DOE/NASA CONTRACTOR REPORT

DOE/NASA CR-150574

THERMAL ENERGY STORAGE SUBSYSTEMS
(A Collection of Quarterly Reports)

Prepared by

Artech Corporation
2816 Fallfax Drive
Falls Church, VA 22042

Under Contract NAS8-32254 with

National Aeronautics and Space Administration
George C. Marshall Space Flight Center, Alabama 35812

for the U. S. Department of Energy

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This work was accomplished under the technical management of Mr. James Hankins, George C. Marshall Space Flight Center, Alabama.

16. ABSTRACT

This report contains five quarterly reports covering the progress made in the development, fabrication, and delivery of three Thermal Energy Storage Subsystems. The report discusses the design, development, and progress toward the delivery of three subsystems. The subsystem uses a salt hydrate mixture for thermal energy storage. Included are the program schedules, technical data, and other program activities from October 1, 1976, through December 31, 1977.

Cost information has been removed from this report.

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SECTION A

THERMAL ENERGY STORAGE SUBSYSTEMS

First Quarterly Report

Covering the Period October 1 -- December 31, 1976

by

Fred Ordway

January 7, 1977

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Contract No. NAS8-32254

ARTECH No. J7750-QR1

CONTENTS PAGE

SECTION I
SUMMARY

Preparations to fabricate three thermal energy storage subsystems are proceeding on schedule. Basic design of plastic containers for the salt hydrate mixtures has been completed and fabrication of experimental models is under way. Arrangements for procurement of materials have been made. Equipment for mixing and filling has been installed. All contract requirements applicable during the report period have been fulfilled.

SECTION II

CONTRACT STATUS

Progress of the work to the end of the report period has revealed no need for modification of terms of the contract.

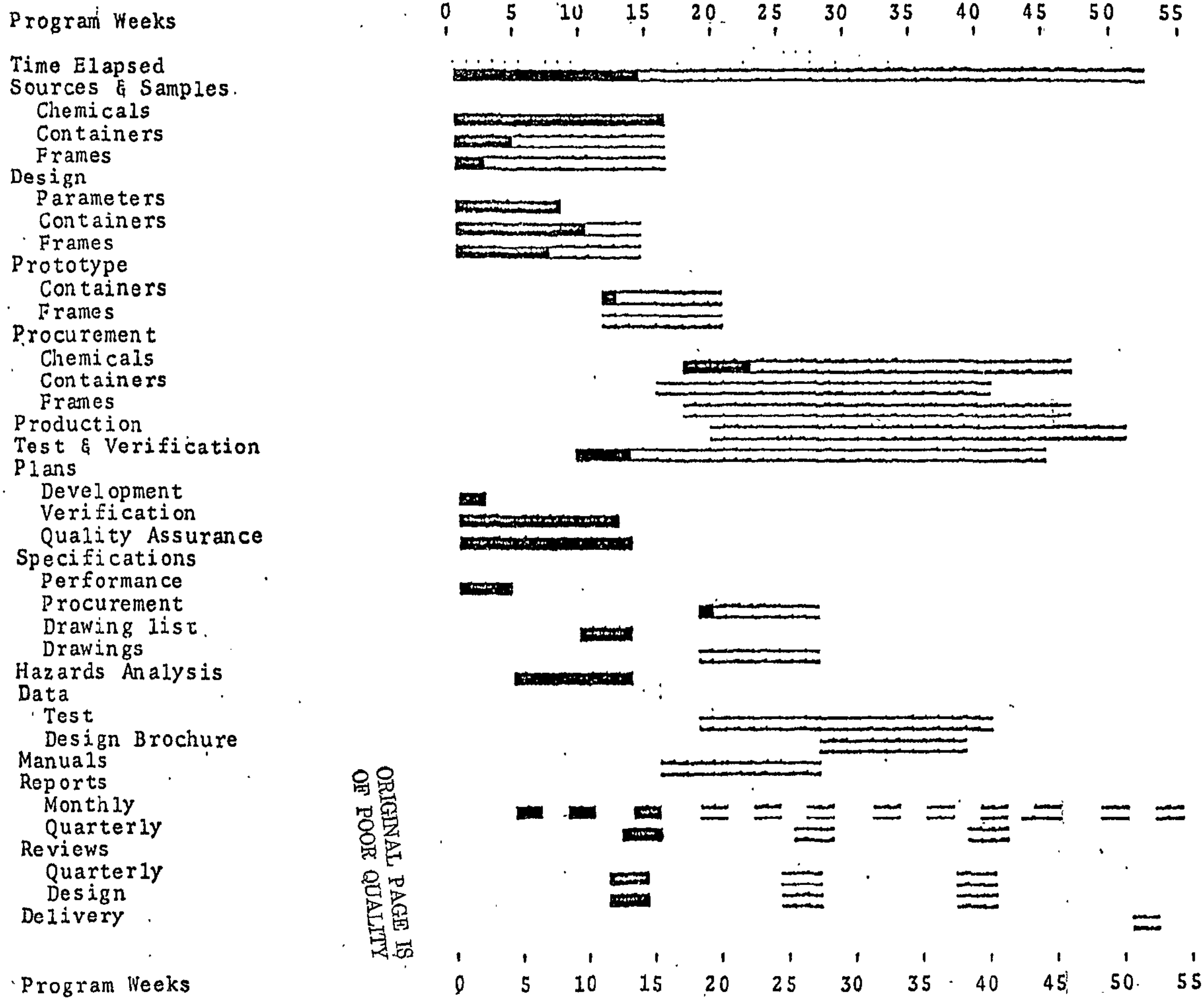
Expenditures and progress of the work show no significant variance from schedule.

SECTION III

SCHEDULES

The chart on the following page shows by blackened lines the estimated progress of the major work elements and contract management functions against the original schedule estimates prepared at the start of work on the contract. Progress is considered to be on schedule.

ARTECH CORP. TES PROGRAM PROGRESS CHART



SECTION IV

TECHNICAL PERFORMANCE

A. Work Accomplished

1. Design and Development

The basic thermal energy storage module is planned as a 2-ft cube. This unit was selected rather than one 2x2 ft in cross section and 6 ft long, as had been considered earlier, because it allows the user greater flexibility in assembling path lengths for air flow other than 6 ft, and makes possible the use of vertical assemblies of two or three modules, which may be more convenient to install, without their being prohibitively heavy.

The 2-ft cubic module will consist of sealed containers of thermal energy storage material installed in a metal frame. The major development task of the program is production of an effective container for the salt hydrate mixtures used for thermal energy storage--one that provides permanent encapsulation, adequate heat transfer, and reasonable economy.

The salt hydrate mixtures are not chemically aggressive, and can be contained in many types of plastics. For example, acrylonitrile-butadiene-styrene (ABS) tubes were used as containers in earlier thermal energy storage modules. There is a possibility, however, of water loss through the container that may affect the choice of a plastic. Analysis of the rates of water permeation through postulated containers (see section IV D3) led to the conclusion that ABS is unsatisfactory but polypropylene and high-density polyethylene should be acceptable. Both of these materials are suitably formable and moderate in price. Accorindgly they have been selected as container materials, the choice between them depending somewhat on price, availability, and expected conditions of use.

There are several possible methods for producing large containers of these thermoplastics: vacuum forming sheets and welding two halves together; blow molding the melted material; or rotating a hot mold containing powder until the melted powder entirely coats the inside. For large-scale production of rugged containers, the blow molding and rotational molding processes are most suitable. When uniformity of the container wall is an important consideration, as in this case, rotational molding is preferable. Inquiries have been instituted among rotational molders and a few blow molders to identify possible sources of containers. Quotations on a tentative design have already been received from one producer of each type. The delivery schedules they offered are compatible with the schedules already established for the program.

For production of initial prototypes, supplies of polypropylene sheet and tubing have been obtained. A vacuum thermoforming unit capable of producing container halves two feet square is being assembled.

The plastic container will be rectangular in overall dimensions, 2 ft wide, 2 ft long (i.e., in the direction of air flow), and 3 in. high. A stack of eight containers will fill the 2x2x2-ft module. The top and bottom faces will be longitudinally ribbed to form air passages between adjacent containers, and to provide adequate heat exchange surface, and one of the narrow faces will be provided with a recessed neck for filling and capping.

Design calculations were made for a number of configurations and proportions were adjusted to achieve performance according to the contract specifications. Details of the performance clacualtions are given in section IVD1. The

24x24x3-in. container has a wall thickness of 0.06 in. and the top and bottom faces have, at identical locations, 18 longitudinal grooves averaging 1.06 in. deep. The grooves provide approximately rectangular air passages 0.75x2.12 in. in cross section. Indentations on the narrow faces of the container will accommodate the module's supporting structure.

The module of eight containers will hold 440 lb of 120°F thermal energy (heat) storage material or 425 lb of 55°F thermal energy (coolness) storage material. Its total cross-sectional area of air flow passages is 1.46 sq. ft. and its total heat exchange surface area is 365 sq. ft. Under the conditions stated in the Subsystem Performance Specification, the 2x2x6-ft assembly of three heat storage modules has a calculated charging rate of 10,500 BTU/hr and the coolness storage assembly a rate of 11,300 BTU/hr, making the estimated charging times 11.1 hr and 5.9 hr respectively.

2. <u>Materials Procurement</u>

Suitable sources for all chemical ingredients of the two salt hydrate mixtures have been located and availability compatible with the contract schedule has been confirmed. Initial quantities for prototype testing have been delivered and tentative schedules for delivery of production lots have been set up.

3. <u>Production</u>

Batch mixing equipment adequate for all production requirements has been procured and installed. Materials storage and processing areas have been cleared. Dispensing apparatus for rapid filling of the containers is being fabricated.

4. Quality Assurance

A quality assurance plan was prepared and submitted to the Contract Technical Manager, received his approval on October 27, 1976, and was immediately put into operation.

(a) Organization

The Quality Assurance function is under the direction of Dr. Frank E. Swindells, who reports directly to the President of ARTECH. The Quality Assurance group is a separate group independent of, and free from control by the TES program management. The group comprises Mr. Robert Morris, a chemist who performs chemical analyses and other laboratory tests as needed, and a senior technician who makes inspections and keeps records. Other ARTECH laboratory personnel will be assigned as needed. Mr. Morris also serves as Quality Assurance Manager in the absence of Dr. Swindells.

(b) Raw Materials Qualification

A separate record is kept of all materials purchased for use in the Thermal Energy Storage program. When an order is placed, a copy of the purchase order, together with applicable specifications, is delivered to the Quality Assurance Manager to be retained in his files. As material is received, it is entered in a Receiving log with its assigned ARTECH lot number. The Receiving log is a permanently bound book in which entries are made in chronological order. All entries are made by the Quality Assurance Manager or his authorized representative.

At the same time an appropriate entry is made in the Raw Material Inventory. This is also a permanently bound book, divided into separate sections for the different materials. A stock card is also filled out. Every piece or container in the shipment is tagged or otherwise given an identifying mark, including the lot number.

Every lot of chemicals and other materials is subjected to an acceptance test as soon as possible after receipt and before being put into production or other use.

An Acceptance Report is prepared by the analyst or inspector and submitted to the Quality Assurance Manager. He distributes copies to the appropriate TES Department Manager (Chemistry, Packaging & Production, or Test & Verification), and to the Controller.

Material which does not meet the specifications after a retest is appropriately marked and segregated. It will be promptly returned to the vendor or otherwise disposed of.

(c) <u>In-Process Qualification</u>

It is the responsibility of the Quality Assurance Group to monitor all work in process for conformity with specifications. In order to perform this function, the TES Program Manager provides copies of complete process and fabrication instructions and drawings. The Quality Assurance Manager determines critical steps in the process to be checked for conformity with the procedure.

A Specification Sheet is prepared for each step to be monitored, based on specifications furnished by the Packaging & Production Manager.

When the inspection is completed, an inspection report is prepared by the inspector and submitted to the Quality Assurance Manager, who transmits a copy to the Packaging & Production Manager.

(d) <u>Inspection and Testing of Completed Item</u>

Final inspection will be performed according to procedures to be determined by agreement with the Test & Verification Department Manager. The responsibility of the Quality Assurance Department is to monitor all steps in the verification procedure to insure that they are in accord with the specifications.

All test equipment used in completed item verification tests is calibrated against standards traceable to the National Bureau of Standards. The inspector records all calibration tests as specified in MIL-C-45662A in his laboratory notebook in chronological order and provides a report of each such test for logging and filing by the Director of Standardization according to the requirements of the ARTECH Calibration System.

The Quality Assurance Manager is responsible for assuring that all manuals for installation, operation, and maintenance are in agreement with the contract and with ARTECH'S engineering experience. All such documents must bear his signature of approval.

5. Test and Verification

Tests will be performed, in a test loop as recommended by the National Bureau of Standards (Information Circular 899), on an assembly of three 2x2x2-ft modules in tandem. Test conditions will be as stated in the Subsystem Performance Specification. Test results will be certified by an independent authority, George R. Smith, licensed Professional Engineer and certified Supervisor of Environmental Testing and Hydronic Systems by the National Environmental Balancing Bureau, who will supervise performance of the tests.

Inquiries regarding code compliance were sent to the building inspection authorities of six major cities and three regional code organizations. Two of the regional organizations have already given their opinion that the use of the thermal energy storage modules is not restricted by existing codes.

B. Forecast of Activities

During the next quarter, the following tasks will be performed:

1. Preparation and evaluation of model containers
2. Preparation of prototype containers

3. Fabrication of prototype frame
4. Assembly of prototype module
5. Test of prototype module
6. Preparation of drawings and procurement specifications
7. Preparation of installation, operation, and maintenance manuals, and drawings
8. Submission of monthly reports
9. Submission of quarterly report
10. Submission of prototype review data package

C. Problem Areas

The one obvious problem in the initial production phase of the program is that with a single mold it may not be possible for a plastics molder to produce containers for more than one to two modules per day. This should not delay final delivery because the schedule established for production allows sufficient time at that rate. Close attention will be paid to scheduling in the next quarter to insure that the time available for container procurement is adequate.

D. Data

1. Thermal Performance Calculations

Performance characteristics of the tandem assembly of three 2x2x2-ft modules were calculated by standard heat transfer formulas (Jakob, "Heat Transfer", John Wiley, New York, 1949; Kreith, "Principles of Heat Transfer", 2nd ed., International Textbook Co., Scranton, Pa., 1965) using available data on properties of the materials involved. Parameters of the assembly required in the calculations but not listed in the foregoing text were

Hydraulic diameter of air flow channels = 1.2 in.

Hydraulic diameter of cross section of filled container = 1.8 in.

Storage capacity (heat) ≐ 116,700 BTU

Storage capacity (coolness) = 66,700 BTU

Calculated performance figures at various flow rates are given in the following table:

Performance - Heat Storage (T_{in}=150°F*)

Air flow rate	cfm	146	292	500*	584	1460
Air velocity in module	ft/min	100	200	342	400	1000
Utilization	$\frac{T_{in}-T_{out}}{T_{in}-120°F}$	80%	64%	72%	71%	63%
Heat transfer rate	BTU/hr	3400	5400	10,500	12,000	27,000
Charging time	hr	34	22	11.1	9.7	4.4
Pressure drop	in. H_2O	0.003	0.006	0.018	0.023	0.12

Performance - Coolness Storage (T_{in}=40°F*)

Air flow rate	cfm	146	292	500	584	1000*	1460
Air velocity in module	ft/min	100	200	342	400	685	1000
Utilization	$\frac{T_{out}-T_{in}}{55°F-T_{in}}$	74%	57%	72%	71%	66%	62%
Heat transfer rate	BTU/hr	1800	2900	6100	7100	11,300	15,400
Charging time	hr	36	23	10.9	9.4	5.9	4.3
Pressure drop	in. H_2O	0.003	0.006	0.019	0.026	0.066	0.13

* Condition prescribed by Subsystem Performance Specification

2. Water Permeability

The water permeability of high density polyethylene is given by the manufacturer as 0.3, and that of polypropylene as 0.7, in the units used for comparison of plastics (grams of water per day at 95°F, 90% relative humidity, through 100 square inches of 0.001-in. film). These permeation rates are higher than would be expected, the equilibrium relative humidity inside the container having been found to be lower than 90% and that outside always being greater than zero; thus they are a reasonable basis for a conservative estimate.

Each container has 4.0×10^3 square inches of surface and contains more than 9 kg of water. The maximum water loss in a five-year period would be 0.85 kg or 9.5% of the amount present. Inasmuch as a 20% water loss can be tolerated without marked loss of efficiency, the useful life of the thermal energy storage module even under worst conditions can be expected to be at least twice the five-year warranty period.

3. Mechanical Loads

The maximum weight of thermal energy storage material per module is estimated as 441 lb. The weight of plastic containers is estimated as 52.2 lb and that of the steel frame as 50 lb. The total weight of a single module is thus 543 lb or 1629 lb for a stack of three.

The four vertical members of the lowermost module frame support a total load of 407 lb each. A tentative choice for the cube edge frame members is 1/2 x 1/2-in. steel angle 1/8 in. thick. This material has a cross section of 0.11-in.^2 area and 0.10-in. radius of gyration. The safety factor, assuming a yield stress of 33,000 psi, is

$$f = \frac{(33{,}000)(0.11)}{(1629/4)} = 9$$

The safety factor as regards column stability is

$$f = \frac{\pi^2 r^2 E A}{L^2 P}$$

where r = radius of gyration

E = elastic modulus = 29×10^6 psi

A = cross-sectional area

L = height of column between cross braces = 3 in.

P = compressive force on column

The calculated value is

$$f = \frac{\pi^2 (0.10)^2 (29 \times 10^6)(0.11)}{3^2 (1629/4)} = 86$$

Thus the 1/2 x 1/2 x 1/8-in. steel angle is ample for the vertical load.

Racking forces may be imposed on the frame during transport or installation although they will not be significant after the modules are installed. Distortion of the frame will be prevented by a combination of diagonal bracing on the sides, cross members on the ends, welding of the edge members to form a solid frame on each face, and corner gussets if necessary.

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SECTION B

THERMAL ENERGY STORAGE SUBSYSTEMS

Second Quarterly Report

Covering the Period January 1 - March 31, 1977

by

Fred Ordway

April 8, 1977

Prepared for

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Contract No. NAS8-32254

ARTECH No. J7750-QR2

CONTENTS

SECTION I
SUMMARY

Delay in obtaining the responses of plastics molders to the initial container design, together with the time requirements for completing a prototype container and tooling for container production, will require that the First Article Review be scheduled for the forty-third to forty-fifth week of the contract. With this modification, the preparations to fabricate three thermal energy storage subsystems are proceeding on schedule. The module frame for supporting the TES containers has been designed and a prototype has been fabricated. Production drawings of the components have been prepared and submitted together with the required data package for the Prototype Design Review. All contract requirements applicable during the report period have been fulfilled.

SECTION II

CONTRACT STATUS

Progress of the work to the end of the report period has revealed no need for modification of terms of the contract.

SECTION III

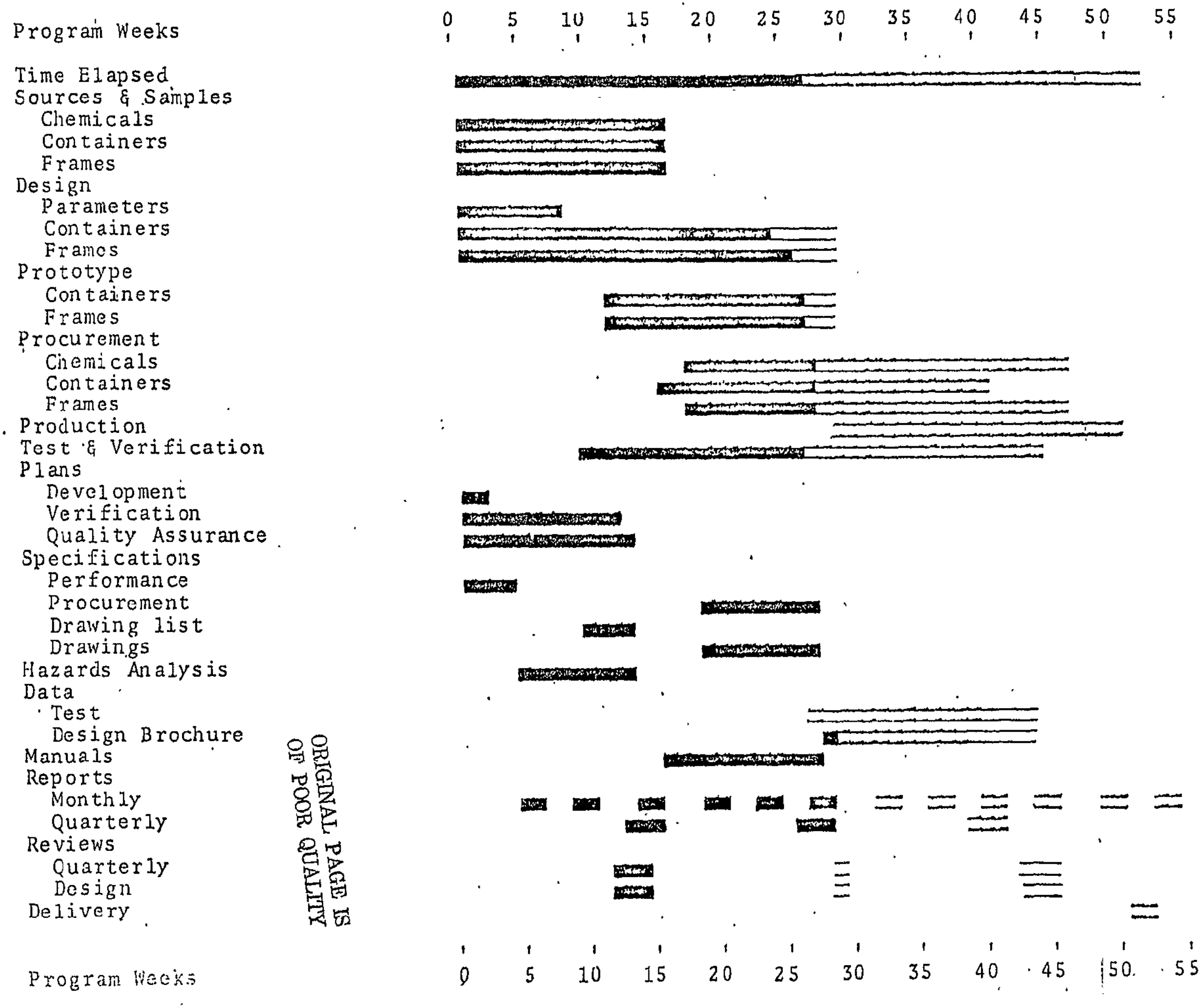
SCHEDULES

When the initial container design had been completed, it was necessary to submit the drawings to a number of plastics molders in order to determine that the proposed container is producible in quantity by conventional molding processes. Fabrication of the prototype was held in abeyance until producibility of the design had been verified. The responses from molding firms were obtained later than contemplated in the original schedule. The estimated times required for prototype fabrication and evaluation and preparation of tooling for container production are such that the first article production and testing cannot be completed in time for the originally scheduled First Article Review. It is estimated, however, that the First Article Review can be completed by the forty-fifth week of the contract, and that sufficient time will remain for completing production of the three subsystems by the scheduled final delivery date.

The chart on the following page shows by blackened lines the estimated progress of the major work elements and contract management functions against the schedule estimates as revised according to the foregoing discussion.

Progress is considered to be on schedule.

ARTECH CORP. TES PROGRAM PROGRESS CHART



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SECTION IV

TECHNICAL PERFORMANCE

A. Work Accomplished

1. Design and Development

Tests of the potentialities of the vacuum thermoforming method, which had been proposed for producing one or more prototypes of the plastic container, showed that this technique was not usable because drawing of the sheet plastic into slots with a depth:width ratio of 6:1 would produce excessive variations in the wall thickness of the resulting shell. The same objection would apply, at least to some extent, to the use of blow molding for production of the containers. For this reason, rotational molding has been tentatively selected as the production process.

As a part of the examination of the design preparatory to final production of containers, an exact size wooden model or pattern of the container is being fabricated. It is planned that an experimental mold will be made from this pattern by use of a suitable casting material. A prototype container will then be assembled from sections of sheet plastic cut and bent by hand to match the contour of the notches and ribs. The material will be cut in 18 sections and welded together by conventional hot-gas plastic welding techniques. The patterns for cutting and bending the sheet material have been developed and the required 1/16-in. plastic sheet has been procured.

A supporting frame design has been developed that is submodular, i.e., employs a separate frame segment for each of the containers. These segments will be capable of assembly on the installation site or at the factory, whichever may turn out to be desirable from the viewpoints of convenience and economics. By use of the segmented frames modules of 2-ft, 4-ft, and 6-ft height, and also various intermediate heights, can be assembled. Whether it may be desirable to offer the designer the entire possible range of modular heights, up to 72 in. in units of 3 in., rather than the 2-, 4-, and 6-ft heights only, has not been decided.

A prototype of the segmented frame for the thermal energy storage module of 2-ft height has been fabricated and examined. The prototype evidenced ample rigidity and it was concluded that the horizontal members of the frame can be made from 3/8x1/8-in. steel strip rather than the 3/8x3/16-in. material used in the prototype.

Data sheets giving the predicted performance of the 2-ft thermal energy storage modules were compiled, and are reproduced in section IV.D.1.

2. Materials Procurement

Arrangements for supplies of chemical ingredients of the salt hydrate mixtures had been made earlier. During this report period, vendors for the plastic containers and steel frames were tentatively selected after circulation of drawings to numerous sources for cost estimates and discussion.

3. Production

Dispensing apparatus that had been fabricated in our shop was found to be somewhat inconvenient in use, but a commercial slurry pump was obtained that has proved quite satisfactory for the purpose. The mixing and dispensing equipment has been used in producing batches of thickened thermal energy storage materials sufficient for 12 2x2x2-ft modules.

4. Quality Assurance

To carry out the assays of chemical ingredients that may be required in performance of the quality assurance operations discussed in the First Quarterly Report, analytical methods have been selected and carried out on samples of the materials to be used in production.

5. Test and Verification

An air handling loop with provisions for heating or venting was set up and used for cyclic charging and discharging of several 2x2x6-ft thermal energy storage modules. The modules tested were of the older tubular style rather than the type being developed in this program, but the cycling loop will be usable also with the planned configuration of three 2x2x2-ft modules in series. The loop was operated with temperature recording equipment and other instrumentation, and in the process provided valuable experience in dealing with the minor operating problems that may be expected in the tests to be done later on the new modules.

The test loop to be used in testing the new modules according to the Subsystem Performance Specification is now being designed.

B. Forecast of Activities

During the next quarter, the following tasks will be performed.

1. Preparation of prototype container
2. Fabrication of new prototype frame
3. Testing of prototypes
4. Placing orders for production

5. Assembling test loop
6. Assembling production prototype for test
7. Submission of monthly reports
8. Submission of quarterly report

C. Problem Areas

Container production schedules are the only visible problem area. Close attention will have to be paid to scheduling in order to insure that testing and first article approval can be performed in time for subsequent production to meet the scheduled delivery date.

D. Data

Data sheets on the design characteristics of the thermal energy storage modules are given in the following pages.

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TECHNICAL DATA ON TES MODULE

TESmod T.M.

Catalog No. 7712

External Dimensions: 2x2x2 ft

Frame: Steel, with four connecting rods

Containers: 8 High density polyethylene containers
Length - 24 in.
Width - 24 in.
Height - 3 in.
Wall - 1/16 in.

Area for:
Heat Exchange 122 sq ft
Air Circulation (cross section) 1.46 sq ft

Weight:		
	TES Material	395 lb
	Containers and Caps	50
	Frame	35
	Total	480 lb

The following data are for 3 modules in series (tandem)

Thermal Energy Storage Capacity:

Latent Heat	106,650	BTU at 120°F
Sensible Heat	505	BTU per °F below 120°F
	805	BTU per °F above 120°F
Latent and Sensible Heat	136,000	BTU from 70°F - 126°F
Maximum Temperature	145°F	

Heat Transfer and Pressure Drop

Charge/discharge rate = $(1.42\ V_{mm}\ \Delta T)$ BTU/hr

V_{mm} = mean air velocity inside module, ft/min
$\Delta T = |T_{in} - T_{out}|$ = absolute value of temperature difference between air streams in and out, °F

Temperature difference utilization and pressure drop are functions of air velocity:

V_{mm}, ft/min.	100	200	400	1000
Air Flow Rate, cfm	146	292	584	1460
$(T_{in} - T_{out})/(T_{in} - 120°F)$	>0.75	0.64	0.71	0.63
ΔP, inches of water	0.003	0.006	0.02	0.12

Consumer Protection • Power Sources • Materials • Instrumentation • Testing • Analysis

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TECHNICAL DATA ON TES MODULE

TESmod T.M.

Catalog No. 7711

External Dimensions: 2x2x2 ft

Frame: Steel, with four connecting rods

Containers: 8 High density polyethylene containers
- Length ~ 24 in.
- Width ~ 24 in.
- Height ~ 3 in.
- Wall ~1/16 in.

Area for:
- Heat Exchange 122 sq ft
- Air Circulation (cross section) 1.46 sq ft

Weight:	
TES Material	380 lb
Containers and Caps	50
Frame	35
Total	465 lb

The following data are for 3 modules in series (tandem)

Thermal Energy Storage Capacity:

Latent Heat	88,920 BTU at 55°F
Sensible Heat	490 BTU per °F below 55°F
	835 BTU per °F above 55°F
Latent and Sensible Heat	108,000 BTU from 50°F - 75°F
Maximum Temperature	145°F

Heat Transfer and Pressure Drop

Charge/discharge rate = $(1.66\ V_{mm}\ \Delta T)$ BTU/hr

V_{mm} = mean air velocity inside module, ft/min

$\Delta T = |T_{in} - T_{out}|$ = absolute value of temperature difference between air streams in and out, °F

Temperature difference utilization and pressure drop are functions of air velocity:

V_{mm}, ft/min	100	200	400	1000
Air Flow Rate, cfm	146	292	584	1460
$(T_{in} - T_{out})/(T_{in} - 55\ °F)$	>0.71	0.57	0.71	0.62
ΔP, inches of water	0.003	0.006	0.03	0.13

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SECTION C

THERMAL ENERGY STORAGE SUBSYSTEMS

Third Quarterly Report

Covering the Period April 1-June 30, 1977

by

Fred Ordway and Leslie J. Toth

July 15, 1977

Prepared for

George C. Marshall Space Flight Center

Marshall Space Flight Center, Alabama 35812

Contract No. NAS8-32254

ARTECH No. J7750-QR3

CONTENTS

SECTION I

SUMMARY

Delays in fabrication and production of the plastic containers led to a required contract extension. A contract modification extending the final delivery and contract completion date to January 15, 1978, was requested and received. Preparations to fabricate the three thermal energy storage subsystems are proceeding according to this revised schedule.

All contract requirements applicable during the report period have been fulfilled.

SECTION II

CONTRACT STATUS

The progress of the work to the end of the report period required an extension of the contract completion and hardware delivery dates to January 15, 1978. A contract modification to that effect was requested and received.

SECTION III

SCHEDULES

The ultimate production schedule is completely dependent on the production of the rotationally molded plastic containers. Container production was delayed by a series of contacts with the rotational molders to insure practicability of the basic design concept and by attempts at in-house construction of a hand-made prototype before the final design was committed to production. These delays necessitated an extension of the final delivery date, and consequently of the contract duration.

Estimates of the time required to complete the work led to the following suggested time extensions:

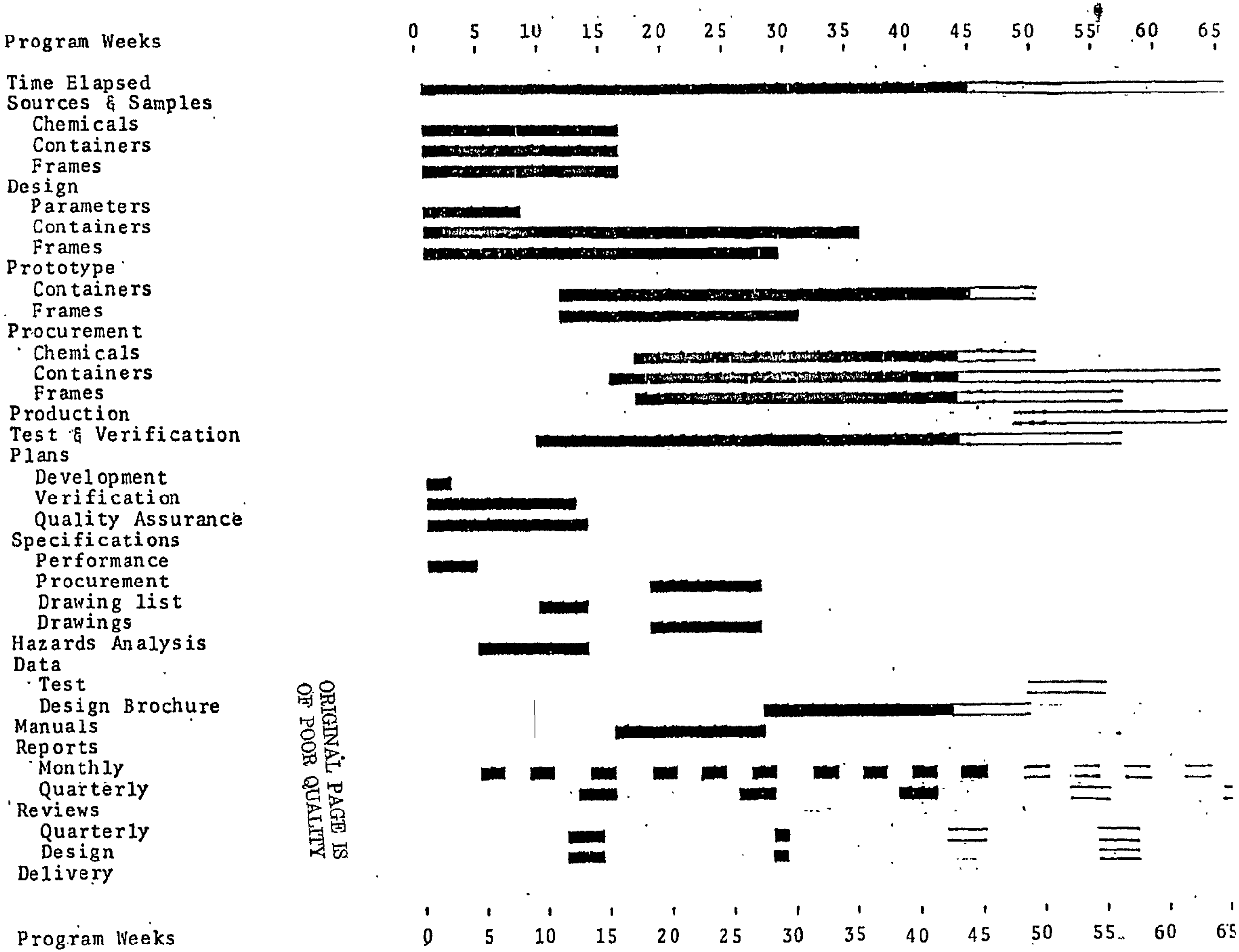
First Article Review	November 17, 1977
Final Delivery and Contract Completion Date	January 15, 1978

A contract modification to that effect was requested and received.

The chart on the following page shows by blackened lines the estimated progress of the major work elements and contract management functions against the schedule estimates as revised according to the foregoing discussion.

Progress is considered to conform to the revised schedule.

ARTECH CORP. TES PROGRAM PROGRESS CHART



SECTION IV

TECHNICAL PERFORMANCE

A. Work Accomplished

1. Design and Development

Rotational molding was selected as the production process most suitable for fabrication of the plastic containers after an extensive evaluation. A method of closure using standard commercially available tapered plugs was developed. This permitted a simple design of the molded filler neck and the use of two seals, one providing mechanical strength and a second to insure a hermetic closure.

Construction of a complete hand-made prototype plastic container was halted due to difficulties in fabrication. The rib structure of the container was fabricated, however, and its stiffening effect was evaluated. The overall design was concluded to be mechanically satisfactory.

The prototype frame with lightened horizontal members was completed and found to have satisfactory structural characteristics. Fastenings were developed for the frame assembly so that the corner rods of a module of any height can be tightened by screws with no protrusion more than 1/8 inches outside the 2 x 2 x (2, 4, or 6)-ft. design envelope.

2. Materials Procurement

Formed Plastics, Inc., was chosen as the rotational molder to produce the plastic containers on the basis of production capability, cost, delivery, and other factors. The container contract was let and tooling for container production was begun.

3. Production

Preparations for mixing and dispensing the thickened thermal energy storage materials are complete and ready for production.

4. Quality Assurance

Analytical methods have been selected and personnel are prepared to sample chemical ingredients to assure proper quality control.

5. Test and Verification

The general design of the test loop to be used in testing the new modules according to the Subsystem Performance Specification has been planned. Detailed specifications are being completed for preparation of shop drawings and construction of the test loop. The apparatus will be approximately 3.5 x 7 x 16 ft. in overall size. It will contain a 7-kW heater, a 18,000-BTU/hr air conditioner, and a 1.0-hp blower. By use of solid-state controls, the input air temperature will be held constant within ±2°F. The loop should be ready for the testing required by the revised schedule.

B. Forecast of Activities

During the next quarter, the following tasks will be performed:

1. Tooling for container production
2. Production and approval of container first lot
3. Assembly and debugging of test loop
4. Filling and cycling of test lot

C. Problem Areas

Container production and test loop fabrication schedules are the only potential problem areas. Current estimates indicate that both container production and test loop fabrication should be completed in time to meet the revised contract schedule.

D. Data Submittals

Data and status reports were submitted according to contract requirements during the report period.

ARTECH CORP. 2816 Fallfax Drive Falls Church, Virginia 22042 (703) 560-3292

SECTION D

THERMAL ENERGY STORAGE SUBSYSTEMS

Fourth Quarterly Report

Covering the Period July 1 - September 30, 1977

by

Fred Ordway and Leslie J. Toth

October 15, 1977

Prepared for

George C. Marshall Space Flight Center

Marshall Space Flight Center, Alabama 35812

Contract No. NAS8-32254

ARTECH No. J7750-QR4

CONTENTS

SECTION I

SUMMARY

Detailed specifications and contract forms for procurement of the air test loop were worked out and bid invitations were distributed to four qualified vendors. The container supplier's plant was inspected and his manufacturing processes approved. Further delays in production of the plastic containers and construction of the test loop were encountered. The effects of these delays on the final delivery schedule was not clear by the end of the report period. All contract requirements applicable during the report period have been fulfilled.

Section II has been deleted.

SECTION III

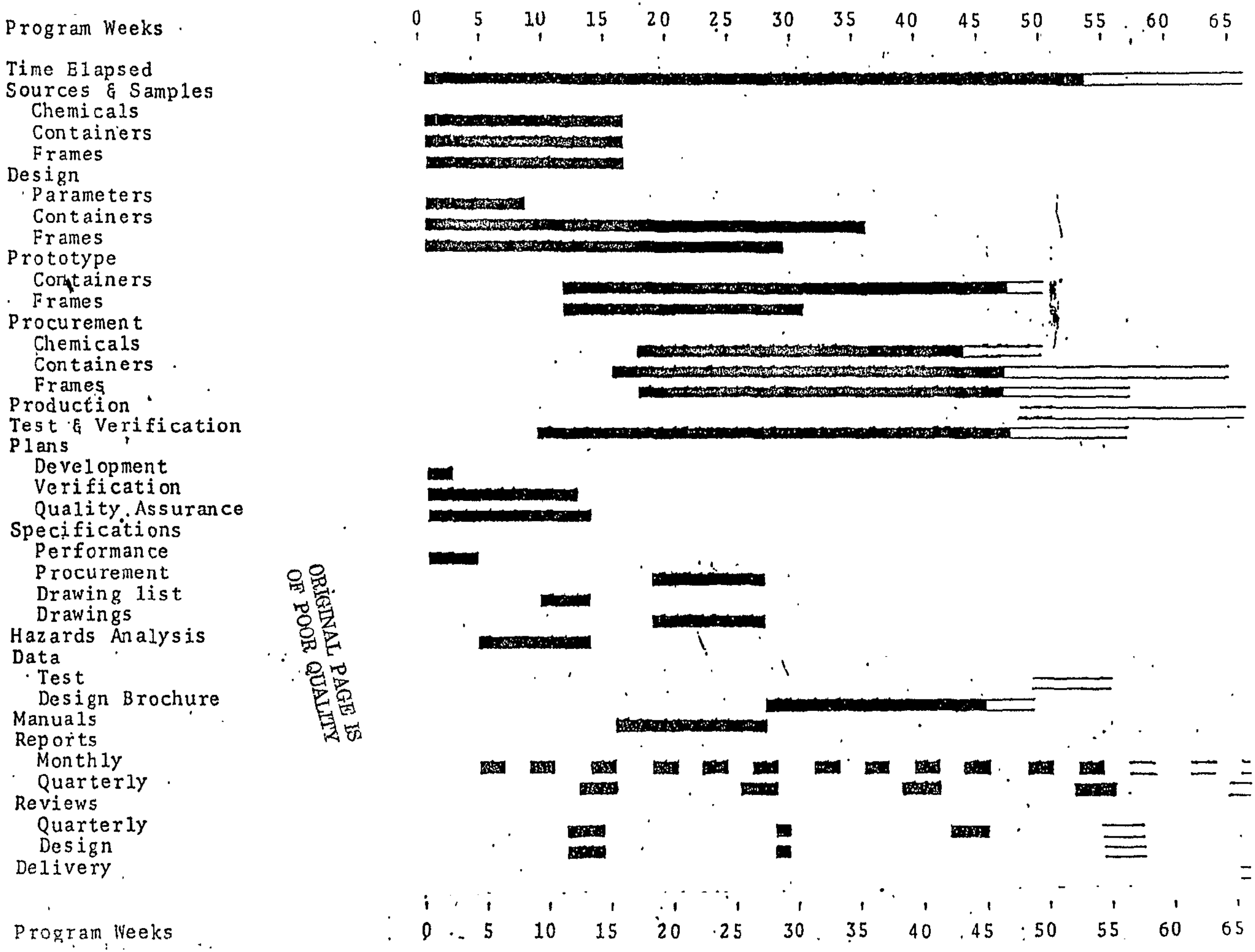
SCHEDULES

Further delays in the delivery of plastic containers for initial testing and in the construction of the test loop have been encountered. The test and production phases cannot be accelerated sufficiently to make up for these delays. The contract delivery schedule will be reevaluated when delivery of containers begins.

The chart on the following page shows by blackened lines the estimated progress of the major work elements and contract management functions against the previously established schedule estimates.

Except for the delays described above, progress is considered to conform to the schedule.

ARTECH CORP. TES PROGRAM PROGRESS CHART



SECTION IV

TECHNICAL PERFORMANCE

A. Work Accomplished

1. Design and Development

A prototype container frame based on lighter structural members and simpler fabrication methods was developed, and is now being tested.

2. Materials Procurement

Materials procurement is up to date with the previously established production schedule.

The plant of the container vendor was visited on August 25 and the production equipment and procedure were inspected.

3. Production

Tooling for container production was completed. The first sample containers are now being rotationally molded.

4. Quality Assurance

Analytical methods have been established and personnel are prepared to sample chemical ingredients and products according to the approved quality control plan.

5. Test and Verification

Detailed specifications and contract forms for design and construction of the test loop were worked out, conforming to published ASHRAE and NBS standards. Invitations to bid were distributed to four qualified vendors. No response had been received by the end of the report period.

B. Forecast of Activities

During the next quarter, the following tasks will be performed:

1. Production and approval of container first lot.
2. Assembly and debugging of test loop.
3. Filling and cycling of test lot.

C. Problem Areas

Delays in container production and test loop fabrication schedules are the main problem areas. Every effort will be made to expedite these activities. When the performance to be expected of the vendors has been clarified, the schedule of program activities will be reevaluated.

D. Data Submittals

Data and status reports were submitted according to contract requirements during the report period.

ARTECH CORP. 2816 Fallfax Drive Falls Church, Virginia 22042 (703) 560-3292

SECTION E
THERMAL ENERGY STORAGE SUBSYSTEMS

Fifth Quarterly Report

Covering the Period October 1 - December 31, 1977

by

Fred Ordway and Leslie J. Toth

January 12, 1978

ORIGINAL PAGE IS
OF POOR QUALITY

Prepared for

George C. Marshall Space Flight Center
Huntsville, Alabama 35812

Contract No. NAS8-32254

ARTECH No. J7750-QR5

CONTENTS

SECTION I

SUMMARY

Responses to the request for bids for construction of the test loop were received, at five to six times the budgeted cost. Accordingly, the decision was made to purchase components for in-house assembly of the test loop at approximately the budgeted cost. Satisfactory plastic containers have still not been received from the manufacturer. The effect of this delay has been incorporated in a proposed schedule revision submitted to the Contract Technical Manager. All contract requirements applicable during the report period have been fulfilled.

Section II has been deleted

SECTION III

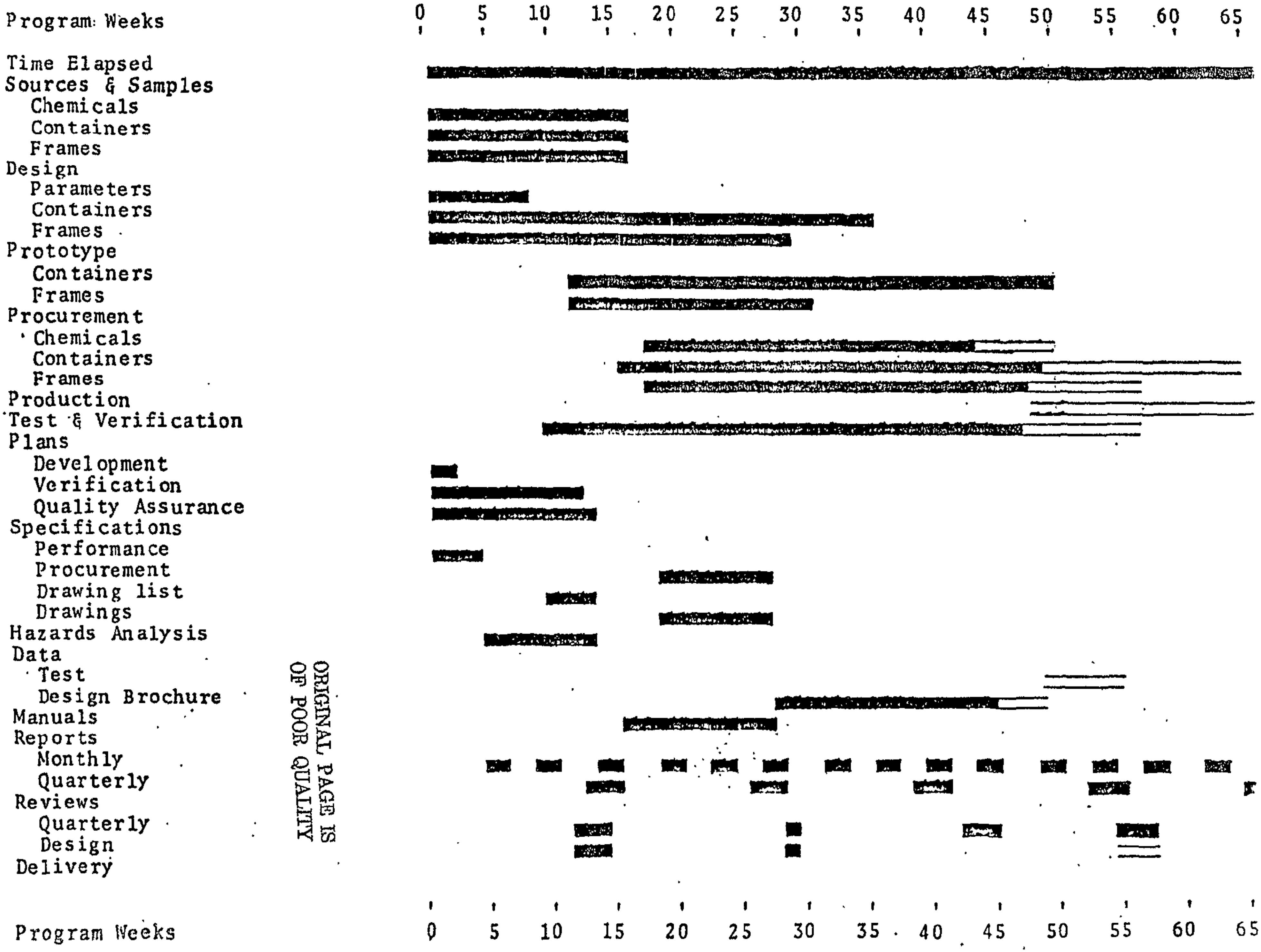
SCHEDULES

Further delays have been encountered in the procurement of plastic containers for initial testing. The test and production phases cannot be accelerated sufficiently to make up for these delays. A revised contract delivery schedule has been proposed.

The chart on the following page shows by blackened lines the estimated progress of the major work elements and contract management functions against the previously established schedule estimates.

Except for the delays described above, progress is considered to conform to the schedule.

ARTECH CORP. TES PROGRAM PROGRESS CHART



SECTION IV

TECHNICAL PERFORMANCE

A. Work Accomplished

1. Design and Development

Testing of the prototype container frame based on lighter structural members and simpler fabrication methods was completed with satisfactory results. Design of a suitable accessory frame for lifting the thermal energy storage modules from the top was completed.

A subroutine for computer simulation of ARTECH's phase change storage system was completed and forwarded to Marshall Space Flight Center.

2. Materials Procurement

Materials procurement is up to date with the currently anticipated production schedule. Some of the production chemicals were ordered and received.

3. Production

First samples of the plastic containers were produced by the vendor but were found to be unsatisfactory owing to nonuniform wall thicknesses and numerous pinholes. The molding process is being modified and the container tooling is being reworked to eliminate these problems.

The induction sealing method for closure of the containers was tested with satisfactory results.

4. Quality Assurance

The approved quality control plan is ready to be implemented.

5. Test and Verification

Responses to the request for bids for construction of the test loop were received, at five to six times the budgeted cost. Accordingly, the decision was made to purchase components for in-house assembly of the test loop. The estimated cost of this construction approximates the budgeted cost.

The test procedure description of NBS Technical Note 899, which was the primary reference when the program began, has been superseded by ASHRAE Standard 94-77, with elimination of certain minor errors and adjustment of certain parameters. A Change Proposal will be initiated to formalize the replacement of the old version by the new in this program.

B. Forecast of Activities

During the next quarter, the following tasks will be performed:

1. Production and approval of container first lot.

2. Assembly and debugging of test loop.

3. Filling and cycling of test lot.

C. Problem Areas

Delay in container production is the main problem area. Test loop fabrication is lagging behind the previously established schedule but is in reasonable conformance with the progress of production. Every effort is being made to expedite these activities. A proposed revision of the schedule has been submitted to the Contract Technical Manager.

D. Data Submittals

Data and status reports were submitted according to contract requirements during the report period.

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