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DEVELOPMENT OF A HIGH EFFICIENCY, AUTOMATIC DEFROSTING REFRIGERATOR/FREEZER

PHASE I — DESIGN AND DEVELOPMENT

FINAL REPORT

VOLUME I — EXECUTIVE SUMMARY

Prepared by
W. David Lee

ARTHUR D. LITTLE, INC.
Acorn Park
Cambridge, Massachusetts 02140

February 1980

Work performed for

OAK RIDGE NATIONAL LABORATORY

Operated by

UNION CARBIDE CORPORATION

for the

U. S. DEPARTMENT OF ENERGY

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DEVELOPMENT OF A HIGH EFFICIENCY, AUTOMATIC DEFROSTING REFRIGERATOR/FREEZER PHASE I - DESIGN AND DEVELOPMENT

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Arthur D Little, Inc

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W. David Lee had overall responsibility for this project with Eugene West in charge of Amana Refrigeration, Inc.'s portion of the program. Technical guidance and analysis of the refrigeration unit was provided by Raymond Moore with support from Siegfried Mathias. Leonard Conrad of Amana was in charge of the cabinet design, prototype fabrication, and laboratory testing. Richard Topping and Janet Stevens developed and operated the cabinet model simulation. Design of the Phase II field test program was the responsibility of W. Thompson Lawrence.

In addition to the contributions from the Arthur D. Little and Amana team members, useful technical inputs and guidance was received from the Oak Ridge National Laboratory technical monitor, Donald J. Walukas.

ABSTRACT

Eighteen energy-saving design options were identified for the automatic defrost refrigerator/freezer unit. Projected energy savings and likely consumer acceptance of the design options were evaluated and seven promising options were selected for the development phase.

Computer and laboratory studies of: an improved condenser and evaporator design, new air flow path and fan housing design, improved defrost and refrigeration expansion valve control, and optimized cabinet insulation were performed. A prototype 16-cubic-foot automatic defrost refrigerator/freezer combining the seven energy saving design options was designed, built, and tested at Amana Refrigeration, Inc.

The Phase I prototype refrigerator/freezer had a 1.8 kwh per day energy consumption under the standard 90°F closed door energy test. This is an energy factor of over 10 cubic feet per kwh per day and it represents better than a 50% improvement in unit efficiency over the most efficient unit presently available.

A field test and market assessment (Phase II) is outlined. The test is designed to evaluate the unit performance in actual home use and marketability in a retail environment.

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1. Introduction

1.1 Background

The purpose of the project summarized in this report is to accelerate the design, development and commercialization of a highly energy efficient refrigerator-freezer.

Arthur D. Little, Inc. (ADL), and Amana Refrigeration, Inc. (Amana), were selected for this research and development program, and began work in June of 1977. By September of 1978, the ADL-Amana team designed, built and tested a prototype automatic defrost unit that achieved an efficiency of 10 cubic ft. per kwh/day. This volume summarizes the work undertaken to develop the prototype and plans for field testing 25 units. A comprehensive discussion of the work and the Phase II field test plan is given in Volume II.

1.2 Scope of Work

The scope of work of the first phase of the project is given below, a discussion of the second phase is given in Section 2.3.2.

Task I.1 - Phase I Program Plan

Submit a detailed project plan for review and approval by Oak Ridge National Laboratory (ORNL) Technical Manager (TM). This plan shall indicate, in more detail than the proposal program plan, final allocation of financial (including subcontractor's cost share) and personnel resources, timing of principal events that are to occur during execution of the project, decision points and milestones, technical approach, and other items of direct relevance to timely and successful accomplishment of the project objectives.

Task I.2 - Improvement Target

Perform the studies necessary to determine the characteristics of the future market into which a high efficiency refrigerator-freezer unit would enter. All problems which may impede commercialization of high efficiency refrigerator-freezer units will be identified, along with solutions planned to overcome the problems. These problems should include, but not be limited to, factors that have a strong effect on buyer acceptance such as noise, selling price and product size, manufacturer capital requirements, applicability to conventional manufacturing, maintenance, safety, and reliability. Develop and apply a rating method to indicate the best unit(s) for demonstrating high efficiency refrigerator-freezers. Rating criteria should include the potential for national energy savings, the time schedule on which such energy savings might realistically be achieved, the difficulty of solving the problems impeding commercialization, and the economic trade offs relating to the performance characteristics of the improvement options.

Task I.3 - Phase I Prototypes

Specify the refrigerator-freezer and perform the work necessary to develop, fabricate, and test a prototype unit(s) which is optimized for the target market identified in Task I.2. Engineering evaluations should be made of the trade offs between performance of the unit and operating factors such as size and noise output of the unit, the reliability and cost-effectiveness of the units, and modifications required to adapt the equipment to other portions of the potential market. Available information from a concurrent DOE-sponsored motor-compressor development project will be evaluated for its applicability. Such information will be supplied by arrangement with the ORNL-TM. The design and fabrication of the prototype(s) must include mass production considerations. Testing should be performed under conditions which are realistic to the chosen application in the target market and which are compatible with any appropriate DOE-FTC* testing and labeling requirements.

Task I.4 - Phase II Plan

Submit, for review and approval by the ORNL-TM, a detailed Phase II project plan for field demonstration of the high efficiency refrigerator-freezer unit, including the plan for production of the demonstration units to be tested and evaluated. The plan for demonstration should be adequate to obtain credible information on energy consumption and efficiency, reliability, performance, safety, cost, and other aspects determined to be important to promoting use of the units. Energy efficiency and cost information should be consistent with any appropriate DOE-FTC labeling and efficiency rating methods.

The plan must include definitive commitments for unit manufacturer participation in a non-trivial, cost-sharing effort.

This plan shall indicate, in more detail than the Phase I plan, the allocation of financial and personnel resources, timing of principal events that are to occur during execution of the project, decision points and milestones, technical approach, additional plans to further promote the improved refrigerator-freezer unit through use of the project-generated information, and other items of direct relevance to timely introduction of the equipment into the marketplace.

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*Department of Energy-Federal Trade Commission

Task I.5 - Phase I Summary

Prepare a final report containing (a) a summary (executive-type) report covering all aspects of the Phase I work, reflecting resolution of comments from the ORNL-TM based on review of draft copy and (b) task reports on Tasks 2, 3, and 4.

1.3 Results

A preliminary market assessment of refrigerator-freezer sales was performed and it indicated that a 16 cubic foot automatic defrost refrigerator-freezer would be the most appropriate unit for demonstrating high efficiency designs. Eighteen energy-saving design options were analyzed for likely consumer perception and 7 design features were selected for further study.

Laboratory tests of the 7 design features indicated that substantial unit energy savings could be achieved by judicious integration. A prototype combining the design changes was designed through the use of a computer program for the cabinet heat flow and a program for the refrigeration unit. The prototype was developed at Amana and tested.

The prototype was tested under standard 90° F closed door conditions and showed an energy consumption of 1.8 kwh per day for the 16 cubic foot automatic defrost unit. This equates to an energy factor of 10 cubic feet* per kwh per day which is about 50% more efficient than the best available unit in the marketplace. Additional tests of the unit cool down capability starting with a warm cabinet and operation in a high humidity room with a door opening schedule showed that the design meets all of the standard test criteria of performance.

A Phase II field demonstration and market evaluation was developed to test the unit performance in the home and to gather market data. Amana proposed to cost share the production and testing of about 25 units based on the Phase I design.

2. Discussion and Findings

The following sections highlight the findings of the Phase I study. Volume II consists of the 3 project task reports and provides a comprehensive discussion of the project.

2.1 Target Refrigerator Design and Improvements

Early in the study, it was realized that nationwide energy savings resulting from the development of new high efficiency refrigerator-freezer would only be realized through successful marketing of the

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* cubic footage is calculated as fresh food volume + 1.63 x freezer volume in accordance with DOE rating procedures

product. To prepare for anticipated market constraints, a preliminary market assessment was undertaken to identify the sector of the marketplace to which the refrigerator-freezer design should be addressed. The factors examined were:

- defrost features;
- freezer vs. fresh food cubic footage;
- style: top-mount, side-by-side, bottom mount;
- unit size in cubic footage.

Recent sales data clearly showed that the top mounted freezer-refrigeration combination automatic defrost unit holds the major share of the unit sales, and typically, these units have a freezer to fresh food volume ratio of 1 to 3.

A survey of food consumption and food storage requirements indicated that the average amount of food stored and average residence time of the storage is likely to increase over the next several years as a result of fewer number of shopping trips per week per household. This suggested a growth in the average size of refrigerator-freezer sold as depicted in Figure S-1. A 16 cubic foot top mount, frost-free refrigerator-freezer was identified as the target market for the high efficiency unit.

Eighteen energy-saving options were conceived for the target market (16 cubic foot automatic defrost refrigerator-freezer). An evaluation of the likely acceptance of the design options was undertaken using a rating factor combining the impact of energy savings, noise, change in unit size and life. The rating factor attempted to recognize the likely consumer perception of a change by setting minimum perceivable changes. Table S-1 summarizes an example of the rating methodology (evaluation of an insulation change). The results of the design rating are shown in Table S-2.

Seven design options were selected in the development phase of the program to undergo comprehensive computer analysis and prototype testing in facilities at Amana Refrigeration, Inc., and Arthur D. Little, Inc. The design options selected were those with a non-negative rating and without a significant design or development uncertainty.

In combination, these seven design options were estimated to reduce the baseline unit (16 cubic foot automatic defrost) energy consumption (from 3.1 kwh per day) to 2.0 kwh per day, which was set as the target energy consumption level for the development.

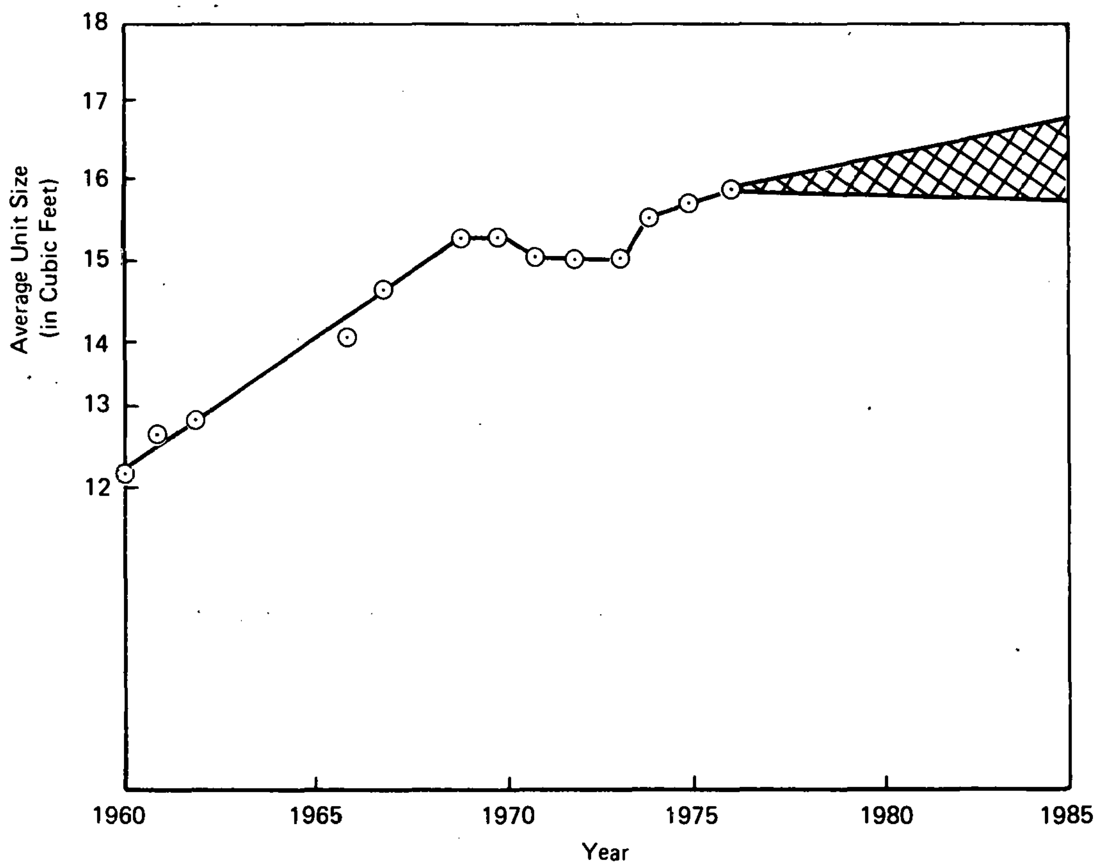


FIGURE S–1 SALES-WEIGHT UNIT SIZE

TABLE S-1

EXAMPLE OF RATING CONSUMER REACTIONS TO ENERGY-SAVING OPTIONS

			Improved Insulation**	
Factor*	Minimum Change to Perceive	Weight	Effect	Rating
Annual Energy Savings	\$8±\$1	2	\$8 saved	+2
Added First Cost	\$48±\$10	3	\$14 added	0
Noise	3 db***	3	0 db	0
Storage	2± 0.5 Cu.Ft.	3	0 Cu.Ft.	0
Unit Life	2.7± 0.5 years	1	0 years	0
				+2

*Assumes subjective factors held constant for an average refrigerator. Many 16-cubic-foot refrigerators will consume about 4.0 kwh/day (California 1979 standard), which means a \$58.40 energy cost per year (4¢/kwh) and 15% of this is \$8.76. Other factors are:

		Consumer Sensitivity		
	Standard	Level	Minimum for Perceptable Change	Perceptable Change
Annual Energy Cost	\$58	Medium	15%±3%	\$8±\$1
First Cost	\$400	High	12%±3%	\$48±\$10
Storage	16Cu.Ft.	High	12%±3%	2±0.5 Cu.Ft.
Unit Life	15 years	Low	18%±3%	2.7±0.5 years
Noise	-	High	NA	3 db***

**If the change is perceivable, the rating reflects the plus or minus weight value.

***Minimum audible level.

TABLE S-2

ENERGY-SAVING OPTIONS

	RATING VALUE	COMMENTS
Selected For This Project		
1. Optimized Insulation Thickness	+2	See Section 2.2.5
2. Alternative Condenser Design	+3	See Section 2.2.4
3. Door Seal Improvement	0	See Section 2.2.2
4. Improved Evaporator Fan System	0	See Section 2.2.3
5. New Evaporator	+2	See Section 2.2.4
6. Expansion Valve	0	See Section 2.2.6
7. Improved Defrost Control	0	See Section 2.2.4
Good Prospects		
8. Improved Static Condenser Design	+2	Significant design uncertainties
9. Hot Water Feature	+2	Problems in implementation and measurement of energy savings
10. Sequential Control	+2	Significant design uncertainties
11. Evacuated Powder Insulation	+2	Development beyond the time frame of 1985 production
Less Promising Prospect		
12. Multiple Evaporator-Compressor	-2	Poor payback period
13. Thermal Storage	-0	Small energy savings, cost benefit (+2 rating) through peak electric pricing
14. Mechanical Expander	-4	Too many uncertainties
15. Other Thermodynamic Cycles	-	No energy savings with known components
16. Hot Gas Defrost	-1	Poor payback periods
17. Inner Doors	-	Option #3 makes this obsolete based on present test procedures
18. Two-Speed Compressor	0	Significant design uncertainties

NOTES ON CLASSIFICATIONS

- "Good Prospects" are options which offer good payback periods but at a perceived higher risk and where not carried into the development phase.
- "Less Promising", see specific comment.

Table S-2 reflects the final disposition of the options examined. It differs slightly from the ordering of options in the Task 2 Report (Volume II). The hot water feature was placed in the Good Prospects category (originally in the Selected category) as problems in implementation and measurement of energy savings increased as initial designs were developed. The thermostatic expansion valve was moved from the Good Prospects to Selected category as it became apparent in the prototype analysis that a performance gain could be achieved.

2.2 Prototype Design and Testing

Individual design studies were undertaken for each of the design concepts to isolate problems and benefits.

2.2.1 Heat Flow Partitioning

Heat flow partitioning analysis of a baseline refrigerator cabinet (ESRFC3-16) was undertaken so that areas for design improvements could be identified. The ESRFC3-16 unit was selected as the baseline as it presently is the most energy efficient unit (Energy Factor = cubic foot ÷ kwh per day = 6.25) that Amana makes. The following partitioning of heat flow was determined:

1) Heat conduction through the walls amounted to 50 Btu/hr in the freezer and 111 Btu/hr in the Fresh Food compartment.

2) Heat flow through the transition area between the parallel cabinet walls and the narrow flange area of the refrigerator (shown in Figure S-2) amounted to 30 Btu/hr. This component of the wall heat flow is referred to as the wedge.

3) Heat flow through the door flange area amounted to 63 Btu/hr with the evaporator fan on and 44 Btu/hr with the evaporator fan off.

2.2.2 Improved Gaskets

Some of the heat flow through the flange area could be inhibited through the use of a secondary door gasket. A vinyl secondary gasket was developed and incorporated into the freezer compartment of the baseline unit. A 3% energy savings was measured which is equivalent to a 47% reduction in the freezer flange heat flow. A secondary gasket was not used in the fresh food compartment since negligible savings could be achieved with a secondary seal in this compartment.

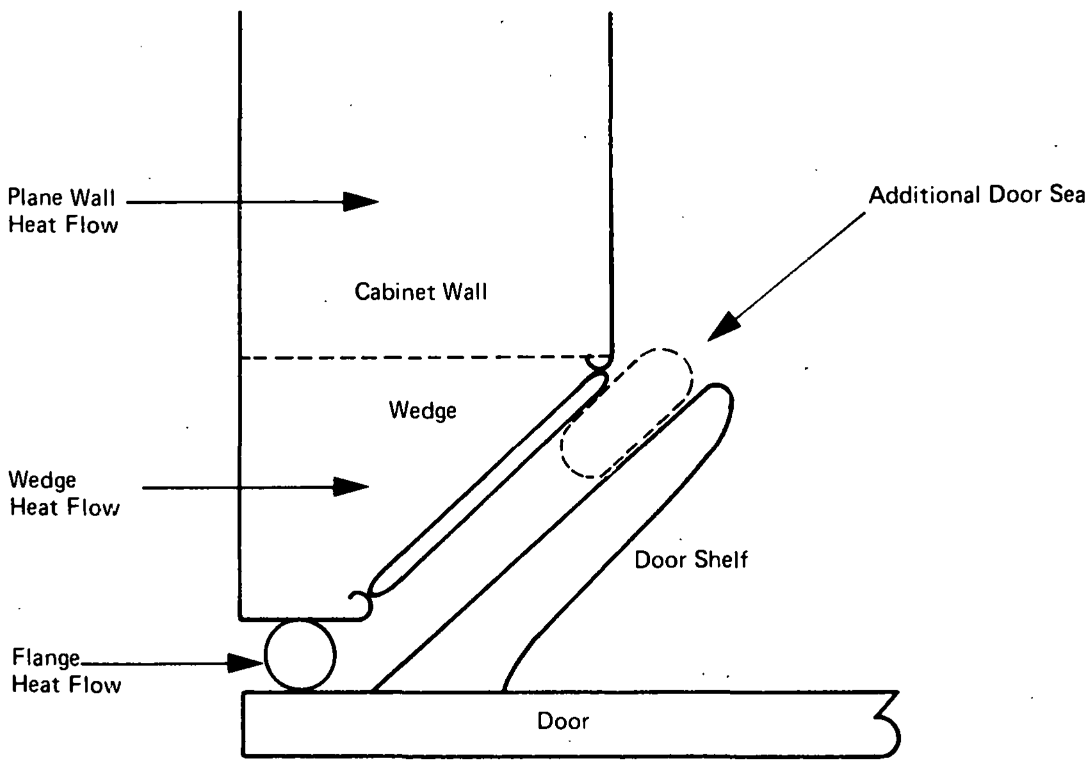


FIGURE S–2 CROSS-SECTION OF DOOR CLOSURE AREA

2.2.3 Fan Tests

Air circulation in the cabinet is accomplished with a motor-driven fan which itself generates heat in the cold compartment. Wind tunnel tests were performed to design an air flow path to reduce the fan power requirements and to permit relocating of the fan motor outside of the cold space. An air flow path design was developed that reduced the fan power consumption by 50% and allowed the motor to be located outside the cold space.

Improvements in the fan and motor design were also considered. Tests on: tube axial fan, centrifugal fan and a split capacitor motor were performed. A 50% reduction in fan power could be achieved with the improved motor fan. The benefits of an improved fan or motor are considerably reduced when combined with the new air flow path design. The added cost to incorporate a new air flow path is negligible while the new fan/motor components will add product cost not offset by the energy savings. As such, only the new air flow path was considered further.

2.2.4 Design Guidance Prototype

A unit combining the major refrigeration unit changes was designed and built as a means of testing the synergistic effects of the component changes. The following design options were incorporated into this pre-prototype:

- Static condenser rather than hot wall condenser
- A standard forced convection evaporator in the freezer was used in conjunction with a natural convection fresh food compartment self-defrosting evaporator
- The time interval between defrosts was increased as the moist air of the fresh food compartment was no longer admitted to the freezer evaporator
- Evaporator fan motor and flow path changes and location of the motor outside of the unit cold space

The unit showed a 33% reduction in energy consumption over a production model using the same cabinet and maintained the desired cabinet temperatures in a high humidity test that included door openings (called the Gulf States test because of the high temperature (90° F) and high humidity conditions (85% RH)).

2.2.5 Optimum Insulation System

Based on the heat flow partitioning of the baseline cabinet (Section 2.2.1) a new cabinet design was studied. A computer program was developed for this purpose and was used to generate a cabinet insulation system for a 16, 18, 20, 22-cubic-foot series of cabinets, reflecting the plan to commercialize the energy savings design through an entire product line. The cabinet series is shown in Table S-3. The series (constant insulation system thickness) offers minimum heat flow for a fixed outside dimensional constraint. The 16-cubic-foot design cabinet was built. Calorimeter tests of its heat flow showed a 175 Btu/hr heat flow and represented a 25% reduction in heat flow from the baseline unit (ESRFC3-16).

2.2.6 Thermostatic Expansion Valves

Analysis of the performance of the Design Guidance refrigeration systems indicated that additional energy savings could be gained if increased refrigerant superheat could be maintained at the evaporator exit. A thermostatic expansion valve (TEV) is designed to provide this control. A small energy savings in the present test procedure was measured in laboratory tests of a thermostatic expansion. The savings were not considered to be sufficient for inclusion of the TEV in the final prototype.

2.2.7 Phase I Prototype Design

A computer simulation of the prototype was developed and along with the data gained from the design guidance test guided the specification of components for the Phase I prototype design. The following energy saving features were included in the prototype:

1) optimized insulation system

2) new static back mounted condenser

3) secondary gasket for the freezer section

4) improved fan air flow path; fan motor mounted outside of cold space;

5) a new fresh food free convection cold plate in series with the standard forced convection evaporator

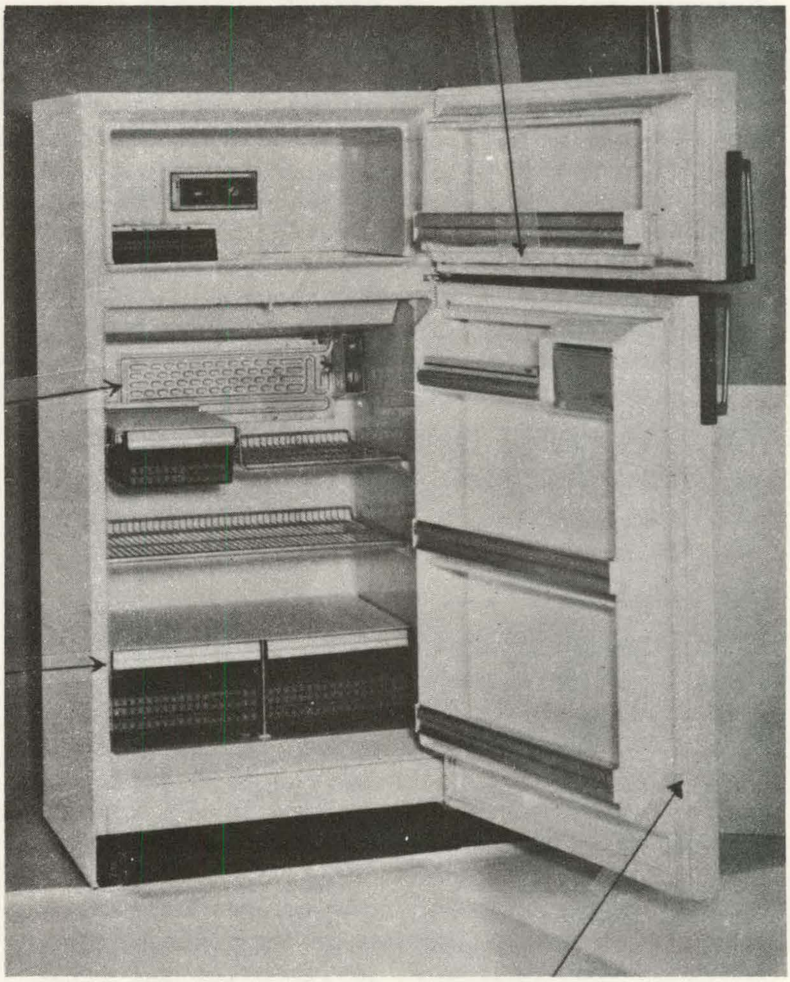
6) new controls (thermostatic switch, defrost)

The prototype was fabricated and tested. A photograph of the unit is shown in Figure S-3. The Phase I prototype has a measured daily energy consumption of 1.8 kwh per day meeting the program goal of 2.0 kwh per day. It passed the normal laboratory performance tests under heavy usage, and was shown to provide the automatic defrosting feature without the normal dehydration of food and cost of energy associated with it.

Table S-3

Cabinet Specifications Prototype Series

Cabinet Size	Insulation Thickness (Inches)							Heat Flow (Btu/hr)						Volumes (cu ft) Unadjusted		Adjusted			
	Freezer				Fresh Food														
	Side	Front	Back	Top	Side	Front	Back	Freezer	Mullion	Fresh Food	Gasket	Wedge	Total	Freezer	Fresh Food	Freezer	Fresh Food	Total	Ratio ($\frac{Frz.}{Total}$)
16 cubic foot Prototype	3.00	2.50	3.00	3.00	2.25	2.50	2.25	43.08	13.28	68.39	41.9	10.06	176.7	3.88	12.66	3.60	12.22	15.82	0.227
18 cubic foot	3.00	2.50	3.00	3.00	2.25	2.50	2.25	47.89	13.94	73.34	40.03	20.62	195.82	4.55	14.13	4.35	13.72	18.07	0.241
20 cubic foot	3.00	2.50	3.00	3.00	2.25	2.50	2.25	56.89	14.98	73.71	40.37	19.81	205.76	5.87	14.90	5.67	14.49	20.16	0.281
23 cubic foot	3.00	2.50	3.00	3.00	2.25	2.50	2.25	58.46	15.28	77.23	56.28	19.85	227.103	6.48	16.45	6.43	16.00	22.42	0.283



INSULATION THICKNESS (INCHES)							HEAT FLOW (BTU/HR)					
Freezer				Fresh Food								
Side	Front	Back	Top	Side	Front	Back	Freezer	Mullion	Fresh Food	Gasket	Wedge	Total
3.00	2.50	3.00	3.00	2.25	2.50	2.25	43.08	13.28	68.39	41.9	10.0	176.7

FIGURE S-3 PROTOTYPE CABINET INSULATION SPECIFICATIONS AND CALCULATED HEAT FLOW

Arthur D. Little manufacturing staff analyzed the major design changes between the baseline (ESRFC3-16) unit and the prototype, from a manufacturing viewpoint. Unit costs are extremely difficult to estimate as costs depend on the existing (capital) equipment. Certain manufacturers will fabricate all of the major components requiring only added materials, while other manufacturers may have to purchase some of the major parts. We have elected to reflect costs with purchase components as this may reflect the initial product introduction cost (low volume). We have assumed that the manufacturer has foam in place machines, and plastic liner equipment and that only tooling for the new cabinet is required. The following manufacturing per unit costs have been estimated:

	$/unit
materials	1.71
labor	.56
purchased parts	17.02
tooling (3 year amortization)	5.00
ex factory cost	$24.29
Estimated Retail Price (2.5 mark-up)	$60.73

2.2.8 Recommendations

The laboratory tests and computer analysis of the Phase I prototype confirm that the design can achieve the energy efficiency target set for it in Task I.2. Using the present Federal guidelines on the maximum feasible energy efficiency target published in the Federal Register No. 47, the prototype represents a substantial energy savings beyond the highest efficiency target likely to be set by the Department of Energy.

After review of the prototype performance with Oak Ridge National Laboratory technical staff and Amana Refrigeration, Inc., Arthur D. Little recommended that a Phase II market and field test demonstration program be undertaken to accelerate the commercialization of the concept.

2.3 Phase II Project Plan

2.3.1 Overview

At the conclusion of Phase I the Amana-Arthur D. Little team decided to focus the Phase II test on an 18 cubic foot version of the prototype. This came as a result of market considerations, and the desire to extend the proof of concept into larger units.

Amana Refrigeration, Inc., and Arthur D. Little proposed a market and field test of the energy saving refrigerator designed to evaluate the commercialization potential of the unit. Two (2) 18-cubic foot (based on the target market analysis of Phase I) preprototypes are to be built and tested to establish the final design specifications. Temporary tooling capable of manufacturing a minimum of 25 units will be used and production of the field test unit will take place at Amana. Quality control and limited testing sufficient to establish baseline prototype energy consumption values will be performed at Amana. The units will then be placed in retail outlets for test marketing purposes. While the units will not actually be sold, consumer reaction to the units will be evaluated under real market conditions. The 25 prototypes and 25 baseline units will be placed in the field, instrumented and monitored on a monthly basis. The energy consumption difference between the two units will be evaluated along with customer opinion of the unit performance. A final report of the findings of the market and field test will be prepared and submitted to Oak Ridge.

2.3.2 Scope of Work for Phase II

Task II.1 - Specifications and Manufacturing Facility

Design, fabricate, and subject to a complete set of engineering tests two high-efficiency refrigerator-freezer units. Specify pilot production tooling and provide specifications to tooling vendors for at least the following items:

- plastic liner mold, including doors
- gaskets
- shelves and crisper

A final specification and engineering design report which describes the refrigerator-freezer and manufacturing facility in detail will be submitted within 11 months of initiation of Phase II.

Task II.2 - Manufacturing, Testing, and Demonstration

Manufacture approximately 25 energy-saving units. Quality control inspection equivalent to standard practice should be performed, and a random sample of units tested according to the standard DOE test procedure (90°F closed door test). Each unit should be instrumented for field tests. A unit should be tested in the laboratory to monitor durability and degradation.

Purchase 25 baseline units for a field test comparison with the 25 high efficiency refrigerator-freezer units. Develop a method for selecting representative families, place units in households, check out instrumentation, and monitor the energy consumption of the baseline and high-efficiency refrigerator-freezer units during one year of use and assess the energy savings of the high efficiency units.

Wherever possible, these units should be placed through a retail marketing effort.

After one year, assess:

- energy consumption;
- maintenance and service requirements;
- user and market acceptance.

A task report summarizing the manufacturing and field test experience will be prepared and will include evaluations of product cost-effectiveness, market experience and recommendations for further work.

Task II.3 - Monthly Reports and Project Management, and Final Summary Report

Monthly reports and oral reports to the ORNL-TM concerning program progress should be prepared. A draft final summary report should be prepared and submitted containing an executive summary and Task Reports 6 and 7. A final summary report will be submitted reflecting resolution of comments from the ORNL-TM on the draft.

Task II. 4 - Long-Term Surveillance

Evaluate the long-term performance of the demonstration units at a reduced, but adequate, level of surveillance to document the important characteristics, such as annual savings, problems, reliability, maintenance, and user acceptance of appliances. The duration of this task is not specified and should be negotiated annually as long as appropriate.

2.3.3 Laboratory and Field Tests

Laboratory tests on the 18 cubic ft. prototypes will be undertaken prior to the final design specifications for tooling and for the 25 field test units. A long-term laboratory durability test of the unit undertaken to evaluate degradation in performance.

Once the units are placed in the field, the energy consumption will be evaluated on a monthly basis. Previous field tests' data indicate that a sample size of 25 should produce a mean energy consumption for the prototype units with a sufficiently small standard deviation to represent, with a reasonable confidence interval, the energy consumption of a large population of the prototypes. If the usage variable is higher than expected then additional instrumentation should be used to compensate for the user related variability. In this instance, the door opening and food load would be monitored and corrections in the energy consumption made to standardize the field test data around the usage.

2.3.4 Market Tests

Units should be placed in Amana retail outlets. Normal sales training and advertising campaigns will be undertaken to promote the sale of the prototype. Customers willing to purchase the prototype will be given the opportunity to participate in the demonstration phase at no cost. Arrangements should be made to allow monthly readings of the unit performance in the participants houses and contracts should be developed with the participants to cover liability and ownership issues.

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