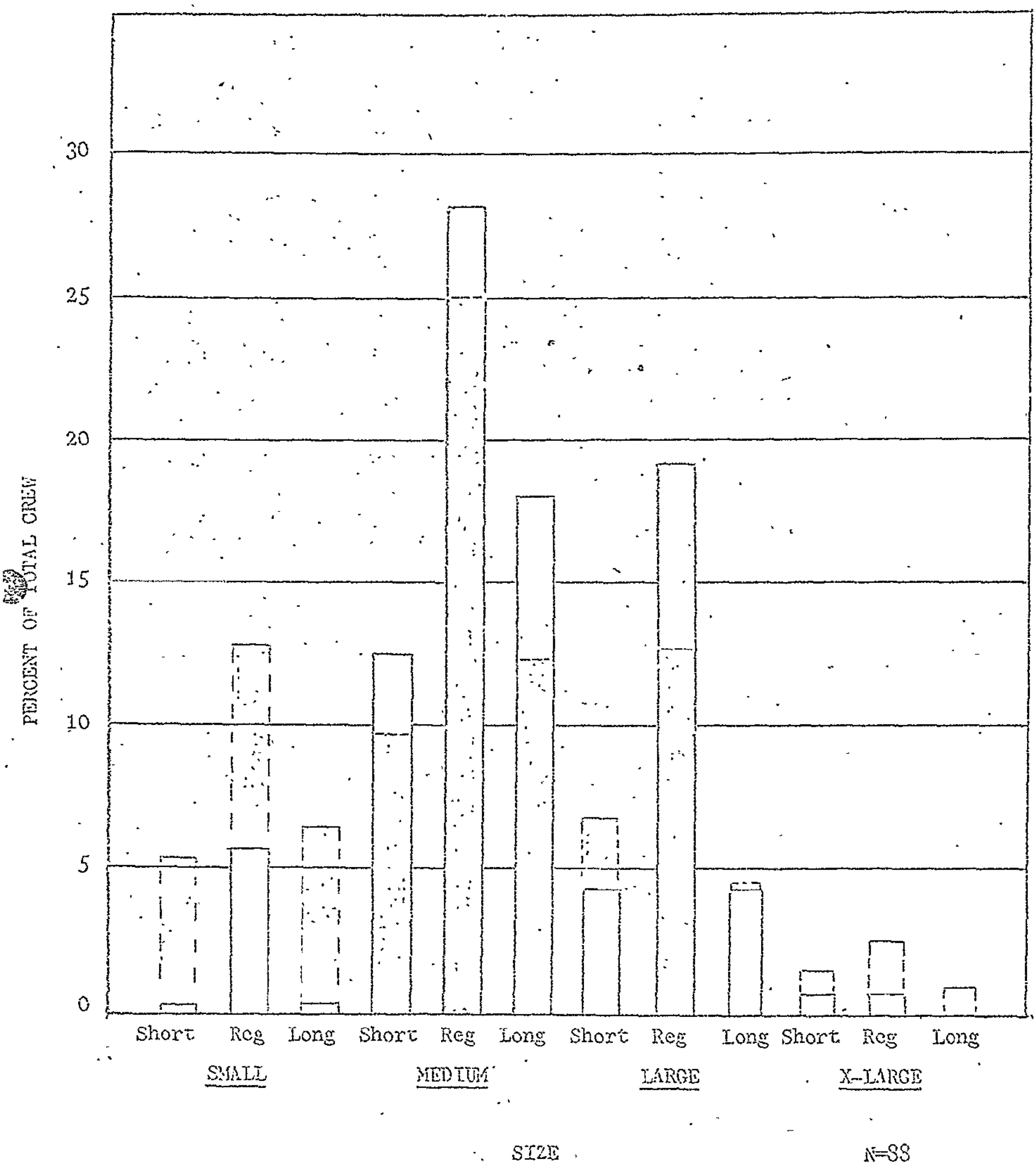
(Size Categories for a 12-Size Program)

NOTE:

Circled numbers indicate number of current astronauts/scientists fitting that particular category.

X – 5th Percentile
Y –50th Percentile
Z –95th Percentile

FIGURE 3.6.3 CREW SIZE DISTRIBUTION



4.0 RELATED STUDY AREAS

In the completed habitability study, effort was expended in the area of spacecraft laundry systems and crew garment concepts. In the performance of these tasks, several areas have been uncovered that require the generation of basic data in order to substantiate certain assumptions made in the study.

4.1 SUMMARY

The performance of a laundry system has been assessed from an overall viewpoint and the relative penalties determined. In the evaluation of this system, several aspects of performance were estimated based upon current available data. In several instances there are wide variations in the data (between sources) and in other instances, no data at all. Since these areas are critical in the determination of the impact of a laundry system, investigation of the areas presented herein is suggested.

There are three general areas of investigation in which meaningful work may be performed. These areas involve the determination of basic laundering data. Each area is described below.

4.2 BASIC LAUNDERING DATA

The removal of soil from clothing has been historically investigated by determining the adaptability of a new fabric or garment to existing laundering techniques. These investigations have been made by such organizations as the American Institute of Laundering and the National Institute of Dry Cleaning. Although acceptable means of clothes cleaning have been determined by careful adjustments in temperature, selection of detergent, and quantity of water, the basic performance of laundry systems is presently not available for use in space station studies. The following areas are those elements that require investigation in order to draw an intelligent conclusion in the field of laundry systems.

4.2.1 CLEANLINESS CRITERIA

One of the most nebulous areas concerned with washing systems is the aspect of clothing cleanliness. In order to determine both short and long term performance characteristics of laundry systems, it is necessary to establish a measurement technique for fabric cleanliness.

4.2.2 LOAD FACTOR DATA

The load factor of a washer is the amount of clothing that may be cleaned per cubic foot of washer tub volume. This value has been found to vary from two pounds per cubic foot to five pounds per cubic foot. As this represents a 150% variation, an assessment of the load factor versus cleaning performance is necessary.

4.2.3 WATER USAGE DATA

In the trade-off analysis made for a laundry system, it is evident that the major impact upon a space station is in the use of water. The relative penalties of water reclamation to the fixed weight of the cleaning system indicate that a reduction in the amount of water to clean clothing is desirable. Present analysis are based upon a "full tank" approach in that the effects of zero gravity (i.e. bubbles and water collection) need not be considered. Since this is the heaviest approach, further investigation is required to reduce the amount of water, if possible.

4.2.4 DETERGENT USE EVALUATION

It is possible to remove a portion of the water soluble soils from clothing without detergents. If no detergent is required, obvious benefits in the water management area will be realized. Further study of detergents is required before the impact upon the water recovery system can be made. A proposed test would be to wash typical articles of clothing worn in an office environment and measure the effective cleaning. Disinfectants and germicides would be added to the clothing after removal from the washer. The comparison with a wash in which detergent was present would be made.

4.2.5 SYSTEM PROCESS DATA

Another potential area of study is concerned with the other systems surrounding the washer system. These include the aspects of water storage and recovery. Two primary areas are considered for evaluation in this category. Both are described below.

4.2.5.1 WASH WATER RECYCLE

In the water penalty analysis conducted during the laundry system study, an assumption was made that a water/detergent solution may be filtered and reused for each cycle as in dry cleaning. The only additives to the "suds" water would be additional detergent to make up for the amount removed with the soil, and the water remaining in the clothes due to absorption.

With the washer test unit, the feasibility of this method may be verified as a minimum penalty process.

4.2.5.2 RINSE WATER PROCESSING

Concurrent with the suds recycle, the rinse water must be processed for reuse in the washer. With a proper selection of detergent and suds recycle, filtration with activated charcoal and millipore filter appears to be a possible technique. A test effort would bear this out.

APPENDIX A

GARMENT DESIGN JUSTIFICATION SHEETS

GARMENT SYSTEM SELECTION
WARDROBE ITEM - DUTY GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Jacket	Material	Cotton Cotton-dacron Cotton-nylon PBI X400	Cotton/ Dacron	Appearance Wrinkle resistance Comfort Absorbency
	Construction	Knit Woven Composite	Woven	Strength Rigidity Wear resistance
	Configuration/Entry	Front Entry Side Entry	Front Entry	Least weight Ease of closure
	Collar	Standard Rib knit	Standard	Compatibility with woven material
	Sleeve	Long Short	Long	Warmth Use of short sleeve shirt
	Cuff	Snap Hook & pile Ribbed Slide	Ribbed	Compatibility with short sleeve shirt. Comfort Ease
	Pockets	Slash External	Slash	Hidden for style
		Open Fastened- Slide Snap Hook & pile	Fastened-slide	Zero Gravity, Compatibility with cleaning Ease of operation
	Entry Fastener	Snap Hook & pile Slide	Slide	Ease of operation, Strength Drape
	Style	Tapered & Fitted Universal	Tapered & Fitted	Subjective Appearance
	Color	Soft Hues	Blue	Subjective

GARMENT SYSTEM SELECTION
WARDROBE ITEM - DUTY GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Shirt	Material	Cotton Cotton-dacron Cotton-nylon PBI X400	Cotton	Comfort Absorbency Appearance
	Construction	Knit Woven Composite	Knit	Warmth Storage Antisnag
	Configuration/Entry	Pull over Front Entry Side Entry	Pull over	Least weight Compatibility with knit construction Storage No fasteners req'd
	Collar	Rib knit Standard Combination	Rib knit	Compatible with knit construction Comfort Light weight No sizing req'd
	Sleeve	Long Short	Short	Compatibility with jacket. Allows greater insulation variation.
	Cuff	Rib Fastener	Rib	Compatibility with knit construction Comfort Storage
	Pockets	Breast Shoulder	Both	Familiar Pencil containment
	Waist Area	Ribbed Loose	Ribbed	Compatibility with knit construction Conformal
	Color	Complementary Hue of Jacket colla[illegible]	Blue	Subjective

GARMENT SYSTEM SELECTION
WARDROBE ITEM - DUTY GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Trousers	Material	Cotton Cotton-dacron Cotton-nylon PBI X400	Cotton/ Dacron	Same material as jacket
	Construction	Woven Knit	Woven	Same as jacket
	Configuration Entry	Front Entry		Standard
	Cuff	Snap Hook & pile Ribbed Slide	Ribbed	Comfort Warmth Appearance
	Entry Fastener	Slide Snaps Hook & pile	Slide	Strenght Ease of operation
	Waist Provisions	Elasticized Belt Combination	Combination	Size Adaptation Style
	Pockets	Slash External	Slash	Adequate storage capacity Style
	Style	Universal Tapered	Tapered	Subjective Appearance
	Color		Blue	Same as jacket Subjective

GARMENT SYSTEM SELECTION
WARDROBE ITEM - DUTY GARMENT

Garment	Detail	Candidate	Selection	Basis
Shoes	Material	Hide Fabric Vinyl	Hide	Suitable for both zero and one g Porous Strength
	Fasteners	Hook & pile Buckle Snaps Slide	Snaps	Subjective
Hat	Material	Fabric Vinyl Polymer (rigid)	Padded Fabric	Head protection
	Style	Round (baseball) Flat sides (hunting)	Flat Sided	Military style Shape retention
	Visor	Long Short	Short	Compatibility with vision requirements
	Color		Blue	Same as jacket

GARMENT SYSTEM SELECTION
WARDROBE ITEM - LEISURE GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Trousers (Leisure)	Material	Cotton Cotton blend PBI X400	Cotton blend	Comfort Absorbency Appearance
	Construction	Woven Knit	Woven	Wear Appearance
	Configuration/Entry	Front Entry		Standard
	Cuff	Snap Hook & pile Ribbed Slide	Ribbed	Comfort Warmth Appearance
	Entry Fastener	Slide Snaps Hook & pile	Slide	Strength Ease of operation
	Waist Provisions	Elasticized Belt Combination	Combination	Size Adaptation Style
	Pockets	Slash External	Slash	Adequate storage capacity Style
	Style	Universal Tapered	Tapered	Subjective Appearance
	Color		Soft Hue Compatible with shorts	Subjective

GARMENT SYSTEM SELECTION
WARDROBE ITEM - LEISURE GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Shirt (Leisure)	Style	Knit polo shirt Woven shirt	Both (2 of each)	Variety
	Color	Soft pastels	By choice	Variety
	Fasteners	Slide Snap Hook & pile	Snap (woven only)	Proximity to current fashion.
	Configuration	Pull over Front Entry	Knit pullover, woven Front Entry	Subjective to current fashion
	Material	Cotton blend Synthetics (or non-flammable synthetic with properties of cotton)	Cotton blend or cotton substitute	Absorbency Appearance

GARMENT SYSTEM SELECTION
WARDROBE ITEM - LEISURE GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Leisure Shoes or Slippers	Construction	Vinyl Leather	Fabric with reinforced heel/sole/toe	Porosity Softners Extreme wear resistance not required
	Material	Knit Woven	Knit - shoe sock with sole	Comfort Warmth Storage capability
	Color	Any	Compatible with leisure garment and sleep wear	Double function with wardrobe items

GARMENT SYSTEM SELECTION
WARDROBE ITEM - EXERCISE GARMENTS

Garment Item	Detail	Candidates	Selection	Basis
Shorts (Exercise)	Material	Cotton Cotton-blend PBI X400	Cotton or Cotton blend	Comfort Absorbency
	Construction	Woven Knit	Woven	Ventilation endurance cleaning
	Style	Briefs Jockey	Briefs	Compatible with woven construction
	Entry	Pull over Front	Pull over	Sizing Storage
	Waist Provision	Belt Elasticized Draw string	Elasticized	Compatibility with entry Simplication
	Color	Subjective	White	Subjective

GARMENT SYSTEM SELECTION
WARDROBE ITEM - EXERCISE GARMENTS

Garment Item	Detail	Candidates	Selection	Basis
T-Shirt	Material	Cotton Cotton blend PBI X400	Cotton or Cotton blend	Absorption Porosity Comfort
	Construction	Knit Woven	Knit (Loose)	Porosity Conformity
	Entry	Frontal Pull over Other	Pull over	Weight Storage Conformal Compatibility with construction
	Collar	Rib knit Standard Combination	Rib knit	Compatibility with knit construction Comfort Light weight Sizing
	Sleeve	Long Short	Short	Ventilation during exercise. Minimum encumberance
	Cuff	Rib knit Loose Fastened	Rib knit	Compatibility with knit construction Storage Conformity
	Waist	Ribbed Loose	Ribbed	Conformal Thermal comfort
	Color	Any	White	Subjective

GARMENT SYSTEM SELECTION
WARDROBE ITEM – EXERCISE GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Socks	Material	Cotton Cotton blend Synthetic	Cotton Cotton/blend	Absorbency Porosity
	Construction	Knit Woven	Knit	Sizing Conformity
	Color	Any	White	Subjective
Sneakers	Material	Vinyl Fabric Hide	Fabric with/sole	Porosity
	Construction		Reinforced heel & toe	Protection
	Entry	Slide String Hook & pile Snap Buckle	Slide	Subjective (as long as sufficiently strong) Ease of entry
	Color	Any	White	Subjective

GARMENT SYSTEM SELECTION
WARDROBE ITEM - SPECIALIZED DUTY GARMENT

Garment Item	Detail	Candidates	Selection	Basis
Clean Room Coverall	Configuration	Two piece One piece	One piece (includes hat and booties)	Body encapsulation
	Entry	Side Front	Front	Ease of donning
	Material	Cotton Cotton blend	Dacron (cont. filament)	No lint or pilling
	Construction	Woven Knit	Woven	Less lint or pilling
	Collar	Rib Standard	Modified Standard	Compatible with woven material Interface with hat
	Sleeve	Long Short	Long	Coverage of body
	Cuffs	Ribbed Fastened Loose Elasticized	Fastened-Snaps	Least particle size generation Interface with glove, booties. Conformal
	Color	Any	White	Subjective Visual indication of cleanliness

GARMENT SYSTEM SELECTION
WARDROBE ITEM – SLEEP WEAR

Garment Item	Detail	Candidates	Selection	Basis
Shirt	Construction	Knit Weave	Knit	Warmth Conformity Storage
	Configuration	Pull over Front Entry	Pull over	Storage Compatibility with knit construction
	Material	Cotton or Synthetic Substitute	Cotton or Cotton blend	Warmth Absorbency
	Collar, Cuff	Rib Standard Fastened	Rib	Compatibility with knit construction Loose fitting
	Sleeve	Long Short	Long	Basic need for sleeping garment is added thermal protection
	Color	Any	Pastel compatible with leisure pants	Can be used alternately with leisure wardrobe

GARMENT SYSTEM SELECTION
WARDROBE ITEM – SLEEP WEAR

Garment Item	Detail	Candidates	Selection	Basis
Pants	Construction	Knit Weave	Knit	Warmth Storage
	Configuration	Loose Tapered	Loose	Non confining
	Material	SAME AS SHIRT		
	Cuff	Standard Fastened Rib	Rib	Best thermal design Comfort
	Waist	Belt Draw string Elasticized	Elasticized	Size adaptable Comfort No possibility of of belt.
	Color	Any pastel	Any pastel	Subjective Can be used during exercise periods as sweat pants
	Fasteners	Slide Snap Hook & pile	None	none needed
Robe	Construction	Knit Weave	Knit	Warmth
	Configuration	Front Entry Pullover	Front Entry	Ease of entry
	Material	Any absorbent material	Coarse weave cotton or flannel	Warmth
	Fasteners	Slide Snap Hook & pile	Snap	Strength not required Simple Light weight
	Color	Any	Soft hue	Subjective

APPENDIX B

WASHABLE VS DISPOSABLE GARMENT TRADEOFF STUDY

1.0 INTRODUCTION

In the present space program, the aspect of crew clothing in space vehicles has been treated with a low priority. The garment needs of the astronauts have been minimal in terms of overall penalty to the mission or vehicle requirements. With the advent of longer missions and larger crews, the clothing penalty and associated systems are no longer negligible and require investigation. One such investigation is the basic decision to employ a laundry system on-board a station, or continue with the present concept of clothing storage and single cycle usage.

This paper presents the assumptions, ground rules, trade off and conclusion regarding the basic decision of the use of a laundry system in a space station.

2.0 TRADE OFF STUDY CRITERIA

One of the most tangible (and common) trade off criteria in the study of concepts for spacecraft use are weight, volume and power. For the Apollo and Skylab missions, these parameters are extremely important due to the mission limitations and systems capabilities. For the longer duration missions with larger vehicles and greater boost capability, these aspects may be reduced in importance from their present status to only one of many equal considerations. Presented below is an assessment of the various criteria in the selection of any candidate system for use in a space station. There are six major categories selected for this trade off study:

1. Physical Characteristics
2. System Utility
3. Reliability
4. Safety
5. Interface
6. Program Impact

2.1 PHYSICAL CHARACTERISTICS

The physical characteristics of a candidate system are its weight, volume, power, moment of inertia and the like. Although these criteria may no longer be the primary considerations, they do constitute one of the major aspects in a system selection. The weight, volume and power may no longer be totally limited due to launch considerations, however, a ceiling still exists upon the total allocation of each of these and a system cannot exceed the allocated limit.

2.2 SYSTEM UTILITY

This criteria is a relatively new aspect in spacecraft system study as all of the previous systems have had an absolute requirement for the items and systems on board. With the anticipated space station environment being one of the improved habitability from the previous space programs, the selection process of spacecraft items changes from its previous criticality to one of assessment of system usefulness. The element of system usefulness with regard to experiments and operational systems will become more prevalent as future vehicles are concepted. Under this category, such elements as crew time demand, crew acceptance, and combined function are evaluated. In the case of crew time demand, it may be desirable to occupy a portion of a crewman's time with a routine task, to avoid boredom. Time saving may not be desirable for a large crew with regimented duty cycles. In the area of crew acceptance, the utility of an item or system may be measured as to the anticipated use, once installed. The element of combined function, i.e. one system being used for several operations (not necessarily related) is also evaluated in the utility category.

2.3 RELIABILITY

The criteria of reliability has been the significant impact in the design of space vehicle systems to date. The aspect of fail-safe design and redundancy has been apparent throughout all spacecraft systems. To this point, the criteria of reliability and safety have been somewhat synonymous as a failure of a system has required assessment of its impact upon mission completion. In the establishment of criteria for a study of a laundry system for a space station, these two areas have been separated. The aspect of reliability is discussed below and safety in paragraph 2.4.

The reliability aspects of system selection are concerned with the probability of malfunction, failure associated maintenance time, diagnosis time, repair time, and spares selection. Also included in the evaluation of the impact of a particular system are the allowable alternatives in the event of failure.

2.4 SAFETY

The safety aspects of system selection for a space station application are evaluated in the same manner as for the present programs. Hazards that may be present must be minimized or the candidate approach with inherently unsafe operation rejected from consideration. Such items as flammability, chemical stability, hazardous operating modes and propagating failures are considered in this category.

2.5 INTERFACE

The interface considerations are those concerned with the impact of the candidate system upon the surrounding systems. The criticality of this criteria is directly dependent upon the point in the program at which the system is assessed. In the requirements definition phase of a space vehicle program, the interface criteria is only one of many critical aspects. This criteria, however, increases in importance as the program progresses. For example, if it were desirable to place a bathing facility on board an Apollo spacecraft, interface considerations render this proposal impossible.

Interface considerations consist of the following items.

1. Physical Interfaces - shapes, mounting points, connections (electrical and mechanical) finishes.
2. Functional Interfaces - cooling/heating requirements, fluid flows, pressure drops, and temperatures.
3. Electrical Interfaces - power, voltages, electrical duty cycles, impedances, wave form and EMI.

2.6 PROGRAM CONSIDERATIONS

The last major consideration in the comparison of systems is the impact of the effort required to fabricate a flight system. This is assessed in terms of development effort, cost, schedule, required research, and future applications.

3.0 TRADE OFF STUDY GROUND RULES

The results of a trade off study may be changed considerably by the biased selection of ground rules. For this reason, a parametric approach to the determination of ground rules yields the greatest insight to the applicability of trade study conclusions. Presented in this section is the establishment of ground rules and the selection of candidate systems for comparison.

3.1 CREW WARDROBE AND CHANGE CYCLE

In determining the advisability of a laundry system, it is necessary to establish the amount of clothing to be worn by the crew. A typical change cycle is presented in Table 1. In the selection of wardrobe, for this study, the quantity of items is based upon intended crew use only, and not upon interface, weight or other consideration. This "baseline" value represents an absolute minimum in the amount of clothing to be used by the crew and offers the least weight approach.

3.2 GARMENT WEIGHT

Both in the case of launderable and disposable items, the garment weight is an important factor. In fact, the actual garments may be identical whether washed or disposed. Table 2 presents the weights of the "baseline" garments and the assumptions made. Once the total weight is determined, then a wear rate (in terms of pounds of clothing per day) may be established. By varying this value, the effects of longer or shorter

TABLE 1

BASELINE CREW WARDROBE

Item	Change Interval (days)
Jacket	3
Trousers	3
Shirt	1
Briefs	1
Socks	1

TABLE 2

WARDROBE WEIGHT

Item	(Item) Weight (lbs.)	Wear Rate (lb/day)
Jacket	0.91	0.303
Trousers	0.75	0.25
Shirt	0.29	0.29
Briefs	0.13	0.13
Socks	0.025	0.025
	Total Wear Rate	.998

$\simeq$ 1.0 lb/day

3.2 GARMENT WEIGHT (CONT'D)

wearing periods or higher or lower garment weights may be seen. As stated above the "baseline" clothing allocation represents the "minimum garment weight" approach.

3.3 DISPOSABLE GARMENT GROUND RULES

For each candidate approach, there are ideal ground rules in which an approach is seen at its best. The ground rules that favor a disposable approach are these assuming light clothing weight, low volume, impregnated germicides, and non-flammable materials. Although these aspects are desirable, there is presently no one material exhibiting all of these characteristics. For this reason the following assumptions are made for the disposable clothing:

A.	Clothing Material -	Cotton/Dacron or equivalent for outer garments - (PBI and Durette are comparable materials) Non woven composite material for underwear (briefs, shirts)
B.	Clothing Weight -	Ranging between 1.0 lb/day and 2.0 lb/day wear rate.
C.	Volume -	45 lb/cubic ft. - based upon folded garment data

3.4 LAUNDRY SYSTEM GROUND RULES

Prior to the comparison study of a disposable garment system approach with a laundry system, it is necessary to determine which laundry technique is to be compared. Since there are many concepts, designs and cycles, a screening process is necessary. The first aspect

3.4 LAUNDRY SYSTEM GROUND RULES (CONT'D)

is the recognition that the laundry system consists of several sections including:

1. Washer and/or dryer.
2. Solvent Storage Section
3. Solvent Recovery Section

The schematic of the system is presented in Figure 1 and each area is discussed below.

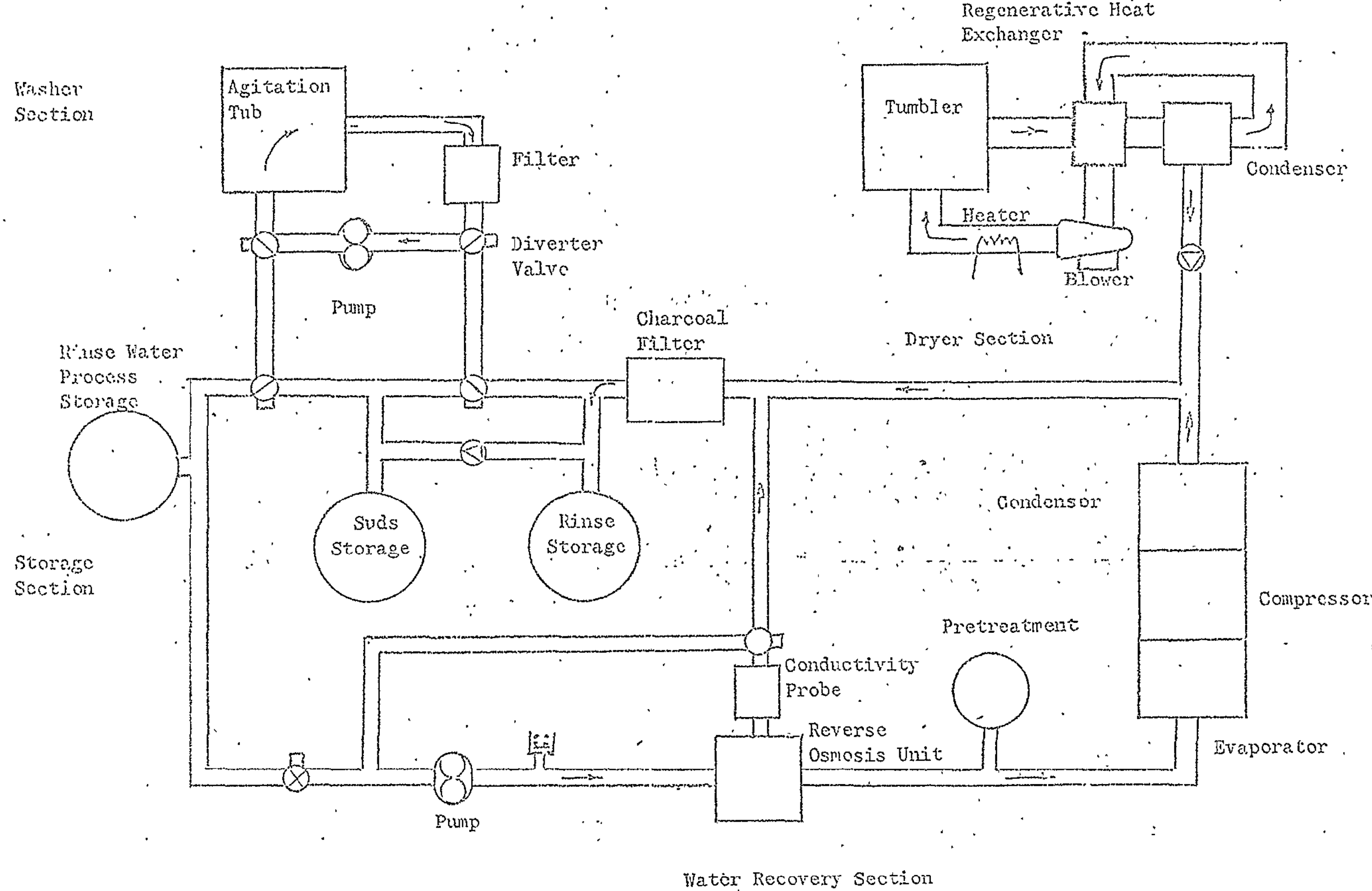
3.4.1 WASHER/DRYER SECTION

The washer/dryer sections contain the clothing agitation or tumbling provision necessary to cleaning. In the washer this agitation may be provided by several techniques including the motions of a rotary drum, oscillatory agitator, mechanical vibrator, ultrasonic input or high velocity jets. For various reasons ranging from the lack of gravity to inapplicability of technique to clothing, the only approach within the present state of the art is by means of an oscillatory washer.[1] This approach involves the use of a fixed tub and centrally located agitator in which the tub is completely filled with clothing and water.

The dryer approach selected for this study is an air tumbling method in which jets of hot air are directed at the clothing. These air jets evaporate the water in the clothing and provide the tumbling mechanism.

1. There have been several other concepts for clothing mastication in zero gravity which may be applicable, however, for the purpose of this study, the oscillatory approach is used.

FIGURE 1 - LAUNDRY SYSTEM



3.4.1 WASHER/DRYER SECTION (CONT'D)

In each of these areas there are several ground rules to be established. These ground rules are presented below:

3.4.1.1 WASHER/DRYER SECTION GROUND RULES

The requirements for a "baseline" washer and dryer system are:

Water Required[1] - 15 lbs. water/lb. clothing/rinse cycle
Load Factor - 3.3 lbs. clothing cu. ft. of washer
Load Size - 7 lbs. of clothing
Washer Use - 2 wash cycles/day
Wash Interval - Weekly
Drying Time - 1 hour
Wash Cycle - 15 minutes suds, 15 minutes rinse
Wash Temperature - 140^{o}F.

Variations to each of the above groundrules may be made, however, the resulting impact upon the washer/dryer section will not be great. Changes in these variables will have effect upon such sections as the water recovery and power systems (as described in the next paragraphs).

3.4.2 SOLVENT STORAGE SECTION

In the review of possible cleaning solvents, it has been found that water is the most desirable. Its selection is based upon:

1. "Dry" cleaning fluids are generally toxic and/or flammable.
2. Water vapor or drops are easily removed from the atmosphere.
3. Reclamation process is interchangable with existing spacecraft facilities.

1. Based upon most conservative, "full tank" approach.

3.4.2 SOLVENT STORAGE SECTION

The amount of water to be stored is a function of the rate of water recovery of the reclamation system. The amount of water required for each washing cycle is conservatively estimated at 15 pounds per pound of clothing for the suds and rinsing operations. Assuming that 2.5 pounds of water are absorbed per pound of clothing, a seven pound wash requires 105 lbs. of water/detergent mixture and 87.5 pounds of rinse water.

Assuming that the suds water may be recycled as in present dry cleaning operations, the only water recovery requirement is to process the rinse water quantity. Assuming that half of the absorbed water in the clothing is collected with the rinse water during a spinning operation (the other half removed during the drying operation), a quantity of 192.5 lbs. must be processed. A rinse water storage quantity of 175 lbs. is required as the wash cycle may occur at any period in the day. Together with 105 lbs. charge of water/detergent solution, the total storage quantity is 280 lbs. As previously mentioned, these values are dependent upon the specific amount of water assumed required to totally clean the clothing.

3.4.3 WATER RECOVERY SECTION

The water recovery section of a cleaning system processes the rinse water and renders it reusable in the washer. For the purposes of this analysis, it is assumed that the suds water need no further processing other than the filtration provided in the washer unit. If further suds processing is required, the water recovery rate is approximately doubled and the storage quantity increases by 33%.

3.4.3 WATER RECOVERY SECTION (CONT'D)

The candidate systems for processing water include the following:

1. Filtration
2. Air Evaporation
3. Reverse Osmosis/Vapor Compression Combination
4. Vapor Compression

For this analysis, a reverse osmosis/vapor compression technique is chosen for the recovery of rinse water. This selection is made on the basis of least weight, power, and volume while properly purifying the water. It is also compatible with the present concepts anticipated for the space station water management system for urine and hygiene water recovery.

4.0 TRADE OFF MATRIX

The summary trade off matrix is shown in Table 3. Each of the evaluation criteria discussed in section 2 is considered in the comparison of the candidate approaches. The trade off is based upon a 12 man crew and 180 day mission period. A summary of the results is presented below:

Criteria	Laundry		Disposables
Weight	X		
Volume	X		
Power			X
Utility	X		
Reliability			X
Safety		Equal	
Interface			X
Program Consideration			X

4.0 TRADE OFF MATRIX (CONT'D)

As it may be seen from the above, the ultimate selection is based upon the weighing factors employed with the criteria. The selection may be changed with the biasing of assumptions in terms of whether it is desirable to obtain an earth type existance on board the space station. The laundry system is advantageous from the conventional standpoint and disposables from an expediency point of view.

By increasing the wardrobe requirements for the crew, the comparison remains approximately the same in that the ranking is the same.

5.0 CONCLUSION

It is concluded that a laundry system should be developed for use in a space station. This position is based upon its ultimate use in space base (to simulate earth conditions) and its relative lack of complexity in view of other space station systems. The "trade off study" between a laundry and disposables appears to be an analysis of the time period of switch over from disposables to the laundry system.

A comparison of this problem may be made to the design of early environmental control systems.. The first units were relatively low complexity systems with high expendable rates (stored oxygen, Lithium Hydroxide, etc.,). In the next generation of systems, the closed cycle or regeneration capability was introduced allowing more mission payload. Although the use of disposables clothing is attractive from several viewpoints at this time, it is a first generation solution which will undergo an ultimate transition to a more sophisticated approach to a laundry system.

TABLE 3 TRADE-OFF MATRIX

CANDIDATE / CRITERIA	LAUNDRY SYSTEM		DISPOSABLE GARMENTS		SELECTION
Physical Characteristics	Item	Weight (lb)	Item	Weight	Laundry System
Weight	Garments (1.0 lb/day-man)----	96	Garments (1.0 lb/day-man)----	2,160	
	Packaging (2% of clothing weight)----	2	Packaging	43	
	Washer (weekly load, two operations a day----	40			
	Dryer----	60			
	Water & Tanks 15 lb water/lb clothing 2 rinse cycles/day----	300			
	Recovery System (rinse water only)	200			
	Expendables (detergent, precipitating agents)----	20			
	Total	718 lbs.	Total	2,203 lbs.	

TABLE 3 TRADE [illegible] MATRIX (CON[illegible]

CRITERIA / CANDIDATE	LAUNDRY SYSTEM		DISPOSABLE GARMENTS		SELECTION
Physical Characteristics (Cont'd)	Item	Volume (Ft^3)	Item	Volume (Ft^3)	Laundry System
Volume	Garments ($45\ lb/ft^3$)	2.1	Garments	48	
	Washer @ $3.0\ lb/ft^3$	2.3	Packaging	1	
	Dryer @ $2.0\ lb/ft^3$	3.5			
	Tankage	5.0			
	Recovery System est.	2.0			
	Expendables est.	.5			
	Total	15.4	Total	49	
Power	Item	Power (Watts)	NONE		Disposables
	Washer (est)	200			
	Dryer	9,000 BTU required per cycle			
	Recovery System	220			
	Total Electrical	440 Watts			
	Thermal	9,000 BTU			

TABLE 3 TRADE OFF MATRIX (CONT'D)

CANDIDATE / CRITERIA	LAUNDRY SYSTEM	DISPOSABLE GARMENTS	SELECTION
System Utility			
Usefulness	The laundry system will be ultimately used in a space base if earth conditions simulation is a goal. Its usefulness an experiment in early space station or Skylab missions is high due to its eventual inclusion in subsequent missions.	The usefulness of disposable garments is based upon the premise that another on-board mechanical system and associated penalties will not be necessary.	Laundry System
Crew Time Demand	The crew time demand is approximately one hour (not necessarily continuous) once a week per member. This consists of transporting, inserting, removing, folding clothing during washing and drying operations.	The time demand for disposable clothing reduction or return to storage is included in the normal time allotted for dressing. The only time associated with garment preparation is concerned with reduction operations such as incineration, shredding or packaging for storage.	Equal Slight advantage to Disposables

TABLE 3 TRADE OFF MATRIX (CONT'D)

CANDIDATE / CRITERIA	LAUNDRY SYSTEM	DISPOSABLES	SELECTION
<u>System Utility (Cont'd)</u>			
Crew Acceptance (Operability)	The clothes cleaning operation is a familiar task that requires little crew training. Crew acceptance should be immediate.	Crew acceptance of disposables depends upon materials used. If fabric articles are used as in present missions, crew acceptance is also easily anticipated.	Equal
Combined Function	Laundry System Washer may be source of small gravity field (during spin) and may be used as centrifuge for experiments. Dryer has application for tumbling of objects with air jets. Either washer/dryer provide storage space when not in use.	Disposable clothing may be cut and used for hygiene purposes - clothes, towels, wipes (once treated with a germicide). If disposable clothing is of proper material, chemically reduce, collect and reuse by-products.	Equal

TABLE 3 TRADE-OFF MATRIX (CONT'D)

CANDIDATE / CRITERIA	LAUNDRY SYSTEM	DISPOSABLE GARMENTS	SELECTION
<u>Reliability</u>			
Probability of Malfunction	System contains several motors, solenoids, valves, filters and as such is likely to have malfunction during mission.	Virtually non-existent. Possible addition of germicide or odor depressant for stored used clothing. Only possible malfunction occurs in clothing reduction equipment (if necessary)	Disposables
Failure Associated Maintenance	The diagnosis of a failure of the laundry system is relatively uncomplicated and repair possible by an on-board technician.		Disposables
Failure Assocaited Penalties	Weight and Storage of on-board spare parts. Alternative to repair is hand washing of clothing until resupply shuttle brings parts.		Disposables

TABLE 3 TRADE-OFF MATRIX (CONT'D)

CRITERIA / CANDIDATE	LAUNDRY SYSTEM	DISPOSABLE GARMENTS	SELECTION
Safety	There are no single point safety hazards (a failure which results in crew injury) in the laundry system. These are eliminated through proper design and system concept. Minor injuries may be reduced (hands in rotating machinery, burns, accidental discharge of water from washer) by the use of interlocks and guards.	With proper selection of materials and processes, no single point failure can result.	Equal
Interface Physical	The laundry system contains the physical interfaces comparable to the complexity of a present state of the art regenerable carbon dioxide removal system. Water, cabin gas, electrical and mounting connections are necessary.	Volume must be allocated for mission period storage for both unused and used clothing. The total volume must be easily accessible to a crew member.	Disposables

TABLE 3 TRADE-OFF MATRIX (CONT'D)

CANDIDATE / CRITERIA	LAUNDRY SYSTEM	DISPOSABLES	SELECTION
Interface (cont'd)			
Functional	Approach requires heat for wash water and dryer air. (Electrical or waste heat). Although recovery system requires heat/high pressure/vacuum, it is already present in defined water management system.	Storage is passive, functional interfaces include material and fire compatibility, with atmosphere and storage.	Disposables
Electrical	Electrical interfaces include power for water heating, washer, dryer and recovery unit.	None	Disposables
Program Considerations	Washer/Dryer are only items requiring development effort.	Fabric development for light weight disposable garment that is absorbent, wear resistant and strong.	Disposables
Development Effort	Water recovery technique is presently being developed in conjunction with ECS.		

TABLE 3 TRADE-OFF MATRIX (CONT'D)

CANDIDATE / CRITERIA	LAUNDRY SYSTEM	DISPOSABLES	SELECTION
Cost/Schedule	The cost of these systems (washer/dryer) is due to the development of two items which have never flown previously. They are, however, within the state of the art and are not complex. (Estimated 10 million)	With fire retardent material average expense and labor at $300. per daily wardrobe - $650,000. for a 180 day period.	Disposables

Back Protection Cover

A Reproduced Copy

OF

Reproduced for NASA

by the

NASA Scientific and Technical Information Facility