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Technical Report

WAREHOUSE AND PRESERVATION METHODS AND ECONOMICS FOR STORING MATERIEL

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U. S. NAVAL CIVIL ENGINEERING LABORATORY
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WAREHOUSE AND PRESERVATION METHODS AND ECONOMICS FOR STORING MATERIEL

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Type C Final Report

by

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ABSTRACT

NCEL has concluded a 5-year storage-test program to determine the type of environment and preservation level best suited for long-term storage of materiel under the Bureau of Yards and Docks technical cognizance.

Similar paired items of military equipment were stored in different storage environments — an open-air slab, a shed, a standard warehouse, a 50% RH warehouse, and a 40% RH warehouse. One of each pair had light domestic treatment and the other full contact-preservation treatment. Deterioration was permitted to develop at its natural rate in each environment. Periodic inspections determined the protection afforded by each storage environment and preservation level by the extent of deterioration encountered.

Results are presented in two parts: (1) efficacy of storage environments, and (2) economy of storage systems. Part 1 shows that protection is poor in open-air storage, fair in a shed, good in the standard warehouse, and excellent in controlled-humidity warehouses. Five components — internal-combustion engines, gear boxes, fuel-injector sets, hydraulic brake systems, and cooling systems — had a high incidence of rust regardless of storage environment and with little regard to preservation level. Compared to domestic treatment, contact preservation decreased the incidence of rust about 58% for open-air storage, 44% for the shed, and 30% for the standard warehouse; no rust due to storage environment occurred in the controlled-humidity warehouses for either preservation level.

Part 2 shows that, under environmental conditions similar to those of the test, storage in the 50% RH warehouse using domestic treatment is usually cheaper, but that the standard warehouse with this treatment is cheaper for automotive and non-metallic equipment. It is cheaper to protect equipment stored for stateside use with domestic treatment, but contact preservation is cheaper for overseas use.

The Navy's standard 40-foot by 100-foot prefabricated metal building appears generally satisfactory for advanced-base dehumidified warehousing, but it has too many joints to be easily sealed and quickly erected.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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PREFACE

After World War II, the Department of Defense inaugurated a reserve-readiness program to provide for possible future military requirements. This program set aside large quantities of materiel for mobilization reserves and peace-time preparedness use. The Prevention of Deterioration Center, Washington, D. C., estimated the DOD materials and equipment in storage as reserves to be worth 51 billion dollars in 1957. This value undoubtedly increases substantially from year to year as replacement purchases are introduced into the program and inventories are adjusted to include new and improved weapons and equipment.

Maintaining reserves in an issuable condition is of paramount importance. Therefore, of necessity, the military became warehousemen and experts in preservation and inspection. Such storage and preservation is expensive. The Construction Battalion Center, Port Hueneme, California, estimates its direct annual storage cost to be about 1.5% of the acquisition value of their stores. If 1.5% is applied to the 51 billion dollars, disregarding yearly increases and replacement of stores, the taxpayer pays over 3/4 billion dollars a year for the storage cost of the reserve-readiness program.

It is generally acknowledged that the underlying cause of deterioration of equipment stored openly is climate, consisting of such factors as oxygen, moisture, sunlight, heat and cold, and wind. Corrosion is the most costly form of deterioration of equipment. The primary contributing factors are oxygen and alternate wetting and drying; secondary are sunlight and variable weather. Oxygen, necessary for the formation of metallic oxides, is continuously present, while condensation, resulting from diurnal changes in temperature, is largely responsible for alternate wetting and drying. Temperature stability, dew point, the partial pressure of the water vapor in the air, and the mass-area relationship of the object all influence the amount of condensation. Corrosion accelerates if condensation includes mineral salts such as those present in ocean air, in certain industrial atmospheres, and in combinations of the two. Dust particles settling on the metal from the air accelerate corrosion markedly. The more protection that is given to stored equipment, the more corrosion decreases; it is almost nonexistent in regions of low relative humidity.

Part 1. EFFICACY OF STORAGE ENVIRONMENTS

INTRODUCTION

The Bureau of Yards and Docks has direct responsibility for the design, erection, and maintenance of all Navy land-based storage facilities and is involved in much of the acquisition of stores for these facilities. In the interest of increasing storage effectiveness and reducing costs, BuDocks initiated a storage test at NCEL in 1955 under Task NY 450 010-8, presently Y-F015-04-004. Following the first 2-1/2 years of tests, a status report, TR-075, was issued 28 June 1960. After 5 years of tests, the task is complete and this final report is issued.

Some of the items in the NCEL test were unprotected and received the full assault of oxygen, wetting, drying, and corrosion accelerators such as sea air and dust. Since rusting is the most serious type of corrosion, this is the type of corrosion with which this task is concerned. As will be described in this report, rusting can be studied in terms of temperature, partial pressure of the water vapor, exposure samples, and corrosion indicators. From detailed periodic inspections, the extent and effect of rust can be studied and evaluated using rusting indices, rust counts, and rehabilitation costs.

DESCRIPTION AND METHODS OF TEST

Storage Environments

The military uses four basic types of storage environments. These are open air, sheds, standard warehouses, and controlled-humidity warehouses. Open-air storage exposes equipment to the full rigors of weather. Shed structures, though not complete buildings, provide considerably more protection than open-air storage, particularly during periods of bad weather. Standard warehouses, widely used commercially, are complete structures, and except for outside-air infiltration, completely protect goods from the elements. Controlled-humidity warehouses, also complete structures, protect not only from the elements, but reduce the effects of moist air by controlling the moisture content of the warehouse air. NCEL tested these four types of environments including two levels of controlled-humidity warehouses, to make a total of five environments.

The open-air storage unit consists of a 40-foot by 100-foot asphaltic concrete floor slab 4 inches thick which is bounded by a portland-cement curb level with the floor slab. The shed and the standard and controlled-humidity warehouses are 40-foot by 100-foot prefabricated metal structures with 4-inch-thick asphaltic concrete floors.

The shed has three sides and a roof; the leeward side (along the length) is open. The standard warehouse, which is prefabricated of 2-foot by 4-foot panels, was erected as received from stock except that it was lined with 1-inch glass-fiber insulation and hard-pressed fiberboard on the interior walls and ceiling in order to dampen the daily temperature fluctuations within the building. The controlled-humidity warehouses were similar to the standard warehouse, including insulation, except that all joints were sealed by caulking with a bituminous cut-back cement, the windows and rear cargo doors were replaced with regular metal siding, and the front cargo doors were sealed after stores were set in place. Access is through gasketed personnel doors cut in each front cargo door. A 200-cfm dual-bed silica-gel dehumidifying machine, installed in each of the two controlled-humidity warehouses, automatically maintained the relative humidity at 50% in one and 40% in the other. Figure 1 is an aerial view of the five storage conditions.

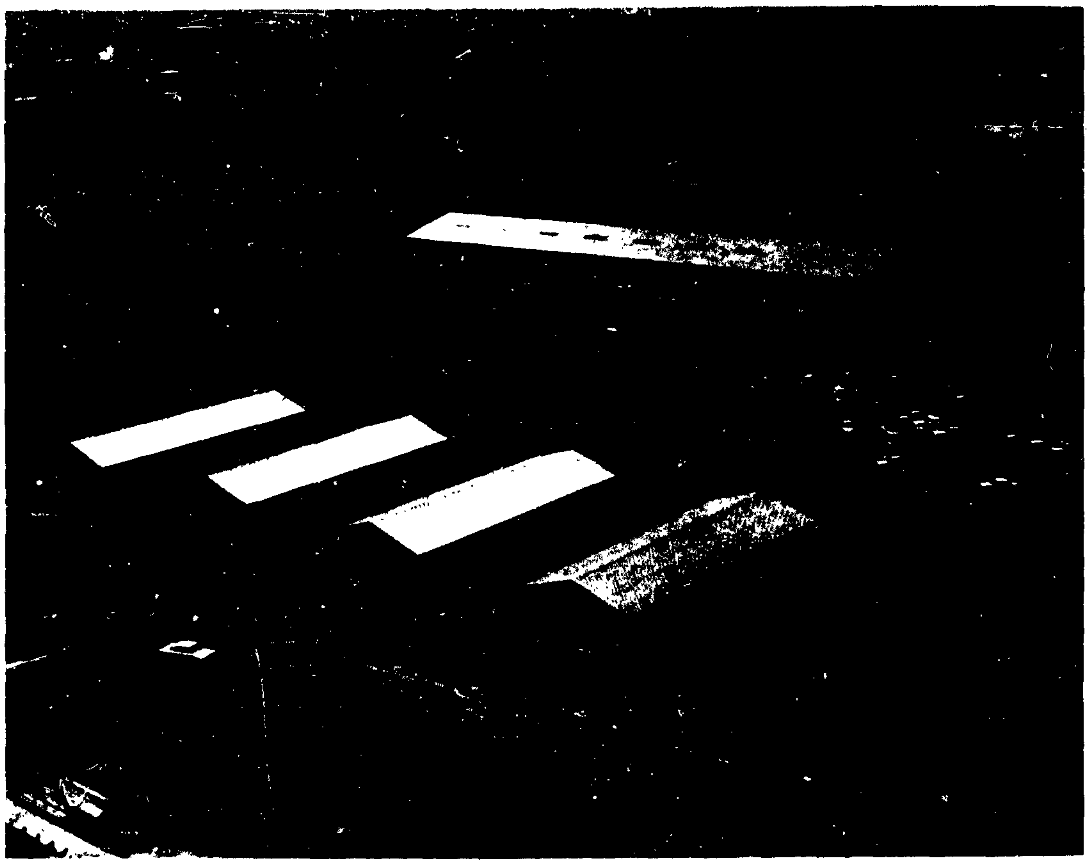

Figure 1. Aerial view of the test storage environments. From left, 40% RH, 50% RH, standard, shed, and open air.

Instrumentation

The corrosion-producing potential of each environment was measured by Corrosometers and motorized wet- and dry-bulb temperature recorders.

The corrosometer, manufactured by the Crest Instrument Co., Santa Fe Springs, California, measures corrosion by a change in resistance of a metal sensing element. It consists of a metered modified Kelvin bridge circuit and wire sensing elements whose resistance increases as they become corroded. The increase is measured by the bridge circuit in units of microinches of corrosion penetration. A steel, an aluminum, and a copper element were placed in each of the five environments.

Psychrometric data, to determine the amount of moisture in the air, were obtained and recorded for all environments by Minneapolis-Honeywell wet- and dry-bulb motorized psychrometers. In the controlled-humidity warehouses, an electronic controller automatically maintained the relative humidity at the desired level. The controlled-humidity warehouses were each equipped with two dew-point recorders, a wattmeter, and a timer. Charts were changed weekly and temperatures were averaged with a polar planimeter for the 7-day period. Figure 2 shows much of this instrumentation.

Air infiltration through unintentional openings such as cracks and loose seals in the controlled-humidity warehouses was estimated by pressurizing the buildings and determining the leakage. A 600-cfm centrifugal fan was installed in each dehumidified warehouse to draw in outside air. From a known rate drawn in and the resultant warehouse air pressure measured by two inclined manometers, the infiltration and relative tightness of the building were determined. Pressurization also indicated whether the joint-sealing compound was remaining supple or was hardening.

Materiel in Storage

The equipment for the test, selected from Naval Construction Battalion stocks, included such items as jeeps, dump trucks, searchlights, steam boilers, pumps, welders, bake ovens, lathes, and telephone switchboards. The five types of storage environments were stocked with similar equipment except that certain types, such as machine tools, not normally stored in open air or sheds were omitted from these environments. The open-air and shed environments each contained 19 different items and the remaining environments each contained 29. Figure 3 shows the placement of items in a warehouse. Appendix A gives a complete listing of all items in the test.

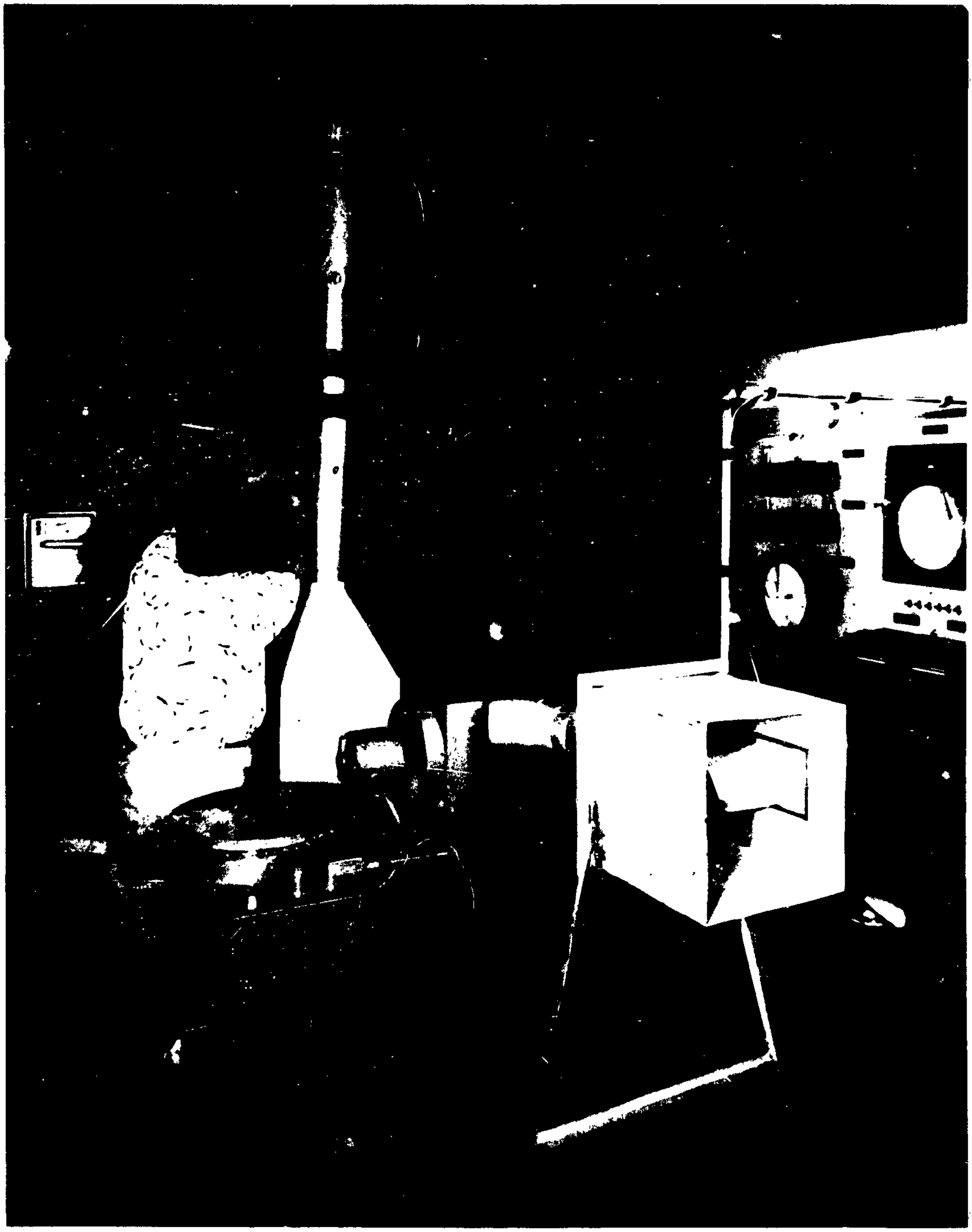

Figure 2. Equipment and instrumentation in the 50% RH warehouse. Desiccant machine is in the foreground.

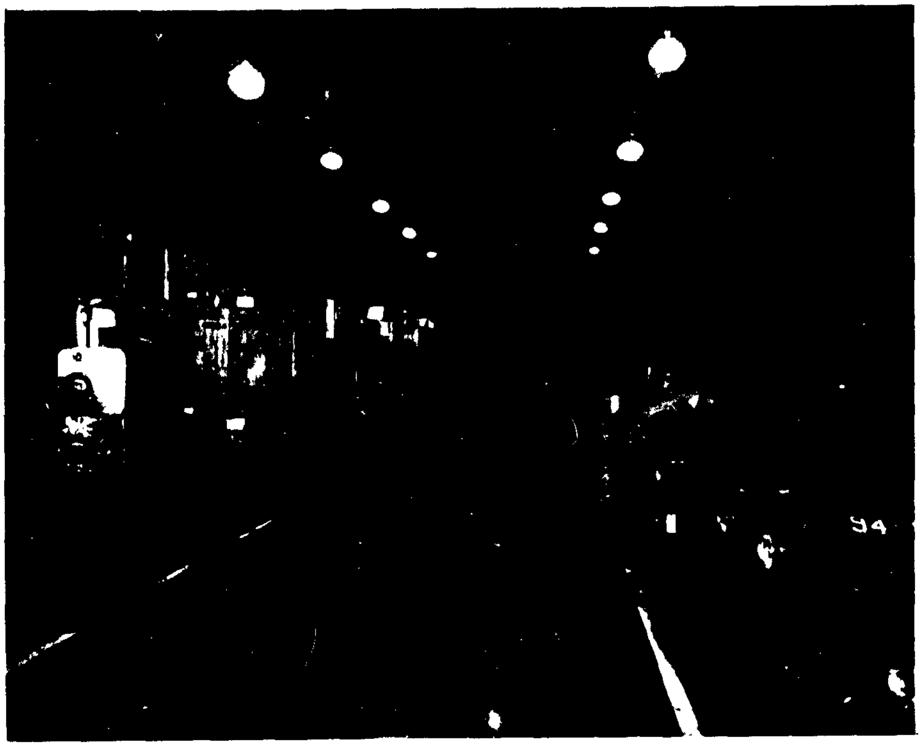

Figure 3. Interior of the 50% RH warehouse. Stock arrangement as shown is identical in all environments.

Preparation of Materiel for Storage

Preparation entailed disassembly of all items, cleaning, inspecting, repairing, photographing, and preserving. Each item was photographed when placed in "as new," or A-1, condition.

Preparing the stores for the test was scheduled so that immediate stocking could begin as each environment was erected. Stocking began with the open-air storage, continuing through the period from July 1955 to February 1956, and was completed with the 40% RH warehouse.

The items were stored in pairs to obtain information on two levels of protective coatings. One unit of the pair was protected by "domestic" treatment and its mate by "contact" preservation. Domestic treatment is a cursory treatment performed by the supplier or manufacturer. It consists of applying a P-1 preservative* to exterior

* P-1 is a corrosion-preventive compound (light oil) which dries to a thin, hard film following application.

nonmachined ferrous-metal surfaces and placing regular in-service oils and greases in the transmission, differentials, and other working parts of the equipment. It also includes retouching paint and taping shut any openings which might admit moisture. Contact preservation is a very thorough treatment and is performed by the Navy. It consists of a range of P-type preservatives applied to all corrodible exterior and interior surfaces, exterior surfaces repainted where necessary, openings sealed to exclude moisture and airborne water vapor, and packaging and packing all according to NavDocks instructions TP-PW-14.

Inspection of Materiel

Materiel was inspected periodically to determine the ability of each environment to protect equipment from rust. Equipment in the open air was inspected every 3 months, in the shed every 6 months, and in the remaining three environments every 12 months. The cargo doors of the controlled-humidity warehouses were unsealed and opened for all inspections.

All inspections except final inspections entailed a partial disassembly of equipment. For example, inspection of automotive equipment involved the removal of various cover plates, wheels, crankcase pans, cylinder heads, etc. These inspections conformed with the instructions of the Quality Control Procedures Manual TP-QC-1 for Class II inspections.

After 30 months, much of the domestic-treated equipment in the open air showed signs of serious deterioration and the contact-preserved equipment appeared to need represervation. Thus this equipment was eliminated from further tests. Such equipment was given a final, Class III inspection, reconditioned, and returned to CBC storage; a Class II inspection had been made 3 months prior at 27 months. Upon completing 5 years of storage, the equipment in the four remaining environments was given the final Class III inspection. All Class III inspections conformed with the instructions of the TP-QC-1 manual, which require "a complete tear-down to conduct a minute examination of a complex equipment item."

Rust and deterioration encountered during each inspection was classed and recorded, and representative areas were photographed. These photographs will be used in a report to be prepared which will list all of the areas which had rusted during the 60 months of testing. Rust classification was in accordance with the Bureau of Yards and Docks uniform terminology, Class I, II, III, or IV, as follows:

Class I — Stain. Discoloration or staining with no evidence of pitting, etching, or other surface damage visible to the naked eye.

Class II — Light Corrosion. Surface corrosion. Loose rust or corrosion. No tight rust or scale. When removed by wiping, leaves a stain but no evidence of pitting, etching, or other surface damage visible to the naked eye.

Class III — Medium Corrosion. Loose or granular rust or corrosion, together with visible evidence of minor pitting or etching.

Class IV — Heavy Corrosion. Powdered scale, or light rust or corrosion together with deep pits, or irregular areas of material removed from the surface.

Dehumidified Storage Effects

An effort was made to determine the probable effects on equipment taken from a dehumidified warehouse and subsequently stored outside, which frequently happens to equipment shipped overseas. Equipment from the 40% RH warehouse was chosen for this because it was felt that all pertinent information concerning efficacy of controlled-humidity storage could be obtained from the 50% RH warehouse. Accordingly; equipment was removed from the 40% RH building at the end of 4 years and placed outside for the final year of the test. Only equipment permitted outside storage by regulations was moved; items such as food machinery, machine tools, and instruments remained indoors. The equipment moved outside was thus given a Class II inspection every 3 months.

In the final inspection, the contact-preserved items were given a Class III inspection, but the domestic-treated items were operationally tested first and then given the Class III inspection. The items were operated at least long enough to reach normal operating temperatures; many items were operated longer to insure that weaknesses could be detected. Whenever possible, items were operated under load; for example, using water for pumps, electrical load panels for motor-generator sets, and road testing for the automotive equipment. The instruments and communications gear left in the 40% RH warehouse were not operated; the rest of the equipment was operated without load.

Rusting Index

A rusting index was devised to measure the severity of rusted components. It is determined by multiplying the portion of an area covered by rust (0 through 1) by the numerical value of the rust classification (1 through 4). For example, an area with 100% coverage of Class IV rust would have an index of 4:

$$1 \times 4 = 4$$

An area with 40% coverage of Class II rust would have an index of 0.8:

$$0.4 \times 2 = 0.8$$

If these two rusted areas were on the same item and were the only areas affected, the total index for the item would be 4.8:

$$4 + 0.8 = 4.8$$

A rusting index obtained by this method permits the severity of rust and the amount of coverage to be represented numerically. It is based on the final Class III inspections and only on surfaces critical to equipment operation.

Rust Count

Rust count is another measure of rust, but unlike the rusting index it measures only the extent of rust, not its severity. It is simply a count of all rusted areas of a particular storage environment and preservation level. The count increased at each inspection as the items continued to rust; only surfaces critical to operation were counted.

Rehabilitation Costs

In the NCEL test, the rehabilitation costs were determined from inspection records of materiel which had been permitted to deteriorate unchecked. These costs will be different from those experienced in the field, for current practice requires deterioration to be corrected when discovered, and cost is computed for work and materials involved in restoration and representation. The field method insures a high degree of readiness for shipping (statistically 96% acceptability). Had deterioration been corrected when discovered in the NCEL test, no useful data could have been obtained since rust removal and represervation would have been synonymous to starting tests anew.

Rehabilitation costs were estimated by the Construction Equipment Department, USNCBC, Port Hueneme, California, from the Laboratory's records of Class III inspections, based on the CED's past experiences in rehabilitating similar deterioration.

TEST RESULTS

The results presented in this part of the report concern only the storage protection of the various environments. Results concerning storage costs are given in Part 2.

Corrosometer Readings

A résumé of Corrosometer readings is given in Table I. Curves based on the table are shown in Figures 4, 5, and 6. The 1 July 1957 readings are from new uncorroded Corrosometer elements at zero exposure time.

The set of curves in Figure 4 are for steel elements. They show a marked difference between rusting rates in the open air and shed and those in the standard and dehumidified warehouses. The data from the 50% and 40% RH warehouses are so nearly the same that it is impossible to separate the curves.

Figure 5 shows the set of curves resulting from the exposure of copper elements. These corroded considerably less than the steel ones in the open air and shed, and about the same in the three warehouses. The data from the warehouses was too near the same to clearly show individual curves.

The set of curves of Figure 6 are for the aluminum elements. These curves show a significant rate of corrosion difference between the open air, the shed, and the remaining environments.

The Corrosometer readings should not be considered entirely indicative of actual rusting progress. The real value of the Corrosometer lies in the fact that, with this instrument, potential significant corrosion may be predicted for any storage environment provided air psychrometry data is known. If, for example, the Corrosometer readings, the temperature, and partial pressures of the water vapor in any given environment are similar to those obtained in these tests, it would be reasonable to expect similar corrosion rates.

Climatic and Psychrometric Data

The climate under which these tests have been conducted is mild the year around because of a prevailing westerly wind from the ocean, relatively high in moisture content. Rainfall usually occurs during the winter months. Psychrometric data obtained inside each storage environment are given over a 5-year span by the temperature, relative-humidity, and vapor partial-pressure curves in Figures 7 through 10. These curves are based on 4-week averages.

Table I. Corrosometer Readings a/

Date	Element Type	Corrosion Penetration (mils)				
		Open Air	Shed	Standard	50% RH	40% RH
1 Jul 1957	Steel	.000	.000	.000	.000	.000
	Copper	.000	.000	.000	.000	.000
	Aluminum	.000	.000	.000	.000	.000
19 Aug 1957	Steel	1.326	.230	.014	.000	.004
	Copper	.032	.012	.018	.022	.038
	Aluminum	.064	.000	.006	.030	.008
30 Sep 1957	Steel	b/	.450	.028	.032	.020
	Copper	.098	.030	.036	.026	.040
	Aluminum	.176	.022	.046	.036	.024
30 Oct 1957	Steel	b/	.542	.018	.016	.010
	Copper	.092	.018	.014	.034	.020
	Aluminum	.196	.030	.000	.022	.020
1 Dec 1957	Steel	b/	.634	.036	.042	.016
	Copper	.138	.044	.042	.060	.046
	Aluminum	.262	.070	.014	.058	.034
8 Feb 1958	Steel	b/	.860	.032	.020	.020
	Copper	.166	.054	.040	.054	.044
	Aluminum	.460	.100	.040	.048	.044
11 Mar 1958	Steel	c/	1.056	.038	.028	.024
	Copper	.208	.058	.024	.052	.044
	Aluminum	.583	.080	.034	.044	.038
29 May 1958	Steel	c/	1.460	.040	.032	.028
	Copper	.250	.094	.026	.036	.028
	Aluminum	.780	.160	.018	.052	.058
20 Jan 1960	Steel	c/	c/	.084	.036	.060
	Copper	.400	.280	.048	.070	.066
	Aluminum	c/	.416	.094	.062	.084
25 Jun 1960	Steel	c/	c/	.130	.066	.064
	Copper	.472	.364	.074	.080	.092
	Aluminum	c/	.600	.104	.120	.084
12 Jan 1961	Steel	c/	c/	.136	.056	.032
	Copper	.478	.390	.064	.076	.060
	Aluminum	c/	c/	.101	.060	.078
1 May 1961	Steel	c/	c/	.138	.064	.064
	Copper	.551	.422	.062	.070	.064
	Aluminum	c/	c/	.096	.056	.084

a/ Readings converted from microinches to mils.
b/ Indicator off Corrosometer scale.
c/ Element completely rusted in two.

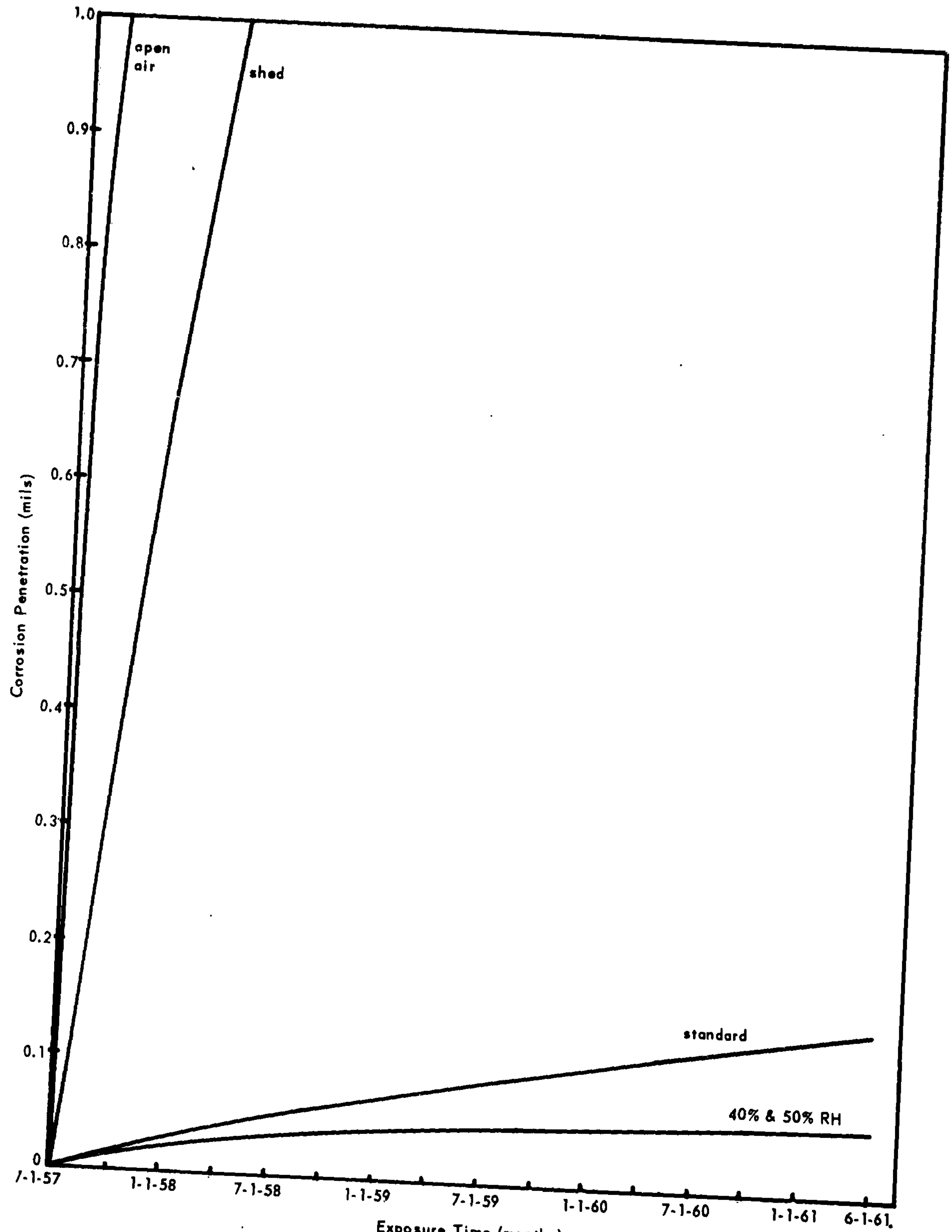

Figure 4. Curve set for Corrosometer steel elements.

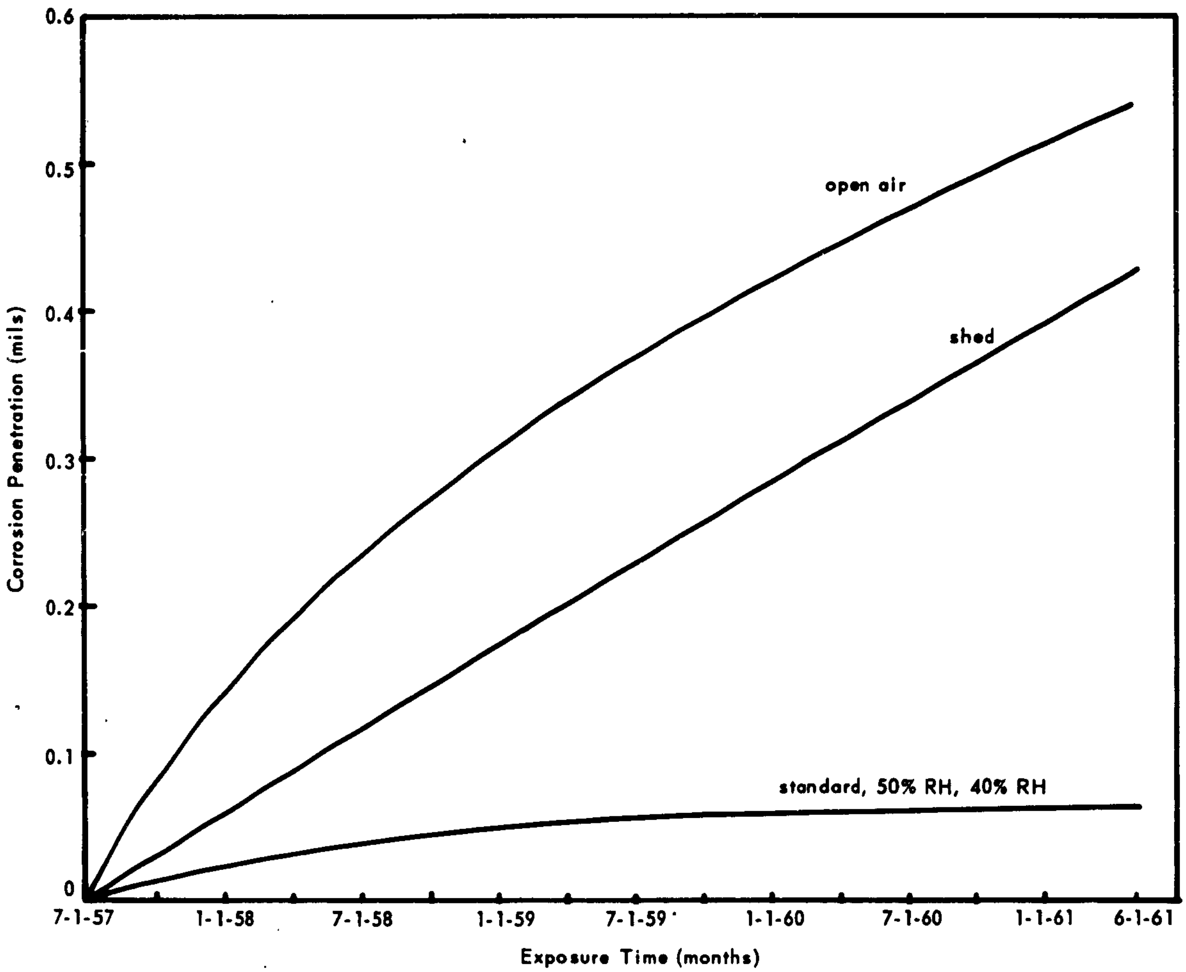

Figure 5. Curve set for Corrosometer copper elements.

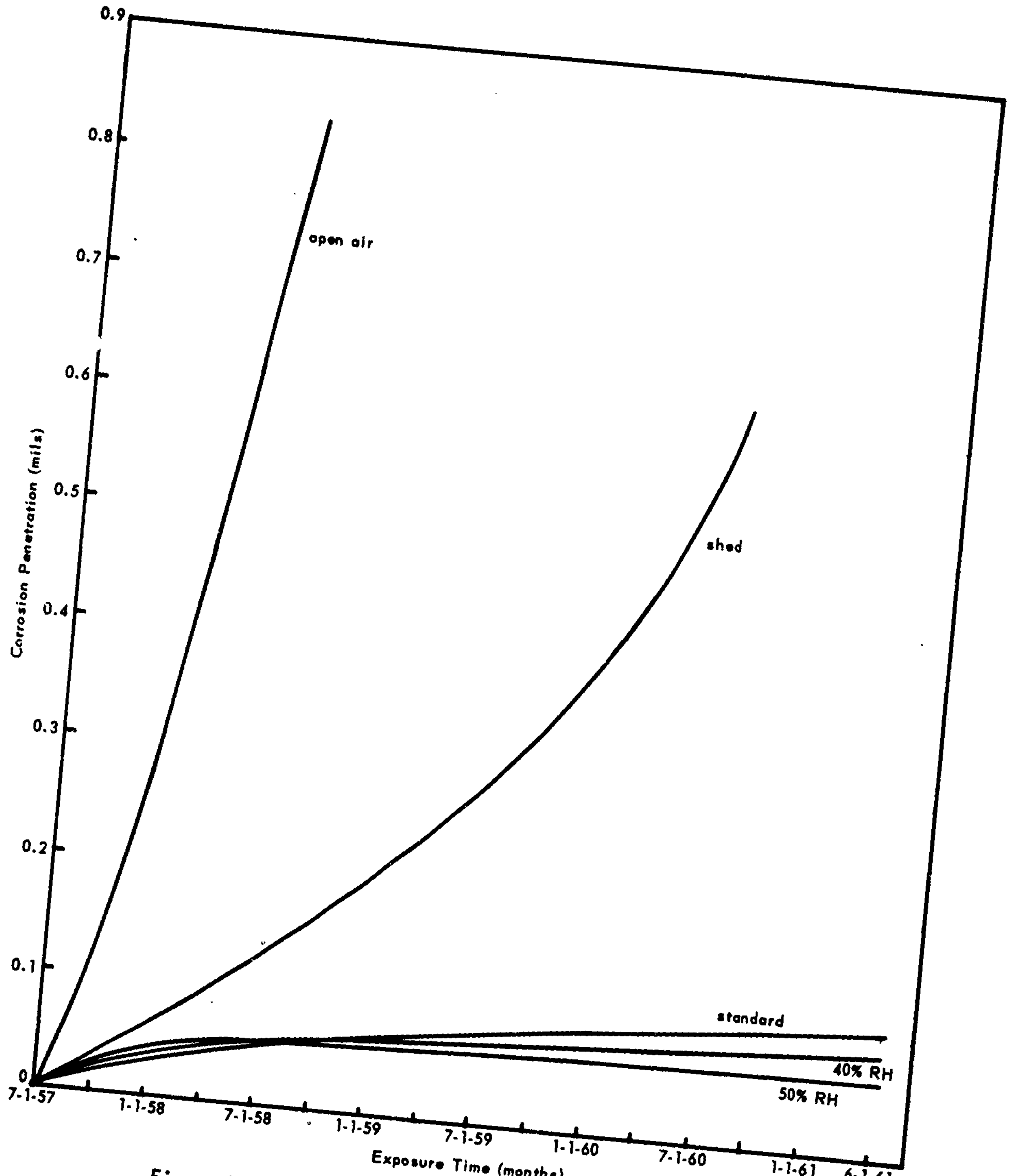

Figure 6. Curve set for Corrosometer aluminum elements.

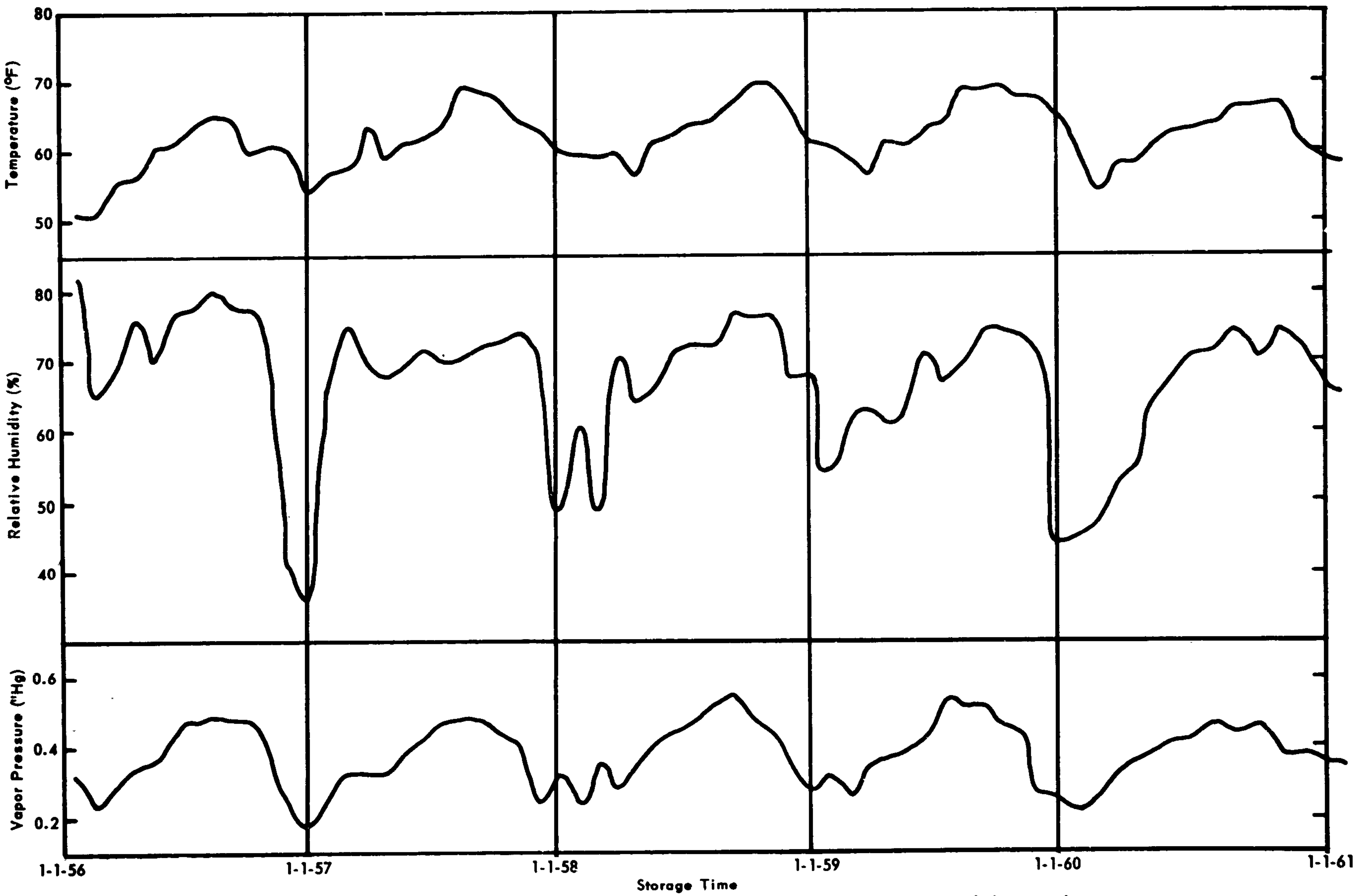

Figure 7. Average temperature, RH, and vapor pressure for open-air slab and shed from 1 February 1956 to 1 February 1961.

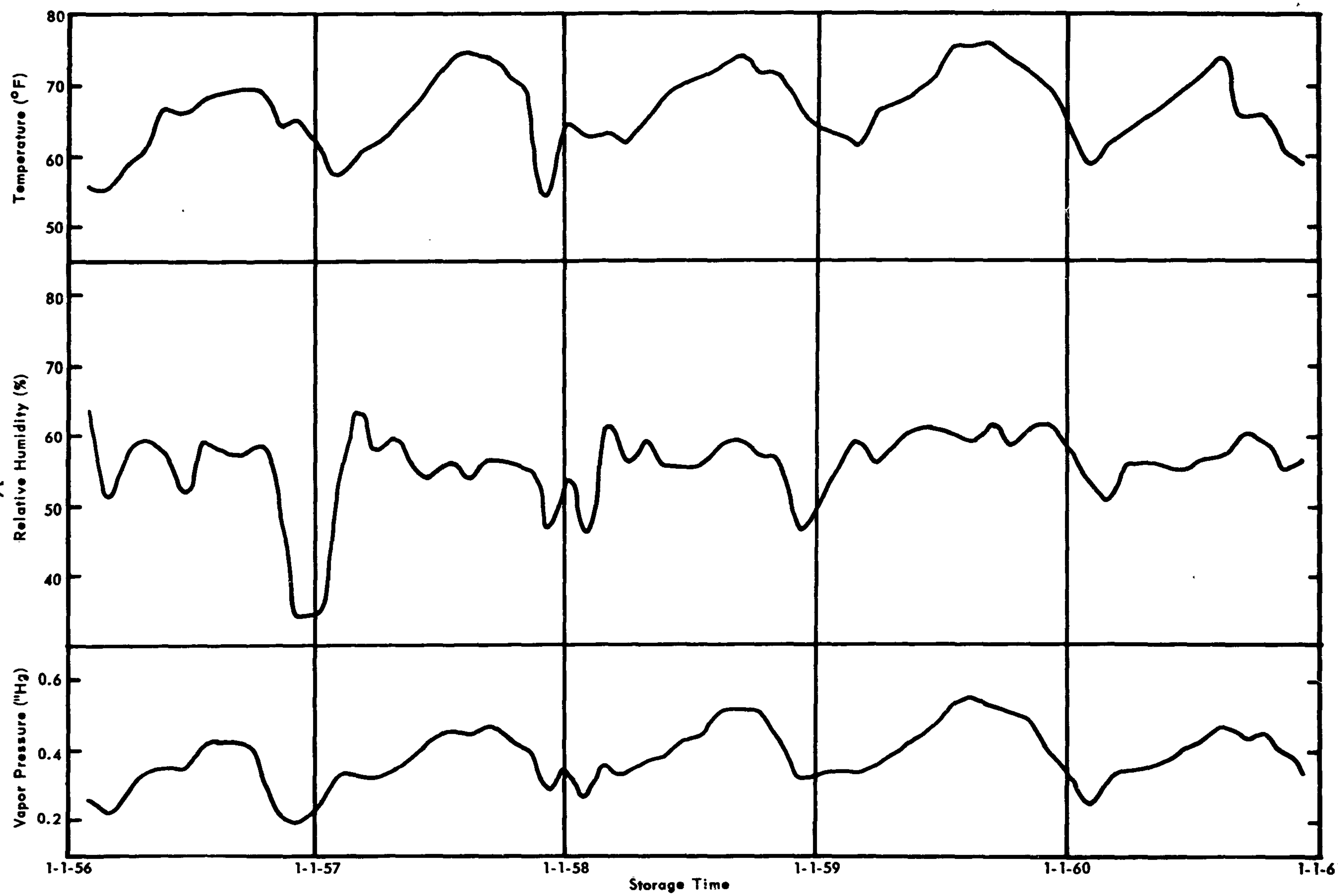

Figure 8. Average temperature, RH, and vapor pressure for standard warehouse from 1 February 1956 to 1 February 1961.

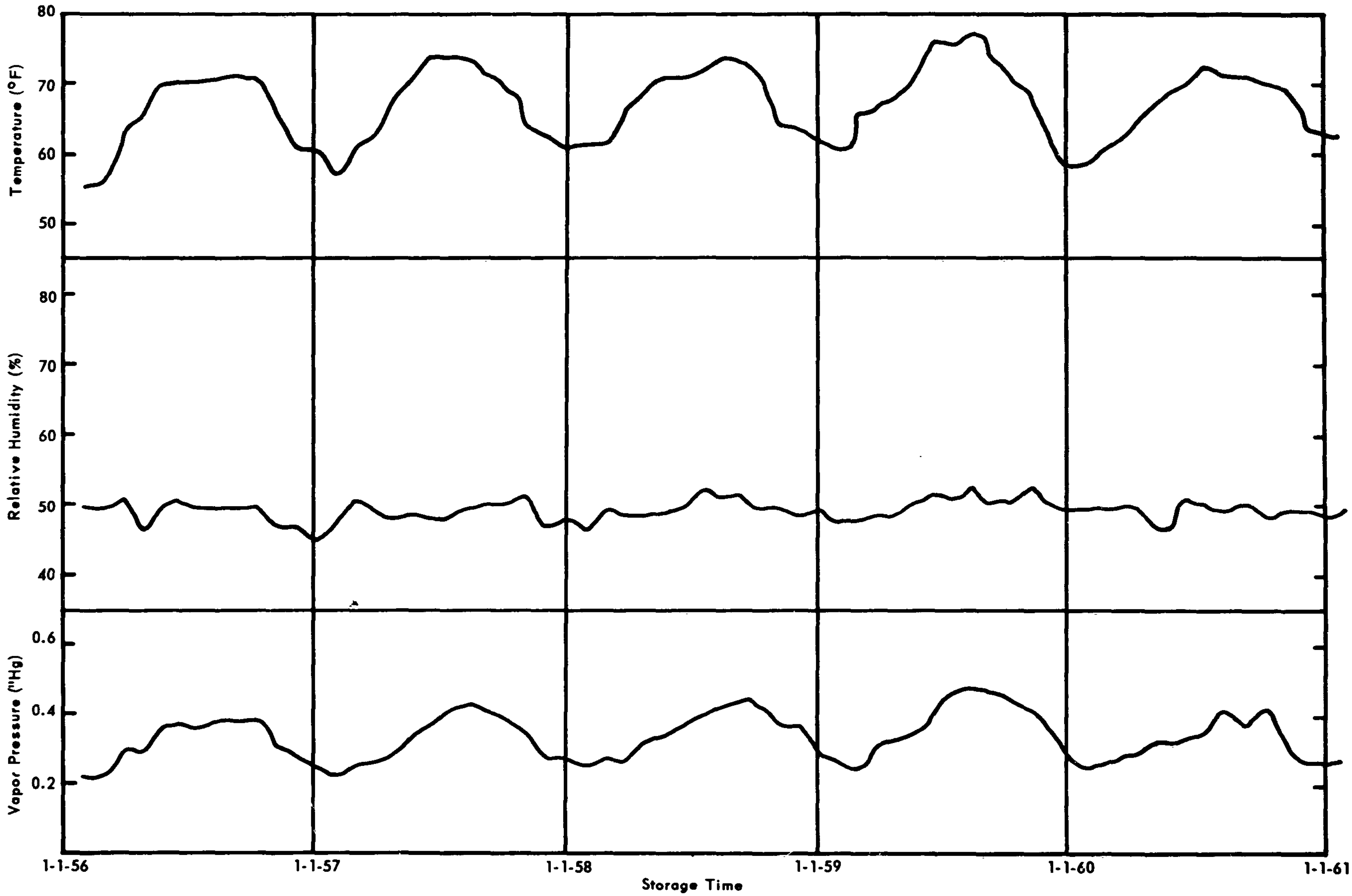

Figure 9. Average temperature, RH, and vapor pressure for 50% RH warehouse from 1 February 1956 to 1 February 1961.

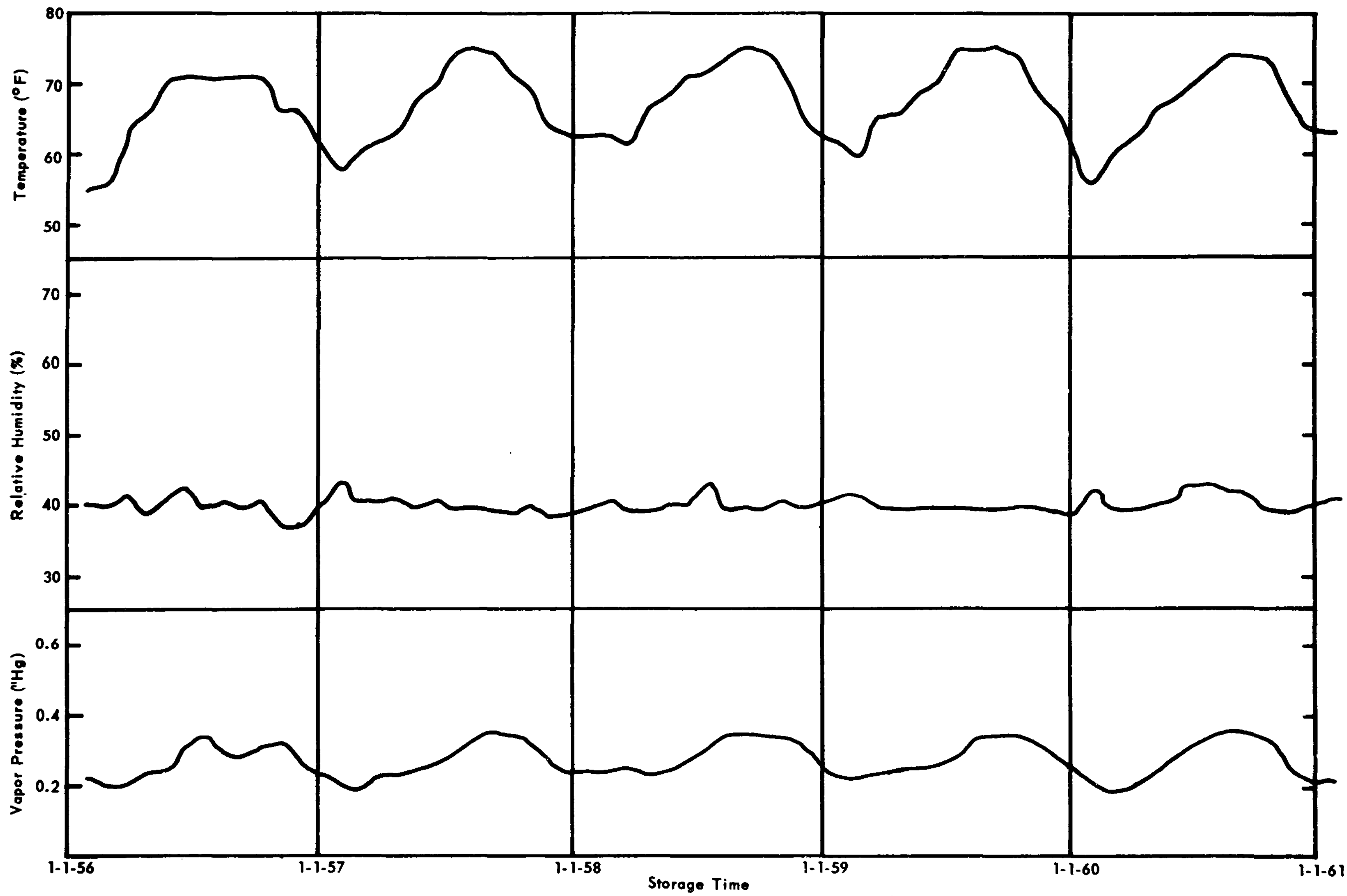

Figure 10. Average temperature, RH, and vapor pressure for 40% RH warehouse from 1 February 1956 to 1 February 1961.

The open-air and shed environments are considered to have the same air psychrometry, and they share the same curve, Figure 7. The yearly temperature is nearly sinusoidal for these environments, with an approximate 15 F amplitude. Mean lows vary from 50 to 55 F and the mean highs from 65 to 70 F. The relative-humidity curve shows conspicuous drops during the late fall and early winter months, caused by frequent hot and dry east winds. These winds are a seasonal occurrence. During this period relative humidities as low as 5% have been occasionally recorded, but the average generally falls between 30% and 40% despite periodic rains. The relative humidity during the remaining time approximates 70%. The vapor partial pressure varies directly with the dry-bulb temperature and relative humidity. The vapor partial-pressure curve is somewhat sinusoidal, with an amplitude of about 0.3 inch of mercury, and varies from 0.2 to 0.5 inch.

The yearly curves for the standard warehouse, Figure 8, are similar to those for the open air and shed, Figure 7. The temperature variation again is nearly sinusoidal with an approximate 15 F amplitude, but it is about 5 F warmer. The mean lows vary from 55 to 62 F and the mean highs from 70 to 75 F. The building itself dampened the fluctuations of the relative humidity somewhat, and the variations are less pronounced during the winter months. During the period of hot, dry east winds, records show that the relative humidity dropped to around 15%, but the averages during the winter months fluctuated between 45% and 55% except during the extreme dry period in late 1956 and early 1957. The relative humidity for the remaining time averaged slightly over 55%. The vapor partial-pressure curve, like the open-air and shed curve, is somewhat sinusoidal, varying from approximately 0.20 to 0.55 inch of mercury.

The yearly curves for the controlled-humidity warehouses are shown in Figures 9 and 10. The temperature curves for both the 50% and 40% RH environments are sinusoidal, with an approximate amplitude of 15 F. The desiccant machines add heat to the warehouse air when a newly reactivated bed is cycled into use; thus, it was slightly warmer in the dehumidified warehouses than in the standard warehouse. Also, because of longer desiccant machine operation, it was a little warmer in the 40% than in the 50% RH building. The relative humidity in each building was held for the most part to within ±3% RH of the designated level. The vapor partial-pressure curves are sinusoidal and vary mostly with the temperature since the RH in each environment was essentially constant. The vapor partial pressure in the 50% RH warehouse varied from approximately 0.20 to 0.44 inch of mercury, and in the 40% RH warehouse from approximately 0.20 to 0.35 inch of mercury.

The overall arithmetical average of the temperature, relative humidity, and vapor partial pressure for each type of storage is given in Table II.

Table II. Average Temperature, Relative Humidity, and Vapor Pressure from 1 February 1956 to 1 February 1961

Environment	Temperature (F)	Relative Humidity (%)	Vapor Pressure (in. Hg)
Open slab & shed	61.9	67.5	.383
Standard warehouse	67.1	56.1	.385
50% RH warehouse	67.2	49.4	.339
40% RH warehouse	67.6	39.9	.276

Rusting Index

Table III gives the rusting index of items in all five environments. The extent of rusting is influenced by three factors — environment, oils and preservatives, and workmanship. The indices show total rusting without identifying these factors; however, one factor may have a pronounced influence on another factor, and it is perhaps this interplay which has disrupted the decending order of the indices for the contact-preserved items.

Rust-Count Curves

An indication of comparative storage effectiveness can be obtained from the rust-count curves in Figures 11 and 12, which were plotted from Class II inspection data of the number of rusted areas encountered in each environment. The start of each curve represents the initial inspection — 3 months for open air, 6 months for shed, 12 months for the standard warehouse; the succeeding inspections determined their trends. The last Class II inspection of the open-air slab was made at 27 months and the final Class III at 30 months of storage. The final Class II and Class III inspections for the remaining environments were made at 60 months without a time lapse between them. A previous report lists all of the areas which had rusted during the first 30 months of test and another more recent one lists those for the entire 60 months.*

* Technical Note N-365, Rusted Components of Materiel in Storage, by J. C. King, 18 October 1960.
Ibid, N-464, 5 September 1962.

Table III. Rusting Index

Description of Equipment	Open Air[a]		Shed[b]		Standard[b]		50% RH[b]		40% RH and[b] Open Air	
	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.
Boiler, vertical	14.7[c]	0	3.9	0.1	0	0	0	0	4.5	0
Compressor set	9.7	3.8	5.6	1.3	2.1	0.1	0.4	0	0	0.2
Distillation unit	9.0	4.2	2.7	3.2	0.4	0.6	0.1	0.3	1.4	0.8
Generator set	6.8[d]	5.0	3.3	3.2	0	1.5	0.1	2.6	1.6	2.6
Heater, oil-fired	16.0	1.5	4.9	0.2	1.8	0	0	0	5.8	0.8
Oven, bake	10.0[c]	0	3.0	0.4	2.0	0	0.1	0	4.2	0
Pump, centrifugal	10.0[c]	0	5.0	1.2	0	0	1.8	0	0	0
Pump, diaphragm	8.7	1.5	3.9	7.4	4.8	5.4	6.0	7.3	2.3	1.5
Refrigeration unit	10.0	1.5	0.8	0	0	0	0	0	3.8	0
Refrigeration panel	8.0	2.0	3.6	0	0	0	0	0	0	0
Searchlight w/pp	20.3	3.3	5.2	6.2	0.1	0	2.1	3.0	8.4	5.7
Tank, canvas	2.0	0	0	0	0	0	0	0	0	0
Trailer, floodlight	16.6	5.4	4.6	1.1	3.6	0	0	0	0.4	0
Transfer unit, CO_2	0.3	0	1.5	0.2	0	0	0	0	0.4	0
Truck, dump	13.5	6.5	13.4	5.9	6.6	0.8	7.1	3.3	6.3	8.7
Truck, jeep	22.8	2.0	20.6	16.3	5.8	2.5	4.9	4.0	11.2	4.8
Washing machine	13.8	0.3	0.6	2.3	0	0	0	0	0	0
Welder, arc	2.5[e]	2.0	12.0	0.5	4.2	1.0	1.1	0	0	1.0
Totals	194.7	39.0	94.6	49.5	31.5	11.9	23.7	20.5	50.3	26.1
Drill press Fan, exhaust Lathe Public-address system Saw, radial Slicer, meat Switchboard Telephone system Transit, surveyor's	These items were not stored in the open air or shed.				No rust was found on these items. Those in the 40% RH environment were not moved outside.					

a/ Items removed from storage after 30 months unless otherwise noted.
b/ Items removed from storage after 60 months.
c/ Item removed from storage after 12 months to prevent permanent damage.
d/ Item removed from storage after 24 months to prevent permanent damage.
e/ Item removed from storage after 12 months for shipment.

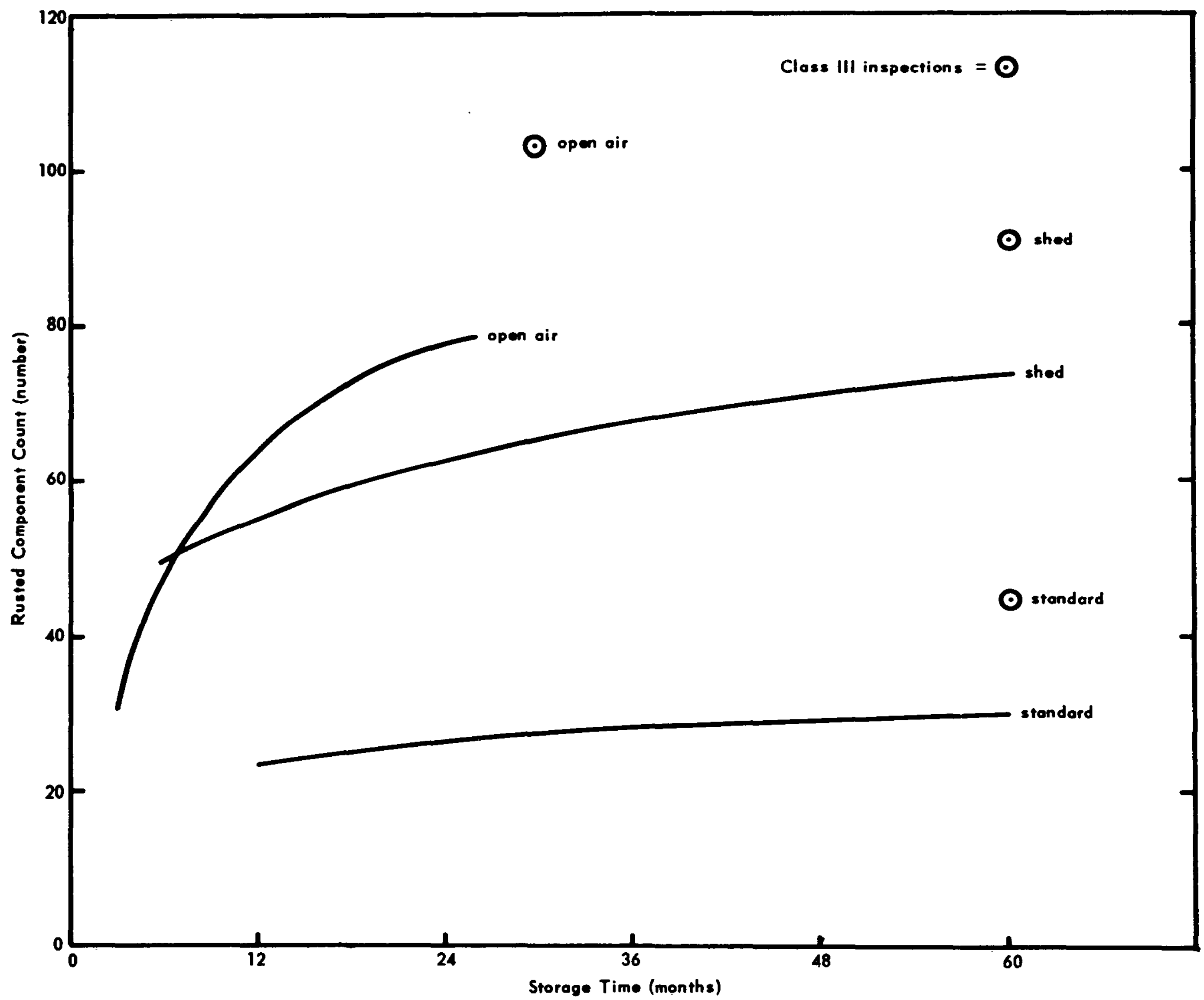

Figure 11. Rust-count curves for domestic-treated items from Class II inspections.

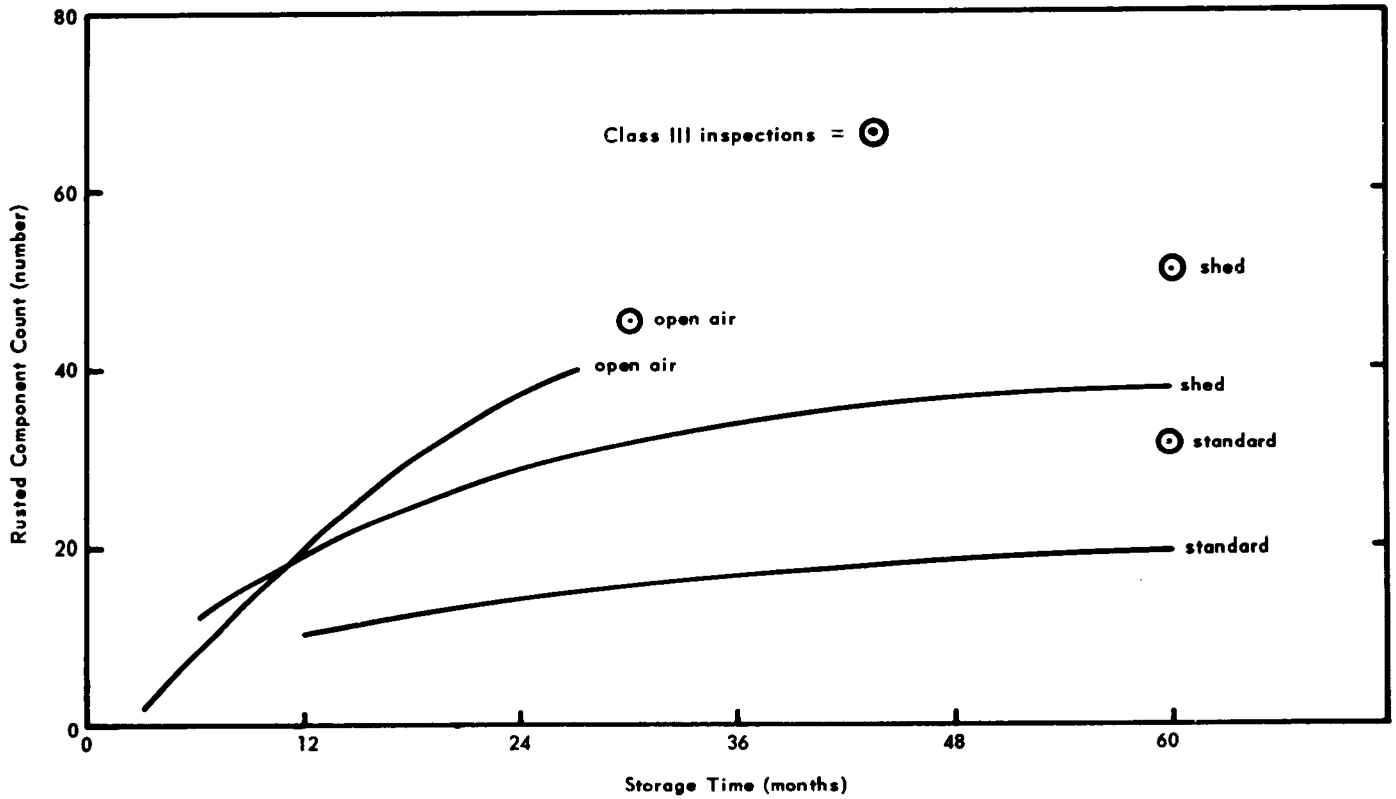

Figure 12. Rust-count curves for contact-preserved items from Class II inspections.

It was expected that many rusted components would be overlooked by Class II inspections. This was borne out by the final Class III inspections. The curves of Figure 11 show that for domestic-treated equipment the Class II inspections missed 23 components after 2-1/2 years of outside storage, and missed 17 in the shed and 15 in the standard warehouse after 5 years of storage. The curves of Figure 12 show that for contact-preserved equipment the Class II inspections missed but 5 rusted components for the 2-1/2 years of outside storage and jumped to 13 for the shed and 12 for the standard warehouse following 5 years of storage.

Final Inspection

This section describes in general the condition of the items of each environment at final inspection. As the final inspection progressed, it became evident that the same components were rusting regardless of environment and with little regard for preservation methods. It was found too that the deterioration was somewhat similar in each environment. Five major components were predominantly involved in this situation: internal-combustion engines, gear boxes, fuel-injector sets, hydraulic brake systems, and cooling systems. The condition of these components in the open-air storage (30 months), however, was less severe than in the remaining environments which were subjected to the causes of deterioration for the full 5 years.

The nature of the deterioration of the internal-combustion engines consisted almost entirely of top cylinder rust, including cylinder walls, valves, and head surfaces. This rust usually occurred when the valves were in a closed or nearly closed position; very little rust was found in cylinders where the valves were open enough to permit air to circulate through the cylinders, except in a few instances where heavy rust was found due to water seeping into cylinders through a leaking head gasket.

Nearly all of the gears in gear boxes, including transmissions, differentials, power take-off units, and transfer cases of the 2-1/2-ton dump truck and the 1/4-ton jeep, were heavily stained by the MIL-L-2105 gear lubricant. The sole exception was the contact-preserved 2-1/2-ton dump truck located in the standard warehouse, whose gears were in excellent condition. In this instance a light oil preservative (P9 or 10) had been fogged into the transfer case, and the transmission, differential, and power take-off unit had been protected with a nonspecification lubricant which was later identified by infrared spectrophotometry as Whitmore gear oil.

The 30-kw diesel generator was the only item with fuel injectors. These injectors, irrespective of preservation level, all had corrosion on such parts as the plunger, sleeve, and spring. It appeared as if these parts had been etched by a weak acid.

In the hydraulic brake systems, rust was predominant in the wheel cylinders and the master cylinder. It is likely that the brake fluid had been contaminated by water since the fluid was hygroscopic.

A high incidence of rust had occurred in the water pumps of engine cooling systems. This rust was the result of water which had pocketed when the system was drained. For reasons unknown, the cooling system of the 2-1/2-ton domestic-treated dump truck in the standard warehouse was incompletely drained and the coolant, it was discovered, was a mixture of water and a water-soluble oil. In this instance the water pump, as well as the entire system, was in excellent condition.

The remaining rust and deterioration encountered at the final inspection appeared to occur randomly and to be caused by environments. In the open-air storage, items which were uncrated or in open crates had extensive exterior rust on places such as control panels, switches, pulleys, flywheels, exposed shaft ends, and universal joints. Boxed items had better protection and had much less exterior rust. For example, the sheet-metal hood over the crated domestic-treated floodlight trailer engine was irreparably damaged, whereas the similar contact-preserved mate, which was boxed, was in good condition. Interior surfaces such as those of the domestic-treated boiler, heater, bake oven, and diesel generator had considerable rust, but the contact-preserved items were in reasonably good condition, especially those that were boxed. The domestic-treated items demonstrated how quickly rust grows after it once has a start.

In the shed storage, the exterior condition of uncrated or open-crated items was poorer than those that were boxed; much like those in the open air, except the rust was less severe. Also, items stored on the open side were generally in poorer condition than those along the wall, where they were more shielded from the weather.

In the standard warehouse storage, some rust occurred which was attributable to environment. This rust, however, was limited to small areas of light rust or stain, with a few exceptions such as the combustion chamber and shell of the domestic-treated oil-fired heater and the interior of compression tanks of the domestic-treated and contact-preserved compressor sets, where rust was more extensive. The general exterior condition of all items was very good with little or no change (except dusty surfaces) being apparent.

In the dehumidified storage, there was no rusting of items in either the 50% or 40% RH warehouse attributable to the environments. Some rust occurred while the items were temporarily stored in a shed (four or more weeks) waiting for the warehouses to be erected prior to initial start of tests; subsequent storage in the dehumidified atmosphere arrested this rusting. With the exception of the rusting due to the temporary storage, preservatives, and the five components mentioned on page 24, all items were in excellent condition, with no apparent difference in the condition of 50% and 40% RH stored items. No detrimental effects of dehumidified environment were detected on seals, rubber, wire harnesses, gaskets, and the like, and the general exterior condition of all items was excellent. Based on these findings, the Navy's standard 40-foot by 100-foot metal warehouse is considered suitable for advanced-base dehumidified storage, with certain modifications as discussed in Appendix B.

The items that were removed from the 40% RH warehouse after 48 months and stored in open air for the following 12 months had the usual rust on the five aforementioned major components plus a considerable amount of other rust caused by the outside environment. The pattern of rusting during the final 12 months followed quite closely that of the domestic-treated items that were originally stored in the open air for the same period of time. The general exterior condition of the items deteriorated rapidly during the 12 months of outside storage.

The final inspection also revealed that an inordinate number of ball bearings, whether sealed, semisealed, or open, were rough or frozen because of hardened grease, and for this reason many were discarded. This again was the situation regardless of storage environment. Further, many of the ball bearings in spare-part kits (sealed and semisealed) were frozen to the extent they could not be turned by hand. Some of the motors could be started with assistance, by hand-turning the pulley or belt, while others would not start until new bearings were installed. These motors that had been hand-started were not operated long enough to determine whether or not hardened grease adversely affected bearing life. However, of particular importance is that the Laboratory found that nearly all of the rough and frozen bearings could be made serviceable by cleaning and relubricating.

The effects that have been brought out in this section are those directly concerned with operation of the equipment. The effects of rain, dust, sunlight, and general weathering as they affect the serviceability and life of the equipment were not determined.

Rehabilitation Costs

Table IV lists the rehabilitation costs that were estimated by CBC Construction Equipment Department from the Laboratory's records of the Class III inspections. As with the rusting index, these costs are given without regard to the cause of rusting and they include the price of gaskets, seals, and other components that would normally be replaced before the item is considered issuable. They also include replacement of rough-turning and frozen bearings.

Table IV. Rehabilitation Costs (Dollars) Based Upon Class III Inspections and 1962 Labor and Parts Costs

Description of Equipment	Open Air[a]		Shed[b]		Standard[b]		50% RH[b]		40% RH and Open Air[b]	
	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.
Boiler, vertical	40[c]	0	9	3	0	0	0	0	12	3
Compressor set	35	31	74	51	27	27	46	0	16	10
Distillation unit	35	29	145	86	72	66	60	118	134	119
Generator set	185[d]	69	56	44	3	42	0	113	99	320
Heater, oil-fired	15	7	0	0	6	0	0	0	18	6
Oven, bake	24[c]	0	39	9	36	0	6	0	36	0
Pump, centrifugal	93[c]	0	157	23	0	0	0	0	88	0
Pump, diaphragm	10	3	59	44	33	33	31	40	21	15
Refrigeration unit	26	7	16	36	15	0	0	0	42	0
Refrigeration panel	45	11	0	0	0	0	0	0	0	0
Searchlight w/pp	151	29	153	95	122	71	104	127	184	129
Tank, canvas	0	0	0	0	0	0	0	0	0	0
Trailer, floodlight	77	72	110	15	98	24	0	18	30	30
Transfer unit, CO_2	6	0	6	6	6	0	0	0	7	0
Truck, dump	204	70	425	350	220	54	450	179	190	220
Truck, jeep	72	4	150	255	155	155	194	104	340	220
Washing machine	17	4	8	8	0	0	0	0	15	6
Welder, arc	51[e]	34	226	22	147	14	118	42	131	34
Drill press	These items were not stored in the open air or shed.				0	6	48	27	28	32
Fan, exhaust					0	0	0	0	0	0
Lathe					14	11	0	0	15	15
Public-address system					0	0	0	0	0	0
Saw, radial					3	3	48	33	36	24
Slicer, meat					6	6	3	3	3	3
Switchboard					0	0	0	0	0	0
Telephone system					0	0	0	0	0	0
Transit, surveyor's					0	0	0	0	0	0

a/ Items removed from storage after 30 months unless otherwise noted.
b/ Items removed from storage after 60 months.
c/ Items removed from storage after 12 months to prevent permanent damage.
d/ Item removed from storage after 24 months to prevent permanent damage.
e/ Item removed from storage after 12 months for shipment.

Table V. Five Major Components Contributing to Rehabilitation Costs and Affected by Factors Other Than Environment

Component and Number of Affectable Pairs in Each Environment	Number of Affected Components									
	Open Air[a]		Shed[b]		Standard[b]		50% RH[b]		40% RH[c]	
	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.	Dom.	Cont.
Internal-combustion engines, 9 pairs	3	0	4	0	3	2	2	2	3	2
Gear boxes, 11 pairs[d]	5	0	9	8	9	3	11	8	10	11
Fuel-injector sets, 1 pair	1	0	1	1	0	1	0	1	1	1
Hydraulic brake systems, 2 pairs	1	0	2	1	2	1	2	1	2	2
Cooling systems, 7 pairs	6	2	6	4	2	1	3	2	7	2

a/ Items in storage for 30 months.
b/ Items in storage for 60 months.
c/ Items in 40% RH storage for 48 months and open-air storage for 12 months.
d/ Includes transmissions, differentials, power take-off units, and transfer cases.

A relationship between rusting index and rehabilitation costs cannot be made. For example, no rust was found on the last nine items listed in Tables III and IV, yet there are rehabilitation costs for many of these items. These costs are for replacement of bearings because of hardened grease, which cannot be related to the rusting index.

There are situations when an item can have a high rehabilitation cost and low rusting index when it is necessary to remove and disassemble a major component to remove a small amount of rust in a highly critical location. The distillation units, both domestic and contact, in the standard and controlled-humidity warehouses are examples of this situation. There are also times when an item can have a low rehabilitation cost and a high rusting index when a relatively inexpensive and easily accessible part has heavy rust. This condition is exemplified by the domestic-treated and contact-preserved diaphragm pumps in all environments.

A large portion of the rehabilitation costs is contributed by the five major components mentioned on page 24. See Table V. Since the rehabilitation costs are largely influenced by these components, the costs are not used to evaluate the efficacy of the storage environments. They are useful, however, in showing that deterioration can be caused by such factors as preservative materials and methods, and not by the storage environment. This is enlarged upon in the following section.

Preservatives and Lubricants

The test has shown that, in general, the less protection a storage environment offers, the quicker the preservative materials will weaken. For instance, the preservative materials on equipment stored in the open air either cracked, pealed, drained, or otherwise weakened to the extent that represervation was necessary after 30 months of storage. But in the remaining environments, preservative weakening was not nearly as severe; in fact, in the dehumidified units, the preservatives appeared to still be in excellent condition after 60 months, though there was some drainage from vertical surfaces.

The test has also shown that a few of the preservative materials become corrosive with time. Illustrating this is the 2105 gear lubricant which caused staining (Class I deterioration) and the hydraulic brake fluid which absorbed water. The 2105 stain was so severe that it failed to rub off during the operational tests of the 40% RH equipment stored outside for the final year.

A most important determination resulted from this test. It was found that nearly all of the deterioration was caused by preservation methods or materials and could have been reduced to an insignificant amount in the dehumidified units had the equipment been stored bare; that is, without any protective or servicing materials whatsoever. For example, various cover plates, which had been removed to permit warehouse air to circulate into cavities, remained bright and lustrous throughout the entire 5 years without protective treatment. If it is necessary to store items fully serviced (operating oils, lubricants, etc.) or with preservatives for quick overseas shipment, then it is desirable to use materials that will not deteriorate the equipment.

Dehumidified Storage Effects

There were no apparent adverse effects of dehumidified storage on equipment which had been removed from the 40% RH warehouse and stored outside for the final year of testing. Before the domestic-treated equipment was operated, it was first necessary to tighten all waterhose clamps because the hoses had taken a set over the 5-year period. Most of the equipment started and operated without undue difficulty and there was no evidence of faulty operation because of storage effects on seals, gaskets, and wiring harnesses. The electric motors, however, would not operate because of hardened grease in the bearings. Some bearings could be freed by hand-turning the rotor, but most were either replaced or cleaned and relubricated before satisfactory operation was obtained. Appendix C gives specific information concerning all equipment operationally tested.

Desiccant Machine Operation and Power Consumption

The comparative operating times and consumptions of power for the desiccant machines in the two dehumidified warehouses are given in Table VI, based on data obtained after the initial RH drawdown was complete and the machines were cycling regularly. The machine in the 50% RH warehouse operated half as much as the machine in the 40% warehouse. The 40% machine used almost two-thirds more power per pound of water removed to obtain a 10% RH reduction because it operates less efficiently in dryer atmospheres.

Table VI. Desiccant Machine Operation and Power Consumption*

Warehouse RH Level	Operating Hours per Year	Kw-Hr per Year	Kw-Hr per Lb of Water Removed
50%	527	1358	1.28
40%	1045	2607	2.00

*Based on weekly averages from 4 October 1956 to 1 December 1960.

Related Tasks

Other Laboratory tasks similar to or related to this task have been reported. Task Y-R007-08-406 was concerned primarily with the effects of open-air storage on certain nonspecification preservatives. Results have been published in Technical Report R-223, "Investigation of Nonspecification Preservatives," dated 10 September 1962. The Whitmore lubricant mentioned earlier is one of the materials that was tested. Another task, Y-R007-08-906, evaluated the ability of a Teflon film to protect the internal working surfaces of a military jeep from corrosion. Results have been published in Technical Report R-095, "Teflon as a Metal Preservative," dated 26 October 1960. A third task, Y-F015-04-005, studied the problem of desiccant dusting from dehumidification machine operation. The results are published in Technical Report R-138, "Investigation of Desiccant Dusting," dated 3 April 1961.

Part 2. ECONOMY OF STORAGE

INTRODUCTION

The preceding sections of this report described various storage environments and compared their ability to protect materiel from rust. Indications of their efficacy were shown by Corrosometer readings, rusting indices, rust-count curves, and rehabilitation costs. These data, while informative and useful, reveal only the part of the storage picture concerning effectiveness. The part that is missing is storage economy, the dollars and cents of storage. The preface to this report indicates that standby storage of war materiel costs the taxpayer about 3/4 billion dollars each year. This cost could be reduced.

Total storage cost is the sum of many individual costs — rehabilitation cost, building cost, maintenance cost, preservative-material and application cost, equipment-inspection cost, and others. Total cost also varies with combinations of storage environments, preservation levels, and time. These factors control storage costs. For example, there is no construction cost if equipment is stored on the ground outdoors, but a sizable construction cost if equipment is stored within a controlled-humidity warehouse. Yet equipment stored outdoors must be thoroughly preserved and frequently inspected, whereas equipment stored indoors requires less preservation and less frequent inspections. Influencing each, however, is time. An item to be stored for only a few days may be kept outdoors with a minimum of preservation, but if it is to be stored for a few years, other storage environments and preservation levels are required. This problem can be resolved by determining which combination of storage environment and preservation level, commensurate with time, costs least.

The NCEL test provided a good opportunity to study storage costs. All the factors necessary for a cost analysis were present or could be obtained from CBC warehousemen and preservative specialists. While costs based on the NCEL tests might not necessarily reflect actual conditions, they could be sufficiently illustrative to provide a useful guide for predicting actual field storage costs.

A lot size of 25 units of each item in the test was chosen, for this size was most representative of CBC stores at the time the data were being accumulated. Any lot size, however, could have been used. For the purpose of uniformity, the procedures specified in the "Quality Control Procedures for Surveillance and Inspection," NavDocks TP-QC-1, were applied to all stored materiel.

EQUATION FOR STORAGE COSTS

All the individual costs attributed to storage were formulated into a cost equation in which the sum of these individual costs are equated to the total cost. By comparing results, it is possible to determine the most economical storage method for any particular item. For expediency, the formula was programmed on the IBM 1620 data-processing computer at NCEL, and all storage-cost calculations were done by this computer. The formula, which is linear and contains 19 factors, is as follows:

$$W = B_{ij} + N_{ij} + S_{ij}P_{jt} + C_iT(D_i + E_i) + R_{ijt}$$
$$+ L(A_{ij} + H_{ij} + M_{ijt} + KF_{ij}U_{ij} + YV_{ij}G_{ij})$$

A brief explanation of each factor in alphabetical order is as follows, and a thorough explanation and the source of machine data is in Appendix D. In all cases, it is assumed that the equipment to be stored is new and not yet deteriorated.

A = The labor hours to initially prepare for storage

B = Material cost to initially prepare for storage

C = Square footage required for storage

D = Unit fixed cost of storage per square foot per month

E = Storage maintenance cost per square foot per month

F = Labor hours for item inspection

G = Labor hours for operational testing only

H = Labor hours for depreservation

i = Subscript that denotes "With respect to type of storage environment"

j = Subscript that denotes "With respect to particular item stored"

K = Ratio of sample size to lot size

L = Hourly labor charge

M = Man-hours for rehabilitation

N = Material cost for crating, dunnage, boxing, etc.

P = Original cost of item less depreciation

R = Parts cost for rehabilitation

S = One (1) if item is found to be unrepairable, zero (0) otherwise

t = Subscript that denotes "With respect to storage time"

T = Storage time in months

U = Number of Class II inspections

V = Number of operational tests

W = Total storage cost

Y = Ratio of operationally tested items to lot size

RESULTS OF STORAGE COST STUDY

All the costs which follow are based on a storage period of 60 months except for open-air items, which are based on 30 months. The equipment has been segregated into categories of similar design or function, and storage cost versus time curves are drawn for each category. There are six equipment groups:

Group I. Fluid-Handling Equipment

1. Centrifugal pump, 350-gpm
2. Compressor set, 30-cfm
3. Diaphragm pump, 50-gpm
4. Distillation unit, 83-gph
5. Refrigeration unit
6. Transfer unit for CO_2
7. Washing machine

Group II. Motor-Generator Equipment

1. Arc welder, 300-amp
2. Floodlight trailer
3. Generator set, 30-kw diesel
4. Searchlight unit with power plant

Group III. Automotive Equipment

1. Dump truck, 2-1/2-ton 6 x 6
2. Jeep, 1/4-ton 4 x 4

Group IV. Heating Equipment

1. Bake oven
2. Oil-fired space heater, 50,000-Btu
3. Vertical boiler, 180,000-Btu

Group V. Nonmetallic Equipment

1. Canvas tank, 3000-gallon
2. Refrigeration panels

Group VI. Tools, Instruments, and Communications Equipment

1. Drill press, 18-inch
2. Exhaust fan, 4900-cfm
3. Lathe, floor model
4. Meat slicer
5. Public-address system
6. Radial saw, 16-inch
7. Surveyor's transit
8. Switchboard, 50-line
9. Telephone system, 13-unit

The equipment of Group VI appears to be somewhat miscellaneous but has been classed together because the items are always stored in either a standard or dehumidified warehouse — never outside or in a shed. The items in the other groups, on the other hand, can be stored in any environment. Tires (8.25 x 30) are missing from Group V and chemical-warfare detector kits from Group VI because rusting does not affect them. Unmounted tires appeared to be in excellent condition, but no comparative in-service test with new tires was made. The chemical-warfare kits consisted of vials of certain liquid chemicals. The chemicals appeared to be in excellent condition.

The curves showing storage costs of the various groups of categories of equipment are given in Appendix E. The cost-time curves of individual items follow their parent group curves as figure-letter subscripts. The group curves graphically show the cost-time relationship of the sum of all items within the group. The individual cost-time curves are a summation of preservation and storage costs including the depreservation cost of contact-preserved items. It is stressed that the curves represent storage-period costs only and do not include subsequent post-storage costs such as preserving domestic-treated equipment for overseas shipment.

Factors affecting storage costs that are common to each environment have been disregarded in this storage-cost analysis. Deterioration of rubber goods is one such factor (e.g., sidewalls and treads of mounted tires — all of which cracked and checked about equally irrespective of the storage environment). The CBC policy is to replace tires on activation of any rolling equipment which has been stored for more than 5 years. Deterioration of stored batteries is another common factor, but this has been largely eliminated by specifying the dry-charge type. These batteries have a maximum shelf life of 10 years if stored in the dry state, according to NavDocks instructions P-400, dated May 1962. The dollar-depreciation of the stored materiel has also been disregarded, for it was presumed that each like item was affected equally regardless of its storage environment. Depreciation due to obsolescence becomes a storage cost factor in areas of fast-moving technology such as ordnance, electronics, and aircraft. Technological advances or radical design changes in construction and other allied equipment required by the naval shore installations may occasionally render some BuDocks stores obsolete; but such instances currently are so few that obsolescence was not included in this study.

Table VII and succeeding tables show an ascending order of storage costs at each preservative treatment for each storage environment for 60 months of storage. The respective storage costs for the open-air stored items for 30 months are included at the end of each table.

In Appendix E the curves of Group I, Figure E-1, show that for 60 months, storing domestic-treated equipment in a 50% RH dehumidified warehouse is least expensive. The costliest method is contact-preserved equipment stored in a shed.

Group II curves, Figure E-2, show that the least expensive storage for a period of 60 months is domestic-treated equipment in a 50% RH warehouse, while the most expensive is domestic-treated equipment stored in a shed. Table VIII shows the storage costs for this group.

Table VII. 60-Month Storage Cost for Group I Equipment

Environment	Treatment	Cost ($)
50% RH warehouse	Domestic	622
40% RH warehouse	Domestic	630
Standard warehouse	Domestic	686
Standard warehouse	Contact	1018
50% RH warehouse	Contact	1026
40% RH warehouse	Domestic	1031
Shed	Domestic	1206
Shed	Contact	1351
Open air (30 months)	Domestic	860
Open air (30 months)	Contact	960

Table VIII. 60-Month Storage Cost for Group II Equipment

Environment	Treatment	Cost ($)
50% RH warehouse	Domestic	565
40% RH warehouse	Domestic	672
Standard warehouse	Domestic	874
Standard warehouse	Contact	1094
50% RH warehouse	Contact	1110
40% RH warehouse	Contact	1118
Shed	Contact	1193
Shed	Domestic	1394
Open air (30 months)	Domestic	1028
Open air (30 months)	Contact	1170

Group III curves in Figure E-3 show domestic treatment in a standard warehouse to be the most economical and contact preservation in a shed to be the least economical storage method for a period of 60 months. Table IX shows the storage costs for this group.

Table IX. 60-Month Storage Cost for Group III Equipment

Environment	Treatment	Cost ($)
Standard warehouse	Domestic	1242
Standard warehouse	Contact	1344
Shed	Domestic	1410
50% RH warehouse	Contact	1585
40% RH warehouse	Contact	1619
50% RH warehouse	Domestic	1674
40% RH warehouse	Domestic	1708
Shed	Contact	1732
Open air (30 months)	Domestic	595
Open air (30 months)	Contact	713

Group IV curves in Figure E-4 show that domestic treatment and storage in either a 40% or 50% RH dehumidified warehouse is the most economical and contact preservation in a shed is least economical for 60 months. Table X lists the storage costs for this group.

Group V curves in Figure E-5 show that domestic treatment and storage in a shed is most economical while contact preservation in a 40% RH dehumidified warehouse is least economical for 60 months. Table XI lists the storage costs for this group.

Group VI curves in Figure E-6 show that domestic treatment in standard warehouse storage is the most economical and contact-preservation in a 40% RH warehouse is least economical. This equipment was stored only in standard or dehumidified warehouses. Storage costs for this group are listed in Table XII.

Table X. 60-Month Storage Cost for Group IV Equipment

Environment	Treatment	Cost ($)
50% RH warehouse	Domestic	137
40% RH warehouse	Domestic	138
Standard warehouse	Domestic	152
Shed	Domestic	221
50% RH warehouse	Contact	227
40% RH warehouse	Contact	227
Standard warehouse	Contact	230
Shed	Contact	257
Open air (30 months)	Domestic	231
Open air (30 months)	Contact	244

Table XI. 60-Month Storage Cost for Group V Equipment

Environment	Treatment	Cost ($)
Shed	Domestic	107
Standard warehouse	Domestic	110
50% RH warehouse	Domestic	120
40% RH warehouse	Domestic	122
Shed	Contact	183
Standard warehouse	Contact	188
50% RH warehouse	Contact	199
40% RH warehouse	Contact	201
Open air (30 months)	Domestic	123
Open air (30 months)	Contact	164

Table XII. 60-Month Storage Cost for Group VI Equipment

Environment	Treatment	Cost ($)
Standard warehouse	Domestic	359
50% RH warehouse	Domestic	420
40% RH warehouse	Domestic	422
Standard warehouse	Contact	666
50% RH warehouse	Contact	671
40% RH warehouse	Contact	674

SENSITIVITY TESTS

Sensitivity tests were carried out in order to find the extent to which the overall cost of storage is affected by the possible variability in the individual factors of the equation for storage costs.

In examining any one factor, three levels of that factor were considered. These were: a high value, the expected value, and a low value. Once the level of that cost factor was fixed, the level of each of the other factors was selected at random from their possible range. The resulting storage cost was then computed using the IBM 1620.

This procedure of holding fixed the level of one factor and then selecting the levels of the other variable factors at random was repeated 100 times for each item. All of the resulting storage costs were averaged together. This average represented the storage cost per item for the fixed level of the factor under consideration.

Since the above procedure was applied at each of three fixed levels for each factor, there resulted the associated three storage costs for that factor. That is:

(1) The storage cost associated with the high level of that factor

(2) The storage cost associated with the expected level of that factor

(3) The storage cost associated with the low level of that factor

The difference between (1) and (2) represents the sensitivity of the storage costs to a higher level of that factor. Similarly, the difference in cost between (2) and (3) represents the sensitivity to the lower level of that factor.

These sensitivities computed in the above manner are an indication of the extent to which the cost function is dependent upon the variability of that factor, in a manner which is independent of the variability of all of the other factors.

The variable factors that were examined were labor cost, lot size, warehouse cost, rehabilitation cost, and dehumidification machine operation time. The sensitivity of the items to these factors are shown on Charts 1 through 5. Shown also on the charts are the range of values used for the variable cost factors. Since the number of items of each group was divided into the cost variation from the mean of that group and since there is a dissimilarity of items in the group, the averages thus obtained are said to be heterogeneous.

Chart 1, which gives the sensitivity to high and low labor costs, shows that Group II and Group III items are the most sensitive, with Group I items somewhat less. Groups IV, V, and VI show only minor sensitivity. This trend is to be expected because the items in Groups II and III are large and complex, requiring a relatively large amount of labor for storage preparation, inspections, rehabilitation, etc. Group I items require less labor and Groups IV, V, and VI require the least.

Chart 2 gives the sensitivity to higher and lower rehabilitation costs. Here again, the larger and more complex items of Groups II and III show the most sensitivity. The Group III sensitivities in many situations are relatively high; however, examination of Table IV shows high rehabilitation costs in these situations.

Chart 3 gives the sensitivity to high and low warehousing costs. The Group III items show very high sensitivity because the items are large and also they are not tiered as are most of the other items, resulting in a large amount of floor space per item.

Chart 4 shows the sensitivity to large and small lot sizes. Using a small lot size shows high sensitivity (with resulting higher cost) for most items, whereas the larger lot size shows relatively low sensitivity (with only small decreases in cost) of most items. The small lot requires an inspection of four of the eight items, whereas the larger lot requires nine of the 180 items to be inspected; thus the prorated inspection cost per item of the small lot is considerably higher than the large lot. The expected lot size of 40 requires five items to be inspected. This resulted in sample ratios of 0.5, 0.125, and 0.05 for the small, expected, and large lot sizes, respectively. The operational tests are also proportional to the lot size in a similar manner and help influence the sensitivities.

Chart 5 shows the sensitivity of dehumidified warehouse stored items to dehumidifying machine operating time. The dehumidifying machine operation cost is prorated over all items on a square-foot-of-floor-space basis; therefore the large items of Group III show the highest sensitivity.

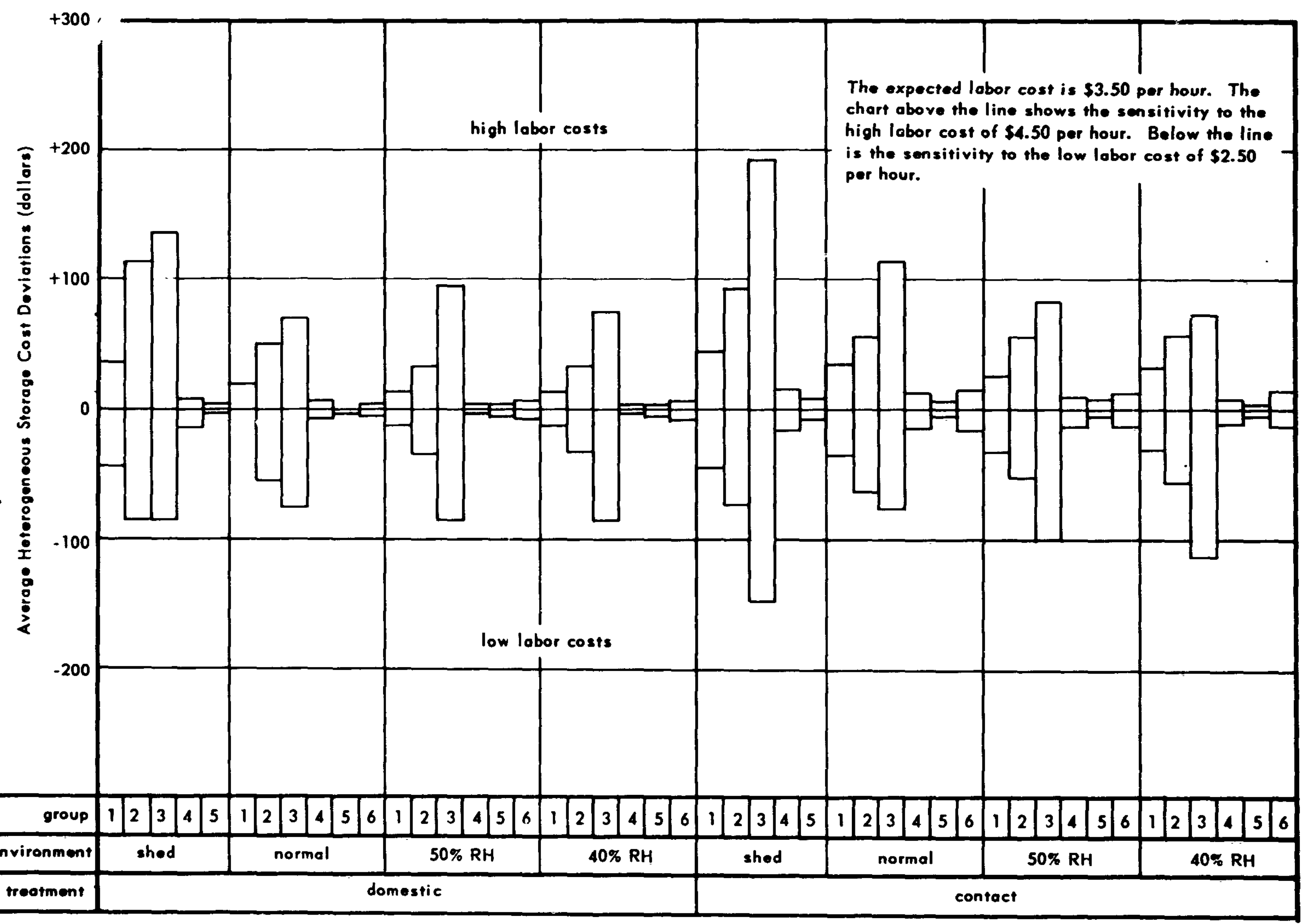

Chart 1. Sensitivity of stored items to high and low labor costs expressed as a heterogeneous average.

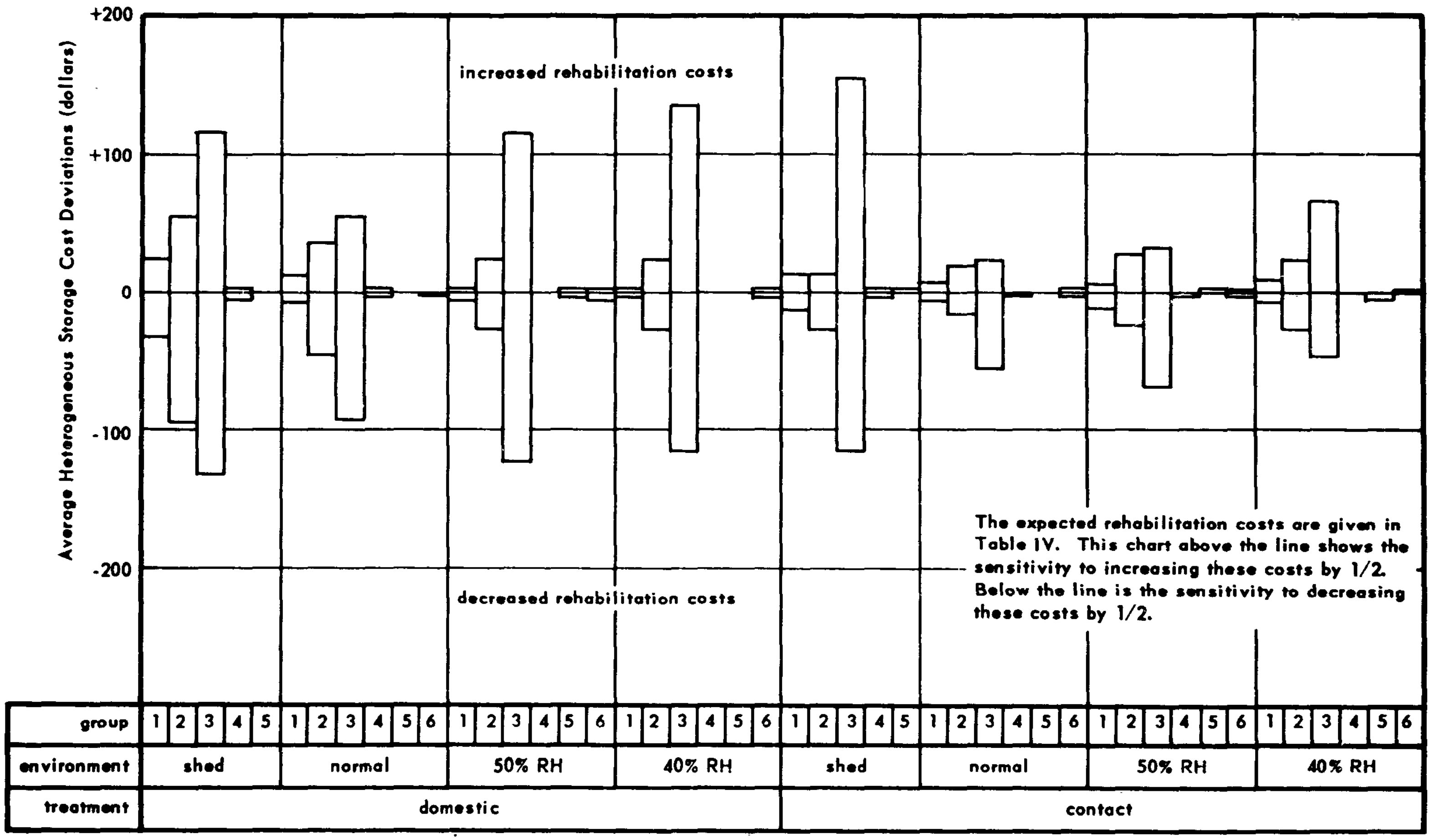

Chart 2. Sensitivity of stored items to high and low rehabilitation costs expressed as a heterogeneous average.

The expected values of warehouse cost per square foot for the various environments are given in Appendix E. This chart above the line shows the sensitivity to having these costs increased by 1/2. Below the line is the sensitivity to having these costs decreased by 1/2.

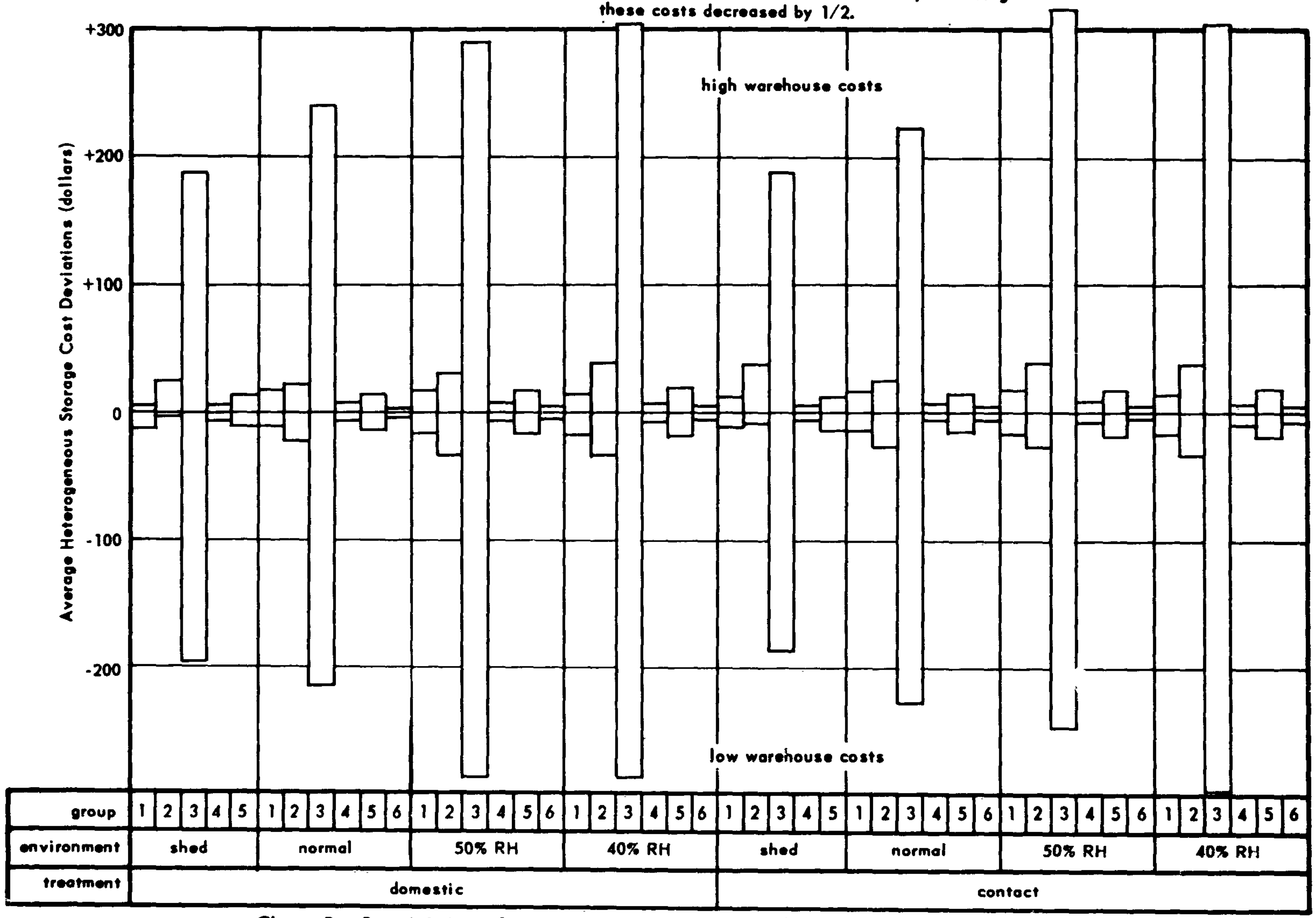

Chart 3. Sensitivity of stored items to high and low warehouse costs expressed as a heterogeneous average.

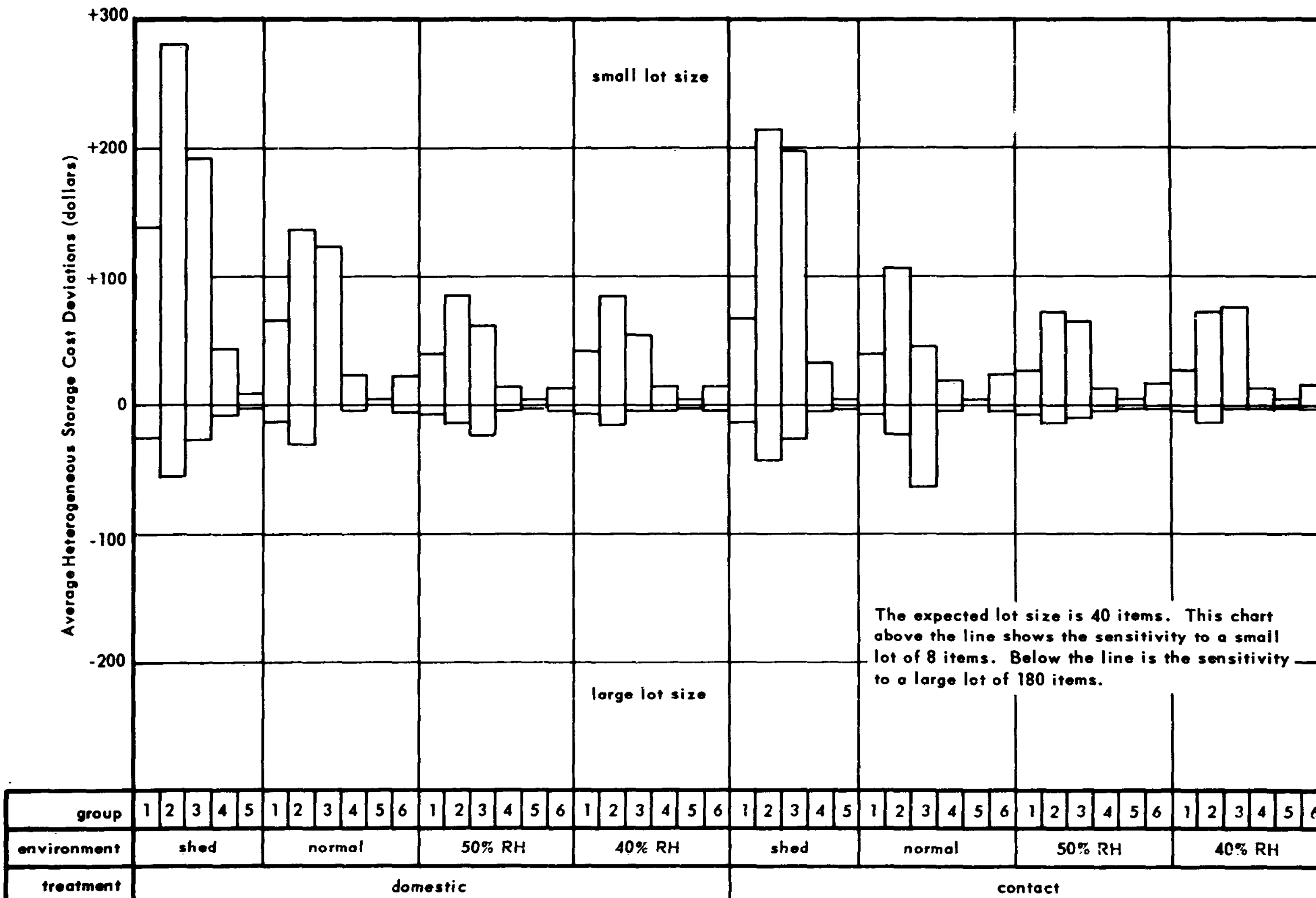

Chart 4. Sensitivity of stored items to large and small lot sizes expressed as a heterogeneous average.

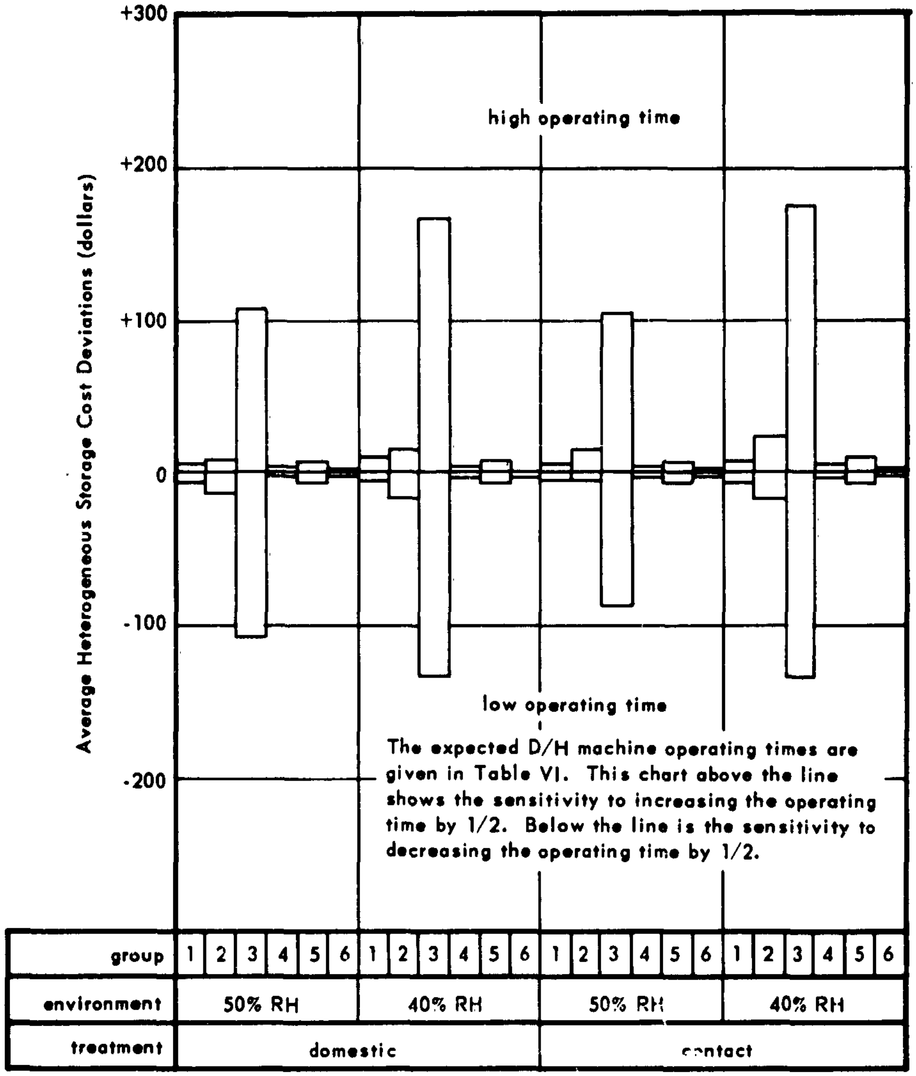

Chart 5. Sensitivity of dehumidified warehouse stored items to high and low dehumidifying machine operating time expressed as a heterogeneous average.

DISCUSSION

Costs are incurred in actual field storage of materiel which are not included in the cost analysis or sensitivity tests. Some of these are price of land, shelving, power for lights, and guard costs. These could be included if it was felt that the field storage situation was sufficiently different from that of the test. If the data, for example, are to be extrapolated to a large-scale operation, these costs perhaps should be considered. As mentioned earlier in the report, depreciation cost is not included, but the formula can be readily modified should it become necessary to include this cost.

Most of the data used in the economic analysis were provided by the CED, CBC, Port Hueneme, California. The CED has indicated by letter that these costs are substantially correct. However, it is pointed out that the NCEL cost formula is not in consonance with the practice and mission of the CBC. That is, the NCEL method of obtaining rehabilitation cost will indicate a different cost than will actually occur in the field under present field practice. This is because rust is removed in the field as soon as possible after detection, and thus involves extra handling of equipment. However, this added cost is offset to some degree by having only light rust to remove. As an example of the extra handling, if rust is discovered at the 3-month inspection in the cylinder wall of a jeep, all jeeps in the lot are taken to the shops and their engines represerved. Then, if at the 6-month inspection rust is discovered on a brake drum, all jeeps of the lot are again taken to the shops and all brake systems represerved. This cycle is repeated whenever rust is found, and could continue throughout the storage time. The difference, based on TP-QC-1, is most pronounced for domestic-treated items in the shed and open air where rusting is the most severe. In these cases, Laboratory figures, which are believed to be conservative, show that this type of storage is generally more expensive than other methods. From a purely economic standpoint, the NCEL analysis of data exposes those areas where major storing expenses occur so that they may be viewed in their proper perspective. For example, it was discovered that even in open-air storage where rusting was the most severe, the rehabilitation cost was not the largest contributor to the total cost. The largest single expense of open-air storage is the frequent inspections which it requires.

Maintaining items in a rust-free condition is not always the most economical method for storage. For some items, a ready-for-issue condition is possible only for a price. For other items, a rust-free, ready-for-issue condition comes as a bonus since dehumidified storage is also the most economical.

In performing studies of this type under actual field conditions, time becomes an important factor. Will there be time to apply contact preservation? When is mobilization most likely? Will the materiel be withdrawn before an emergency breaks? If all the factors concerning storage are readily available, storage programs can be tailored to fit the prevailing situation, thereby achieving the best results at the lowest cost.

Finally, there are several other DOD activities actively engaged in the areas of storage, packaging, handling, containerization, automation, etc. Some of these activities are the Transportation Corps, the Quartermaster Corps, the Signal Corps, BuSanda, and the Maritime Commission. Any contemplated changes in storage procedures brought about by this report should be considered in the light of the requirements of these other activities. In the final analysis, all efforts relative to logistics, although there is presently no official coordination among the activities, should result in the quickest, most efficient, and most economical method of supplying materiel to the fighting man on the battlefield.

Part 3. SUMMARY AND CONCLUSIONS

SUMMARY OF RESULTS

The following results, based on information obtained over a 5-year period, are only valid under the test conditions. However, a certain amount of extrapolation can be done without undue distortion.

1. No rust or corrosion attributed to the environment has been discovered on equipment while stored in 40% and 50% controlled-humidity warehouses.

2. Irrespective of preservation level, rust and corrosion attributed to the environment occurred most in open-air storage, less in the shed, little in the standard warehouse, and none in the controlled-humidity warehouses.

3. Compared to domestic treatment, contact preservation decreased rust incidence of stored items about 58% for open-air storage, 44% for the shed, and 30% for the standard warehouse.

4. Sensitivity of total storage cost to labor cost for any given storage environment and preservative treatment is high for Groups II and III items, less for Group I items, and least for Groups IV, V, and VI items.

5. Sensitivity of total storage cost to rehabilitation cost for any given storage environment and preservative treatment is high for Group III items, less for Group II items, and least for the remaining.

6. Sensitivity of total storage cost to warehouse cost for any given storage environment and preservative treatment is very high for Group III items and much less for items in the remaining groups.

7. Total storage cost is insensitive to large lot size for nearly all of the groups. But for the small lot size, sensitivity is high for Groups II and III items, lower for Group I items, and lowest for Groups IV, V, and VI items.

8. Sensitivity of total storage cost to dehumidifying machine operation for the 40% and 50% RH environments with domestic or contact preservation is very high for Group III items and much lower for the items in the remaining groups.

9. For the outside environment encountered, the dehumidifying machine in the 40% RH building operated twice as long as the one in the 50% building, and thus used twice the power.

10. The Navy's standard 40-foot by 100-foot rigid-frame metal building has been satisfactory with limited modifications as a dehumidified warehouse during 5 years of use.

CONCLUSIONS

1. Under the present TP-QC-1 requirements, the stock that is apportioned as mobilization reserve must be ready for overseas shipment during the initial phase of any naval emergency. These reserves must be contact-preserved beforehand because there might not be sufficient time to do so in the event of an emergency. Therefore, by using the results of the economic analysis as a guide, the most economical way to store various types of contact-preserved mobilization reserves can be determined.

2. While it is well to bear the extra expense of maintaining equipment necessary for the security of the United States in a condition that is rust-free and ready for overseas shipment, maintaining additional equipment in this condition is unduly costly. For nonemergency items or items for stateside use where the time-lag between removal from storage and usage is short, the least costly methods of storage as shown by the economic analysis should be seriously considered.

3. If a study could be made of the usual time-lag of various items going overseas, limited contact preservation could be applied to protect items during the time of exposure before being used. In this way, items could be domestic treated, stored in a 50% RH warehouse (which is the cheapest for most items), and then shipped with only the necessary preservation. The preservation could be applied at any time during storage since results show that dehumidified storage does not harm preservatives. The preservation might even be applied enroute.

4. Since no rust attributed to the environment has been detected on the items stored in the dehumidified warehouses and only modest amounts in the standard one, it is believed that inspection frequencies for these conditions could be lengthened. This would lower the overall storage cost, and the cost analysis might indicate a different pattern of results.

5. An advantage of dehumidified storage is that if an item has rust when put into storage (from faulty preparation, delays in getting into the warehouse, etc.), growth of the rust will be stopped. All other storage conditions permitted rust growth.

6. Since it is twice as costly to maintain a 40% RH level than a 50% RH level, and since no rusting attributable to these environments has been detected, it is concluded that a 50% RH level is suitable for a period of at least 5 years.

7. Careful consideration should be given to the storage of Group III items (automotive equipment) since the sensitivity tests have shown this equipment to be most affected by changes in the labor costs, rehabilitation costs, etc.

8. The Navy's standard prefabricated 40-foot by 100-foot metal building is considered suitable for advanced-base dehumidified storage if the louvers and windows are eliminated and the fit tightened around the cargo door. A building which has fewer joints would be more desirable.

9. To achieve the lowest possible storage cost, a number of things must be considered about each item: (1) overseas or stateside destination; (2) degree of necessary readiness; (3) time-lag between removal from storage and actual use; (4) weather conditions at the storage site; and (5) labor costs at the storage site; thus it is impossible to conclude that there is any one best method of storage. With consideration given to these factors, the economic anlysis in this report can be used to determine the most economical storage method. If building limitations prevent the most economical method from being used, the least expensive method of the available alternatives can also be determined from the economic analysis.

ACKNOWLEDGMENTS

Mr. J. A. Young, director of the Quality Control Division, and Mr. S. N. Slebiska, manager of the Preservation Process Branch of the Quality Control Division, and their staffs, Construction Equipment Department, CBC, Port Hueneme, California, devoted considerable time and effort to provide information on costs and storage procedures. Without this information much of the analyses of storage costs could not have been properly prepared.

Acknowledgment is also extended to Mr. E. C. Morales, NCEL engineering aid, whose competent observations and inspection records aided materially in determining rehabilitation costs.

Appendix A

TYPES OF EQUIPMENT IN STORAGE

Following is a list of the items, with SNS numbers, that were in the storage test. Two of each item, one domestic-treated and the other contact-preserved, were in each environment. The open-air and shed environments each contained 19 pairs of items, and the remaining environments contained 29 pairs — the 19 items listed under "A" plus the 10 listed under "B."

A. Equipment in All Storage Environments	SNS No.
1. Boiler, vertical, 180,000-Btu	4520-184-3708
2. Compressor set, air, 30-cfm	4310-L60-0089
3. Distillation unit, 83-gph	4620-185-0857
4. Generator set, diesel, 30-kw	6115-295-0973
5. Heater, space, oil-fired, 50,000-Btu	4520-200-0647
6. Oven, bake	7310-275-6180
7. Pump, centrifugal, 350-gpm	4320-273-8574
8. Pump, diaphragm, 50-gpm	4320-132-5382
9. Refrigeration unit (675-6800)	4110-287-3184
10. Refrigeration panels for 6800 unit	4110-287-3179
11. Searchlight, 60-inch, with power plant	6230-L60-0142
12. Tank, canvas, 3000-gallon	5430-222-1923
13. Tires, 8.25 x 20	Y8-T-9076
14. Trailer, floodlight, mobile	6230-283-9760
15. Transfer unit, CO_2	3655-245-0073
16. Truck, dump, 2-1/2-ton, 6 x 6	2320-835-8595
17. Truck, jeep, 1/4-ton, 4 x 4	2320-835-8317
18. Washing machine	3510-240-6552
19. Welder, arc, GED, trailer, 300-amp	3432-224-7722

B. Standard & Controlled-Humidity Warehouses Only	
1. Chemical-warfare detector kit	6665-L60-0123
2. Drill press, 18-inch swing	3413-L60-0001
3. Fan, exhaust, 4900-cfm	YS66-F-70020-50
4. Lathe, floor model, 14-1/2-inch swing	3416-174-1535
5. Public-address system	5830-501-4724
6. Saw, radial, 16-inch	YL40-S-1365-200
7. Slicer, meat	7320-222-417
8. Switchboard, 50-line	5805-501-4725
9. Telephone system, 13-unit	5805-501-4726
10. Transit, surveyors's	YZ18-T-3311-750

Appendix B

SUITABILITY OF STANDARD WAREHOUSE FOR DEHUMIDIFIED STORAGE

The Navy's standard prefabricated 40-foot by 100-foot metal building appears to be a suitable building for advanced-base dehumidified storage. It would be necessary, however, to eliminate the louvers and windows and tighten the cargo door fit if the building is adopted. Depending upon circumstances, it might also be desirable to eliminate the cargo door at one end to preclude the chance of through ventilation. In locales of high partial-vapor pressures, the building needs insulation to dampen daily temperature variations and to reduce the possibility of water-vapor condensation on equipment. But in locales of low partial-vapor pressure areas (arid and cold regions), insulation is not needed to prevent condensation because the dew point would rarely drop to condensing temperatures.

Sealing the building may or may not be required. The cost of sealing the test buildings was about $600 each, and the annual power cost for the desiccant machine in the 50% RH building was $52 (4 cents per kilowatt-hour). If the machine operated four times longer in an unsealed building than in the sealed test building, the annual power cost would then be $208. This divided into the $600 sealing cost equals approximately 3 years. Thus, sealing becomes economically feasible only if the building is to be used longer than 3 years. The annual measured power cost for the desiccant machine in the 40% RH building was $101. The economical break-even point at the RH level would be about 1-1/2 years assuming a building with the same degree of looseness. Actually, the economical break-even point will vary with the factors of building tightness, geographical location, and power and labor costs. Whether or not a building needs sealing should be determined on an individual basis, by minimizing, with time as the independent variable, the sum cost of sealing and desiccant machine operation. For its dehumidified test buildings, NCEL used a bituminous, cut-back cement sealing material. Table B-1 tabulates pressurization tests for building tightness. In each test the buildings were pressurized by introducing a known rate of outside air. This same rate was used for all six pressurization tests. Apparently the 50% RH building was not initially sealed as well as the 40% RH building, as evidenced by the lower resultant pressures. From January 1957, pressurization of the 50% RH building did not change significantly, nor did the 40% RH building from February 1956. It appears that the sealing compound has remained supple for at least 5 years. The variations in pressure may well be caused by the variations in resealing the cargo doors after each inspection.

Table B-1. Pressurization Test

Date	Building	Manometer Reading (In. H_2O)
February 1956	50% RH	0.16
	40% RH	0.22
January 1957	50% RH	0.11
	40% RH	0.23
October 1957	50% RH	0.10
	40% RH	0.21
November 1958	50% RH	0.11
	40% RH	0.21
January 1960	50% RH	0.09
	40% RH	0.21
January 1961	50% RH	0.10
	40% RH	0.20

Appendix C

OPERATIONAL TEST DATA

Table C-I. Operation of Equipment in Outside Storage

Item	Length of Run (min)	Did Item Operate Satisfactorily?	Remarks
Compressor set, air	30	Yes	Air was bled from storage tank to prevent cycling.
Distillation unit	60	Yes	The compressor was operated 15 minutes and then uncoupled from engine, which operated 45 minutes longer. No distillate was made.
Generator set	60	Yes	Loaded fully with a 30-kw bank.
Power plant for searchlight	60	Yes	Correctly loaded with load bank.
Pump, centrifugal	30	Yes	With a storage tank of water the pump was operated in a closed pipe circuit at approximately 350 gpm.
Pump, diaphragm	60	Yes	Same as above, except pumping rate was 50 gpm.
Refrigeration unit	60	Yes	Bearings on electric-drive motor were frozen. They were freed by turning rotor by hand. Unit was then started and compressor checked for freon leaks and head and suction pressures. These were satisfactory. The compressor was then uncoupled from the motor, which was operated for 60 minutes.

Table C-I. Operation of Equipment in Outside Storage (Cont'd)

Item	Length of Run (min)	Did Item Operate Satisfactorily?	Remarks
Trailer, floodlight		No	No output; moisture in armature. Unit was operated intermittently about an hour in attempt to obtain output.
Transfer unit, CO_2	30	Yes	No-load operation.
Truck, dump	90	Yes	Unit placed on blocks and operated 15 minutes in each forward gear. Blocks removed and unit driven about the station for 30 minutes with empty bed.
Truck, jeep	90	Yes	Same as above.
Washing machine	30	Yes	Bearings on motor were frozen. After bearings were freed, operation was satisfactory. The machine was not loaded.
Welder, arc	60	Yes	No-load operation.
Boiler, vertical			
Heater, oil-fired			
Oven, bake			These items were not operated.
Refrigeration panels			
Tank, canvas			

Table C-II. Operation of Equipment Left in 40% RH Warehouse

Item	Length of Run (min)	Did Item Operate Satisfactorily?	Remarks
Drill press	60	Yes	The bearings in the electric motors of each item were frozen because of hardened grease. After the bearings were freed, the items were operated without load.
Exhaust fan	60	Yes	
Lathe	60	Yes	
Meat slicer	60	Yes	
Radial saw	60	Yes	
Public-address system			These items were not operated.
Surveyor's transit			
Switchboard			
Telephone system			

Appendix D

DESCRIPTION AND EXPLANATION OF COST FACTORS

A = The Labor Hours to Initially Prepare For Storage

Stored equipment was either domestic-treated or contact-preserved. Domestic treatment is furnished by the manufacturer and no additional preservation expense is incurred if the equipment is stored in this condition. But the equipment to be contact-preserved must be partially disassembled, cleaned, preserved, and reassembled; this requires an expenditure of labor. The Quality Control Division, Construction Equipment Department, CBC, Port Hueneme, California, furnished information about the man-hours required to initially prepare the items for the NCEL test.

B = Material Cost to Initially Prepare For Storage

Similar to Factor A, no material costs are incurred if the stored equipment is domestic-treated; they are absorbed by the manufacturer. But contact preservation requires cleaning solvents and preservation materials. Articles such as rags, gloves, brushes, and spraying equipment were not included, for their cost prorated over each individual item would have been insignificant. Material costs to initially prepare for storage were obtained from the Quality Control Division.

C = Square Footage Required For Storage

The area allotted to each item was based on current warehouse tiering and palleting and service space procedures. Service space, such as aisles, firebreaks, receiving and shipping space, etc., has been set at 40% of the total floor area in a 200-foot by 600-foot warehouse storing equipment similar to that of the NCEL test. A factor of 1.67 was thus used to determine the total space needed for a test item. If an item covered 6 square feet of floor area, it needed 10 square feet (6 x 1.67); however, if a similar item was tiered on top of the first then the space allotment was 5 square feet per item. The same procedure was followed with palleted items.

D = Unit Fixed Cost of Storage Per Square Foot Per Month

Except for the original price of land, this factor took into account all initial costs of the environments amortized over a certain period of time. Included are costs of site preparation, foundation and slab, building and erection, electrical installation, insulation, exterior painting, and desiccant machinery for the dehumidifying units. Factor D for the test environments giving amortization periods is given on the following page.

Environment	Cost (ft^2/month)	Amortization Period (years)
1. Open slab	\$.0069	10
2. Shed	.0115	25
3. Standard warehouse	.0131	25
4. 40% & 50% RH warehouse	.0151	25

E = Storage Maintenance Cost Per Square Foot Per Month

This factor took into account such maintenance and operating expenses as painting (every 3 years), power, and maintenance costs of dehumidifying machinery. Not included were taxes, guard costs, and insurance costs. Factor E for each test environment is given as follows:

1. Open Slab	\$ 0	/ft^2/month
2. Shed	.0050	
3. Standard Warehouse	.0063	
4. 50% RH Warehouse	.0094	
5. 40% RH Warehouse	.0102	

F = Labor Hours for Item Inspection

Inspection labor hours upon which this factor is based were determined from the CBC, Port Hueneme time-cost accounting records. These are records of the actual time required to make the equipment inspections at the times specified by the Quality Control Procedures Manual TP-QC-1. These times, when average, become reliable statistical data. The periodic inspections of test items mentioned earlier in the report are for the purpose of determining the state of deterioration only and are not included in Factor F.

G = Labor Hours for Operational Testing Only

There are two parts to the operational tests specified in TP-QC-1. One part tests equipment in dead storage, the other tests new receipts for acceptability.

Dead-storage equipment need not be tested if Class I and II inspections are satisfactory. Thus, operational tests have not been made at Port Hueneme. Operational test costs were included in this analysis, however, because the adequacy requirements of Class I and II inspections may in time vary, and because the standards for adequacy may vary at each CBC depot. Representative costs were furnished by the Quality Control Division of CED, Port Hueneme.

Costs of acceptability tests for new receipts were not included in this analysis.

H = Labor Hours for Depreservation

Before contact-preserved equipment can be placed in service, the preservation material must be removed. If the equipment is to be used stateside, the preservatives are generally removed by the center issuing the equipment. If the equipment is to be shipped overseas, the preservative material is generally left intact for the receiving station to remove. But regardless of who removes the preservative, the removal is a chargeable storage cost. Similar to Factor E, labor hours, H, have been obtained from time-cost accounting records. Depreserving domestic-treated equipment is not necessary since this equipment is stored with service oils and greases and in a ready-to-use condition.

i = Subscript denoting "With respect to type of storage environment."

j = Subscript denoting "With respect to particular item stored."

K = Ratio of Sample Size to Lot Size

Actual periodic field inspections are made on random samples; the number of samples required for inspection is specified by the TP-QC-1 manual. For example, of 25 jeeps, five must be inspected. This gives a sample-to-population ratio of 1:5, which was used in the basic equation. This ratio, however, will vary with different lot sizes, with the percentage of samples decreasing as the lot size increases. In a lot of two to eight items, the sample size would be 4, but for a lot of 66 to 110 items, the sample size would be 7.

L = Hourly Labor Charge

This is the average hourly rate paid to employees associated with the preservation and storage of equipment. The average current rate at CBC, Port Hueneme, $3.50 per hour, was used in the formula.

M = Man-Hours for Rehabilitation

Records of the Class III inspection were used to obtain parts and labor required for rehabilitation. The actual figures that were incurred could not be used because, for purposes of the test only, the items were completely disassembled. To obtain information from the inspection records, data for each item was analyzed to determine the location and extent of rust, and the approximate number of man-hours and costs of replacement parts to perform the repair were charged to the item. Other costs, if normally incurred in a similar repair, were also charged to the item, such as removal and replacement of a component from the item, and the necessary gaskets and seals used for reassembly. Only the man-hours to perform the rehabilitation are included in the M factor; the replacement parts are in the R factor.

Costs for intervals between the start of the test and the Class III inspection were obtained by adjusting the cost to the magnitude of the rust-count curve for the appropriate environment and preservation level.

N = Material Cost For Crating, Dunnage, Boxing, Etc.

All items in storage except automotive equipment are boxed or crated. In general, contact-preserved items are boxed, and domestic-treated items are open-crated. Boxes and crates can be stacked to conserve space, and boxes offer additional protection. Most service items are crated by the vendor, and their cost is included in the original price of the items. Information about the cost of packing materials came from the Supply and Disbursing Department, CBC, Port Hueneme, and is given in Appendix F.

P = Original Cost of Item Less Depreciation

To allow for the possibility that an item in storage could deteriorate beyond repair, the expression $S_{ij}P_{it}$ was included in the formula. If the item cannot be repaired, the remaining value of the item would be added to the storage cost. P should indicate the net value according to accepted accounting procedures of that type of item.

As long as the item is repairable, the S_{ij} which is multiplied by P in the equation, will be zero, and the expression drops out of the equation. If the item is beyond repair, S will equal one (1) and charge the loss to the storage environment.

R = Parts Cost For Rehabilitation

This is the cost in dollars of replacement parts for rehabilitation. The source of these costs are included in the explanation of M.

S = One (1) if item is found to be unrepairable; zero (0) if otherwise.

Use of this expression is included in the explanation of P.

t = Subscript denoting "With respect to time."

T = Storage Time in Months

This indicates the total time in months the item has been in any particular storage environment.

U = Number of Class II Inspections

The inspection frequency used for the cost calculation is presented in TP-QC-1. The number of inspections is the whole number obtained from dividing the storage time by the inspection frequency. No fractional parts of an inspection are used. For example, if an item with an inspection frequency of 6 months were stored for 21 months, the number of inspections computed would be 3, not 3-1/2.

V = Number of Operational Tests

The operational testing frequency used in the calculations is presented in TP-QC-1 as every second Class II inspection. No fractional part of a test was considered.

W = Total Storage Cost

This represents the total cost in dollars for the storage of an item within the limits of the Laboratory test.

Y = Ratio of Operationally Tested Items to Lot Size

At every other Class II inspection, an operational test is given to applicable items.

A "Sampling Plan for Operational Tests" table in TP-QC-1 gives the number of items to be operationally tested for any given sample size. For example, out of five samples for a Class II inspection selected at random from a lot of 25 items, four of the five items would be operationally tested. This example would have a ratio of 4 to 25 and was used in the storage cost equation in the main text; however, the ratio will vary with different sample sizes.

Appendix E

STORAGE COST CURVES FOR GROUPS I THROUGH VI

(Figures E-1 through E-6)

LEGEND:

C = Contact treatment

D = Domestic treatment

O = Open-air storage

Sh = Shed

St = Standard warehouse

40 = 40% RH warehouse

50 = 50% RH warehouse

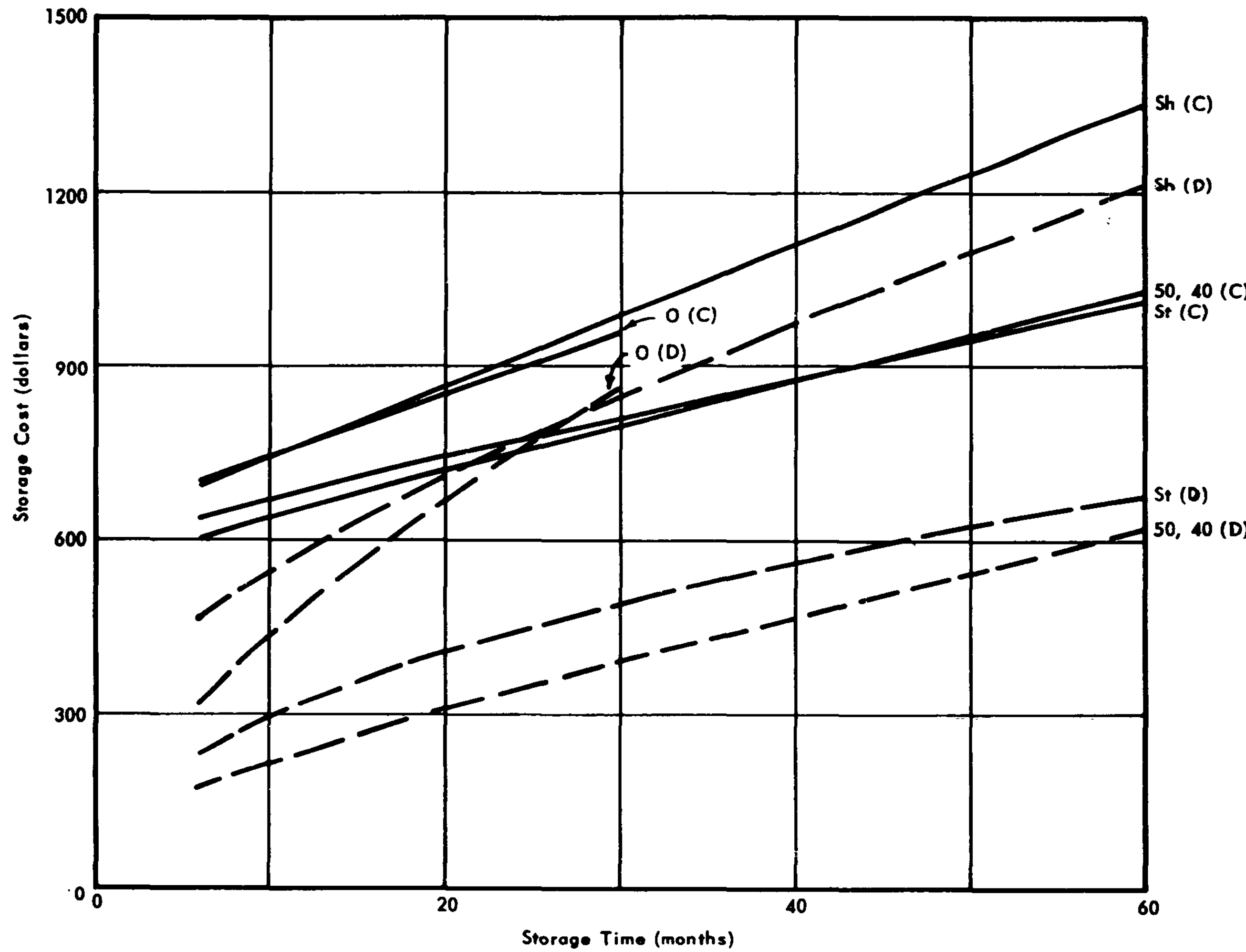

Figure E-1. Storage cost versus storage time for Group I items.

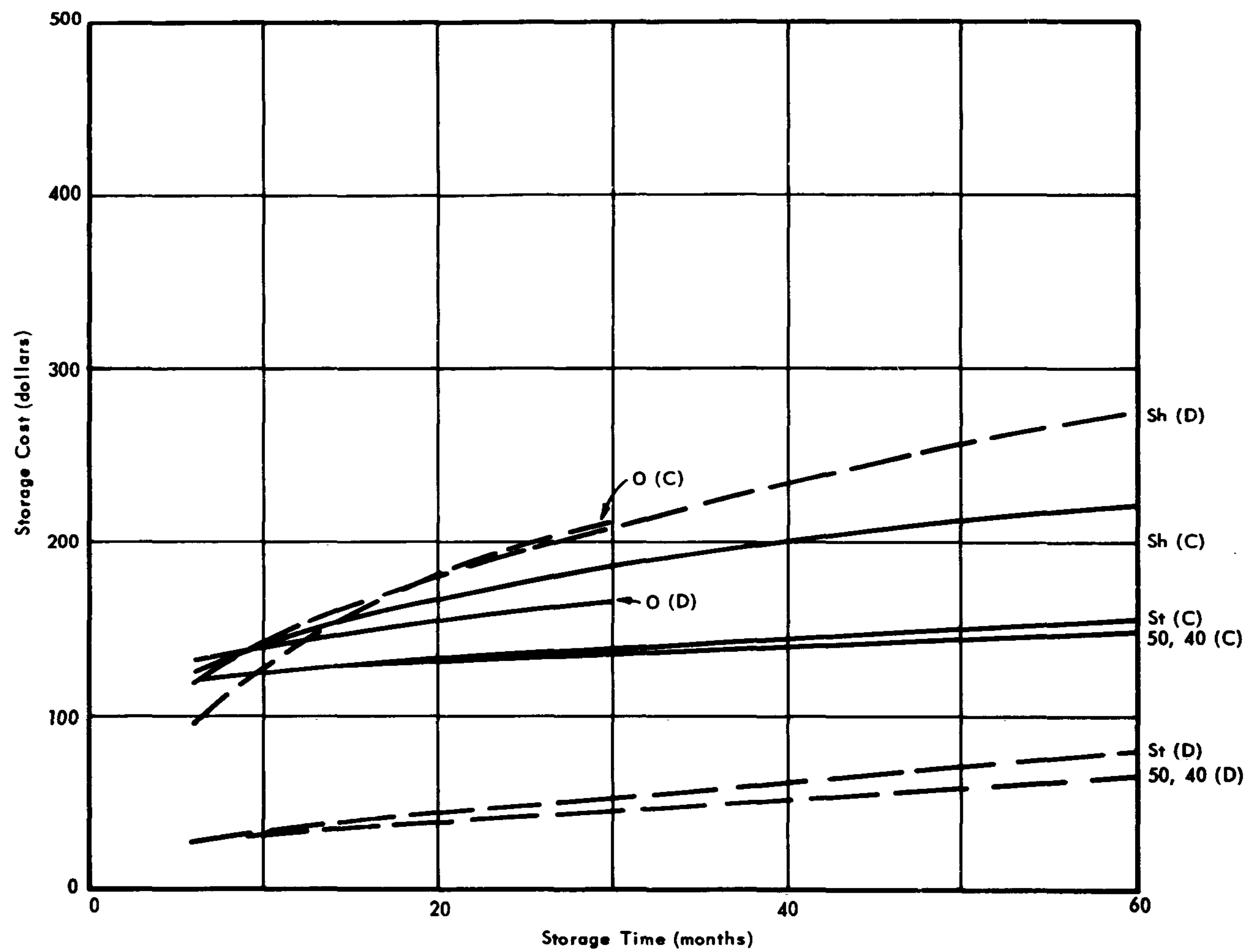

Figure E-1a. Centrifugal pump, 350-gpm.

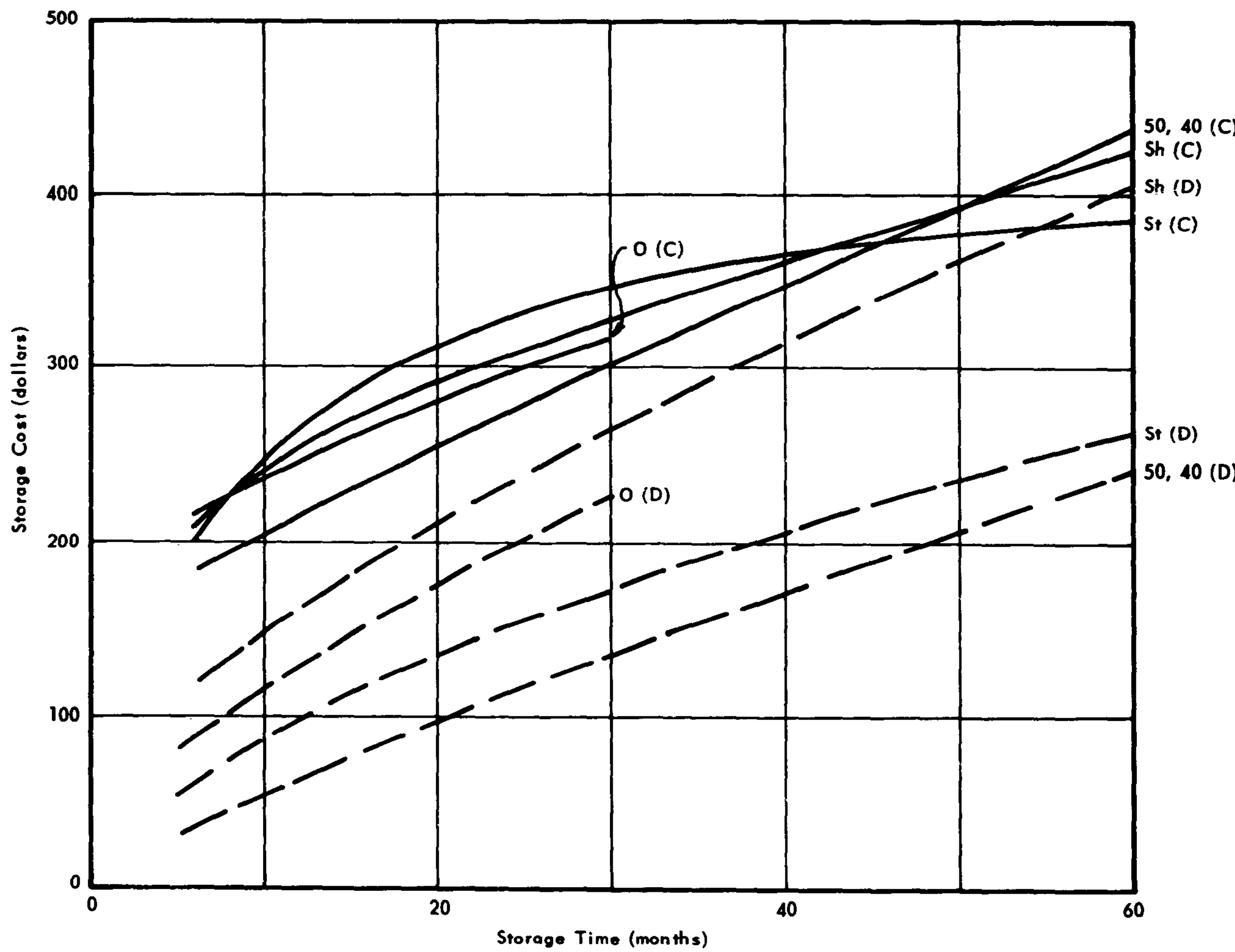

Figure E-1b. Distillation unit, 83-gph.

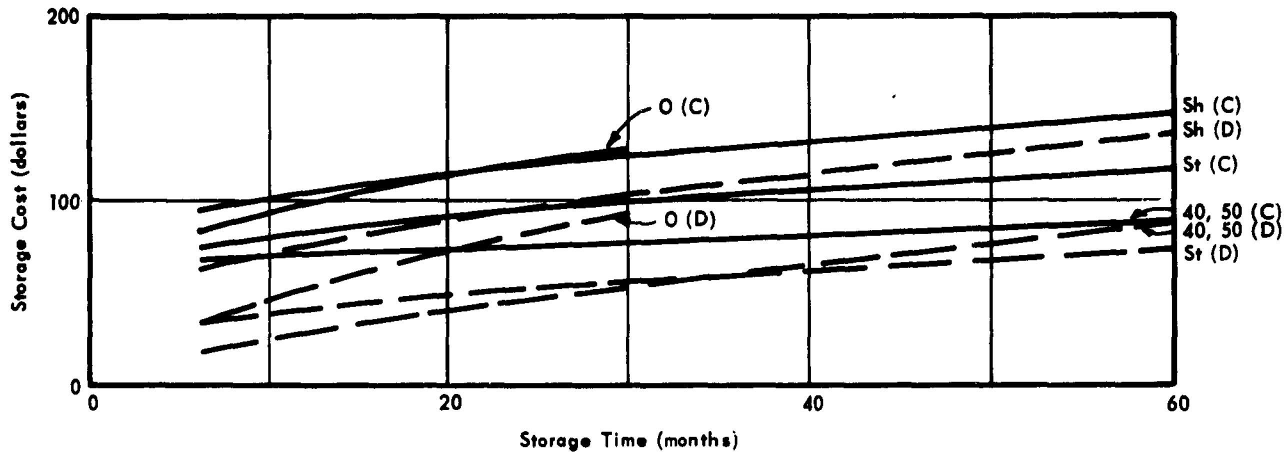

Figure E-1c. Compressor set, 30-cfm.

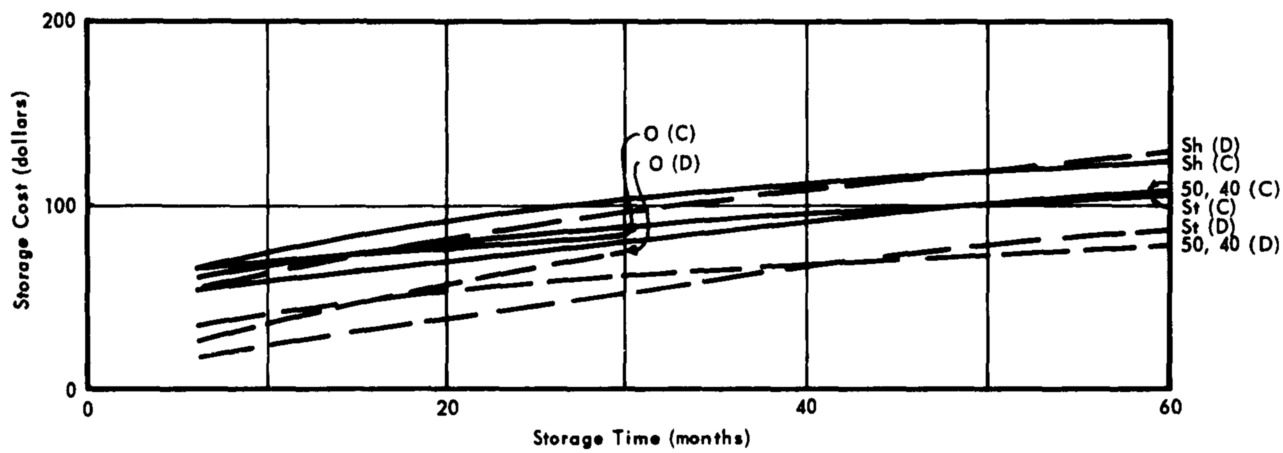

Figure E-1d. Diaphragm pump, 50-gpm.

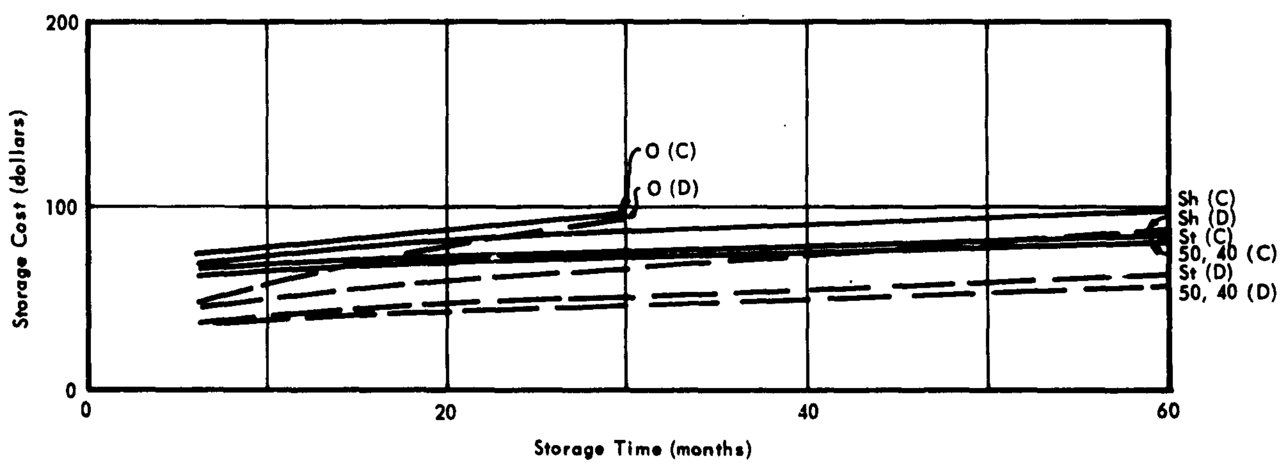

Figure E-1e. Washing machine.

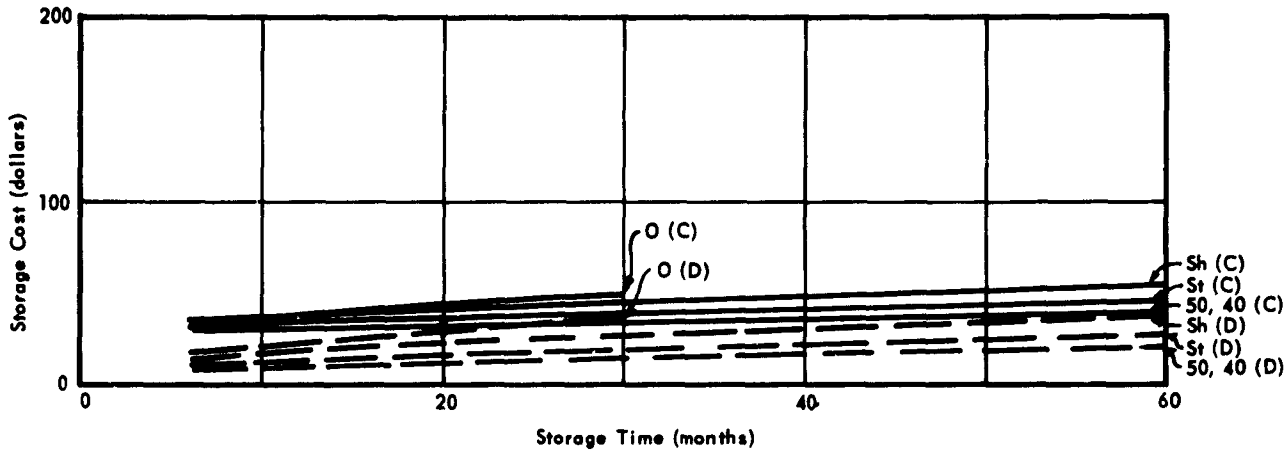

Figure E-1f. Transfer unit for CO_2

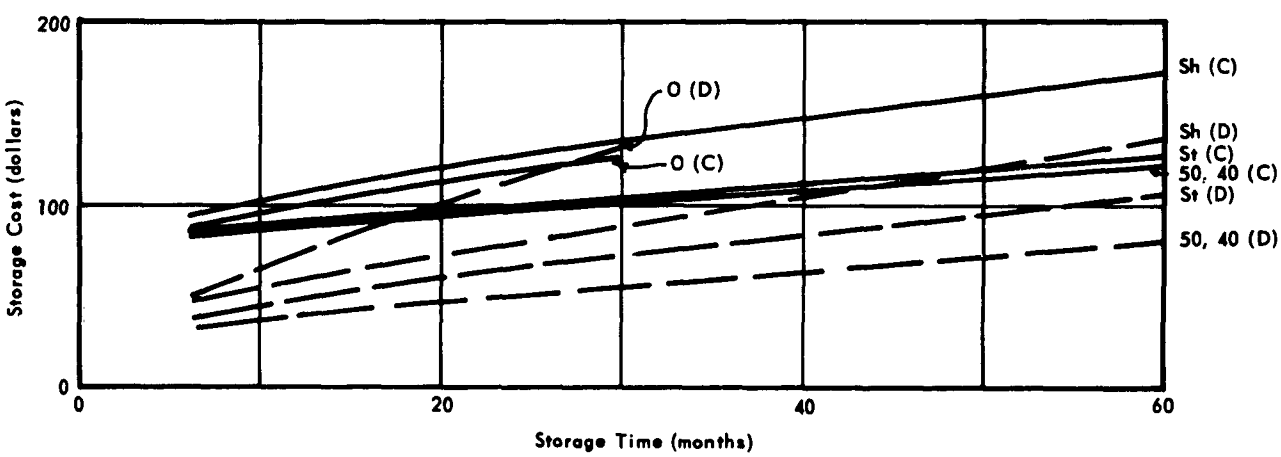

Figure E-1g. Refrigeration unit.

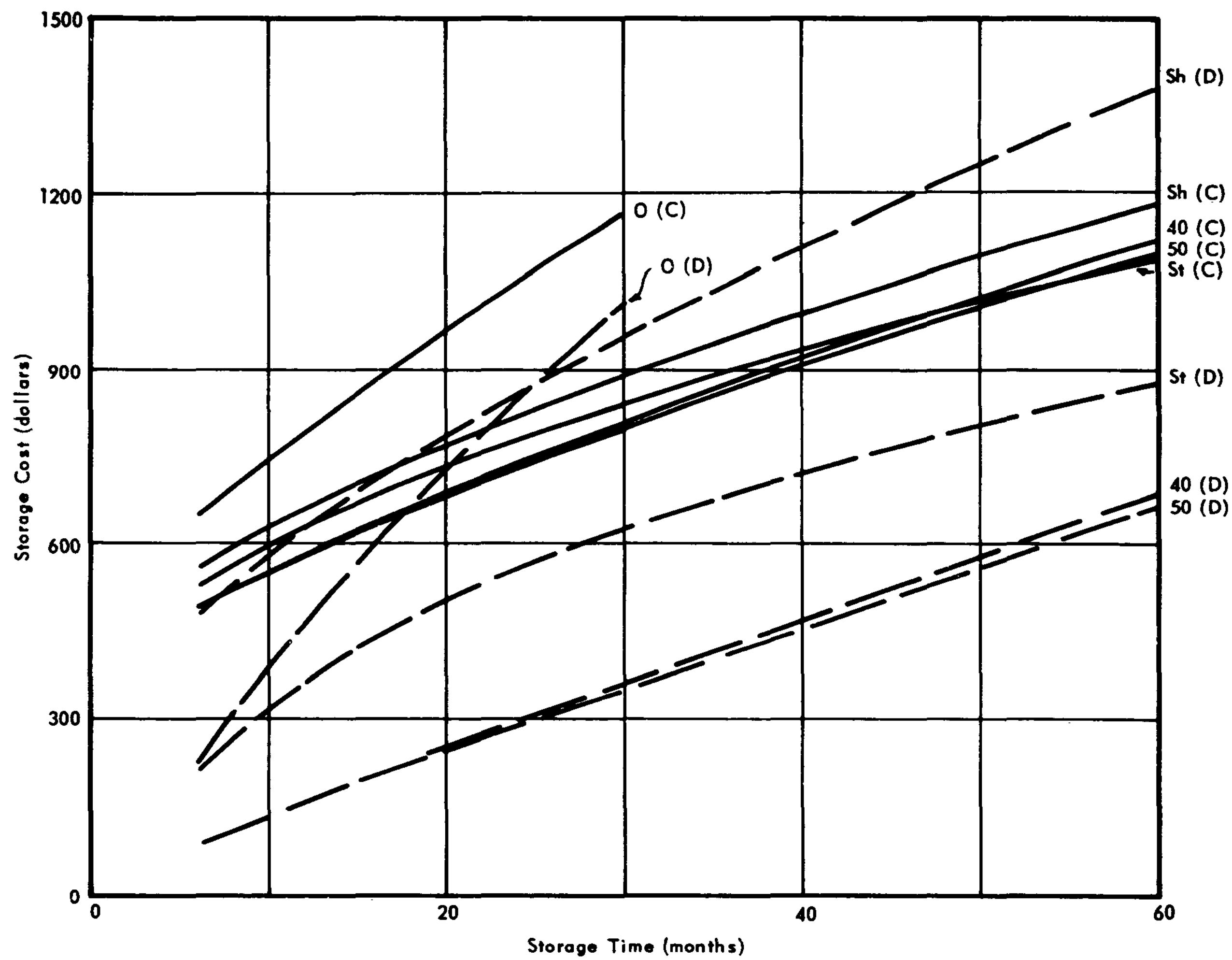

Figure E-2. Storage costs versus storage time for Group II items.

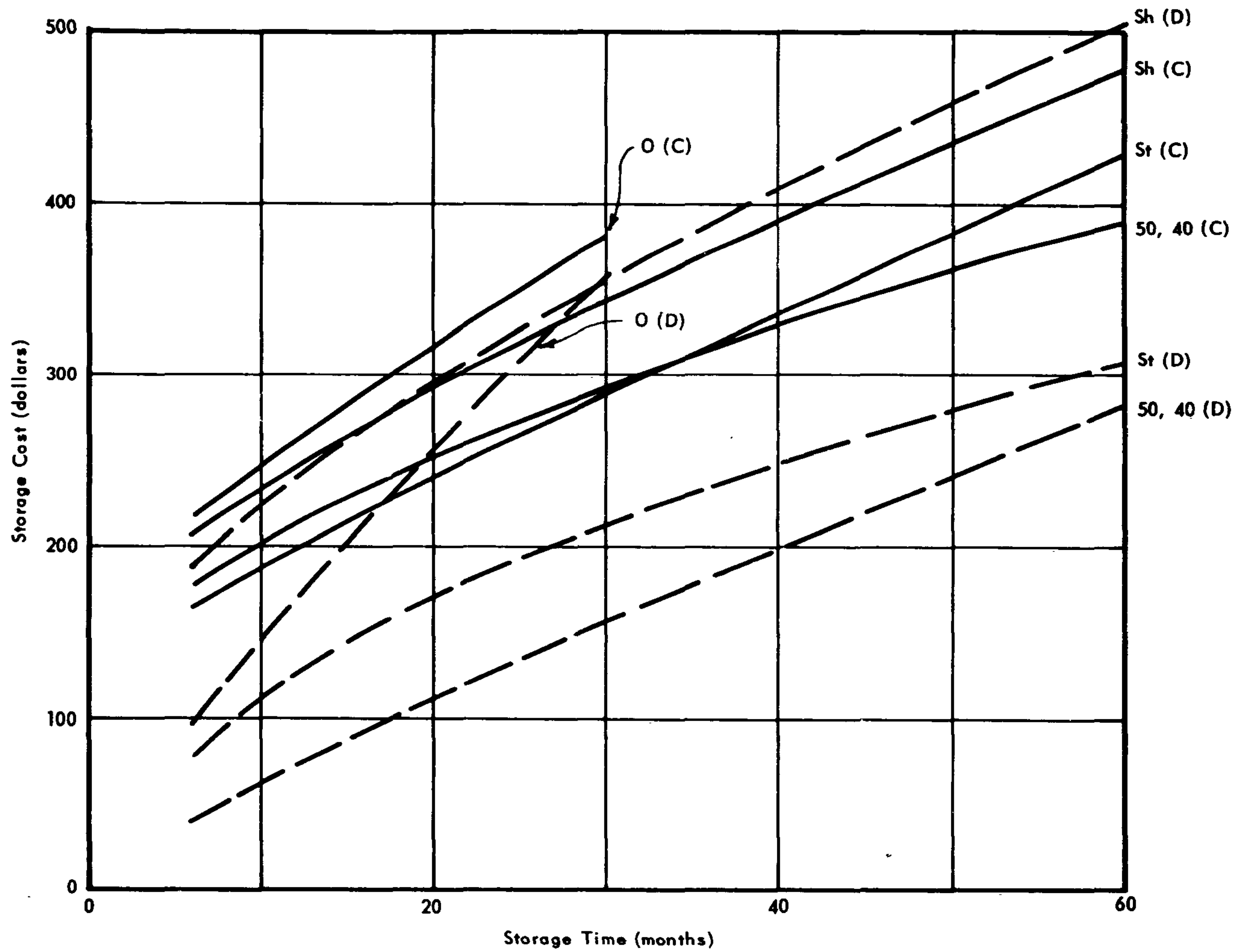

Figure E-2a. Searchlight with power plant.

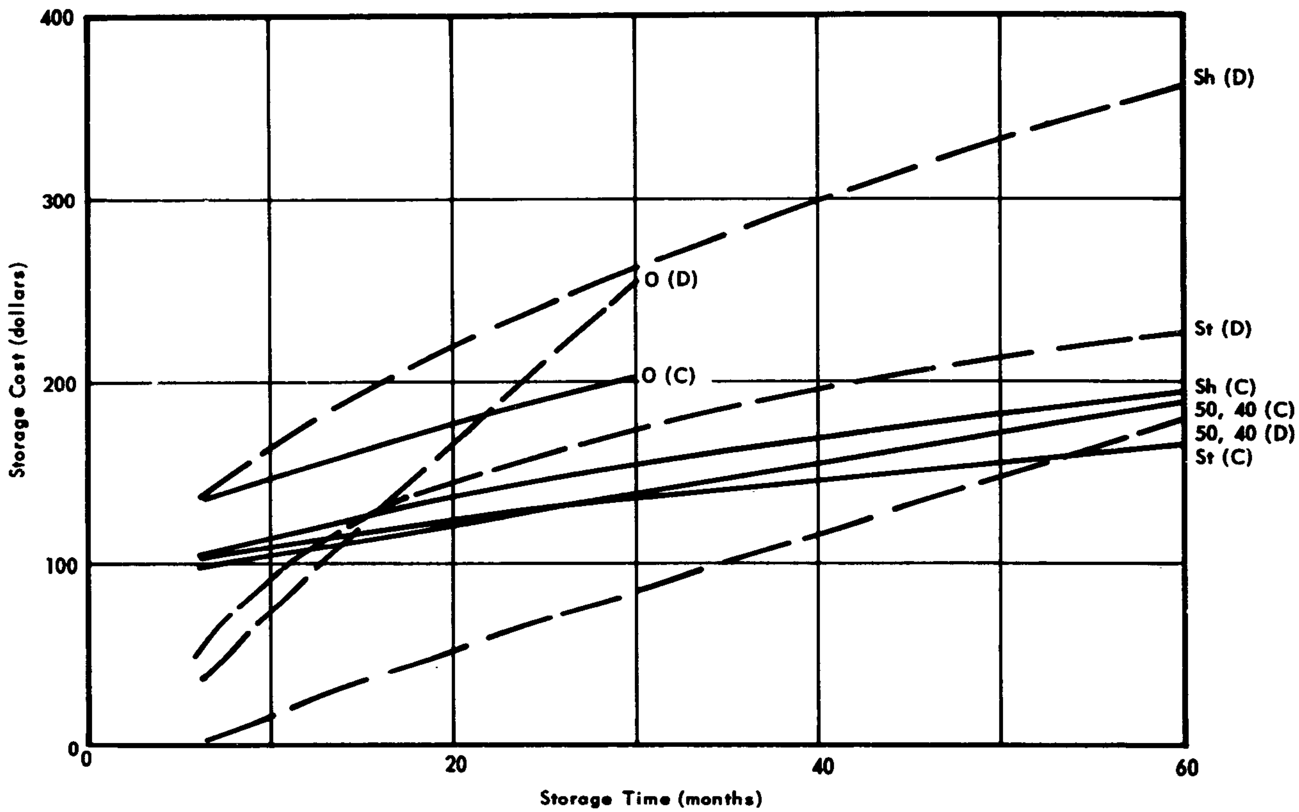

Figure E-2b. Arc welder, 300-amp, GED trailer.

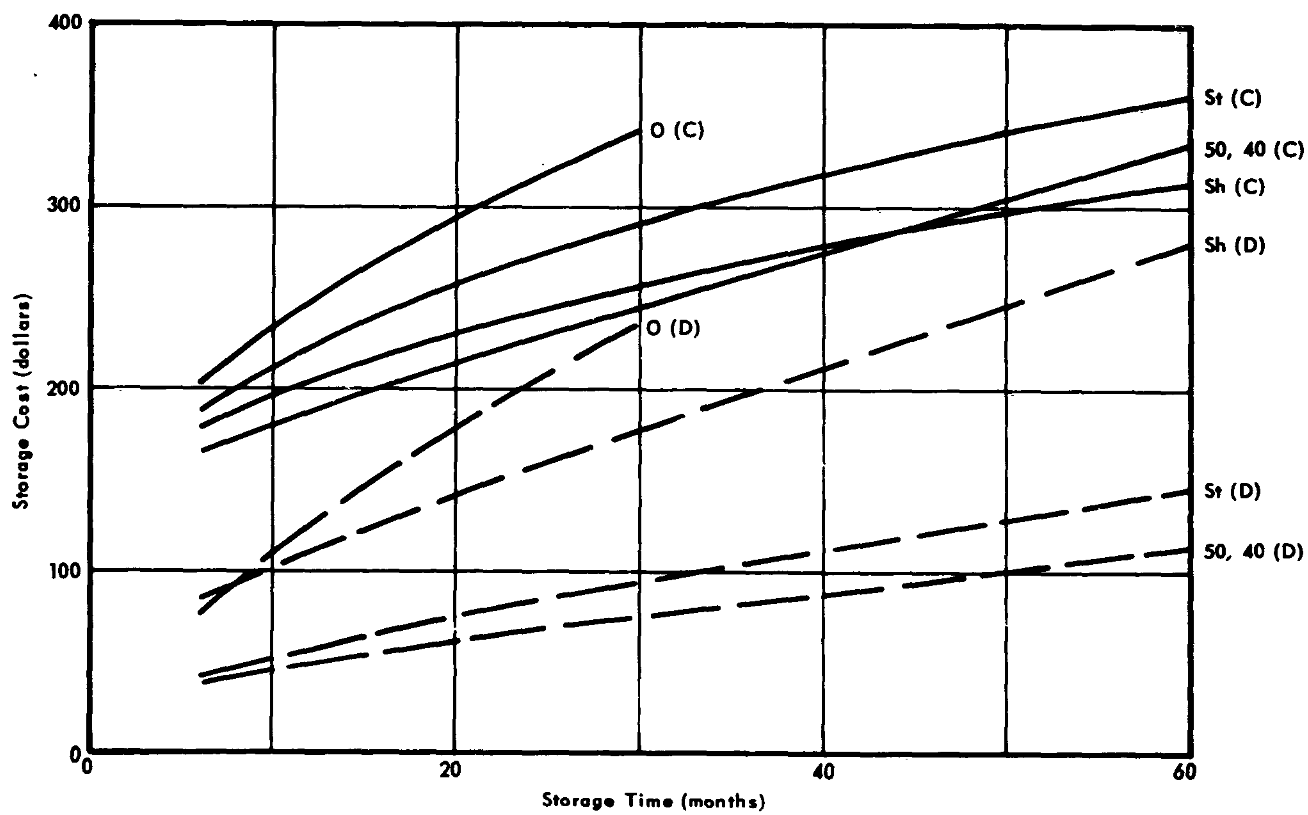

Figure E-2c. Generator set, 30-kw diesel.

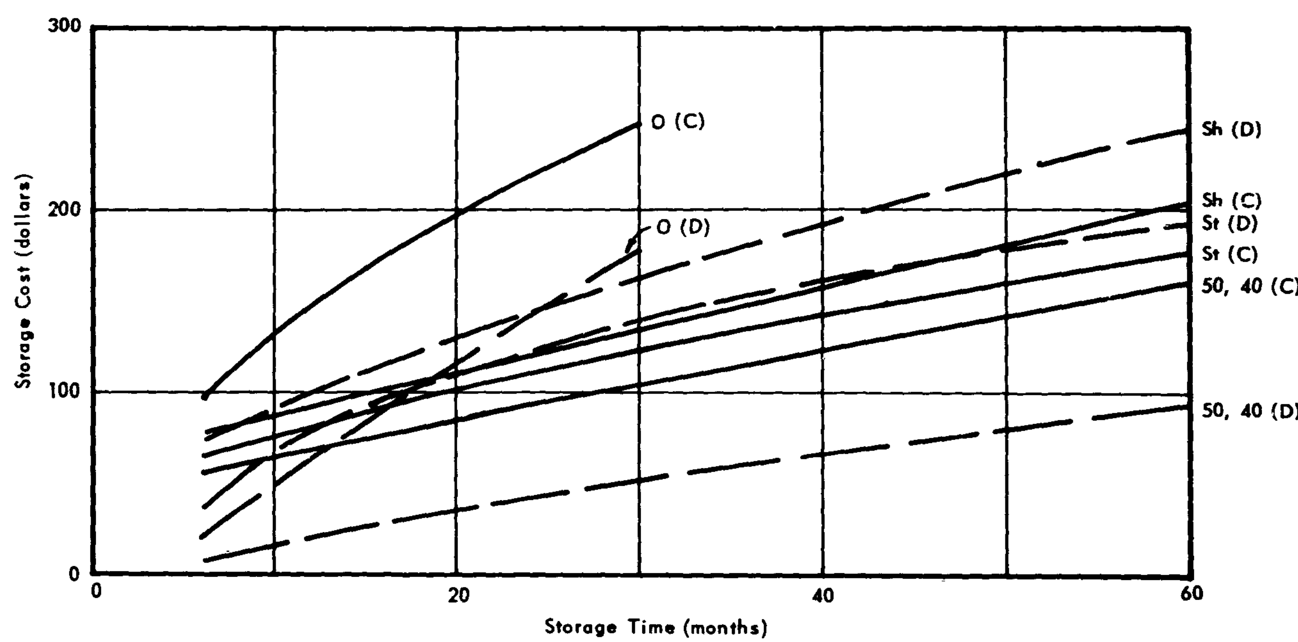

Figure E-2d. Floodlight trailer, mobile.

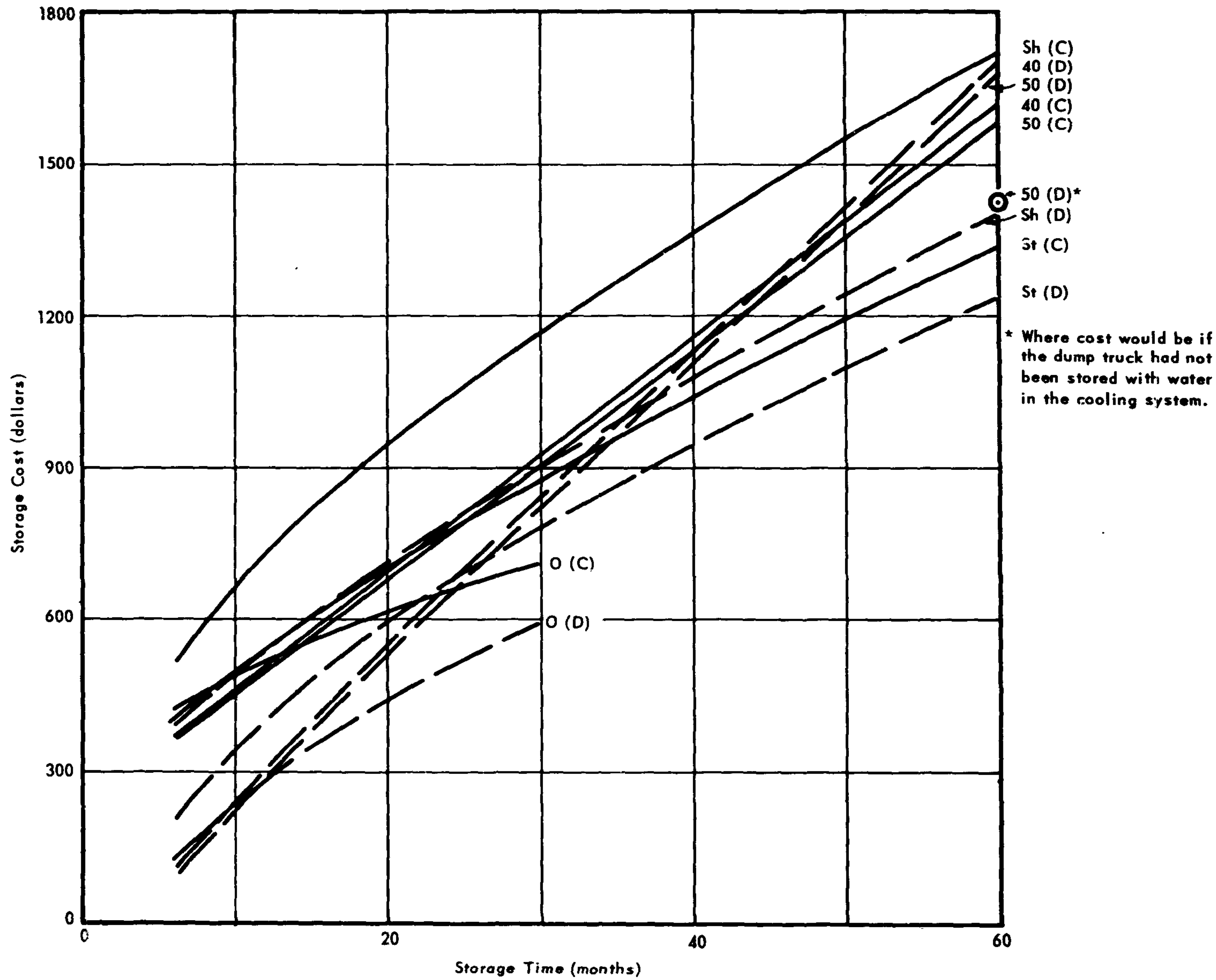

Figure E-3. Storage costs versus storage time for Group III items.

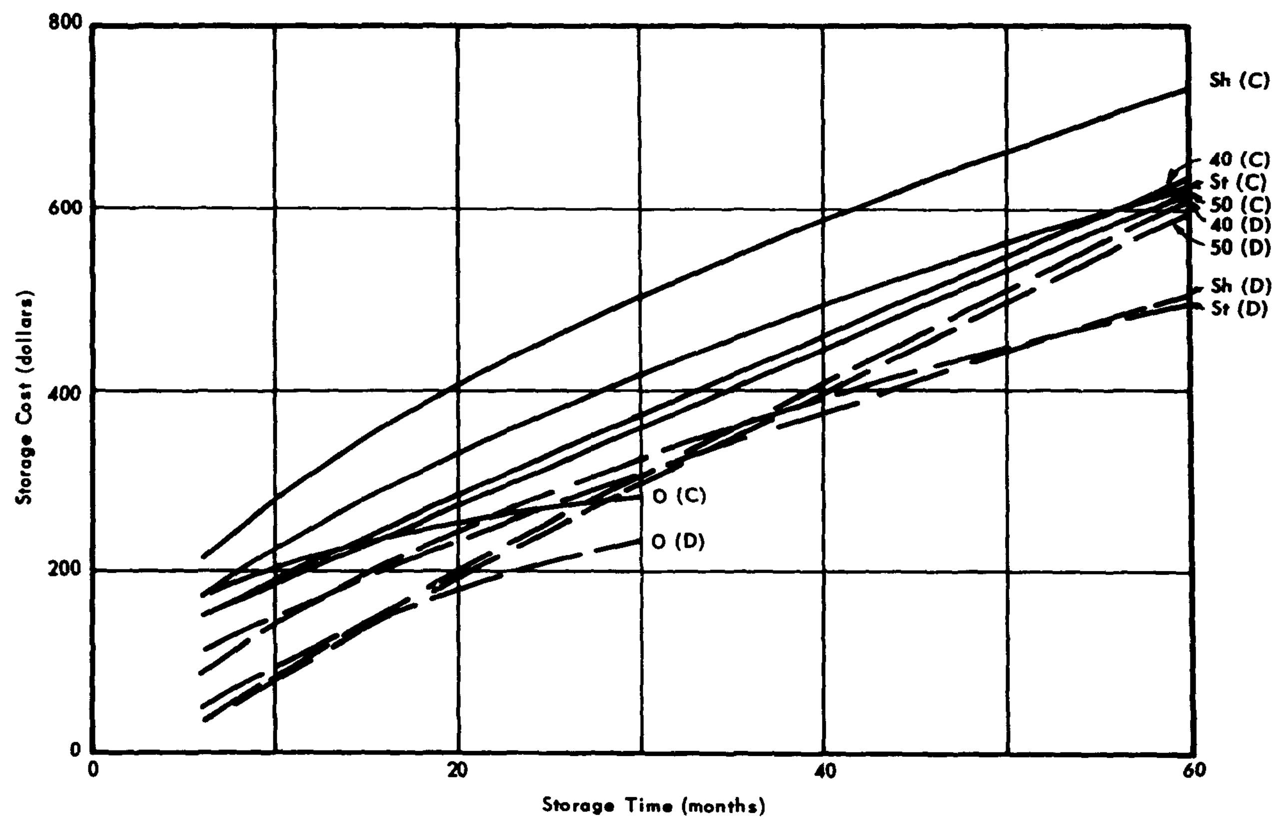

Figure E-3a. Jeep, 1/4-ton 4 x 4.

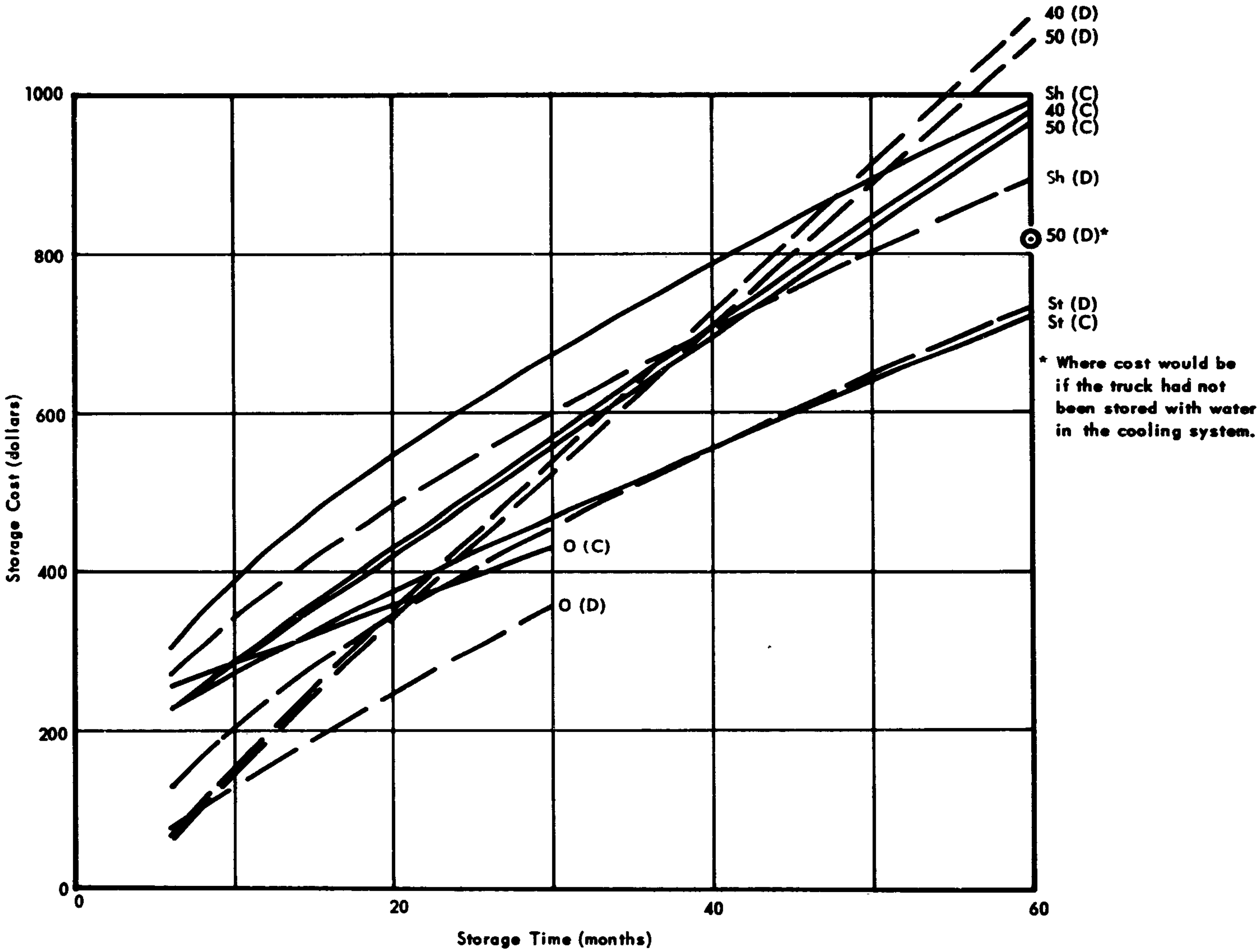

Figure E-3b. Dump truck, 2-1/2-ton 6 x 6.

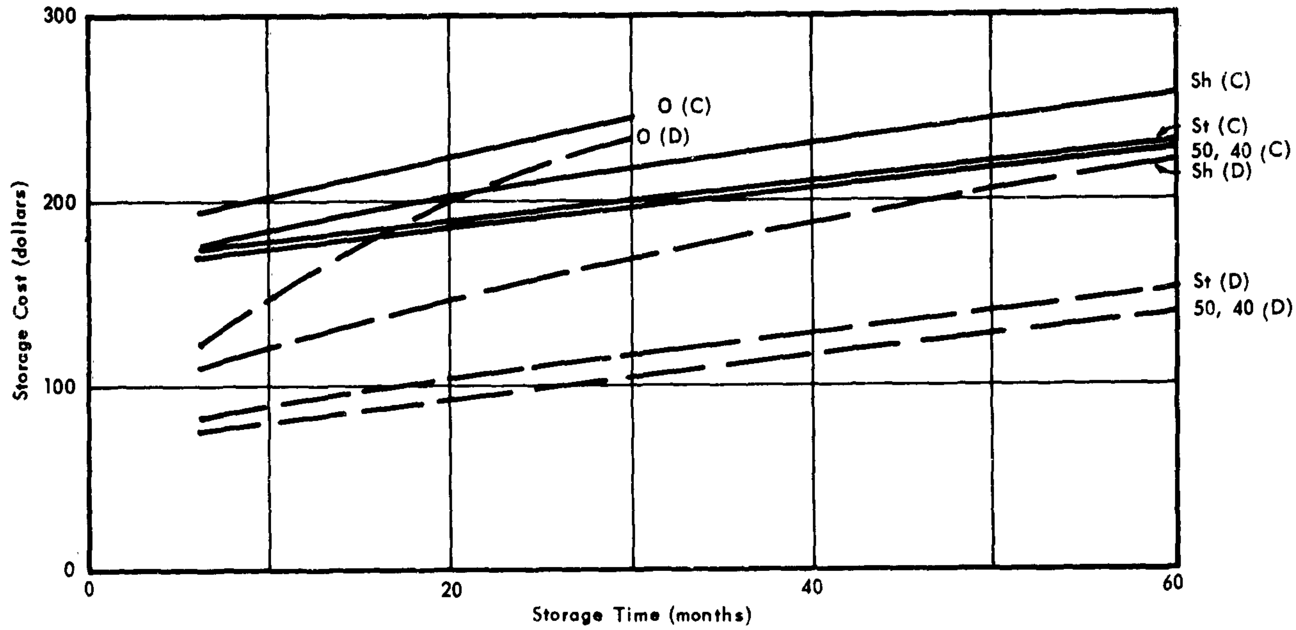

Figure E-4. Storage cost versus storage time for Group IV items.

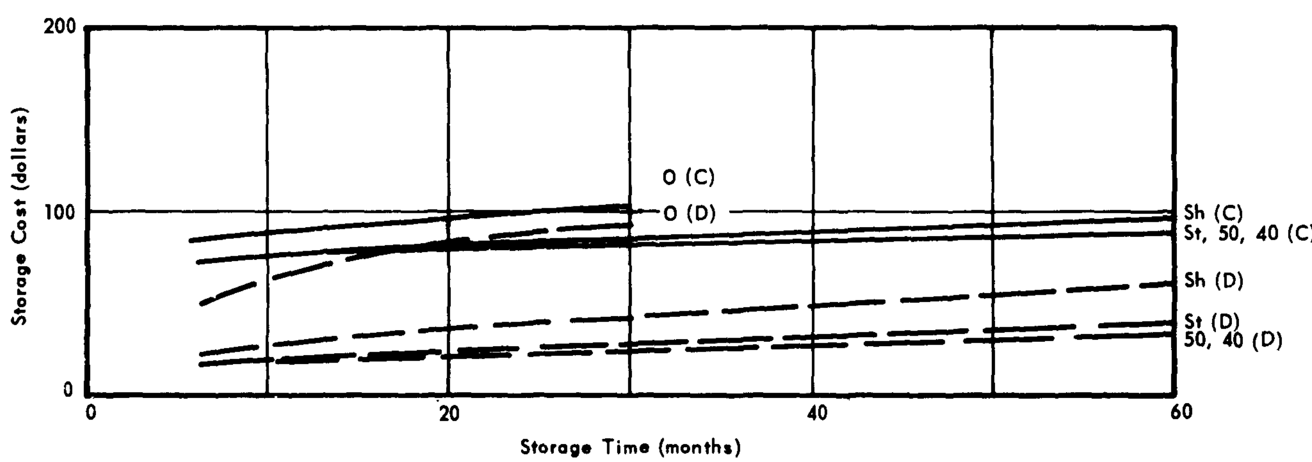

Figure E-4a. Vertical boiler, 180,000-Btu.

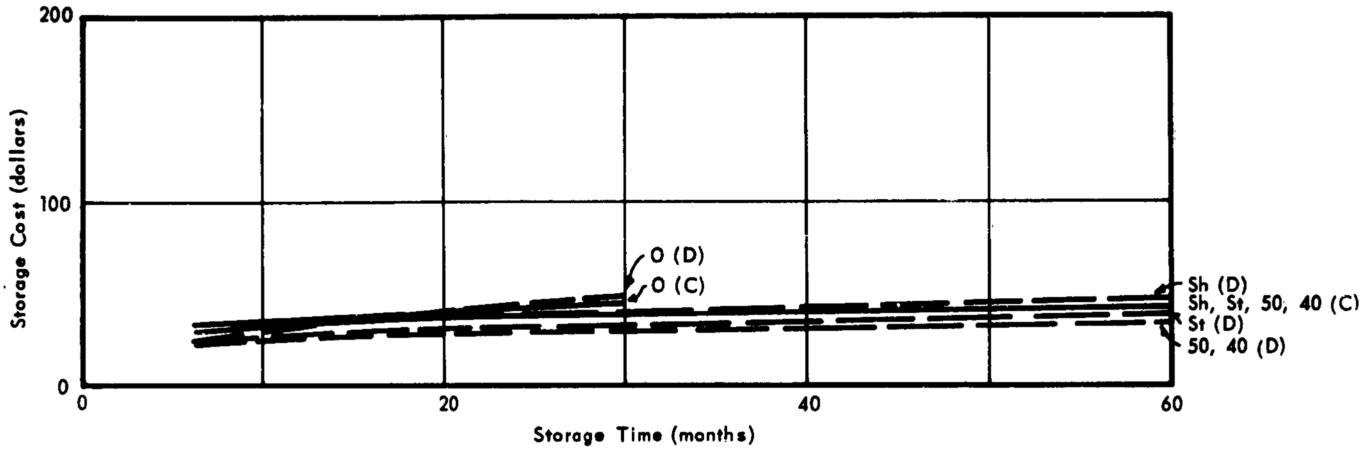

Figure E-4b. Oil-fired space heater, 50,000-Btu.

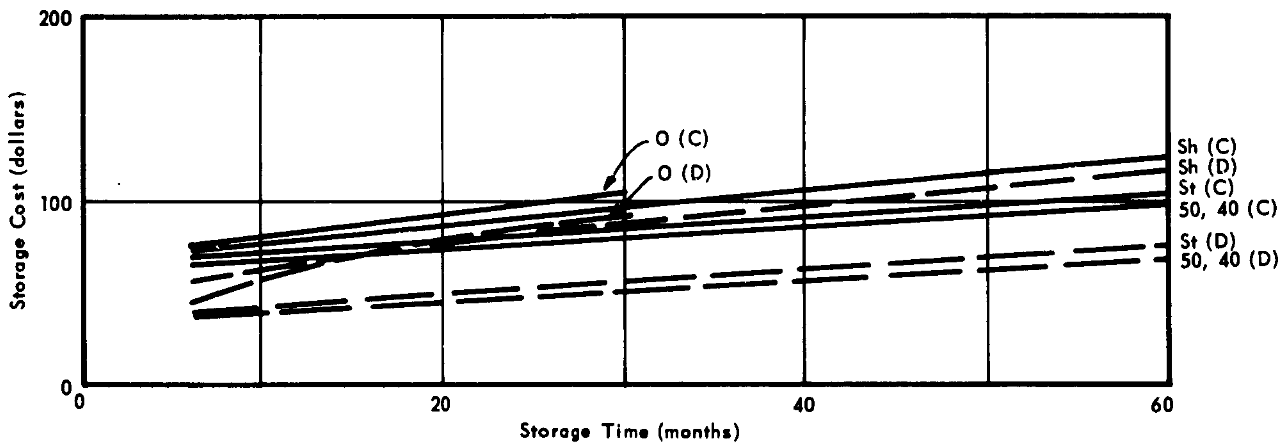

Figure E-4c. Bake oven.

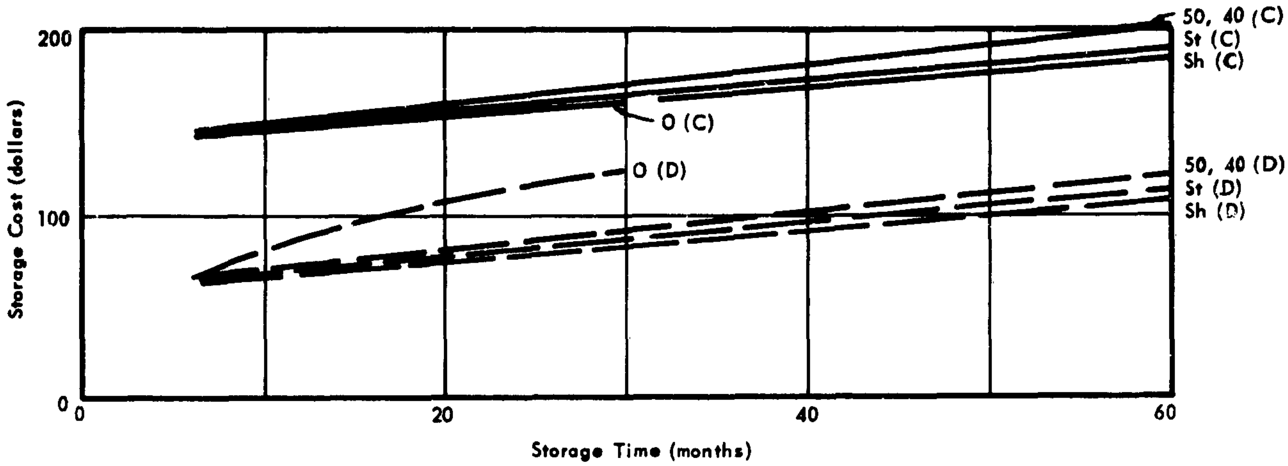

Figure E-5. Storage cost versus storage time for Group V items.

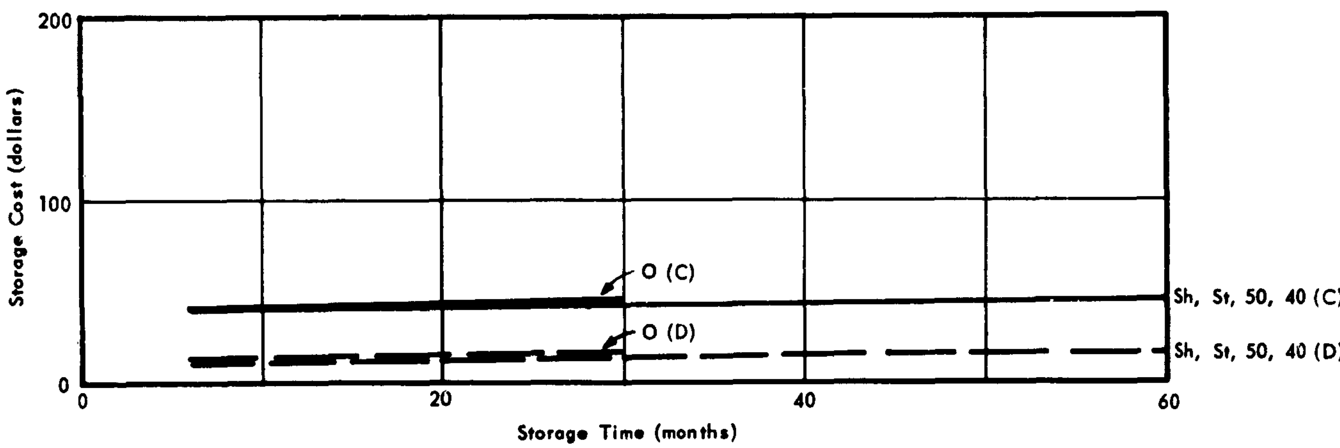

Figure E-5a. Canvas tank, 3000-gallon.

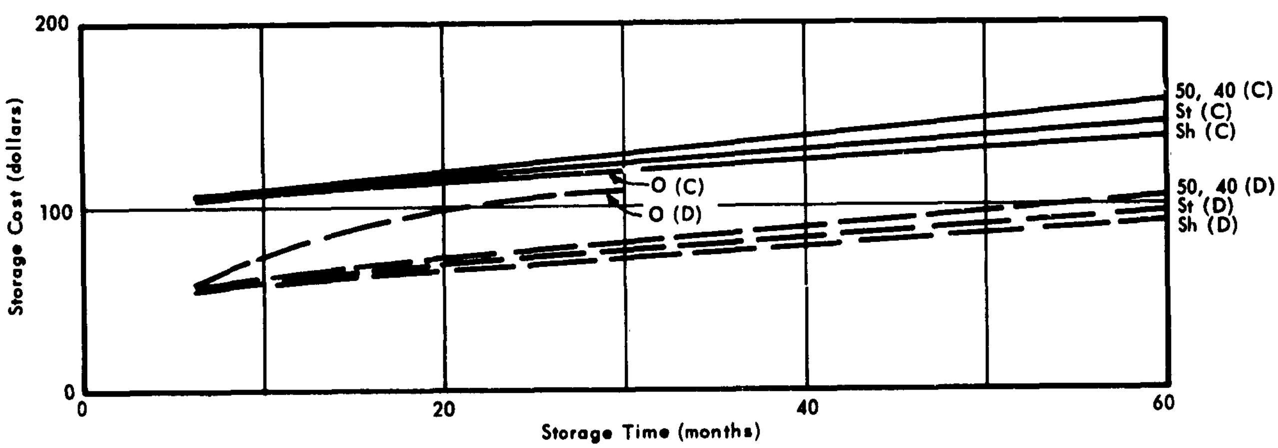

Figure E-5b. Refrigeration panels.

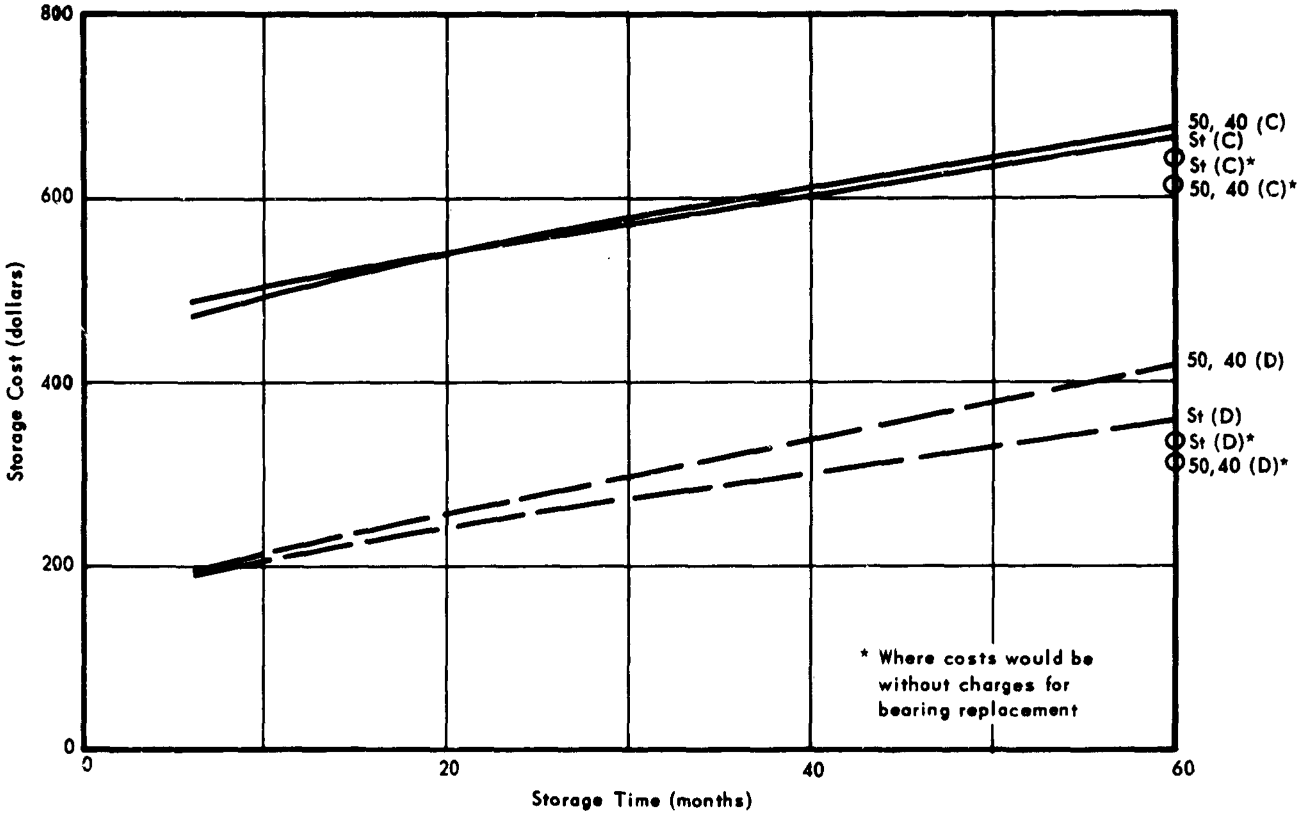

Figure E-6. Storage cost versus storage time for Group VI items.

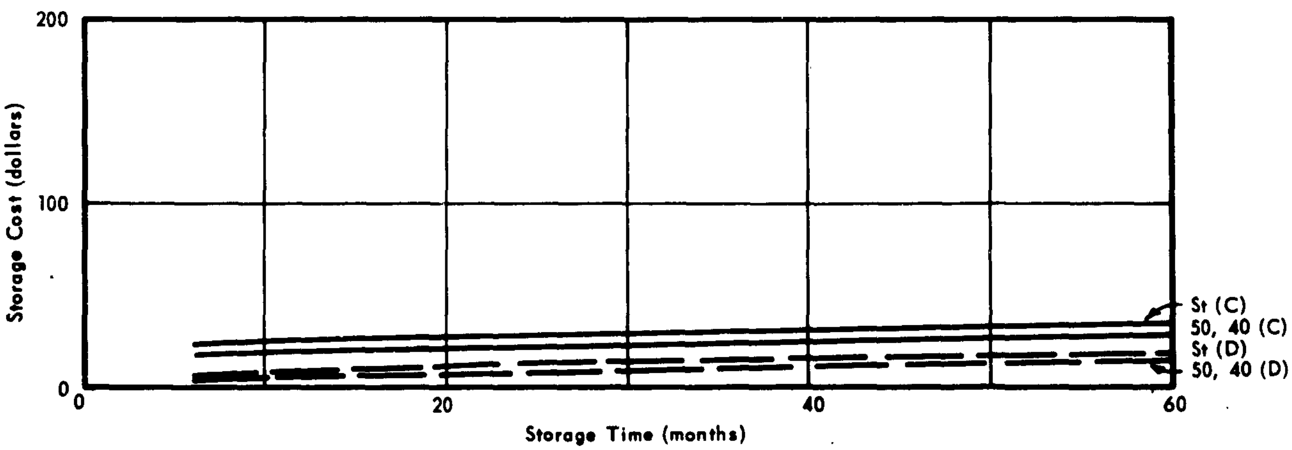

Figure E-6a. Meat slicer.

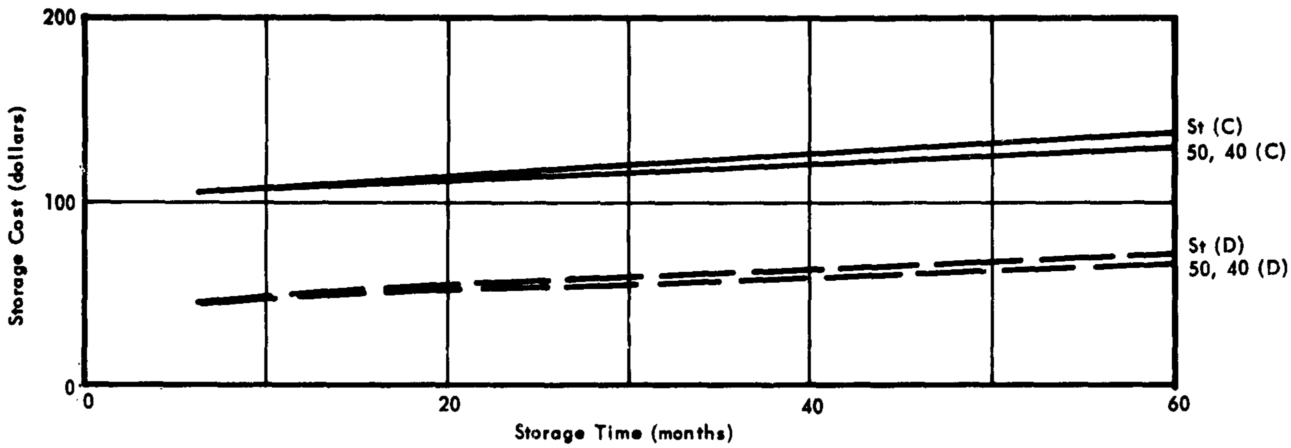

Figure E-6b. Public-address system.

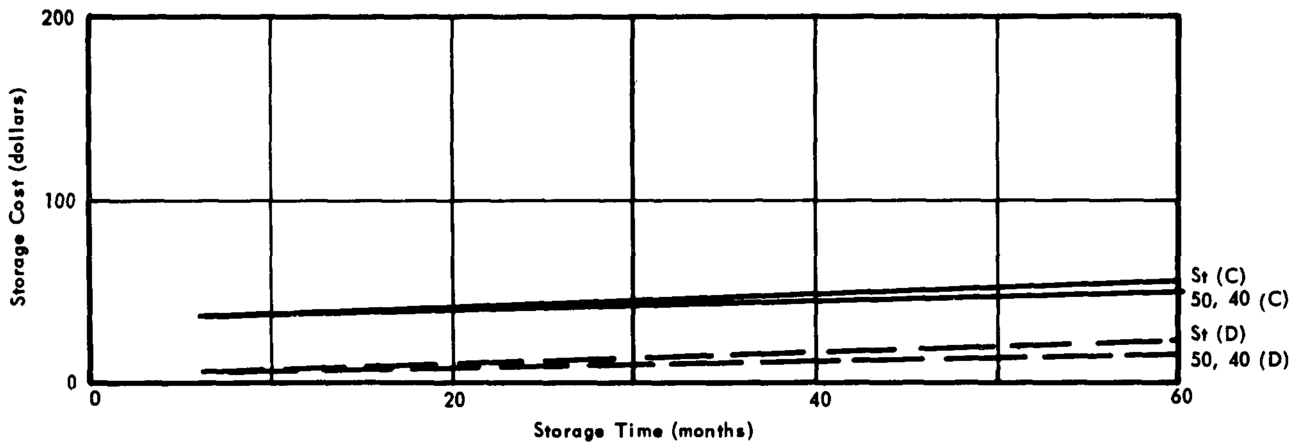

Figure E-6c. Telephone system, 13-unit.

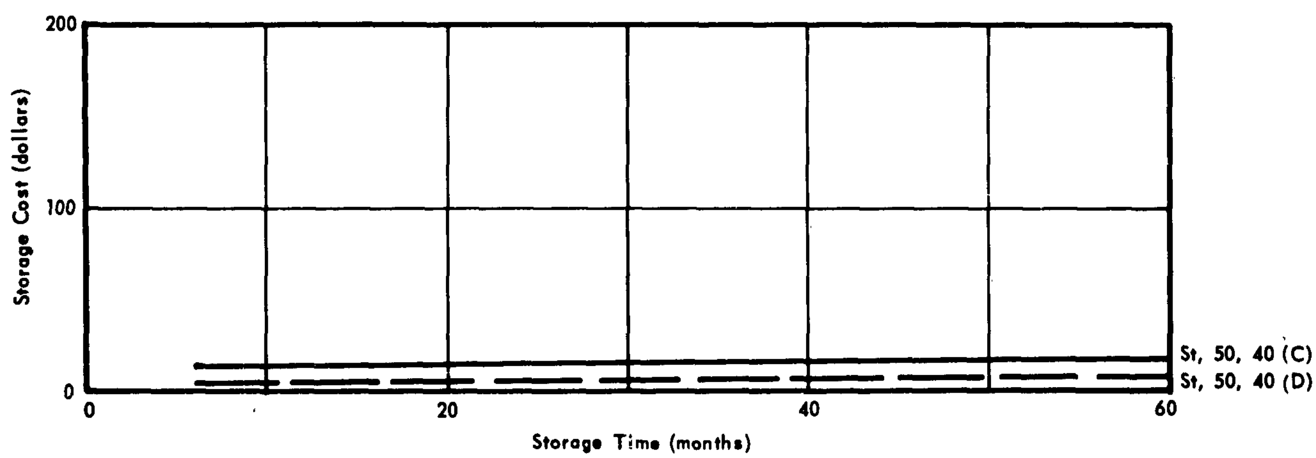

Figure E-6d. Surveyor's transit.

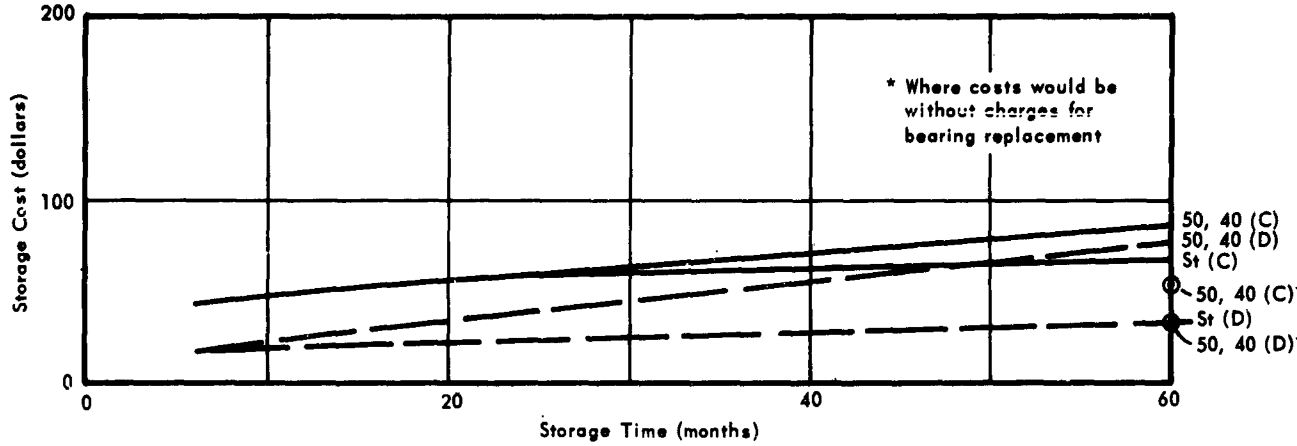

Figure E-6e. Drill press, 18-inch.

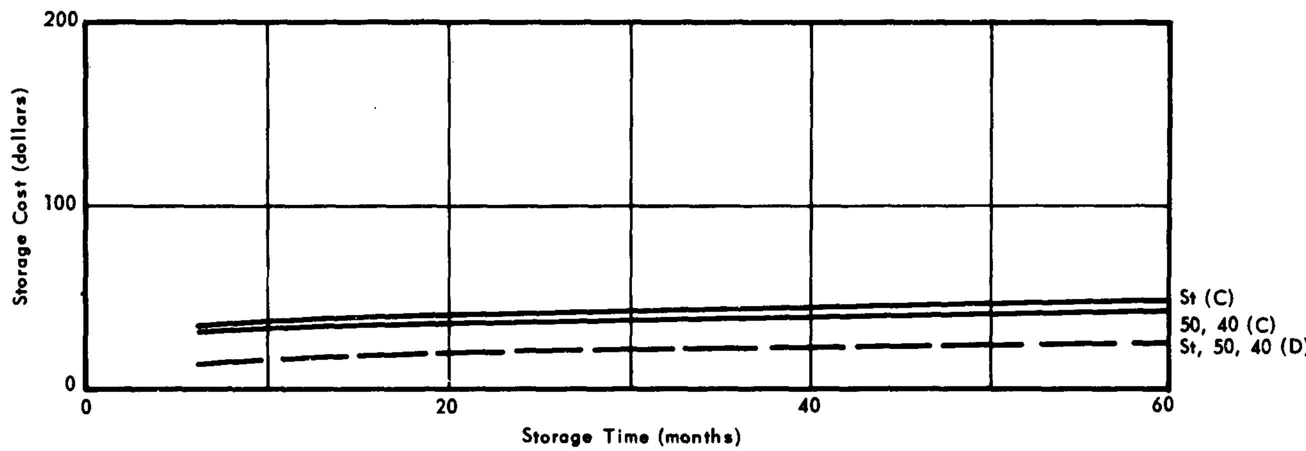

Figure E-6f. Lathe, floor model.

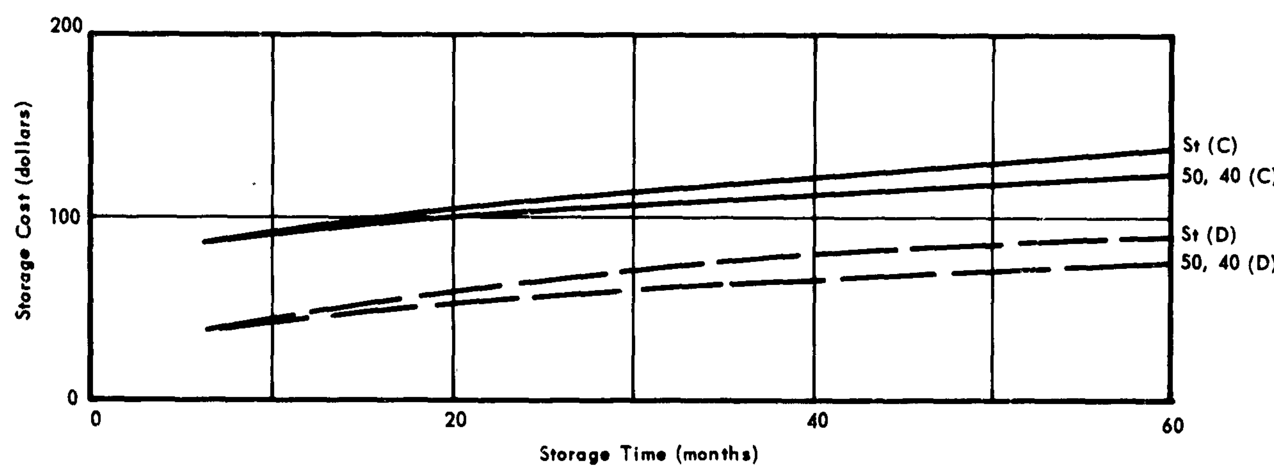

Figure E-6g. Exhaust fan, 4900-cfm.

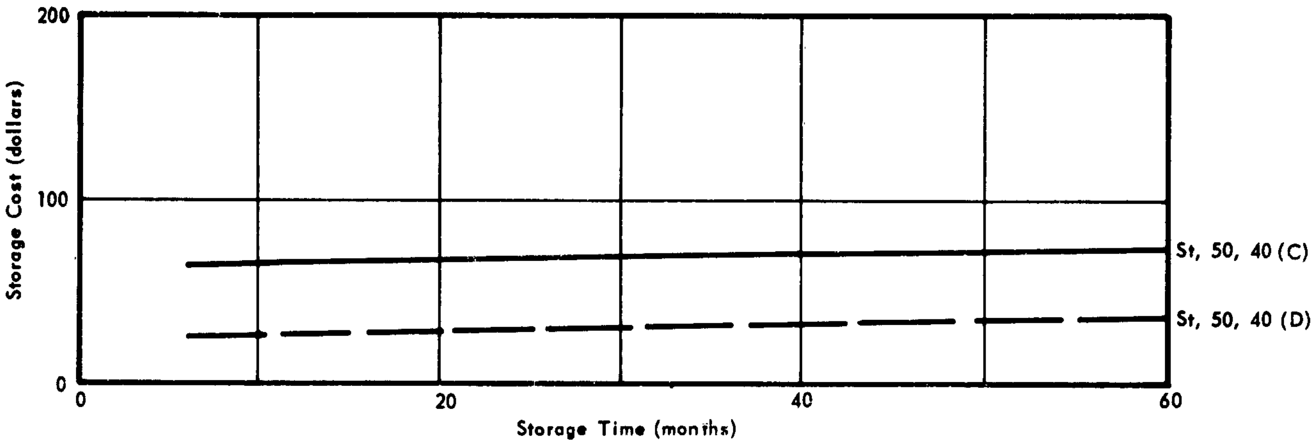

Figure E-6h. Switchboard, 50-line.

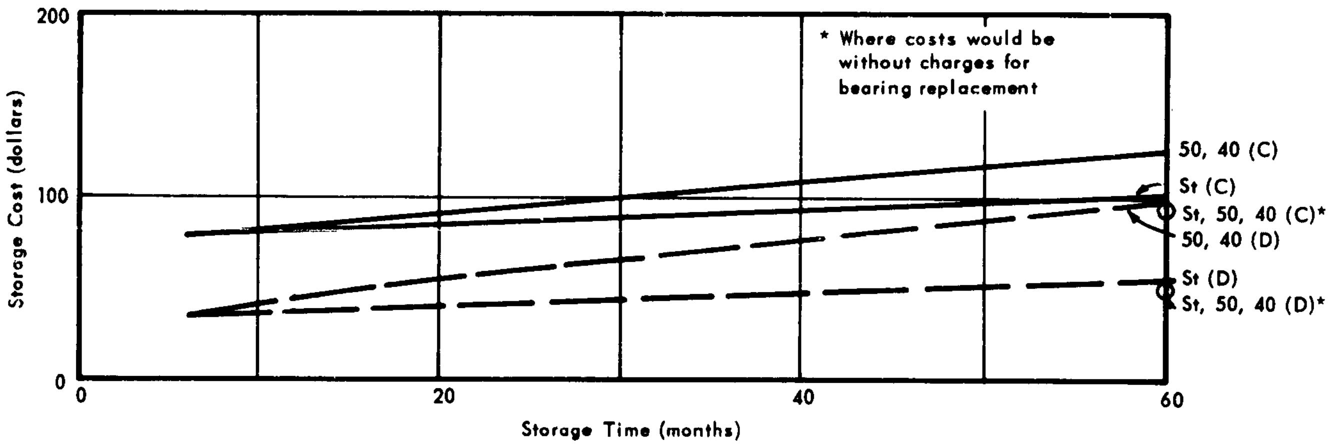

Figure E-6i. Radial saw, 16-inch.

Appendix F

ESTIMATED COST OF PACKING (BOXES & CRATES) FOR STORAGE

Item	SNS No.	Estimated Cost ($)	
		Domestic	Contact
Boiler, vertical 180,000-Btu	4520-184-3708	16	27
Chemical-warfare detector kit	6665-L60-0123	2	2
Compressor set, 30-cfm	4310-L60-0089	19	31
Distillation unit, 83-gph	4620-185-0857	20	33
Drill press, 18-inch swing	3413-L60-0001	19	19
Fan, exhaust, 4900-cfm	YS66-F-70020-50	15	15
Floodlight trailer, mobile	6230-283-9760	2	4
Generator Set, 30-kw diesel	6115-295-0973	38	63
Heater, oil-fired, 50,000-Btu	4520-200-0647	23	23
Lathe, floor model, 14-1/2-inch swing	3416-174-1535	37	37
Oven, bake	7310-275-6180	35	35
Public-address system	5830-501-4724	45	45
Pump, centrifugal, 350-gpm	4320-273-8574	28	46

Item	SNS No.	Estimated Cost ($)	
		Domestic	Contact
Pump, diaphragm, 50-gpm	4320-132-5382	19	33
Refrigeration panels for 6800 unit	4110-287-3179	49	89
Refrigerator unit, 675-6800	4110-287-3184	32	54
Saw, radial, 16-inch	YL40-S-1365-200	34	34
Searchlight, 60-inch, w/power plant	6230-L60-0142	30	30
Slicer, meat	7320-222-417	6	6
Switchboard, 50-line	5805-501-4725	23	23
Tank, canvas, 3000-gallon	5430-222-1923	11	11
Telephone system, 13-unit	5805-501-4726	6	6
Tires, 8.25 x 20, 10-ply	Y8-T-9076	Uncrated	Uncrated
Transfer unit, CO_2	3655-245-0073	9	9
Transit, surveyor's	YZ18-T-3311-750	4	4
Truck, dump, 2-1/2-ton, 6 x 6	2320-835-8595	Uncrated	Uncrated
Truck, jeep, 1/4-ton, 4 x 4	2320-835-8317	Uncrated	Uncrated
Washing machine	3510-240-6552	38	38
Welder, arc, GED, trailer, 300-amp	3432-224-7722	53	53

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